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Sustainable Throughput – QoE Perspective

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ABSTRACT

In recent years, there has been a significant increase in the demand for streaming of high quality videos on the smart mobile phones. In order to meet the user quality requirements, it is important to maintain the end user quality while taking the resource consumption into consideration. This demand caught the attention of the research communities and network providers to prioritize Quality of Experience (QoE) in addition to the Quality of Service (QoS). In order to meet the users' expectations, the QoE studies have gained utmost importance, thus creating the challenge of evaluating it in such a way that the quality, cost and energy consumption are taken into account. This gave way to the concept of QoE-aware sustainable throughput, which denotes the maximal throughput at which QoE problems can be still kept at a desired level.

The aim of the thesis is to determine the sustainable throughput values from the QoE perspective. The values are observed for different delay and packet loss values in wireless and mobile scenarios. The evaluation is done using the subjective video quality assessment method.

In the subjective assessment method, the evaluation is done using the ITU-T recommended Absolute Category Rating (ACR). The video quality ratings are taken from the users, and are then averaged to obtain the Mean Opinion Score (MOS). The obtained scores are used for analysis in determining the sustainable throughput values from the users' perspective.

From the results it is determined that, for all the video test cases, the videos are rated better quality at low packet loss values and low delay values. The quality of the videos with the presence of delay is rated high compared to the video quality in the case of packet loss. It was observed that the high resolution videos are feeble in the presence of higher disturbances i.e. high packet loss and larger delays. From considering all the cases, it can be observed that the QoE disturbances due to the delivery issues is at an acceptable minimum for the 360px video. Hence, the 480x360 video is the threshold to sustain the video quality.

Keywords: Mean Opinion Score, Quality of Experience, Sustainable Throughput

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ACRONYMS

ACR	Absolute Category Rating
FPS	Frames per Second
ITU-T	International Telecommunication Unit, Telecommunications Sector
QoE	Quality of Experience
QoS	Quality of Service
RTSP	Real Time Streaming Protocol
HTTP	Hyper Text Transfer Protocol
MOS	Mean Opinion Score
PDH	Provisioning-Delivery Hysteresis
R_{target}	Target Throughput
QoE_P	QoE of the provisioning branch
QoE_D	QoE of the delivery branch
δ_{QoE}	tolerance between provisioning and delivery
VCEG	Video Coding Experts Group
MPEG	Motion Picture Experts Group
AVC	Advanced Video Coding
VLC	Video LAN Client
TC	Traffic Control
TCP	Transmission Control Protocol
GNU	General Public License
GUI	Graphical User Interface
UDP	User Datagram Protocol

1 INTRODUCTION

This chapter provides an overview of the entire thesis document. It focuses on the problem statement, followed by research questions, hypothesis and gives the outline for the remainder of the thesis.

1.1 Motivation

The demand for streaming of high quality videos on hand held mobile terminals with limited battery life is increasing. In order to meet the user quality requirements, it is important to maintain the end user quality while taking the resource consumption into consideration [7]. This demand caught the attention of the research communities and network providers to prioritize Quality of Experience (QoE) in addition to the Quality of Service (QoS). The newest definition of QoE is "*the degree of delight or annoyance of the user of an application service* [2]. The end user is more interested in the video quality rather than the quality of service which makes QoE interesting. The main aim of QoE is to maintain good quality while avoiding as much annoyance as possible [5]. QoE assessment is conducted close to the end user. To interpret the relation between the impairments at the user interface and the subjectively perceived QoE.

For video streaming, the quality of experience is influenced by video compression and transmission techniques. Video compression is a technique used to compress the raw videos that are to be streamed so that it consumes less resources during transmission. Video clips can be streamed on the mobile terminals using Real Time Streaming Protocol (RTSP) or Hyper Text Transfer Protocol (HTTP). RTSP streaming is based on the User Datagram Protocol whereas the HTTP streaming is based on the Transport Control Protocol.

The concept of Sustainable throughput builds on the QoE provisioning delivery hysteresis and is defined as the highest throughput that an application can use such that the disturbances, and thus any negative and typically random sidekicks on QoE are avoided [7]. It is introduced as the bit rate threshold that enables comparisons of streaming solutions in terms of QoE.

The main aim of the thesis is to determine the relationship between sustainable throughput values and Quality of Experience, through subjective evaluations using MOS (Mean Opinion Score) when network impairments are introduced while streaming videos from server to the mobile terminal over wireless and mobile links. With introducing packet loss and delay in the network, the video quality is degraded by freezes and jerks.

The focus of this work is on the end-user video quality and studying the impact of the metrics like delay and packet loss which are important for measuring the video quality performance and impact on the end users' QoE.

1.2 Aim and Objectives

The main aim of this research is to study the sustainable throughput with respect to the Quality of Experience (QoE). The work includes the following objectives.

- To understand the video Quality of Experience for encoded videos of different resolutions that are streamed over wireless and mobile network scenarios.
- To investigate the sustainable throughput values and analyze the results obtained from the experimentation using the subjective video quality assessment techniques.
- To analyze the user Quality of Experience by observing the Mean Opinion Score values.

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1.3 Research Questions

The main goal of this thesis is to find the relation between sustainable throughput values and user QoE while investigating the impact of network impairments like packet loss and delay on the test videos streamed from the server to the mobile client over Wi-Fi. The subjective ratings are obtained for the different test cases of the video streams and MOS quality assessment will be performed. The aim of this thesis is to answer the research questions listed below.

1. How is the quality of the videos of different resolutions streamed when packet loss and delay are introduced in wireless and mobile network scenario?
2. How does the packet loss and delay affect the end-user QoE of the video streams?
3. What is the sustainable throughput value in all the cases?

1.4 Methodology

This thesis mainly includes the experimentation on QoE and sustainable throughput on video streaming. A client and server were used for carrying out the experiment. Initially, a video has been streamed from server to the mobile client and the values of the sustainable throughput were determined using the subjective video quality assessment techniques.

1. In the early stage of the research, a detailed literature review is performed on the concept of sustainable throughput, provisioning-delivery hysteresis, video streaming servers and quality assessment techniques.
2. Suitable video streaming server and client is selected for streaming the videos.
3. One of the videos recommended by the standard groups is chosen for the experimentation and are taken in different resolutions.
4. Experimentation is carried out with streaming the video from appropriate streaming server from server to the client.
5. Delay and packet loss are introduced using the appropriate traffic shaper in the network

6. Streaming is done from server to the client in a controlled environment.
7. When stream is received at the client side, the application level values are noted and the user QoE for each video stream is documented.
8. Based on the final results and analysis, conclusions were drawn and recommendations are provided for the future work.

1.5 Outline of the Thesis

The remaining parts of the thesis are organized as follows: Chapter two gives the background on the concepts involved in the thesis like QoE, Sustainable Throughput, and Video Quality Assessment. Chapter three gives the review of related works. Chapter four provides the experimental setup, and tabulated results from the experiment. Chapter five will feature the analysis of the results, discussions on thesis experimental observations and answers to the research questions.

1.6 Split of Work

Two thesis topics were designed for determining the sustainable throughput values for video streaming from server to mobile client. The experimentation setup for both the theses are the same and this thesis carries out the user experiments while the other student thesis [17] analyzes the data obtained from these experiments. Though the data sources are shared, the data analysis is different for both the theses.

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Table 1.6 Split of Work

2 BACKGROUND

This chapter describes the background knowledge related to the thesis work. It provides an overview of the concepts of Quality of Experience (QoE), sustainable throughput, video streaming, video compression, and video quality assessment.

2.1 Quality of Experience

Quality of Experience (QoE) is defined as the degree of delight or annoyance of the user of an application or service. It results from the fulfillment of his or her expectations with respect to the utility and / or enjoyment of the application or service in the light of the user's personality and current state [2]. It is the overall acceptability of the application or service, as perceived subjectively by the end user. In the context of communication services, it is influenced by content, network, device, application, user expectations and goals and context of use. While the Quality of Service (QoS) deals with physical, measurable performance factors and application level factors, QoE deals with the users' assessment of the system performance. QoE assessment is conducted close to the end user in order to interpret the relationship between the impairments at the user interface and the subjective QoE [6].

2.2 Provisioning-Delivery Hysteresis

QoE ratings can be categorized as satisfaction ratings, which increase with the degree of user satisfaction or delight and dissatisfaction ratings, which grow with the degree of user dissatisfaction or annoyance. The two sides of QoE i.e. delight and annoyance coincide with the Provisioning-Delivery Hysteresis (PDH), as discussed in reference [5]. The PDH states that impacts on QoE are pretty much different to whether the QoE is built up by provisioning measures; that contribute to delight, or torn down by delivery issues; contributing to annoyance. An illustration of the PDH is provided in Figure 1.

