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Improving 5G Network Operations with Software-Defined Network Control

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Abstract

The fifth generation (5G) mobile network is being created to keep up with the Internet of Things (IoT) and the rapid expansion of communication technologies, which generate large amounts of data. This mobile network provides expanded communication features for cellular phones. However, there are limitations to this strategy. Programming Characterized Organization (SDN) technology is being developed as a basic solution to the problem of dealing with many devices running multiple administrations. In 5G portable organizations, SDN architecture improves adaptation, versatility, cost-effectiveness, and energy efficiency. Many alternative designs are often utilized to build the SDN control plane. For 5G networks, we analyze several setups and recommend using the. Controller management architecture for Logically Centralized-Physically Distributed (LC-PD) systems. This solution outperforms traditional control plane systems, delivering superior throughput and reduced latency. This study demonstrates how the LC-PD control plane architecture improves internet services' QoS and communication efficiency in 5G mobile networks. We conduct simulation experiments utilizing the Mini net-WIFI emulator. Our simulations show that the LC-PD control plane architecture increases the quality of service (QoS) compared to other SDN implementations of Internet services in 5G networks.
Keywords: Software-Defined Networking (SDN), 5G networks, network administration, and controller placement.

1. Introduction

The latest version of cellphone technology is referred to as 5G. This is the oldest and most recent edition of the mobile communication system. Wireless technology used in mobile devices is more complex than fourth-generation (4G) technology, allowing for unlimited international connections and other benefits (Eze, Kelechi G., Matthew NO Sadiku, et al. 2018).

Unlike previous generations (for example, 4G), 5G technology increases connection by offering users cloud-based services. 5G networks are built on cloud computing, virtualization, and software. This cellular technology enables the Internet of Things (IoT), other emerging technologies, and the increased need for information and communication. This mobile technology supports virtual private networks (VPNs) and the Wireless World Wide Web. Furthermore, this mobile network optimizes spectrum usage (Yonghong, et al 2015).

Contrary to the current 4G mobile standard, the 5G standard features a new wireless interface that supports high-frequency bands, enabling mobile technology to also support flat IP and IPv6 (Patil, Ganesh R et al. 2012). Instead of utilizing standard IP addresses to identify devices, flat IP design uses symbolic names. 5G wireless operates in the 3-300 GHz frequency spectrum employing Orthogonal Frequency Division Multiplexing (OFDM) (Gupta, et al.2016).

Unfortunately, some things could be improved with this mobile communication technology. One key barrier to the 5G network is the high expense of transitioning from 4G to 5G. Older mobile generations (Vitthal, 2016) have less compatibility with this technology. It is challenging to manage a large number of linked devices and services on the 5G mobile network. Flexibility is required to manage networks and overcome limits in the mobile age. The architectural flexibility of 5G mobile networks will increase with the usage of Software Defined Networks (SDN). SDN separates traffic into control and data planes and manages it using software. Network isolation improves administration, scalability, flexibility, and dependability (A., et al. 2019). The Software-Defined Networking (SDN) architecture revolutionizes traditional network hardware, such as switches and routers, by decoupling their cognitive functions - like routing, processing, and management - and consolidating control in a centralized SDN controller unit, which orchestrates all network operations(Fu, Yonghong, et al.2014).

Controller placement is an essential consideration in SDN networks. In addition, the number of controllers installed affects network performance. Various SDN architectures can influence network performance. SDN may be installed based on the controllers' number, positioning, and network connection. Three SDN control plane designs were examined: centralized, distributed, and LC-PD. As discussed in Section III, the distributed control plane architecture was formerly widely employed to eliminate single points of failure. As will be proven later, we have successfully demonstrated that the LC-PD controller management architecture is the most usable control plane design for a 5G network. Our simulation findings indicate that the LC-PD controller management architecture best suits a 5G network (Kgotlaetsile Mathews, et al. 2019).

This article examines how the 5G mobile network uses the LC-PD control plane architecture. This control plane design enables effective Quality of Service (QoS) management for various services. SDN allows for more flexible network administration. Consequently, the 5G mobile network will become simpler and more cost-effective (Kobo et, al. 2019). Network clustering is the foundation of the LC-PD control plane design. The following is an overview of the paper's key contributions. The LC-PD control plane architecture may be used to run a variety of services with high efficiency and quality.

