CP-SDN: A New Approach for the Control Operation of 5G Mobile Networks to Improve QoS

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Abstract-Today, the Software Defined Network (SDN) technology gives more efficiency and flexibility to the 5G mobile networks that are expected to support an enormous amount of data relating to various constrained services. The 5G network should implement newer approaches and technologies that allow supporting the scalability and mobility of the network. The SDN approach consists of decoupling between the control operation and the networking operation, where the control operation is held by the SDN controller that is responsible for defining the management and the control rules. Data forwarding is performed by switches that apply rules defined by their controllers. In the current study, we have proposed and defined a new approach named CP-SDN: Cooperative Protocol-SDN, as an extension to the existing Software Defined Networks, especially when the network experiences saturation due to the huge amount of exchanged data. This congestion may affect the constrained flow and leads to an undesired delay that affects the network Quality of Service (QoS). CP-SDN consists of a cooperation technique between neighboring controllers that aims to relieve the congested centers and redirect the extra flow through neighbors. CP-SDN processing keeps controller databases updated and assures the optimized path for the extra flow when network congestion occurs. The performed simulations on calculating the e-Mbb and M-iOT delay performances for various probability densities show that CP-SDN brings more reliability and efficiency in reducing the transmission delay and overcome the existing SDN scheme. This makes it a prime candidate for the evolved high scalable 5G networks.

Keywords-5G; SDN; CP-SDN; QoS; IoT; m-IoT; eMBB; MFT

I. Introduction

A huge increase of exchanged data is conducted globally by the deployment of 5G networks. These networks are expected to support several media services that need very high speeds, even Internet of Things (IoT) networks that contain a dense amount of connected devices with different requirements and constraints. 5G networks are deployed to satisfy the need of multiple vertical industries over a shared infrastructure with the use of concepts inclusive of community slicing [1]. Regarding the transport stream held by 5G, video-primarily based totally clients represent a big portion of the data stream carried, with approximately 79% of cell information [2]. The significant increase of the connected smart devices with greedy smart applications like video streaming, requires a higher spectral efficiency and represents a big challenge of 5G [3]. Authors in [4] illustrate that 5G is expected to reach 4.7 times more data amount than the regular 4G, with more than 12.3 billion users, which exceeds the world population, in the next decade. The new 5G network systems need to deliver capacity a thousand times more than the current cellular 4G systems, synchronizing with the expansion of the application development with personal communications, knowing that mobile devices will reach an immense number timing with the 5G commercial initiation. Owing to the mobile data explosion, current mobile networks suffer from scalability and performance degradation problems[4].

The main goal of the SDN technology resides in separating of the software network management and the hardware based management network (packet forwarding). SDN in its new version leads to an opened standard with optimization in resources with the virtualization development concept. Even LTE disruption level is less critical than SDN deployment. 5G could reap SDN technology features and benefit from combining other compaction technologies such as mm-wave, DAS (Distributed Antenna System) to achieve a 1000-fold capacity, 100-fold rate and 100-fold more active connections than LTE existing networks [5]. SDN, as the up-and-coming technology, dissociates the forwarding logic from the management logic in the existing network. SDN abstracts all management functions into the centralized controller, whereas sanctioning programmability for the network [6, 7]. SDN/NFV is an emerging technology that intends to deploy flexible, more efficient, and cost-effective networks with a high security level [8]. Moreover, SDN philosophy splits the network in two main planes, a management plane and user plane [9]. The management plane is considered as the brain of the network with a centralized controller that runs a software package and that is responsible for controlling the user plane. The latter consists of low-price network devices, such as common switches. The controller runs the Open Flow (OF) protocol in order to configure routing tables and monitor packet statistics

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of the user plane. In the other side, NFV offers operators the virtualization of the network operations and functionalities by implementing standard servers instead of high-expensive and non-standard appliances [10]. Therefore, the SDN design pattern should keep the network infrastructure transparent for the applications level [11].

