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On the features of Software Defined Networking for the QoS provision in data networks

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Sobre las características de las Redes Definidas por Software para la provisión de calidad del servicio en redes de datos

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Abstract

Introduction– The traditional networks mostly implement devices where the control plane is distributed and mixed with the data plane; this fact does not allow a fast evolution towards a process that contributes to improving the transport of services. Otherwise, Software Defined Networking is a set of transport services that optimize the use of resources as these have a centralized network structure.

Objective– To determine the aspects that enable the software-defined networking to provide quality of service features in data networks.

Methodology– This study is performed through network simulation over the same base network and under the same working conditions by carrying out measurements of the packet forwarding response time and management of the transported bandwidth. This study includes the demonstration of the multimedia content transport over a network architecture defining priorities to the links.

Results– The outcomes show how the Software Defined Networking achieves better management of data transmission through the base network. In the same way, the previous outcomes are reinforced with those obtained in the quality of service test performed on the streaming of a multimedia flow.

Conclusions– Due to the centralized control of Software Defined Networking, forwarding functions with the quality of service features are enabled in data networks based on layer-2 devices.

Keywords– Software Defined Networking, SDN, Floodlight, Mininet, Packet Tracer, quality of service, bandwidth, queuing, transmission rate, response time.

Resumen

Introducción– Las redes tradicionales implementan en su gran mayoría dispositivos donde el control es distribuido y mezclado con el plano de datos, aspecto que no permite una evolución rápida hacia un proceso que contribuya a mejorar el transporte de los servicios. Por el contrario, las Redes Definidas por Software son un conjunto de servicios de transporte que optimizan la utilización de los recursos al poseer una estructura de red centralizada.

Objetivo– Determinar los aspectos que hacen que las redes definidas por software puedan ofrecer características de calidad de servicio en redes de datos.

Metodología– Este estudio se realiza mediante simulación, sobre una misma red base y bajo las mismas condiciones de trabajo, llevando a cabo medidas del tiempo de respuesta del envío de paquetes y gestión del ancho de banda transportado. El estudio también incluye una prueba mediante la transmisión de contenido multimedia a través de una arquitectura de red definiendo prioridades a los enlaces.

Resultados– Los resultados muestran la forma en que las Redes Definidas por Software logran una mejor gestión del envío de datos a través de la red base. Del mismo modo, los resultados previos fueron respaldados con los obtenidos en la prueba de calidad de servicio para un flujo multimedia.

Conclusiones– Las redes definidas por software debido a su control centralizado habilitan el encaminamiento y provisión de calidad del servicio en redes de datos basadas en dispositivos de capa-2.

Palabras clave– Redes Definidas por Software, SDN, Floodlight, Mininet, Packet Tracer, Calidad de servicio, Ancho de banda, Encolamiento, Tasa de transmisión, tiempo de respuesta.

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I. Introduction

The Internet designers, the standardization bodies, manufacturers and service providers have always been looking for solutions that guarantee Quality of Service (QoS) and in particular better management of the network resources. Today, Internet service providers must maintain certain conditions in the network that allow them to offer the best possible service to their users. Some of these parameters are related to latency and bandwidth [1].

All these requirements are, by far, challenging to achieve for traditional IP network architectures due to two important reasons. The first one is due to what many people know as "Ossification of the Internet". That is, the Internet has become extremely difficult to evolve as a consequence of the wide deployment and investment carried out over the years. The Internet is one of the most important and critical infrastructures of our current society [2]. The second one is due to the fact that the architecture in which it works, is organized vertically, in other words, the data plane and the control plane are mixed within each one of the network devices, reducing the flexibility, innovation, and evolution of the network infrastructure [2], [3].

Software Defined Networking (SDN) is a set of network transport services that increase flexibility and the use of resources, reducing overhead costs in the network. These networks are characterized by their centralized structure, in which the control plane (software) makes automated decisions through the implementation of algorithms that decide paths and management of the packets that will be transmitted through data plane (hardware) [4].

This paper presents a study in which the performance of traditional networking is compared with the performance of an SDN in order to determine the main features that make the centralized way of network control conducted by SDN be suitable to provide QoS. Both environments, traditional networking, and SDN, where evaluated under the same network topology with the same traffic conditions. Thus, the advantages and disadvantages of each type of network were obtained. In section II, the methodology and necessary elements to carry out the process for the evaluation of the SDN capabilities in terms of QoS are presented. In section III, the results obtained are presented as well as the analysis and observations found in this study. Finally, section IV summarizes the paper.

