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In-service Video Quality Assessment based on SDN/NFV techniques

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***Abstract*—This paper discusses the utilization of SDN/NFV as enabling technology for the provision of in-service video quality assessment. The proposed method is based on a reduced reference extension of the widely used full reference SSIM metric, proving how the applicability of SDN/NFV can support the development of novel value-added service. The proposed video quality assessment method is based on a two-step process, where in the first step a test pattern is used as a reference for the assessment of the original and the degraded signal and in the second step the SSIM value is estimated by the combination of these measurements. For the validation of the proposed method, a SDN/NFV infrastructure was deployed, supporting traffic steering of selected video flows through the VNF instantiation of the proposed method. The evaluation results demonstrated the advantages in terms of agility and flexibility of the SDN/NFV combination in the provision of the proposed in-service video quality assessment methodology.**

Keywords— video quality; SDN; NFV; SSIM; MPEG-4; H.264.

I. Introduction

The emergence of Network Function Virtualisation (NFV) in combination with the network programmability introduced by Software Defined Networking (SDN) has been recently embraced at large by the industry, promising agility, flexibility and optimization in network management and orchestration [1], creating also the basis for the definition and development of novel value-added services.

NFV [2], [3] refers to the migration of network functions traditionally hosted in monolithic hardware-based network appliances (e.g. hardware-based quality meters), to software counterparts hosted in generic hardware commodity servers. The level of flexibility offered by NFV allows network operators create and provide new service types, such as the one addressed in this paper.

SDN is an emerging networking paradigm that changes the limitations of current network infrastructures [4]. Firstly, it separates the network's control plane from the underlying network elements that forward the traffic (the data plane). Secondly, with the separation of the control and data planes, the control logic is implemented in a logically centralized controller. This change of control [5] enables the underlying network infrastructure to be abstracted for various applications and network services and as a consequence of this the network can be treated as a logical or virtual entity. Some of the benefits of the SDN are: the centralized control of multi-vendor environments, the reduced complexity through automation, the increased network reliability and security, the more granular network control, and finally the user experience enhancement (i.e. QoE). Thus, there is a need for expanding the current range of QoE assessment methods in order to involve new ones that will be in line with these SDN requirements. A possible approach, which is followed by this paper, towards this, involves the deployment of the new generation of QoE models as Virtual Network Functions (VNFs) over the SDN network, exploiting the concept of NFV.

Under this consideration, ETSI NFV ISG has announced various NFV use cases that illustrate the application of NFV in combination with SDN [3]. Among the various use cases, the concept of the Virtual Network Function as-a-Service (VNFaaS) is defined, which prescribes the provision to the customer of an end-to-end connectivity service (virtual network) along with embedded VNFs. The connectivity service specifications would allow dictating certain limits for the provided QoS, but the QoS assurance will need monitoring mechanisms in place. There are numerous approaches to QoS assessment models, but the most dominant now is the Quality of Experience (QoE) concept because it provides a direct link to the user-satisfaction in relevance to a specific QoS-sensitive service (e.g. IPTV, VoD etc.) [6].

In this context, this paper presents an in-service video quality assessment method, which has been implemented as VNFaaS and validated utilizing SDN/NFV techniques. This SDN/NFV-enabled QoE evaluation is able to be embedded into the network provisioning, and management processes and will give to the service provider and network operator the capability to efficiently manage the network resources by allocating to the virtual network instance only the ones that are necessary to maintain a specific level of user satisfaction according to the QoE assessment made along the service delivery chain. Thus, such VNFaaS QoE methods are critical for vendors, network operators and service providers to assess, predict and control the end-to-end QoS constraints of the service.

The rest of the paper is organised as follows: Section II, provides a description of the proposed NFV-based method. Section III describes the experimental SDN and NFV-enabled testbed that was utilized for the validation of the proposed metric. Section IV provides the experimental validation results of the paper, showing satisfactory performance of the proposed method. Section V discusses future work. Finally, section VI concludes the paper.

II. THE PROPOSED IN-SERVICE QOE ASSESSMENT

The QoE research, which fits well to the needs of SDN for in-service integration of the network provision, is based on developing methods that can evaluate the video quality level based on metrics, which use only some extracted structural features from the original signal (i.e. Reduced Reference Methods). In this framework, taking advantage of the Structural SIMilarity (SSIM) metric in measuring the video perceptual quality, a SSIM-based reduced reference approach is proposed in this paper –and thoroughly described in the next section- as a VNF to assess the perceptual quality for real-time video streaming across SDN and NFV-enabled network domains.

