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ARQUITECTURA PARA IMPLEMENTACIÓN DE SERVICIOS DE VIDEO SOBRE REDES MÓVILES MEDIANTE REDES DEFINIDAS POR SOFTWARE Y SEGMENTACIÓN DE RED

ARCHITECTURE FOR VIDEO STREAMING SERVICES DEPLOYMENT ON MOBILE NETWORKS USING SOFTWARE-DEFINED NETWORKING AND NETWORK SLICING

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Resumen: El presente artículo propone el diseño de una arquitectura para el despliegue de servicios de videostreaming sobre una infraestructura de redes móviles teniendo en cuenta los conceptos de redes definidas por software, radio definida por software y segmentación de red, con el objetivo de que sea flexible y escalable. Como principal contribución de este artículo, se presenta una arquitectura para el despliegue y consumo de servicios de videostreaming sobre infraestructura de red móvil basada en enfoques de redes definidas por software y segmentación de red. La arquitectura propuesta se especificó a través de la vista funcional y la vista de implementación, las cuales definieron los módulos funcionales extremo a extremo del servicio de videostreaming, así como las tecnologías utilizadas para la implementación de estas funcionalidades. El prototipo obtenido como instancia de la arquitectura propuesta permitió demostrar que puede ser considerado como un referente en diferentes entornos académicos y empresariales.

Palabras clave: Arquitectura, SDN, SDR, Segmentación, Videostreaming.

Abstract: This article proposes the design of an architecture for the deployment of videostreaming services on a mobile network infrastructure taking into account the concepts of software-defined networks (SDN), software-defined radio (SDR) and network slicing, with the aim of being flexible and scalable. As the main contribution of this article, an architecture for the deployment and consumption of videostreaming services over mobile network infrastructure is presented based on software-defined networking and network slicing approaches. The proposed architecture was specified through the functional view and the implementation view, which defined the end-to-end functional modules of the videostreaming service, as well as the technologies used for the implementation of these functionalities. The prototype obtained as an instance of the proposed architecture allowed us to demonstrate that it can be considered as a reference in different academic and business environments.

Keywords: Architecture, Network slicing, SDN, SDR, Video streaming.

1. INTRODUCTION

The technological evolution in recent years and the growing adoption of communication technologies and services led to a continuous increase in the number of mobile broadband subscribers and the appearance of new smart devices capable of connecting to the network (Ge et al., 2019; Nallappan et al., 2018; Saltarin et al., 2017; Shayea et al., 2020). This is causing high congestion in mobile networks due to the exponential increase in information traffic, which harms their performance (Bonati et al., 2020; Perez et al., 2017; Xiao et al., 2020; Yan et al., 2018). Along with this, the inflexible infrastructure of conventional networks makes them unable to handle the increasing demands in terms of capacity and higher data performance (Bonati et al., 2020; Castañeda Herrera et al., 2021).
Therefore, there is a need to improve the architecture of traditional networks to meet the expansion in the adoption of communication technologies and the new needs of next-generation networks. These aim to change the traditional business model with new use cases launched by a wide range of markets (Bonati et al., 2020; Khan et al., 2020; Song et al., 2019). This vision points towards a flexible network ecosystem that is dynamically programmable and adaptable to different requirements with optimized characteristics to serve a particular purpose or a service category. To do so, 5G technology tends towards a more intelligent architecture, where the use of software and the virtualization of networks are key for the abstraction of infrastructure resources and the delivery of networks as a service improved for each use case (Condoluci & Mahmoodi, 2018; Ghosh et al., 2019). In this sense, technologies such as SDN and Network Functions Virtualization (NFV) play an important role because they enable the flexibility to meet each service need in a personalized way (Barakabitze et al., 2020; Flores Moyano et al., 2020).