Various resource allocation and management solutions have been proposed to contribute with 5G and 6G networks. Virtual Network Embedding (VNE) is such a strategy that meets with the knowledge of the management plane for 5G/6G. The Radio Atmosphere Map (REM) is mainly considered as one of the pioneers of psychological feature systems. However, most of these schemes are close to GPP and GTP, and their quality management planes meet with some particular conditions. The future need of 5G networks needs a development of new patterns that satisfy, not only the decoupling between the management plane and the user plane, but should support hot-spots with high-capacity and coverage functionalities [12]. In addition, the virtualization technology aims to emulate the hardware platforms running in software packages. These packages are installed in industrial servers named as COTS (Commercial Off-The-Shelf) servers, which are accessible via Virtual Machines (VMs), instead of hardware dedicated appliances. These VMs can be mounted over different platforms, which makes virtualization more flexible and the technology versatile [13]. More research articles and case studies have been proposed to depict the SDN features and what they can bring to the 5G mobile industry. Authors in [10] proposed a solution for the adjustability support in SDN-based mobile networks. Authors in [14] developed a protocol that evaluates the handover execution time. Moreover, they focused on the open flow protocol to achieve S5/S8 constraint while keeping the main standard rules of SDN. SDN is presently known as a trending technology in the networking domain. In such networks, the controller runs as a network monitor and defines the forwarding rules of the data flows. Switches perform the forwarding and dropping of packets according to the rules defined by the controller. Thus, the controller should be able to implement a centralized control strategy for every exchanging data flow by using the header packet reporting technique [15].

The main advantage of the proposed approach in the current paper resides in the slicing feature that splits the processing functionality into more than a dedicated core for each service. This increases the delivering flexibility and ensures the QoS requirements, instead of having ad-hoc U/C plane functionalities for each business case. Moreover, this feature will assure high scalability and will lead to augmented efficiency in terms of signaling and latency, by avoiding the unnecessary processing.

II. MODELS AND METHODS

A. SDN for 5G Networks

5G mobile networks are expected to fulfill the users' and applications' increasing requirements in terms of bandwidth and QoS [16]. The Network Function Virtualization (NFV) is taking a part in the new IT world and evolves the networking strategy. Both SDN and NFV can operate together and lead to the deployment of sophisticated future networks [17]. Despite the growth of several mobile networks in 2020, various challenges should be taken into account: high scalability with IoT implementation, energy constraints for the devices and mobile stations, delay and bandwidth optimization, optimization of resource allocation, reduction of deployment costs, etc. [18]. Although several types of mobile networks will dominate the 2020's, there are also many challenges, such as the extenuating power consumption in devices and base stations, better resource allocation, higher data rates, ensuring lower round trip times, decreasing all costs, developing and boosting the mobility management policies, elasticity, agility, and scalability [18].

SDN is an innovative technology within the networking domain that consists on defining the network functionalities in software packages. It enhances the efficiency of the network configuration and its resources allocation. By the separation between the control plane and the data plane, SDN guarantees the transparency between the network infrastructure and the running applications. Thus, each controller manages various network devices as switches and expects more flexible and intelligent control of the exchanged data [19]. Unlike the trivial pattern networking which experiences a difficulty in the resource allocation and its arrangement, SDN is a favorable candidate for such unmanaged networks by decoupling the management and the user pane [20]. To do so, SDN implements OpenFlow as a communication protocol that is standardized by ONF (Open Networking Foundation) [21]. In SDN, the topology discovery is considered as the masterpiece of the SDN controllers and it enables controlling various applications like data routing, network virtualization, live migration, resource optimization, etc. The network topology is not only intended to determine routing tables for forwarding data, but also to manage the network resources [8, 22]. Within the SDN network, the data plane is responsible for forwarding data between the connected devices and the controllers. Switches running the OF protocol form the information plane, while the controllers are distributed and connected together in order to form the control plane [23]. This new organization may have a positive impact in terms of flexibility and programmability [24]. Thus, SDN is a way to introduce the virtualization within the classical IP networks [25], offering a new vision and gathering new features in terms of knowledge and deployment. Furthermore, mobile networks can in turn benefit from SDN advantages, leading to enhanced network control and management [26]. At the front haul part of the network, the present SDN technology does not define a clear vision due to the particular characteristics of this part in power consumption and cost of the elements that spread on a defined geographical area [27].

Figure 1 illustrates the common SDN Architecture. It can be seen that the network is divided into two main planes. The connected devices that constitute the data plane are responsible for forwarding the network traffic. To do so, the open flow enabled-switches should follow switching rules and strategies received form the SDN controller that forms the control plane.

