Measurement of Quality of Service of Real-time Video Transmissions

Annepu Sai Sriharsha[#1], Ananth Pranihith[#2], Prasanth. B[#3], Sumitro Bhaumik[#4]

[#]Department of Computer Science and Engineering,

Indian Institute of Technology, Kharagpur-721302, India

{[1]annepuharsha, [2]ananthpranihith, [3]prasanth.b, [4]sumitros}@gmail.com

***Abstract*—This paper presents the results of the analysis of the quality of service and buffer occupancy measurements for real-time video transmissions on IP networks. IP networks are designed for non real-time traffic but now are being used for various types of multimedia transmissions, like video streaming, multiplayer gaming, which are inherently different from non-real time traffic with different characteristics and requirements. QoS(quality of service) requirements are strict and important in the case of multimedia applications. This paper considers one example of multimedia transmissions - real-time video traffic and analyzes the changes in the values of video quality metrics - peak signal-to-noise ratio (PSNR), structural similarity (SSIM), visual information fidelity (VIF) with varying loads of real-time and non real-time flows in the network. Mininet, an emulator for deploying networks on a single virtual machine, is used for simulating a network on which the readings were recorded. The buffer occupancy at the immediate switches is also measured in varying load conditions.**

Keywords—Real-time video traffic, Buffer Occupancy, PSNR, SSIM.

I. INTRODUCTION

Quality of Service (QoS) is defined by the International Telecommunication Union (ITU) as totality of characteristics of a telecommunication/networking service that bear on its ability to satisfy stated and implied needs of the users of the service [1]. It is a measure of the overall performance of a computer network as seen by the users of the network. The concept of treating all the network traffic equally does not provide any guarantees on delay, jitter or reliability. In such a situation, one bandwidth-intensive application can affect the performance of all other applications. QoS aims at providing users/applications preferential service in accordance with their requirements. Multimedia traffic, like Voice over IP (VOIP), video conferencing, live video streaming and online multiplayer gaming, fall under the category of applications requiring preferential service. Multimedia applications have stringent QoS requirements which need to be satisfied. IP video traffic accounted for 70% of all the IP traffic in 2015 and is expected to be 82% of all the IP traffic by 2016 according to the Cisco Virtual Networking Index [2]. The amount of real-time video streaming has skyrocketed in the recent years with the world's biggest events like Olympics, World cups being streamed live to billions. This resulted in lot of study and research in the area of video optimization so as to reduce the bandwidth required for the transmissions of live video. To build such technologies which can optimize video traffic, it is important to quantify the QoS parameters for such type of real-time video traffic. This paper presents the measurements of important video quality metrics obtained over RTP transmissions of video under varying load conditions in a network simulated using Mininet.

II. BACKGROUND

There exist different kind of metrics that have been designed for assessing the quality of video which is transmitted over IP networks. Most of these metrics can be classified into one of the two types - No-reference metrics and Full-reference metrics. No-reference metrics just take in one video as an input and try to assess its quality, which can be less accurate due to the lack of comparison with a reference video. Whereas, full-reference metrics take in one original (reference) video and also another video that is to be compared with earlier one. This kind of comparison with an original video is done frame-by-frame and hence requires higher amount of time for computation but provides more accurate results.

Video quality assessment metrics can also be categorized into subjective and objective types. Subjective metrics take the help of human opinion scoring schemes for measuring the quality level of a video which is the most reliable way of evaluating the video quality. However, they are more expensive and time-consuming. On the other hand, objective metrics use mathematical models to estimate the quality level of the video and these models try to approximate the results produced by the subjective human evaluation methods. All the video quality metrics that have been used in this paper are full-reference metrics and a brief description about each of them is given below.

A. Peak Signal-to-Noise Ratio (PSNR)

It is one of the oldest full-reference metric and also widely used objective video quality metric. A PSNR value is computed in between every frame of the original video and the corresponding frame of the processed video (whose quality is to be assessed). The average of these values of all the frames is given as a PSNR metric value between the two videos. A higher value of PSNR indicates a better quality. Though it is found to work well for many applications, it does not always provide a good approximation of how humans would perceive the quality and thereby, is not always consistent with the subjective quality assessment.