The upper branch is the resource-related branch, which is obtained by dimensioning, and can thus be used to control the quality. This provisioning branch of the PDH follows a logarithmic relationship according to the Weber-Fechner-Law [18].

$$QoEP \sim \log(R)$$

Due to its concave shape, it is well-suited for optimizations. It indicates that the growth of QoE over additional resources is initially rather intense, but it is getting smaller with higher amount of resources. This indicates that a multiplicative increase of the throughput yields an additive QoE improvement until QoE becomes saturated. A goodput ratio, that is the ratio of the available throughput and the desirable throughput less than 1 can be implemented in a controlled manner, for instance by choosing a lower video resolution, which comes along with reduced quality [5].

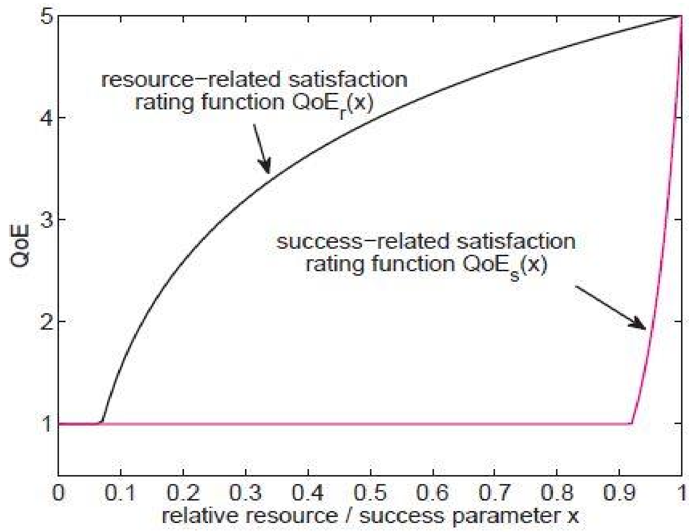


Fig. 2.1 QoE provisioning delivery hysteresis [5]

The delivery branch is related to success or failure of the service. It is observed in the context of quality distortion, such as data loss of rate. In contrast to provisioning, the delivery may not be controllable. The QoE-QoS relationship according is commonly known as IQX Hypothesis [6]. This indicates that an additive increase of the disturbance yields a multiplicative decrease of the QoE. It can be proven that, for the same amount of resources R, the provisioning branch supersedes the delivery branch [5]. Thus, it is preferable to ride the upper curve of the hysteresis i.e. the PDH provisioning branch in a controlled way, like for e.g. through adaptation of coding, resolutions and data rates than to being exposed to the PDH delivery branch due to bad network conditions and uncontrollable sidekicks on QoE.

2.3 QoE aware Sustainable Throughput

The QoE-aware sustainable throughput (ST) R_s is defined as the maximal value of the throughput R_{target} that keeps the QoE disturbances due to delivery problems at an acceptable minimum [7]. It denotes the maximal throughput at which the QoE problems can still be kept at a desired level. The concept of this QoE-aware sustainable throughput is introduced as a means to maximize QoE provisioning without deteriorating it. It is used as a basis for power efficiency and QoE comparisons of the systems. It builds on the QoE provisioning-delivery hysteresis [5]. A stochastic fluid flow model that allows for calculation of the sustainable throughput values is discussed in reference [7]. It discusses the key parameters for sustainable throughput, their impact and shows how to use sustainable throughput for comparing different mobile video streaming solutions.

$$R_s = \max\{R_{target} | QoE_P(R_{target}) - QoE_D(R_{target}) < \delta_{QoE}\}$$

where, R_{Target} is the target throughput
QoE_P is the QoE of the provisioning branch
QoE_D is the QoE of the delivery branch
δ_{QoE} - tolerance between provisioning and delivery to calculate sustainable throughput

2.4 Video Streaming

Video streaming refers to the process of videos being transferred from a source to one or more destinations. The video is usually streamed from server to clients. The video streaming is basically comprised of two fundamental activities:

1. Creation of digital content using compression techniques.
2. Content transmission over the network.

The creation of digital content is done using compression techniques, as it is expensive to transmit a raw video over the network. Streaming a raw video over the network consumes more network resources as well as storage resources [19]. Thus video compression plays a key role in the process of video streaming.

2.5 Video Compression

Video compression refers to the process, where the raw video is compressed using various compression based algorithms and mechanisms. This is done in order to reduce the size of the videos, so as to ensure transmission of videos over a network without consuming more network resources. Generally, in wired or wireless networks, an uncompressed video consumes more bandwidth and storage. Thus, increasing the end user cost with respect to bandwidth and data transmission capacity in the network. In order to maximize bandwidth utilization of the network while transmission of videos, it is indispensable to use video compression. The video compression is done in two ways, namely lossless compression and lossy compression [19].

- Lossless compression: It is a technique in which no information is lost. The lossless compression technique can reduce the size of the video to a small extent. The videos compressed using lossless techniques are not suitable to be streamed over a network due to their large size.

- Lossy compression: Is a technique that compresses a video by discarding information. Thus, in lossy compression, some information is lost which leads to reduction in the size of video along with degradation of video quality.

The main goal of video compression is to maintain a fine balance between video quality and size of the video. Several video codecs have been developed for this purpose.

2.6 H.264 Video Codec

Video compression involves two components, namely Coder and Decoder, which is called as CODEC. Video codec is a software program capable of encoding and decoding. It compresses the raw video into a small sized video that can be easily transmitted over network without consuming more bandwidth resources. Video codec is used to compress a video file where as an audio codec is used to compress an audio file. Due to increase in video communication nowadays, many efficient video coding techniques have been developed to provide high quality video streams using the available bandwidth.

H.264 is a video compression technology that was jointly developed and standardized by ITU-T Video Coding Experts Group (VCEG) and ISO/IEC Moving Picture Experts Group (MPEG). It is also known as MPEG4 part 10 or AVC (Advanced Video Coding). It is quite complex and flexible. It has been developed to cover a wide range of video streaming services from mobile video streaming to hi-definition video streaming or broadcasts. H.264 compresses the video more effectively, when compared to previous H.26x standards. It has some optimized features such as utilization of temporal and spatial correlation, usage of entropy coder, which were taken from previous encoding standards [20]. Some of the important features of H.264 video codec are as follows:

- It uses a 4x4 spatial block transform instead of 8x8 DCT as found in older video codecs.
- An additional Hadamard transform (2x2 on chroma and 4x4 on luma) can be usually performed to obtain more compression in smooth regions.
- Quarter sample motion vector accuracy.
- In-the-loop deblocking filtering.
- It houses latest enhanced entropy coding method namely Context Adaptive
- Variable Length Coding (CAVLC) and Context Adaptive Binary Arithmetic Coding (CABAC).
- Complex spatial prediction for intra frame compression has been introduced in H.264.
- Multiple reference frames, allowing up to 16 reference pictures to be used unlike previous standards where 1 or 2 reference frames were used.
- Network Abstraction Layer (NAL) which facilitates simple and effective video streaming over networks [20].

Special attention has been given by the developers to improve the robustness to data losses during video transmission. H.264 codec has three types of frames namely I-frame, P-frame, and B-frame. I-frame (Intra-frame) is independent and does not reference any other frames. P-frame (Predicted frame) is decoded predictively from the closest previous reference frame that can be either I-frame or P-frame. P frames are more compressible when compared to I frames. Finally, B-frame (Bi-directional frame) depends on both past and future frames for decoding and is the most compressed frame amongst the three frames. Therefore, I-frame is the most important frame when compared to other two frames.

H.264/AVC standard defines mainly three encoding profiles which are frequently used namely Main profile, Baseline profile and High profile. The baseline profile has less amount of video data compared to other profiles due to lower quality versions of the video. Baseline profile is suitable for video conferencing. Whereas the main profile and high profile are suitable for high- end video broadcast and video storage. These profiles are classified in levels indicating the limits of various parameters, namely video resolution, coding bit rate, max decoding speed and max frame size. These profiles and levels are used as limits to encode/decode videos which targets respective classes of video communication applications [20].

2.7 User Datagram Protocol

The user datagram protocol is one of the core members of the internet protocol suite. It uses simple connectionless transmission model with a minimum of protocol mechanism. It has no handshaking dialogues and thus exposes the user programs to any unreliability of the underlying network and hence there is no guarantee of delivery or ordering. It is suitable for time sensitive applications, and lack of retransmission delays makes it suitable for real time applications.

2.8 Hypertext Transfer Protocol

The Hypertext transfer protocol is an application protocol which functions as a request-response protocol for a client-server model. It is designed within the framework of the internet protocol suite. Its definition presumes an underlying and reliable transport layer protocol, and TCP is commonly used. It is a stateless protocol [1].

2.9 VLC Media Player

The Video Lan Client (VLC) media player is an open source which is released under the General Public License (GNU) and written by Video Lan Project. VLC is free software and any licensed version can be used without any legal restriction. VLC started in 1996 as an academic project. Its main purpose is to stream videos between clients and server across a campus network by the students of Ecole Centrale Paris. It is mainly developed for research purposes rather than entertainment. It can run or installed directly from Flash Drive and can be extended using the LUA scripting language. The GUI is based on QT4 for Windows and Linux. QT4 is classified as Widget toolkit. The QT4 is the default, plain, graphical interface to VLC made using QT library to streamline the creation of application to windows, Mac OS X and Linux. Now, the Video Lan Project was developed by contributors all around the world and coordinated by Video Lan non-profit organization. VLC 1.1.0 has more than 380 modules [19].

