# Virtualized Module for Distributed Quality Assessment Applied to Video Streaming in 5G Networks Environments

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***Abstract*— The success of streaming platforms and the expansion of advanced multimedia formats, such as UHD that presents 4K and 8K resolutions, demand better network conditions for transmitting higher amounts of data. 5G Networks offer a collection of improvements over their predecessors including an increase of bandwidth and lower latency. Additionally, 5G architecture allows the network nodes to improve their capabilities with the inclusion of Software-Defined Networking (SDN) and Network Function Virtualization (NFV) technologies, which provide an opportunity to control media flows and distribute the processing tools through the delocation of remote virtual machines. As a consequence of this fact, different types of applications for broadcast and multimedia analysis can be implemented for different purposes in the network distribution chain, such as image or audio assessment, video edition, metadata addition and other kinds of system processing. For this paper, among these applications, we present a software module that is able to assess video quality when applied in any point of the network in order to determine remotely the state of the network. This module known as "probe" checks the transmission through image evaluation metrics and sends a resulting report to the network backbone for communication the retransmission if necessary, to fulfill the requirements and demands of the users. Tests developed in different network distributions and with a variety of video sequences demonstrate the validity of this innovative software.**

***Keywords—5G Networks, Video Quality Assessment, Multimedia, Virtualization, SDN, NFV, Artefacts, QoE, Streaming.***

## I. Introduction

According to Cisco report [1] about future trends in video transmission, it is expected that by 2021 the amount of data streamed exceed the million minutes of video per second. Additionally, the expansion of services [2], such as Video on Demand (VoD) and the challenges impose by mobility, Ultra HD formats in 4K and, recently presented, 8K resolutions or the increasingly popular High Dynamic Range (HDR) and High Frame Rate (HFR), oblige the broadcasters to improve the techniques to assure the demands from the users.

The 5G networks, i.e., the fifth generation of mobile technology are positioned to fulfil the user requirements, which are demanding the triple A (Anytime, Any device, Anywhere), offering higher bandwidth with low latency for improving the service. But the amount of traffic generated through this type of network is necessary to be controlled by broadcasters and intelligently balanced through the resources available, which are still limited.

Multimedia Network Functions Virtualization (NFV) [3] and Software-Defined Networking (SDN) [4] technologies provide an infrastructure and the necessary tools for controlling media flows across contribution network transforming the vision of distribution facilities for video streaming NFV and SDN-based applications and services are expected to help with these challenges [5], adding processing intelligence through remote access to virtualized software, reducing the necessities of the network itself while improving its management saving resources.

Among these applications, this paper presents a SDN-based model for adding virtualized modules to the 5G Networks to improve their management. The development is focused on a concrete case use for assessing video quality in any node of the network through the usage of VQA metrics based on image analysis [6], which allows the reporting of malfunctioning in the content distribution when transmitting multimedia, i.e. in big sport or entertainment events broadcasted worldwide. These metrics require high processing load to work real time, which is possible through powerful virtual machines (VM) containing the application [7], working remotely with higher computational capacity.

Different applications involving technologies such as Internet of Things (IoT) and IoT-based systems, cloud computing, video coding, and mobile devices reception have advanced in recent years [8]. For that reason, IoT-based surveillance systems can be an interest example of applying virtualization and remote connection for ubiquitous healthcare monitoring, because the system needs a special mesh topology composed by a collection of sensors, actuators, and cameras. Big Data (BD) and Cloud Computing (CC) are other technologies that grows rapidly where data storage and processing take place outside of the user's device. For that reason, it is necessary to deeply analyze the security and privacy issues of both technologies. There is an extensive survey developed by

Stergiou et al [9] about the challenges of the integration of BD and CC related to their security level, highlighting important information to be taken into account when developing this kind of systems. Another survey proposes solutions for managing and collecting big amounts of data from sensors from the IoT environment of a smart building. These systems are easily controlled from distance through remote devices operating on a network, helping to improve the structure of future Green Smart Buildings (GSB).

Actual trends revealed that there are still numerous aspects to be solved and standardized in relation to 5G technology before an average end-user can benefit from them on a daily basis [11]. Fur assuring the Quality of Experience when transmitting 4K and other advanced formats Ge et al [12] proposed a novel system architecture called MVP (Mobile edge Virtualization with adaptive Prefetching), which enables content providers to embed their content intelligence as a virtual network function (VNF) into the mobile network operator's (MNO) infrastructure edge. The areas with high demands for multimedia contents must support adequate QoE for mobile users in the integration of cloud computing. For that reason, operational impacts and benefits, analyzed by Rosario et al [13] and associated with service migration from the cloud to multi-tier fog computing for video distribution, must by contemplated.