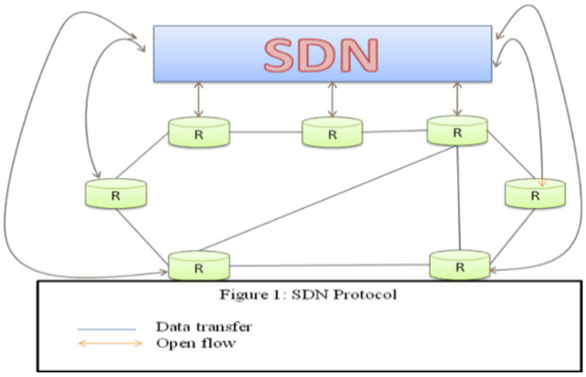

Fig. 1. SDN architecture.

B. Switching in SDN

SDN enables more flexibility in the routing operation than a traditional mobile network. Unlike the existing cellular networks where the traffic passes through the middle boxes using the same routing path, the SDN strategy offers a flexible routing, where only the necessary traffic is conducted via the middle boxes reducing their complexity. Moreover, this strategy allows a dynamic network topology with a flexible routing path that fulfills the change of the network behavior and the user needs [28]. To do so, data packets are forwarded by switches according to an existing matching rule. Otherwise, the concerned switch sends a packet-in message to the controller which determines a forwarding rule for the present packet. Then, the controller sends a flow-mod message to the switches concerned by the new route in order to update their routing tables. Various studies focused on the pipeline MFT process. In [29], authors proposed a framework that divides a large flow table into a number of smaller ones. An SDN switch implementing such method can be seen in [28]. It forwards all the data coming from mobile terminals and m-IOT devices implementing the respective rules, enabling connectivity between the edge devices, and empowering the transport traffic between the core network and other edge clouds [30]. Other studies [12, 30] focused on implementing learning techniques to improve the control performance while selecting the optimized links into the satellite communication system.

C. CP-SDN

This section describes the proposed framework, as a new scheme for enhancing the control flexibility of the existing SDN networks.

CP-SDN is considered as en extension to the existing SDN technology. CP-SDN aims to optimize the delay and enhance the flexibility in the control operation when the network experiences saturation. This may happen when the network is very dense and supports a huge amount of traffic data, as it is expected in 5G technology. The network may contain millions of fixed and mobiles devices, or even IoT systems. The idea consists on using two SDN controllers instead of one, as shown in Figure 3. In the normal case, both controllers are responsible for defining and broadcasting the switching rules to the switches that belong to them. When the network experiences saturation, the saturated controller forwards the superfluous data packets to its CP-SDN neighboring controller in order to assure load balancing in terms of control. The second controller will be responsible of defining rules to assure the forwarding of the remaining data belonging to the first controller. This aims to relieve the saturated controller, to avoid packet loss and to optimize the data forwarding process. CP-SDN is a proactive protocol that allows controllers to periodically exchange their switching rules for updating the control operation.

D. CP-SDN Control

In SDN, the controller is considered as the core of the system, by gathering the traffic requirements and the status of the network devices. Based on this information, it defines the control rules to the data plane in order to provide an optimized and efficient network for forwarding data services [30]. In case of saturation due to the amount of exchanged data, the controller may take more time to perform the control operation and thus, the transmission delay may increase. This represents one of the main problems experienced by an SDN network. Thereby, real-time services will be affected and the network QoS will be degraded. CP-SDN as a proposed scheme, takes part when the network experiences a saturation issue. As depicted in Figure 2, the CP-SDN consists on liaising between two or more controllers in order to unload the saturated point. The CP-SDN protocol operates between the two SDN centers by allowing the controllers to exchange control information and update their rules. Thus, both centers will have the whole information of the connected data planes.

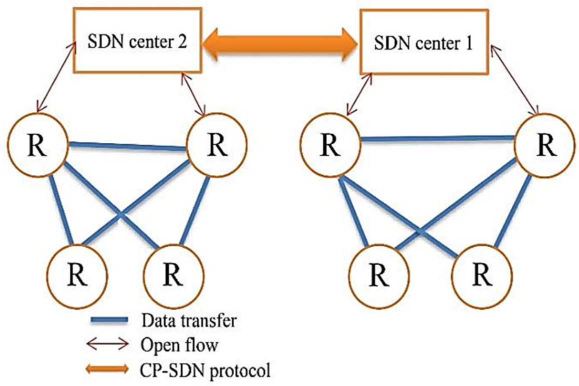

Fig. 2. CP-SDN architecture.

