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Mobile network construction with NSA technology and QoE analysis for Video Streaming service

Construcción de red móvil con tecnología NSA y análisis de QoE para servicio de Videostreaming

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Abstract: The exponential growth of data traffic has put pressure on existing mobile network infrastructures, which are challenged to provide a satisfactory user experience. Therefore, this paper addresses the construction of a mobile network by using open source technology such as Mosaic5G and the analysis of objective quality of experience (QoE) metrics of a video streaming service. During the process, the server and client were set up for video streaming, SIM cards were programmed for network access, and the FFmpeg tool was used to obtain objective QoE metrics. The results revealed the robustness of open source technologies in building functional mobile networks and their ability to provide good QoE for the most demanded and bandwidth-intensive service using H.264 and H.265 video encoders.

Keywords: Quality of Experience, Mobile Network, SDN, SDR, Video Streaming.

Resumen: El crecimiento exponencial del tráfico de datos ha generado una presión en las infraestructuras de redes móviles existentes, que se ven desafiadas a proporcionar una experiencia de usuario satisfactoria. Por tanto, este artículo aborda la construcción de una red móvil utilizando tecnología de código abierto como Mosaic5G y el análisis de métricas objetivas de calidad de experiencia (QoE) de un servicio de videostreaming. Durante el proceso, se estableció un servidor y un cliente para la transmisión de video, se programaron tarjetas SIM para el acceso a la red y se utilizó la herramienta FFmpeg para obtener métricas objetivas de QoE. Los resultados revelaron la robustez de las tecnologías de software libre en la construcción de redes móviles funcionales y su capacidad para brindar una QoE buena para el servicio más demandado y con mayor consumo de ancho de banda mediante los codificadores de video H.264 y H.265.

Palabras clave: Calidad de Experiencia, Red Móvil, SDN, SDR, Videostreaming.

1. INTRODUCTION

In the current context of rapid technological evolution, the exponential increase in the adoption of smart devices and the growing demand for mobile connectivity has put unprecedented pressure on existing network infrastructures. [1]. By 2025, total mobile data traffic is projected to increase by nearly five times compared to 2019 levels, reaching 164 Exabytes (EB) per month [2]. This volume will be consumed by a population of more than 6 billion devices [3]. This will be driven largely by the proliferation of multimedia applications and video streaming services.

On the other hand, the evolution of cloud computing and open source technologies, allow mobile network architectures to be deployed through software, that is, Infrastructure as a Service (IaaS) [4], [5] giving rise to technologies such as Open Radio Access Networks (OpenRAN), Software Defined Networking (SDN) and Network Functions Virtualization (NFV), which promise to address the challenges of flexibility and scalability faced by network infrastructures. However, the success of these technologies lies largely in the user experience. This becomes even more relevant for the video streaming service, which represents 65% of the traffic in data networks [5], [6].

In accordance with the above, this paper addresses the challenge of obtaining the Quality of Experience (QoE) for the video streaming service over a mobile network built under the IaaS concept. QoE estimation is an open problem because it is subject to user subjectivity [6], so different researches have focused on obtaining QoE by using objective metrics [7], [8], [9], [10], [11]. Therefore, in this paper we analyze objective QoE metrics such as Maximum Signal to Noise Ratio (PSNR), Structural Similarity Index (SSIM) and Video Multi-Method Assessment Fusion (VMAF) [12].

Therefore, this paper presents two contributions: the construction of a mobile cellular network using Open Source technologies (OSS) and the analysis of objective QoE metrics for video streaming service. To achieve this purpose, a fourth generation Long Term Evolution-Non-Standalone (4G-LTE-NSA) mobile network is built from the open source ecosystem, called Mosaic5G [13]. A server and a client are deployed in this network, by means of User Equipment (UE), in order to obtain and analyze objective QoE metrics.The experiments are performed for 480p and 720p video qualities, each encoded in both H.264 and H.265. The results obtained demonstrate the stability of the constructed network and adequate values of objective QoE metrics for Video on Demand (VoD) transmission.

The article is organized in the following way: section 1, presents the introduction and its respective contextualization of the subject; section 2, describes the methodology with the materials and methods; section 3, presents the results and analysis of the experiments; finally section 4, contains the conclusions and future work derived from this article.