VLC has a remote control interface and acts as a streaming server via the media player. It can be controlled from a remote location and different interfaces, e.g. via HTTP. When the video is streamed, by using remote control interface the receiver can play or stop the video as required by receiver not a person. From the option playback, the video can be viewed at faster or slower rate. Furthermore, the video can be viewed frame by frame using advanced options, and subtitles can be added to the video. We can use firewire cable to monitor HDV camera video during playing. VLC can play ISO image files from disk image. VLC can also play all audio and video formats supported by libavcodec and libavformat. It can support H.264 or MPEG-4 as well as FLV or MXF file formats. It has modules for codec which are not based on FFMPEG libraries [19].

VLC Player Modules:

VLC utilizes a measured framework, which permits including effortlessly new functionalities and configurations. Taking after substance gives a presentation of some VLC modules. There are more than 380 modules for VLC 1.1.0. They assume a critical part for streaming, converting, sharing and so forth.

Access Modules: VLC can be used for streaming as it provides accessibility to different protocols. For each protocol a module with that name is characterized. VLC pursues a stream from distinctive sources using these modules, for instance: HTTP, UDP, RTP, FTP, and RTSP. The CDDA (Compact Disc Digital Audio) is utilized for sound CD data. The DVB (Digital Video Broadcasting) module permits pursuing DVB-T, DVB-S and DBC-C satellite, physical alternately link cards. The DVD info module has been superseded by the DVDPLAY. The VCD module is utilized for pursuing VIDEOCD data.

Demuxers: When a video is streamed, both audio and video is received in containers format. The Demuxers extract the video and audio content from the video stream and pass them to the decoders. These modules permit the player to pursue various types of configurations as indicated by their type such as AVI, ASF, AAC, OGG, AIFF, AU, WAV, MP4, MKV, FFMPEG, REAL.

Video Outputs: The video output modules permit VLC to show feature on the screen. In view of the kind of the framework, VLC picks the most suitable feature module. We can compel any particular module from the order line by utilizing "vout modulename". The DirectX module show feature utilising "Microsoft Direct X" libraries and it is suggested for Win32 port. This is a fundamental feature yield module of sort X11. The xvideo is for GNU/Linux working frameworks, what's more, it requires an xvideo-agreeable realistic card.

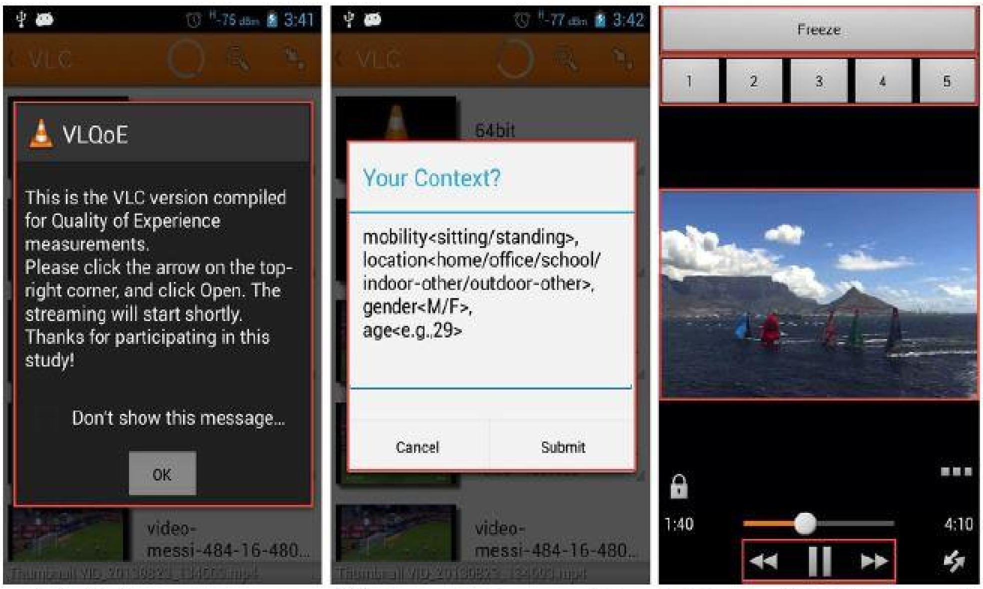
Video Filters: The video filters channel modules permit performing alterations of the rendered picture (de-interlacing, contrast, saturation, adjusting and cropping etc.). They are accessible from the command line control and but not from the GUI. The adjust module permits to alter image contrast, saturation and brightness. The CRT (Cathode Ray Tube) screens are equipped for playing simple feature outlines which is troublesome for present day screens. Consequently a de-interlace channel module was acquainted with proselyte simple casing into computerized one and it is helpful with streams originating from advanced satellite station. The transform module allows rotating the image to 90, 180 and 270, flat flip (hflip) and vertical-flip (vflip). The distort filter channel module makes twisting to the video and the invert channel modules reverses all the colors of the video which is empowered as a matter of course.

Audio Outputs: These modules help us to choose the kind of output for audio framework. It picks the most appropriate module or else we can drive to change particular module from command line using "-aout modulename". The OSS module actualizes the open sound framework, which is utilized as a part of the Linux environment. The wave output is an audio output module which is used for the windows port and other modules are CORE AUDIO, DIRECT, OSS, ALSA, ESD, and ARTS.

Interface Modules: These are either graphical or control interfaces. The dummy interface is used when no interface is required (i.e. show feature with no control keys). The motion modules allow the client to control VLC using mouse gestures. The HTTP interface module allows the client to control VLC through web browser remotely. RC is a remote control interface module with which the client can control VLC using command line controls, for instance play, stop and so forth. The skin modules permits the users to create themes for VLC media player using XML files. There are operating system support modules and miscellaneous modules for supporting different operating systems and additional modules for random purposes. For Example: The disable function from the command line is used to debilitate the player. The SOUT module is an incidental module which is a propelled element of VLC that allows streaming an MPEG-1, MPEG-2, MPEG- 4/DivX record or DVD and HEVC [19].

2.10 VLQoE Tool

The VLQoE tool was developed by adding new functionalities to the VLC player source code in order to record the user data, picture display times and the perceived quality ratings while video streaming [9]. The smartphone based version of the tool consists of the video pane to display the video, control buttons like play / pause / rewind / forward, freeze button to indicate when a the user observes a freeze, and user rating buttons to record the user feedback on the spot. When the user launches the player, a welcome message appears on the screen; after which the user is asked to enter information on his/her mobility, location, gender and age. The data that can be recorded using the VLQoE tool include the screen display information, screen touch events, rebuffering events, packets, interface type, service provider, signal strength, GPS coordinates, battery level and device id.



(a) Welcome message (b) Context, Demographics (c)Freeze, UR, Display, and Control

Fig. 2.2 Snapshots from the VLQoE player

2.11 Video Quality Assessment

With the increase in the usage of various video based applications, has led to a fierce competition between service providers and also between developers to provide better quality than each other. This has given rise to the importance of assessment of video quality. Basically, the video quality assessment is done in two methods:

1. Objective video quality assessment method based on mathematical calculations.
2. Subjective video quality assessment method based on tests performed by users.

2.12 Subjective Video Quality Assessment

The subjective video quality assessment method is the most reliable video quality measurement method to evaluate the video service. It is the assessment of video quality as perceived by the user. In QoE the subjective results are different from user to user. Human perception involves various aspects of human psychology and various factors such as illumination, vision ability and other viewing conditions. MOS stands for Mean Opinion Score which is a metric obtained from the user ratings given by the subjects for the video quality perceived by them [3].

3 RELATED WORKS

In this section the related works the done in the field of video QoE is discussed. Several studies have been presented with the quality of experience (QoE) with respect to the videos. In reference, the authors presented a conceptual model of QoE, which considers both measurable and non-measurable parameters in quality evaluations. They have used their model to measure QoE in mobile scenarios.

In reference [10] authors have proposed a QoE assessment model for video streaming service using QoS parameters in wired and wireless network through which the network operators can correspond to poor quality by monitoring the QoE of video streaming service. In reference [6] authors address the video quality correlation with respect to QoE and QoS. In this study, a generic formula has been proposed in which QoE and QoS parameters are connected through an exponential relationship which has been validated for streaming servers. The importance of the relationship between QoE and technical parameters to manage the user perceived quality is explained. In reference [4], it has been observed that the initial delays before the video has started have no severe impact on QoE.

The concept of sustainable throughput was introduced for the first time in reference [16]. It is termed as achievable throughput in a multi-hop WLAN scenario. Reference [19] investigated the throughput that can be sustained under non-saturation condition and considered the sustainable throughput to be the maximal throughput in order to assure stability. The throughput values are obtained from traffic modeling through analytic models. Reference [8] deals with the impact of initial delay on the user perceived QoE, while reference [15] analyzes the impact of initial delays and service interruptions in the context of waiting times.