PSNR-HVS and PSNR-HVS-M are modified forms of PSNR that take into account contrast sensitivity function. PSNR-HVS-M also considers the between-coefficient masking of DCT basis functions. These modified forms of PSNR are found to perform better than many of the existing objective measurements in approximating the subjective methods of estimating the video quality.

B. Structural Similarity (SSIM)

This is also a full-reference video quality metric which is based on degradation of structural information in the image. Unlike many other objective quality measuring metrics which depend on the absolute error between the distorted image and the reference image, it is a perception based model that relies on and considers that human visual system (HVS) is accustomed to extract structural information from the images. Existence of strong inter-dependencies between the pixels which are spatially closer, is the basic idea of structural information. Some of the important phenomena of perception like luminance masking and contrast masking are also integrated into this metric.

Multi-scale Structural Similarity (MS-SSIM) is an advanced form of SSIM that provides more flexibility as compared to the single-scale form, by allowing the calibration of parameters which characterize the relative significance of different scales.

C. Visual Information Fidelity (VIF)

This metric is based upon a fidelity measure which relates the quality of the test video with the amount of Shannon information that is shared between the test and the reference videos with respect to the reference video itself. It makes use of a distortion model and the Natural Scene Statistics (NSS). The value computed by this metric increases with the quality of test video and can reach a maximum value of unity.

III. Experimental Setup/ Methodology

Mininet is a network emulation orchestration system which runs a collection of end-hosts, switches, routers and links on a single linux kernel.It uses lightweight virtualization to make a single system look like a complete network, running the same kernel, system, and user code. A Mininet host behaves just like a real machine [3]. The network topology present in the Figure 1 is created using Mininet. Experiments were carried out under different load conditions created with both real-time and non real-time flows between the hosts present in the network and the video quality metrics for the RTP streamed video are obtained using the MMSPG - Video Quality Measurement Tool VQMT [4]. The real-time flows between the hosts were generated using RTP/MPEG transport streaming provided by VLC media player (version 2.2.2). Two video flows - SD, HD of different qualities were considered. SD flow corresponds to a low quality video flow. HD flow refers to a high quality video flow. Nonreal-time flows were generated using “`wget`” (file size - 140MB).

The parameters of the network under consideration and also the video under consideration are mentioned below.

A. Network Parameters

- Link bandwidth : 1.5 Mbps (all links)
- Queue size : 100 (packets)

B. Video Parameters

- Bit-Rate: SD - 1259142 bps, HD - 1925682 bps
- Frame Rate : SD - 25 fps, HD - 25 fps
- Resolution : SD - 1280x720, HD - 704x400
- Duration : SD - 10 sec, HD - 15 sec

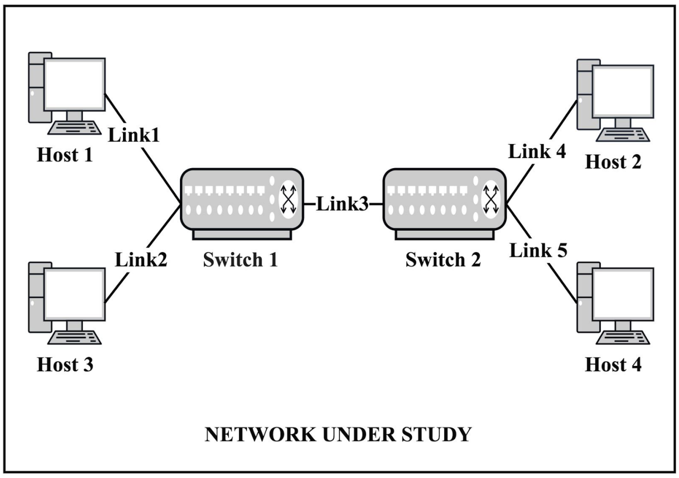


Fig. 1. Network Topology

IV. Observations/Results

Experiments were conducted to observe

1. Effect of varying number of flows in the network on the video quality.
2. In presence of two real-time video flows of different quality, difference in sufferings of the two flows.
3. Effect of scaling up the whole network - link bandwidths and the number of flows