II. Materials and methods

QoS is related to the ability of a network to provide different levels of services to ensure different traffic profiles. In this regard, a set of requirements focused on the transport of flows must be fulfilled. Quality of service can be implemented to manage congestion network and to avoid it. Overall, through QoS, it is possible to assure significant characteristics of packet transmission such as bandwidth, latency and packet loss in the network [5], [6].

In traditional networking, the QoS is mainly determined by queuing strategies performed on the routers. Queuing is a data structure, characterized by being a sequence of elements in which the insertion operation *push* is carried out at one end and the extraction operation *pop* on the other. Priority Queue (PQ) is a technique that offers preferential treatment to the packets in which at the moment of entering the interface, the priority field (Type of Service) in the header allows to identify them. PQ adjusts to conditions where there is significant traffic but can cause a total lack of attention low-priority queues. Customized Queues (CQ) is a conventional mechanism to prioritize traffic, avoiding set aside low-priority queues, where the number of packets that must be addressed by each queue is specified. Finally, low latency queues are the recommended queuing method for Voice over IP (VoIP) and IP telephony. It consists of custom priority queues based on traffic classes, along with a priority queue that has preference over the other queues. Thus, a limited bandwidth reserved for the priority queue must be configured [7]. Nowadays, traditional IP networks use by default First-In-First-Out (FIFO) queuing in which all packets are treated equally. Due to its simplicity, this queuing strategy is not suited for QoS assurances.

A QoS assurance in SDN is feasible due to its centralized way of operation as the control plane and the data plane are decoupled. In this context, a centralized controller through OpenFlow commands the routing and forwarding operations according to the rules defined for different classes of flow traffic [8]. These rules involve the management of the bandwidth that each interface provides to a given flow or class of service, resulting in better use of the available network resources. Also, transmission and processing delays due to queuing are reduced as the routing does not follow a store and forward operation as usually occurs in traditional networking [9]. Additional features of SDN include network slicing and load balancing strategies [10]. While the former deals with the definition of different slices of network resources to assist specific requirements of the transported traffic, the latter distributes the end-to-end transported traffic among different paths in order to assure bandwidth resources and delay times.

SDN controllers such as Floodlight, Open-Daylight and Open Network Operating System (ONOS) include libraries that provide QoS capabilities.

In addition, customized libraries for specific QoS requirements can be developed. In this context, Open vSwitch (OVS) is an open source software that makes a switch to behave as a virtual switch. OVS offers a centralized model simpler to manage networks, allowing to implement Virtual Local Area Networks (VLANs), Generic Routing Encapsulation (GRE) tunnels, Virtual Extensible LAN (VXLAN), basic QoS policies, IPsec and Link Aggregation Control Protocol (LACP) among others [11]. In addition, OVS works independently of the SDN controller used [12].

Packet Tracer [13] and Mininet [14] software, were used in this study. While Packet Tracer performs the routing and forwarding operations in a decentralized way using the Open Shortest Path First (OSPF), Mininet includes Floodlight as a controller. The same network topologies and network conditions were implemented in both environments. Aspects such as forwarding, delay time and bandwidth management were evaluated for both centralized and decentralized controllers.

III. Results

In this section is described the main facts that we consider might comprises the cornerstone for the QoS assurances in next generation of data networks.

A. Test scenarios

Fig. 1, shows the first proposed test scenario in which the network topology is composed of switches that define a distributed mesh network. This scenario emulates a network topology commonly found in the access and transport segments, where hosts are connected to access switches that forward the data traffic to the core switches. A significant amount of links in the mesh based core network enables the connectivity between any pair of end devices. The topology was implemented in Packet Tracer and Mininet in order to evaluate the forwarding function between end-to-end devices under a decentralized and centralized control plane operation, that is, using traditional networking and SDN respectively.

