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Software Defined Network-Based Management for Enhanced 5G Network Services

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ABSTRACT Due to the fast development in communication technology and the emerging usage of Internet of Things (IoT) devices that produce a huge amount of data, the fifth generation (5G) mobile network is introduced to support this development. This mobile network can provide many advanced communication features in cellular phones. But unfortunately, this technology faces many challenges. One of its defective challenges is the management of a massive number of devices running different services, so Software Defined Network (SDN) is proposed as a key technology to overcome this drawback. SDN architecture provides higher flexibility, scalability, cost-effectiveness, and energy efficiency in 5G mobile networks. There are usually different architectures for the SDN control plane. We study some of these architectures, and we conciliate the usage of Logically Centralized-Physically Distributed (LC-PD) controller management architecture in 5G networks. This architecture enables providing higher throughput, and lower latency compared to other control plane architectures. In this paper, we focus on the demonstration that the LC-PD control plane architecture improves communication efficiency and the Quality of Services (QoS) of running internet services in the 5G mobile network. We use the Mininet-WIFI emulator in our simulation tests. Our conducted simulations show that employing the LC-PD control plane architecture in 5G networks enhances the QoS of Internet services compared to other SDN implementations.

INDEX TERMS Software defined network, 5G networks, quality of service, network management, controller placement.

I. INTRODUCTION

5G stands for fifth generation mobile technology. It's the latest mobile wireless system iteration. This mobile wireless technology is more intelligent as it allows the interconnection of the entire world without limitations and adds more services and benefits to the world compared to fourth generation mobile technology (4G) [1].

While earlier generations of cellular technology (such as 4G) focused on connectivity, 5G brings connectivity to the next level, by delivering connected experiences from the cloud to customers. 5G networks are software-driven and virtualized and utilize cloud technologies. This cellular technology is intended to satisfy the big development of contemporary society's information and connectivity of the Internet of Things (IoT) with billions of linked computers, and the technologies of tomorrow. This mobile technology supports Wireless World Wide Web (WWWW), and virtual private networks (VPN) [2], [3]. This mobile network also provides improved spectrum efficiency.

Compared to the existing 4G mobile standard, the 5G standard possesses a new wireless interface supporting high frequencies [1]. This mobile technology will support IPv6 and flat IP [3]. In contrast to normal IP addresses, flat IP architecture provides a way to identify devices using symbolic names. 5G wireless uses Orthogonal Frequency Division Multiplexing (OFDM) [1] [3]–[5], and frequency band of 3-300 GHz [4], [6].

Unfortunately, this mobile communication technology faces many challenges. One of the major challenges facing the 5G network is its highest cost in the transition from 4G to 5G. This technology is less compatible with the previous mobile generation [7]. Also, the 5G mobile network suffers from the management of a large number of connected devices

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running different services. So, to manage such a network and overcome these drawbacks, flexibility will be the key feature of this mobile generation. This architectural flexibility will be released by implementing the Software Defined Network (SDN) in the 5G mobile network [8]–[10]. SDN is based on the separation between the control plane, and the data plane allowing the handling of the traffic by means of software [11]–[14]. This separation helps improving scalability, flexibility, reliability, and simplification of network management [10], [15]–[18]. SDN architecture transforms network devices (e.g. switches and routers) into dummy devices with no intelligence functions such as routing, major processing, and management [8]. All these functions are handled by the brain of the network, the SDN controller unit [12], [13], [17], [19].

One of the key issues in the SDN network is controller placement [18] [20]–[23]. Also, the number of used controllers which both affect network performance [24], [25]. There are usually different SDN architectures that reduce network performance, and Quality of Services (QoS) [26]. SDN can be implemented according to the number of controllers used, their location and their way of connectivity in the network [14], [18], [21], [22]. We have studied a set of SDN control plane architectures, which are namely, centralized control plane, distributed control plane, and Logically Centralized-Physically Distributed (LC-PD) control plane architectures [27], [28]. Previously the distributed control plane architecture was widely used to prevent the single point of failure problem as will be shown in section III. So, we have implemented all these architectures in the 5G mobile network environment, and we have compared their performances. We have used the Mininet-WiFi emulator to test these SDN different control plane architecture. Mininet-WiFi emulator is one of the few available simulators used for building wireless networks. We have used throughput and latency parameters as indicators for the 5G network performance. These parameters indicate the speed of the communication process between two users. So, our main goal in this paper was to illustrate the importance of LC-PD control plane architecture in the management of a 5G network in improving communication. We have succeeded to prove that LC-PD controller management architecture is the convenient control plane architecture with a 5G network from simulation results as will be clarified later.

In this paper, we focus on the adoption of the LC-PD control plane architecture into the 5G mobile network. This control plane architecture enables the management of various services with high QoS. Also, SDN provides flexibility in the management of the network. This by turn will reduce complexity and cost factor issues facing the 5G mobile network. LC-PD control plane architecture is based on the clustering of the network. The main contributions of this paper are summarized below:

- The usage of LC-PD control plane architecture in conjunction with 5G.
- The possibility to run multiple services with high QoS and efficiency using LC-PD control plane architecture.
- The reduction of complexity and cost factor due to the implementation of SDN into the 5G network.

The rest of this paper is organized as follows. Section II introduces the 5G mobile network, and the usage of the SDN-based management approach to address different 5G network challenges. Also, it provides an overview of previous work implemented in managing the 5G network using SDN. Section III clarifies different SDN architectures used in the 5G mobile network. Section IV compares quantitatively different SDN control plane architectures and proves that the LC-PD control plane architecture is the best choice for the 5G networks. Section V concludes the paper and highlights future work.