1. Effect of varying number of flows in the network

The readings of the video quality metrics measured for the 10 second RTP video (SD) flow from host H1 to host H2, mentioned in each case are presented in Table 1. Buffer occupancy plots for all the cases are shown in Fig 2.

Case 1.1:

- Flows in the network
  - Real-time flow from H1 to H2

Case 1.2:

- Flows in the network
  - Real-time flow from H1 to H2
  - Real-time flow from H3 to H4

Case 1.3:

- Flows in the network
    - Real-time flow from H1 to H2
    - Two real-time flows from H3 to H4

Case 1.4:

- Flows in the network
    - Real-time flow from H1 to H2
    - Non-real-time flow from H3 to H4

Case 1.5:

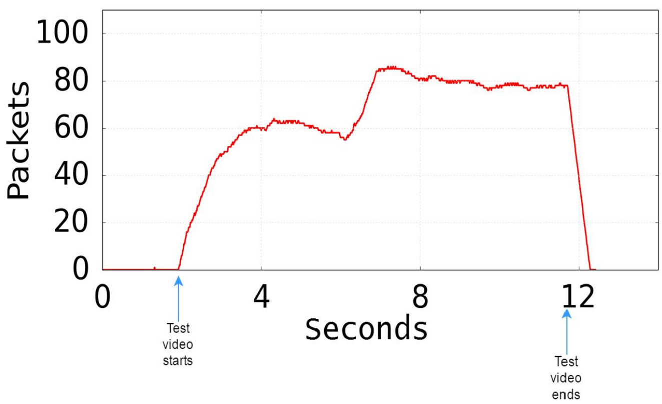
- Flows in the network
    - Real-time flows from H1 to H2, H3 to H4
    - Non-real-time flow from H1 to H2

Case 1.6:

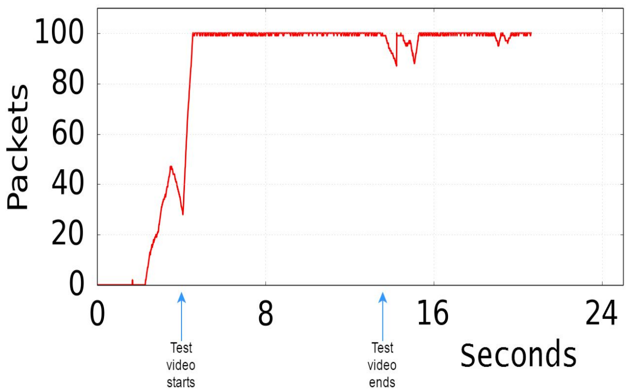
- Flows in the network
    - Real-time flow from H1 to H2
    - Two non-real-time flows from H3 to H4

Quality Parameter	SSIM	MS-SSIM	VIFP	PSNR	PSNR-HVS	PSNR-HVS-M
Case 1.1	0.917780196	0.52272604	0.2298979	22.00248303	17.33238777	17.40683249
Case 1.2	0.387942538	0.145734749	0.074343	15.12091108	10.86377294	10.88569879
Case 1.3	0.328280538	0.137358519	0.0694367	15.34922456	11.06329288	11.08850365
Case 1.4	0.594818819	0.23696308	0.10505	16.85343017	12.51047312	12.54765605
Case 1.5	0.485109558	0.200580764	0.0957388	15.40083916	11.14612767	11.17039779
Case 1.6	0.645730121	0.328005487	0.157697	18.52884173	14.10678456	14.15624749

