An NFV-based Video Quality Assessment Method over 5G Small Cell Networks

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***Abstract*—This paper proposes a novel video quality assessment mechanism aimed for the next generation (5G) mobile networks, following the small cell deployment architecture. The proposed method is based on a novel usage of the structural similarity (SSIM) index, as a Reduced Reference metric and is suitable for implementation as a Virtual Network Function (VNF) within an IT infrastructure located close to the small cell. It enables the in-service monitoring of the delivered video quality, which is a very useful tool for the mobile network operators, to monitor their customers' satisfaction. An advantage of the proposed method is that the complex and power consuming process of video quality assessment is performed at the edge of the network, and not at the UE itself, thus significantly reducing its power consumption. A Small Cell experimental testbed was used for the implementation and performance evaluation of the proposed method. The experimental results show that the proposed method is able to monitor the video quality, when the network is degraded.**

Keywords— video quality; SSIM; NFV; 5G; small cell.

I. Introduction

The proliferation of mobile wireless broadband technologies during the last decade, has triggered the ascension of 5G Mobile Networks, which is designed to ensure scalability, efficiency and versatility [1]. Although there are no clear definitions or standards, as yet, for '5G', there are a few assumptions already being agreed about 5G, which are virtualization, small cells and expansion into high frequency bands [2].

The virtualization of network functions has been initially applied to large IT data center and has turned data-centers into service-oriented architectures that are able to rapidly respond to the dynamic business environment. Network function virtualization (NFV) techniques have been proven to offer great benefits to the world of IT, in terms of sharing compute, storage and network resources, as well as service agility and ultimately bringing higher revenues and competitiveness.

NFV is impacting all service provider segments and is therefore affecting the realization of future mobile networks. Mobile network operators having realized the benefits, encourage the development and deployment of NFV techniques in their networks. Today, virtualization is a well-examined topic within core networks and macro-cell access networks (Cloud Radio Access Network C-RAN). Nevertheless, the impact of virtualization for a small cell network have received very limited attention and its benefits have not been considered thoroughly. Much of the work on virtualization has been undertaken by ETSI [3], including the definition of virtualization use cases. In particular, use case #6 'Virtualization of the mobile base-station' is of interest to a small cell network.

The applicability of NFV techniques to small cell base stations has specific individualities, which are examined in the Small Cell Forum (SCF) [4]. A basic requirement is that a subset of small cell functionalities that support at least the RF functions is run on a physical network function (PNF). The hardware on which the PNFs will run is a small cell radio unit consisting of at least a single cell radio transceiver (with multiple antennas as required). The remaining functionality is run as one or more VNFs on virtualized compute platforms. The split of the functions, i.e. which will remain as PNFs and which will become VNFs is a challenge that is thoroughly examined in SCF, but it is out of the scope of this paper.

There are specific small cell functions, which refer to layers L1, L2 and L3 and functions related to application services (such as content caching, firewalls, QoS monitoring etc) and small cell management functions, (such as Radio Resource Management - RRM). This paper addresses a function that belongs to the second category.

Another individuality of small cell networks is their unreliable backhaul. It is anticipated that the non-ideal backhaul networks, which are commonly found in today's small cell deployments, are highly applicable to 5G scenarios too [5]. Considering that the connectivity of small cells with the core network of the LTE system (i.e. the Evolved Packet Core (EPC)) is based on best-effort/Internet links, its quality cannot be guaranteed. As a consequence, neither the end-user satisfaction, nor the quality of the provided services can be guaranteed. On the other hand, the quality of the Radio Frequency (RF) link, between the User Equipment (UE) and the small cell, is generally considered satisfactory, due to the short distance between UE and the small cell and the low number of mobile subscribers connected to the specific small cell.

Among the various services that are planned to be provisioned over the future 5G networks, video services are expected to be the most sensitive to network impairments, and their quality assurance is a significant factor for the wider penetration of 5G networks. In the small cell network (SCN) deployments, the mobile subscriber may experience degraded quality of the delivered service mainly due to the unreliable and unmanaged backhaul link. Thus, it has created the need by the mobile operators to consider Quality of Experience (QoE) aspects within the 5G architecture, allowing the monitoring, assessment and adaptation of the delivered service, aiming at the improvement of the delivered quality and the experience of the mobile subscribers.