Reference [12] dwells into the optimization of QoE through proper dimensioning of the video buffers. The M/M/1 model used for analyzing the video buffer is complementary to the fluid flow model-based approach to QoE-related input flow restriction. Reference [12] deals with the video quality measurement for progressive download video services. A network based QoE estimation method where the video is downloaded into a buffer and played is proposed. The Provisioning-Delivery-Hysteresis has been used in [7] to define the sustainable throughput and formulate the corresponding mathematical descriptions.

In reference [13], authors have evaluated the sensitivity of mobile video to packet loss and packet delay. It has been observed that mobile video (H.264 baseline) is very sensitive to packet loss and packet delay variation. The authors have made a comparative study of objective and subjective video quality for the codec in which they found that jitter had the biggest effect when loss, delay and jitter has been introduced to the same video sequence. In reference [11], authors have investigated the effect of artifacts on user perceived quality where the video quality assessment is done by analyzing the effects of artifacts and packet loss. Moreover, in references [12, 14], the authors have investigated the impact of video freezes and video jump on user perception.

4 METHODOLOGY

This chapter describes the research methodology employed to fulfil the thesis goals and explains the experimental setup and video quality assessment based on the user study i.e. subjective assessment.

4.1 Experimental Settings

This section explains the experimental setup, to observe the effect of packet loss and packet delay variations on the quality of the video, from end-user perspective. In this experiment, the test video is streamed from the server on Ubuntu 16.04 to the LG Nexus 4 android smartphone client via UDP.

4.1.1 Video Parameters

The test video sequence is the Big-Buck-Bunny video clip taken from the standard test media [http://trace.eas.asu.edu/yuv/]. It is taken in 4 resolutions 352x240 (240p), 480x360 (360p), 858x480 (480p), and 1280x720 (720p) with frame rate 25fps and encoded with 500 kbit/s, 600 kbit/s, 800kbit/s, and 1000 kbit/s bitrates respectively. Frame rate is the rate at which the video system projects or displays the images (Frames) per second. It is measured in fps. The bit rate refers to the amount of information (number of bits) that the video will process in a given period of time. The duration of the video is reduced to 120 seconds for the convenience of subjective assessment. The results obtained from the short videos are termed to be consistent as the subjects' rate the video based on the quality rather than the content. For longer videos, there is a chance the subject might focus on the content rather than the quality. The streamed video is displayed on the smartphone screen with a resolution of 1280x768 pixels.

4.2 Setup Design

4.2.1 Wireless scenario

The experimental setup consists of a video streaming server, a video player at the client and a traffic shaper. VLQoE tool is installed in the mobile phone. The VLC streaming server is used to send the encoded video sequences to the client for subjective quality assessment. The video is streamed to the client using UDP protocol. The procedure to initiate streaming from the server is as follows.

- Open VLC media player
- Select 'streaming' option
- Insert the file to be streamed
- Click 'stream' to continue
- Choose the UDP protocol for streaming
- Enter the IP and UDP port details of the client.

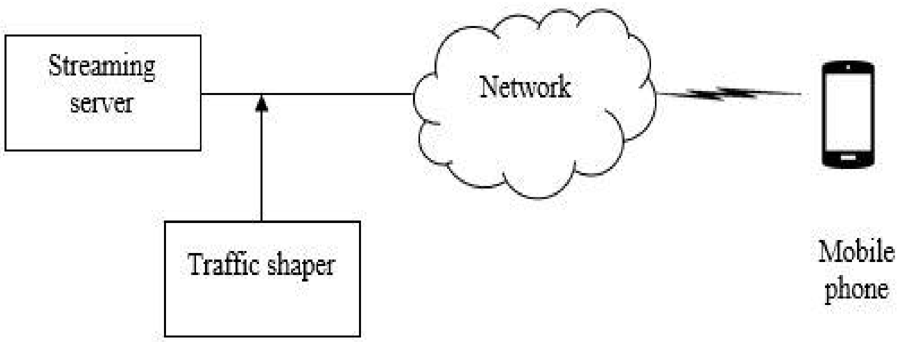


Fig 4.1. Experimental Setup

NetEm traffic shaper belongs to the Traffic Control (TC) bandwidth provisioning package of Linux. NetEm is used for dropping some packets, to control the loss and variable delay of the traffic in the network when streamed from server to client. The parameters like delay, packet loss, duplication, re-ordering etc. can be configured using NetEm. Only delay and packet loss parameters are considered for this thesis.

The percentage of packet losses used in this thesis are 0.1%, 0.2% and 1%, i.e. if the packet loss is set to 0.1%, the shaper in average drops 1 packet for every thousand packets transmitted from the server to the client. The delay conditions under investigation are no delay, 200ms and 500ms delay i.e. if the delay is set to 200ms, NetEm adds a 200ms delay to all the outgoing packets. The streamer is installed on the Linux Ubuntu 16.04 and the shaper is also run on the same platform whereas the client is installed on the android device. Before starting the video streaming at the server, the client has to be ready by opening the VLQoE and choosing the network stream. This is essential because the client does not have the specific information as to when the video starts streaming at the server.

4.2.2 Mobile scenario

The experimental setup consists of a video streaming server, a video player at the client and a traffic shaper. VLQoE tool is installed in the mobile phone. The VLC streaming server is used to send the encoded video sequences to the client for subjective quality assessment. The server is hosted in a public IP network and the client is connected to a local mobile network. The video is streamed from the server to client using HTTP protocol. The procedure to initiate streaming from the server is as follows.

- Open VLC media player
- Select ‘streaming’ option
- Insert the file to be streamed
- Click ‘stream’ to continue
- Choose HTTP for streaming

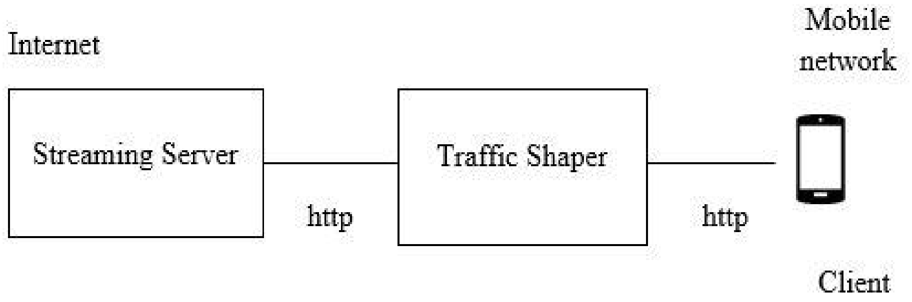


Fig 4.2. Experimental setup

The streamer is installed on the Linux Ubuntu 16.04 and the shaper is also run on the same platform whereas the client is installed on the android device. Before starting the video streaming at the server, the client has to be ready by opening the VLQoE and choosing the network stream. Netem is used for traffic shaping in order to introduce 0ms, 200ms and 500ms delays and 0.1%, 0.2% and 1% packet losses when streaming from server to client.

4.3 Video Quality Assessment – User Study

For the subjective part of the study, user experiments are conducted on 40 test subjects from Karlskrona, Sweden. The subjective method referred to as Mean Opinion Score (MOS) was employed to determine the quality of the received streams. According to the ITU-T standard, MOS is classified into 5 quality groups namely Excellent (5), Good (4), Fair (3), Poor (2), and Bad (1). It can be said that excellent rating means the video quality impairment is imperceptible, good refers that the impairment is perceptible but not annoying, fair means that the impairment is slightly annoying, poor means that the video quality is annoying and bad means that the received video is very annoying.

Scale	Quality	Impairment	Color indicated
5	Excellent	Imperceptible	Green
4	Good	Perceptible, but not annoying	Green
3	Fair	Slightly annoying	Yellow
2	Poor	Annoying	Red
1	Bad	Very annoying	Red

Table 4.1: ITU-T Scale of Media Quality Impairment

The user experiment was performed with 40 people: 26 male and 14 female subjects who have no experience in quality assessment. Each user watched the streamed videos on the smartphone client for 4 test videos and 6 test cases (total=6x4=24). The subjects were asked to hold the smartphone at a comfortable distance, and take a convenient position in a silent room. All the users streamed the same videos on the smartphone with portrait orientation, with the same screen brightness and sound turned on.

The order of resolutions and sequences of the different video clips was randomized. A total of 360 videos (40 usersx24 videos per user) were rated for overall-quality on a five-level MOS scale after the completion of each video. Also, the details of the test subjects like age, gender, and occupation were collected after the experiments. The collected data from the MOS scale is color-coded as follows. A sample is shown in fig 4.2.

U1-23/M	no delay	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	4	4	3	4	3
360px	4	4	3	5	2	3
480px	2	3	4	4	3	1
720px	2	5	4	3	3	1

Fig.4.2 Color coded sample user data

5 RESULTS AND DISCUSSION

This chapter explains the detailed description of the obtained results. These results are based on the experiments performed in the previous chapter. These results give the Subjective assessment of the various test videos based on delay and packet loss for both wireless and mobile scenarios. However, MOS rating gives best opinion on video quality.

To discuss and achieve these results we had used statistical methods such as the average value, standard deviation, 95% confidence intervals acquired from the set of data of the subjective assessment of video quality survey. Later these results are analyzed.