II. RELATED WORK

The 5G mobile systems model is an all-IP based model for wireless and mobile networks. Network Architecture in the 5G network consists of a user terminal and some different Radio Access Technologies (RAT). In 5G Network architecture, all IP-based mobile applications and services are offered via Cloud Computing Resources (CCR), such as mobile portals, mobile commerce, mobile health care, mobile government, and others. Cloud computing enables consumers to use applications without installation and access to their personal data on any internet-accessed computer. The basic 5G network architecture is presented in Fig. 1.

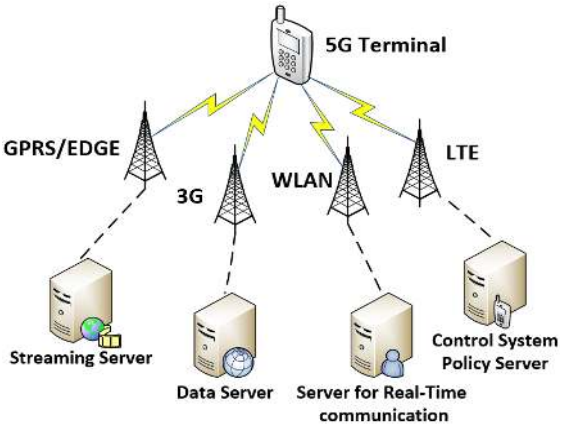

FIGURE 1. 5G mobile network architecture.

A. 5G MAIN FEATURES

This mobile technology has some key benefits compared to the previous cellular network such as:

1) HIGHER SPEEDS THAN EVER BEFORE

High speed is the biggest benefit of 5G connectivity. Data rates can exceed 10 GB/s in a 5G device [10], [29], almost a thousand times faster than a 4G device [1], [3], [30]. This higher throughput rates will also make crazy speeds feasible for online gaming and overall 4K video streaming [4], [32], [33]. This technology supports nearly 65,000 connections at a time, with a large broadcast capacity [5], [33]. The average response time will also go down a lot (1 ms in 5G and 45-50 ms in 4G) [10], [33] because the bandwidth will be much higher.

2) ENERGY SAVING

Due to the highest transfer speed, no more frustrating waiting to load a web page. This by turn will ensure low latency (stop delays) [29] and low battery consumption while using 5G, thus increasing battery life by up to 10 years and reducing network energy consumption by 90% [5], [31].

3) EFFICIENT AND EFFECTIVE

5G will function better and more efficiently than other networks. It offers faster speed, low latency, better quality, and bidirectional shaping of large bandwidth. Several new technologies such as wireless virtual reality headsets or remote-controlled vehicles will also be introduced, which in turn help make transportation easier [4], [5], [31].

4) A SOLUTION FOR THE "LAST-MILE ISSUE"

5G gives a way to address the much-discussed (last-mile problem) associated with the non-availability of network connectivity in rural / sparsely populated semi-urban regions. These issues occur mostly in advanced countries like the United States, and also where hi-speed fiber-based networking is not an economically feasible solution for these fields. Using 5G technology, powerful wireless hotspots can be built and the internet can become more mainstream in non-urban areas [1], [32].

5) SUPPORT FOR PARALLEL MULTIPLE SERVICES AND HETEROGENEOUS SERVICES

5G will revolutionize mobile technology with bi-directional bandwidth shaping, larger antenna sizes and much larger bandwidths [2]. People will be able to use various facilities at the same time (for example, during a voice call you can monitor weather updates). 5G's underlying technologies will also be strong enough to support private networks and other heterogeneous high-end services [3], [5], [32].

6) ROLE OF 5G IN IOT

5G wireless technology will be at the core of the emerging IoT revolution along with artificial intelligence (AI) and edge computing [34]. In addition to expanding the scope of the Industrial Internet of Things (IIoT) possibilities, 5G is also expected to play a major role in smart city applications, smart industrial software, connected car powering, and smart homes and buildings. Seamless mobility, negligible latency, complete scalability, and reliability will help 5G to facilitate the implementation of many high-end, mission-critical IoT initiatives [6]. This by turn will make 5G technology as the main driver of (massive IoT) due to enhanced efficiency levels and network capabilities [32], [35].

B. HOW 5G WORKS

5G technology will attain its anticipated high effectiveness using most modern modulation techniques and network terminologies such as:

1) CARRIER AGGREGATION

Carrier aggregation is a sophisticated method used in LTE to enhance the effectiveness of the scheme [29]. Two or more carrier signals are aggregated in carrier aggregation to support wider bandwidth allowing up to 100 MHz [36]. The aggregation of carriers utilizes three aggregation methods:

- Contiguous intra-band: two carriers are transferred on adjacent channels [3], [35], [37], [38].
- Non-contiguous intra-band: two carriers are transmitted with channel spacing [3], [35], [37], [38].
- Inter-band: various LTE bands are used concurrently in this method for transmission [3], [35], [37], [38].

2) SMALL CELL CONCEPT

Like other cellular networks, 5G networks consist of cells that are divided into sectors. These cells send their data through radio waves. Each of these cells is connected to the network backbone either through a wired or wireless connection. The cell is subdivided into micro and Pico cells to increase network efficiency [33]. Reusability of the spectrum enables the addition of more customers in a tiny geographical region and the more efficient handling of the network [1], [3], [38].

3) MIMO CONCEPT

5G uses Multiple Input Multiple Output (MIMO) to increase network capacity significantly [1]. MIMO is a transmission technology for the transmission and reception using various antennas [36]. This technology makes it possible to simultaneously transfer information, thus offering an effective data rate [30]. The more the number of antennas, the more it is possible to transmit and receive more information [3], [5], [6], [29], [35], [37], [38].

