Exploiting NFV techniques towards future VQA methods

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***Abstract*—This paper introduces a novel approximation of the widely used full reference SSIM metric, ideal for the in-network assessment of QoE for multimedia streams. The QoE estimation approximation algorithm has been implemented as a Virtualised Network Function (VNF) in order to be deployed over Network Function Virtualisation (NFV) infrastructures. The proposed method is based on a two steps evaluation process, making use of a test pattern as an intermediate reference according to which the quality of the original and degraded signal is estimated and expands the applicability of SSIM as a reduced reference metric. For the evaluation of the proposed method as a VNF, a laboratory-scale prototype NFV infrastructure was used, supporting dynamic steering of selected video flows towards the proposed nQoEe estimator VNF via an SDN Control Plane application using OpenFlow protocol for the communication with the physical and virtual switches. The evaluation results validate the efficiency of the proposed method as a VNF, in addition the reported accuracy of the proposed method is proven as satisfactory with an average estimation error of 5%.**

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

I. Introduction

The emergence of Network Functions Virtualisation in combination with the network programmability introduced by Software Defined Networking (SDN) has been recently embraced at large by the industry. Their exploitation in datacenters but also in WAN deployments are promising CAPEX and OPEX reduction, revenue increase, decrease in the Time to Market, while at the same time guarantee availability, targeted service deployment, and openness [1]. The NFV application besides the virtualisation of well-known hardware appliances has identified the need for new, innovative VNFs that could offer better customer experience or increase support for innovative services. In this context this paper proposes an innovative in-network QoE estimator (nQoEe) VNF,, which has the potential to radically redefine the current Quality of Service (QoS) provision and Quality of Experience (QoE) evaluation. The motivation behind the implementation of this VNF is to support multimedia delivery services, allowing in-network assessment of the QoE with minimal overhead, supporting cognitive management schemes via SDN practices. For example it makes sense to have some appliances, such QoEe nodes, housed on the network element or at Network Function Virtualisation Infrastructure Points-of-Presence (NFVI-PoP) allowing cognitive management especially in 5G infrastructures.

The SDN via the abstraction of physical infrastructure and the centralized network control, enables the creation of logical virtual network infrastructures with isolated dedicated resources. As a consequence, it is possible to allow multi-tenancy and per-tenant network resource management. This capability is exploited especially in datacenter environments where a vast number of VMs belonging to different tenants and with a variety of workloads create a complex and demanding environment. The effort of orchestrating and managing this environment is greatly benefited by the employment of SDN.

In the NFV context, that is anticipated to employ datacenters at the edges of the network, used as execution environment for the VNFs the application of SDN is considered as a complementary technology for the management and control of the virtual infrastructures. Recent opensource efforts i.e. OPNFV [2] are approaching exactly this objective, trying to integrate various opensource building blocks with the aim of providing a unique deployable platform for NFV support.

Under this consideration ETSI NFV ISG has released a series NFV Use Cases that illustrate the application of NFV [3]. One of those services that is exploited in this work is the Network Function Virtualisation as-a-Service (VNFaaS). The aforementioned use case, 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, while 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.) [4]

Under this frame a nQoEe VNF would enable QoE degradation information detected at selected (deployed) network locations to be exploited by the management system (either per-tenant or overall) in order to enable enhanced cognition features and optimally manage the assigned resources, or in another case control the multimedia delivery at the source.

This NFV-enabled QoE evaluation will be 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 QoE as NFV 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: the following section provides a brief description on the relative background concepts of the paper, namely NFV, SDN and video quality assessment. Section III, provides a description of the proposed NFV-based SSIM approximation. Section IV describes the experimental SND and NFV-enabled network domain that was utilized for the validation purposes of the paper. Section V provides the experimental validation results of the paper, showing good performance of the proposed metric. Finally, section VI concludes the paper.

II. BACKGROUND

A. The Network Functions Virtualisation (NFV)

NFV 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 provision new types of services, such as the one addressed in this paper.

The capability to deploy VNFs at designated locations in the network topology, where the execution environment supports it (e.g NFVI-PoPs or NFV enabled network devices), is one of the strong characteristics of NFV. The allocation of these VNFs requires assignment of IT and network resources so that the VNF can operate and end-to-end orchestration in order to make sure that the correct data are steered to the through the appropriate VNFs. The first is handled by cloud frameworks capable of controlling the IT resources (e.g. Openstack), while the latter are controlled by SDN controllers (e.g. Opendaylight).