This recent research complements the object of this analysis and it is discussed as background information about existing approaches in the context of proposed work addressed in this paper.

## II. Objectives

Video Quality Assessment (VQA), Audio Quality Assessment (AQA), Quality of Service (QoS) or Video Edition are necessary applications in multimedia content networks that require intensive computational load and processing charge to obtain a result in real time.

5G Networks and SDN-based services accessed through virtual machines aim at generating cost-reduced and adaptive solutions for developing ubiquitous infrastructure for saving resources and computational capacity. NFV and SDN applications are flexible to program for allocating the functions and capacities of the network orchestrated by a specific technology called MANO (ETSI Management and Orchestration), which performs in conjunction with a software, such as OpenStack, for controlling storage, large pools of computation and networking resources. The system allows the monitoring of the network with information regarding the content distributed and also modifying the resources.

The use case presented in this paper allows the flexibility of configuration of resources in the content distribution network through an application for assessing video quality. As shown in the Fig. 1, the application can be connected to any of the nodes of the content route to perform a measurement. A virtual machine contains the VQA or any other customized application which works remotely without work limitations. In this case, the VQA module returns a JSON message with the result of the evaluation of the metrics, which is sent to the network backbone retransmission. This module can be substituted by another module depending on the preferences of the network manager.

## III. Probe for Video Quality Assessment (VQA)

The module known as "Quality Probe", that contains the quality algorithm, operates as a Virtual Network Function (VNF). After testing the quality of the content, it communicates with the monitoring application which take the decision or not to optimize the content delivery allowing the user to enjoy the best quality with the lowest delay, sending a Quality Assessment report through a JSON message, as seen in Fig. 1.

The VQA, AQA, QoS or another custom module is instantiated as a Virtual Network Function (VNF) in the network and orchestrated by the NFV Orchestrator used by the 5G system. The module exchange data about the contents monitored and provides additional information to the network for its adaptation or reconfiguration. The application performs as Broadcast-as-a-Service, using the 5G network as a facility for management of the instantiation, deployment and provision of the involved resources. The objective is monitor the network reducing the delays in the data exchanged for optimizing the resources for content distribution and, consequently, improving the user's experience.

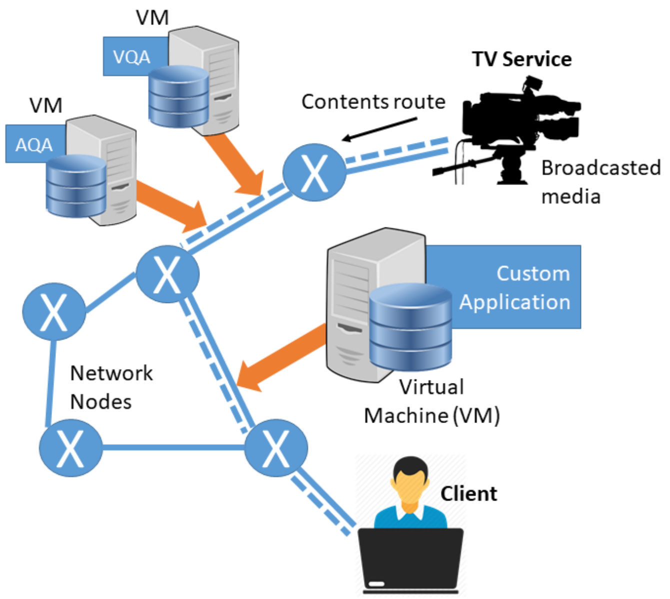

Fig. 1 Virtualized applications applied to content distribution 5G-Network.

The errors contained in the video sequences that belong to the database and distortion effects created simulate the typical 5G-networks to be identifies for fulfilling the requirements of end users. Fig. 3 shows the workflow and functionalities implemented in the algorithm, highlighting the different modules for VQA, AQA or QoS and paths of the signal to configure the final QoE model. Different transformations are applied to the multimedia signal including demultiplexing audio and video, separating the RGB channel and the luminance from the chrominance or applying transformation in time and frequence, such as Hough, Canny or Sobel.