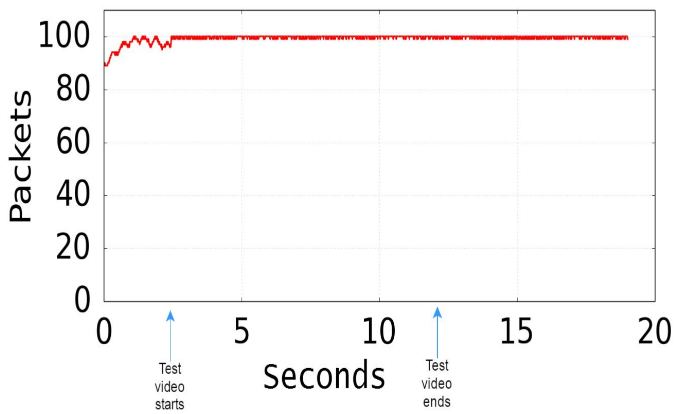
Table 1. Effect of number of flows in the network on video quality parameters



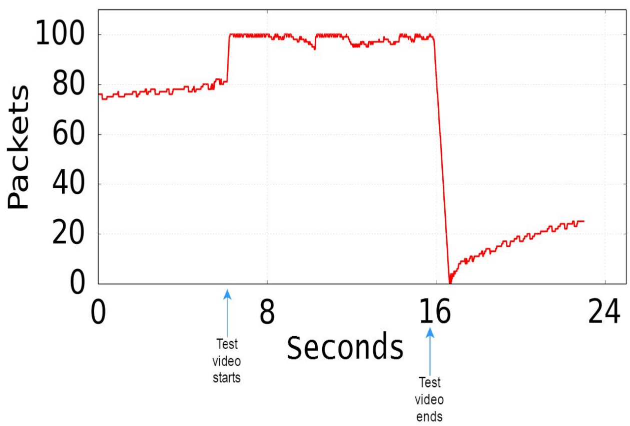
Case 1.1



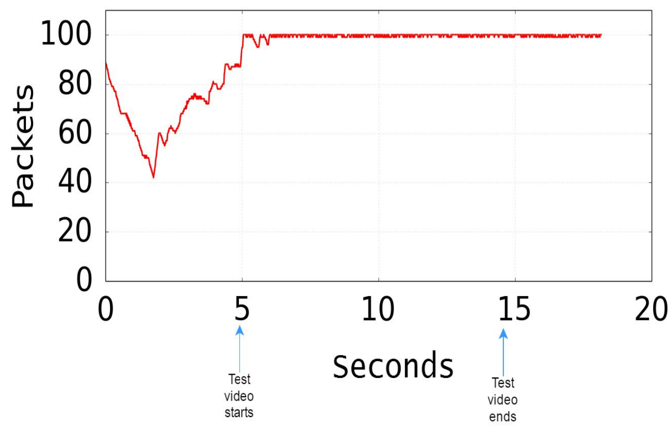
Case 1.2



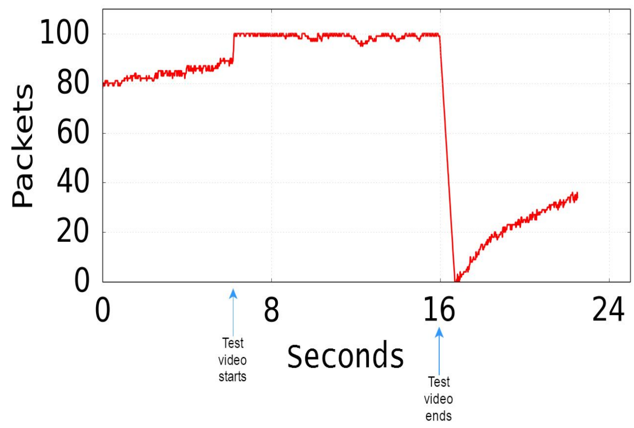
Case 1.3



Case 1.4



Case 1.5



Case 1.6

Fig 2. Buffer occupancy plots

The objective was to observe the effect of varying the number of flows on the video streaming quality. Six cases have been considered out of which the first three are involved only with real-time flows and the remaining three also include non-real time flows. In all the cases, the test video flow (10sec) is streamed from host H1 to host H2, and the corresponding received video is used for computing the video quality metric values. In case 1.1, only the test video flow is present and it was observed from its plot that the buffer is not getting occupied completely during its streaming. It is also noticeable that there is an increase in the buffer occupancy of this plot at 6 seconds, which is due to the increase in the amount of information that is being streamed at that time instant as per the requirement of video which was containing the frames that are nearly static till then. It is also observed from Table 1 that high values are being provided by the video quality metrics for this streamed video. In case 1.2, another real time flow was simultaneously streamed from host H3 to host H4. It is noticeable from its plot that the buffer is getting full due to which some packets are dropped and consequently, the values given by the metrics for the received video have decreased. In case 1.3, another real time flow was added to system and there is further decrease in the values given by some of the video quality metrics and also, the buffer is remaining completely occupied for most of the time.

