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Quality of service evaluation based on network slicing for software-defined 5G systems

Evaluación de la calidad de servicio basada en segmentación de red para sistemas 5G definidos por software

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Abstract

This paper presents the evaluation of the quality of service parameters provided by the network slicing approach for 5G networks based on a software-defined networking environment. The open source controller Floodlight made bandwidth allocation decisions by assigning network slices to user profiles on particular topologies. The objective is to control the bandwidth resources that allow to guarantee latency and reliability values according to the type of service in a sliced 5G network. Thus, it was possible to demonstrate the versatility and scalability of the Floodlight controller, which reduced the loss rate by 10% in a congested network and ensured delays of less than 700ms in applications such as VoIP and video streaming sharing a channel with a limited bit rate of 5 Mbps.

Keywords

5G-fifth generation mobile, Network Slicing, Software-Defined Networking, Floodlight, quality of service.

Resumen

Este artículo presenta la evaluación de los parámetros de calidad del servicio proporcionadas por la segmentación de recursos para redes 5G basadas en un entorno de red definido por software. El controlador Floodlight realizó decisiones de asignación de ancho de banda definiendo segmentos de red a perfiles de usuario en topologías particulares. El objetivo es controlar los recursos de ancho de banda que permiten garantizar valores de latencia y confiabilidad de acuerdo con el tipo de servicio en una red 5G. De esta forma, fue posible demostrar la versatilidad y escalabilidad del controlador Floodlight, que redujo la tasa de pérdida en un 10% en una red congestionada y permitió retrasos de menos de 700ms en aplicaciones como VoIP y transmisión de video compartiendo un canal con una velocidad de bits limitada de 5 Mbps.

Palabras clave

5G- quinta generación móvil, segmentación de red, redes definidas por software, calidad de servicio.

1. INTRODUCTION

The high volume of traffic in current and next generation networks makes network management and operation more complex than ever. As a result, network models should be reinvented in order to find a solution that allows managers to perform management operations without having to individually configure the devices that compose the network. That is, to centralize the administration of a complex network while avoiding the tedious task of verifying and validating routing and Quality of Service (QoS) parameters one by one in each one of the network elements.

To meet these requirements, the paradigm of Software-Defined Networking (SDN) was proposed in [1], [2], [3]. SDN consists of separating the control plane and the data plane in each intermediate device in the network. In this context, a centralized controller computes the routing operations and controls the network elements by commanding their corresponding forwarding operations. In this way, the SDN controller must be able to communicate with both the control plane (application) and the data plane (infrastructure). Nowadays, the most commonly used standard to perform this function is the OpenFlow protocol, which allows the communication of the controller with the nodes in the networks [4].

Simultaneously, a new generation of mobile networks known as 5G (fifth generation) is being considered and undergoing a standardization process [5]. 5G consists of communication systems, mainly mobile, that offer a real possibility of supporting the needs of a hyper connected world. Because the requirements of networks are always more and more demanding and diverse, user profiles are better defined but also have different needs. This is where the concept of network slicing plays an extremely important role: it allows to develop a novel network model by virtually segmenting the resources offered by a physical infrastructure [6], [7], [8].

As a result, 5G network slicing and the SDN architecture converge and complement each other. The SDN paradigm enables network architectures capable of managing an infrastructure in a virtual way by providing dynamic characteristics to a network that does not change in its physical elements, but in terms of configuration.

A related work on SDN and 5G reports service differentiation provisioning for virtual wireless networks in a Heterogeneous Network (HetNet) cloud model [9]. Besides, a converged control plane of a Wide Area Network (WAN) and wireless access under the SDN paradigm are described in [10]. While the two previously mentioned studies limit the SDN operation to the Packet Data Network Gateway (P-GW) of a Long Term Evolution (LTE) network, our proposal is based on the approach presented in [11], [12], where network slicing is not considered, but the architecture enables application awareness flow control from the Base Station (BS). This is a very important feature to be adopted in 5G because networks are expected to handle user equipment based on their individual characteristics or usage-class types [13].

To the best of our knowledge, the approaches above constitute the most recent and relevant work about the modeling of a 5G network under the SDN paradigm using Mininet. Related studies that involve prototyping include the approach presented in [14]: a proposal for managing network slices in the Cloud Radio Access Network (C-RAN). Such approach uses the FlexRAN controller in Open Air Interface (OAI) software. Additional demonstrations based on this controller are found in [15], which proposes on-demand creation and configuration of network slices. A 5G-EmPOWER controller was used to prototype a Radio Access

Network (RAN) Slicing on a wireless LAN environment [16]. Furthermore, a multi-service orchestrator that was developed as a part of the Mosaic5G opensource ecosystem called JOX is described in [17]. Mosaic5G provides agile mobile network service delivery platforms for research and development of 4G and 5G mobile networks. The work described in [18] presents an adaptive network slicing approach using NS-3. However, as NS-3 is not a native SDN platform, the basic functionalities of a controller were implemented. Regarding radio resource slicing, a discussion on the concept and the impact on the end-to-end quality of service in 5G networks is presented in [19] and [20]. In addition, a proof of concept of RAN slicing is presented in [21] using OAI and FlexRAN.