4) WI-FI OFFLOADING

WIFI offloading is one of the future networks' primary features. It enables the user to communicate via the WIFI network and it is possible to allocate the cellular network to other users. It would be appropriate for some locations where the quality of the cellular network is poor and users still have the choice of connecting without cellular reception to the network [3].

5) DEVICE TO DEVICE COMMUNICATION (D2D)

D2D communication is a method where two adjoining devices are straight communicated by the network [30], [34]. The network will have device control and enable an operator to determine the routing of traffic between direct and network paths. One device can connect to another device during the absence of the network [3], [5], [6], [29], [35], [37], [38].

6) CLOUD-RADIO ACCESS NETWORK (C-RAN)

C-RAN is a network technology used to communicate effectively with a remotely performed centralized information processing within the cloud system [39]. The signal is processed at a distant place and most effective fiber optic links are linked to the base stations [13], [36], [40]. It offers many benefits for more efficient network upgrades, enhancements, testing, monitoring, and maintenance [3], [6], [29], [35], [38].

C. 5G NETWORK CHALLENGES

Despite, all features gained from this cellular network, this technology suffers from several challenges as follows:

1) MULTIPLE SERVICES

5G differs from other radio signals because it would have an enormous job in providing services to heterogeneous networks, techniques, and devices working in separate geographic areas. Thus, standardization is the task of providing vibrant, universal, user-centered and data-rich wireless services to meet people's high expectations [32].

2) THE COST FACTOR

5G technology isn't compatible with previous generations. This leads to building the groundwork for something new, not the establishment of just a layer on top of an existing network. So, building a network is costly and money will be also raised by carriers. Also, 5G technology requires skilled engineers to install and maintain the 5G networks, 5G equipment is expensive, which increases 5G deployment and maintenance costs [32], [41].

3) OLD DEVICES MAY GO OUT OF USE

Due to the usage of new technologies in 5G, older devices will be useless because their system and characteristics won't support the latest 5G technology features. There will be a demand for completely new sets of smartphones to be purchased by everyone to use 5G if people don't want to stick to older devices and services. This by turn may cost some money [41].

4) DEPLOYMENT AND COVERAGE

The coverage range is up to 2 meters (indoors) and 300 meters (outdoors) due to higher frequency losses [32], [41]. 3G cell towers could cover vast territory with relatively few cells because the network did not require as much bandwidth. This means that networks had to deploy fewer cells because when cells produce more bandwidth, the coverage radius of each cell becomes smaller. So, it will be challenging to spread access to rural regions as it was with LTE. So, coverage may drop more frequently than the 3G network. The 5G network requires more cell towers to produce this huge bandwidth because the cells can not cover as much space as the 3G or 4G cells, more cells will need to be rolled out.

5) ULTRA-LOW LATENCY SERVICE

To guarantee smooth operation, mission-critical apps and self-driving cars involve ultra-low latency facilities. Any delay in mission-critical apps could lead to unexpected and catastrophic outcomes. It is necessary to achieve a latency of less than 1 millisecond to fulfill medical apps such as remote surgery [35].

6) SECURITY ISSUES

Security is one of the most significant variables of any wireless transmission system. A 5G Network must guarantee safety and privacy for end customers. Given the number of devices linked to the network and the variety of techniques, ensuring safety is a difficult job. The IoT can make life simple for the masses, but it brings out a lot of private data through the mode of exchange [32], [34].

7) COMPLEXITY

Previously, we have clarified that the 5G mobile network uses MIMO technology. So, to provide consumers with high-speed data transmission, complex MIMO antenna arrays will be used [30], [34]. MIMO technology in both base stations and user equipment needs complicated algorithms and device capabilities. Also, the new generation wireless transmission technology will use beamforming techniques to effectively communicate information to user devices to prevent transmission energy wastage. This technique helps in reducing the base station's operating power. However, beamforming is a complicated task of locating each device within a specific cell and requires a high processing level at base stations [32].

SDN is an intelligent network that minimizes the usage of hardware. SDN's value in the 5G wireless networks lies specifically in its ability to deliver new capabilities in secure and trusted networks, such as network virtualization, automation and creation of new services in addition to virtualized resources. Also, SDN principles solve the Radio Resource Management problem in 5G networks for several use cases (interference management, mobile edge computing, RAN sharing) [42].

So, to cope with all previous challenges in the 5G mobile network and reduce costs, SDN was proposed to provide the flexibility required in the 5G network architecture [37]. SDN also helps in the simplification of network management and configuration. It also reduces costs by the softwarization of the 5G network functions. This is achieved due to SDN virtualized services in the network by separating the data transmission from the control of the network [7], [43]. In the SDN, the controller maintains the intelligence of the whole network. But on the other hand, the data plane is distributed into multiples of switches and routers that are responsible for flow forwarding or routing based on flow entries generated by the control plane [8]. In SDN architecture, the Open Flow protocol is used to define data structures, messages, and procedures, to describe all the physical and logical elements within a data path and to ensure traditional functions of the control plane, such as modifying packets, managing the routing table, and managing the different flows. Also, this protocol supports the IPv6 features as access control, quality of service and tunneling through VPN and IPsec. In 5G mobile networks, the controller will use an Open flow protocol to communicate with 5G core devices, to maintain network topologies, set new flows, and collect network statistics to reach the QoS requirement. SDN will also introduce many security levels in the 5G network such as Data integrity, Data confidentiality, authentication, and access control. Thus, implementing SDN in the 5G mobile network transforms core network nodes into pure forwarding elements and exports the control plane to a centralized SDN controller node [7].