For detecting every issue in video streaming content it is necessary to identify which cases occur the most often. This cases include the distortion derived by the metrics implemented for frozen frames, color errors or packet loss detection. Once the video streaming is object of study in one node of the 5G-

Network, the first thing to measure is the availability and reception of these contents. On the other hand, the metrics related to video are based in image (IQA) and video quality assessment (VQA), and the AQA metrics are based on analyzing the audio samples in module and frequency. The decoded video composed of N (N: defined number of frames in one block of pictures to analyzed) captured RGB frames is analyzed in order to simulate the perceived quality.

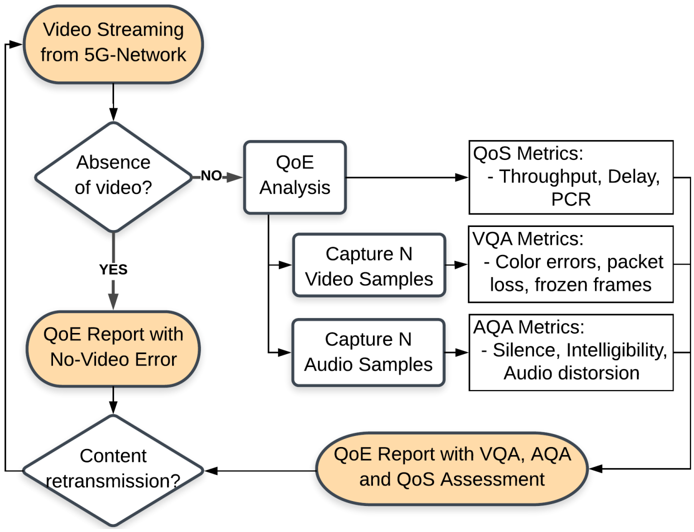


Fig. 2 Scheme of Algorithm functioning for QoE assessment.

### *A. Frozen frames detection*

One of the most common problem occurred when playing a video is the frozen frames detection. The freezing artefact occurs when a video is streamed and the source video signal flow stops from being transmitted. Consequently to this effect, the frame is repeated two or more times instead of the natural changing with temporal evolution according to the frame rate. The algorithm implemented for this detection is based on the comparison between adjacent frames in the video sequence. The formula for detecting individual frozen frames is collected next.

$$frozenFrames(i) \rightarrow if\ \frac{1}{MN}\sum_{y=0}^{N}\sum_{x=0}^{M}\left|Y_i(x,y) - Y_{i+1}(x,y)\right| > \varepsilon$$

where "MxN" are the dimensions of the frame, x and y the spatial coordinates of the pixel, "i" is the number of the frame and "i+1" is the number of the following frame, Y is the luminance function and $\varepsilon$ is a threshold approximately 0, in this case 0.1.

### *B. Throughput and Color errors detection*

Demanded network throughput is necessary for supporting the required video quality, avoiding the occurrence of artefacts formed of structures and pixels with unnatural saturated colors that are caused by the propagation of errors through the frames of the streamed video sequence. For that reason, the loss of information appears both in luminance and chrominance, but subjective assessment revealed that the effect in the color component is more visible for human perception. The algorithm for color error detection is focused on the chrominance component, as seen in the next formula that detects the probability of pixel with values out of the range of natural image colors.

$$f\big(chrom(x,y)\big) = \begin{cases} 1, if\ |chrominance(x,y)| > AChV + \delta \\ 0, otherwise \end{cases}$$

where AChV is the Average Chrominance Value, which is dependent of the number of bits to represent the pixels, for 8 bits this value is 128, chrominance(x,y) is the value of one of the chrominance component of the pixel Cb or Cr, in this case Cb is used because it obtains more accuracy. Finally, $\delta$ is a threshold that defines the range of values of chrominance in which the color obtained correspond to a natural image.

$$color.error(i) \rightarrow \frac{1}{MN}\sum_{y=0}^{N-1}\sum_{x=0}^{M-1} f\big(chrominance(x,y)\big) > \gamma$$

where "MxN" are the dimensions of the frame, x and y the spatial coordinates of the pixel, "i" is the number of the frame and "i+1" is the number of the following frame, Y is the luminance function and $\gamma$ is a threshold that indicates the visibility of this factor by the human eye, in this case 0.60 i.e. when 60% of the pixels of the frame are distorted.