As can be seen, the network slicing paradigm has become a hot topic in the context of the development of future 5G networks and relevant works have revealed discussions, modeling, assessments and network implementation environments. This paper characterizes the capabilities of an SDN to allow network slicing strategies in which awareness flow control is enabled and different slices serve specific user-declared needs on demand in the context of a future 5G network. To this aim, several user profiles with specific requirements were defined in the Mininet software environment and parameters such as delays, losses and bandwidth were used to evaluate the QoS of the network considering the allocated resources of different network slices. Based on this characterization, we envisioned a 5G network topology over which the benefits of a network slicing strategy are evaluated and compared with a conventional network without network slicing. The remainder of this paper is organized as follows. Section 2 describes the controller, algorithms and topologies used in the simulations as well as the flow descriptions and traffic definitions used to assess our approach. The results of the network slicing characterization based on QoS evaluation for potential 5G topologies are described in section 3. Finally, section 4 summarizes the paper.

2. MATERIALS AND METHODS

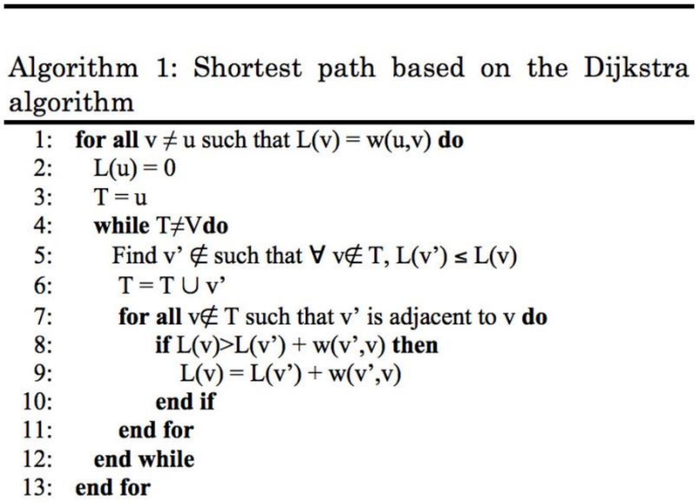
An SDN architecture will be used for slicing evaluation in 5G networks. The network controller employed in this work was Floodlight due to its modular structure in which different software pieces are responsible for specific tasks [22]. Some of them serve general purposes, such as Dynamic Host Control Protocol (DHCP) services; others were developed for a specific function, e.g. routing, forwarding, and QoS management.

In this work, routing is based on Dijkstra's algorithm, in which a new node in the list T is added for each iteration of the algorithm [23]. This is achieved by choosing a node v' that does not belong to T yet and has a minimum tag $L(v')$. In other words, the authors selected the node v' closest to u that was also excluded from the T list. Subsequently, the labels of the nodes on which v' exerts an influence were updated, so that a new calculation of the distances from u to these nodes is made and this node v' is added to T. The process is repeated until all the nodes in the graph are in the list. The pseudo code is shown in Fig.1.

The QoS module is built-in as an add-on to the controller and consists of different Python scripts. These small applications are responsible for managing the policies that will be implemented in the network [24].

The SDN controller manages the Open vSwitches through the QoS module, using priority queuing to guarantee the QoS in the network. Said module creates different queues in each port with a specific bandwidth through *ovs-vsctl* commands, thus the bandwidth is limited independently of the link. This configuration allows QoS management when different kinds of services are allocated to the right queue.

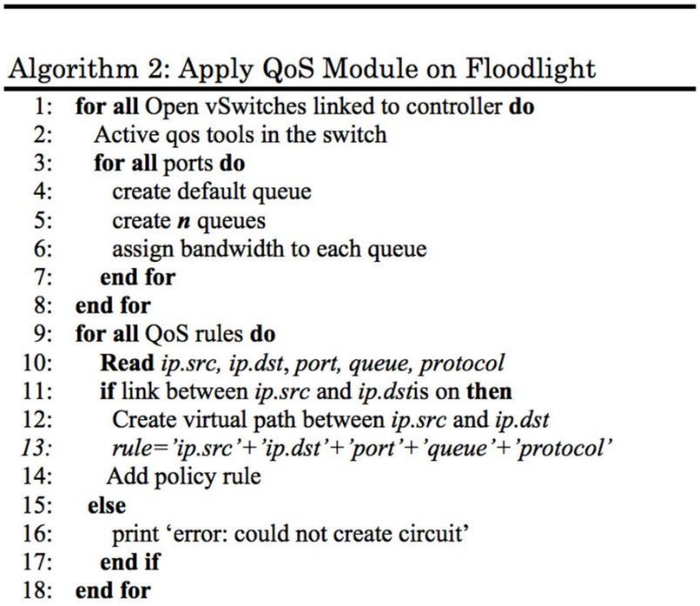
In order to enable network slicing, different queues were created and their bandwidth was set based on this bandwidth traffic treatment. Afterward, the traffic was associated with a service and allocated to a virtual channel or queue. This process employs the controller's rules, which separate packets depending on parameters like IP address, protocol or TCP/UDP port and associate them with a given queue. Once the algorithm is running, changes to the slices can be commanded from the controller on the fly if a given user profile declares the need for different resources. The pseudocode that describes the implemented network slicing approach is described in Fig. 2