The work in this paper is motivated and inspired by other works on approximating the SSIM metric with reduced reference methods, such as [7], which exploits the Divisive Normalization Transform (DNT) – domain image statistical properties and the algorithm steps of the SSIM metric. Other works [8] have approximated the SSIM metric by quantifying visual degradations generated by channel transmission errors on the transmitted signal.

The proposed approximation of SSIM goes beyond the previous works, because it is not limited to specific types of distortion errors and its implementation is appropriate for NFV deployment (i.e. SSIM as a Service).

In the typical SSIM index evaluation process, given that it is based on a FR assessment process, it is assumed that both the original and the test video sequences are available at the same site. $SSIM(x,y)$ evaluation can be based on any software implementation, where x is the original video sequence VS_o, y is the transmitted video sequence VS_t (or test signal) and $SSIM_{ot}$ is their $SSIM(x,y)$ index.

This paper introduces an innovative In-Service QoE (IS-QoE) method for objective video quality assessment, which is based on SSIM index, but the video quality is not directly evaluated by comparing the original and test video sequences but on the contrary is based on reduced reference framework, alleviating from the restriction of being available the original signal.

The proposed method described in figure 1, where an initial $SSIM_{ow}$ value is evaluated at the service provider site, by comparing the original video sequence (VS_o) with a white-video pattern (VS_w), i.e. a video sequence of white video frames of the same resolution and frame rate, following a relative SSIM measurement with point of reference being the white pattern. The evaluation of $SSIM_{ow}$, where x is VS_o and y is VS_{ow} and refers to each frame, can be sent to the consumer site by any means, i.e. either through the same communication channel as the video, or any other communication channel with a sufficient bandwidth, or by embedding it inside the transport stream of the video sequence. In any case, it is considered that the $SSIM_{ow}$ value is recovered at the consumer site.

Referring to Fig. 1, an $SSIM_{tw}$ value is evaluated at the consumer site, by comparing the received (test) video signal (VS_t) with a reference white-video pattern (VS_w), which is identical to the one used at the service provider site and therefore the same relative point of reference. The evaluation of $SSIM_{tw}$ can be based on any software implementation of SSIM and refers to each frame of the test video sequence.

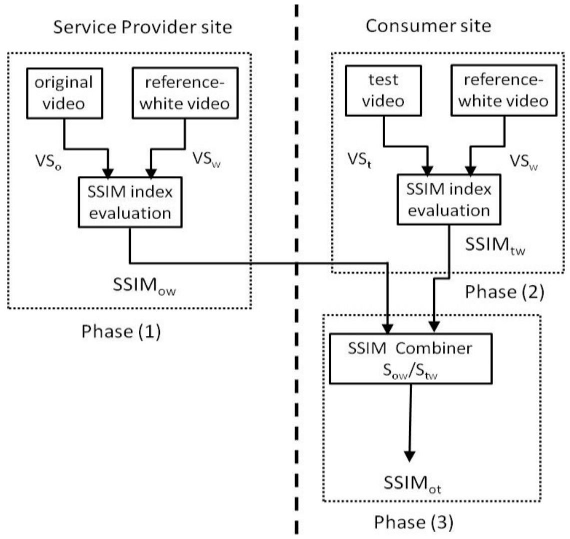

Fig. 1. The proposed approximated SSIM with relative point of reference

The two SSIM values $SSIM_{ow}$ and $SSIM_{tw}$, which have been calculated in a relative manner based on the reference white-video pattern, can be used in order to approximate with satisfactory accuracy the SSIM index between the original and the test video sequences $SSIM_{ot}$ by calculating their ratio.

$$SSIM_{ot} = (SSIM_{ow} / SSIM_{tw}) \tag{1}$$

Concerning the channel requirements and the overhead of the proposed method, $SSIM_{ow}$ is a number less than 1 and it can be represented by 2 bytes per frame for an accuracy of four decimal places (10^{-4}).