According to the above and considering the existing gap in traditional network architectures, which are focused on an inflexible infrastructure that has limitations for the adequate handling of traffic demand in terms of capacity and higher data performance, we propose the design of an architecture for the deployment of services based on video streaming technology (video on demand, live video) over a mobile network infrastructure considering the concepts of SDN and SDR. Additionally, we suggest including the functionalities provided by the Network Slicing technology to make it flexible (Barakabitze et al., 2020; Zhang, 2019). To describe the architecture presented in this article, two views (functional and implementation) were defined based on what is presented (Quiroga, Montoya et al., 2017). The authors describe the architecture of a telecommunications hardware-software system considering that the 4+1 view architectural model is more suitable for the description of software. The proposed views describe the end-to-end components of the value chain of video streaming services over mobile networks, as well as the technologies and tools selected to implement them. Our architecture includes general-purpose hardware such as the Universal Software Radio Peripheral (USRP) along with free software for the implementation of the Core Network (CN), the Radio Access Network (RAN), Network Slicing technology, and network monitoring functionalities. The implementation of a proof-of-concept derived from the proposed architecture made it possible to demonstrate that it can serve as a reference for both academic scenarios and network providers regarding the implementation of high-quality video streaming services on the infrastructure of 5G networks. In this same vein, our architecture aims to serve as a contribution to service providers in the progressive transition from a network architecture based on an inflexible infrastructure to a flexible network architecture based on SDN and SDR. Likewise, from the views defined for this architecture, it is possible to extrapolate the proposal to carry out related research and develop new services on that technological infrastructure.

The paper is organized as follows: section 2 presents the methodology phases of this research; section 3 shows the results, which include the description of the functional view and the implementation view, as well as the proof-of-concept of the proposed architecture; and section 4 presents the conclusions.

2. RESEARCH METHOD

To conduct this research, four methodological phases were defined (Figure 1): 1) An exploration of technologies and tools; 2) The definition of the functional view from the architecture; 3) The definition of the implementation view; and 4) The prototype or proof-of-concept derived from the architecture based on what was presented in (Chanchí et al., 2020; Quiroga, Montoya et al., 2017). In phase 1, a set of technologies and tools were explored to know the configuration of the architecture. In phase 2, the functional view of the proposed architecture was defined, it includes the functional modules that comprise the end-to-end value chain of video distribution services such as video on demand. In phase 3, the implementation view was defined, it describes the different techniques and technologies that allow complying with the functionalities defined in phase 2. Finally, in phase 4, a proof-of-concept of the architecture was presented, and its relevance was validated.

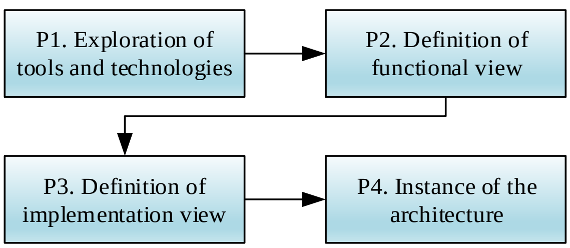

Fig. 1. Considered methodology

3. RESULTS AND DISCUSSIONS

This section presents the results obtained from this research. It describes the functional view and the architecture implementation view for the deployment of video streaming services on mobile networks based on Software-Defined RAN (SD-RAN) and Network Slicing. Likewise, considering that one of the ways to validate the relevance of the architecture is to develop prototypes derived from it (Capilla et al., 2020), we present a proof-of-concept that allows us to do so.

3.1 Functional View

The functional view of the architecture describes different modules (Figure 2) and three main domains can be distinguished: (1) service provider, (2) network provider, and (3) customer. The functional modules that compose these domains represent the value chain of the video streaming service deployed on mobile networks.