SDN can be used to provide an overall framework to enable 5G to function across a control plane. It can also provide better data flows, as data moves across the 5G network. Also, SDN provides a way to manage and automate network redundancy from a centralized control plane. So, the integration of SDN with 5G mobile networks will minimize the changes in network elements and will introduce centralized management [10] and higher programmability in 5G, which by turn will provide the possibility to share the network resources between the different mobile operators. As aforementioned, this mobile technology will support the IPv6 protocol, this combination between IPv6 and SDN will provide scalability, operational savings, enhance management and improve network [17].

Regardless of the technical benefits of SDN, especially in dynamic behavior, the separation of the control plane from the data plane can generate some performance issues related to network reliability and security. It can additionally generate new issues, such as the controller placement problem [20]. This issue focuses on searching for the best location of the controller to satisfy the optimum design for a given SDN topology [10], [23]. This concept of separation can affect both fixed and dynamic network performance. Hence, the switch should be continuously controlled and assigned to controllers on the shortest path, controllers should be interconnected through an overlay network, and finally, controller failures or disconnections between control and data plane should be fixed, which may result in packet loss or other network problems. These functional concepts of SDN networks must, therefore, be taken into account in formulating the problem of controller placement for designing and planning fixed and mobile networks [14], [20]–[22].

The idea of managing the 5G network using SDN was proposed by Yonghong Fu *et al.* in [9], [44]–[46] to enhance network performance and provide flexibility. They have proposed the usage of a distributed control plane architecture consisting of two types of controllers: the area controllers and the domain controllers [21]. Area refers to a region that can be controlled by a single SDN controller. They have proposed this hierarchical design to solve two main problems, the growth of the network in the future and the stretch path problem [19], [23], [25]. This hierarchical control plane architecture of SDN is called Orion design [24]. The area controller is responsible for gathering information about physical devices and linking information, managing topology in the intra-area, processing requests and updates for intra-area routing. The domain controller treats area controllers as devices and, through a distributed protocol, synchronizes the global view of the abstracted network. So, a horizontal communication module was proposed to enable the synchronization of network information among the domain controllers. They have evaluated their design based on the Dijkstra algorithm [18], [23] and they have measured the average delay and the throughput [9], [39], [46]. They have calculated the average delay using a different number of areas as shown in Fig. 2. The delay time increases gradually when the number of areas increases. To compare our new suggestion and previous work, we will focus on the readings taken in case of using four areas only. In our simulation test, we have also used four areas to be able to make a precise comparison.

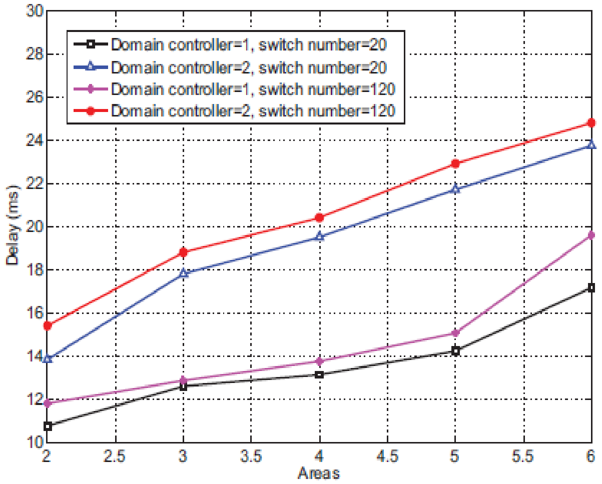

FIGURE 2. **Average delay time in Orion [9], [46].**

Table 1, clarifies the average delay readings in the case of using four area controllers only.

TABLE 1. **Average delay readings.**

Number of controllers	Number of switches	Delay value (ms)
1	20	13
2	20	14
1	120	19.5
2	120	20.5

This table shows that the average value of delay is approximately 16.75 ms, which is very high compared to our proposed LC-PD control plane architecture as will be shown later. LC-PD control plane architecture reduces latency and enhances network performance due to the usage of many controllers spread over different areas as will be seen in our simulation. This was the reason that has motivated us to focus on the LC-PD control plane architecture in our research study and proving its importance in the 5G cellular network. But, Orion design does not introduce much overhead in their tests. The CPU utilization of the domain controller is 40% only, which ensures the highest throughput values.

III. SDN BASED MANAGEMENT OF 5G NETWORK

As aforementioned, the SDN concept provides more flexibility in network management due to the separation between the control plane and the data plane, allowing handling the traffic network through software [18]. The SDN control plane is usually composed of a centralized unit called Software Defined Network Controller, which is the manager of the whole network [15], [16].

The SDN controller location will affect network performance. So, there are usually many SDN control plane architectures, such as centralized, distributed and LC-PD control plane architecture, which all are emulated in Mininet-WIFI [47].

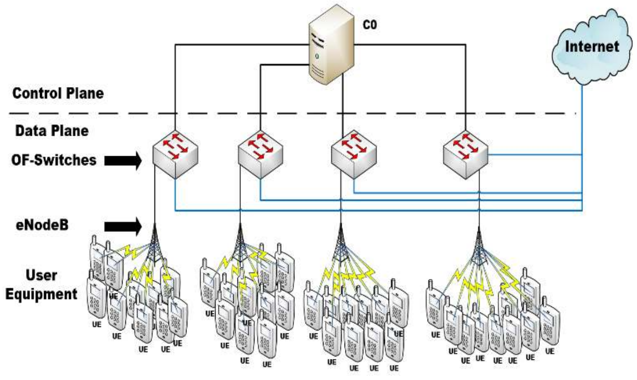

FIGURE 3. Centralized control plane architecture implemented.