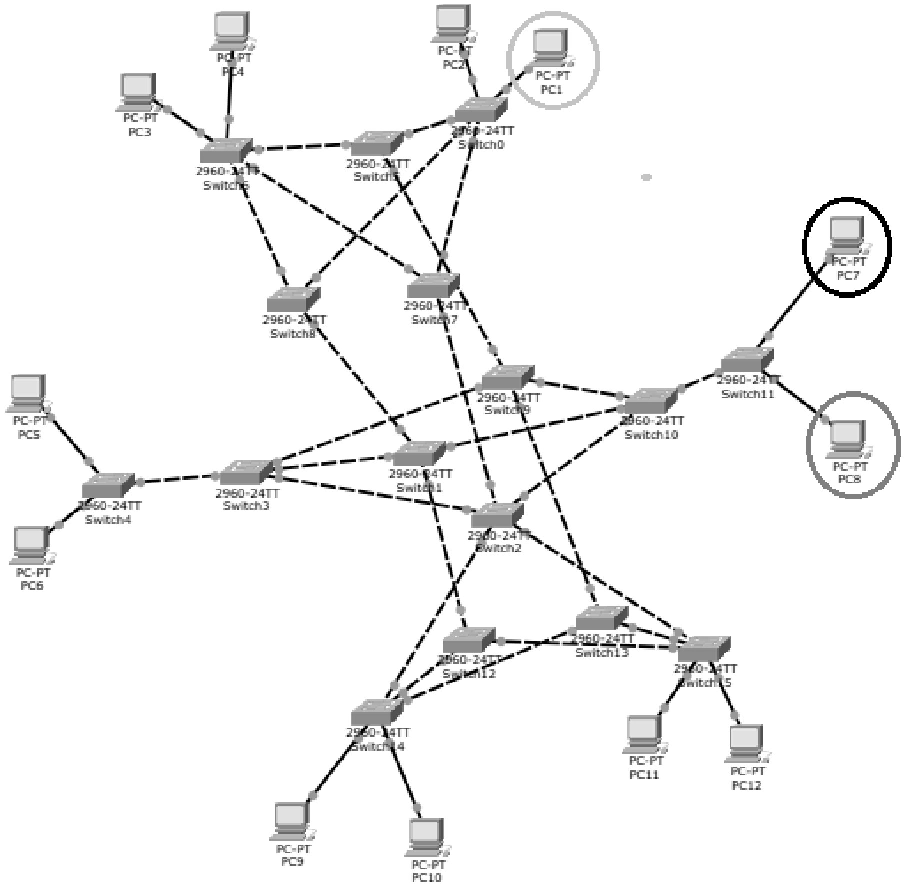

Fig. 1. Network composed only of switches.
Source: Authors.

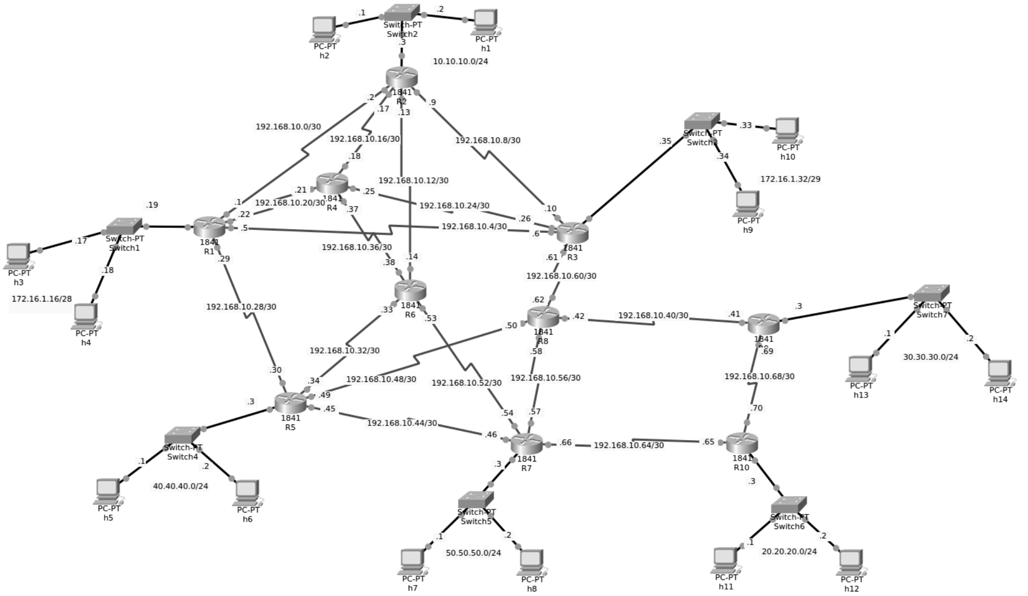

Fig. 2. Network created in the Packet Tracer network simulator.
Source: Authors.

