Master Thesis
Electrical Engineering
Thesis no: MEE10:45
May, 2010

Effect of Delay/ Delay Variation on QoE in Video Streaming

Vasanthi Dwaraka Bhamidipati
Swetha Kilari

This thesis is submitted to the School of Computing at Blekinge Institute of Technology in partial fulfillment of the requirements for the degree of Master of Science in Electrical Engineering. The thesis is equivalent to 20 weeks of full time studies.

Contact Information:

Author(s):

1. Vasanthi Dwaraka Bhamidipati
   Address: Lgh 97, Snapphanevägen 8A, 37140, Karlskrona
   E-mail: vasanthi.dwarakabhamidipati@gmail.com

2. Swetha Kilari
   Address: Lgh 24, Uttridarevagen 3A, 37140, Karlskrona
   E-mail: kilari.swetha@gmail.com

Examiner:
Dr. Patrik Arlos (PhD)
School of Computing.

Supervisor:
Tahir Nawaz Minhas
School of Computing

School of Computing
Blekinge Institute of Technology
Box 520
SE – 372 25 Karlskrona
Sweden

Internet : www.bth.se/com
Phone : +46 457 38 50 00
Fax : + 46 457 271 25

ABSTRACT

Video streaming has become the most important way to share video and audio over a network. It is being used for video conferencing, e-learning etc. The user’s quality of experience of watching a video is of utmost importance for the content providers. The video quality is much affected because of packet loss and delay in the network which in turn lowers user’s perception on quality of the received videos. In our thesis we try to find out the effect of delay/delay variation on the quality of experience of the users. We try to evaluate the quality of experience using mean opinion score. The quality of experience as perceived by the user is analyzed for all the videos that we have taken and are streamed with constant and varying delay. From this we were able to find the threshold level of delay that is acceptable by the users. The user’s tolerance towards the quality of the video in a network with a varying delay is analyzed. The effect of packet delay has also been investigated and the results have been analyzed using Excel.

Keywords: QoE, Delay, Delay variation, Streaming server, Shaper, MOS.

Acknowledgement

First of all we would like to thank our Supervisor Mr. Tahir Nawaz Minhas for his kind guidance and ideas that helped us a lot in completing this thesis work. We would also like to thank Dr. Patrik Arlos who guided us to Mr. Tahir Nawaz Minhas and we would also like to thank Mr. Junaid Shaik for his help academically. Finally we would like to thank one and all who were with us during this period.

Thank you very much.

Vasanthi & Swetha.

CONTENTS

List of Acronyms

CIF	- Common Intermediate Format
GNU	- General Public License
HTTP	- Hyper Text Transport Protocol
ITU-T	- International Telecommunication Union-Telecommunication
LAN	- Local Area Network
MOS	- Mean Opinion Score
MPEG	- Moving Pictures Experts Group
NetEm	- Network Emulator
QCIF	- Quarter Common Intermediate Format
QoS	- Quality of Service
QoE	- Quality of Experience
RTP	- Real-time Transport Protocol
RTSP	- Real Time Streaming Protocol
SQCIF	- Sub Quarter Common Intermediate Format
TCP	- Transmission Control Protocol
UDP	- User Datagram Protocol
VLC	- Video LAN Client
VoD	- Video on Demand
MArC	- Measurement Area Controller
MP	- Measurement Point
MAr	- Measurement Area

List of Figures

List of Tables

1 INTRODUCTION

Video streaming over the internet or over a network has been increasing since many years. This video streaming has been particularly important because of its adoption by several users around the world. The increasing demand to deliver rich multimedia content over the network has also made the video streaming an interesting area for research. There are several areas that have to be taken care for video streaming. These may include delay, bandwidth allocation, packet loss etc. Among these, delay and delay variation (jitter) are important issues as it may result in degradation of quality of video. Due to this the end user may suffer a poor quality of experience.

1.1 Background

Due to the ever increasing demand for the multimedia applications in the computer world, video streaming has became a prominent method to exchange the media over a network or on the internet. This kind of video streaming suffers from several factors which are network dependant and independent [8]. The network dependant factors like delay, throughput etc. can be assessed using QoS, while the network independent factors such as encoding, audio-video synchronization, user perceived quality etc can be assessed using QoE. Moreover lots of network service providers are concentrating much on QoE rather than QoS [9]. There are two ways to transmit the video over the network, download mode and streaming mode [11]. In our thesis, we use the streaming mode to broadcast video over the network. While in the other mode, download mode, the user has to download the entire file to his/her system and then can play the video. This requires lot of empty space on the user's system in order to save the file. Moreover, with the streaming mode the user can watch the video whenever network connection is available.

Video streaming can be done by using several protocols that can be applied to transmit the visual media over the internet [1] of which UDP, RTP, RTSP, TCP etc are widely used. All these protocols are having their own advantages and disadvantages and among these protocols we are going to use UDP which is at transport layer. UDP is traditionally used protocol for video streaming [6] and moreover, UDP does not have re-transmission and data-rate management services, which means it is fast enough for real-time audio and video delivery. UDP traffic also enjoys a high-priority status on the Internet, making it fairly smooth [7] and hence we have chosen the same protocol. Moreover there are some other advantages of using UDP like congestion control, rate control, multiplexing etc. The IP protocol is the basic protocol to send the UDP packets over the network [3]. Lot of research has been done on the packet loss and network bandwidth allocation [4]. UDP can also be used for low-bandwidth networks. However there is a lack of research in analyzing the effect of delay and delay variation on video streaming. QoE depends on several factors which include packet loss and transmission delay [12] and we are concentrating on the delay and delay variation (jitter). The online streaming of video requires minimum end-to-end delay/delay variation in order to have a good quality. If the packet does not arrive at the client side on time (due to delay), then it can be treated as a lost packet and so the video frame is also lost, and the quality of the video is decreased [2].

In our thesis, we use a streaming server which is operated on windows environment, Network Emulator (NetEm) which is in Linux environment and at the receiver side we use a windows client. From the streaming server we stream the video to the receiver end with the help of a Network Emulator (NetEm) in between. NetEm is a Network Emulator in Linux kernel which allows dropping, duplicating, delaying of packets. The motivation behind selecting NetEm is that it helps to provide real-time environment in laboratory [13].

The quality of experience is composed of different elements such as zapping, mean opinion score etc [5]. Different research articles have proposed several ways to collect and analyze the MOS which also includes statistical methods as well [14] [15] [16]. The relationship between mean opinion score and delay/delay variation gives a clear view of the user quality of experience by watching the videos. A good MOS (Mean Opinion Score) indicates a good qualitative video streaming.

To maintain the user perceived quality at acceptable level it is quite important to know the feedback from the end users and MOS scale will be used for this purpose. We performed subjective test for different users from various background and of different age groups. The MOS ratings are collected for each streamed video with delay variations, then comparison graphs are drawn and analysis has been made which is presented in chapter 4.

1.2 Problem Statement

Due to the ever increasing demand for video streaming and to watch the video without downloading (VoD) streaming is used. Delay in video streaming cannot be kept constant and varies by the throughput. Due to this, the quality of the streaming video may suffer. Delay cannot be controlled by the content providers and this delay also depends on the network through which the video is streamed. User's perception towards the video quality is very important. Since, delay variation may vary the quality of video, the user's acceptance level of delay is tested. We undertake a subjective test by taking 41 people and showing them the streaming videos at CIF (352X288 resolution, 25fps) standard of varying delay and to know up to what level of delay the users can accept. However the relationship between MOS and delay variation should also be analyzed.