- Integrating SDN into the 5G network reduces complexity and costs.
- The LC-PD control plane architecture optimizes QoS and efficiency while operating several services simultaneously.
- Implementing SDN in 5G networks can minimize complexity and expenses.

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This is how the remainder of the article is organized. Section II introduces the 5G mobile network and how SDN-based management may handle a variety of difficulties. It also summarizes previous research on utilizing SDN to govern a 5G network. Section III describes many SDN ideas for the 5G mobile network. After assessing a variety of SDN control plane architectures, Section IV concludes that the LC-PD is the best option for 5G networks. Section V finishes the article and discusses future research (Hicham et al., 2018).

2. Literature Review

The IP-based 5G mobile system paradigm covers applications for wireless and mobile networks. The 5G network's architecture consists of a variety of user terminals and Radio Access Technologies. The 5G Organization Design makes distributed computing assets (CCR) available for all IP-based versatile applications and administrations, including versatile gateways, internet businesses, medical services, and government. Clients may use distributed computing to access their information from any web-connected device and use apps without needing to install them. Figure 1 displays a 5G network's fundamental architecture (Jie, et al., 2019)

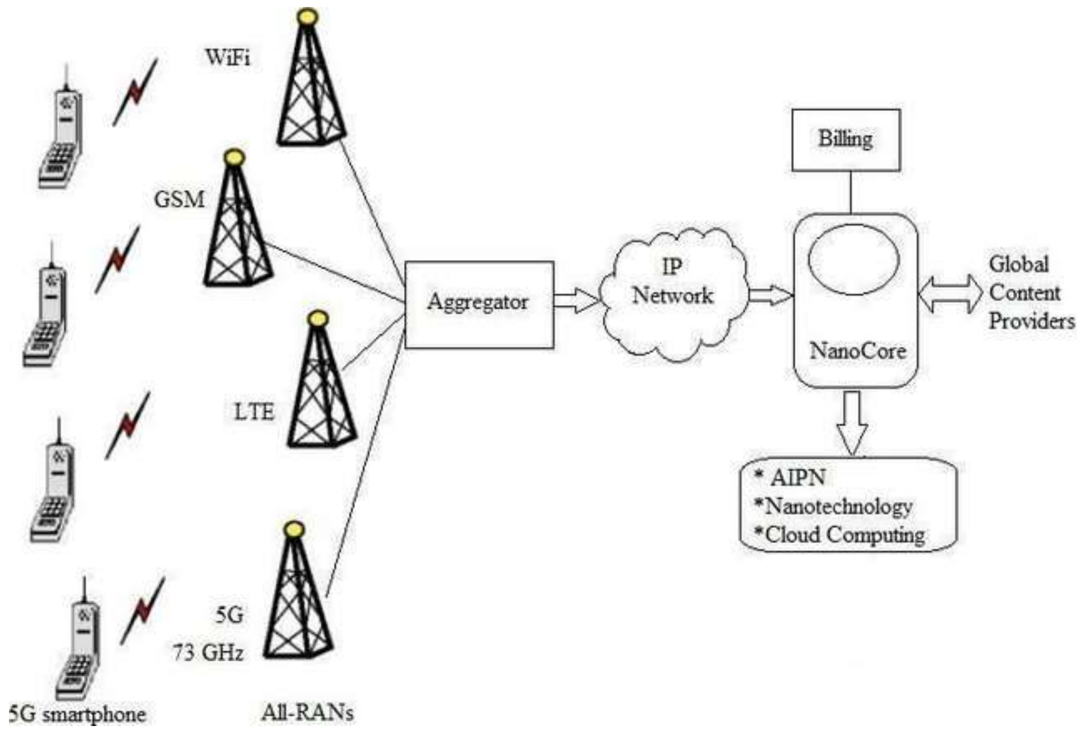

Figure 1: 5G Network's Fundamental Architecture (Arunachalam, S., et al.).