A. CENTRALIZED CONTROL PLANE ARCHITECTURE

In this architecture, only one single controller is used to manage the entire network, and this is the basic SDN control plane architecture [24], [33]. This architecture provides a global network overview, which leads to a better and informed decision [18], [48]. But on the other hand, the usage of one single controller represents a weakness in the network as it is a single point of failure with no redundancy [26]–[28]. This architecture suffers from reliability, congestion, scalability and performance degradation due to the large distance between the control plane and the data plane devices [15], [16], [18]. This control plane architecture is convenient with a small scale network [10]. Fig. 3 presents the simulated centralized control plane architecture with only one centralized controller. This scenario is composed of only one controller directly connected to four Open-Flow switches (OF-switch), which are connected to the internet to make mobile users able to use the internet. Each OF-switch is directly connected to one access point (base station), which is responsible for serving some users' equipment (10 UE).

B. DISTRIBUTED CONTROL PLANE ARCHITECTURE

This control plane architecture was introduced to overcome the drawbacks of the centralized control plane architecture clarified before. This architecture consists of using multiple distributed controllers together, also known as cluster-based architecture [24], [33], [48]. The network is organized in clusters, a cluster with an SDN controller is called an SDN domain [40]. This network architecture reduces network size into SDN domains and hence ensures scalability due to the simplicity of control exchange between different domains. One of the key benefits of this control plane architecture is the quick decision response due to the availability of many controllers in the network. But this network architecture sometimes suffers from unbalanced load distribution and the constant synchronization of a large amount of data. This control plane architecture is costly due to the usage of many controllers in the network [16], [27], [28]. Hence, Fig. 4 presents the distributed control plane implementation with four distributed controllers that are all connected and at the same time connected to all OF-switches. Similar to the previous architecture all switches are directly connected to the internet. Also, each OF-switch is connected to one access point (base station). These base stations are distributed to serve a large number of mobile users. Each base station is connected to 10 stations (UE).

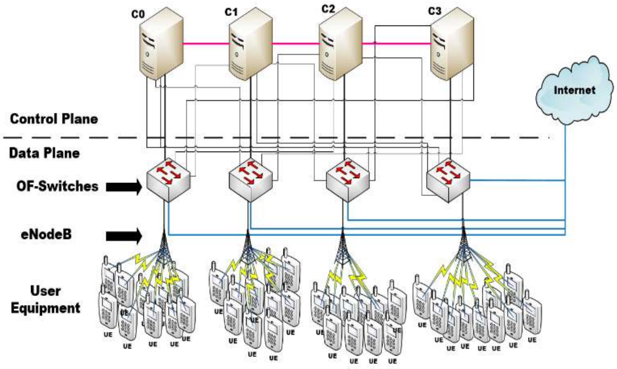

FIGURE 4. Distributed control plane architecture implemented.

C. LOGICALLY CENTRALIZED-PHYSICALLY DISTRIBUTED (LC-PD) CONTROL PLANE ARCHITECTURE

This SDN controller management architecture usually combines the advantage of using multiple controllers from the distributed control plane architecture, but at the same time considering the presence of a single controller logically [14], [26]–[28]. This network architecture is like that there is just one controller that commands the whole network. In other words, the LC-PD controller management architecture resembles the basic SDN control plane architecture, which uses a single controller, or a multicore controller to improve the performance. All distributed controllers have the same responsibilities in this control plane architecture and divide the charge equally. These distributed controllers are aware of any change in the network, and they have all the same information due to network synchronization. So in this control plane architecture, all distributed controllers have the same data control, but each controller is away from other controllers. Unlike the distributed controller management architecture, which consists of multiple distributed controller physically in the same area. In this architecture, each controller makes decision-based on the global network view.

Unlike the distributed control plane architecture, in which every controller has a view of the domain it is responsible for only, and hence can decide for it [26]. This SDN control plane architecture doesn't only improve the number of flow requests per second but also reduces the flow time for each flow request [16], [27], [28], [48]. We have implemented this control plane architecture in the 5G mobile network but with some modification. Fig. 5 illustrates the usage of many controllers that are physically distributed but logically acts as a centralized controller for its directly connected network. Also, all OF-switch are connected to the internet as in previous cases. All controllers are connected, but each OF switch is connected to only one controller. Each controller is responsible for handling different internet traffic. Each switch is directly connected to only one access point like other control plane architecture. Each access point can serve ten users. All stations are dynamic with a minimum speed of 1.25 m/s and a maximum speed of 1.3 m/s, this movement is in a random direction as in the case of the mobile user.

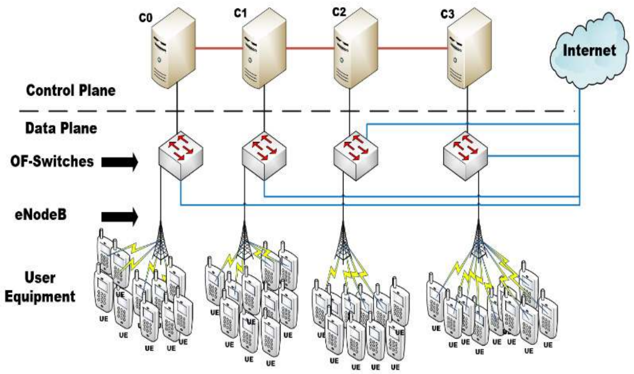

FIGURE 5. LC-PD control plane architecture implemented.