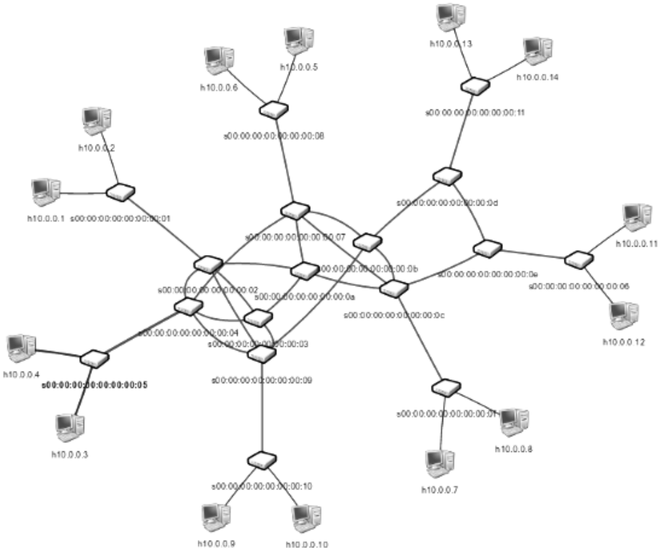

Fig. 3. Network created on Mininet network simulator.
Source: Authors.

The second scenario aiming at evaluating the delay time of a traditional network and a SDN is shown in Fig. 2 and 3, respectively. Fig. 2, depicts the implementation in Packet Tracer of a traditional networking environment based on access switches and core routers. Fig. 3, represents the same topology under the SDN paradigm implemented in Mininet. Similarly, to the previous scenario, we believe that the complexity of this topology describes a base network usually found in today's data communications systems. Note that unlike the traditional networking that is based on layer-3 devices as seen in Fig. 2, the core of the SDN is composed of only switches.

The third scenario allows the evaluation of the link bandwidth management capability of SDN in order to assess the packet loss rate as a function of the allocated bandwidth and classes of service. As the transport of video traffic was carried out between end devices in this scenario, a simpler network topology was used in order to prevent long emulation times. The network topology implemented in Mininet is shown in Fig. 4.

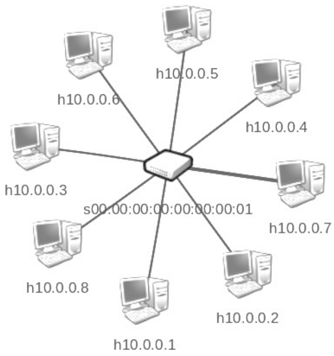

Fig. 4. Network test for QoS.
Source: Authors.

B. Experiments configuration

The first experiment deals with the evaluation of the forwarding capabilities of a switch-based network under a traditional networking operation and an SDN paradigm. To this aim, four tests of one hundred ping requests each were sent out from the end device PC7 (black) to the end device PC8 (gray) in the network topology shown in Fig. 1. This first configuration allows evaluating the connectivity and delays between nearby hosts. Subsequently, the same test was carried out between remote hosts PC7 (black) and PC1 (gray) in order to assess the forwarding capabilities of both networking paradigms. Algorithm 1 represents the pseudocode that defines the first experiment as follows:

Algorithm 1 IP and SDN forwarding testing

```
Size = TotalNumberOfHosts
Hosts[Size]
for i = 1; i ≤ size; i++ do
    Hosts[i] = IpAddress
end for
for i = 1; i ≤ size; i++ do
    for j = 1; j ≤ size; j++ do
        Connection = PingRequest(Hosts[i],Hosts[j])[0]
        Time = PingRequest(Hosts[i],Hosts[j])[1]
        if Connection == True then
            Print(’Successful Connection between ’ + Hosts[i] + ’ y ’ + Hosts[j] + ’ with reply time of ’ + Time + ’.’)
        else
            Print(’Failed Connection between ’ + Hosts[i] + ’ y ’ + Hosts[j] + ’. Timeout expired.’)
        end if
    end for
end for
```

The second experiment aims at evaluating the delay time imposed by the traditional IP networking and the SDN paradigm. In this context, the routing protocol used in the Packet Tracer simulator is the Open Shortest Path First (OSPF), which implements the Dijkstra algorithm and calculates the best path between any two nodes within the network. Likewise, load-balancing modules are implemented in the SDN to find out the shortest paths between the network devices. The test was performed by sending out 100 ping requests from host h1 (IP 10.0.0.1) and host h11 (IP 10.0.0.11) in the SDN environment shown in Fig. 2, which corresponds to host h1 (IP 10.10.10.28) and host h11 (IP 20.20.20.1) on the IP network shown in Fig. 3. The algorithm 2 describes the OSPF operation in the contexts of the second experiment as follows:

Algorithm 2 IP and SDN routing testing

```
for all v ≠ u such that L(v) = w(u,v) do
    L(u) = 0
    T = u
    while T ≠ V do
        Find v’ ∉ T such that ∀ v∉ T, L(v’) ≤ L(v)
        T = T ∪ v’
        for all v∉ T such that v’ is adjacent to v do
            if L(v) > L(v’) + w(v’,v) then
                L(v) = L(v’) + w(v’,v)
            end if
        end for
    end while
end for
```

Finally, the bandwidth management capability of an SDN was evaluated in the third experiment. The purpose is to measure the packet loss rate as a function of the available bandwidth link using prioritization of traffic based queuing. This test was only performed in Mininet as traditional IP networking is primarily based in a FIFO queuing strategy. Therefore, in the context of an SDN, it is possible to prioritize the traffic of packets coming from different interfaces or ports using queues through Open vSwitch (OVS). Thus, packets arriving at different input interfaces and forwarded through the same output interface will have a different priority by restricting the allocated bandwidth through determined queues. Algorithm 3 describes the pseudocode that defines the third experiment as follows:

Algorithm 3 Prioritization of traffic based queuing

```
queue1=Bw1, queue2=Bw2,... queueN=BwN
PacketSent1 = A, PacketsSent2 = B,.. PacketSent = Z;
for i = 1; i ≤ N; i++ do
    queue[i] ∈ Port[i]
    PacketSent[i] ∈ Host[i]
    Host[i] ∈ Port[i]
    PacketsLimit[i]=BWi/seg
end for
N = 1
for i = 1; i ≤ N; i++ do
    if PacketSent[i] ≤ PacketLimit[i] then
        Information[i] = PacketSent[i]
    else
        Information[i] = PacketSent[i]-PacketsLimit[i]
    end if
end for
```

Consequently, QoS rules that limit the maximum bandwidth to a specific value for a given queue were defined as shown in Table 2.

Table. 2. QoS rules.

QoS policies	Bandwidth
QoS general	100 Mb/s
Queue 1	5 Mb/s
Queue 2	10 Mb/s
Queue 3	15 Mb/s
Queue 4	20 Mb/s

Source: Authors.

These queues were associated to the input interfaces of the switch, so that, depending on the port through which the packet enters, there will be a different priority to forward such packet to the output port. In this scenario, host h10.0.0.1 is used as a receiver and it is connected to port 1, the other hosts are used as transmitters. Thus, these interfaces are associated with the queues to establish different priorities for each link created. The multimedia content was sent out through the User Datagram Protocol (UDP) in order to avoid the retransmission of lost packets that might infer a wrong interpretation of the obtained measurements.

C. Outcomes

Regarding the first experiment, results of the average delay time for each one of the four tests of one hundred ping requests between the end device PC7 (black color in Fig. 1) and the end device PC8 (gray color in Fig. 1) are presented in Table 1. As observed, there are significant differences in the delay times between the selected nodes. These results show the capability of an SDN controller when it comes to forward packets in a network composed only of layer-2 switches.

Table 1. Ping request time in both environments

Ping request	Packet Tracer	Mininet
	Average time out of 100 pings	
Test 1	1855 ms	6.44 ms
Test 2	12 ms	0.923 ms
Test 3	1541 ms	0.176 ms
Test 4	640 ms	0.094 ms

Source: Authors.

As far as the test between host 7 and host 1 in Fig. 1, is concerned, the connection was not successful on the IP network and the ping request timeout expired repeatedly, whereas the connection on the SDN was performed without issues. As expected, the communication in the traditional IP network between two remote end devices was not feasible to achieve because of the lack of a routing process that allows finding a path. Likewise, the network efficiency would be jeopardized in this case due to the existence of only one broadcast domain. This fact makes that broadcast protocols such as the Address Resolution Protocol (ARP) and the Dynamic Host Control Protocol (DHCP), among others, flood the entire network with their request-response messages.