E. CP-SDN Control Switching

The SDN controller is updated to track each TCP connection state established between the switches belonging to its data plane [31]. The switching in CP-SDN is performed in two separate levels. The first level is between the SDN switches, while the second level is between the SDN controllers. CP-SDN implements an algorithm based on two tables (i,j). The first table contains the MFT pipeline processing data for the first level (between switches), and the second table contains the respective data for the second level. As illustrated in Figure 3, the SDN controllers are updated by the same control databases allowing each controller to take decisions about the traffic rules of data packets exchanged in their belonging data planes. Furthermore, in case of an overload of a part of the network, the controllers should relieve each other and decide about the optimized path to route data packets from source to destination. The diagram illustrated in Figure 4, shows the CP-SDN functioning. Thus, in case of a constrained traffic such as a real-time service, the data will not be queued due to saturation, but processed by the relieved controller. By this way, network optimization is guaranteed and a certain network QoS level for the constrained traffic is assured.

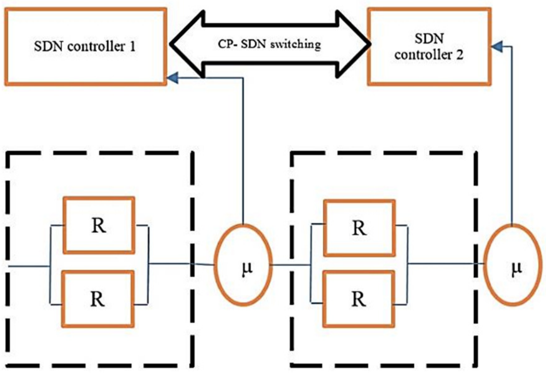

Fig. 3. CP-SDN switching.

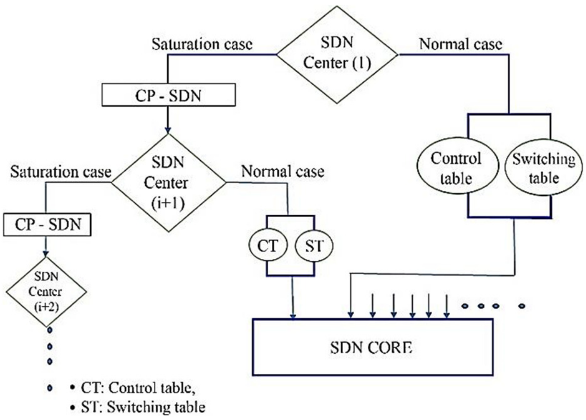

Fig. 4. CP-SDN operational diagram.

III. RESULTS AND DISCUSSION

Let us consider a sub-urban cell covering area A=2km^2 and having on average a β_1=1000 eMBB (enhanced Mobile Broadband) users, with only a percentage pA=0.5, 0.6, and 0.7 active at a time, and an average of a β2= 1000 active m-IoT (massive IoT) devices, in each respective service slice. The slicing should be deployed across all network domains, i.e. a network slice instance consists of network slice subnet instances from different domains [32]. The data rates are kept at 50Mbps for eMBBs and 100kbps for m-IoT, following the standards [31]. We take μ=1024pkt/ms with a length L=2kbytes. These values are taken from one node from our network. Figure 5 shows the eMBB packet control time in a single cell by varying number of eMBB slices (n) for the three probabilities pA=0.5, 0.6 and 0.7.

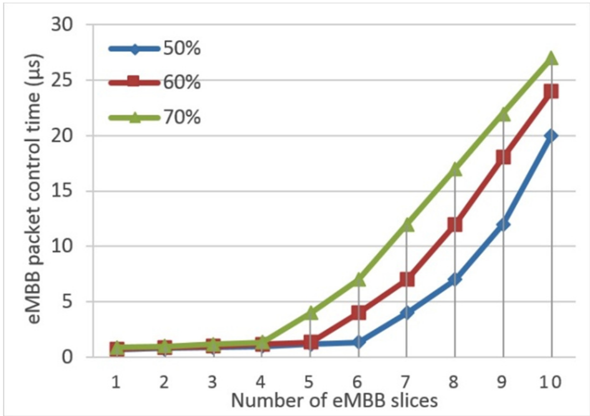

Fig. 5. eMBB delay performance for different numbers of slices.