This architecture considers the distribution of video content supported by the Dynamic Adaptive Streaming over HTTP (DASH) standard; an International Organization for Standardization (ISO) standard defined for the transmission of video over wireless mobile networks (Kua et al., 2017). In the service provider domain, a video database stores the content offered to the customer. The source of information may be an external content provider. The multimedia files are taken to a DASH stream encoder module responsible for segmenting and encoding them in different qualities. The encoded video segments are stored on a web server, which in turn distributes them to the client. Based on this, the DASH encoder defines a manifest file called the Media Presentation Description (MPD), that describes the multimedia content, the qualities, and how it is divided into segments depending on the available bandwidth on the client-side. This descriptor is necessary to synchronize communication with the client to serve content as needed. Moreover, the domain of the network provider is in charge of providing a gateway for end-to-end communication between the client and the server. In this case, a cellular mobile network is based on an architecture supported by the IP protocol. The functional modules that make up the mobile network are the CN and the SD-RAN. The CN performs the tasks of registration and authentication of the user terminal equipment through the components of the mobility management sub-module and other tasks from the control plane such as session management, tracking and paging of the user terminal, and the establishment of terminal-network connections. The nodes SPGW-C and SPGW-U are responsible for providing service and connectivity to the subscriber through an internal packet data network that allows communication with external networks (Habibi et al., 2019). They represent the border between the CN and the RAN and are divided into two entities to enable the separation of the control plane from the user plane (Estrada-Solano et al., 2017). This characteristic represents a structural improvement in the architecture since it favors the reduction of latency in the user plane (Mohammadkhan et al., 2020).

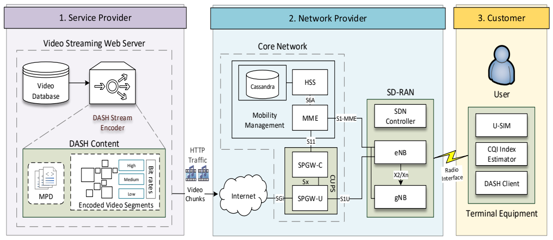

Fig. 2. Functional view of the architecture

The SD-RAN module is composed of the Evolved Node B (eNB) sub-module, the Next Generation Node B (gNB) sub-module, and the SDN controller. The eNB and gNB constitute the base stations of the mobile network, which operate based on radio access technologies, as well as 4G and 5G communication protocols, respectively. That is, a 5G Non-Standalone Architecture (NSA) where communication between the terminal equipment and the antenna is carried out using 5G protocols. However, the data communication with external networks is created using 4G technology. The eNB node serves as a bridge for communication in the control plane between the CN and the gNB of the mobile network. Both the eNB and the gNB transmit IP packets from and to the UEs together with the signaling messages necessary to control the operation of the radio interface. The latter is supported by the SDR paradigm; it is based on a technology that allows implementing the software on the hardware components of the radio frequency interface including modulators, mixers, and filters (Papa et al., 2022). Finally, the SDN controller sub-module implements the functionalities of the SDN paradigm in the RAN domain that enables separating the data and the control plane. The latter is consolidated in a logically centralized entity called the controller, which facilitates the flexible programmability and coordination of the RAN and enables monitoring, reconfiguration, and control of the RAN status.

Finally, the client's domain is made up of the terminal equipment module. Here, the U-SIM sub-module is in charge of storing customer identification data for registration and authentication in the mobile network. In the DASH client sub-module, an MPD decoder and a video player are necessary to use the video streaming service. The decoder allows the interpretation of descriptors of the video content present on the server-side. To access the multimedia content, the client chooses the quality of each content segment and downloads it sequentially using the HTTP protocol. This request is made based on the channel status experienced by the terminal equipment on the radio link. To do this, the Channel Quality Indicator (CQI) index estimator sub-module estimates the available average bandwidth represented in an index that indicates to the base station what level of modulation and coding must be used to ensure communication with the UE. This CQI is mapped to a video segment encoded at a rate that allows maintaining a service level agreement. For this, a communication channel must be generated between the client and the server through the UE's web browser application, using the TCP protocol, which allows it to communicate the video segment to the server and the quality required to consume the video content.