1.3 Research Questions

The analysis of delay/delay variation on the video streaming gives a better view of the user's QoE. In order to perform this analysis a research has been done and the research questions that we are going to answer in this thesis work are

1. What is the effect of packet delay/delay variation on video QoE?
2. What is threshold level of delay/delay variation on video QoE in user's perspective?
3. What is the relation between MOS and Delay/Delay Variation for the videos?

These research questions have been answered through experiment conducted and survey in which the streamed videos were shown to different users (users from different background, age, sex, profession) and MOS from each user is collected. Our thesis can be helpful for content providers to know the threshold level of delay that is acceptable for the users and it can also be helpful for researchers to work on the delay variation to find the effect of delay variation on the quality of video.

1.4 Research Methodology

The research methodology that we are using in our thesis consists of both qualitative and quantitative study. The qualitative part has a detailed literature review and the quantitative part consist empirical study with an experimental setup. The literature review gives the information that is required to study about the video streaming, UDP, adding delay etc. This will be helpful to setup the experiment and to setup the VLC configuration to stream the video over a network. After conducting the experiment the video clips have been shown to different users and a survey is taken to collect statistics of MOS from each user, the results are analyzed to answer the proposed research questions.

1.5 Thesis Outline

In the next Chapter 2 the introduction of VLC is presented. The selection of videos is done. The succeeding sub-section includes the introduction of traffic shaper, adding delay and other NetEm settings are discussed. This will be helpful to conduct the experiment in an easier way. This chapter also consist the QoE measurements and the preparation of the feedback form which has to be presented to the users for subjective test. Chapter 3 contains the details about the design and implementation of experiment for the thesis. A detailed discussion about the experiment is presented and the architecture that is used for the experiment is discussed. The streaming of video's over a network using VLC and other experimental setup has also been discussed. Chapter 4 contains information about the survey results that we have conducted. MOS from different users is taken and presented in this section along with a detailed discussion of the entire experiment. Then we conclude our thesis report in Chapter 5.

2 OVERVIEW OF VLC, NETEM AND QOE

This chapter contains introduction to VLC, Introduction to shaper (Network Emulator), the settings and configuration required to stream the video over the network. These settings are used in our experiment setup to record the videos which were streamed by introducing delay/delay variation. The sub-sections of this chapter consist of the selection of videos, about the codec we used and about UDP protocol, are presented. The QoE and MOS scale that we used for the subjective analysis have also been discussed in this chapter.

2.1 Introduction to VLC

VLC is an open source media player which is released under GNU (General Public License). It can support several file formats including MPEG, AVI, MKV etc and several encoding formats like H.264, DIV3, MPEG-4 etc. It can also act as a streaming server and can accommodate several protocols such as HTTP, UDP, RTP, RTSP etc. The architecture of VLC streaming server can be found in [17].

VLC player include features like media and codec information. One can know the information about the media file that is playing like it's codec information, frame rate, bit rate, total number of frames in the file, etc. One can take snapshots of a video in VLC. Web interface can also be added to VLC player so that when the video is streamed, the receiver can play or stop the video as required by him/her. There are options to view the video at a faster or slower rate and this can be seen from the option playback. It is possible to check the video frame by frame by using the advanced options that is found in view option. Subtitles can be added to the video from video option found in the main menu of VLC. Video can also be zoomed to max. 2:1 double. There is an option to add effects to the video from the effects like rotating the video, adding contrast, sharpness etc to the video and also have other filters option to change the effects of the video that is being played.

There are some other streaming servers, players like Windows Media Server Suite, it is having some disadvantages and it introduces more latency into the network. Moreover VLC is developed for research purposes rather than for entertainment [18]. The reason for using the VLC player is because of its accommodation of several file formats, transcoding techniques and different protocols. Moreover it is free to use, so the licensed version can be used and any legal restrictions can be avoided.

VLC player has several transcoding techniques and it can also allow several codec's to stream the video over a network. In our thesis we are using MPEG-4 codec and the protocol is UDP. MPEG-4 is an international standard codec that provides various tools for compression of audio and video and is standardized by ITU [24]. In our thesis we are using MPEG-4 with CIF resolution videos to evaluate the QoE of the user. We use MPEG-4 video codec due to its efficiency towards no frame skip or quality loss compromise etc [23]. As per [32], H.264 and MPEG-4 AVC are same and moreover this codec is more sophisticated when compared to others. This codec H.264 is developed from the previous versions H.262, MPEG-2 etc to provide better coding efficiency. The H.264 codec has both the encoder and decoder. The decoding method of H.264 is simple than its encoding methods. It is developed to use with the transmission media that does not support higher data rates. The advantages of H.264 are error resiliency and adaptability to various networks. While at the same time it also has some disadvantages like the increase of complexity and computation load [33] [34].

In comparison with its previous standards, H.264 gives about 50% improved bit-rate efficiency. It has also been used in several applications such as HD DVD, HD-

DTV etc. It is flexible and handles a number of tools and also well designed for applications ranging from low bit rate and low resolution to high bit rate and high resolution [36] [37].

Since UDP is real time protocol, it is used for streaming videos over the network. The complexity of using UDP is very low and at the client's end as well as at server, no extra memory is needed and it is also helpful to get good subjective quality results [19]. The drawback of using UDP is that it does not support reordering of packets.

2.2 Selection of Videos for Streaming

The resolution of the video plays an important role to assess the quality of the video. The users will feel uncomfortable if the video is of low quality. We use CIF standard video resolution which was proposed by ITU-T [20] [21]. There are some other video resolutions like QCIF, SQCIF, 4CIF etc. However we used CIF (352X288 pixels, 25 fps) standard resolution.

Fig 2.1 Foreman

Fig 2.2 News

Fig 2.3 Football

In the above figures Fig. 2.1 represents slow moving video, Fig. 2.2 shows the combination of slow and fast moving video and Fig. 2.3 represents fast moving video. All these three videos are downloaded in y4m format as said earlier and were converted to AVI format. All these three are downloaded from [22].

2.3 Traffic Shaper (NetEm)

Traffic shaping is also called as packet shaping, regulates network data transfer to meet certain level of performance quality of service (QoS).Traffic shaping controls certain features of packets to accomplish the predefined task and this control is always done by delaying the packets. Traffic shaping is implemented at network edges to control the incoming and outgoing traffic of the network.

The performance of many protocols and applications is poor when disclosed to a network with parameters packet loss and delay .It is hard to reproduce the network behavior in a controlled environment. "*Network emulation is one way to evaluate the network performance in a controlled and repeatable environment*" [25].Traffic shaping is used in network emulation to analyze the impact of network on protocols and applications.

In our experimental analysis NetEm is used to introduce the variable delay for the incoming packets. There are many other network emulators which can be used to introduce the constant delay on packets. Dummynet and NIST Net are the other two network emulators which have the similar design as NetEm.

Dummynet has the features similar to NetEm which can also introduce packet filtering. Dummynet produces a "pipe" object and configures this object with the loss parameters and the delay metrics. However it is more independent and not extendible. NIST Net is a Linux kernel extension, provides emulation of network such as delay, packet duplication and packet loss. Many features of NIST Net are used in NetEm as

NIST Net is a public domain. NIST Net is similar to Dummynet it does not have its own filtering and queuing [13].

NetEm is one of the network emulators which provide network emulation by emulating network properties. NetEm is the recent enhancement of the Linux designed by applying existing QoS and differentiated services in the Linux kernel. NetEm comprises of two components namely kernel module for queuing discipline and command line utility for configuration. Communication between command line and Linux kernel is achieved by Net link socket interface [13].The queuing discipline used by NetEm is the FIFO queuing, the queuing discipline is in between the network device and the protocol output.