Algorithm 1: Shortest path based on the Dijkstra algorithm

```
for all $v \neq u$ such that $L(v) = w(u,v)$ do
  $L(u) = 0$
  $T = u$
  while $T \neq V$ do
    Find v' ∉ such that $\forall$ v∉ T, $L(v') \leq L(v)$
     $T = T \cup v'$
     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
```

Fig. 1. Pseudocode used to implement the shortest path based on Dijkstra's algorithm. Source: Authors' own work.



Algorithm 2: Apply QoS Module on Floodlight

```
for all Open vSwitches linked to controller do
  Active qos tools in the switch
  for all ports do
    create default queue
    create n queues
    assign bandwidth to each queue
  end for
end for
for all QoS rules do
  Read ip.src, ip.dst, port, queue, protocol
  if link between ip.src and ip.dstis on then
    Create virtual path between ip.src and ip.dst
    rule='ip.src'+'ip.dst'+'port'+'queue'+'protocol'
   Add policy rule
 else
    print 'error: could not create circuit'
  end if
end for
```

Fig. 2. Pseudocode used to implement the network slicing in the controller. Source: Authors' own work.

The slicing approach is assessed two times. First, the SDN network was characterized for a throughput greater than the available bandwidth. In this context, delays and packet losses are evaluated based on the resource segmentation defined by the controller and the corresponding QoS descriptions for different traffic profiles. Subsequently, the second part uses the results of the characterization to evaluate the performance of a 5G network that supports different types of traffic that are common in a mobile network. Fig. 3 shows the flow graph used for the evaluation of the slicing in 5G networks.

Four underlying topologies are proposed in order to singularize the characteristics of future 5G networks. Such topologies are shown in Fig. 4, where switches replicate BS functions, hosts represent end-user devices in a conventional mobile network, and the links transport a maximum bandwidth of 5Mbps. In this context, data traffic was sent simultaneously from h1 towards h4 and from h2 towards h3. Data packets were differentiated by source and destination addresses in order to make channel segmentation evident. The evaluation was carried out by assigning different distributions of the available bandwidth, starting with an equitable share of 50% for each flow and then giving priority to the flow between hosts h1 and h4 (1-4).