In case 1.4, a non-real time flow is considered along with the test video flow. It is noted that most of the bandwidth is being utilized by the real time flow during the simultaneous transmission and the data rate of non-real time flow is decreasing to a very low value. From the buffer occupancy plot it can be observed that as soon as the real time flow starts, the buffer is getting full. As per the TCP slow start mechanism that is followed by the considered non-real time flow (‘`wget`’), there is a consistent increase in the buffer occupancy after the test video flow is streamed completely. It is noticeable that the values provided by the metrics are dropping by some extent, as compared to case 1.1 but they appear better than those of case 1.2 where there are two non-real time flows in the network.

In case 1.5, another real time flow was added to the system and it is noted that the non-real time flow is getting paused and the case has become similar to case 1.2 where there are only two real time flows, which is also evident by the closeness of values given by most of the metrics in the respective cases. In case 1.6, two non-real time flows are considered along with the real time test video flow and it was showing the same behaviour as of case 1.4, where there is only a single non-real time flow along with the test video flow. As most of the bandwidth is being utilized by the real time flow, the non-real time flows are having a minor role to play and thereby not able make any difference from that of case 1.4.

2. Comparison of sufferings in different quality videos

Two real-time video flows of different quality were streamed between the same hosts. Analysis of sufferings faced by both the flows when present simultaneously is presented in Table 2, Fig 3. SD flow indicates a low quality video flow. HD flow indicates a high quality video flow.

Case 2.1:

- Flows in the network
  - SD flow from H1 to H2

Case 2.2:

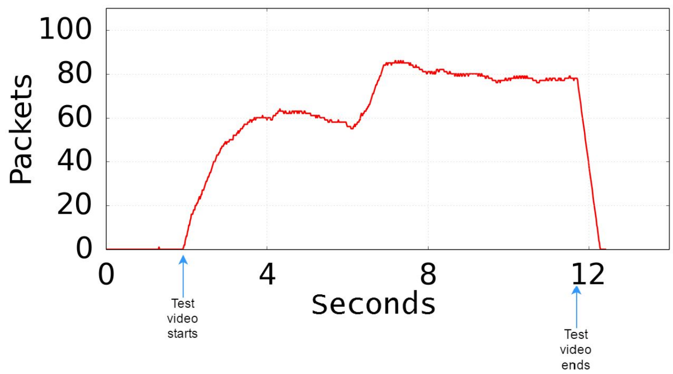
- Flows in the network
  - HD flow from H1 to H2

Case 2.3:

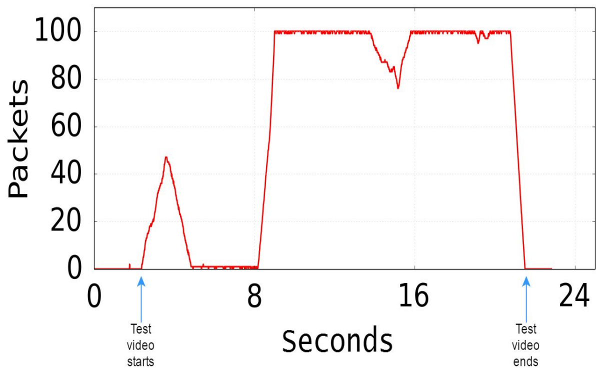
- Flows in the network
  - SD flow from H1 to H2
  - HD flow from H1 to H2