Software-defined networking does not require the deployment of routers to perform routing and forwarding operations since it can be done seamlessly through switches commanded by a centralized controller that performs the routing decisions over each one of the switches of the network. Thus, the obtained results show that having a control plane separated from the data plane enables the switches to operate as routers featuring fast node discovery and straightforward packet forwarding.

For the evaluation of the delay time based on the network topology shown in Fig. 2 and 3, the results represented in Fig. 5, show the significant differences found in the IP network and in the SDN environment. While a constant delay in the order of microseconds were obtained in the SDN, the IP network operated with average delays of 4.7ms. It should be pointed out that in the case of the IP network simulation on Packet Tracer, the first request is not successful and the message "Request timed out" appears. Thus, the waiting time runs out and therefore this delay was not included in the graph. The delay of the first ping in the SDN was larger due to the network discovery functions performed by the Floodlight controller. This fact improves the behavior of all the remaining packets of a given flow. This fact represents a significant improvement compared to an IP network where different paths and queuing operations in each one of the routers imposes larger delays and higher packet losses.

Finally, regarding the evaluation of the prioritized traffic based on queuing and the available bandwidth using the topology shown in Fig. 4, the results obtained for the transmission of multimedia content through different bandwidth allocation and queues are shown in Fig. 6.

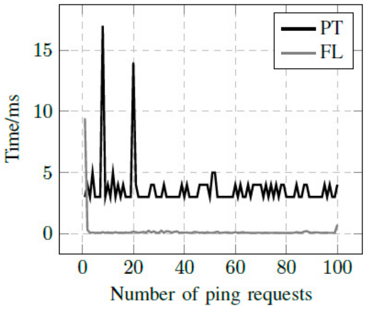

Fig. 5. Response times for ping requests on Packet Tracer (PT) and on Mininet using the Floodlight controller (FL).
Source: Authors.

Fig. 6(a). Image quality associated with the queue of 5Mb/s.
Source: Authors.

Fig. 6(b). Image quality associated with the queue of 10Mb/s.
Source: Authors.

Fig. 6(c). Image quality associated with the queue of 15Mb/s.
Source: Authors.

Fig. 6(d). Image quality associated with the queue of 20Mb/s.
Source: Authors.

In the previous images, on the left side there is a thumbnail of the sent video and on the right side, an image of the received video. It can be observed how the quality of the image deteriorates at the receiver host depending on the queue that was associated with the host that is transmitting. Thus, the greater the bandwidth established in the queue, the quality of the image would be better because there is a low loss of information. By making traffic analysis in Wireshark, it is possible to determine the amount of information transmitted and received in order to calculate the percentage of packet loss. Fig. 7 shows the number of transmitted packets and the time at which each one of the queues defined in Table 2 started the data transfer, i.e. queue 2 at roughly 391ms, queue 3 at 455ms, queue 4 at 500ms and queue 1 at 560ms. Likewise, Fig. 8, depicts the number of received packets for such defined queues and the time at which the packets were received. It can be observed that the receiving time for queues 2, 3, 4 and 1 was 402ms, 461ms, 510ms, and 570ms respectively.

Based on the results found in Fig. 7 and 8, the Fig. 9 shows the packet loss percentage as a function of the bandwidth allocated to each one of the four queues. For a bandwidth of 5 Mbit/s, the percentage of losses was 71.11%, that is, only 28.89% of the information was received. For a bandwidth of 10 Mbit/s, the percentage of losses was 44.44%, that is, only 55.56% of the information was received. For a bandwidth of 15 Mbit/s, the percentage of losses was 15.56%, that is, only 84.44% of the information was received. For a bandwidth of 20 Mbit/s, in theory, there are no losses because the channel of 2.35 Mb/s is higher than the required 2.25 Mb/s. Theoretically, since the video size is 52.1 MB which is equivalent to 416.8 Mb and has a duration of 24 seconds, for a bandwidth of 5 Mb/s only 120 Mb can be transmitted in that time, for 10 Mb/s bandwidth can only be transmitted 240 Mb, for 15 Mb/s bandwidth up to 360 Mb can be transmitted and for 20 Mb/s bandwidth can be transmitted 480 Mb. These percentages are equivalent to 28.77%, 57.5%, 86.33% and 100% of the information transmitted respectively.