Towards envisaging an appropriate in-service QoE assessment solution within the 5G architecture, this paper proposes a novel video quality assessment method, which addresses the quality degradation, introduced by a potential bottleneck of the small cell backhaul. The proposed method is based on a novel usage of the structural similarity (SSIM) index, as a Reduced Reference (SRR) metric [6], which has been implemented as a VNF, specially tailored for the needs of a small cell network. The advantage of the proposed method is that the complex and power consuming process of video quality assessment is performed at the edge of the network, and not at the UE itself, thus significantly reducing the impact into UE's battery life. Nevertheless, it is equivalent to the corresponding video quality assessment at the UE, because, as earlier explained, the main reason for video quality degradation in 5G small cell architectures is due to the unreliable backhaul link over the Internet, and not on the RF link between the UE and the small cell.

For the implementation, test and evaluation of the proposed video quality assessment method, an LTE infrastructure has been used, based on OpenAirInterface [7] hardware. It comprises of an EPC and an e-Node B, acting as a small cell access point, including of course a UE. This experimental infrastructure has been further enhanced with the appropriate IT infrastructure, which hosts the VNF that implements the SRR metric as a Service, as detailed explained in section IV. The implementation of SRR as a Service (SRRaaS), offers to the mobile network operators the capability to efficiently manage the network resources, by allocating only the ones that are necessary to maintain a specific level of user satisfaction.

The rest of the paper is organized as follows: Section II presents the general Network Function Virtualization architecture and how it can be applied to mobile networks and more specifically in small cell networks. It also refers to the individualities, when a virtualized execution platform is inserted just next to the small cell i.e. the unreliable backhaul link and the GTP re-encapsulation process that is required. Section III describes in details the proposed SRRaaS method, how the video quality is calculated and its relation to SSIM. Section IV describes the experimental testbed, which is based on an LTE platform enhanced with NFV capabilities and presents the GTP packet manipulation method that was used. Section V provides the experimental performance evaluation of the proposed method, and tests the ability of SRRaaS to monitor the video quality degradation, when the backhaul link is congested. Finally, section VI concludes the paper.

II. Virtualisation in Small Cell networks

The NFV architecture [8] is shown in Fig. 1 and comprises of major components – including virtualized network functions (VNFs), NFV Infrastructure (NFVI) and NFV management and orchestration (MANO), the last falling outside the scope of this paper.

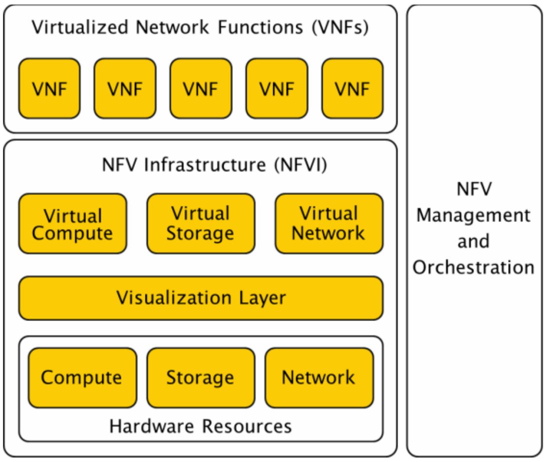

Fig. 1. NFV Architecture

NFVI is composed of NFV infrastructure points-of-presence (NFVI-PoPs), which host the VNFs and include resources for computation, storage, and networking. NFVI creates a virtualization layer that rests right above the hardware and abstracts the HW resources, so they can be logically partitioned and provided to the VNFs to perform their functions. NFVI networks interconnect the computing and storage resources contained in an NFVI-PoP.

Unlike other virtualization use cases, applying NFV techniques to a small cell base station still necessitates a physical network function (PNF), that is responsible at least for supporting the RF functions of the base station. This requires a different architecture and ETSI-NFV and 3GPP [5] have created an architectural framework that support combined PNF and VNF systems, a simplified version of which is shown in Fig. 2. According to Fig. 2, the small cell functionality is decomposed into physical (PNF) and virtual (VNF) network functions.

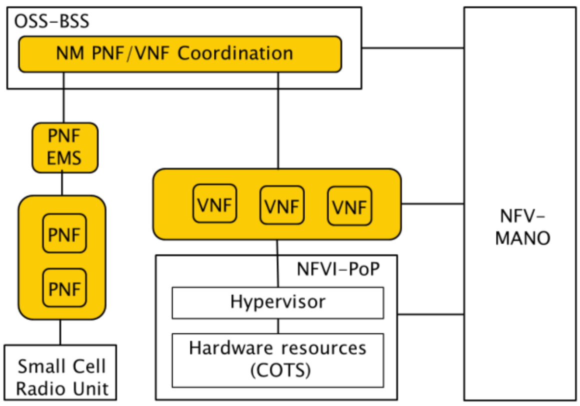

Fig. 2. Architectural framework for combined PNF and VNF systems.