Quality Parameter	SSIM	MS-SSIM	VIFP	PSNR	PSNR-HVS	PSNR-HVS-M
Case 2.1 - SD	0.921264678	0.540367658	0.252326975	23.6110613	19.06344185	19.13767072
Case 2.2 - HD	0.775944291	0.54508998	0.265666608	25.78035021	21.62169111	21.85715639
Case 2.3 - SD	0.513803945	0.18967966	0.0845342345	16.09731182	11.74910194	11.78915763
Case 2.3 - HD	0.686145394	0.318294203	0.212758384	23.1760836	19.56299192	19.6250452

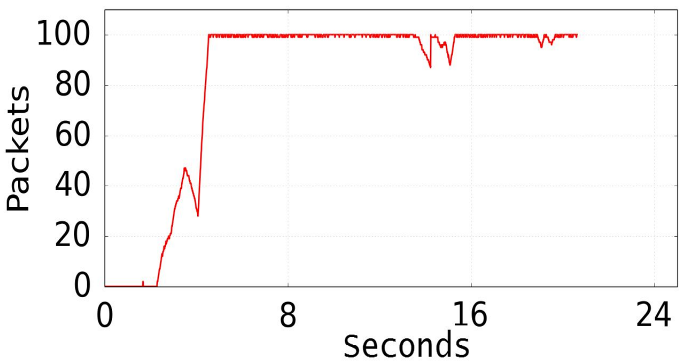
Table 2. Comparison of suffering in two different quality videos



Case 2.1



Case 2.2



Case 2.3

Fig 3. Buffer occupancy plots

The objective was to observe the sufferings of the two videos of different qualities when they are streamed simultaneously. The low quality video (SD) and the high quality video (HD) were streamed individually in cases 2.1 and 2.2 respectively and simultaneously in case 2.3. The buffer occupancy plot in the simultaneous streaming case is a superposition of the buffer occupancy plots of the individual streaming cases. The buffer is also getting completely occupied a little earlier in the simultaneous streaming case and the packets begin to get dropped from that instant itself. As the default scheduling policy provided for a switch by the mininet was used, none of the flows receive any kind of priority and the proportion in which the packets are dropped (when the buffer at the switch is full) from the low quality video and from the high quality video is equal.

With the examination of the values obtained from the metrics for these cases in Table 2, it is noticed that the low quality flow is being penalized more as compared to the high quality flow. For example, the value of SSIM for the low quality video flow has decreased from 0.92 (during individual streaming case) to 0.51 (during simultaneous streaming case), whereas it is only decreasing from 0.77 to 0.68 for the high quality video flow. As the amount of information that is to be streamed is going to be very high for the high quality flow as compared to the low quality flow, even after losing some amount of information (packets), the high quality flow, with the remaining amount of information, is still able to maintain the quality of the received video to some extent. But the low quality flow, having lesser amount information (comparatively) to stream, is not be able to do so after the same amount of loss in the information (packets).

3. Effect of scaling

The whole network was scaled up in terms of the number of flows and bandwidth of the links. Comparison of the video quality parameters and buffer occupancy is presented in Table 3, Fig 4, Fig 5.