NetEm is controlled by a command line tool ‘tc’ (Traffic Control) which is a part of iproute2 package of tools. Four basic operations are available in the current version of NetEm: variable delay, packet loss, duplication and re-ordering of packets. The paper focuses on introducing variable delay on all outgoing packets from an interface.

The commands that are used to add delay on the packets must be used in the Linux kernel. The commands are as follows:

```
tc qdisc add dev eth2 root NetEm delay 100ms
tc qdisc change dev eth2 root NetEm delay 100ms 10ms
```

Where ‘tc’ command is used for configuration of the traffic control in the Linux kernel. Traffic control consists of shaping, scheduling, policing and dropping.

‘qdisc’ means queuing discipline which understands the traffic control. A simple ‘qdisc’ is the First In, First Out queue.

‘add’ is a tc command which adds qdisc to a node. ‘Change’ shares the syntax of ‘add’ which allows changing some entities

The first command adds a constant delay of 100ms to all packets going out of a local Ethernet ‘eth2’ and the second line introduces an added delay of 10ms to the constant delay 100ms.This added delay is not uniform in the network ,delay can be made uniform by adding a label ‘distribution normal’ to the above commands.

In our experiment, NetEm is placed in between VLC server and VLC client in LAN through an Ethernet cable. We introduce a delay of D±ΔD in NetEm through the commands as discussed above. This introduces certain amount of delay to all the traffic going out of local network, where D is the fixed delay and ΔD is the variable delay. NetEm used in the experiment was installed on Intel platform. NetEm implemented in the experiment as discussed in Section 3 is working properly and is validated in the paper [25]. For instance if a delay of 100ms is set then the packets are delayed with an of 100.3ms.

2.4 Users Quality of Experience (QoE) using MOS

Most resource reservation mechanisms for multimedia applications are driven by QoS and service level agreements. Such policy decisions are based on QoE, which can evaluate subjective video perception even better. *"QoE is a measure of performance expectations of the end-user; it augments QoS by providing the quantitative link to user perception"* [29]. According to Daniel R. Scoggin *“The only way to know how customers see your business is to look at it through their eyes”*. It is very important for a service provider to estimate the end users perception to survive in today's competitive market. The streamed video quality at the receiver side depends on a variety of network conditions like delay, packet loss etc.

The following are the two common methods to estimate the QoE:

1. Objective assessment
2. Subjective assessment

Objective quality measurements are mathematical models which estimate human perceptual behavior. This approach can be used to provide quick and cost effective measurements. These models are strongly dependent on type of codec used and the encoded parameters. The objective quality measurements should be in similar to subjective quality measurements or should reflect the subjective measurements. There are many methods for calculation of objective video quality. An objective measurement always doesn't correlate well with the reality. So, it is always recommended to estimate the quality with subjective methods.

Subjective quality measurement is the measure of user perceived video. Subjective measurement is based on the human perceptual quality. However it is difficult to obtain the accurate results from subjective video quality measurements. To obtain the accurate results, the tests should be repeated for several times which could be a time consuming process. The test should be carried out with large number of test subjects causing the test expensive and unmanageable to carry out the experiment.

The subjective quality measurements are based on the analysis of MOS that is given by the assessors (viewers).Subjective measurements involves in exhibiting the viewers with bunch of short video sequences. The viewer is asked to judge the subjective video quality of the test video sequences shown.

The test consists of showing the alternate versions of the video sequences with different delay settings. For each scenario the viewer should watch the video and grade the particular video separately. After the completion of each video, assessors will rate the quality of video clip by marking on a continuous scale ranging from 5 as excellent to 1 as bad as shown in the Table 2.1. The time taken to perform the experiment linearly increases as the number of videos increases.

In our thesis we use subjective assessment in which viewers are given the chance of viewing videos and are asked to rate the video quality. This is called MOS and consist values starting from 5 to 1 and is recommended by ITU [10].The values calculated from MOS will judge the quality of the video.

Table 2.1 Mean Opinion Score [27]

MOS	**Quality**	**Perception**
5	Excellent	Imperceptible
4	Good	Perceptible
3	Fair	Slightly annoying
2	Poor	Annoying
1	Bad	Very annoying

Moreover there are some drawbacks of using the MOS to evaluate the QoE and are discussed in [8]. Since it is easy to use and users will feel more comfortable to rate, we use mean opinion score to evaluate QoE. Rating 5 is termed as 'Excellent' and rating 1 is 'Bad'. We placed 'RT' which is nothing but Repeating Time and it is number of times that user wants to see a particular video. People from different background and different age groups are made part of this subjective analysis. The rating for each video (even for videos with different delay values) is calculated and then graphs are made which can found in appendix A.

This feedback form is presented to 41 human subjects and the videos with different delay values are shown. The feedbacks are collected from all the participants and are evaluated using graphs that are presented in appendix A. This can be helpful to find out the acceptable level of delay or threshold delay according to user's perspective and this helps to answer our second research question.

3 Experiment

In order to analyze the impact of delay and delay variation on user's perceived quality in video streaming, we designed an experiment in which users were asked to rate the quality for three different types of video clips.

3.1 Experiment Setup

The experimental setup consists of a video streaming server, video client and a Network Emulator "NetEm". The traffic between server and client is forwarded by the network emulator which introduces artificial delay. Experiment is carried out by streaming videos from a streaming server to a client. VLC server and VLC client set up were built on windows environment while the shaper (NetEm) was configured with Linux kernel. The design of the experiment is shown in the Fig 3.1.

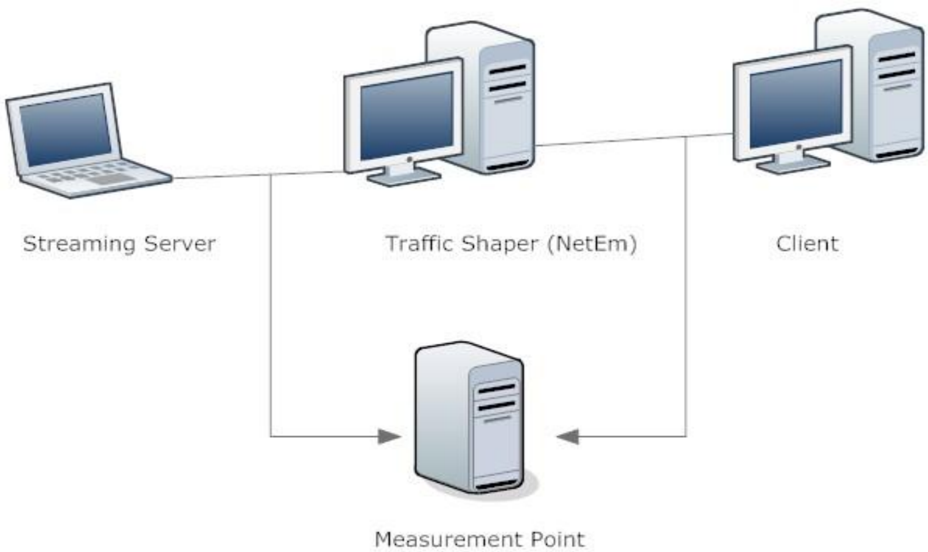

Fig. 3.1 Design of the Experiment

In our experiment the traffic metrics are captured at 'Measurement Point (MP)'. The important tasks of MP include packet capturing, packet filtering etc. The packet capturing at the MP is managed by Measurement Area Controller (MArC) which in turn transfers these packets to the consumer. MP can be classified as logical or a physical device. A logical MP is a program whereas, a physical device is a dedicated system [35]. In our experiment we use a physical device which is shown in Fig 3.1. In MP we use two DAG (Digital Acquisition and Generation) cards namely DAG0 and DAG1. The purpose of DAG0 is to capture the traffic between sender and shaper. DAG1 is used to capture the traffic between shaper and receiver. From this we can find the exact delay measurements.