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The application of the above architectural framework to small cells has been analyzed by SCF through several small cell virtualization use cases [2], which examine the impact and benefits of virtualizing different layers and functions of a small cell. To facilitate the analysis, a small cell is split into two components; a Central Small Cell where functions are virtualized (VNF), and Remote Small Cell with non-virtualized functions (PNF), (see Fig. 3). According to this approach functions are split in two types:

- Functions which are within L1, L2 and L3 layers, referred as PHY (Physical), MAC (Media Access Control), RLC (Radio Link Control), and PDCP (Packet Data Convergence Protocol) [5].
- Functions that are not part of L3, L2 or L1 and include service functions (such as content caching, firewalls, QoS monitoring etc.) and small cell management functions, such as RRM and Self Organizing Network (SON) features).

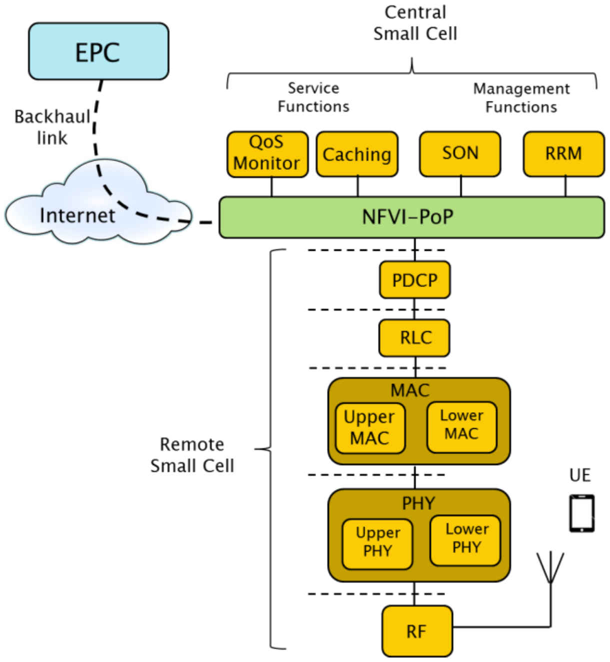

Fig. 3. Virtualisation of a Small Cell and split of functions between PNF and VNF

The virtualization of small cell layers and functions are investigated with a bottom-up approach, where gradually more functions are moved from the remote small cell to the central small cell. The split points are shown as dashed lines in Fig. 3. For example, PDCP may be either a PNF running in Remote Small Cell or a VNF running in the NFVI-PoP of Central Small Cell. A key differentiator for the split points is the front haul link (i.e. the link between the Central and the Access Small Cells) in terms of latency and bandwidths requirements.

In a more general architecture, there may be many NFVI-PoPs distributed among the EPC and the Central Small Cells. Also, a VNF may be comprised of more than one components (Virtual Network Function Components-VNFCs). Depending on the VNF and the network topology, the VNFCs may be instantiated within the same NFVI-PoP or in different ones.

Furthermore, among the ETSI NFV ISG [9] 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. Of course, the automatic deployment of a large number of VNFs comprised of many VNFCs requires an orchestrator to manage the location of the deployment of the VNFCs and their network interconnections.

The approach, followed by this paper involves the deployment of the widely used novel SSIM [10] Reduced Reference (SRR) metric as a Service (SRRaaS) [6] by implementing it as a Virtual Network Function as a Service (VNFaaS), in a small cell network. As explained in section III, the proposed video quality assessment metric (SRRaaS), is a VNF, which can be decomposed in three functions, i.e. it comprises of three VNFCs, one of which is instantiated in the NFVI-PoP of the EPC, while the other two are instantiated in the NFVI-PoP of the Central Small Cell.

The target of a video quality assessment metric is to measure the video quality at the consumer's terminal, which in this case is the UE. Actually, SRR metric can run in a UE. However, the SRR running in the UE would consume much of the battery power because, as all video processing methods, it requires a lot of CPU power. Furthermore, it is not necessary to run SRR in the UE, because the main reason for quality degradation in SCNs is the backhaul link (which is over the Internet) and not the RF link between the SC and the UE. Thus, the measurement of the video quality in the SC is the same as in the UE. This makes the proposed method a useful tool for video service providers and mobile network operators that wish to provide video services over small cell networks, in order to assess the quality of the provided services and probably take appropriate measures.