Case 3.1:

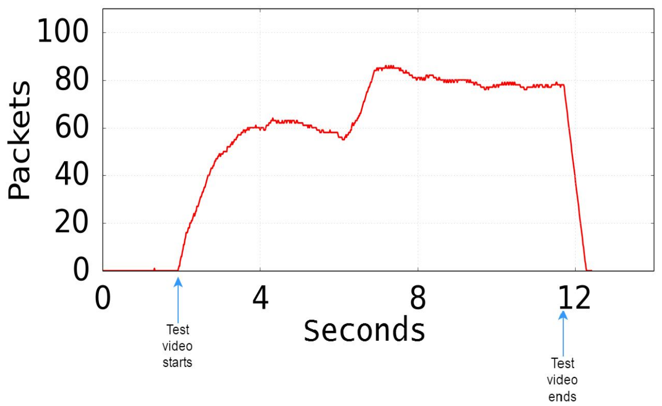
- Flows in the network
  - Real-time flow from H1 to H2

Case 3.2:

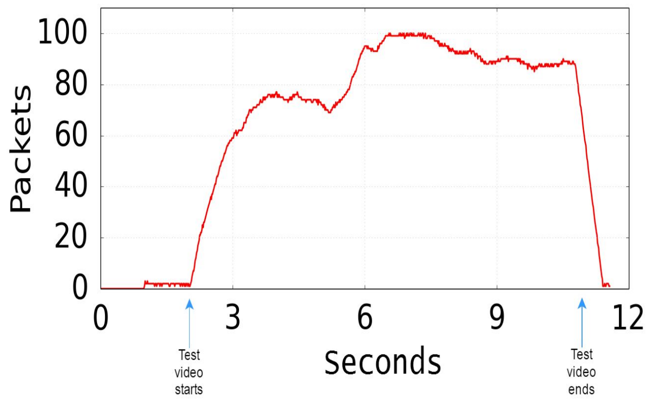
- Flows in the network
  - Real-time flow from H1 to H2
  - Non-real-time flow from H3 to H

Quality Parameter	SSIM	MS-SSIM	VIFP	PSNR	PSNR-HVS	PSNR-HVS-M
Case 3.1 - Scale x1	0.917780196	0.52272604	0.229897915	22.00248303	17.33238777	17.40683249
Case 3.1 - Scale x2	0.900188357	0.507525266	0.25180896	23.89924778	19.55711242	19.62233571
Case 3.1 - Scale x3	0.903455985	0.507495462	0.247752698	23.91299301	19.59577173	19.66693924
Case 3.2 - Scale x1	0.594818819	0.23696308	0.10504999	16.85343017	12.51047312	12.54765605
Case 3.2 - Scale x2	0.717777764	0.270300281	0.127666884	16.81691016	12.50707651	12.53787284
Case 3.2 - Scale x3	0.623537131	0.267858121	0.125002296	16.78846855	12.46047047	12.49364631