The following figure (Fig. 3) shows an image corresponding to the sequence "CrowdRun" with very high throughput "1.r.512.ts", generated with original sequence. Defining $\delta$ as 30 for the threshold of natural chrominance values and a $\gamma$ of 0.6, with a result of 95% of distorted pixels, with is over of the value of $\gamma$, then the algorithm detects the color error.

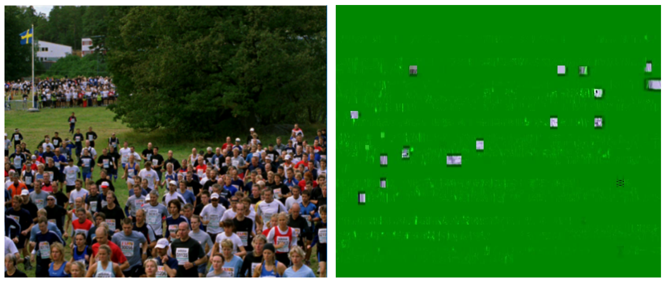

Fig. 3 High throughput image (1.r.512.ts) compared to original "CrowdRun".

### *C. Packet loss*

During the transmission of the content, some oscillation appear, typically as a consequence of network congestion, leading to the loss of data. Moreover, almost all contents delivered by streaming are compressed by using compression algorithms (H.264/AVC or H.265/HEVC, for example) which reduce the weight of content to broadcast.

The subjective amplification of packet loss in the video is derived by this process of compression that generates the easy propagation of errors through consecutive frames of the sequence. Artefacts included in the image are transmitted through the network and remain visible until the user plays the video. Repeated lines and unnatural structures such as squares and lines are present on the areas of the frame where information is lost, as seen in Fig. 4.

Fig. 4 High packet loss image compared to original "CrowdRun".

This algorithm based on the Hough transform is able to detect those structures and repeated lines by searching unnatural colored shapes in images, which reflect the areas where packet loss has occurred. By using a Hough Line Transform, it is possible to detect straight lines in an image as shown in Fig. 5.

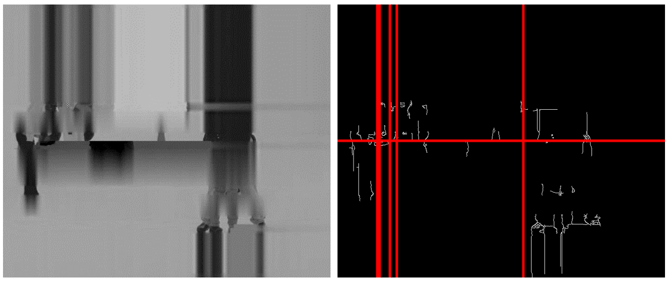

Fig. 5 Unnatural structures detected with Hough Line Transform (red lines) compared to distorted frame

## IV. Tests and Results

### A. *QoE and Video Quality Assessment for Video Streaming*

For assessing the effectiveness of the QoE algorithms, the metrics were applied to sequences included in the ReTRiEVED Video Quality Database [6]. These sequences include, which contains the most common artefacts for IP video, were streamed through the network simulating the behavior of a real network. Then, the Quality Probe performed the analysis through different graphs and numeric values.

The algorithm was tested with different types of sequences with variations of distortions contained. First of all, there is an example of the analysis of absence of video signal after the frame 89 (of the block of N frames selected) in Fig. 6.


Fig. 6 Absence of video detected through 89 frame of the video sequence.

Fig. 7 contains a second example were the freezing frames are analyzed in which a threshold indicated by the red line identifies the period of signal loss discarding the oscillations, which is a consequence of the codification.


Fig. 7 Detection of frozen frames in the video streaming comparing to a threshold (red line).

Finally, Fig. 8 shows an example on how the color distortions are detected when the throughput is high in the video sequence. The threshold of 30 separates the values which are considered problematic for the visual experience of the end user.

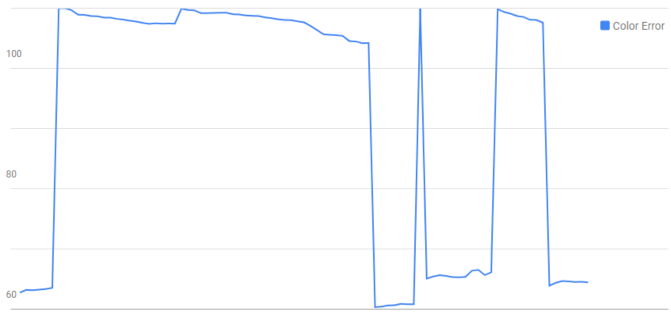


Fig. 8 Detection of color error frames in the video streaming comparing.