2. METHODOLOGY

For the development of this research, a cascading methodology was adopted [14], where two specific sequential tasks or emphases can be identified: the development of the Network Core (NC) and the analysis of the objective QoE metrics, see Fig. 1.

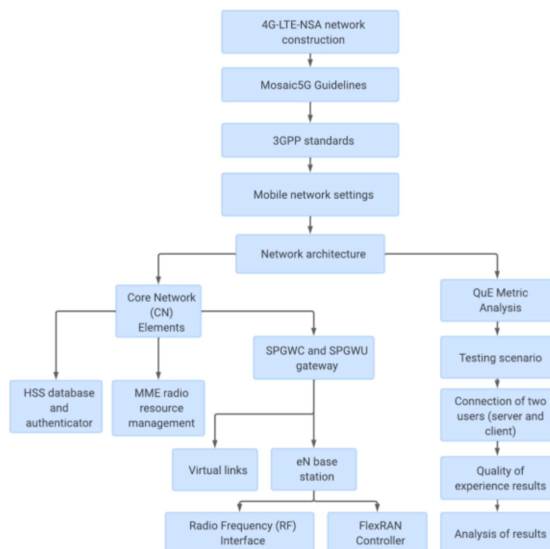

Fig. 1. *Explanation of methods.*
Source: *own elaboration.*

In order to obtain QoE metrics, a 4G-LTE-NSA network was built on an Acer Aspire Nitro Intel Core i5 10300H portable computing device with 8GB of RAM, within a Linux Ubuntu 20. 04, under the guidelines of Mosaic5G, which follows the standards of the Third Generation Partnership

Project (3GPP) that constitute the parameters for mobile network configurations [15]; and likewise, the network architecture that was chosen is the same as the one found in the official repository of this ecosystem.[13].

This architecture describes the elements of the CN such as the database and the Home Subscriber Server Authenticator (HSS), the Mobility Management Entity (MME), the Gateway between the Control Plane (SPGWC) and the Gateway between the User Plane (SPGWU). Each of these elements are interconnected with each other by means of virtual interfaces; and in turn, directly connected to the evolved NodeB base station (eNB) that incorporates a Radio Frequency (RF) interface, for which the Etthus USRP B200 ENC hardware module with VERT2450 (2.4-2.5 and 4.9-5.9 GHz) Dual Band antennas, the Radio Access Network (RAN) and the FlexRAN controller are used.

Fig. 2 shows the complete experimental scenario, where the network architecture provides network services to two UEs, which play the role of server and client.

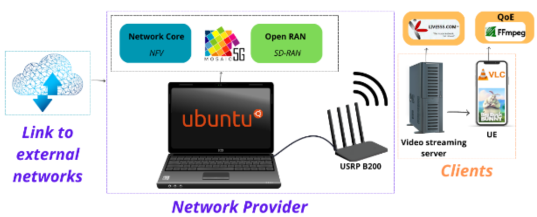

Fig. 2. *Test scenario.*
Source: *Own elaboration.*

The server, deployed inside a Xiaomi 11 Mi Lite 5G NE mobile device, was responsible for providing and streaming videos in 480p and 720p qualities each under H.264 and H.265 video encoders, via the Live555 server; the client is deployed on an Asus Zenphone mobile device, where they are received and stored via VLC (Video-LAN client). The roles of these devices were achieved through Linux within Termux and RealVNC [16], [17].

A Sysmocom SJS1 SIM card was integrated in both mobile devices to access the network resources being authenticated within the network; which was programmed by means of the MV PS/SC ISO 7816 card reader with the validation parameters stored in the HSS.

With the network built and the video service in operation, the objective QoE metrics were obtained, which correspond to full reference metrics, which means that it compares the source video with the video at the client, to determine the effect caused by the network on it [18]. To carry out this process, the free software tool FFmpeg was used, which allows obtaining the values of the signal to noise ratio PSNR, luminance, contrast and SSIM structure; and the VMAF frames.

3. RESULTS AND ANALYSIS

The following is a description of the process by which the experimentation scenario was consolidated, consisting of three components, the first of which is the mobile network infrastructure built using OSS; the second corresponds to the construction and consumption of the video streaming service over the network infrastructure; and finally, the third component is related to obtaining and analyzing the objective QoE metrics.