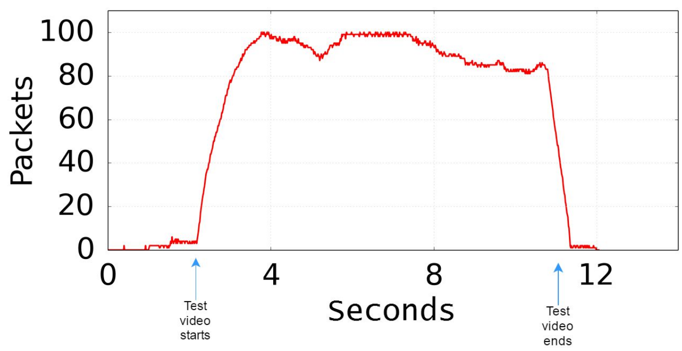
Table 3. Effect of scaling up



Scale x1

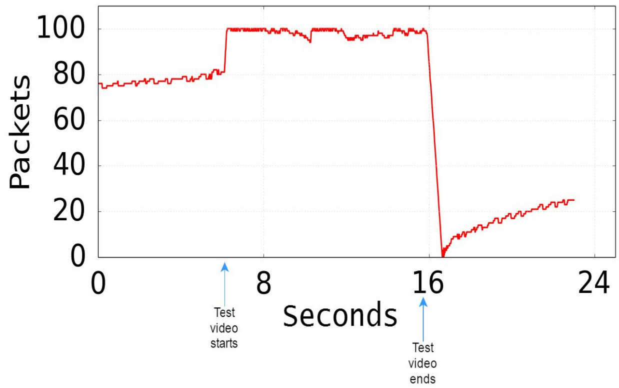


Scale x2

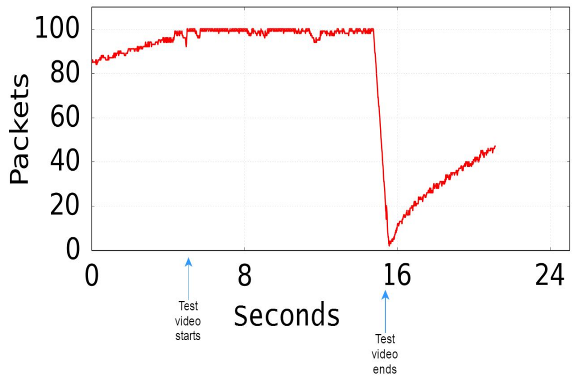


Scale x3

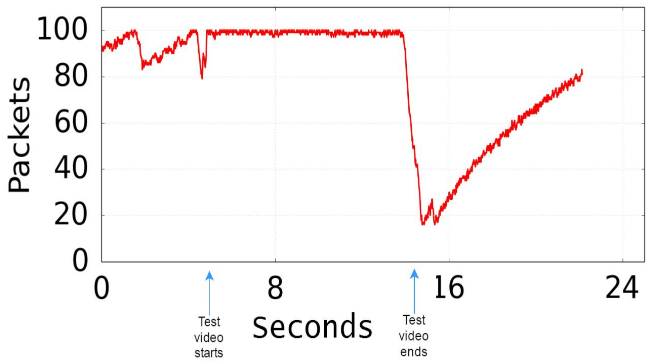
Fig 4. Buffer occupancy plots for Case 3.1



Scale x1



Scale x2



Scale x3

Fig 5. Buffer occupancy plots for Case 3.2

The objective was to analyse the level of performance of the system upon scaling. Two cases were considered - only a single real-time flow present in the network, both real-time and non real-time flows present in the network. For each of the cases the system was scaled up by increasing the number of flows and also the bandwidth of the links present in the network, up to a scaling factor of 3. The respective scaling factors for the buffer occupancy plots are mentioned near the plots. By observing the buffer occupancy plots for case 3.1, other than slight increase in the amount of buffer being occupied, there were no significant changes. It is also the same in case 3.2, but one noticeable thing in the buffer occupancy plots of case 3.2 is that, after the test video streaming gets ended at 16 seconds, there is an immediate consistent increase in the buffer occupancy which is actually due to the non real-time flows (‘`wget`’). The rate at which this rise in buffer occupancy is taking place is increasing with the scaling factor as the number of non real-time flows increase, which seems appropriate. With the examination of values obtained for different metrics in Table 3, it is observed that values are remaining almost the same as we are increasing the scaling factor for case 3.1. Also, for case 3.2, other than some slight changes in the values of SSIM, no significant variations are observed in the values provided by the other metrics.

As a whole, no remarkable changes were observed by scaling up the system (both in terms of the number of flows and the bandwidth of the links) upto a scaling factor of 3. But it might be possible that scaling by a large factor much beyond 3 would produce some significant changes, as it is usually expected that scaling up reduces the performance offered by a network.

V. Conclusion

The effect of varying the number of flows on the video transmission quality has been analyzed and it is observed that the quality of the received video is decreasing with the increase in the number of flows and the quality was also reducing by more amount when the transmission was accompanied by a real time flow as compared to the case when it was accompanied by a non-real time flow. The difference in the amount of suffering undergone by two different kinds of video flows when streamed simultaneously, has also been analyzed and it is observed that the low quality video flow was being penalized more as compared to high quality video flow. The level of performance of the system on scaling up is also analyzed up to a scaling factor of 3 and no significant changes were noticed.

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