The reliable method to assess the video quality as perceived by a human observer is to ask the subjects for their opinion, termed as subjective video quality assessment. It is used to compare the visual impression of the video sequences based on user perception.

Based on the Recommendation BT. 500 subjective assessment in the quality of television pictures, of the International Telecommunications Union Radio communications Sector (ITU-R) mean scores of the MOS and Confidence Interval (CI) were calculated for wireless and mobile scenarios for the set of Big Buck bunny videos based on the packet loss and delay.

- The 240px video for no delay, 200ms delay, 500ms delay, 0.1% packet loss, 0.2% packet loss and 1% packet loss.
- The 360px video for no delay, 200ms delay, 500ms delay, 0.1% packet loss, 0.2% packet loss and 1% packet loss.
- The 480px video for no delay, 200ms delay, 500ms delay, 0.1% packet loss, 0.2% packet loss and 1% packet loss.
- The 780px video for no delay, 200ms delay, 500ms delay, 0.1% packet loss, 0.2% packet loss and 1% packet loss.

5.1 Mean Scores Calculations

We have to calculate, the mean score for each and every single presentation, and the mean is defined as,

The average value is calculated using the below formula:

$$\bar{X} = \frac{\sum X_i}{N}$$

Where,

- $\bar{X}$ is Mean,
- $\sum X_i$ is sum of all data values,
- N is number of all data values.

Standard deviation:

The formula for calculating standard deviation is as follows:

$$\sigma = \sqrt{\sigma^2} = \sqrt{\sum(\frac{(X_i - \bar{X})^2}{N}}$$

Where,

- σ is Standard deviation,

- σ^2 is Variance,
- $\bar{X}$ is Mean,
- X_i is each data value,
- N is number of all data values.

5.2 Confidence Interval Calculations

Once all the results of mean scores are calculated, and as the mean scores are always associated with CI, 95 % Confidence Intervals for all the mean scores are calculated. With the 95% Confidence Interval, the exact value of difference between experimental mean score and the true mean score, will be obtained.

The formula for calculating the confidence interval is given by

$$[\ \bar{X} - Z_{1-\frac{\alpha}{2}} \frac{s}{\sqrt{n}}\ ,\ \bar{X} - Z_1 + \frac{\propto}{2} \frac{s}{\sqrt{n}}\ ]$$

Where,

- $\bar{X}$ = average; series as an estimator for μ,
- $\frac{s}{\sqrt{n}}$ = estimation of the variation of the mean $\sqrt{Var[\bar{X}]}$,
- $Z_{1-\frac{\alpha}{2}}$ = percentile of the Normal distribution,
- $\bar{X} - Z_{1-\frac{\alpha}{2}} \frac{s}{\sqrt{n}}$ = half-size of the confidence interval.

The obtained MOS values for the respective metrics are recorded for the no delay case first and then a delay of 200ms and 500ms were injected. A loss ratio of 0.1%, 0.2% and 1% respectively were later included for the analysis part. The video sequences were rated on a 5 grade scale Excellent (5), Good (4), Fair (3), Poor (2) and Bad (1). Each video is assessed by 40 human subjects. The observed average MOS values, standard deviation and confidence interval values for the test cases are tabulated from table 5.1-5.16.

5.3 Analysis

Packet loss case - Wi-Fi scenario:

For all the video test cases, the subjects felt that the videos had a better quality at low packet loss. It can be observed from the results that the quality of the video degrades as the packet loss value increases. The videos streamed without visible impairments are graded with a MOS rating, Excellent (5) and Good (4).

Fig. 5.1 represents the behavior of the videos with respect to different packet loss values. The average MOS ratings are plotted against the respective packet loss values. It can be observed from the figure that at 0.1% packet loss, user ratings for all the videos are higher when compared to the 0.2% and 1% cases. The average MOS value is in between 3 and 4 for 240px, 360px videos indicating that there are human perceptible artifacts for these video. For 420px and 720px videos, the average MOS is slightly less than the other two videos which indicate that there are perceptible artifacts in the video are slightly annoying to the user. For the 0.2% and 1% packet loss values, 240px video has the highest user MOS ratings than the other videos. These observations reveal that the subjects felt the 360px video had better quality at lower packet loss values and 240px video had better resistance for higher packet loss values. The 480px and 720px videos on the other hand were rated fair for lower packet loss values but are feeble for higher disturbances.

MOS – 240px	0.1%	0.2%	1%
Average Value	3.55	3.1	2.75
Standard Deviation	0.554	0.379	0.439
Confidence Interval	0.172	0.117	0.136

Table 5.1. 40 Users Mean Opinion Score – 240px Packet Loss case

MOS – 360px	0.1%	0.2%	1%
Average Value	3.625	3.025	2.375
Standard Deviation	0.667	0.768	0.540
Confidence Interval	0.207	0.238	0.167

Table 5.2. 40 Users Mean Opinion Score – 360px Packet Loss case

MOS – 480px	0.1%	0.2%	1%
Average Value	3.1	2.4	1.675
Standard Deviation	0.545	0.744	0.616
Confidence Interval	0.169	0.231	0.191

Table 5.3. 40 Users Mean Opinion Score – 480px Packet Loss case

MOS – 720px	0.1%	0.2%	1%
Average Value	2.925	1.675	1.075
Standard Deviation	0.572	0.764	0.267
Confidence Interval	0.177	0.237	0.083

Table 5.4. 40 Users Mean Opinion Score – 720px Packet Loss case

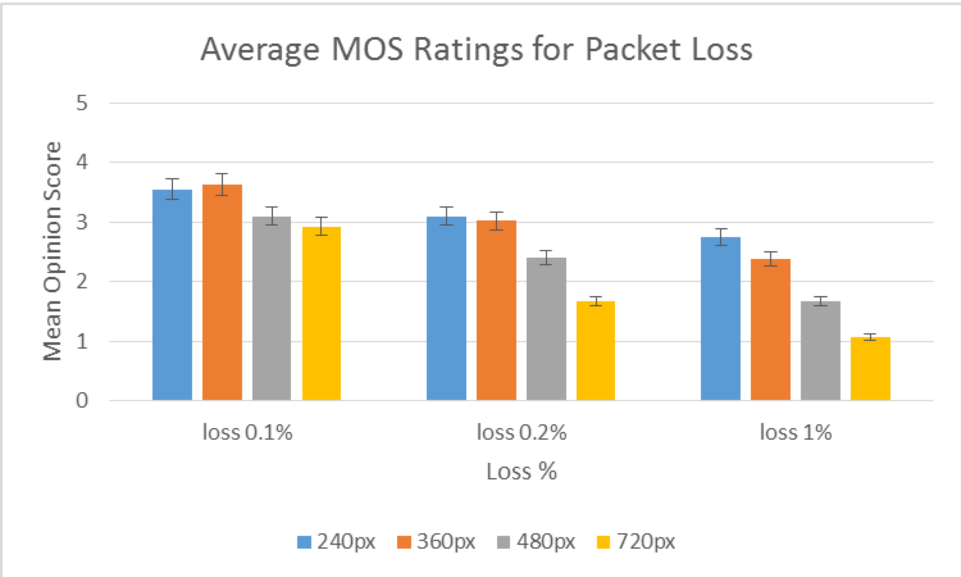


Fig.5.1 Average MOS ratings for packet loss

Delay case – Wi-Fi scenario:

Fig 5.2 represents the behavior of the test videos with respect to different packet delays introduced in the network. The average MOS ratings are plotted against the respective delay values. It can be observed that for the no delay case, the 240px and 360px videos are rated Good as the human perceptible artifacts in the videos are not annoying the users, while the

480px and 720px video has an average MOS rating higher than 3 and less than 4 which indicate that the human perceptible artifacts are present and are slightly annoying to the subjects. For the 200ms delay case the all the videos are rated a MOS score greater than 3 and less than 4 indicating the human perceptible artifacts which are slightly annoying. For the 500ms delay case, 240px video is rated high MOS score when compared to the others indicating better resistance for high delay values. However, the 480px and 720px videos are feeble to the disturbances.

Taking into account all the test cases, it can be seen that the QoE disturbances due to the delivery issues is at an acceptable minimum for the 360px video. Hence, the 480x360 video can be considered the sustainable throughput in all the cases.