The eMBB delay performance for different numbers of slices shows the control time of the eMBB packets based on the number of slices (n). It can be seen that for n from 1 to 4, almost the same time is needed, which is <1μs. Starting from n=4, the case p=0.7 shows a different behavior that indicates a start of saturation, where it shows a continuous increase, to reach 27μs for n=10. This needed control time may lead to network latency. The same behavior is shown in the case of p=0.6 and 0.5, where an increase is noticed from n=6 and n=5, to reach 24 and 20μs respectively for n=10.

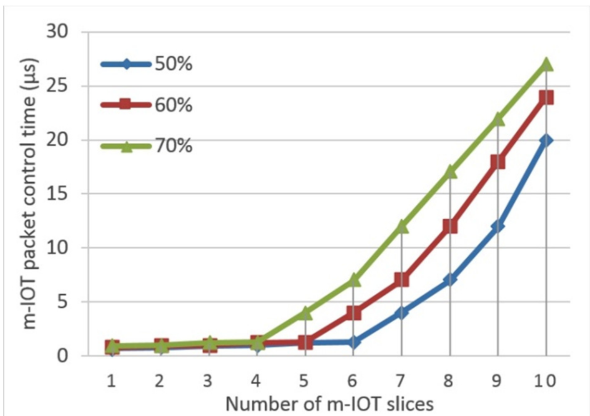

Fig. 6. m-IOT delay performance for different numbers of slices.

Figure 6 illustrates the m-IOT packet control time in a single cell by varying number of m-IOT slices (n) for three probabilities pA=0.5, 0.6 and 0.7. The m-IOT delay performance shows the control time of the m-IOT packets based on n. It can be seen that for n from 1 to 4, almost the same time is required, which is <1μs. Beyond n=4, the case pA=0.7 shows a different behavior exhibiting the start of saturation, where it shows an increase to 27μs for n=10. This produced control time may affect the network latency. In the same diagram, in the case of pA=0.6 and 0.5, a growth is noticed from n=6 and n=5, to respectively reach 24 and 20μs for n=10.

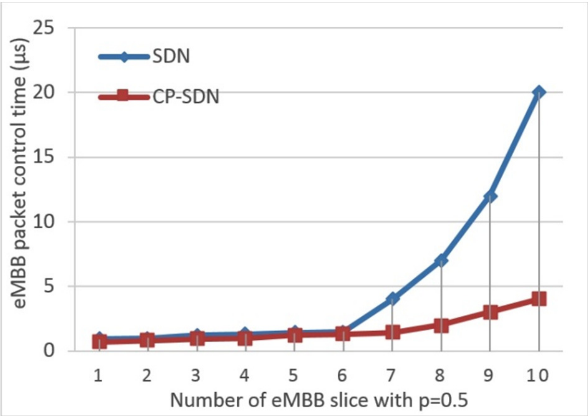

Fig. 7. eMBB delay performance for different values of n using the SDN and the CP-SDN at pA=0.5.

Figure 7 depicts a comparison of the eMBB delay performance for different values of n using SDN and CP-SDN with the probability of 0.5. The simulation results show that both SDN and CP-SDN have the same performances for n≤6, where the time spent in the control is equal to 1µs. The CP-SDN shows a slight increase compared to the SDN, for values of n from 6 to 10, where the induced delay in the case of SDN is 5 times greater than in CP-SDN. This enhancement is the result of the use of a second controller, to share the control operation. The difference in the behavior, noticed from n=6 (the beginning of the saturation), is due to the collaboration with a second station. The use of a second station is not always enough, where the CP-SDN shows a saturation from n=8, which requires a third collaborative station.

Figure 8 illustrates the comparison between the eMBB delay performance variation for different values of n when using SDN and CP-SDN.

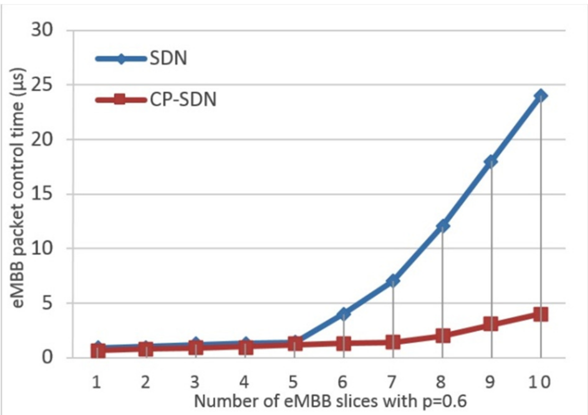

Fig. 8. eMBB delay performance for different values of n using the SDN and the CP-SDN at p=0.6.