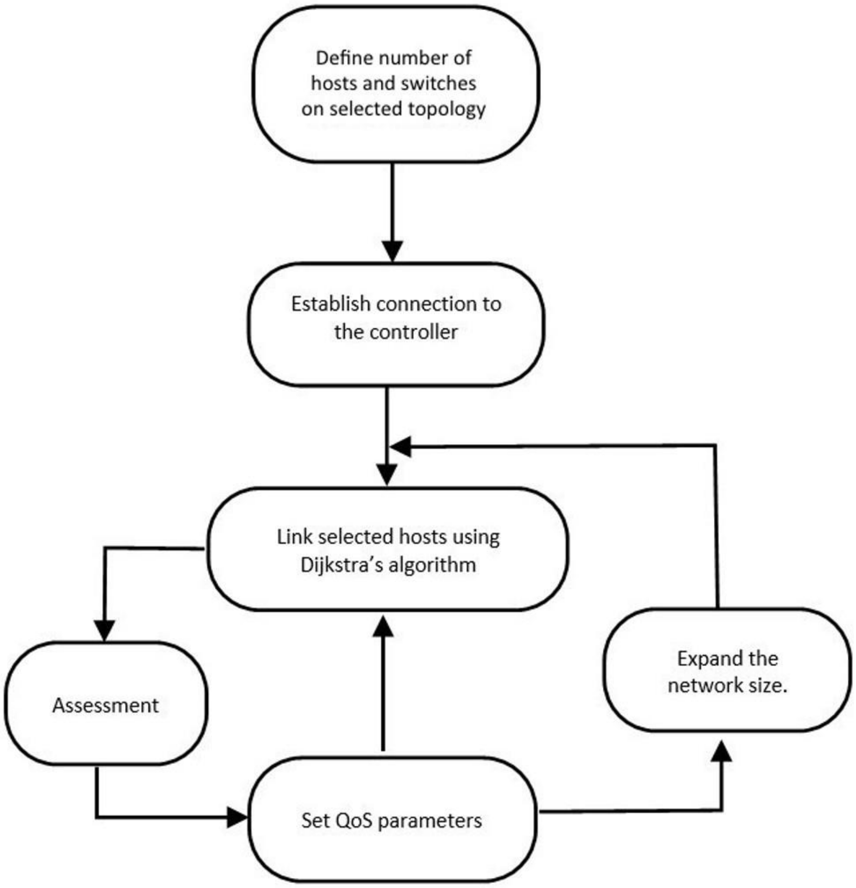
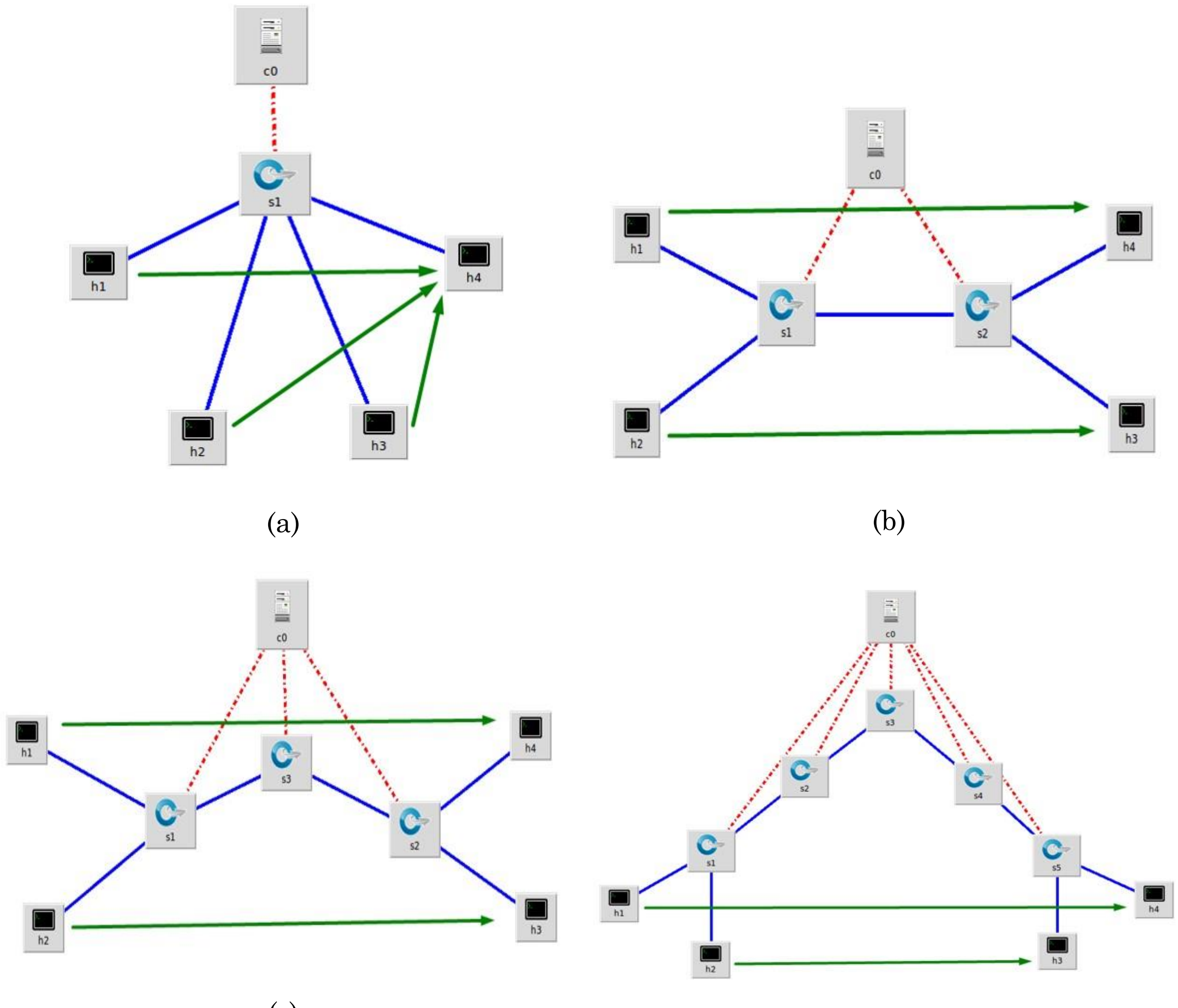


Fig. 3. Flow graph of the proposed 5G slicing evaluation. Source: Authors' own work.



(a) (b)

(c) (d)

Fig. 4. Topologies used for the characterization of the slicing. Arrows indicate the linked hosts. Source: Authors' own work.

Once the evaluation to characterize the performance of the SDN using different bandwidth distributions was completed, the environment of a 5G network based on a dense distribution of base stations was implemented and evaluated under common traffic patterns (e.g. VoIP, streaming video and a 3D game) as well as other application flows (e.g. mail and messaging). Fig. 5 shows the evaluated 5G topology. The description of the service, packet lengths, bandwidth, transmission protocol, and port are presented in Table 1.

Afterward, based on ITU's recommendation Y.1541 for IP network QoS and class definitions, the flows were classified in order to guarantee the performance parameters. Table 2 shows the network performance objectives and the recommended values of the metrics that should be assured for each class.

Each type of traffic in Table 2 is associated to a class. As a result, VoIP belongs to class 1, in which packet delay should be lower than 400 ms; the jitter, under 50 ms; and the losses ratio, below 0.1%. Similarly, the 3D game and the video streaming fit into class 0, in which delays should be lower than 100 ms; the jitter, under 50 ms; and the losses ratio, below 0.1%. On the other hand, Flow 1 and Flow 2 should meet class-4 objectives. Finally, Flow 3 is part of the class-5 traffic that does not have any specification.