III. EXPERIMENTAL SDN/NFV PLATFORM

This section describes the experimental testbed that was implemented for the validation of the proposed IS-QoE method as a VNF, using real-time video streaming. The testbed, as Fig. 2 shows, implements a small scale but fully operational network domain with SDN capabilities enabled and controlled centrally by OpenDaylight controller (the SDN-enabled network consists of Open Virtual Switches (OVS)). At the ingress and engress points of the domains, two cloud platforms (i.e. NFVI-PoPs) are installed, which are capable of instantiating VNFs and performing also the appropriate network traffic steering in order to support service chaining (i.e. the forwarding of the traffic seamlessly from the sender through the VNFs of the two NFVI-PoPs and then to the receiver).

A video server is considered in the testbed, which host the videos at its original encoded form. In order maintain an acceptable video service delivery, we consider that our testbed is equipped with a real time video adaptation system, which is capable of performing in real-time transcoding, which results in video streams adapted to the current network conditions, but of degraded video quality. This video transcoder is implemented for the needs of the paper based on the widely used FFMPEG [10] and is instantiated as VNF_2 at the ingress NFVI PoP. The adaptation triggering event may differ depending on the specific use case, ranging from the user terminal specifications to the available bandwidth of the delivery channel. For the scope of this paper, the triggering event is manually controlled in order to perform the experimental validation of the proposed IS-QoE under various transcoding profiles.

The implementation of the proposed IS-QoE method is split into two functions: The first one is instantiated as VNF_1 and is located at the ingress NFVI-PoP, calculating the $SSIM_{ow}$ (i.e. phase 1 of the method), while the second function is instantiated as VNF_3 and calculates the $SSIM_{tw}$ (i.e. phase 2 of the method). It should be noted that VNF_1 sends the calculated $SSIM_{ow}$ of each frame at the VNF_3 in order to be calculated the ratio $SSIM_{ow}/SSIM_{tw}$ (i.e. phase 3), which provides us the proposed estimated SSIM value at the IS-QoE monitoring terminal device.

The typical served user request for a specific video is depicted in Fig. 2 with the blue dotted line at the bottom, which shows the path that the user conceives for the media delivery, since the steering of the video stream through the two NFVI-PoPs, the transcoding of the content and the QoE measurement are totally seamless to the end-user.

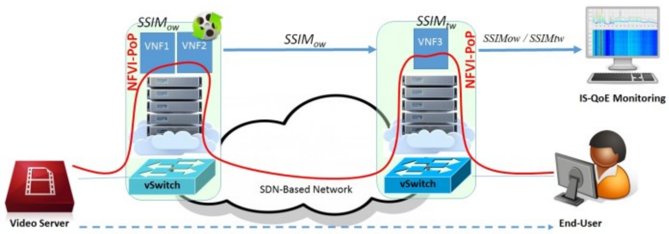

Fig. 2. An overview of the experimental topology

Considering the SDN-based traffic steering mechanism within the NFVI-PoPs, Fig. 3 zooms in the Openstack cloud computing platform of the ingress NFVI-PoP, where VNF_1 and VNF_2 are hosted. More specifically, the figure presents the complex L2/L3 traffic steering process, which is achieved using SDN/Openflow mechanisms to alter per hop in the traffic flow the values of the destination IP address, destination MAC address and source IP address. For better representation of these SDN-based network programming, the label of Fig. 4 has been used at each hop of Fig. 3.

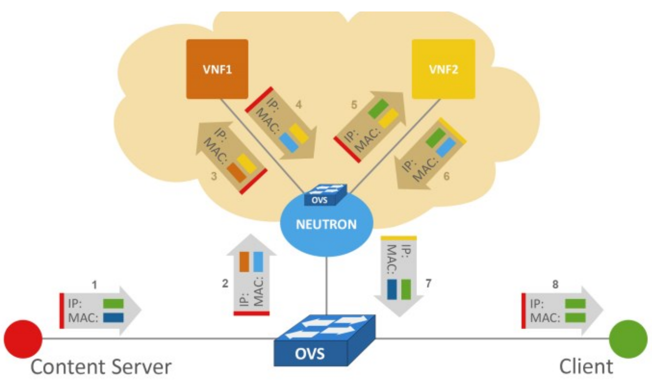

Fig. 3. Openflow-based traffic steering within Openstack platform

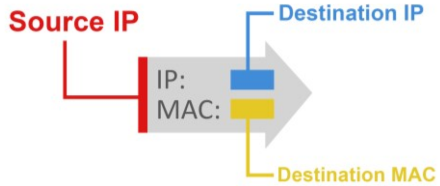

Fig. 4. Label used to show the SDN-based traffic steering commands per hop

As seen in Fig. 3, we use Open vSwitches (OVS: software-based Openflow-capable virtual switches), in order to divert the traffic through VNF_1 and VNF_2 by altering the destination MAC and IP address fields of the packets. The OpenStack network node (Neutron) plays an active role in the process.