3.1 Component One: 4G-LTE-NSA network core construction

As a preliminary step to build the network, it is necessary to download the official documentation from the Mosaic5G repository from [13]. In addition to containing the code base, it shows the step-by-step installation of the necessary resources, such as the snap folders of the CN elements and the Radio Access Network (RAN). It also presents complementary components for the construction of the network core, such as the RF interface drivers, the SIM card programming drivers, which come with virtualization functions, among others.

As part of the complementary steps, a connection was made to the Cassandra DB database hosted in a Docker container so that the HSS can efficiently manage the information; subsequently, the Domain Name System (DNS) was modified within the spgwc.conf configuration file to ensure that the network properly recognizes the requests sent by the users.

With the previously mentioned modifications, the execution of the NC is started by means of the following command lines: sudo oai-hss, oai-mme, oai-spgwc and oai-spgwu; in an orderly manner, since each one depends on the previous one, whose response is shown in Fig. 3.

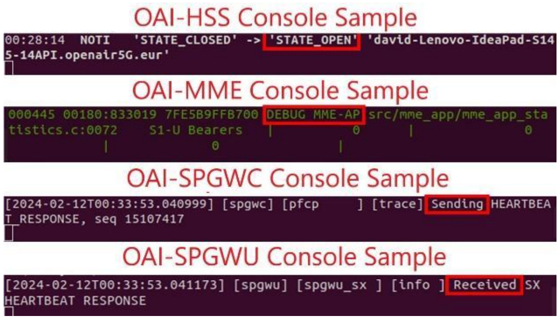

***Fig. 3**. Operation of the CN.*
***Source:** Own elaboration.*

Where the HSS generates a "STATE_OPEN", indicating that it is open to incoming user requests, the MME which displays its register table; and the spgwc and spgwu interfaces which constantly send a "HEARTBEAT_RESPONSE" to each other to be permanently acknowledging the state of themselves, until the arrival of a user.

Since the purpose is to transmit wirelessly, it is necessary to have a radio unit, for this purpose SDR technology is required by using the USRP B200, which was connected via USB 3.0 port to the computer containing the NC; and by means of the command: sudo uhd_usrp_probe, the connection status of this RF device was verified.

With the radio unit connected, the RAN and the respective FlexRAN controller are deployed, which are responsible for the operation of the eNB node, where the RAN is responsible for providing radiated access to users, and the controller is responsible for graphically and efficiently managing all the parameters associated with the users and the data flow that they will present.

In addition, to configure the RAN properly, it was necessary to make a series of previous adjustments within the ran document. enb-conf, to modify the Public Land Mobile Network (PLMN) identifier, which is responsible for defining the location and the mobile network to which the user will belong; where specific values of 208 in the Mobile Country Code (MCC) and 95 in the Mobile Network Code (MNC) are assigned, respectively; the modification within the SGI interface, with the Internet Protocol (IP) address of the service provider network so that the user has access to external networks; and finally, the parallel configuration in: PARALLEL_SINGLE_THREAD, this being an appropriate configuration for the computational resources used for the CN and RAN.

Once these configurations have been made, Fig. 4 shows the display of these two elements, the RAN and the CN, where the line "SCHED_MODE = 0" indicates that the RAN is in full operation to radiate and receive user requests and the FlexRAN is in charge of designating a numerical value for the base station (BS).

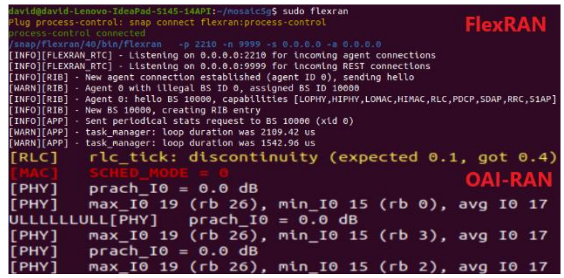

***Fig. 4.** RAN operation and connection to FlexRAN.*
***Source:** Own elaboration.*

Once the RAN is up and running, the MME module adds the station to its control tables, indicating that the NC elements are connected to the RAN and ready to operate, see Fig. 5.