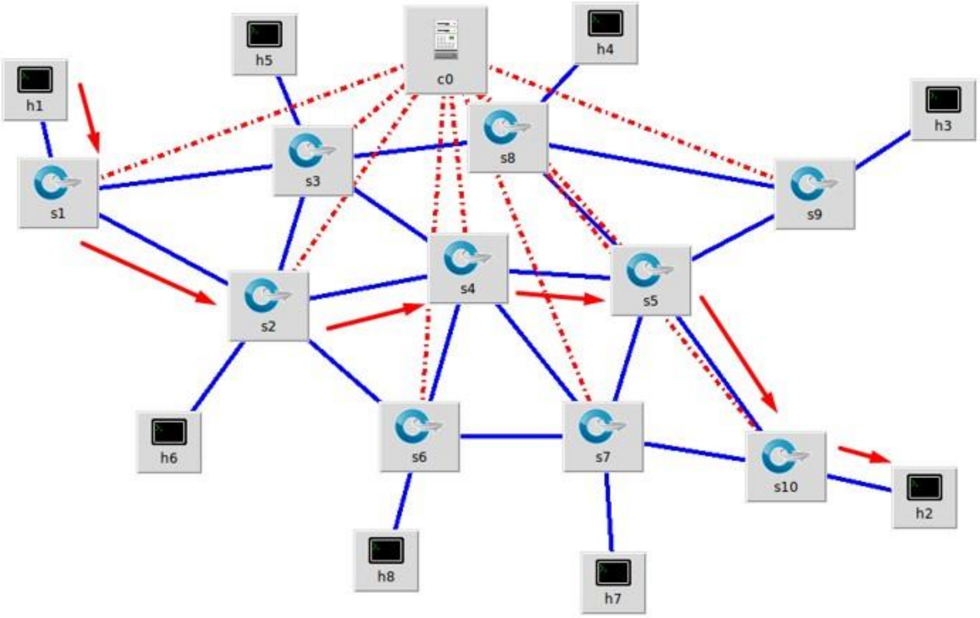


Fig. 5. Network environment for 5G slicing evaluation. Source: Authors' own work.

Table 1. Description of the flows in the application of 5G network slicing. Source: Authors' own work.

Traffic Name	Packet Size [Mbyte]	Transmission rate [Packet/s]	Protoco l	Port
VoIP	Random	Random	UDP	1000
Video	1450	110	UDP	2000
3D Game	1500	300	UDP	3000
Flow 1	1000	512	TCP	8000
Flow 2	1000	512	TCP	8001
Flow 3	1000	512	UDP	8002

Table 2. IP network QoS class definitions and network performance objectives. Sources: Table 1 and Rec. Y.1541 ITU.

Network performance parameter	QoS Classes					
	Class 0	Class 1	Class 2	Class 3	Class 4	Class 5
Delay [ms]	100	400	100	400	1000	U
Jitter [ms]	50	50	U	U	U	U
Loss Ratio	$1x10^{-3}$	$1x10^{-3}$	$1x10^{-3}$	$1x10^{-3}$	$1x10^{-3}$	U

"U" means "unspecified" or "unbounded".

Afterward, the resources were distributed according to the needs of each service, the transport protocol, and the port. Table 3 shows the QoS policies defined to evaluate 5G slicing performance. In particular, a video streaming using UDP on port 2000 will have a bandwidth of 1.2 Mbps. A 3D game will be allocated 3.2 Mbps and a call over VoIP on port 1000, a bandwidth of 100 kbps. On the other hand, a few additional general traffic definitions were implemented because all the TCP traffic from any port will be allotted only 100 kbps. Similarly, all the UDP traffic that does not follow the other rules will have an available virtual channel of 300 kbps. In this case, the priority associated with the policy is important, since assigning a higher value to the general rule for UDP flows would generate conflicts. For example, the 3D game flow would coincide with the rule with the highest priority which, in this case, is related to a sliced channel narrower than the one truly assigned to this flow.

The Mininet network emulator including the Floodlight controller was used to carry out the tests. This tool creates hosts that run the Linux kernel and allows to execute applications such as Wireshark to analyze traffic, *iperf* to generate homogeneous traffic, and D-ITG to generate customized traffic flows. The latter was used to inject traffic into in this work.

Table 3. Quality of service policies for 5G network slicing. Source: Authors' own work.

Protocol	Port	Priority	Bandwidth
TCP	Any	3000	100 kbps
UDP	Any	3000	300 kbps
UDP	1000	5000	100 kbps
UDP	2000	5000	1.2 Mbps
UDP	3000	5000	3.2 Mbps

3. RESULTS

A. Characterization of the network slicing

Fig. 6 shows the bandwidth assigned to flows between host h1 and h4 and flows between host h2 and h3. Fig. 6(a) shows the bandwidth distribution according to the assignment by the controller, e.g. for the distribution of 80% and 20%, the allocated bandwidths are 4 Mbps and 1 Mbps, respectively. This behavior was found to be similar in all the evaluated topologies. Fig. 6(b) shows that the accumulated bandwidth in the different configurations reaches approximately 4.86 Mbps regardless of the bandwidth allocation.