The insertion of an NFVI-PoP between the EPC and the Central Small Cell has to deal with the GPRS Transport Protocol (GTP) [12], [18]. The traffic exchanged between the EPC and the Small Cell is encapsulated using GTP, for the reasons of multiplexing and scalability. So, when an NFVI-PoP is inserted in this link, it has to perform both the GTP de-capsulation and re-encapsulation processes of the IP packets travelling from EPC to small cell and reverse. The de-capsulation is required to retrieve the pure IP packets, which are travelling from the EPC or the small cell to the NFVI-PoP, while the re-encapsulation is required for the pure IP packets from the NFVI-PoP to the EPC or the small cell. The implementation of the GTP en/de-capsulation processes, for the needs of this paper, is described in section IV.

III. The Proposed SRRaaS

The work in this paper extents the applicability of the SRR metric [6] within the 5G architecture, following the VNF as a Service Paradigm. The SRR modifies the full reference SSIM metric [10] to a reduced reference one, which is suitable to be applied on 5G mobile networks, following the small cell deployment architecture.

The SSIM is a full reference metric for measuring the structural similarity between two image sequences, exploiting the general principle that the main function of the human visual system is the extraction of structural information from the viewing field. If x and y are two video signals, then *SSIM* is defined as:

$$SSIM(x,y) = \frac{(2\mu_x \mu_y + C_1)(2\sigma_{xy} + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)(\sigma_x^2 + \sigma_y^2 + C_2)} \quad (1)$$

where μ_x, μ_y are the mean of x and y, σ_x, σ_y, σ_{xy} are the variances of x, y and the covariance of x and y, respectively. The constants C_1 and C_2 are defined as:

$$C_1 = (K_1 L)^2 \; C_2 = (K_2 L)^2 \quad (2)$$

where L is the dynamic pixel range and $K_1 = 0.01$ and $K_2 = 0.03$, respectively.

The SSIM index between the original video sequence VS_o (at the EPC) and the target video sequence VS_t (that arrives at the Central Small Cell) can be calculated using equation (1), where x is VS_o, y is the VS_t and $SSIM_{ot}$ is their SSIM(x,y) index.

The SRRasaS method is described in Fig. 4, where an initial $SSIM_{ow}$ value is evaluated at the EPC, 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. $SSIM_{ow}$ can be calculated from equation (1), by substituting x with VS_o and y is VS_w In this respect, $SSIM_{ow}$ is :

$$SSIM_{ow} = SSIM(VSo, VSw) = \\ = \frac{(2\mu_{VSo}\mu_{VSw} + C_1)(2\sigma_{VSoVSw} + C_2)}{(\mu_{VSo}^2 + \mu_{VSw}^2 + C_1)(\sigma_{VSo}^2 + \sigma_{VSw}^2 + C_2)} \quad (3)$$

and refers to each frame. The value of $SSIM_{ow}$ can be sent to the Central Small Cell in various ways, as for example embedded in the video frame, as metadata of the video signal or being saved to a local relational database, as is the case for this paper. The database exposes a REST webservice interface, so that $SSIM_{ow}$ can be retrieved through an HTTP REST-based request initiated by the corresponding VNFC, at the Central Small Cell NFVI-PoP.

Referring to Fig. 4, an $SSIM_{tw}$ value is evaluated at the Central Small Cell, by comparing the received (target) video (VS_t) with a reference white-video pattern (VS_w), which is identical to the one used at the core NFVI-PoP.

$SSIM_{tw}$ can be calculated from equation (1), by substituting x with VS_t and y is VS_w In this respect, $SSIM_{tw}$ is :

$$SSIM_{tw} = SSIM(VSt, VSw) = \\ = \frac{(2\mu_{VSt}\mu_{VSw} + C_1)(2\sigma_{VStVSw} + C_2)}{(\mu_{VSt}^2 + \mu_{VSw}^2 + C_1)(\sigma_{VSt}^2 + \sigma_{VSw}^2 + C_2)} \quad (4)$$