2.1. 5G Components

This mobile technology provides various benefits over prior cellular networks, including:

- **Faster Than Ever Before**

The biggest benefit of 5G connectivity is its speed. Approximately 1,000 times faster than 4G devices 5G devices may achieve data rates exceeding 10 GB/s. Faster internet gaming and 4K video streaming are made possible by higher throughput rates. This system can accommodate over 65,000 simultaneous connections and has a big broadcast capacity. Increased bandwidth will result in much shorter average reaction times (1 ms in 5G and 45-50 ms in 4G).

- **Energy Borrower**

The high transmission speed removes the inconvenience of waiting for online pages to load. Low battery consumption and latency (stop delays) in 5G applications can reduce network energy usage by 90% while increasing battery life by up to ten years (Yonghong, et al 2015).

- **Economical and reliable**

Compared to previous networks, 5G will be more efficient and effective. Faster speeds, lower latency, higher quality, and bidirectional shaping of enormous bandwidths are all available. New technologies, such as remote-controlled cars and wireless virtual reality headsets, will enhance transportation (Yonghong, et al 2015).

- **Responding to the Last Mile Issue**

5G technology addresses the issue of poor network coverage in rural and semi-urban areas, known as the "last-mile problem." Many concerns primarily affect sophisticated countries, such as the fact that high-speed fiber-based networking is not economically feasible in the United States, making it an option for many professions. 5G technology permits the establishment of powerful wireless hotspots, increasing internet availability in non-urban areas.

- **Support for Parallel and Diverse Services**

Bigger antenna diameters, much bigger bandwidths, and bi-directional bandwidth shaping are just a few of the technologies that will propel 5G mobile technology forward. Many features may be utilized concurrently by users, such as tracking weather updates while on the phone. High-end services and private networks will be feasible because of 5G technology's resiliency.

2.2. Importance of 5G for IoT

The Internet of Things revolution will focus on 5G wireless technology, artificial intelligence, and edge computing. 5G technology is expected to impact significantly and expand the possibilities for the contemporary Internet of Things (IoT), as well as clever city applications, cunning modern programming, connected auto charging, and smart homes and buildings. 5G is ideal for mission-critical IoT deployments because it offers seamless mobility, low latency, scalability, and dependability. Because of its increased efficiency and network capabilities, 5G technology will be the driving factor behind large IoT.

2.3. How its 5G works

5G technology is expected to achieve high efficiency and performance by leveraging advanced modulation techniques and optimized network conditions, including

- **Carry a Grouping**
  - ❖ Transporter collecting is a complex technology in LTE that enhances its feasibility. Carrier aggregation combines several signals to create a bandwidth of up to 100 MHz. The collecting of transporters uses three total techniques:
  - ❖ Intra-band trading occurs when two transporters share adjacent channels.
  - ❖ Non-adjoining intra-band transmission involves two transporters with a channel separating.
  - ❖ This technique utilizes several LTE bands simultaneously for transmission.
- **Small Cell Structure**

5G networks are made up of cells separated into zones. These cells use radio waves to communicate. Each cell communicates with the organization's spine via wired or remote connections. Micro and Pico cells are utilized to split cells and create more efficient networks. The reuse range accommodates more consumers in a limited area and improves network efficiency.

- **Multiple Input Multiple Output (MIMO)**

5G considerably improves network capacity by utilizing Multiple Input Multiple Output (MIMO). MIMO is a transmission technology that uses multiple antennas to broadcast and receive data. This technique, which allows for simultaneous information transfer, may attain a high data rate. Adding extra antennas improves data transmission and reception.

- **WIFI Unburdening**

WIFI unburdening is an essential feature of future networks. This function enables users to communicate over WiFi and share their cellular network with others. This option is appropriate for places with poor cellular network quality, as it allows users to connect even without cellular reception.

- **Device to Device Communication (D2D)**

Direct-to-Gadget (D2D) correspondence permits two gadgets to cooperate straightforwardly across an organization (30, 34). The organization will incorporate gadget control, allowing operators to route data between direct and network pathways. According to (Abhishek, and Bhavesh et, al.2012) devices can connect even when the network is unavailable.

- **Cloud Radio Access Network (C-RAN)**

Effective connection with remote centralized information processing within a cloud system is made possible by a network technology called C-RAN. Signal processing occurs remotely, using optimal fiber optic lines connecting base stations. It provides several benefits for effective network upgrades, improvements, testing, monitoring, and maintenance (Yonghong, et al 2015).