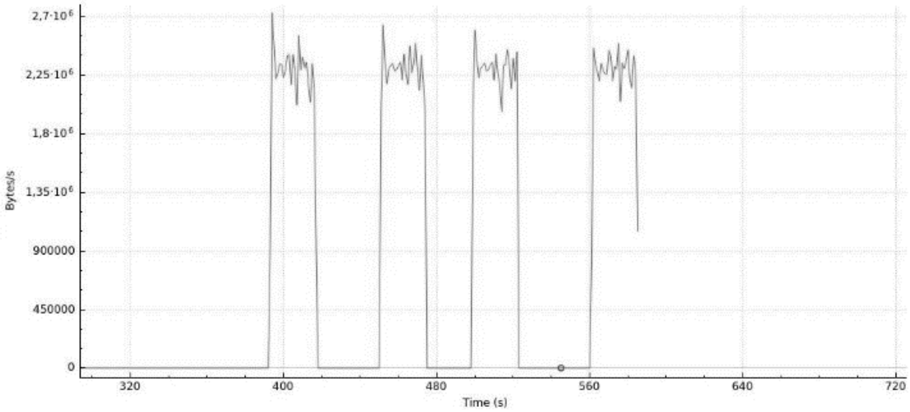

Fig. 7. Transfer rate in B/s for the queues of 10 Mb/s, 15 Mb/s, 20 Mb/s and 5 Mb/s.
Source: Authors.

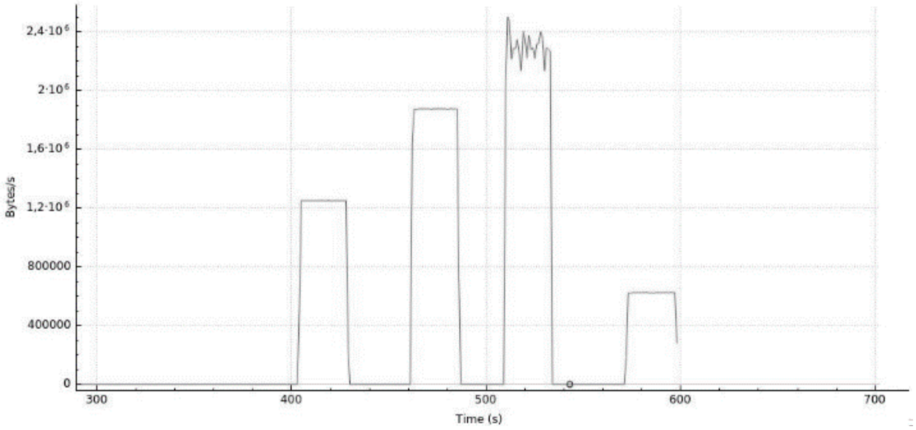

Fig. 8. Reception rate in B/s for the queues of 10 Mb/s, 15 Mb/s, 20 Mb/s and 5 Mb/s.
Source: Authors.

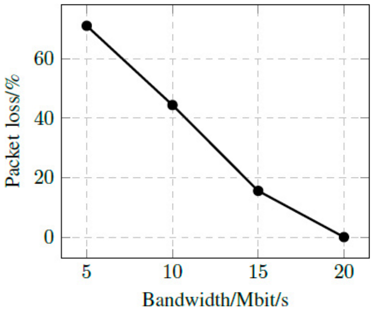

Fig. 9. Percentage of lost packets as a function of the queue and bandwidth allocated.
Source: Authors.

IV. CONCLUSIONS

A significant difference between traditional networks where network control is decentralized and carried out by routers as routing devices and Software Defined Networking where control is centralized and executed by a programmable controller, is related to the possibility of enabling routing operations in networks composed of a large number of switches. This fact simplifies the network management and packet forwarding on each device. On the other hand, it was observed in the comparative development between traditional networks and SDN, that for the same network topology the delay time of end-to-end connections was reduced significantly in the SDN paradigm as compared to the values obtained in the IP environment. It means that having separated the control plane from the data plane results in faster forwarding operations that reduce the delay time in end-to-end connections.

Also, through the establishment of quality of service between two points of a network by prioritizing the interfaces, it was possible to observe how the allocation of different priorities affects a link when transporting information. Thus, in the test of the streaming multimedia content transmission, it was clearly observed that when assigning different priorities to a switch port through which the content is transmitted, the quality of the image was affected depending on the assigned priority due to the packet loss that was caused by the bandwidth associated to the queues.

Future work includes the experimental validation of the SDN capabilities described in this paper by means of a small-scale demonstrator that allows comparing the results obtained for the evaluated metrics.

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