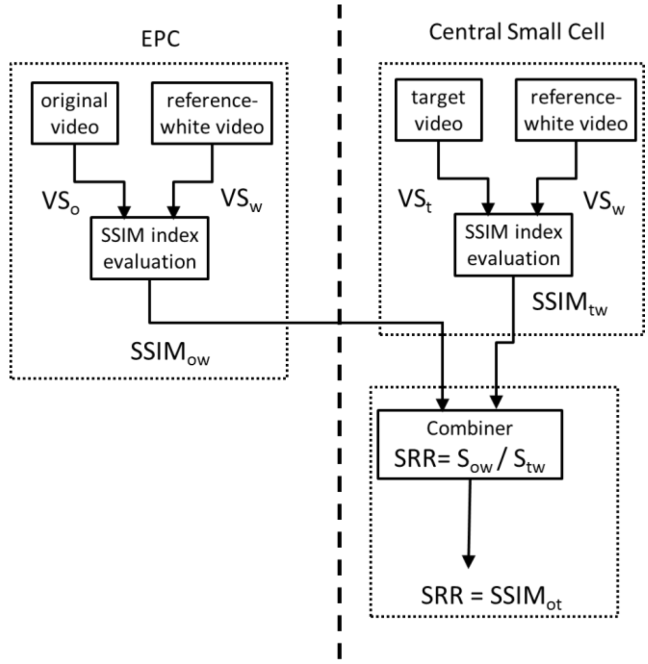

Fig. 4. SRRaaS video quality evaluation method using a white video pattern as reference at both the EPC and the Central Small Cell

In [6] it is shown that the ratio of 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 target video sequences $SSIM_{ot}$. In this respect :

$$SSIM_{ot} = (SSIM_{ow} / SSIM_{tw}) \quad (5)$$

Equation (5) shows that the video quality can be assessed at the small cell using the proposed SRaaS method.

The Spearman Rank Order Correlation Coefficient (SROCC) and the Pearson's Linear Correlation Coefficient (LCC) are computed between the objective scores and the subjective scores. Table I shows the performance of the proposed SRR model against other VQA methods, both FR and RR, in terms of the SROCC and LCC.

TABLE I
COMPARISON OF THE PERFORMANCE OF VQA ALGORITHMS LCC AND SROCC

VQA Method	Type	LCC	SROCC
RR-LHS [13]	RR	0.4557	0.4082
J.246 [14]	RR	0.4488	0.4157
PSNR	FR	0.5493	0.4585
Yang's RR VQA [15]	RR	0.5654	0.5366
VSNR [16]	FR	0.6216	0.6460
Proposed SRR Method	**RR**	**0.6260**	**0.5862**
VQM	FR	0.6459	0.6520
SSIM	FR	0.6656	0.6514
RR metric [17]	RR	0.7567	0.7486

According to Table I, the accuracy of the proposed SRR method is performing better than the RR VQA methods RR-LHS [13], J.246 [14], Yang's RR VQA [15] both in terms of LCC and monotonicity (SROCC), except from RR metric [17], which provides better results. Similarly, the accuracy of the proposed SRR method is better than the PSNR and VSNR full reference VQA methods in terms of LCC, while it is slightly lower than the performance of VQM and SSIM index, as expected, due to the reduce reference nature of the proposed methodology. In terms of monotonicity (SROCC), the proposed method performs better than the PSNR, but lower than the rest VQA methods, without however significant deviating from their performance range.

Regarding alternative methods, the RR VQA metric proposed in [5] introduces significant complexity in the evaluation process, whereas the proposed SRR method inherits the complexity of SSIM, which is relatively lightweight. Concerning the second proposed No-reference method is inferior to FR VQA metrics in correlation to subjective test results. Whereas, in the proposed method we have achieved FR VQA performance using a RR method. The SRR metric is described in detail in [6], as an extensive study on the performance comparison to other metrics reduced, or full reference ones.

IV. EXPERIMENTAL TESTBED

This section describes the experimental testbed that was implemented for the validation of the proposed SRRaaS using real-time video streaming. The testbed, as Fig. 5 shows, implements a fully operational LTE mobile network domain and it consists of an EPC, a small cell, a UE, two NFVI-PoPs and a video server.

The LTE network is built upon OpenAirInterface (OAI) [7] wireless technology platform. The OAI EPC software runs on a 64 bit x86 based computer, while the small cell is implemented using a B210 Ettus card, installed on a similar computer, running the appropriate OAI eNode B software, which for our case is acting as the Remote Small Cell. The UE is based on a laptop equipped with 4G LTE USB Adapter, which includes a USIM card with the appropriate keys stored in it, so that the UE can be authenticated by the EPC. The two computers (EPC and small cell) are interconnected over an S1 interface [11], which provides all the control signaling and data transport between EPC and eNode B.

Referring to Fig. 5, the first NFVI-PoP is located between the video server and the EPC and the other is the Central Small Cell NFVI-PoP, located between the EPC and the Remote Small Cell. The virtualization platform of both the NFVI-PoPs is supported by the Openstack open source cloud computing platform. The release used was the Liberty candidate, which was the latest stable version during the time of the experimental tests.

Both NFVI-PoPs 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 one VNFC to the next) and finally to the UE. The video server in the testbed hosts the video files to be tested at their original encoded format. In order to stream the video files through the network and also adapt their bit rate to the desired level, a vTranscoder is instantiated at the EPC NFVI-PoP. The vTranscoder implementation is based on the widely used FFMPEG [19] and is instantiated as a VNF in the EPC NFVI-PoP.