### B. *Orchestration of resources based on traffic load variations for video streaming*

The time analysis revealed the behavior of the quality probe in different architectures. A use case with a distribution of three nodes in the network contributed in fulfilling the research objectives on service deployment time of hours (minutes in this case, for media services) and orchestration of the complete system resources based on traffic load variations.

The TV broadcasting and Video on Demand (VoD) services are easily deployed on the 5G-network using the module called 5G Control Infrastructure (XCI) and the different 5G-based applications. Different experiments revealed the feasibility of deploying virtual media in CDN and TV broadcasting infrastructure by exploiting the services offered by the XCI module. From the XCI services perspective, the provisioning time and the self-healing capabilities have been evaluated, in order to evaluate the quality of retransmission of the system. For Virtual Content Distribution Network (vCDN) services, the provisioning time varies from 157 s for a vCDN with one replica server to 217 s for a vCDN with four replica servers. The biggest contributor to this process is the time needed by the virtual machines to boot and complete the network configurations, ranging from 118 s to 135 s for vCDNs with 1 to 4 replica servers. The self-healing worst case scenario would require a new replica server due to a detected network failure. The process of instantiating a new virtual media distribution to boot and apply network configurations, takes 45.641 s where 30 s of them correspond to the time needed by the VM (Virtual Machine). Regarding the load balancing offered by the vCDN, the results have shown that the values obtained for latency and throughput are better when the user is assigned to a replica server closer to the user's location (0.771ms for latency and 749 Kbits/s for throughput) than when the user is assigned to a server located in different subnetworks (20.888ms for latency and 354 Kbits/s for throughput).

In the same way, for the instantiation of a TV Broadcasting Application (TVBA), the average and standard deviation of the multicast provisioning time to deploy the TVBA quality probe (TVBAQP) for the first time of deployment are 92.72 s ± 4.54 s (8.58 s ± 0.37 s when it was pre-deployed) and it consist of: 1) average user's provisioning time of 1.47 s ± 0.41 s, 2) average Quality Probe's deployment time of 83.62 s ± 4.47 s, 3) average Quality Probe's starting time of 0.33 s ± 0.13 s, and 4) average Quality Probe's analyzing time of 5.72 s ± 0.46 s. On the other hand, the TVBA can self-heal the system in an average time of 41.67 s ± 7.28 s consisting of: 1) average reaction time of 15.88 s ± 9.10 s, 2) average TVBA's decision time of 0.16 s ± 0 s, 3) average solution time of 1.72 s ± 0.39 s and 4) same Quality Probe's times as before.

## V. CONCLUSIONS

The quality algorithm composed by different modules for assessment of the multimedia signal demonstrated the validity for instantiation of virtual media and applications based on VND, such as the TV Broadcasting Quality Probe Application. The TVBAQP is an important module, which is primary for streaming video contents in 5G networks to fulfill the requirements of end users. Data streaming analyzed in the different nodes of the system is able to improve the performance of the network and assuring quality requirements when streaming arrives to the user device.

The necessity of providing better quality to the system is determined by Video/Audio Quality Assessment and QoS (Quality of Service) metrics, which enable the analysis of the network state, deciding the resubmission of low quality video: This fact means the convergence between content delivery and 5G networks. The metrics developed for detecting the absence of video, frozen frames, color distortions or packet loss are part of the first approximation to the model that trends expect to be the future 5G multimedia distribution content, improved by the AQA by intelligibility, detection of silence and other audio distortions.

The database of common network errors was useful to test the individual metrics, obtaining good results for measuring frozen frames, packet loss or throughput generated errors. The image and visual quality techniques, help to simulate the user's perceived experience, better than QoS traditional metrics, which are less adapted to subjective human eye visualization. First tests highlight the necessity of developing intelligent nodes that are ready to detect common transmission errors to improve the efficiency of 5G networks and increase the users' satisfaction. The analysis of time to deploy virtual machines, applications, such as the TVBAQP or virtual media revealed the importance of balanced the time, in accordance to the time for content retransmission, especially for big live events, in which the end user demands a fast performance of the network distributor.

The quality algorithm demonstrated the necessity of definition, standardization and implementation of intelligent network nodes that are automatically adaptable to the 5G network state with the objective of improving video transmission, with the enhancement of users' viewing quality.

## ACKNOWLEDGMENT

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