3.2 Implementation View

This section presents the implementation view of the architecture. We present the selected hardware and software components for the implementation of the end-to-end functional modules defined in the functional view of the architecture (see Figure 3). In the domain of the service provider, the video streaming web server module is implemented using the MPEG-DASH content webserver hosted in (Akamai CDN, 2020). This provides a set of test videos that are segmented and encoded at different qualities with their respective MPD for experimentation with live and on-demand streaming technology. To access the video streaming service from the user terminal equipment, the open-source DASH client was used, which was provided by DASH Industry Forum (DASH Industry Forum, 2012). This web client, generally made of an MPD file interpreter and a MPEG-DASH content player, can play DASH content hosted on any web server based on its MPD. To implement a video streaming web server, it is recommended to use the free and open-source software packages NGINX (Kong et al., 2020) and FFMPEG (Yang et al., 2020). FFMPEG acts as a transcoder and enables encoding multimedia files. NGINX is a web server/reverse proxy that has a module based on the Real-Time Messaging Protocol (RTMP) that enables communication in real-time with the transcoder node. This web server can be set to transmit the received video stream using the DASH or HTTP Live Streaming (HLS) protocols. The information source can be based on a video database hosted on the website, for consumption on demand, or from a live video source. For the latter, it is suggested to use the OBS Studio software (Hayaty et al., 2021), an open-source tool that allows live video to be transmitted from a workstation to the NGINX server. It receives this information through the RTMP protocol and relays it using DASH or HLS.

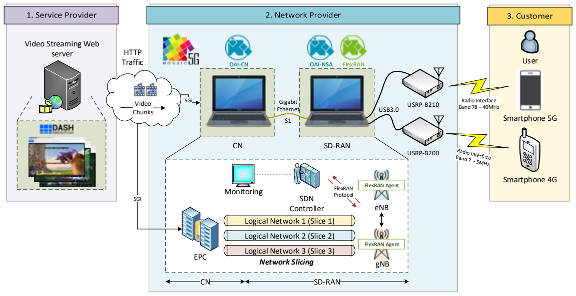

Fig. 3. Implementation view of the architecture

To manage the client-server communication and content distribution, a mobile network based on the 5G NSA architecture is implemented in the network provider domain. The elements that make up the CN and SD-RAN modules at the software level have been built using open-source tools. To do so, the Mosaic-5G software platform (Wiranata et al., 2020) was used. This platform provides installation packages that enable the implementation of the CN and the RAN in computer systems with an operating system based on Linux. The recommended distribution is Ubuntu 18.04.5 LTS or later versions. The OpenAirInterface (OAI)-CN, OAI-RAN, and OAI-5G-NSA installation packages implement the software elements that make up the CN, 4G-based RAN, and 5G NSA-based RAN, respectively. A fourth installation package called FlexRAN enables the implementation of the SDN paradigm in the RAN domain. With this, the separation of the data and control plane is achieved, allowing flexible programmability and coordination of the RAN from a logically centralized controller node, which has a generalized view of the RAN. That is, an SD-RAN. This software platform has a set of tools such as Software Development Kit and Application Programming Interface that facilitate the creation and implementation of applications to monitor, control, and coordinate the status of the RAN, besides collecting statistical data and dynamically managing the available radio resources at runtime.
Thanks to the programmability that SDN introduces on the RAN control plane and the software tools provided by the FlexRAN platform, the functionalities of Network Slicing technology were implemented on the RAN domain. In this way, it is possible to create virtually independent logical networks hosted on the same network infrastructure. The bandwidth resources or available resource blocks are managed through the SDN controller and assigned to each virtual network as needed to maintain an adequate level of Quality of Service (QoS) for the consumption of video streaming services. The radiofrequency interface of the base stations in the SD-RAN module is supported in the SDR paradigm. For its implementation, general-purpose hardware such as the USRP has been used (Izydorczyk et al., 2019); particularly the Ettus Research USRP (model B210) (Ettus Research, 2023) and transmission antennas as upstream and downstream carriers in band 7 (Fc: 2600MHz and Bw: 10MHz) and band 78 (Fc: 3500 MHz and Bw: 40MHz) for 4G and 5G NSA, respectively. These devices perform the signal processing related to the physical layer. It should be noted that these open-source platforms have created a field for experimentation in the academic and industrial community, thus enabling the implementation and testing of new algorithms for the allocation of resources, the creation and management of logical networks in Network Slicing. They could also be used to test new technologies such as Multi-access Edge Computing (MEC), which allow the implementation of mechanisms to optimize the delivery of video content or delay-sensitive services in general. All of the contributors are on the way to the standardization, adoption, and implementation of 5G.