2.4. 5G Network Challenges

Although this cellular network offers several benefits, it also faces various obstacles, including:

- **Multiple Servers**

5G stands apart from existing radio signals due to its ability to connect diverse networks, procedures, and devices beyond geographical boundaries. Standardization aims to provide wireless services that are dynamic, universal, user-centered, and data-rich, meeting high expectations (Tanzeena et al. 2016).

- **Cost Factors**

5G technology is incompatible with prior generations. This approach lays the basis for a new network rather than just adding a layer to an existing one. Building a network is expensive, and carriers will incur additional costs. 5G technology requires trained engineers to construct and operate networks, and the equipment is costly, leading to higher deployment and maintenance costs.

- **Old Devices May Be Out of Use**

As 5G technology advances, older devices may become obsolete due to incompatibility with newer capabilities. To use 5G, individuals must acquire new cell phones instead of relying on outdated ones. This may result in additional expenses (Israat Tanzeena et al. 2016).

- **Deployment and Coverage**

The coverage range is limited to 300 meters outside and 2 meters within due to higher frequency losses. Because 3G networks require less bandwidth, they can cover wide areas with fewer cells. Fewer cells had to be deployed by networks since more bandwidth results in a smaller coverage area. Like LTE, expanding service to rural regions will not be easy. Coverage can drop more often than it would over a 3G network. To achieve the high bandwidth of the 5G network, additional cell towers are needed due to the cells' limited coverage compared to 3G or 4G networks (Mauro Conti et, al. 2019).

- **Ultra-low latency network**

Ultra-low latency is necessary for self-driving cars and mission-critical apps to operate correctly. Delays in mission-critical programs might result in disastrous effects. Medical applications like remote surgery require a delay of less than 1 millisecond (Yonghong, et al 2015).

- **Security**

One of the most crucial elements of any wireless communication system is security. End-user privacy and safety must be given top priority in a 5G network. Network safety management is difficult because there are many connected devices and different approaches. The promise of the Internet of Things (IoT) is to simplify life for many, but it also exposes personal information through data interchange (Israat Tanzeena et al. 2016).

- **Reliability**

We already explained that MIMO is used in the 5G mobile network. Complicated MIMO antenna arrays are required for high-speed data transmission. Complex algorithms and device capabilities are needed for MIMO technology, which is used in base stations and consumer electronics. The new wireless transmission system will use beam shaping to send data to consumer devices, reducing energy waste. This strategy reduces base station operational power. Beamforming, which involves finding each device inside a cell, is a complex activity that demands significant computing power from base stations. SDN is a canny systems administration that utilizes little equipment. SDN enhances 5G remote organizations by making it feasible for digitalization, network virtualization, and the production of new administrations related to virtualized assets. In 5G organizations, SDN standards efficiently handle problems related to radio resource control, such as RAN sharing, mobile edge computing, and interference control (Israat Tanzeena et al. 2016).

In SDN design, the open-flow protocol is used to specify the logical and physical components of a data stream as well as data structures, messages, and operations. Additionally, it carries out conventional control plane tasks including flow management, routing table maintenance, and packet modification. The IPv6 features supported by this protocol include access control, tunneling via IPsec and VPN, and quality of service (Mauro Conti et, al. 2019). To cooperate with center gadgets, keep up with network geographies, make new streams, and gather information to fulfill QoS necessities, the regulator in 5G portable organizations utilizes an Open stream convention. SDN will further develop access control, information honesty, mystery, confirmation, and other security highlights in the 5G organization. At the point when SDN is utilized in a 5G versatile organization, control plane information is sent from center organization hubs to sending components and sends data to the centralized controller node.

SDN provides a foundation for 5G to perform over a control plane. It can also improve data flow throughout the 5G network. SDN allows for centralized management and automation of network redundancy. Integrating SDN with 5G mobile networks reduces network modifications, introduces centralized management, and improves programmability. This allows for resource sharing across mobile carriers. This mobile solution supports IPv6 and SDN, resulting in scalability, operational savings, enhanced management, and improved network performance (Israat Tanzeena et al. 2016).