The simulation results indicate that both SDN and CP-SDN, express the same behavior for n≤5, where the time exhausted in the control operation is equal to 1µs. The CP-SDN shows an obvious improvement compared to the SDN, for values from 5 to 10, where the produced delay in the case of SDN is 6 times more than the CP-SDN. This efficiency in the case of CP-SDN is the result of using a second station, to divide control. The difference in the behavior noticed from n=5 that indicates the beginning of a saturation state, is due to the alliance with the second station. The use of a second station is not usually sufficient, where the CP-SDN shows a saturation from n=8, that requires a third corporate station.

In Figure 9, the same results are gained as in Figure 7 and 8 with the change of saturation initiation, which occurs when n=4. The second saturation state remains n=8, the same as for pA=0.5 and pA=0.6. As depicted by the various simulations performed during our work, the CP-SDN acts better than SDN, especially when saturation occurs. This happens when the network is dense and supports a huge amount of data exchanged between various segments and supporting multiple services. CP-SDN implementation leads to an optimization in terms of the delay for processing packets and therefore, an enhancement in the QoS of the 5G network. Table I summarizes the CP-SDN performance compared to the basic SDN.

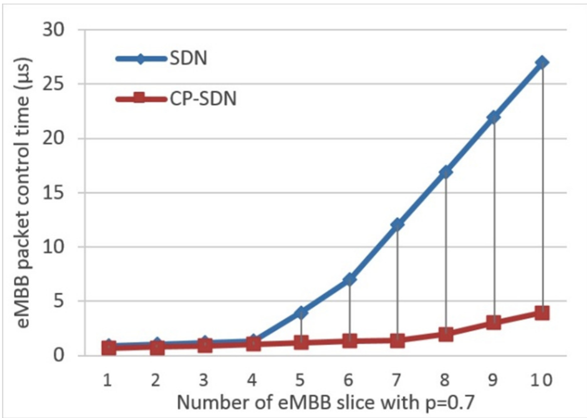

Fig. 9. eMBB delay performance for various values of n using the SDN and the CP-SDN at pA=0.7.

TABLE I. CP-SDN AND SDN PERFORMANCE COMPARISON

Packet control time (µs)	**Network probability density**					
	0.5		**0.6**		**0.7**	
	eMBB	**m-IOT**	**eMBB**	**m-IOT**	**eMBB**	**m-IOT**
SDN, current work results	20	19	24	22.5	27	26
SDN [31]	15	10.5	18	13.8	23.5	16.4
Proposed CP-SDN	3.5	3.4	3.6	3.5	4	3.9

In the case of CP-SDN, the control time doesn't exceed 4µs for both e-MBB and m-IOT slices, for various probabilities of network density. However, for the SDN case the control time is more significant and it increases when the network becomes dense and experiences congestion. This illustrates the outcome of the CP-SDN for dense networks and its efficiency for real-time traffic, compared to the basic SDN. This quality improvement is directly related to the new mechanism implementation of CP-SDN which relieves controllers by their neighbors. The main drawback of the CP-SDN that may be observed is the increase in the energy needed for the transmission. In the case of cooperation between two or more controllers, we can perceive more energy consumption in the cooperative station. More energy consumed means more cost charging of power consumption.

IV. CONCLUSION

SDN technology involved in 5G networks has a leading role by giving more flexibility and efficiency in terms of network management and data traffic, knowing that 5G networks are very scalable and connect billions of stationed and mobile devices with different requirements and characteristics. The traffic flow passing through the 5G network has different throughput and priority needs that should be in charge by the networks elements. This is achieved by splitting the network into two planes, the control and the data plane. The proposed extension scheme named CP-SDN, gives more efficiency and optimization to the existing SDN network, by relieving centers that experience saturation due to the huge supported data traffic. The simulation results show that CP-SDN offers a greater outcome for the 5G networks in terms of processing delay optimization and thus can assure a high QoS level, especially for the constrained services. The obtained results make CP-SDN a strong candidate for future dense and mobile 5G networks.

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