The concept of adding QoE monitoring capabilities in the above picture would allow the Network Operators to use this information in order to manage more efficiently their resources whether this might be IT resource or network resources. Alternatively in a multi-tenant environment the information can be used by the tenant in order to better manage its own acquired resources in a NFaaS model.

The challenge of a QoE estimation and monitoring VNF is the overhead that it will need to introduce to the monitored flows in order to assess the perceived QoE in real-time. Additionally the proposed nQoEe VNF will exploit the NFV concept in order to be dynamically deployed, configured and operated. . In this framework, this paper focuses in the case of the SSIM metric and proposes a two-step approximation method for its calculation in order to expand its applicability as a VNF. The next sub-section describes a brief review on similar works on the SSIM approximation as a reduced reference metric.

B. The Software Defined Network (SDN) paradigm

Software-Defined Networking (SDN) is an emerging networking paradigm that changes the limitations of current network infrastructures [5]. 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 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.

A well-known northbound interface protocol used in SDN configuration is Openflow, which has recently gained a lot of attention for SDN applications. Network devices can fully support OpenFlow-based forwarding as well as traditional forwarding, and in this way it makes it very easy and convenient for enterprises and carriers to progressively introduce OpenFlow technologies. Moreover, it is crucial that the OpenFlow protocol can be integrated seamlessly within an enterprise or carrier's existing infrastructure in order to provide a simple migration path for the SDN compatible segments of the network [6]. Some of the benefits of the OpenFlow protocol 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 satisfy to the SDN requirements. A possible approach, which is followed by this paper, towards this, involves the deployment of the new generation QoE models as Virtual Network Functions (VNFs) over the SDN network, exploiting the concept of NFV, which is briefly discussed in the next sub-section.

C. SSIM approximations suitable for VNF deployment

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 (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 VNF-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).

III. IN-NETWORK QOE ESTIMATOR

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 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.

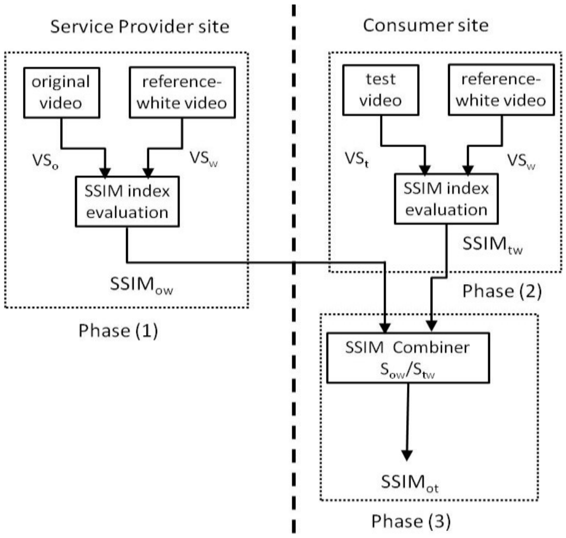

Fig. 1. The proposed approximated SSIM with relative point of reference

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.

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.

$$SSIMot = (SSIMow / SSIMtw) \quad (1)$$

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}).

IV. Experimental Platform

This section describes the experimental network platform that was implemented for the validation of the proposed approximated SSIM method as a VNF. The platform implements a small scale but fully operational network domain with SDN capabilities enabled and controlled centrally by OpenDaylight controler. A network app developed for this SDN control framework, controls the traffic sterring within the aforementioned testbed, in order to make sure that selected flow pass through the nQoEe VNF while other flows use the default forwarding path.