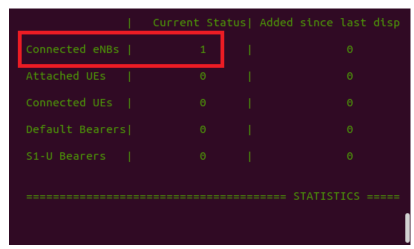

***Fig. 5.** eNB station connected to the MME.*
***Source:** Own elaboration.*

When connecting a real mobile user, it is important to declare and configure the key authentication parameters of the users both in the HSS module and the respective programming of the SIM cards so that they are congruent; these parameters are the International Mobile Unique Identifier (IMSI), the Authentication Key (Ki) and the Encryption Key (OPC), and through the command: sudo oai-hss. add-users -I(IMSI) -k(Ki) -o(OPC) -aoai.openair5G.eur, they are attached to the HSS module. Table 1 shows how the values for 3 users are stored in the NC.

***Table 1:** Values assigned to SIM cards*

IMSI	Ki	OPC
20895000000005	CC19D59E808F0877F 1FC085A1EA2D1F0	8f60a0419289f779e e2c168c7e967d8c
20895000000001	8baf473f2f8fd09487cc cbd7097C6862	8e27b6af0e692e75 0f 32667a3b14605d

2089500 0000000 2	A5862EA2F7DE137C 2B9F2CDE59467E65	5ca47dbaff3e17db0 d72b015a5cc4321

Source: *Own elaboration.*

For SIM card programming, the official Pysim [19], repository from Sysmocom is copied in order to extract all the necessary elements for programming, and by means of the SIM card reader, the programming is carried out, taking into account the parameters presented in Table 1.

Once the card is programmed and installed in the mobile device, the UE is registered and connected to the network, which can be evidenced through the MME control tables, the RAN interface and FlexRAN interface, see Fig. 6.

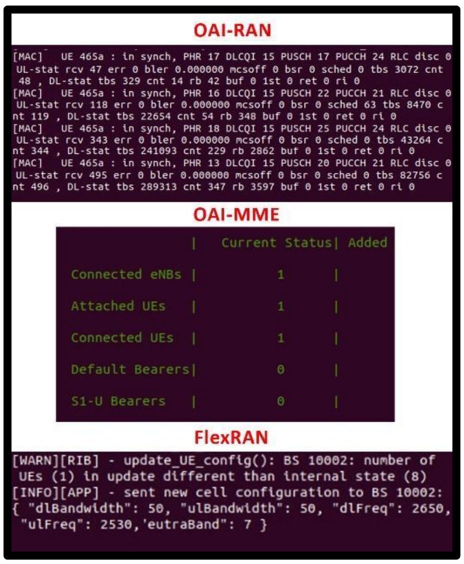

Fig. 6. *Link from a real mobile user.*
Source: *Own elaboration.*

Where the FlexRAN indicates the "update" status to refer to an update in its tables with the arrival of the mobile user; the MME authenticates the user in its database and provides network services to the user; and finally, the RAN indicates the Uplink and Downlink resources it provides to the user.

Additionally, the FlexRAN has a Representational State Transfer-based Application Programming Interface (REST API) that generates a Software-Defined Radio Access Network (SD-RAN) module, which defines the connections between the user, the eNB and the CN, along with detailed information, such as the user's IMSI, UpLink and DownLink bit rate, bandwidth and channel, see Fig. 7.

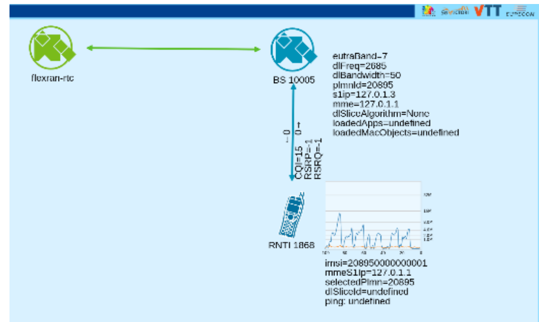

Fig. 7. *Interfaz del controlador FlexRAN como SD-RAN.*
Fuente: *Elaboración propia.*

For the second user's connection, we chose to activate the "Mobile Hotspot" function from the main device (called UEs 1, according to the MME). This transformed the cell phone into a packet router, allowing the mobile data connection to be shared with other devices [20]. In this way, the second user assumes the role of server within the architecture, enabling an effective connection in the network. It should be noted that the network address of the device connected to the Hotspot comes from the CN.