MArC is a central subsystem in Measurement Area (MAr). It is used to provide filters to MP so that no packet can arrive at MP more than once. MArC is being notified if there is any packet loss and so it can take actions to prevent any future losses. MArC helps to keep track of MP such that it knows the number of filters that the MP can handle so that it does not have performance problems [35]

Consumer is a user-controlled system and it is used to filter the contents of the measurement frames. The consumer can reduce the load on MP by providing some filtering of its own. Both MP and Consumer come under the Measurement Area, which is a common point that controls one or more MP'S [35].

To start our experimental setup, we first need to startup MArC followed by Consumer. In Consumer, we specified the file name for capturing the packet traffic of the video. Then we started MP where the traffic is captured.

Before streaming the video, we start the shaper and add an initial delay of 100ms. Then in the server system we initialize VLC to stream the videos. In order to save another file in consumer, we first need to kill MP and then kill consumer and specify another file name by varying the delay. The commands required for this setup are in [B.2].

Total of three video clips Football, News, and Foreman were used in the experiment where we had nine different scenarios with different delay settings. Original video sequences having the container format of .AVI that are transcoded and streamed using the encapsulation method MP4.

Streaming starts with football video of length 10sec. At the client side, windows based VLC client is used to receive the video stream. Before starting the streaming procedure at the server side, the VLC client should be initialized with required settings to save the video. If the VLC client is initialized after streaming from server there are chances of missing initial frames. Shaper was set with 100ms of constant delay for the first football video. This streamed video with 100ms delay is saved at VLC client computer with a different file name. For each session the delay settings in shaper should be changed with the values as shown in the Table 3.2. Football video is streamed for nine times with different delay settings starting with the constant delay 100ms and 100ms±{2,4,6,8,10,12,14,16}ms. The same streaming procedure was continued for the other two videos news and foreman. All the videos are saved at the client end and are compared with the original videos. Finally a total of twenty seven videos were streamed and stored at the client end, nine video clips from each category such as football, news and foreman.

Testing of the Experimental Setup: The total setup was checked beforehand to avoid further complications. We checked the connectivity between server, client and shaper before streaming. We tested if the same number of packets is being transmitted at the client side. Devices Mp, shaper and consumer were also tested before. MP was tested based on the DAG cards i.e., it was checked that the DAG cards are working properly (we could test this by streaming the video and check if the packets have been captured in between shaper and MP; between MP and client). Shaper was tested by giving the delay to the streamed video and it was working well because we could see the difference in the original video and the videos with delay.

3.1.1 Videos used for the Experiment

Three video clips football, news and foreman are used for the implementation of the experiment. According to ITU-R [26], the length of the video should be at least 5sec.The selected football video is of 10sec duration, news and foreman are of 12sec duration. Short duration videos are selected as subjective analysis is carried out in our experiment. If the longer duration videos were used then the users may get bored to watch each and every video and rate them. Three different types of videos are used because of their different characteristics: high, alternating, and low movements. The characteristics of the videos are shown in the table. Each video sequence is of 25 fps and of CIF resolution. For the fast movement category, a football video is used, it is fast moving sport clip where the entire video moves uniformly. For the alternating movement category, a news video is used, which contains male and female speakers in a news room with a combination of fast movement in the background. For the slow movement category, foreman video has been used, which contains fair amount of movement with change of background. All the videos football, news and foreman are taken from the source [22].The video sequences of YUV file format are converted to .AVI format using an open source software tool called FFMPEG encoder. YUV model specifies the color space in terms of luminance and chrominance. Y stands for one luma and other two represents chrominance components.AVI is the widely used container stands for Audio Video Interleave.AVI format is used because is supports multiple streaming audio and video files.

Table 3.1 Characteristics of the videos

File	**Football**	**News**	**Foreman**
Action	High movement	Alternating movement	Slow movement
Resolution	CIF(352x288)	CIF(352x288)	CIF(352x288)
Duration	10sec	12sec	12sec
Frames	260	300	300
FPS	25	25	25

3.2 Streaming of Videos over a Network

In this chapter the streaming method for videos and configuration settings for streaming server of VLC is presented. In order to stream the video, a streaming server to stream and a client to receive the stream is needed. The client should be connected to the streaming server via a wired/wireless connection. A more detailed explanation with screenshots of how to stream the above selected videos is presented in the next sub-sections.

3.2.1 Streaming of Videos

In order to stream the videos, both the server and client should have VLC player installed. Both the systems have to be connected in LAN through an Ethernet cable. After the server and client systems are connected, the configuration for server and client is presented separately.

Configuration at the Streaming Server

1. Start the VLC player and then press ‘Media’ option on the main menu
2. Then click on ‘Streaming’ button.
3. In the next menu click on ‘Add’ to add the video files and then click on ‘Stream’ button can be found at the end of menu, this can found in Fig. 3.2