The experimental platform aims to validate the proposed nQoEe VNF under laboratory based scenarios using real-time video streaming and QoE assessement performed by the proposed VNF. The walkpath of this scenario is as follows:

- the end-user asks for a specific video from the content provider;
- the video is streamed from the video server towards the end-user;
- at the first switch data packets headers information is send to the Controller where is checked against rules that allow the identification of the video flows that need to be steered;
- matching flows are intercepted and steered towards the NFVI-PoP;
- at the NFVI-PoP traffic is forwarded to the compute node that hosts the virtual machine where the nQoEe VNF operates;
- packets leaving the nQoEe, are consequently matched by the SDN Controller and steered towards the end user;

In order to divert the video flows towards the nQoEe the control plane when a packet is matched against the set rules, ip destination re-rewrite action is signaled at the switch. This way the video traffic passes through the nQoEe VNF instead going directly to the end-user. Correspondingly, the above actions is reversed (i.e. destination address re-written) when the flow leaves the nQoEe VNF, in order to direct the flow to its original destination.

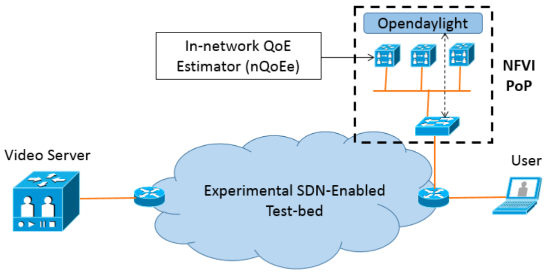

Fig. 2. An overview of the proposed experimental network platform, as it was implemented and tested for the needs of the paper.

The implementation of the experimental network platform, as designed in Fig. 2, comprises of a Dell R310 used for the Video Server and the SDN enabled network, a Dell R510 that is used for the NFVI-PoP implemented with Openstack Icehouse installed. More specifically the SDN-enabled network consists of three Ubuntu VMs with OpenVSwitch, and two Ubuntu VMs for server and client. The nQoEe VNF was deployed on the NFVI-PoP using one Ubuntu VM and another VM running the OpenDaylight Controller (Beryllium version).

V. PERFORMANCE EVALUATION

The performance of the proposed method is evaluated in this section in an experimental quantitative process by comparing the comparing its result with the original SSIM index. For the experimental needs of this paper, a wide range video set was selected, which includes forty video signals of various frame resolution and content. The selected set of videos consists of eleven reference video signals [9], two long duration sequences (BigBuckBunny, Elephant's Dream), and twenty-seven non-reference video signals retrieved from motion pictures. Tthe total number of unique frames, which used for evaluating the proposed method is 60,866. Figure 3 provides a collections of representatives frames of each one of the forty test signals, for reference purposes.

Fig. 3. Representative Frames of the 40 test signals of the evaluation process

Across all the experimental section of the paper, the original uncompressed test signals are encoded at the following QP values 12, 22, 32, and 42, in order the proposed method to be tested not only a variety of contents, but also on a wide range of encoded signals, covering different quality levels and therefore a wide variety of distortion types that occur by the encoding process of various video contents at different quality levels.

The experimental process of the paper includes two parts:

In the first part of the experimental section, the proposed method is applied on the experimental set, using the white color as relative reference video pattern. Then comparison with the SSIM index and the proposed method is performed both quantitatively and qualitatively with Q-Q plots and comparative graphs.

In the second part of the experimental section, different colors, other than the white, are selected as relative reference video pattern, such as black, red, green, blue, yellow, pink, aqua, and gray. The selected color set portrays a distinct color and luma diversity, which is essential to demonstrate and evaluate the behavior of the proposed method on different relative reference video patterns. The results of this validation process are presented in a averaged and quantitative way per color for the signals under test at the various QMs.

A. *Performance Evaluation with White relative reference*

To measure the performance of the proposed method in comparison to the FR SSIM index, the Mean Absolute Percentage Deviation (MAPD) for each frame t between the two methods is calculated, which is a widely used as a measure of accuracy for a prediction method, specifically in trend estimation, like the proposed method.

$$MAPD = \frac{1}{n}\sum_{t=1}^{n}\frac{|SSIM_t - Predicted\_SSIM_t|}{SSIM_t} \qquad (2)$$

Where $SSIM_t$ is the SSIM index per frame t and $Predicted\_SSIM_t$ is the estimated SSIM by the proposed method at the frame t according to the equation (1).