This behavior confirms the versatility of the SDN architecture because no modifications were made in the physical layer and multiple configurations were created in the logical infrastructure, thus influencing the results presented in the following figures. Fig. 7(a) shows the network latency measurements, and it can be observed that the delays are directly related to the assigned bandwidth. For example, in a 90% - 10% allocation, host h1 is assigned 4.5 Mbps of bandwidth and exhibits a delay of 0.48s. Likewise, host h2 was assigned a bandwidth of 0.5 Mbps and its delay was found to exceed 22s. Briefly, the lower the allocated bandwidth, the longer the delay.

Fig. 7(b) summarizes the behavioral trend of this scenario and shows that the global delay of the network is minimal when the bandwidth is distributed equally and it increases as the allocation is more uneven. Minimum and maximum average delays were found to be 2.64s and approximately 11.4s, respectively.

Packet loss rate was also evaluated (Fig. 8). In particular, Fig. 8(a) shows the relationship between packet loss rate and assigned bandwidth, in which it is possible to have an efficient percentage of only 0.82% losses with an allocation of 90% of the channel's resources, that is, 4.5 Mbps. However, with the same configuration, the other flow is assigned only 10% of the channel, which results in losses close to 80% given the high demand in the network. Fig. 8(b) shows that the global average packet loss rate remains unchanged at 40% with different bandwidth allocations.

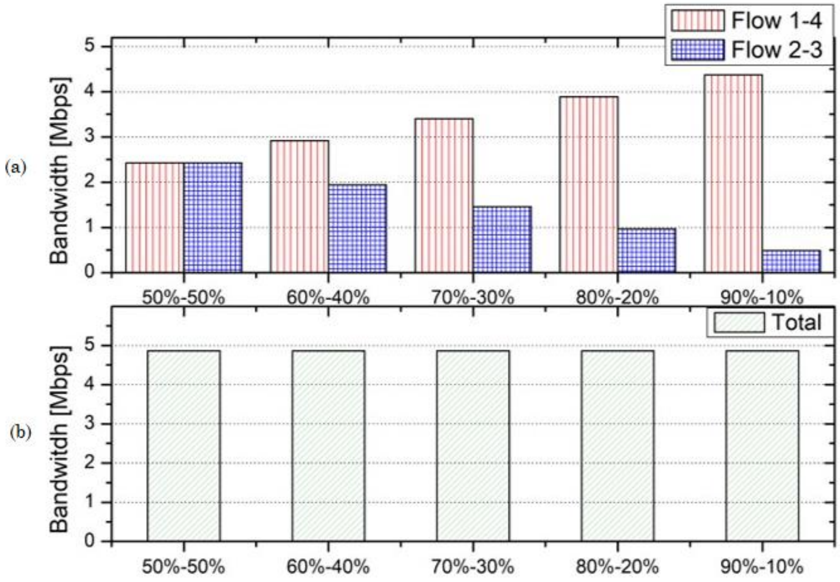


Fig. 6. Bandwidth assigned using QoS policies. (a) Performance of individual flows. (b) Global performance. Source: Authors' own work.

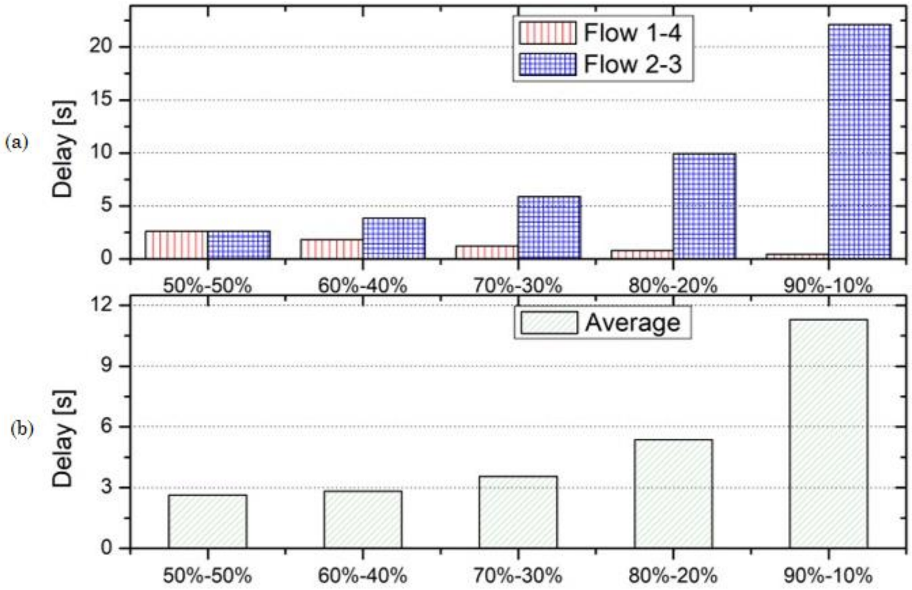


Fig. 7. Delay obtained using QoS policies. (a) Performance of individual flows. (b) Global performance. Source: Authors' own work.