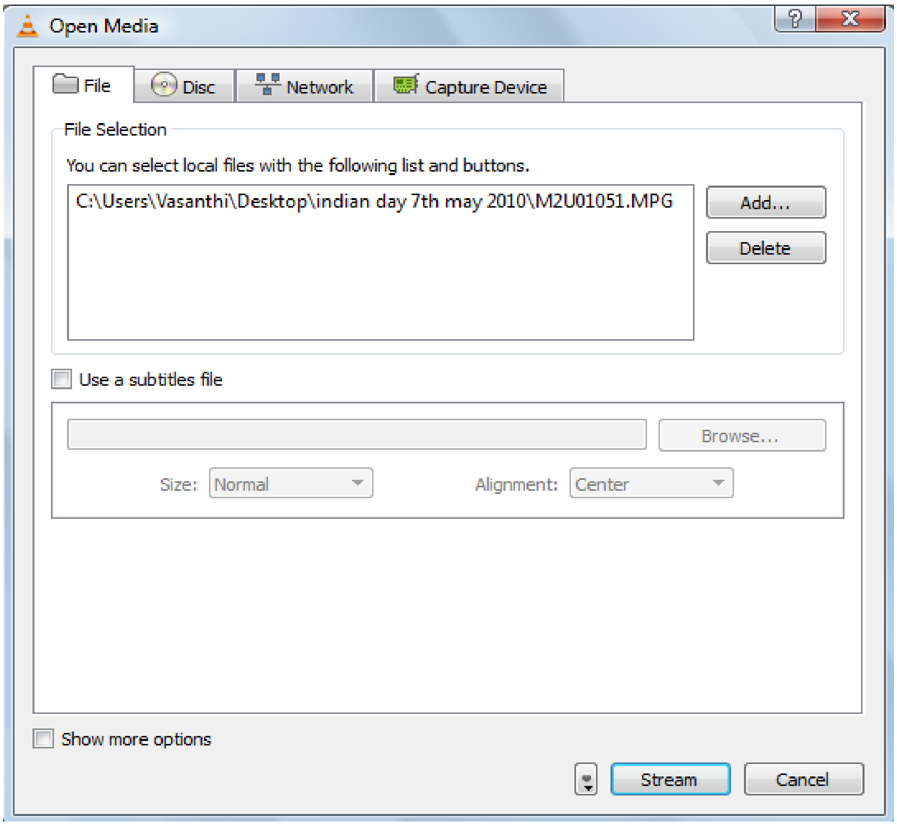

Fig. 3.2 Adding a file to VLC for streaming

4. In the next menu as in Fig. 3.3, under New Destination select UDP and click on Add button

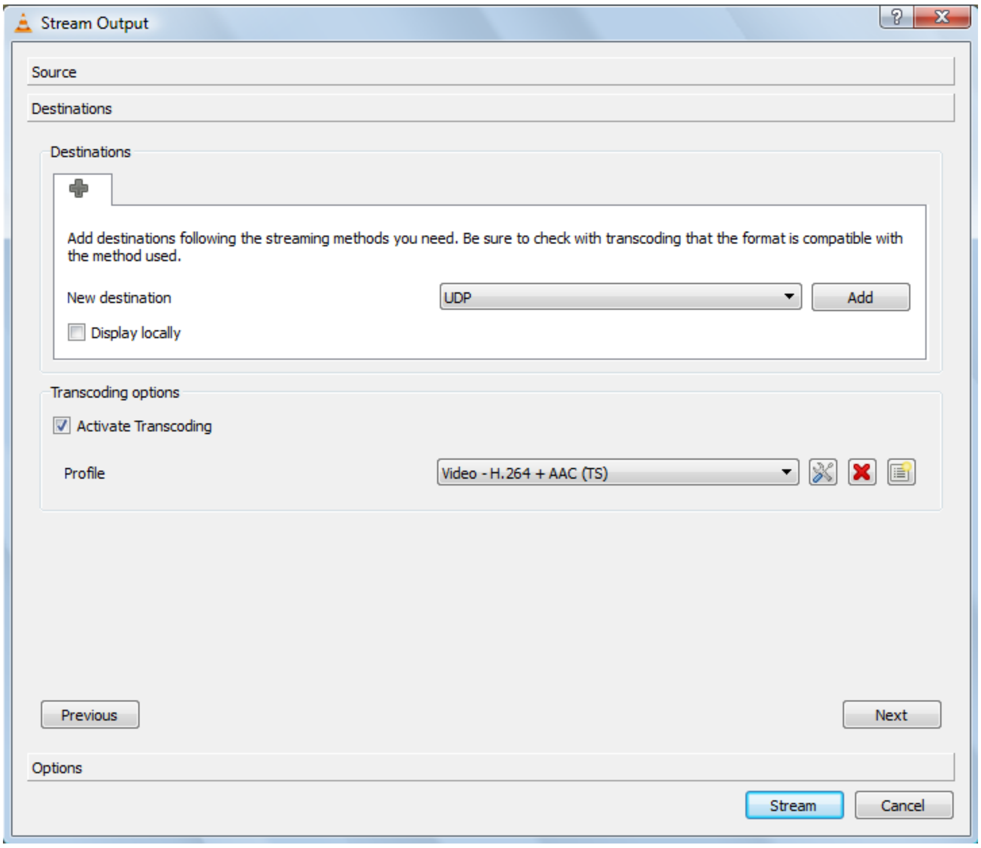

Fig. 3.3 Adding new destination to stream the video

5. In the next menu from Fig. 3.4 fill in the ‘Address’ field with the IP address of the destination or client and leave the port number as ‘1234’.

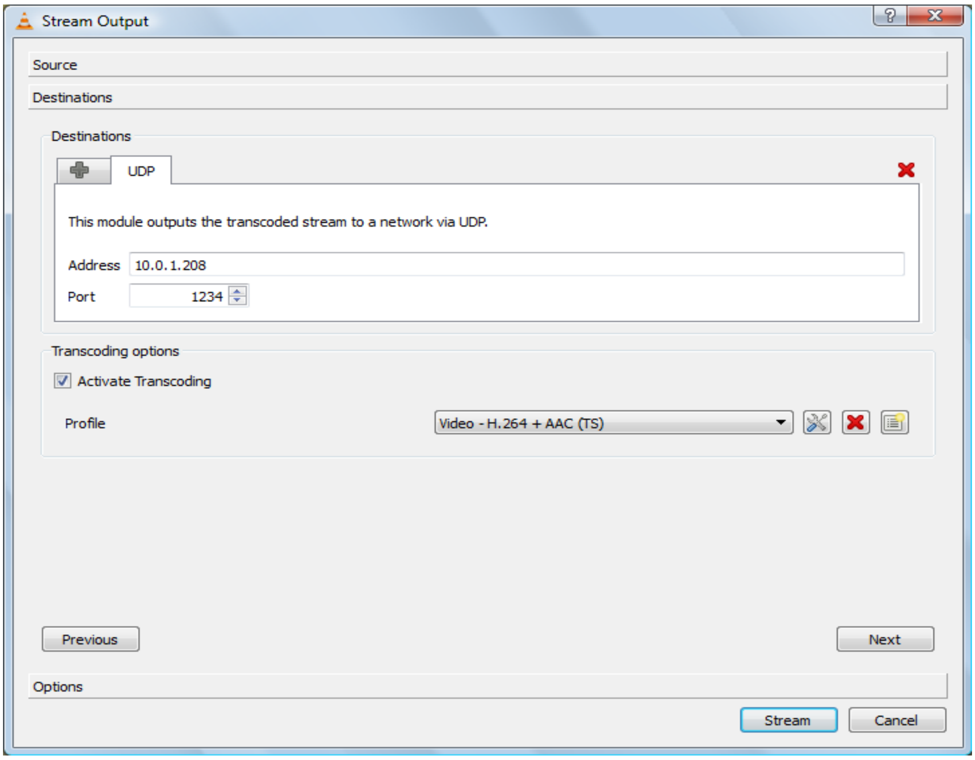

Fig. 3.4 Adding Destination address

6. Then click on ‘Edit selected profile’ in the profile menu and then in video codec keep the bit rate at 800 kb/s which is a default value and then the frame rate to 25fps.
7. Click on save and then click on ‘Next’ and then in the next screen just click on ‘Stream’.

Configuration at the Client (User) Side

1. At the client side open VLC player and click on ‘Media’ and then click on ‘Open Network Stream’
2. In the next screen select the protocol as ‘UDP’ and leave the Address as blank and port number as 1234 as shown in Fig. 3.5