IV. Performance Evaluation of IS-QoE

The performance of the proposed IS-QoE is evaluated in this section by comparing it with the original SSIM index. For the experimental needs of this paper, a set of test signals was selected, which includes twelve reference video signals [9].

Utilizing the experimental testbed of Fig. 2, the storyline of the experimental scenario is as follows:

- The video server initially hosts the test signals in their original MPEG-4 form (i.e. Quantization Parameter (QP) equal to one (QP=1)), which are considered as the reference signals for the video quality assessment.
- The end-user requests a specific video from the video server;
- The video server initiates the streaming process, which for the experimental validation was selected unicast UDP-based streaming.
- The video is streamed from the video server towards the end-user over the SDN-enabled network domain.
- At the ingress NFVI-PoP the video stream is steered through the VNF_1, which performs the calculation of the $SSIM_{ow}$ of the original signal. The $SSIM_{ow}$ value is sent to VNF_3.
- Then the traffic is further steered within the ingress NFVI-PoP to the VNF_2, which transcodes the MPEG-4 signal in real time at lower video quality levels, by altering the QP value of the streaming video to either 12, 22, 32 or 42.
- The video stream is further forwarded outside of the ingress NFVI-PoP and over the SDN-enabled network till the egress NFVI-PoP.
- At the egress NFVI-PoP the video stream is steered via VNF_3, which calculates in real time the $SSIM_{tw}$ and the ratio of $SSIM_{ow}/SSIM_{tw}$ (i.e. the proposed IS-QoE) is calculated (utilizing the $SSIM_{ow}$ value that has been sent by VNF_1).
- The video stream is further forwarded outside the egress NFVI-PoP and reaches finally the end-user.

Focusing more on the validation process of the proposed IS-QoE, the original test signals are transcoded by VNF_2 at the following QP values 12, 22, 32, and 42, in order the proposed method to be tested not only on a variety of contents, but also on a wide range of encoding qualities. Then, comparison of the calculated IS-QoE values of each test signal is performed with the SSIM index values, which is also calculated offline in parallel. Finally, *Q-Q* plots and comparative graphs are derived in order to demonstrate graphically the good performance of the proposed IS-QoE method in comparison to the SSIM index. Similarly, in order to estimate quantitatively the performance of the proposed IS-QoE method in comparison to the SSIM index, the Mean Absolute Percentage Deviation (MAPD) per frame is derived.

TABLE I
MAPD FOR IS-QOE

Video Name	Resolution	Frames	QP:12	QP:22	QP:32	QP:42
bigbuckbunny	640x360	14315	0.01091	0.020527	0.039061	0.08247
elephantsdream	640x360	15691	0.008501	0.013748	0.040883	0.07121
basketballpass	416x240	501	0.011807	0.007371	0.022277	0.052565
Bqsquare	416x240	601	0.006849	0.028219	0.101372	0.040488
Bubbles	416x240	501	0.005385	0.015653	0.069205	0.045971
basketballdrill	832x480	501	0.016819	0.00973	0.0052	0.07707
Bqmall	832x480	601	0.008256	0.005319	0.009498	0.044177
Racehorses	832x480	300	0.009953	0.00794	0.022274	0.03739
Partyscene	832x480	501	0.005572	0.01613	0.075519	0.028829
Stockholm	1280x720	604	0.000514	0.030779	0.047909	0.037135
Kristen&Sara	1280x720	600	0.008666	0.006363	0.010176	0.036755
Foupeople	1280x720	600	0.009949	0.001049	0.001995	0.039007

In Table I, the MAPD is presented for the experimental set of the test signals at the four QP values (i,e, 12, 22, 32 and 42) that were used by VNF_2 during the transcoding process. As it can be deduced from the experimental results of Table I, the proposed method approximates satisfactorily the SSIM index measurements with an averaged MAPD across all the experimental set of approximately 4.5%. More specifically, the lower the QP value (i.e. better quality of the encoded signal), the better the performance of the proposed IS-QoE method (i.e. lower MAPD between the IS-QoE and SSIM). So, the proposed IS-QoE method achieves better accuracy at encoded signals of high video quality levels, while the accuracy of the methods drops for low quality signals, but it still remains at satisfactory levels and lower than 8.2% (in the worst case).