Finally, a smartphone-compatible with 4G and 5G wireless technologies is required in the customer domain. For its identification, authentication, and registration in the mobile network, a programmable sim card (a Sysmocom Sysmosim-SJS1-4FF card) was used. For its parameterization, a PC/SC Smart-Card USB-CCID ISO7816 reference programmer and the Pysim software (Osmocom.org, 2017) were used. For the consumption of the video streaming service, a web browser has been used to access the DASH client available in (DASH Industry Forum, 2012). From there, it is possible to select a live or on-demand video source that has already been encoded at different rates to provide the video streaming service supported in the DASH protocol.

Thus, the view allows the implementation of a proof-of-concept derived from this architecture; a detailed process is described in (Chavez Picon et al., 2021).

3.3 Functional Prototype of the Architecture

To validate the relevance of the architecture proposed in this paper, a proof-of-concept has been implemented. This section shows the throughput results obtained in the descending link from the cellular mobile network when consuming videos on the on demand streaming service deployed from the provider domain. To access this service, a pair of user terminal equipment has been used; it is located in the client's domain and is compatible with 4G wireless technologies. Figure 4 shows the service prototype built from the architecture defined in this paper.

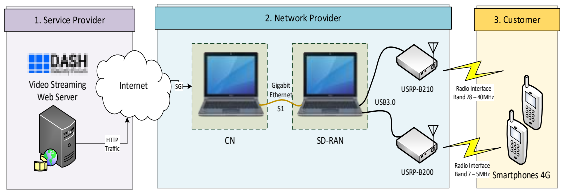

Fig. 4. Prototype implementation view

In the network provider domain, the SDN paradigm was implemented in the RAN of the cellular mobile network, as well as the functionalities of the Network Slicing technology. From the SDN controller, two virtually independent logical networks were created and labeled Slice 0 and Slice 2. Each one was assigned a different percentage of bandwidth: 70 percent of the total bandwidth available on the descending link for Slice 2, and 30 percent for Slice 0. The system has a total of 50 Resource Blocks (RB) equivalent to 10MHz of total bandwidth for the descending link. Each user terminal equipment has been associated with a different logical network.

The software platform Mosaic-5G (Wiranata et al., 2020) provides demo applications that allow interaction with the SD-RAN system to program the control plane and monitor the network. The “DRONE” application was used to graphically display the status of the SD-RAN execution in a web browser. Likewise, the application "mac_rate_app" was used to obtain the throughput from the mobile network in the descending link. Figure 5 shows the SD-RAN diagram generated by the application. It shows specifically the side of the RAN that contains the value chain: SDN controller, 4G base station, and the user terminal equipment associated with that station. The latter is identified with the code "International Mobile Subscriber Identity" (IMSI) 208950000000001 and 208950000000002.

Once authenticated and registered in the mobile network, the user terminal equipment was assigned to a different Slice for the descending link. The terminal equipment identified with the IMSI 208950000000002 was assigned to Slice 0, and the one identified with the IMSI 208950000000001 to Slice 2.

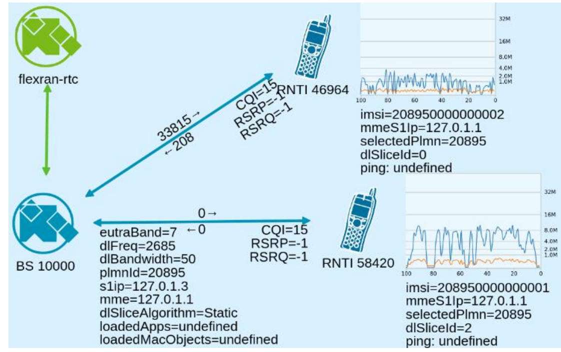

Fig. 5. SD-RAN diagram generated with the DRONE application

In addition, it is possible to observe a graph of the throughput experienced by the mobile network next to each user terminal equipment in the ascending link and descending link for each Slice. It should be noted that the Network Slicing functionalities were not applied to the ascending link channel (the network was not segmented). Both terminal types of equipment share the same channel in the ascending link. Figure 6 shows the throughput behavior (a) in Slice 0 and (b) Slice 2. It also indicates that the average throughput experienced by Slice 0 is less than the one achieved by Slice 2. Since the allocation of resources has been asymmetric, Slice 2 has more bandwidth resources, 70 percent of the total available (50 RB) enables higher transfer rates.