In Fig. 8, you can see the actual assembly of all the elements of the NC and RAN, together with the users and the USRP module.

Fig. 8. *Actual assembly of the CN and RAN.*
Source: *Own elaboration.*

3.2 Component two: Server and client configuration

To guarantee the video streaming service and the VoD viewing and playback of the service, an Android Linux system called Termux was installed on both UE1 and UE2 users, respectively.

In Fig. 9, it is evident from the Termux terminal, the assignment of the IP addresses of the mobile network, also in the upper part of Fig. 9 the UE1 is anchored to the 4G band, while the UE2 has the WiFi connection corresponding to the mobile Hotspot.

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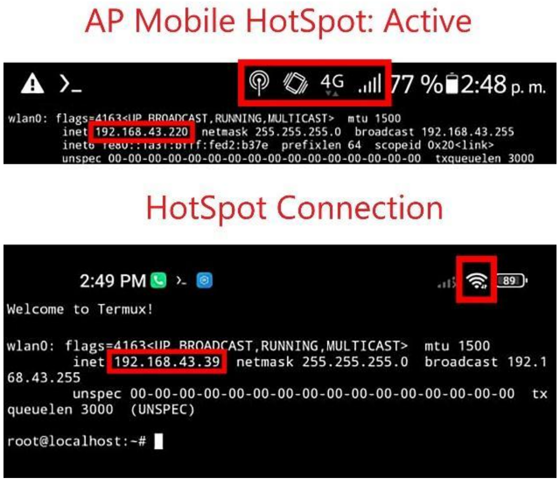

Fig. 9. *User IP addresses.*
Source: *Own elaboration.*

For the server, it was necessary to install additional dependencies within Termux, such as the Ubuntu 20.04 operating system for compatibility issues, the XFCE desktop environment and the Virtual Network Computing (VNC) algorithm, for the operation of an application called RealVNC that serves as a viewer and controller of a Graphical User Interface (GUI).

Fig. 10 shows how, by means of the command: "live555MediaServer", the URL address is generated with the transmission protocol, in this case, Real Time Streaming Protocol (RTSP), the socket and the space to designate the video file.

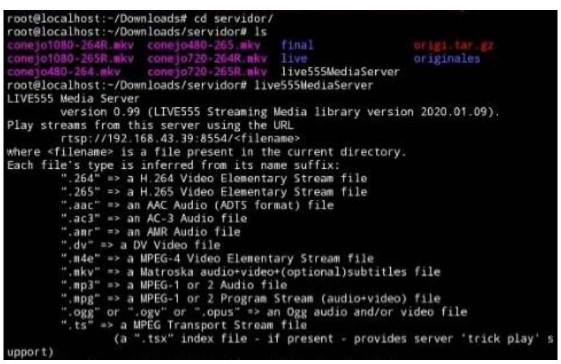

Fig. 10. *Running the Live555 server on UE2.*
Source: *Own elaboration.*

Finally, to consume the video from the client side, the URL coming from the server (UE2) is inserted through the VLC API as shown in Fig. 11.

Fig. 11. *VLC playback from UE1.*
Source: *Own elaboration.*

3.3 Component Three: Estimation and analysis of objective QoE metrics

The analysis of objective QoE metrics was carried out under the H.264 encoding formats, for its adaptability to different environments and hardware requirements, and its evolution H.265, which requires precisely half the bandwidth [21]. This for 480p and 720p video qualities.

For the estimation of the objective metrics of full QoE reference, the FFmpeg tool is used, which uses the received video and the original video.

As for obtaining the received video, an additional computational device anchored by means of the Hotspot was used, which is called UEs3 (according to the MME).

Based on the above, Fig. 12 shows the execution of the command for recording from the new computational device.