In our design, we have used different bandwidth in each access point (eNodeB) to generate different internet traffic. So, controller 1 handles web surfing and we have used 1 Mb/s bandwidth to represent this. Controller 2 was used for file transfer by using 3 Mb/s bandwidth. But, controller 3 was used for VOIP by using 5 Mb/s bandwidth. Controller 4 was used for video streaming using 7 Mb/s bandwidth. These bandwidths are just used for simulation to differentiate between different user applications.

The SDN model centralizes the control of the whole network in the controller. This will increase the risk of the entire network failure and availability. This by turn will affect the performance of the network as a result of the overhead in the control plane. This proves that the usage of a centralized controller will make the whole network at risk, so it is better to use many SDN controllers together to prevent failure and overhead. So, the number of controllers used in a network relies on the network characteristics among user requirements. This makes the centralized controller suitable in a small scale network. While for large scale networks like 5G mobile networks, multiple domains have to be created and multiple controllers should be used. In a domain, each SDN controller can control a part of the whole network like in any cellular network where the base station is responsible for serving some users. So, the major constraints that must be taken into consideration are the controller capacity, the number of domains in the network, and the inter-SDN controller communication approach. Also, the placement of these controllers in a network has a direct influence on the communication between switches and a controller, which by turn will affect the main performance functions such as latency, load-balancing, redundancy, connectivity, and survivability. Another issue that must be taken in concern, controller overload which happens when many switches are connected to the same controller, so we should distribute the load among controllers to avoid the controller congestion.

IV. PRELIMINARY EVALUATION AND RESULTS

The objective of this section is to ensure that the LC-PD controller management architecture is suitable in the case of a wireless network in general. This architecture also clarifies the benefits of using SDN in a 5G mobile network. So, we have used delay and throughput parameters to demonstrate that this control plane architecture is the one that can better enhance network performance. This control plane architecture is the one that possesses less latency and higher throughput compared to other implemented SDN controller management architectures as will be explained.

A. SIMULATION PARAMETERS

In this section, we have implemented the SDN in 5G mobile networks using the Mininet-WIFI emulator [47]. It is an open-source network emulator that can make networks from virtual stations, access points, and SDN controllers. We have used all different control plane architecture studied previously to choose the one with higher throughput and lower latency at the same time. We have demonstrated that the LC-PD control plane architecture is the one that provides better network performance and higher QoS. In all our simulation tests we have used the Open-Flow SDN controller, which uses the Open Flow protocol to connect and configure the network devices (routers, switches, etc.) to determine the suitable path for application traffic. Stations (user mobile) usually collect data and transfer it to the directly connected access point (base station) for this user. Then this data traffic is directed to the controller, in which there are all flow rules to direct all requests in the required direction. We have added some

TABLE 2. HTTP traffic specification.

Station	Station 1	Station 20
Sending Rate	5.5 Mbit/s	9 Mbit/s
Signal	-72 dBm	-74 dBm
Frequency	2.412 Hz	2.412 Hz
Transmit power	14 W	14 W
Distance Between Sta1 and Sta20	444.33 m	

internet services (HTTP traffic) on all stations to be able to run different web applications.

So, table 2 clarifies the main specification of the HTTP traffic used in all simulation tests between station 1 and station 20.

All stations in all simulation tests are mobile with dynamic motion (random direction model). We have supposed that the channel propagation loss in all simulated tests is 0.5 dB. We have used station 1 from area 1 and station 20 from area 2 for all measurements.

Table 3, clarifies the main simulation parameters used in each scenario to have a better overview of each network to be able to make the best decision.

TABLE 3. Simulation parameters.

Control plane type	Centralized control plane	Distributed control plane	LC-PD control plane
Number of stations	40	40	40
Number of the access point	4	4	4
Number of switches	4	4	4
Number of controllers	1	4	4
Min speed of stations	1.25 m/s	1.25 m/s	1.25 m/s
Max speed of stations	1.3 m/s	1.3 m/s	1.3 m/s
X	1000 m	1000 m	1000 m
Y	1000 m	1000 m	1000 m
Test duration	20 s	20 s	20 s
Note: Access point are fixed in all scenarios only stations are moving in mobile scenarios			

We choose the delay and throughput parameters to clarify the architecture that best serves the 5G mobile networks.

The measured delay between two stations (two mobile users) is expressed as

$$\text{Delay} = \text{Uplink Time} + \text{Downlink Time [44]}, \tag{1}$$

The throughput between different stations is given by

$$\text{Throughput} = \text{Number of received packets} \\ /\text{Transmission time}(b/s), \tag{2}$$

We have also used the confidence interval [3] in calculating delay and throughput. The confidence interval is the probability of a value falling between the upper and lower bound of a probability distribution. So, we have also used the recommended confidence interval of 95% to have a better overview using different readings according to

$$C = \bar{X} \pm Z\frac{S}{\sqrt{n}}, \tag{3}$$

where $\bar{X}$ is the mean, Z is the chosen Z-value from the table of the confidence interval and it is 1.96 in case of a 95% confidence interval. S is interpreted as the standard deviation and n is the number of observations and it was taken 5.

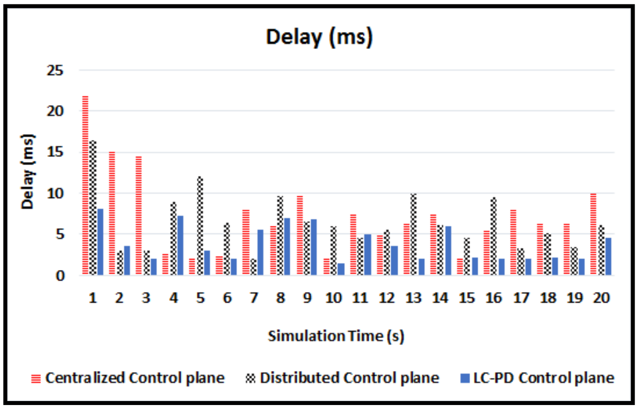

FIGURE 6. Delay of Centralized vs. Distributed vs. LC-PD control plane architecture during the 20s.