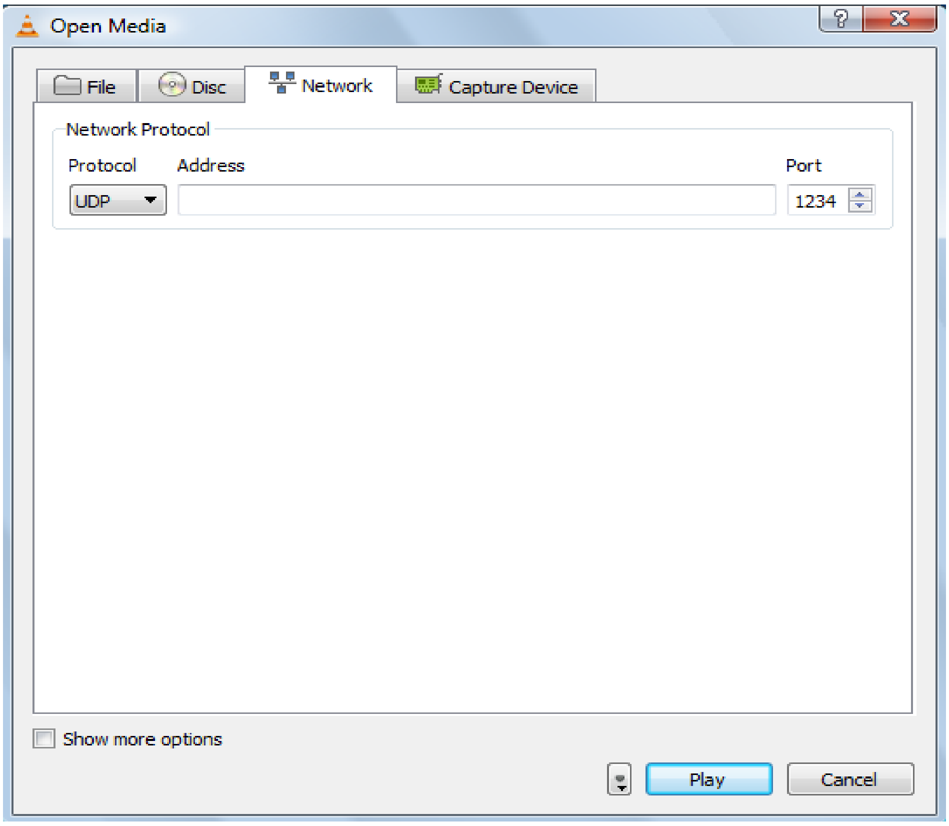

Fig. 3.5 Receiving video stream

3. Then click on 'Play' and the video will be streamed to the client and will be played.

3.2.2 Record/Save of Streaming Videos

VLC media player can convert and save different videos that are being streamed over a network. This option is much useful for the users to save the streaming videos. In this section the configuration for saving on streamed videos is presented.

1. Click on 'View' in the VLC's main menu and then select 'Advanced Controls'
2. When playing a stream video in the network at the client end, click on 'Record' button in the advanced controls and the video is saved to default location
3. Video can also be saved by going to the 'Media' option in the main menu and click convert/save then select the Network option that comes on the next window, select the destination where the file needs to be saved.
4. Check mark on Dump Raw I/P and click play.

3.3 Delay Settings

This section discusses the different delay settings used in the experiment. In order to analyze the impact of delay on video QoE, we selected three video clips and these video clips are streamed by introducing different delays and delay variations using a network emulator (NetEm). The delay introduced in NetEm is D±ΔD, where D is the fixed delay and ΔD is variable delay. We conducted many experiments for the selection of delay settings, the delay values were selected such that the impact of the selected delay does not affect the video quality of experience to a greater extent. The delay used in our experiment is the combination of fixed delay and variable delay, fixed delay doesn't have much impact on the video QoE because it just introduces a constant delay on all the outgoing packets, where as a variable delay varies from packet to packet which in turn affects the quality of video badly. The combination of these two is applied on three videos football, news and foreman to analyze the delay impact on user's perceived video quality. Videos are streamed with different delay settings with different combinations of fixed and variable delays. If the selected delay is very large, then the video quality completely degrades and no information is seen from the videos.

Experiments were conducted with fixed delay values of 25ms,50ms,75ms and 100ms and variable delays of [±{0, 2, 3, 4, 6, 8, 10, 15}ms]. We have also taken the constant delay values of 150ms, 200ms, 250ms, and 300ms and these delay settings did not have much effect on the videos. Apart from these delay settings ,we also conducted experiments with some other variable delay values but the impact of variable delays [±{1,5,7,9,11,12,13,14,}ms] are approximately similar with the variable delay set[±{0, 2, 4, 6, 8, 10, 16}ms] . Out of the four fixed delay values, 100ms is selected for the experimental analysis based upon a small survey conducted on users. The football video has been selected for this survey and was streamed with combination of fixed and variable delay values [{25, 50, 75,100} ± {0, 2, 3,4, 6, 8, 10, 15}] ms resulting four football video sequences. Football1 with fixed delay 25ms,football 2 with 50ms fixed delay,football3 with fixed delay75ms and football4 with 100ms fixed delay, all these four videos have the same variable delay [±{0, 2, 3, 4, 6, 8, 10, 15}ms]. Each football video sequence contains eight videos. These streamed videos are saved at the client end and are shown to the users. A feedback form was designed as shown in appendix A and was given to users where the users need to enter their profile information and rate the four football video sequences. The results of the users are quite similar for four fixed delays and no variation with the change of delays.

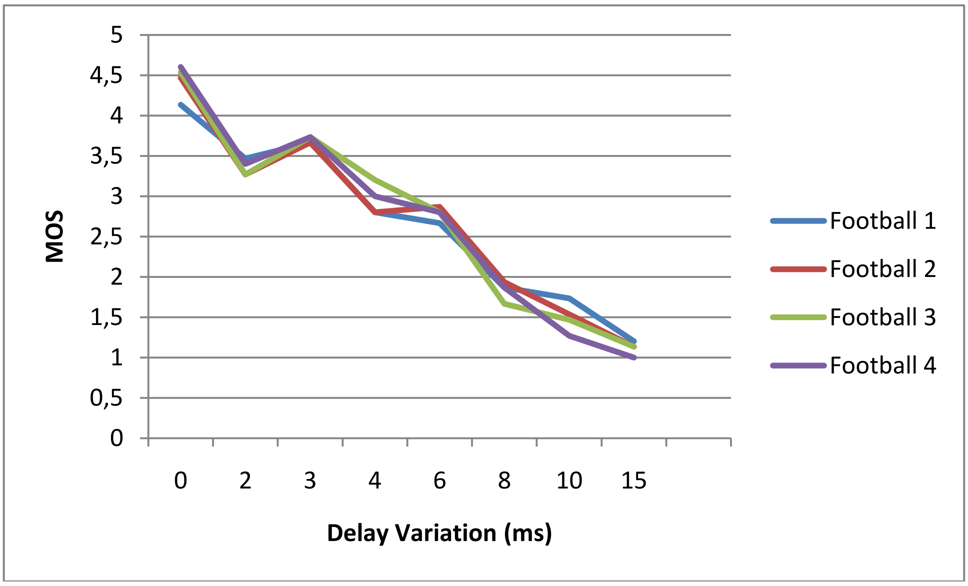

Fig. 3.6 MOS ratings for four football videos

Fig 3.6 illustrates the rating of the users with different delay settings. Where X-axis represents the delay D±ΔD i.e. [{25, 50, 75,100} ± {0, 2, 4, 6, 8, 10, 12, 14, 16}] ms and Y-axis represents the user ratings. The blue line represents the video sequence football1, red line for video sequence football2, green line for video sequence football3 and purple for the video sequence football4.The MOS ratings four videos sequences were aggregated in one graph to make the comparison easy. It is observed that the user quality of experience for four video sequences football1, 2, 3, and 4 is approximately similar. This shows that there is no difference between the videos recorded with different fixed delays. As there is no significant difference with different fixed delays, and the rating for the football 4 video sequence is maximum for lower delay values and minimum for higher delay values. Hence, the fixed delay of 100ms was set for the total experimental analysis.

It is observed that the user quality of experience for four videos football1, 2, 3, and 4 with fixed delays of 25ms, 50ms, 75ms, and 100ms is approximately similar. rating for football 4 is maximum for lower delay values and minimum for higher delay values. Hence, the fixed delay of 100ms was set for the total experimental analysis.