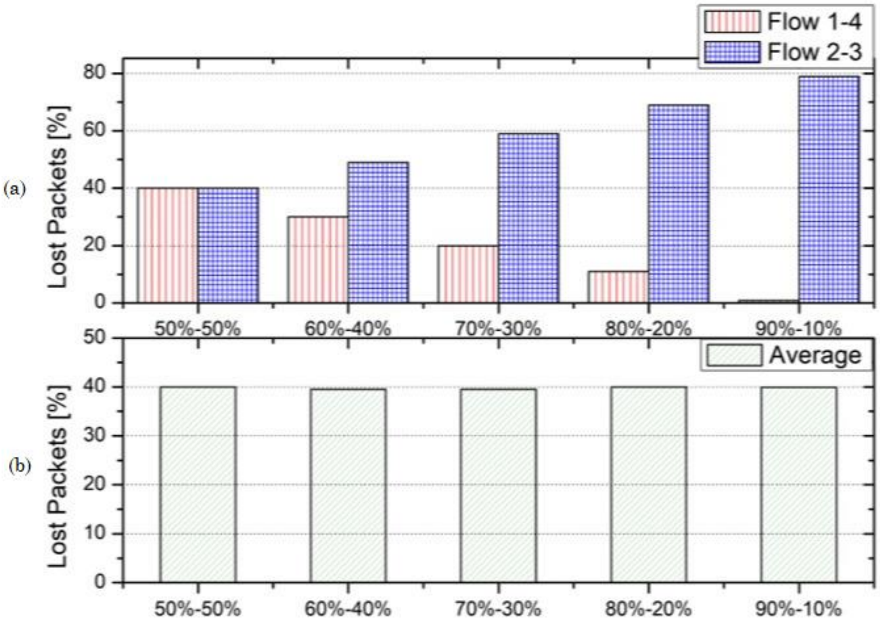


Fig. 8. Packet losses obtained using QoS policies. (a) Performance of individual flows. (b) Global performance. Source: Authors' own work.

This process results in a value 10% lower than the scenario without applying QoS policies, where the global packet loss rate was around 50%.

This fact means that the links' reliability is improved as the need for packet retransmissions is reduced, which results in better management of the available bandwidth.

Fig. 9 shows the plot of the delay in the network with respect to the percentage of assigned resources. The function that describes the relationship is exponential, and it should be noted that there are significant differences in the delay for the same variation of the assigned resource. For instance, the delay is reduced from 22s to 10s when the bandwidth allocation changed from 10% to 20%; however, when such allocation climbed from 80% to 90%, the delay was reduced only 300ms.

It should also be noted that the more resources are available, the lower the packet loss. This can be seen from Fig. 10: when 10% of the resources were assigned, an 80% packet loss was calculated. On the contrary, with 90% of the channel capacity, the losses are almost nil at values close to 0.5%. This dependence of delay and packet loss on bandwidth availability enables an SDN to allocate slices in accordance with the service application requirements in order to reach a target delay and assure an adequate QoS policy.

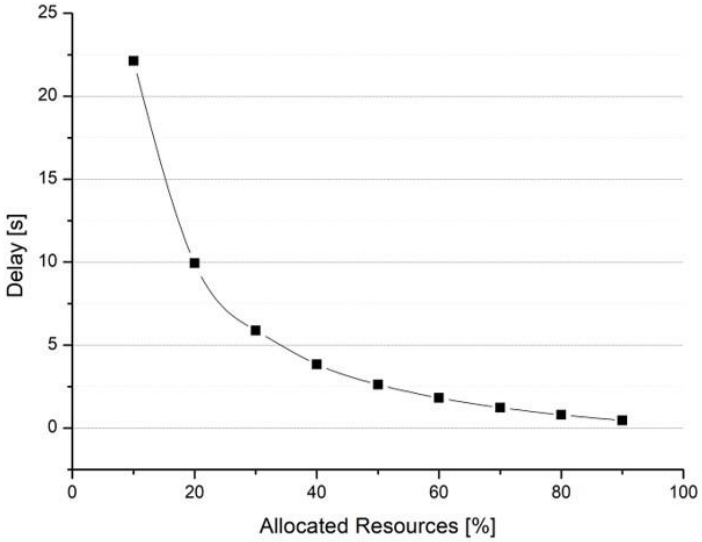


Fig. 9. Delay vs. allocated resources. Source: Authors' own work.