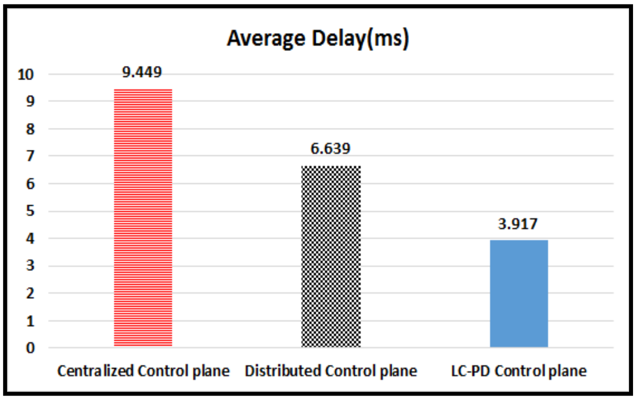

FIGURE 7. Average Delay of Centralized vs. Distributed vs. LC-PD control plane architecture during the 20s.

B. FINDINGS AND RESULT CONCLUSION

As clarified before, each base station can serve ten stations. So, we begin by calculating the delay for each station in the different controller management architecture aforementioned. To make a clear comparison between different control plane architecture, the delay is calculated between station 1 which is connected to access point 1 and station 20 which is connected to access point 2 in all scenarios. Similarly, throughput was calculated between station 1 and station 20 in different architectures for comparison. But, at the same time, all other stations connected to different stations are sending and receiving (not idle). We have only highlighted access point 1 and access point 2 to be able to compare readings from the same stations. So, Fig. 6 presents the measured delay between station 1 and station 20 during the simulation time of the 20s. Fig. 7 clarifies the average value of delay during the 20s of simulation time presented in Fig. 6. This indicates that the delay increases in the centralized scenario more than others and it is minimum in LC-PD control plane architecture. This due to the presence of many controllers in LC-PD controller management architecture, which all have some information policies about all stations. This plays an important role in reducing overhead in the network and hence improves network performance.

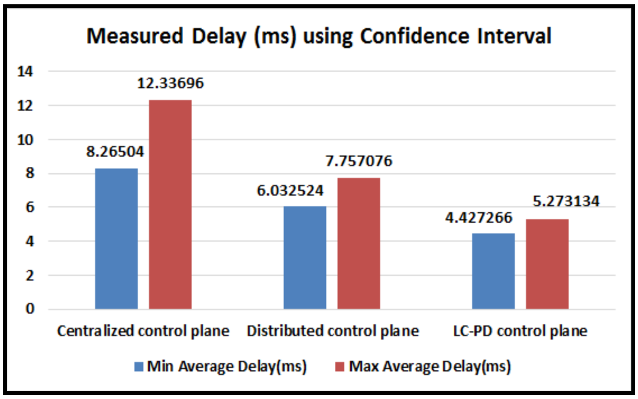

FIGURE 8. Measured delay of Centralized vs. Distributed vs. LC-PD control plane architecture using confidence interval (95

Then, Fig. 8 explores the possible interval of measured values of delay in each SDN architecture between station 1 and station 20. We have used a 95% confidence interval to calculate the probability of measured values during five rounds each one lasts 20s. This experiment is held to get more precise readings about the delay by taking many readings because the motion of user equipment is random. This by turnassures that the LC-PD control plane architecture possesses fewer delay values compared to other control plane architecture.

According to the previous readings using the confidence interval, the percentage change in the measured delay is expressed as

$$\text{Change rate} = \frac{\text{Max delay} - \text{Min } \textbf{delay}}{\text{Avg delay}} \times 100, \tag{4}$$

where Max delay is the maximum delay, Min delay is the minimum delay measured and Avg delay is the average delay measured.

Table 4 clarifies the different percentages of the delay change rate of each control plane architecture.

This table shows that the LC-PD control plane architecture is the best choice for the 5G network with less delay change percentage.

TABLE 4. Percent relative change of delay.

Controller architecture	Max. Delay	Min. Delay	Avg. Delay	Percent change Rate %
Centralized	12.33696	8.26504	10.301	39.5 %
Distributed	7.757076	6.032524	6.8948	25 %
LC-PD	5.273134	4.427266	4.8502	17.4 %

Throughput was measured between station1 (sta1) and station20 (sta20) by supposing sta20 as a server and sta1 as a client. So, when sta1 calls sta20, the request will be first transferred from sta1 to ap1. Then ap1 will after that send the request for its logical controller. Finally, the controller will handle the request to ap2 and sta20 will answer ap1. So, throughput was measured between sta1 and sta20 during that call.

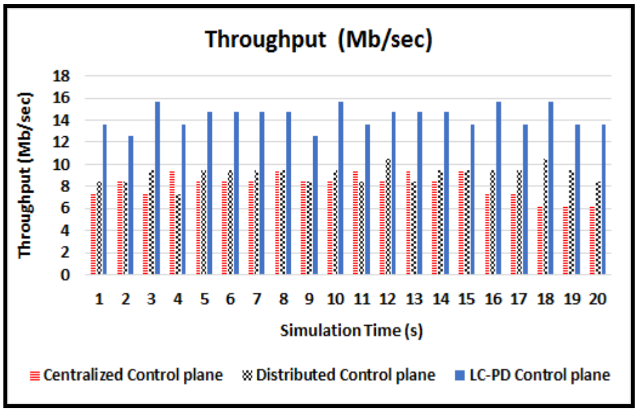

FIGURE 9. Throughput of Centralized vs. Distributed vs. LC-PD control plane architecture during the 20.