The variation in video is caused with the variable delay introduced in combination with fixed delay. Fixed delay introduces constant delay on video sequences and has no significant impact on the video quality. Variable delay, for instance100ms±8ms introduces delay between 92 and 108 which has higher impact on video quality.

Table 3.2 Delay settings for experiment

FILE			Delay(D±ΔD)ms
Football	**News**	**Foreman**	
Football a	News a	Foreman a	100ms
Football b	News b	Foreman b	100ms±2ms
Football c	News c	Foreman c	100ms±4ms
Football d	News d	Foreman d	100ms±6ms
Football e	News e	Foreman e	100ms±8ms
Football f	News f	Foreman f	100ms±10ms
Football g	News g	Foreman g	100ms±12ms
Football h	News h	Foreman h	100ms±14ms
Football i	News i	Foreman i	100ms±16ms

Three video clips football, news and foreman were streamed with wide range of delay settings. The videos with 100ms, 100ms±{1, 2, 3, 4,} ms delay settings have lower impact on user's perception of quality and was comparable with original video. As the delay increased beyond 4ms, the video quality was tending towards low user's QoE and at 100ms±16ms the video quality was very annoying without any information in the frames. So, the delay values were selected such that the video frames contain some information. The different delay settings which are used in the experiment are as shown in Table 3.2.

3.4 Data Collection

Total of 41 users were made part of our experiment. All the viewers were students of different disciplines mostly from telecommunication and software department. Out of 41 users 11 viewers were females and 30 were males with age group of 22 to 30. Each user was tested with twenty seven video sequences, nine from each category.

For displaying the streaming video, the viewing conditions were mostly followed as recommended by ITU-R Rec. BT.5005 [26] and ITU-T Rec. P.910 [27]. Each user was allotted a PC and the content was viewed only by a single user. For subjective testing, LCD screens are used as monitors because laptops and mobile devices nowadays have LCD screens. The particular screen used, DELL INSPIRON 1525 has the following display specifications:

Resolution: 1440x900
Size: 15.4
Illumination: Backlight illumination
Length x Height: 13.1" x 8.2"

A feedback form was given to each user, where he/she was asked to provide the profile information: Name, Gender, age and opinion on the videos depicted. The viewers should go across 27 videos, nine from each class.

The users were unaware of the delay settings on the videos, they were asked to rate according to the video quality as they perceived. Original video was displayed initially followed by other video sequences. The screen shots of the videos are as shown in the Figures [3.7 - 3.18]. The video files are given different names such that the user has no clue about delay settings. Care was taken so that the videos were not played in ascending or descending order of delays. Each Session took 15min approximately. After watching each video, the users were asked to record their opinions on video quality by picking out one of the five quality levels as show in Table 2.1.

Fig. 3.7 Original Video

Fig. 3.8 100ms ±4ms delay

Fig. 3.9 100ms±10ms delay

Fig. 3.10 100ms±16ms delay

The screenshots for the football videos are as shown in the figures 3.7-3.10.The video quality of experience for each football video is different because of the different added delay. The screen shot in the fig 3.7 is the original video without any delay. The video frame of fig 3.8 consists of delay 100ms±4ms which has the low video quality compared with the original video. The video clip as shown in fig 3.9 with delay 100ms±10ms degrades a little but, the video still contains some information. The video frame in the fig 3.10 completely degrades which contains no information. This is due to the large delay 100ms ± 16ms added on the video. As the football video is fast moving video which has video frames of people moving with high speed, the movements are still visible with larger delays.

Fig. 3.11 Original Video

Fig 3.12 100ms±4ms delay


Fig. 3.13 100ms±10ms delay


Fig. 3.14 100ms±16ms delay

The figures 3.11-3.14 are the screen shots of the news video. The original news video clip without any delay is as shown in the fig 3.11.The video frame with 100ms±4ms delay is exactly similar to that of the original video. When the video is added with delay of 100ms±10ms the video quality degraded to a greater extent, where the image of the girl dancing is visible. The video completely degrades without any information with delay 100ms±16ms.News video is a combination of low and high movements. With larger delays, the fast movements like dancing are still perceivable but the slow movement frames are completely degraded.


Fig. 3.15 Original Video


Fig. 3.16 100ms±4ms delay


Fig. 3.17 100ms±10ms delay

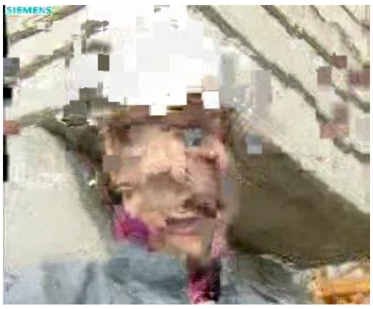
Fig. 3.18 100ms±16ms delay

The screen shots of the foreman videos with different delays are shown in the figures 3.15-3.18.The original video frame and the video frame with 100ms±4ms delay seems to be the same when viewed. When the delay was increased to 100ms±10ms delay as shown in the figure 3.17 the image of the person becomes unperceivable. At 100ms±16ms delay the video frame becomes worst compared to 100ms±10ms delay and the complete video frame degrades leaving no information. Foreman is a slow moving video which focuses on a closure image of a person, so a small change in delay causes adverse effects on the video frames.

4 RESULTS

In this chapter, we analyze the available results obtained by streaming the videos Football, News, Foreman with different delay settings. The data obtained from the above scenario was gathered and graphs were plotted on user rating versus delay variation, followed by an observation of delay impact on video quality of experience.

4.1 MOS ratings

Results to different video sequences were recorded according to the user's video quality perception to each scenario in experiments. If the user's considered the video quality to be fully satisfied then they rated it as Excellent, Good was given to the videos if they were merely satisfied and perceptible, fair was given while the user's felt the video quality is slightly annoying, videos are rated poor if the video quality was annoying and bad to the videos without any information and very annoying.

To determine if a streaming video with a particular delay was acceptable for user's the data collected were d over all users. Table 4.1 shows the MOS ratings for different video sequences with different delay settings. The table is divided into three columns, where the first column is assigned to the video sequence football, second for news video sequence and third is allocated to the foreman video sequence. User's ratings are convincing for videos with lower delay values of 100ms and ±{2ms, 4ms}, where as for higher delay values ±{6ms, 8ms, 10ms, 12ms, 14ms, 16ms} the user's ratings are very poor.

Table 4.1 MOS ratings and Delay for football, news and foreman videos

FOOTBALL		**NEWS**		**FOREMAN**	
Delay	MOS	Delay	MOS	Delay	MOS
100ms	4.38	100ms	4.68	100ms	3.73
100ms±2ms	3.95	100ms±2ms	4.22	100ms±2ms	3.61
100ms±4ms	3.46	100ms±4ms	3.41	100ms±4ms	2.95
100ms±6ms	2.83	100ms±6ms	2.68	100ms±6ms	2.15
100ms±8ms	2.19	100ms±8ms	2.12	100ms±8ms	1.68
100ms±10ms	1.46	100ms±10ms	1.44	100ms±10ms	1.41
100ms±12ms	1.38	100ms±12ms	1.27	100ms±12ms	1.32
100ms±14ms	1.04	100ms±14ms	1.04	100ms±14ms	1.12
100ms±16ms	1.04	100ms±16ms	1.15	100ms±16ms	1.15

The user responses provided us an inference, on how the user perception is impacted because of changes in videos with delays. When the users were exhibited a video with 100ms delay *fair* ratings were given, QoE ratings were decreased when introduced with higher delay videos, where as the QoE ratings increased to *excellent* and *good* when the user's experienced with videos of delay settings ±2ms and ±4ms. The video with 100ms has better quality when compared to ±2ms and ±4ms. This shows how the user perception affected with experience of delay settings.