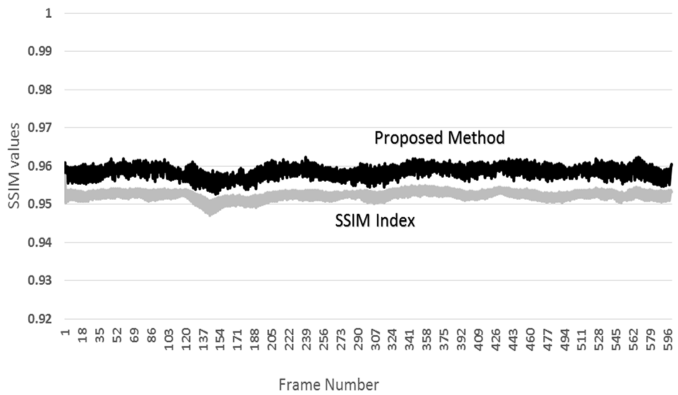

Fig. 5. The IS-QoE compared to the SSIM index on Kristen&Sara with QP=22

For the quantitative comparison of the proposed method and the SSIM index, in Fig 5 the respective graph for the test signal Kristen&Sara and QP=22 is presented as a representative one to portray and delineate the proposed method's satisfactory performance. It can be clearly observed that the proposed IS-QoE method follows satisfactorily the SSIM index graph.

Finally, for the same video signal, the *Q-Q* plots between the SSIM index and the IS-QoE method are also presented in order to show the relation between the SSIM index and the proposed IS-QoE method.

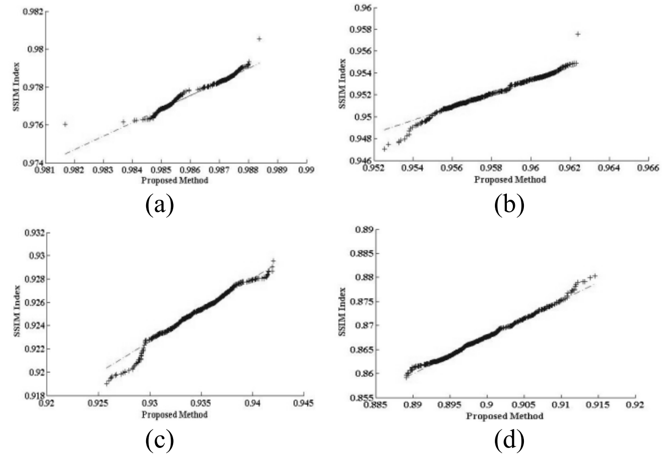

Fig. 6. *Q-Q* plots of the SSIM index vs. IS-QoE for the test signal Kristen&Sara at QP (a):12 (b):22 (c):32 (d):42

As it can be deduced by the *Q-Q* plots of Fig. 6 (a, b, c, d), the proposed method maintains a satisfactory level of performance across all QPs, observing a distribution of the experimental points to be very close to the linear diagonal, showing a satisfactory statistical correlation of the two experimental sets.

V. FUTURE WORK

The proposed IS-QoE method is based on a reduced reference extension of the widely used full reference SSIM metric, proving how the applicability of SDN/NFV can support the development of novel video quality assessment methods, which can be integrated and delivered in-service. The presented validation process has been limited to the assessment of video signals which have been degraded with encoding artifacts due to higher quantization parameter values. Future work includes the validation of the proposed method under a wider variety of degradation artifacts, which will include also error propagations caused by network congestion and impairments. Further tests of the IS-QoE VNFs are also foreseen for http-based streaming services, where adaptation actions are performed at the client side and therefore further integration opportunities of the proposed IS-QoE method with the http-based video client (e.g. MPEG-DASH) and the video server are possible.

VI. CONCLUSIONS

The work presented in this paper has focused on the utilization of SDN/NFV as enabling technology for the provision of novel in-service video quality assessment methods. In this framework, the paper introduced a novel method on assessing video quality of an encoded signal, by expanding the applicability of the SSIM index as a VNF over a SDN-enabled domain with NFV capabilities. The proposed method was tested on an experimental SDN/NFV-enabled testbed with a set of 12 reference video signals and a VNF-based transcoder, achieving accuracy rates in relevance to the SSIM index of approximately 5%.

ACKNOWLEDGMENT

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