Although SDN has technological advantages like dynamic behavior, performance issues with network security, and dependability may arise from separating the control and data planes. Additionally, it may result in fresh difficulties, like the controller location problem (Mohamed RM Rizk et al. 2020).

The goal of this challenge is to find the best controller position for a specific SDN topology. The separation concept affects both fixed and dynamic network performance. To ensure maximum performance, switches should be connected to controllers through a dedicated network, and assigned to the closest controller. This setup helps avoid packet loss and other issues by minimizing controller failures and disconnections between the control and data plane. To build and plan fixed and mobile networks, controller placement must consider the functional ideas of SDN networks.

The adoption of SDN to manage 5G networks for improved performance and flexibility. The authors suggest an area controller and a domain controller are the two types of controllers in a distributed control plane design. A territory that is under the authority of a single SDN controller is called an area. The suggested hierarchical architecture addresses two major issues: future network expansion and the stretch path problem (Mohamed RM Rizk et al. 2020).

3. Methodology

3.1. Software Define Network (SDN) of 5G Networks

The SDN idea allows for more flexible network administration by separating software for managing traffic on the control and data planes. The Software Defined Network Controller, a centralized device that oversees the whole network, makes up the SDN control plane. The location of the SDN controller will impact network performance. Therefore, Mininet-WIFI emulates a variety of SDN control plane topologies, including distributed, centralized, and LC-PD control plane architectures (Mathews, et al. 2018).

The fundamental SDN control plane design involves managing the whole network with a single controller. This design gives a global network picture, allowing for more informed decisions. Because it lacks redundancy and produces a single point of failure, using a single controller in a network may be vulnerable. Because of the great distance between the control and data plane devices, this design presents problems with performance, congestion, scalability, and reliability. A small-scale network can use this control plane design. A simulated centralized control plane configuration with a single controller. In this case, mobile users can access the internet through four Open-Flow switches (OF-switches) connected to a single controller. Ten UEs are served by a single access point (base station) connected to each OF switch (Israat Tanzeena et al. 2016).

3.2. Distributed Control Plane Architecture

This new control plane design overcomes the limitations of the previous centralized architecture, providing a more efficient and resilient network control solution. This system, sometimes referred to as cluster-based architecture, makes use of several distributed controllers. Clusters with an SDN controller are referred to as SDN domains. This network design divides the network into SDN domains, allowing for scalability through easy control interchange between them (Mohamed RM Rizk et al. 2020). The control plane architecture's availability of several controllers in the network allows for rapid decision response, which is a crucial feature. However, this network design might have imbalanced load distribution and requires continual synchronization of big data sets. The control plane design is expensive due to the network's number of controllers. A control plane system with a distributed architecture that includes four controllers connected to each OF switch is seen in Figure 4. All switches have direct connections to the internet, just like in the prior architecture. Every OF switch also has a single access point (base station) linked to it. Several base stations are spread out to serve a large number of mobile users. Ten user equipment (UE) stations are connected to each base station (Mauro Conti et, al. 2019).

3.3. LC-PD Control Plane Architecture

This SDN controller architecture takes the benefit of numerous controllers while conceptually considering existence of a single controller. Network topology, a single controller directs the whole network. The LC-PD is similar to the fundamental SDN control plane design, which utilizes a single or multicore controller to enhance performance. In this design, all dispersed controllers share equal duties and charges (Mathews, et al. 2018). Network synchronization ensures that dispersed controllers are aware of changes in the network and have consistent information (Hamid & Iqbal, 2022). In this control plane design, dispersed controllers share data control but are isolated from one another (Mohamed RM Rizk et al. 2020). Unlike the distributed controller management design, where numerous controllers are physically located together. In this design, each controller makes choices using the global network view. Every controller is located in charge of managing various types of internet traffic. Each switch connects directly to a single access point. Each access point supports 10 users. Stations move randomly, at speeds between 1.25 to 1.3 meters per second, similar to mobile users.

Our system generates distinct internet traffic by leveraging different bandwidths in every access point (eNodeB). Web browsing is handled by Controller 1, which has a bandwidth of 1 Mb/s. Controller 2 has used a bandwidth of 3 Mb/s to send files. Controller 3 with a 5 Mb/s bandwidth was used for VoIP. A bandwidth of 7 Mb/s was used for video streaming via Controller 4. Only simulation is utilized to differentiate between user applications using these bandwidths (Mauro Conti et, al. 2019).