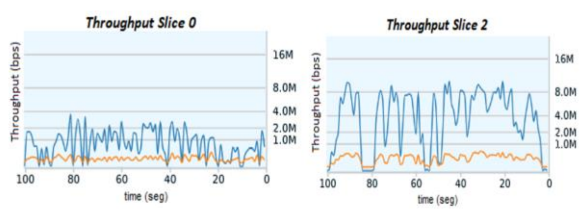

Fig. 6. Descending link throughput monitoring

From the previous results, it is possible to conclude that the prototype derived from the SDN and SDR-based architecture allows the proper handling of high transfer rates (similar to those of the actual traffic of current video services). This represents a competitive advantage for network service providers concerning traditional architectures based on inflexible network infrastructure.

Finally, Figure 7 shows images that validate the consumption of the video streaming service on demand from the client's domain through user terminal equipment. This is made using the DASH client provided by DASH Industry Forum (DASH Industry Forum, 2012) accessed through the Firefox browser application.

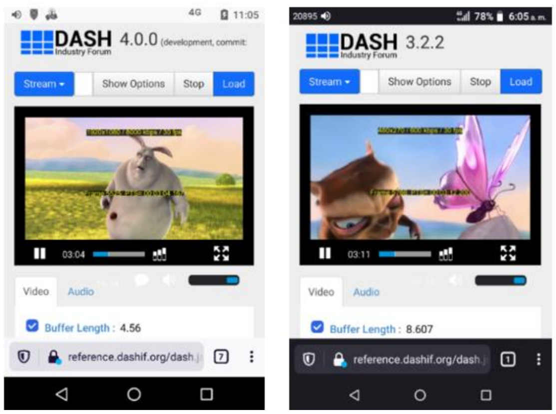

Fig. 7. On-demand video streaming service consumption from each user terminal equipment

4. CONCLUSIONS

Considering the existing gap in traditional network architectures related to the limitations of inflexible infrastructure for the adequate handling of traffic demand in terms of capacity and higher data performance the main contribution of this paper is an architecture for mobile networks based on SD-RAN and general-purpose hardware. Additionally, we propose Network Slicing to support of the video streaming service. Our architecture was represented by two views: the functional and the implementation. Each one includes the end-to-end components of the chain of consumption and distribution of video streaming services.

The proof-of-concept derived from the proposed architecture allowed us to demonstrate that it can be taken as a reference for the construction of distribution services and to consume high-quality video streaming on mobile networks using SDN and Network Slicing. In this sense, starting from the views defined for the architecture from the academic and business community, it is possible to extrapolate this proposal to develop related research and new services on the described technological infrastructure.
The results obtained in the throughput tests performed with the prototype derived from the architecture confirmed that, regarding the traditional architecture based on inflexible infrastructure, our architecture allows handling high transfer rates adequately, e.g., those associated with the traffic of current video-on-demand services. Thus, it is intended to serve as a reference for the transition from an inflexible infrastructure-based architecture to a flexible infrastructure based on SDN and SDR.

For future work, we intend to link the MEC technology to the architecture to provide it with computing capabilities and a service environment at the edge of the network. It opens a field for the development and implementation of applications on the edge of the RAN to optimize and provide multimedia content according to the conditions of the communication channel experienced by the user terminal equipment. This helps to significantly reduce latency in service delivery.

It also aims to expand the network to create scenarios with multiple base stations based on SDR technology and USRP devices, and multi-cell environments for the experimentation with handover algorithms managed from the SDN controller.

RECONOCIMIENTO

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