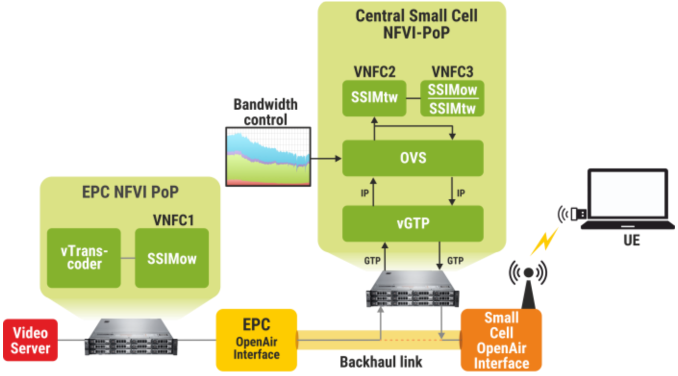

Fig. 5. An overview of the experimental testbed.

The implementation of the proposed SRRaaS method is split into three VNFCs, distributed between the two NFVI-PoPs : The first VNFC1 Fig. 5 instantiates the calculation of the $SSIM_{ow}$ (as explained in section III) at the EPC NFVI-PoP. It also stores the calculated values in a local relational database (not shown in Fig. 5 for simplicity reasons). The second VNFC2 instantiates the calculation of the $SSIM_{tw}$ (also see section III) and is located at the Central Small Cell NFVI PoP. The third VNFC3 calculates the SRR as the ratio $SSIM_{ow}/SSIM_{tw}$ for each frame. This VNFC is also responsible to HTTP REST-based request to the relational database, where the values of $SSIM_{ow}$ are stored. It is located at the Central Small Cell NFVI- PoP, as well. The proposed method provides a description of a QoE VQA assessment as a virtualized network service. The proposed VNF already provides QoS and QoE feedback, and can be complimentary to any system that provides multimedia content and wants to have additional QoE relevant input from the backhaul network. The SRRaaS can be deployed in a lightweight virtual machine, requiring at least 512 MB of memory and 1 virtual CPU, as it is built on top of FFMPEG. However, if the workload is increased significantly, it would require a larger amount of resources, to maintain a satisfactory quality of operation.

In order to perform the tests, a mechanism to vary the bandwidth of the backhaul link (and thus its quality) is required. For this reason, an Open vSwitch (OVS) is deployed in the testbed, as shown in Fig. 5. OVS is a virtual switch, licensed under the open source Apache 2.0 license, and is very suitable for virtualization purposes. OVS is able to perform many network functions, one of which is the control of the bandwidth of the IP traffic among its ports. An OVS was installed in the Central Small Cell NFVI PoP, controlling the traffic between the vGTP and the VNFCs. The deployed OVS was able to receive commands through OpenFlow protocol [20]. So, through OpenFlow commands to the OVS, it was possible to emulate conditions, where the backhaul link was congested and there was limited bandwidth for the video service, causing its quality degradation.

In the typical LTE architecture, the traffic exchanged between the EPC and the Small Cell, either data or control

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signals, is encapsulated using the GPRS Transport Protocol (GTP), as previously explained. On the other hand, the SRRaaS as well as the OVS require pure IP packets, so it is necessary for the traffic to be de-capsulated from its GTP headers and then forward the inner IP packets, which contain the actual video service data, to the upper modules. For the needs of the paper, a vGTP decapsulation and re-encapsulation software has been implemented, running on top of the widely used packet processing library PF_RING [21]. The software is running as a VNF, in the Central Small Cell NFVI-PoP forwarding the traffic both directions. It also passes through all the control and data traffic between EPC and small cell, thus preserving the connectivity of the two nodes. The video traffic is filtered from the rest of the control traffic, the GTP header is removed from the filtered packets, which are then forwarded to the OVS. There, a bandwidth regulation rule is applied and the output IP traffic is forwarded to the VNFC2 for calculating the $SSIM_{tw}$ value. The bandwidth regulated IP traffic, is sent back to the vGTP through OVS, where they are re-encapsulated with the valid GTP header and further on forwarded to their original path, to arrive at the UE. As the decapsulation and re-encapsulation operations can introduce a penalty to the performance of the system, they are performed in a parallel manner to the rest of the process. The control and the rest of the traffic are forwarded using the zero-copy PF_RING library, and only the video service packets are copied to memory, as they need to be further processed by a GTP agnostic mechanism. The GTP header storage for the re-encapsulation is considered insignificant as the GTP header, merely allocates 8 bytes to the memory.