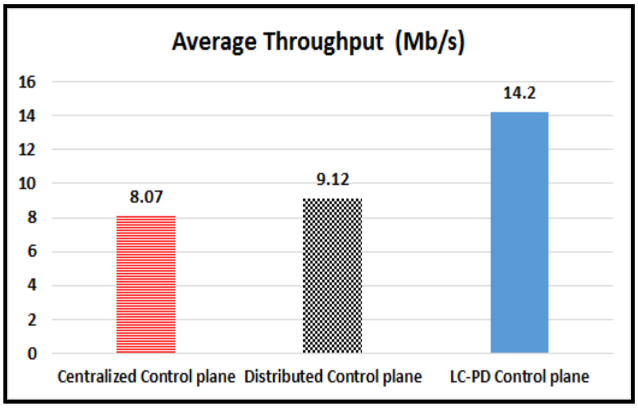

FIGURE 10. Average Throughput of Centralized vs. Distributed vs. LC-PD control plane architecture during the 20.

The obtained results in Fig. 9, shows the values of measured throughput during the 20s of simulation time. But we can see that the LC-PD controller management architecture readings are much higher compared to other control plane architecture. The obtained results in Fig. 10, represents the average value taken during the 20s of simulation time presented in Fig. 9.

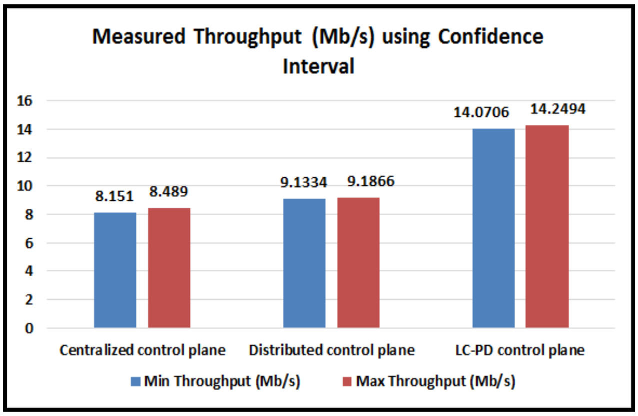

FIGURE 11. Measured Throughput of Centralized vs. Distributed vs. LC-PD control plane architecture using confidence interval (95%) during five rounds.

This proves that throughput is minimum in centralized architecture but higher in LC-PD control plane architecture than in other scenarios, which makes this controller management architecture better than others in network improvement. Hence, Fig. 11 presents the measured throughput values in each SDN controller management architecture using a 95% confidence interval.

This experiment helps get more precise readings by taking many readings, because of the random motion of user equipment. This experiment is processed during five rounds, each of these rounds lasts for 20s. Then we calculate the minimum and the maximum of these readings to get the average reading of throughput in all scenarios. This explores that LC-PD control plane architecture is the one with the highest throughput value compared to other control plane architecture studied.

According to the previous readings using the confidence interval, the percentage change in the measured throughput is given by

$$\text{Change rate}=\frac{\text{Max throughput}-\text{Min }\mathbf{throughput}}{\text{Avg throughput}}\times 100, \tag{5}$$

where Max throughput is the maximum throughput, Min throughput is the minimum throughput measured and Avg throughput is the average value of throughput.

TABLE 5. Percent relative change in throughput.

Controller architecture	Max. Throughput	Min. Throughput	Avg. Throughput	Percent change Rate%
Centralized	8.489	8.151	8.32	4 %
Distributed	9.1866	9.1334	9.16	0.6 %
LC-PD	14.2494	14.0706	14.16	1.3 %

Table 5 clarifies the different percentages of the throughput change rate of each control plane architecture.

We concluded that the LC-PD control plane architecture has the highest change rate in throughput but at the same time, it is the control plane architecture with the highest throughput values.

So, as seen from previous simulation results we have proved that the LC-PD controller management architecture is usually the one with less delay, higher throughput and hence better network performance than others. This control plane architecture is better than a distributed control plane architecture as in this architecture each switch is connected to only one controller. By turn, each of these controllers has some caching information from other controllers as they are connected. But, in distributed controller management architecture all switches are connected to all controllers, which are all similar in serving service and possess the same information. This makes the connection longer in case of the unavailability of a controller in the distributed control plane architecture. This enhances network performance when using the LC-PD controller management architecture compared to the distributed one. This also clarifies the benefit of implementing SDN in the wireless environment in general including mobile network, IoT and Wireless Sensor Networks.

V. CONCLUSION AND FUTURE WORK

In this paper, we have studied the rise of the 5G and its main challenges. This cellular network consists of a large number of connected devices and therefore a large amount of data is generated. So, to cope with this issue, we have applied SDN into this mobile network to improve communication efficiency and QoS of running Internet services. We adopted the LC-PD controller management architecture into this cellular network to better enhance the network performance compared with other SDN control plane architectures. Then we have simulated and compared the different studied SDN control plane architecture using Mininet-WIFI. We concluded that the LC-PD controller management architecture is the one with less latency and higher throughput. Our next set of experiments are held to enlarge the tested environment area using different application scenarios. At the same time, a lightweight communication protocol enabling low overhead communication between various SDN controllers will be addressed and simulated in our tests.

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