Much like base stations in cellular networks cater to individual users, SDN controllers can control a section of the network (Hamid, Iqbal, Ashraf, Alghamdi, Bahadad, & Almarhabi, 2022). The number of network domains, controller capacity, and inter-SDN controller communication strategy are the three basic constraints to take into account. Controller placement in a network affects performance aspects including latency, load balancing, redundancy, connectivity, and survivability via influencing communication between switches and controllers (Hamid et al., 2023). It's critical to distribute the load amongst controllers to reduce controller overload brought on by multiple switches connected to a single controller (Mohamed RM Rizk et al. 2020).

4. Results

This section assesses the suitability of the LC-PD controller management architecture for wireless networks. This design highlights the advantages of implementing SDN in a 5G mobile network. We utilized latency and throughput characteristics to show that the control plane design improves network performance. This control plane design outperforms previous SDN controller management systems in the context of throughput and latency (Mathews, et al. 2018).

4.1. Parameters

The Mininet-WIFI simulator was used to implement in 5G mobile networks. This open-source simulator enables the creation of virtual networks featuring virtual stations, access points, and SDN controllers (Hamid, Muhammad, Iqbal, et al., 2022). We examined all of the previously analyzed control plane designs to select the one that provided more throughput while also having reduced latency. Our findings demonstrate how the LC-PD control plane design improves QoS and network performance. The Open-Flow SDN controller, which links and sets up network elements (such as switches and routers) to determine the best routing for application traffic, was used in our simulation research.

Data is collected by stations, or mobile devices, and sent immediately to the user's directly linked base station. The controller receives data traffic and route requests according to flow rules. We made internet services (HTTP traffic) available to every station to support various online applications.

Table 1: HTTP traffic

Station	Station 1	Station 20
Sending Rate	55 Mbit/s	9 Mbit/s
Signal	-72 dBm	-74 dBm
Frequency	2.412 Hz	2.412 Hz
Transmit Power	14W	14W
Stations 1 To 20	444.3m	444.3m

Table 1 specifies the HTTP traffic utilized in simulation testing between stations 1 and 20. During simulation tests, all stations move dynamically in random directions. In all simulations, we assume a channel propagation loss of 0.5 dB. All measurements were taken at stations 1 and 20 in areas 1 and 2, respectively.

4.2. Findings

As previously stated, each base station may service 10 stations. To begin, we calculated the delay for each station using the different controller management architectures outlined above. To compare control plane architectures, we evaluate the delay in every situation, between station 1 (linked to access point 1) and station 20 (linked to access point 2). For comparison, throughput was also calculated for stations 1 through 20 over a range of topologies. Every connected station sends and receives simultaneously (not idle). Simply put, we have marked access points 1 and 2 in other readings from the identical stations. The measured latency between stations 1 and 20 throughout the 20s simulation is displayed in Figure 2. The LC-PD control plane design has the lowest delays while the centralized scenario has higher delays. The architecture of the LC-PD controller management has many controllers, each with its own set of information rules for all stations. This helps reduce network overhead and increase speed (Mohamed RM Rizk et al. 2020).

For network augmentation, the LC-PD control plane design is a preferable option because it performs better in terms of throughput than the centralized architecture. Provides measured throughput values with a 95% confidence interval for every SDN controller management architecture. Several readings are necessary because user equipment moves unpredictably, leading to more accurate results. There are five rounds in the experiment, each lasting twenty minutes. We compute the minimum and maximum readings to calculate the average throughput under all conditions. According to this study, the LC-PD control plane design fared better in terms of throughput than other control plane structures (Yonghong, et al. 2014).

The LC-PD control plane design boasts the highest throughput gains and maximum throughput values. As previously observed in simulations, the LC-PD controller management design yields improved network performance, marked by lower latency and higher throughput. This control plane design is superior to scattered control planes because it connects each switch to a single controller (Mathews, et al. 2018). Each controller receives caching information from linked controllers. In a distributed controller management architecture, all switches link to identical controllers that serve comparable services and share the same information. In a distributed control plane design, the connection becomes longer if a controller is unavailable. Using an LC-PD controller management design improves network performance over a scattered one. This also highlights the advantages of applying SDN in the wireless environment in general, such as mobile networks, IoT, and Wireless Sensor Networks.