The functionality provided by the vGTP is vital to the proposed framework, as it handles GTP traffic and delivers it in a valid IP format to the SRRaaS VNFCs to process it. The vGTP enables the integration of the Small Cell architecture and environment into a multimedia-over-IP environment seamlessly, by handling the Small Cell GTP traffic.

V. Performance Evaluation of SRRaaS

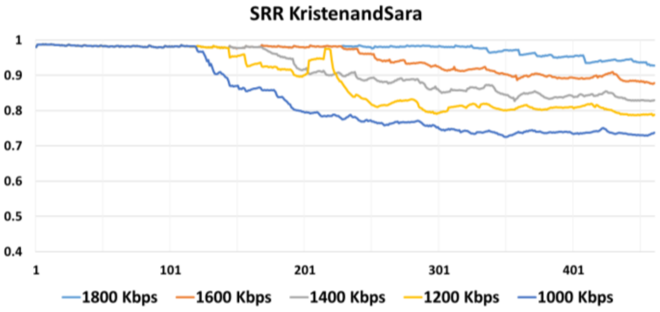
The purpose of this section is to test the capability of the proposed SRR method to detect the degradation of the video quality, when the backhaul link becomes congested and its bandwidth is restricted.

For the experimental needs of this paper, two reference video signals were selected: the KristenandSara and the BasketballDrill sequences, which can be found from database [22]. They were selected as representative ones for the two extreme cases in video content categorization: the former with low spatial and temporal activity (KristenandSara, a talk show) and the latter with high activity (BasketballDrill).

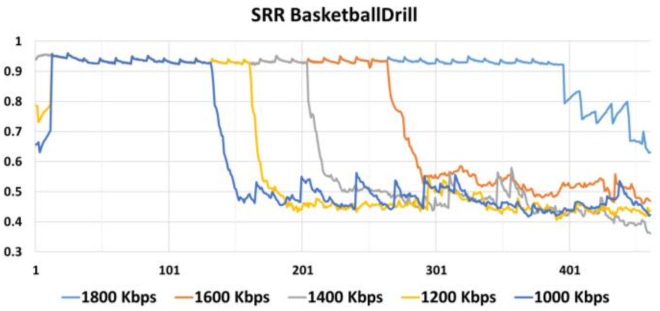
The two reference videos were stored in the video server of the testbed. The vTranscoder transcoded each video sequence to MPEG-4 format with bit rate of about 2.000 Kbps. The transcoded videos were considered as the reference signals for the video quality assessment.

For each video, the vTranscoder initiated a unicast UDP streaming over the experimentation testbed with destination IP, the IP address of the UE. The video stream passed through all the VNFCs described in section IV, where the appropriate calculations were performed. Finally, the value of SRR was calculated for each frame. The unicast streaming was repeated 5 times with the same bit rate (2.000 Kbps) for each video and each time a different backhaul bandwidth was set to the OVS, through OpenFlow commands. For the experiments, the bandwidth ranged from 1800 Kbps to 1000 Kbps at a step of 200 Kbps.

The results are shown in Fig. 6 (a) and (b) for KristenandSara and BasketballDrill, respectively. Fig. 6 shows a plot of SRR vs the sequence number of the frames, for various values of the bandwidth for the backhaul link.



(a)



(b)

Fig. 6. SRR variation vs frame sequence number without source adaptation for videos (a) KristenandSara and (b) BasketballDrill for various values of the backhaul bandwidth.

From Fig. 6 it is evident that after a short delay, which is explained in the following, the video quality is reduced, when the backhaul link is degraded. In the case of low spatial and temporal activity, Fig. 6 (a) shows that the quality is associated to the bandwidth reduction. For example, the SRR drops to 0,9 for bandwidth 1.800 Kbps, while it drops to 0,7 for bandwidth 1.000 Kbps, i.e. the less the bandwidth the less is the quality of the video. However, in the case of high activity video, Fig. 6 (b) shows that the quality drops significantly, without being linked to the bandwidth reduction.