MOS – 240px	0ms	200ms	500ms
Average Value	4.05	3.45	3.725
Standard Deviation	0.552	0.639	0.554
Confidence Interval	0.171	0.198	0.172

Table 5.5. 40 Users Mean Opinion Score – 240px Delay case

MOS – 360px	0ms	200ms	500ms
Average Value	4.175	3.825	3.25
Standard Deviation	0.675	0.501	0.494
Confidence Interval	0.209	0.155	0.153

Table 5.6. 40 Users Mean Opinion Score – 360px Delay case

MOS – 480px	0ms	200ms	500ms
Average Value	3.475	3.475	2.8
Standard Deviation	0.751	0.64	0.823
Confidence Interval	0.233	0.198	0.255

Table 5.7. 40 Users Mean Opinion Score – 480px Delay case

MOS – 720px	0ms	200ms	500ms
Average Value	3	3.25	2.9
Standard Deviation	0.599	0.543	0.744
Confidence Interval	0.186	0.168	0.231

Table 5.8. 40 Users Mean Opinion Score – 720px Delay case

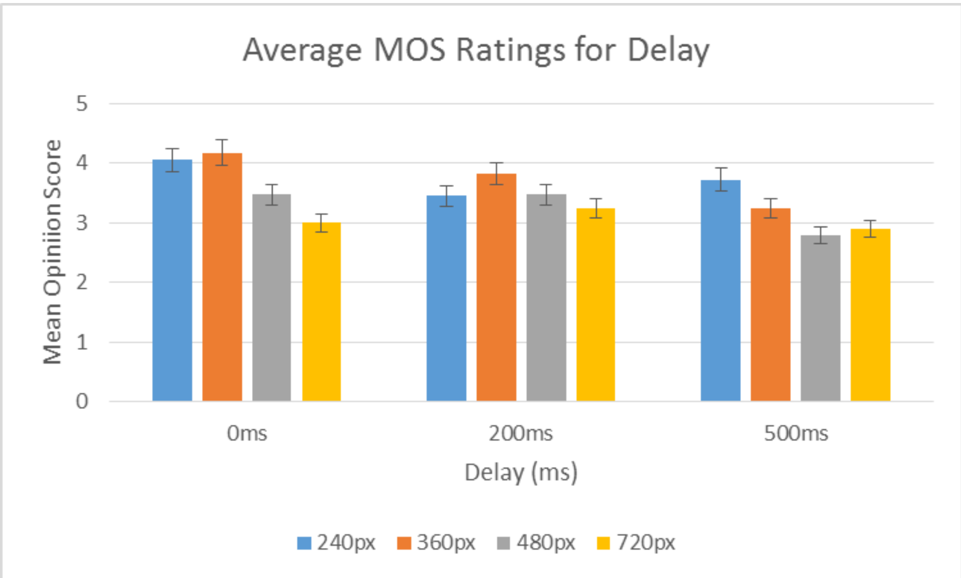


Fig 5.2. Average MOS ratings for 0ms, 200ms and 500ms delays

Packet loss case – mobile scenario:

Fig. 5.3 represents the behavior of the videos with respect to different packet loss values. The average MOS ratings are plotted against the respective packet loss values. It can be observed from the figure that at 0.1% packet loss, user ratings for all the videos are higher when compared to the 0.2% and 1% cases. The average MOS value is in between 3 and 4 for 240px, 360px videos indicating that there are human perceptible artifacts for these video. For 420px and 720px videos, the average MOS is slightly less than the other two videos which indicate that there are perceptible artifacts in the video are more annoying to the user. For the 0.2% and 1% packet loss cases, 240px video has the highest user MOS ratings than the other videos. These observations reveal that the subjects felt the 360px video had better quality at lower packet loss values and 240px video had better resistance for higher packet loss values. The 480px and 720px videos on the other hand were rated fair for lower packet loss values and poor as the packet loss levels are increased.

MOS – 240px	0.1%	0.2%	1%
Average Value	3.725	3.525	2.925
Standard Deviation	0.506	0.506	0.35
Confidence Interval	0.157	0.157	0.108

Table 5.9. 40 Users Mean Opinion Score – 240px Packet Loss case

MOS – 360px	0.1%	0.2%	1%
Average Value	3.575	3.45	2.65
Standard Deviation	0.594	0.639	0.58
Confidence Interval	0.184	0.198	0.180

Table 5.10. 40 Users Mean Opinion Score – 360px Packet Loss case

MOS – 480px	0.1%	0.2%	1%
Average Value	3.15	3.075	2.875
Standard Deviation	0.622	0.417	0.404
Confidence Interval	0.193	0.129	0.125

Table 5.11. 40 Users Mean Opinion Score – 480px Packet Loss case

MOS – 720px	0.1%	0.2%	1%
Average Value	2.65	2.5	2.15
Standard Deviation	0.736	0.555	0.58
Confidence Interval	0.228	0.172	0.180

Table 5.12. 40 Users Mean Opinion Score – 720px Packet Loss case

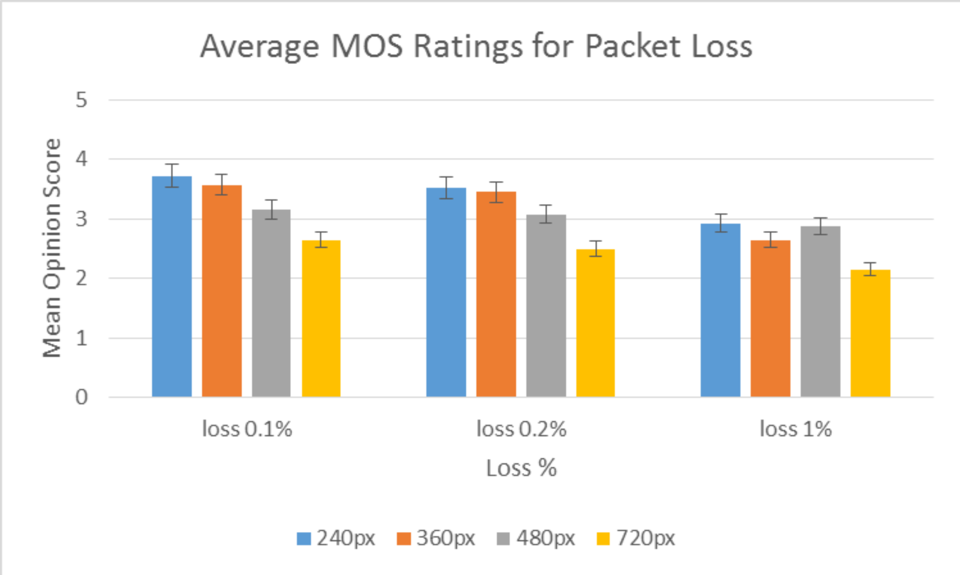


Fig. 5.3. Average MOS ratings for 0.1%, 0.2% and 1% packet loss

Delay case – mobile scenario:

Fig 5.4 represents the behavior of the test videos with respect to different delays introduced in the network. The average MOS ratings are plotted against the respective delay values. It can be observed that for the no delay case, the 240px and 360px videos are rated Good as the human perceptible artifacts in the videos are not annoying the users, while the 480px and 720px video has an average MOS rating in between 3 and 4 which indicate that the human perceptible artifacts are present and are annoying to the subjects. For the 200ms delay case the all the videos are rated a MOS score greater than 3 and less than 4 indicating the human perceptible artifacts which are slightly annoying. For the 500ms delay case, 360px video is rated high MOS score when compared to the others indicating better resistance for high delay values. However, the 480px and 720px videos are feeble to the disturbances.

Taking into account all the test cases, it can be seen that the QoE disturbances due to the delivery issues is at an acceptable minimum for the 360px video. Hence, the 480x360 video can be the threshold to sustain the video quality.

MOS – 240px	0ms	200ms	500ms
Average Value	3.95	3.6	3.25
Standard Deviation	0.677	0.900	0.707
Confidence Interval	0.21	0.279	0.219

Table 5.13. 40 Users Mean Opinion Score – 240px Delay case

MOS – 360px	0ms	200ms	500ms
Average Value	4.2	3.625	3.425
Standard Deviation	0.608	0.586	0.594
Confidence Interval	0.188	0.181	0.184

Table 5.14. 40 Users Mean Opinion Score – 360px Delay case

MOS – 480px	0ms	200ms	500ms
Average Value	3.675	3.625	2.95
Standard Deviation	0.764	0.628	0.597
Confidence Interval	0.237	0.195	0.185

Table 5.15. 40 Users Mean Opinion Score – 480px Delay case

MOS – 720px	0ms	200ms	500ms

Average Value	3.3	2.85	2.6
Standard Deviation	0.564	0.533	0.672
Confidence Interval	0.175	0.165	0.208