In table I, it is presented the MAPD for the experimental set of the 40 test signals at the four QP values (i,e, 12, 22, 32, and 42) that were selected for evaluating the proposed method. As it can be deduced from the experimental results of Table I, it can be clearly deduced that the proposed method predicts satisfactorily the SSIM index, through the indirect estimation utilizing the white reference video pattern, with an averaged MAPD across all the experimental set and QP values of approx. 4.5%. More specifically, the lower the QP value (i.e. better quality of the encoded signal), the better the performance of the proposed method (i.e. lower MAPD between the predicted and the calculated SSIM). It can be clearly observed that at QP 12, in the case of the sequence insideman4, the percentage error margin remains at 0.01%. Furthermore, as the QP value increases the error percentage value also increases reaching its highest value at the parameter value of QP 42, where in the case of apocalypto4 it reaches 9%. So, the proposed method achieves very high accuracy at encoded signals of high video quality level, while the accuracy of the methods drops for low quality signals.

TABLE I
MAPD FOR WHITE REFERENCE VIDEO PATTERN

Video Name	Resolution	Frames	QP:12	QP:22	QP:32	QP:42
apocalypto1	352x288	990	0.003053	0.005581	0.033561	0.087794
apocalypto2	352x288	990	0.004793	0.005936	0.020171	0.055745
apocalypto3	352x288	990	0.005903	0.007334	0.021447	0.074754
apocalypto4	352x288	501	0.005136	0.009094	0.017331	0.092961
mission1	352x288	990	0.005578	0.007233	0.016888	0.065433
mission2	352x288	990	0.006228	0.006695	0.019181	0.053884
mission3	352x288	293	0.004423	0.005531	0.016902	0.077755
superman1	352x288	990	0.004448	0.006062	0.019283	0.075533

superman2	352x288	990	0.00459	0.0069	0.021657	0.043845
superman3	352x288	268	0.001328	0.003436	0.035995	0.053591
insideman1	352x288	990	0.003798	0.004191	0.019316	0.066451
insideman2	352x288	990	0.006988	0.008945	0.012651	0.031442
insideman3	352x288	990	0.00526	0.006288	0.012146	0.04527
insideman4	352x288	376	0.00125	0.001084	0.027495	0.050189
davinci1	352x288	990	0.0029	0.003661	0.014045	0.054189
davinci2	352x288	990	0.005846	0.007804	0.019533	0.043835
davinci3	352x288	990	0.005416	0.005909	0.012271	0.036922
davinci4	352x288	627	0.007838	0.009838	0.018827	0.044248
basic1	352x288	990	0.005603	0.006751	0.015259	0.06152
basic2	352x288	990	0.00652	0.009051	0.015006	0.048394
basic3	352x288	990	0.006734	0.00765	0.014208	0.040948
basic4	352x288	351	0.003842	0.004624	0.010905	0.063068
16blocks1	352x288	990	0.004517	0.004992	0.017711	0.044576
16block2	352x288	990	0.006962	0.006389	0.012574	0.035462
16block3	352x288	990	0.005295	0.005044	0.01225	0.05988
16block4	352x288	451	0.003401	0.00297	0.007796	0.038091
batman1	352x288	2659	0.010258	0.014053	0.042584	0.088853
batman2	352x288	913	0.00619	0.011052	0.070104	0.076392
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

For the quantitative comparison of the proposed method and the SSIM index a set of four graphs are presented for the test signal Kristen&Sara in order to portray and delineate the proposed method's satisfactory performance. Finally for the aforementioned video signal the QQ plots between the SSIM index and the proposed method are also presented in order to show the similarity of the statistical properties of the SSIM data and the proposed method data, demonstrating their quantitative similarity.

VI. Future Work

The work performed in this paper has focused on the experimental validation of a proposed approximation of the full reference metric SSIM with scope to be further exploited as a VNF over an SDN-enabled network with NFV capabilities. The experimental validation presented in this paper has proved the suitability of the proposed approximation of the SSIM to be used as a VNF and also the satisfactory performance of it for assessing signals that have been encoded at different quality levels. Future work includes the proposed method to be further validated in more complicated scenarios, which will include also quality degradation caused by network impairments and therefore involving different types of artifacts.

VII. Conclusions

This paper introduces 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 the introduction of a reference video pattern, which is used as an intermediate step in the assessment process between the original and the compressed video signal. The proposed method, which approximates the SSIM index in a reduced reference framework, was tested on an experimental set of 40 reference video signals, with spatial resolution ranging from CIF to HD, achieving accuracy rates of approximately 5%.

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