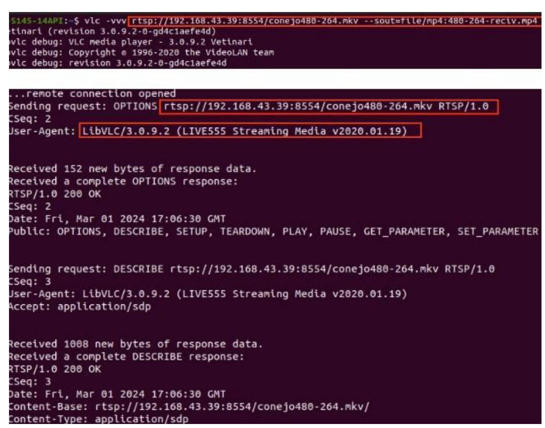

Fig. 12. *VLC recording on the client.*
Source: *Own elaboration.*

Subsequently, the objective QoE metrics obtained by FFmpeg are:

- PSNR: responsible for defining the ratio between the maximum possible energy of a signal and the noise. It is generally expressed in decibels (dB) and its typical values are between 30 and 50 dB, being higher the better the encoding [22], [23].

- SSIM: it is responsible for the structural evaluation between the reference image and the test image, analyzing the luminance and contrast components, assigning a score of 1 to the highest structural similarity generated [22].

- VMAF: incorporates a human visual perception algorithm which was developed by Netflix for analysis under a range of conditions such as compression, encoding and transmission; where the range of values goes from 0 to 100, being values above 70 considered as good within an objective evaluation [24], [25].

In Fig. 13, you can see the command for the extraction of each of these metrics, together with the VMAF library, since it is not included by default in FFmpeg, and the indication of data storage in the ".txt" format.

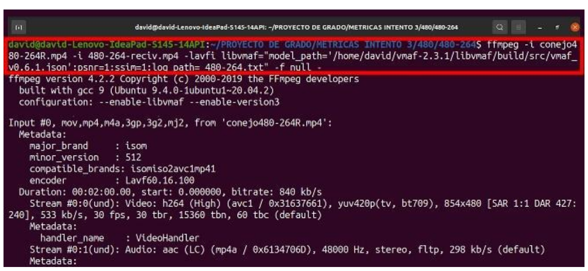

Fig. 13. *Running FFmpeg for metrics extraction.*
Source: *Own elaboration.*

In order to display the results using curves, the data are processed in MATLAB [26]. From Fig. 14 to Fig. 16 the results can be observed for video in 480p quality with H.264 and H.265 encoders.

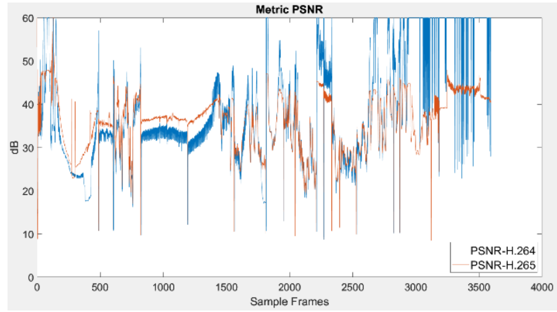

Fig. 14. *480p PSNR metric with H.264 and H.265.*
Source: *Own elaboration.*

Fig. 14 shows that the PSNR curves show values above 30 dB for both the H.264 and H.265 encoders, indicating a good signal to noise ratio.

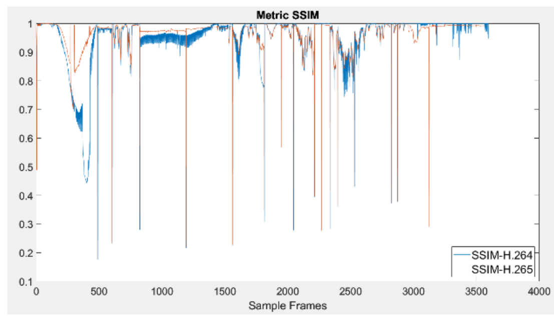

Fig. 15. *480p SSIM metric with H.264 and H.265.*
Source: *Own elaboration.*

In Fig. 15, we can observe the SSIM values, which are close to 1, so the structural similarity is close to the ideal value, in both video encoders, indicating that the source video is not negatively impacted with respect to luminance and contrast parameters, when transmitted and consumed in the mobile network.