Table 5.16. 40 Users Mean Opinion Score – 720px Delay case

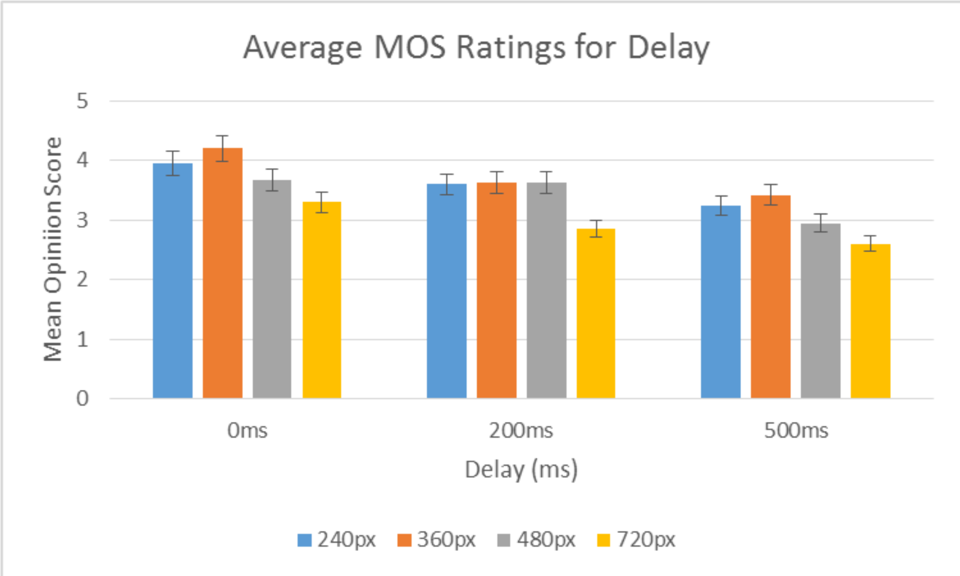


Fig. 5.4. Average MOS ratings for 0.1%, 0.2% and 1% packet loss

6 CONCLUSION AND FUTURE WORK

In this thesis work, results of the experiments have shown how the QoE varies for different resolutions of the videos in the presence of different levels of delays and packet loss. An emulated network setup was created in order to obtain the streamed video sequences for video quality assessment in wireless and mobile scenarios. For the subjective video quality assessment, user experience survey has been performed and the QoE for 40 users with respect to the video impairments have been collected. The ratings have been collected for the video in four different video resolutions i.e. 240px, 360px, 480px and 720px in the presence of 0ms, 200ms, 500ms delay and 0.1%, 0.2%, 1% packet loss. The ratings for all these cases are averaged to obtain the mean opinion score (MOS).

From the analysis, for all the video test cases, the videos are rated better quality at low packet loss values and low delay values. The quality of the videos with the presence of delay is rated high compared to the video quality in the case of packet loss. The 240px video had better resistance for higher packet loss values while the 360px video had slightly greater quality for the 0.1% loss case. From this, it can be observed that the high resolution videos are feeble in the presence of higher disturbances i.e. high packet loss and larger delays. From considering all the cases, it can be observed that the QoE disturbances due to the delivery issues is at an acceptable minimum for the 360px video. Hence, the 480x360 video is the threshold to sustain the video quality.

The QoE evaluation in this thesis is done by streaming the standard videos from server to a single android mobile client in wireless and mobile scenarios. The future work can be extended on to performing the quality assessments by streaming to a tablet client. Also, the concept of sustainable throughput can further be extended for comparing the video streaming solutions in terms of QoE and Energy Efficiency.

Linking to Research Questions

1. How does the user experience the quality of the videos of different resolutions in video streaming when packet loss and delay are introduced in wireless and mobile network scenario?
   Ans: We can observe that for both Wi-Fi and mobile scenarios, as the packet loss values increase, the user quality ratings decrease. In case of low packet loss, the lower resolution videos i.e. 240px and the 360px videos are rated between good and fair. As the loss values increase, the videos with lower resolutions had better ratings than the high resolution videos, which were rated bad or poor. In the case of delay, the lower resolution videos have been rated between fair and excellent and the high resolution videos between good and fair. As the delay is increased, it is observed that the lower resolution videos have been rated better than the high resolution videos that had more freezes and/or jerks.

2. How does the packet loss and delay affect the end-user QoE of the video streams?
   Ans: When the delay and packet loss are introduced with the help of a traffic shaper, with increase in the packet loss percentage and resolution, the end user QoE had been rated between poor and bad as the impairments became more

annoying. And when the delay is injected into the network, the videos with high resolutions suffered a low user rating than the lower resolution videos. It was observed that the high resolution videos are more susceptible to disturbances than the low resolution videos.

3. What is the sustainable throughput value in all the cases?
   Ans: For all the test cases considered in the thesis, for both Wi-Fi and mobile cases it can be observed from the analysis section that the QoE disturbances due to the delivery issues is at an acceptable minimum for the 360px video. Hence, the 480x360 video is threshold to sustain the video quality for all the considered cases.

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APPENDICES

APPENDIX A

A.1 Network Configuration

For the proper network configurations of the device, the configuration settings are changed at /etc/network/interfaces in the terminal. The laptop is now configured as

```
Auto eth0
iface inet eth0 dhcp

Auto eth1
iface inet eth1 dhcp
```

The following commands are then entered to know the device IP address

```
# sudo ifdown –a && sudo ifup –a
```

Restart to the networking service under Linux using

```
#sudo /etc/init.d/networking restart
```

A.2 Emulator Commands

Packet Loss:

```
#tc qdisc add dev wlp6s0 root netem loss X%
#tc qdisc change dev wlp6s0 root netem loss X%
#tc qdisc del dev wlp6s0 root
```

Delay:

```
#tc qdisc add dev wlp6s0 root netem delay Yms
#tc qdisc change dev wlp6s0 root netem delay Yms
#tc qdisc del dev wlp6s0 root
```

Where X is the packet loss and Y is the delay value.

A.3 VLC Media Player Installation

```
#sudo apt-get update
#sudo apt-get upgrade
#sudo apt-get install vlc
```

APPENDIX B: 40 USER EXPERIMENTATION RESULTS WIRELESS CASE

U1-23/M	no delay	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	4	4	3	4	3
360px	4	4	3	5	2	3
480px	2	3	4	4	3	1
720px	2	5	4	3	3	1

U2-22/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	3	3	3	3	3
360px	4	4	3	4	4	2
480px	3	5	4	4	3	2
720px	2	4	4	3	2	1

U3-23/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	3	4	4	3	3
360px	4	3	3	3	2	2
480px	4	4	1	3	2	3
720px	3	3	4	3	1	1

U4-21/F	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	2	4	4	3	2
360px	4	4	3	3	3	2
480px	3	3	3	2	3	3
720px	3	3	2	4	1	1

U5-22/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	3	5	4	3	3
360px	5	4	4	3	4	2
480px	3	3	1	3	2	1
720px	2	3	4	2	1	1

U6-23/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	3	4	4	3	3
360px	4	3	4	3	3	2
480px	4	3	3	3	2	1
720px	3	4	3	4	1	1

U7-22/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	2	5	4	2	3
360px	2	4	4	3	4	4
480px	4	4	3	2	3	2

720px	3	3	3	3	1	1

U8-23/F	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	4	3	3	3	3
360px	4	4	3	4	3	2
480px	3	3	3	3	3	2
720px	2	3	3	2	2	1

U9-23/F	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	4	3	3	3	2
360px	3	4	3	3	4	2
480px	2	3	3	3	3	2
720px	3	3	3	3	2	1

U10-23/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	4	3	3	3	3
360px	4	4	3	4	4	3
480px	2	3	3	3	4	2
720px	3	3	4	3	2	1

U11-22/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	3	4	3	3	2
360px	4	4	3	4	3	3
480px	3	4	1	3	2	2
720px	3	3	3	3	1	1

U12-24/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	4	4	3	4	3
360px	4	3	3	4	2	2
480px	3	3	3	4	3	1
720px	2	4	4	3	3	1

U13-22/F	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	3	3	4	3	3	2
360px	4	4	3	4	2	2
480px	4	3	4	3	1	1
720px	3	3	3	3	1	1

U14-23/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	3	4	3	3	3
360px	4	4	3	4	3	2

480px	5	4	4	3	1	2
720px	3	3	4	3	1	1

U15-22/F	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	3	4	3	3	3
360px	3	4	3	4	2	2
480px	3	3	3	3	3	1
720px	3	3	3	3	1	1

U16-23/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	5	4	4	4	3	3
360px	4	4	4	3	4	2
480px	4	3	3	3	2	2
720px	3	3	3	3	2	1

U17-22/F	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	4	4	3	3	3
360px	5	4	3	3	4	2
480px	4	4	2	3	3	2
720px	3	3	2	2	2	1

U18-22/F	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	5	4	4	4	3	3
360px	5	5	3	4	3	3
480px	4	3	3	3	3	1
720px	3	3	2	3	2	1

U19-21/F	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	3	3	4	3	3	3
360px	4	4	5	5	4	2
480px	4	5	2	5	3	2
720px	3	4	2	3	2	1

U20-21/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	3	3	4	3	3
360px	5	4	3	3	4	2
480px	3	4	1	3	3	3
720px	3	3	2	3	3	1

U21-22/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	4	4	4	3	3

360px	5	4	4	3	3	2
480px	5	3	3	3	2	1
720px	4	3	3	4	1	1

U22-22/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	4	4	4	3	3
360px	5	3	4	4	3	3
480px	4	4	3	3	3	2
720px	4	3	3	2	3	2

U23-22/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	3	4	3	3	4	3
360px	4	4	3	4	4	2
480px	3	3	3	3	3	2
720px	3	3	2	3	2	1

U24-21/F	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	3	4	4	3	2
360px	5	4	3	4	2	3
480px	3	5	2	3	1	2
720px	2	3	2	3	1	1

U25-22/F	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	4	4	4	3	3
360px	5	3	3	5	2	2
480px	3	3	3	4	3	1
720px	3	4	2	3	3	1