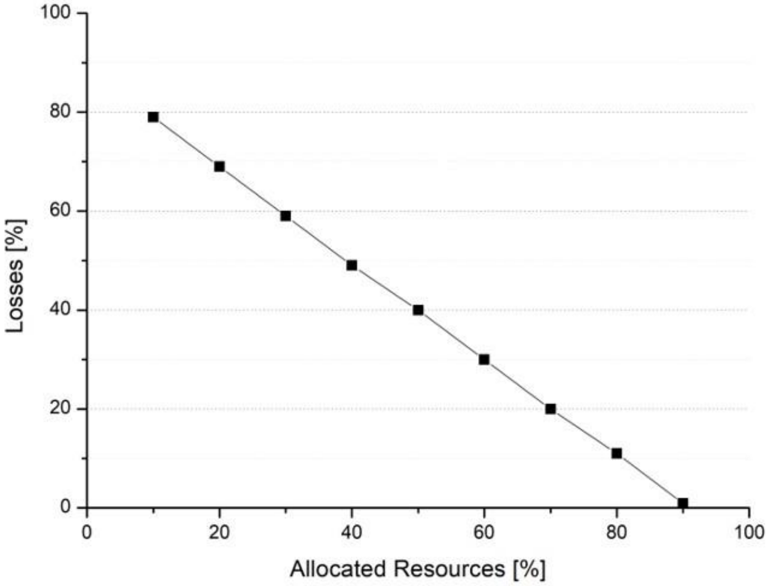


Fig. 10. Packet loss vs. allocated resources. Source: Authors' own work.

B. Network slicing in a 5G environment

This section presents the results of the 5G network slicing using the topology shown in Fig. 5. In order to compare the impact of the slicing, the authors evaluated the performance of different services (according to Table 1) with different QoS requirements and without implementing slicing strategies. The results are shown in Table 4. It should be noted that the flows transported on TCP (Flow 1 and Flow 2) ensure 100% packet delivery despite the bandwidth limitation imposed by the slicing. Likewise, the delay increases, which is consistent with the slicing characterization described in the previous section. It can also be observed that all the application services present a very high delay and flows transported on UDP undergo significant packet losses.

Considering the results in Table 4, the rules described in Table 3 were implemented in the 5G network topology. The results obtained after implementing the QoS policies are shown in Table 5. It can be seen that including QoS policies improves the performance of the evaluated metrics (e.g. delay and jitter) for specific services by creating slices with the available resources, which generates dedicated channels for critical services while neglecting others. For example, Flow 3 transported on UDP undergoes a significant packet loss of around 85%. On the contrary, the rest of the application services do not experience packet losses and the delays are reduced: 0.69s for video streaming and 0.62s for online 3D gaming. It should be pointed out that even though the delay is reduced, it does not completely fulfill ITU's Y.1541 recommendation regarding QoS for class-0 traffic. In order to do so, a higher bandwidth allocation should have been assigned to the corresponding slice due to the trade-off between the allocated resources and delay, as shown in Fig. 9.

Table 4. Results without network slicing. Source: Authors' own work.

Traffic Name	Delay [s]	Jitter [ms]	Losses [%]	Throughput
VoIP	1.21	8.3	41.38	24 kbps
Video	1.19	4.9	48.76	576 kbps
3D Game	1.19	2.0	44.51	1.73 Mbps
Flow 1	5.27	2.1	0	229 kbps
Flow 2	6.36	1.7	0	281 kbps
Flow 3	1.21	1.0	36.99	2.12 Mbps
Total	1.9	9.5	35.9	4.79 Mbps

Table 5. Results with network slicing. Source: Authors' own work.

Traffic Name	Delay [s]	Jitter [ms]	Losses [%]	Throughput
VoIP	1.0	0.1	0	46.15 kbps
Video	0.69	0.58	0	1.25 Mbps
3D Game	0.62	0.48	0	3.42 Mbps
Flow 1	50.75	67.0	0	61.91 kbps
Flow 2	53.75	88.5	0	49.03 kbps
Flow 3	25558.8	36.0	85.1	92.52 kbps
Total	7.36	0.035	54.29	4.92 Mbps

4. CONCLUSIONS

Throughout this work, specific functionalities of the Floodlight controller were explored in order to implement network slicing capabilities by segmenting available hardware resources in the context of future 5G networks. The slicing was characterized as a function of delay and packet loss. The results show that these metrics are inversely correlated to the slice of available resources; however, they depend on the topology because the results were similar in the four network models that were evaluated. This is a significant feature of the centralized control of the SDN that keeps the predefined channel conditions in an end-to-end transport environment. In particular, a global average packet loss rate of 40% was found with different bandwidth allocations as well as an increase in the global delay of roughly 9s for uneven network slices. Once the potential of the SDN infrastructure was recognized, a group of specific service profiles was defined for different applications to verify that the network slicing implemented in the Floodlight controller over different links perfectly fulfilled the basic requirements to assure different degrees of QoS for 5G networks.

These results enable to conclude that network slicing, along with the definition of basic QoS policies on the proposed scenarios, allows to differentiate services and thereby improve the performance of SDN networks in specific aspects associated with the needs of application services. This fact is a fundamental element in the implementation of 5G slicing. By comparing the results of the evaluated metrics, network slicing was found to benefit QoS performance for differentiated application services. In the context of the evaluation presented in this paper, services such as VoIP, video, and 3D gaming significantly improved their performance when they were transported in a sliced network.

5. ACKNOWLEDGMENTS

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