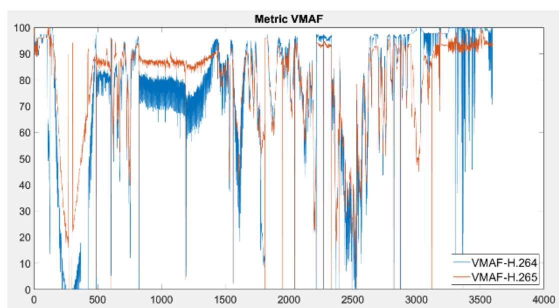

Fig. 16. *480p VMAF metric with H.264 and H.265.*
Source: *Own elaboration.*

Fig. 16 shows the VMAF values, which have a large fluctuation due to the wireless channel and the capture of frames per second. Therefore, for VMAF, an additional analysis was performed by means of a regression line since, within the three metrics, it plays a fundamental role by taking into account perceptual aspects of vision that a real user may experience.

A positive slope with an average of approximately 70 can be seen in Fig. 17 between the VMAF values and the frame samples, indicating that the perceived quality is improving as the video progresses.

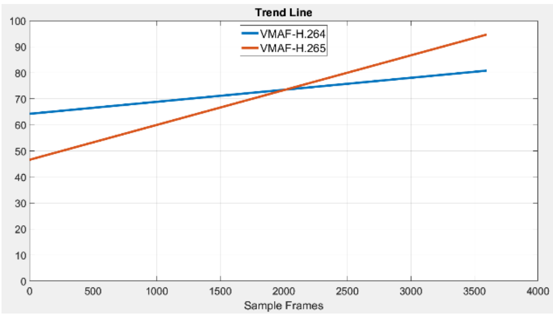

Fig. 17. *VMAF regression line for 480p video with H.264 and H.265.*
Source: *Own elaboration.*

From Fig. 18 to Fig. 20, we can observe the PSNR, SSIM and VMAF metrics of the video in 720p quality with H.264 and H.265 encoders.

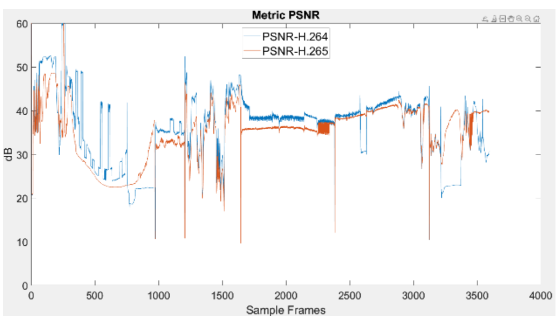

Fig. 18. *720p PSNR metric with H.264 and H.265.*
Source: *Own elaboration.*

In Fig. 18, it can be observed that the PSNR metric for the first 27% of the frame samples presents fluctuations, generating a descending curve, and for the rest of the curve it becomes values close to or equal to 30 dB which represents a good signal to noise correlation.

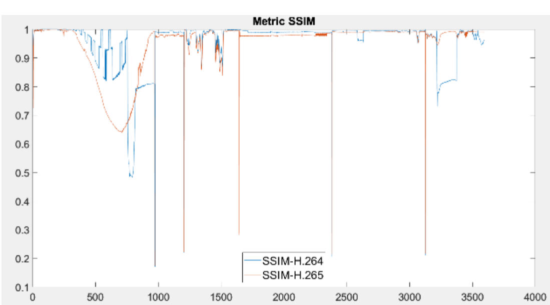

Fig. 19. *720p SSIM metric with H.264 and H.265.*
Source: *Own elaboration.*

Fig. 19 shows the SSIM metric with a pattern similar to the previous one. In the first 11% with values of 1 and later between 11% and 27% a negative curve is presented, which stabilizes reaching again values of 1 for both encodings. These results indicate a high structural similarity between the original and the processed video, suggesting a satisfactory visual quality in both cases.

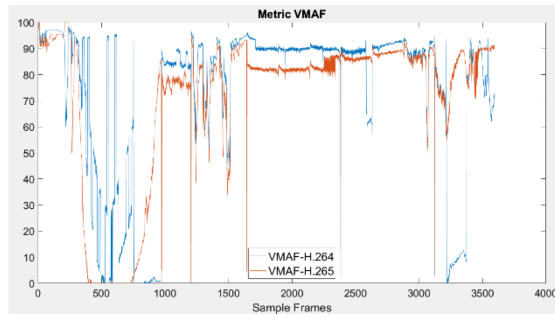

Fig. 20. *720p VMAF metric with H.264 and H.265.*
Source: *Own elaboration.*

In Fig. 20, in the VMAF values for both codings, a behavior similar to that of the two previously mentioned metrics is observed. In the first 11%, values of 90 are obtained and between 11% and 27% of the evaluation, values close to zero are recorded; however, as the analysis progresses, these values begin to increase until reaching figures between 70 and 90, with their respective fluctuations.