U26-23/F	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	3	3	4	3	3	3
360px	4	4	3	4	3	3
480px	4	4	3	3	2	2
720px	3	3	4	3	1	1

U27-22/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	4	3	4	3	3
360px	4	4	3	3	3	2
480px	4	3	3	3	2	1
720px	3	3	2	3	2	1

U28-20/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%

240px	4	3	3	4	3	3
360px	5	4	3	4	3	3
480px	4	3	3	3	3	2
720px	5	3	3	3	3	2

U29-23/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	3	4	4	3	3	2
360px	4	4	3	4	2	2
480px	4	3	4	3	1	2
720px	3	4	3	3	1	1

U30-23/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	5	3	4	5	3	3
360px	4	3	3	3	2	2
480px	5	4	2	3	2	2
720px	3	3	2	3	2	1

U31-22/F	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	3	3	4	3	2
360px	4	3	3	3	3	2
480px	3	3	2	3	2	2
720px	3	3	3	1	1	1

U32-25/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	5	4	4	4	3	3
360px	5	4	3	3	3	2
480px	3	3	3	3	2	1
720px	3	3	3	3	2	1

U33-24/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	5	4	3	4	3
360px	5	5	3	5	3	3
480px	3	3	4	4	2	1
720px	3	3	3	3	3	1

U34-21/F	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	5	3	4	4	4	3
360px	5	3	3	3	3	2
480px	4	3	3	3	2	1
720px	3	4	3	4	1	1

U35-	no	200ms	500ms	loss	loss	loss 1%

22/M				0.1%	0.2%	
240px	4	3	4	3	3	2
360px	4	4	3	4	3	3
480px	3	4	3	3	3	2
720px	3	3	3	3	1	1

U36-22/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	3	4	4	3	3
360px	4	3	3	3	2	3
480px	4	4	3	3	3	2
720px	3	3	4	3	1	1

U37-23/F	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	3	3	4	3	3
360px	5	4	4	3	4	3
480px	3	4	3	2	3	1
720px	4	4	2	3	1	1

U38-22/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	3	3	4	3	3	2
360px	4	4	3	4	3	2
480px	4	3	3	3	1	1
720px	3	3	3	2	1	1

U39-23/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	4	3	3	3	3
360px	4	4	3	3	2	2
480px	3	3	3	3	2	2
720px	3	4	2	3	2	2

U40-22/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	5	4	3	4	3	2
360px	4	4	4	3	4	3
480px	3	4	2	3	2	1
720px	4	2	2	3	1	1

APPENDIX C: 40 USER EXPERIMENTATION RESULTS MOBILE CASE

U1-22/M	no delay	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	2	3	3	4	3
360px	4	3	3	3	2	3
480px	3	3	4	4	3	2
720px	3	3	3	3	2	2

U2-21/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	3	3	2	4	3	3
360px	3	3	4	3	3	4
480px	4	4	2	3	2	3
720px	3	2	3	2	3	2

U3-23/F	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	4	3	3	4	3
360px	4	4	3	4	3	3
480px	4	4	3	4	3	3
720px	4	3	3	4	3	3

U4-23/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	3	2	3	4	3	3
360px	4	4	3	3	4	2
480px	3	3	3	2	3	3
720px	3	2	2	3	3	3

U5-22/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	3	2	3	4	3
360px	4	4	4	3	2	2
480px	2	3	3	4	3	3
720px	2	3	3	2	3	2

U6-21/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	4	3	4	4	3
360px	5	4	3	4	3	3
480px	4	3	3	3	3	3
720px	3	3	2	4	3	2

U7-22/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	3	2	2	4	4	2
360px	4	3	3	3	3	3

480px	3	4	2	3	3	2
720px	4	3	3	2	3	2

U8-23/F	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	4	3	4	3	2
360px	4	3	4	3	4	2
480px	4	4	2	2	2	3
720px	3	2	2	2	2	2

U9-23/F	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	4	3	4	4	3
360px	4	3	4	3	4	2
480px	4	4	2	3	3	3
720px	4	3	2	2	2	2

U10-23/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	4	3	3	3	3
360px	4	4	3	4	4	3
480px	2	3	3	3	4	2
720px	3	3	4	3	2	1

U11-22/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	2	3	3	4	3
360px	4	3	3	3	3	3
480px	4	4	3	4	3	3
720px	4	3	3	4	2	3

U12-24/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	3	2	2	3	3	2
360px	4	3	3	3	4	2
480px	4	4	2	3	3	3
720px	3	2	2	2	2	2

U13-22/F	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	3	3	3	3	4	3
360px	4	3	4	4	4	2
480px	2	3	3	2	3	3
720px	3	3	2	2	2	2

U14-23/F	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	5	5	4	4	3	3

360px	5	4	4	4	3	3
480px	4	4	3	3	3	3
720px	4	3	3	2	3	2

U15-22/F	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	3	3	2	4	4	3
360px	4	3	3	3	4	3
480px	4	4	2	3	3	3
720px	3	3	3	3	3	3

U16-23/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	3	3	4	4	3
360px	3	3	3	4	3	3
480px	4	3	3	4	3	2
720px	3	2	2	3	2	2

U17-24/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	5	4	4	4	3
360px	5	5	4	5	4	3
480px	4	4	4	4	3	3
720px	3	3	3	4	3	3

U18-22/F	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	5	4	4	4	3	3
360px	5	4	4	4	4	3
480px	4	4	3	4	3	3
720px	4	2	2	3	3	2

U19-21/F	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	5	4	4	5	4	3
360px	4	4	5	5	4	3
480px	4	5	4	4	3	3
720px	4	4	3	4	3	3

U20-23/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	3	2	3	3	3	3
360px	3	3	4	3	4	2
480px	2	4	2	2	3	3
720px	3	2	2	2	2	2

U21-22/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%

240px	3	4	3	4	3	3
360px	4	4	4	3	4	3
480px	4	4	3	3	3	3
720px	3	3	2	3	2	2

U22-22/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	4	4	4	4	3
360px	5	3	4	4	4	3
480px	4	4	3	3	3	3
720px	4	3	4	2	3	1

U23-22/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	5	4	4	3	3	3
360px	5	4	3	4	4	2
480px	5	3	3	3	3	3
720px	5	4	3	2	2	3

U24-21/F	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	4	4	4	3	2
360px	5	4	3	4	3	3
480px	3	5	3	3	3	2
720px	3	3	3	3	2	2

U25-22/F	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	4	3	3	4	3
360px	5	4	4	4	4	3
480px	4	3	3	3	4	3
720px	3	4	4	3	3	2

U26-23/F	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	4	4	4	3	3
360px	4	4	3	4	4	3
480px	4	3	3	3	4	3
720px	3	3	4	3	3	3

U27-22/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	5	5	4	4	3	3
360px	5	4	3	3	3	3
480px	4	4	3	3	3	3
720px	3	3	2	3	2	2

U28-	no	200ms	500ms	loss	loss	loss 1%

20/M				0.1%	0.2%	
240px	4	3	3	4	4	3
360px	4	4	4	3	4	2
480px	3	4	3	3	3	3
720px	3	3	3	3	3	2

U29-23/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	5	5	4	4	3	3
360px	5	4	3	4	4	3
480px	4	3	3	3	3	3
720px	3	3	2	2	2	2

U30-23/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	5	4	4	4	4	3
360px	5	3	3	4	3	3
480px	5	4	3	3	3	2
720px	4	3	2	3	3	3

U31-22/F	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	4	4	3	3	3
360px	4	4	4	3	3	2
480px	4	2	4	3	3	3
720px	3	3	2	2	3	3

U32-25/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	4	3	3	4	3
360px	4	3	3	4	3	3
480px	4	4	4	4	3	4
720px	3	3	2	2	2	1

U33-22/F	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	3	3	2	4	3	3
360px	4	4	3	3	3	2
480px	3	3	2	2	3	3
720px	3	2	2	3	2	2

U34-21/F	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	3	3	3	4	3	3
360px	4	3	3	3	3	3
480px	3	4	3	3	3	3
720px	4	3	3	3	3	2

U35-22/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	4	4	4	4	4
360px	4	4	3	4	3	3
480px	4	3	3	4	4	3
720px	3	3	3	3	3	2

U36-22/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	5	4	4	4	3
360px	3	5	4	4	3	3
480px	4	4	3	3	3	3
720px	3	3	3	3	1	2

U37-23/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	4	3	4	4	3
360px	4	3	2	3	2	2
480px	4	4	4	4	3	3
720px	3	2	2	1	2	2

U38-22/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	4	4	4	3	3
360px	5	4	3	3	4	3
480px	5	4	3	3	3	3
720px	4	3	2	2	2	2

U39-23/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	4	4	3	4	4	3
360px	4	3	4	4	4	2
480px	3	3	3	3	3	3
720px	3	3	2	3	3	1

U40-22/M	no	200ms	500ms	loss 0.1%	loss 0.2%	loss 1%
240px	5	4	4	4	3	3
360px	4	4	3	4	4	1
480px	4	3	3	3	4	3
720px	3	3	2	2	3	2