This is due to the different statistical significance of each frame between the two test signals in the decoding process. More specifically, for low dynamic video signals, each frame differ very little from the next one, which results to very small residual information. Thus the loss of such a frame does not affect significantly the decoding process and thus the quality is degraded gradually (in an analogous manner to the decrease of the backhauling bandwidth). However, in the case of high dynamic video content, each video frame contains significantly

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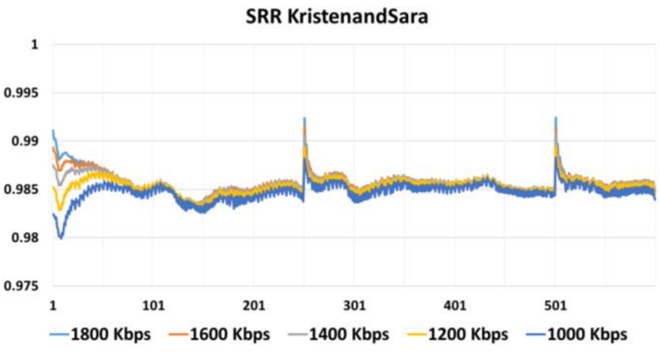
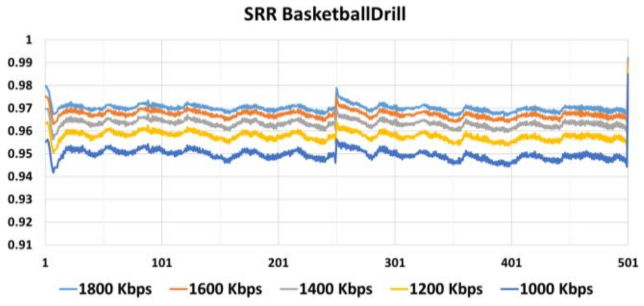
higher residual information, which means that it is much more important for the proper deciding process. Thus, a loss of such a frame, which contains significant residual information, affects seriously the decoding process, causing error propagations and decoding artifacts that cause the quality to drop very fast.

From both Fig. 6 (a) and (b) it is evident that initially, and although the bandwidth reduction command has been applied to the OVS, the video quality remains high and it drops after a delay of a few hundreds of frames. This is because the OVS follows the Leaky Bucket algorithm [23] to limit the bandwidth. This means that there is a buffer which receives the IP packets to be sent and forwards them to their destination at a constant bit rate, determined by the bandwidth limit. At the beginning, while the buffer is not full, all IP packets received at the buffer are forwarded to their destination. So, there is a short time interval (until the buffer is full) where the bandwidth limitation is not applied (no packets are dropped) and SRR remains unaffected. After some time (or equivalently some frames) the buffer becomes full and bandwidth decreases, causing the gradation of the video quality. It is evident that the lower the bandwidth, the shorter is the time required to fill the buffer, as verified in Fig.6.

Of course, in a typical deployment, the video quality would not be allowed to drop that much and a mechanism of source rate adaptation, loss protection (e.g. FEC) or error concealment techniques would be applied, to keep video quality degradation as small as possible. In order to adapt to such an event, further experiments were performed, in the presence of a source rate adaptation mechanism through a transcoder. So, for various backhaul bandwidths ranging from 1800 to 1000 Kbps, the initial video source rate of 2000 Kbps was transcoded down to the corresponding bit rate to match the available bandwidth. The results are shown in Fig. 7 (a) and (b) for KristenandSara and BasketballDrill, respectively. Fig. 7 shows a plot of SRR vs the sequence number of the frames, for various values of the bandwidth for the backhaul link, when the video rate matches the available bandwidth. From figures a and b it is evident that the video quality is slightly degraded and in the case of KristenandSara remains higher than 0.98, while for BasketballDrill is higher than 0.94.



(a)



(b)

Fig. 7. SRR variation vs frame sequence number with source adaptation for videos (a) KristenandSara and (b) BasketballDrill for various values of the backhaul bandwidth.

Resuming, the experimental results show that the proposed method is able to detect successfully the video quality reduction when the backhaul link is degraded. Another conclusion is that the video quality reduction is associated to the bandwidth variation for low activity videos, while it is not linked to the bandwidth variation, for high activity videos. Finally, the proposed method achieves very small video quality degradation, when video source rate adaptation mechanisms are applied.

VI. Conclusions

The work presented in this paper is focused on the implementation and performance evaluation of a novel video quality assessment method, which is applicable to next generation (5G) mobile networks, following the small cell deployment architecture. The proposed SRR method is an extension of the widely used SSIM index to a reduced reference model and expands the applicability of SSIM index as a VNF. An LTE-small cell experimental platform has been implemented, to test and evaluate the performance of the proposed method. The testbed has been enhanced with two NFVI-PoPs, which host the three VNFCs, out of which the SRR is comprised. The experimental results show that the proposed method can detect successfully the impact of the backhaul link degradation on the video quality. The proposed SRR method can be offered as a Service to the mobile networks operators and it provides them with a tool to monitor their customers' satisfaction. An additional advantage of the proposed method is that the complex and power consuming process of video quality assessment is performed at the edge of the network, and not at the UE itself, thus significantly reducing its power consumption.

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