In relation to this last metric, despite the initial declines, further analysis using the regression line reveals that, based on the correlation and averages obtained in the mathematical analysis, an average of 70% is achieved for both video encodings, see Fig. 21.

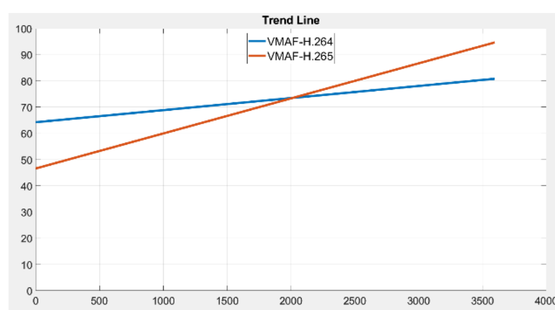

Fig. 21. *VMAF regression line for 720p video with H.264 and H.265.*
Source: *Own elaboration.*

The fluctuations observed in the quality of 720p for the two video encodings indicate that the increase in the level of detail of the image, the improvement in the fluidity of the video and the sharpness of the shadows, characteristics of a higher video quality,

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lead to a saturation in the compression and reconstruction of the video in the receiving device, for this reason in the range of 11% to 27% a negative curve is presented because at the beginning of the video the processed image usually has more distortion due to noise, blurring or compression that is involved. However, this difference becomes smaller as the video progresses.

In Fig. 22 and Fig. 23, we can see the fluctuations in the video transmission in 720p quality for H.264 and H.265 encodings, respectively.

Fig. 22. *Video behavior at 720p H.264 coding.*
Source: *Own elaboration.*

Fig. 23. *Video behavior at 720p H.265 coding.*
Source: *Own elaboration.*

Therefore, the objective QoE metrics obtained with the FFmpeg tool are congruent with the results during video viewing. For example, in Fig. 22 and Fig. 23, it is observed how the pixelation errors coincide with the low values of the three metrics. Consequently, these metrics provide an objective assessment of the QoE of the video, being a pertinent choice since it eliminates the need for subjective tests that require surveys and direct user participation.

4. CONCLUSIONS

The implementation of open source technologies such as Mosaic5G and FlexRAN proved their robustness in creating a fully functional LTE-NSA mobile network. This network is capable of meeting the most demanding bandwidth requirements, particularly for services such as video streaming. In addition, objective QoE metrics are obtained with good results considering the values for each metric, using the open source tool FFmpeg.

These advances highlight the feasibility of building a functional LTE-NSA network using personal computational resources, which implies low costs and opens opportunities for experimentation, research and education in the field of mobile communications. This approach is especially relevant in environments that seek to explore and understand in depth the operation of these emerging technologies.

A controlled experimentation environment has been established where both the server and client are deployed locally, eliminating the need to use a proxy for access to external networks. This configuration reflects an effective management of requests between users. The characteristics of this environment make it possible to obtain objective metrics of full reference QoE, since there is access to both the video on the server and the client.

The obtained results of 30 dB for PSNR, approximately 1 for SSIM and 70 for VMAF metrics for both H.264 and H.265 encodings are within the good range in terms of QoE. In addition, the FFmpeg tool offers the possibility to use mathematical algorithms for interpretation and visualization, allowing to keep a history of the transmitted data and make decisions on what to improve for future transmissions.

The results of the tests performed in the experimental scenario, show the efficiency of both the H.264 and H.265 video encoders. These findings suggest that, during periods of network fluctuations, it is preferable to choose the latter, since it requires half the bandwidth compared to the radio resources needed for the former.

As for future work, it is suggested to establish stability guidelines to avoid network fluctuations and aim for values above 80 in VMAF. In addition, it is proposed to investigate areas such as Network Segmentation (NS), handover and adaptive protocols for video transmission.

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