4.3. Delay LC-PD

"Delay = Uplink Time + Downlink Time" is the formula used to compute the delay between two stations, or mobile users. The number of packets received divided by the transmission time (b/s) yields the throughput between stations.

We also used the confidence interval to determine throughput and delay. The chance that a value will lie between the upper and lower bounds of a probability distribution is known as the confidence interval (Yonghong, et al. 2014). We used a 95% confidence interval with various readings to help provide a greater understanding; in this case, the Z-value from the confidence interval table is 1.96, and X¯ is the mean. The number of observations, n, is represented by the symbol S, and it was fixed at 5 (Mathews, et al. 2018).

C=X¯±ZSn

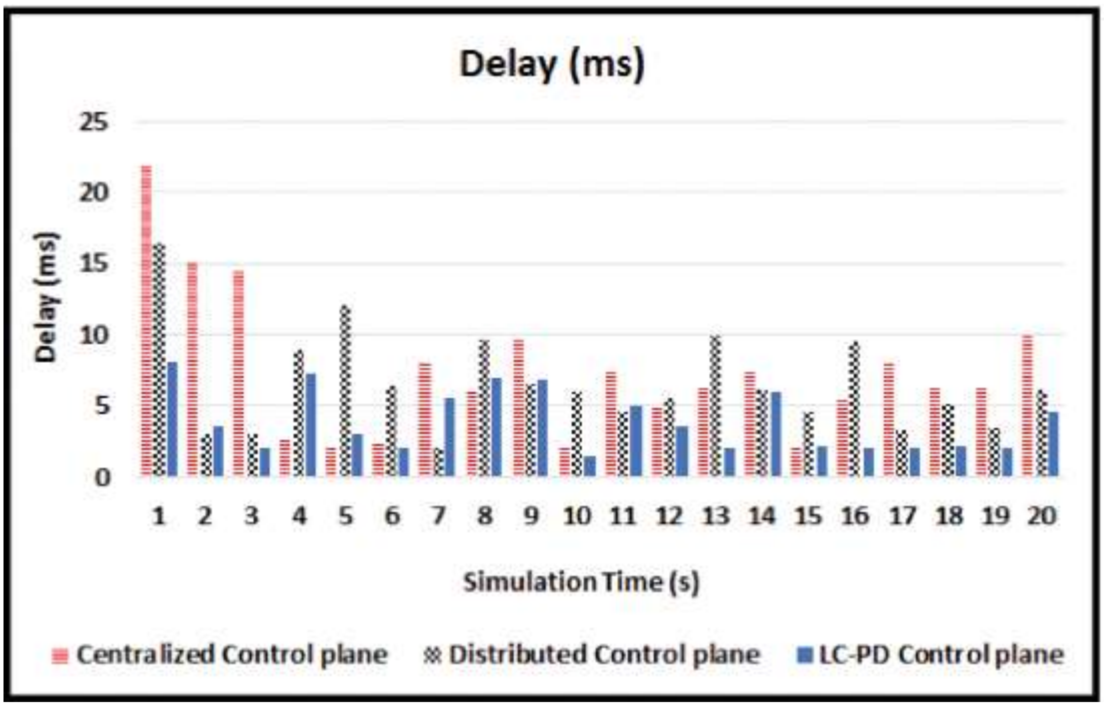

Figure 2: Delay LC-PD Control

5. Conclusion

This study examines the emergence of 5G and its key problems. The cellular network generates significant amounts of data due to its many linked devices. To address this issue, we used SDN on the mobile network to improve Internet service quality of experience and communication effectiveness. In our cellular network, we leveraged the LC-PD controller management architecture to outperform other SDN control plane architectures in terms of performance. Using Mininet-WIFI, we compared and simulated various SDN control plane designs. We discovered that the LC-PD controller management scheme offers higher throughput and reduced latency. Our next round of tests aims to expand the testing environment by utilizing other application situations. Our testing will focus on a lightweight communication PR protocol that allows for minimal overhead communication across SDN controllers.

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