4.2 Data analysis:

As discussed in the section 2.4, users need to rate the video by picking out one of the quality levels: Excellent, Good, Fair, Poor and bad. For quantitative analysis EXCELLENT is rated as 5, GOOD as 4, FAIR as 3, POOR as 2 and BAD as 1.

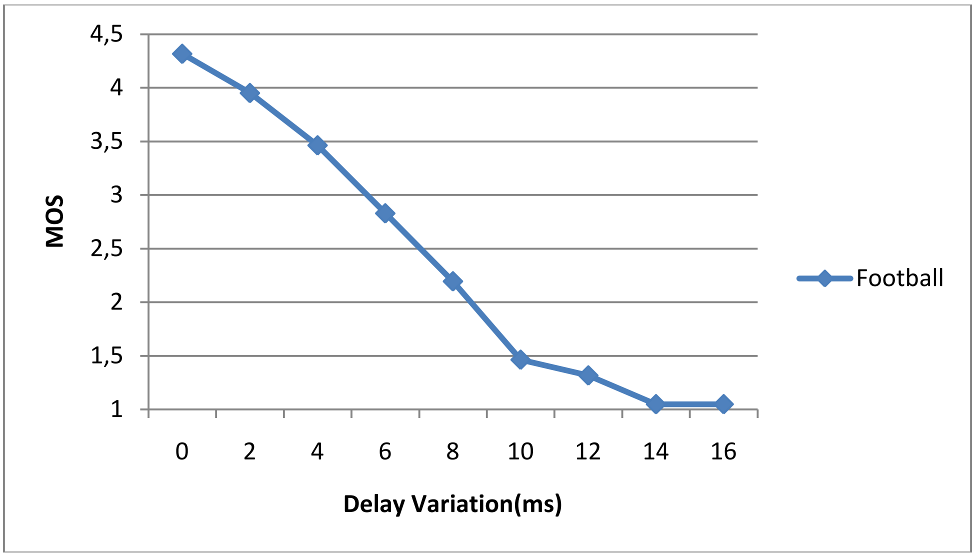

Fig. 4.1 MOS ratings for football video

The MOS ratings for the football video are shown in the fig 4.1.The X-axis consists of the Delay variation and Y-axis represents the Avg MOS calculated from the 41 individual users results obtained. At 0ms variable delay the quality of video is approximately equal to the original video. The user MOS ratings at this delay are high i.e. around 4.5. As the delay increased to the higer levels the graph linearly decreases and a sudden change occurs at ±10ms .The ratings from this point of delay gradually decreases and at ±16ms the Avg MOS is very bad.

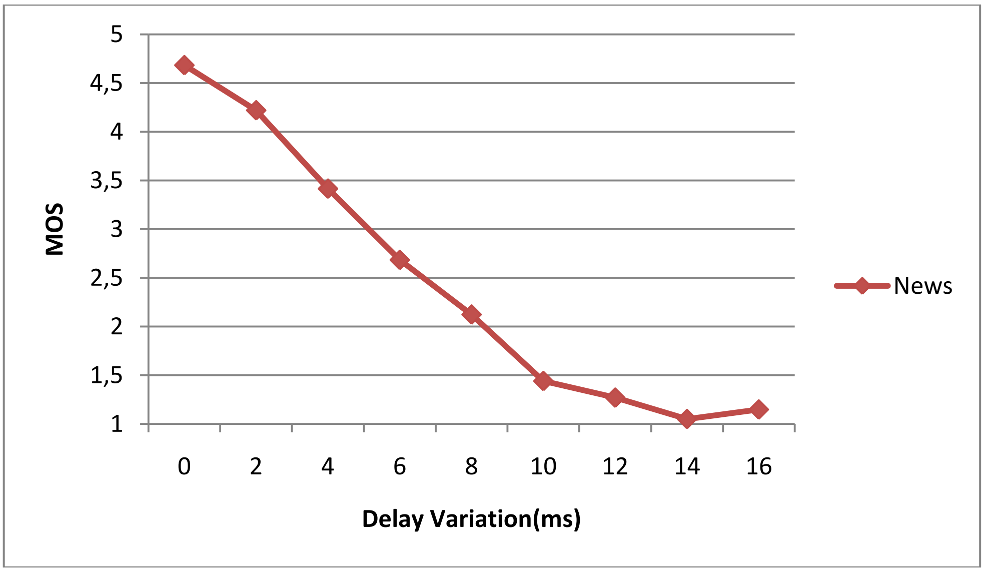

Fig. 4.2 MOS ratings for news video

The MOS ratings for the News video are shown in the fig 4.2.The X-axis of the graph shows the Delay variation and Y-axis represents the MOS ratings of the 41 users. The quality of the news video at 0ms of variable delay is good and resembles the original video. News video is given good rating for the initial variable delays compared to the video clips football and foreman, which is clearly seen from the fig

4.4.As the delay increased beyond ±2ms the MOS ratings linearly decreased until ±8ms. As delay increases beyond ±8ms the graph is tending towards MOS scale 1.At higher delays the football and news videos are approximately equal.

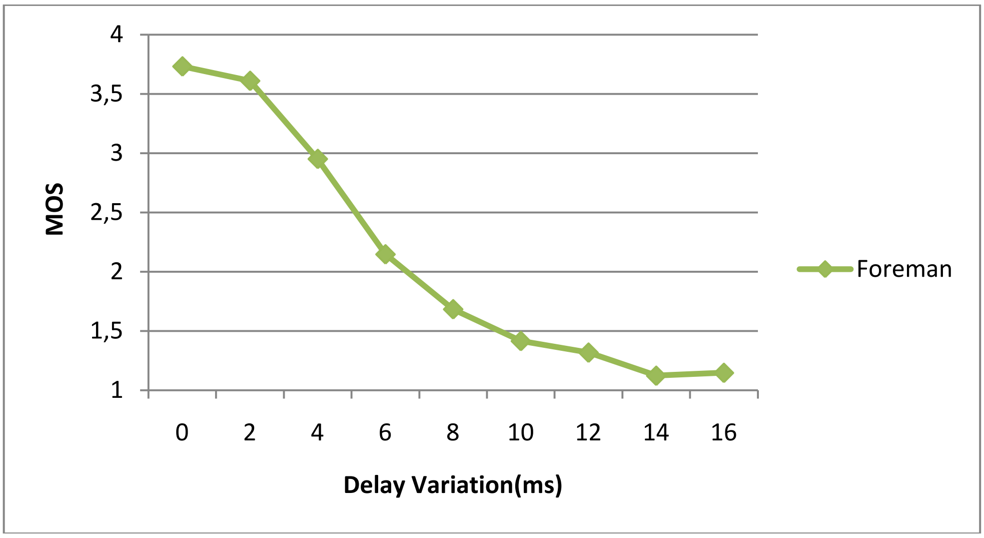

Fig. 4.3 MOS ratings for foreman video

The MOS ratings for the foreman video are shown in the fig 4.3.The X-axis represents the Delay variation applied on the videos and Y-axis represents the Mos ratings obtained for the videos. At 0ms of variable delay,the foreman video has rating around 3.7, which is the very poor rating for this point of delay when compared to football and news. At ±4ms the graph abruptly falls down to a scale of 2.9 and continues until ±8ms. At ±10ms the graph tends towards the MOS scale 1.The foreman video has got a very bad rating when comapred to the videos football and news.

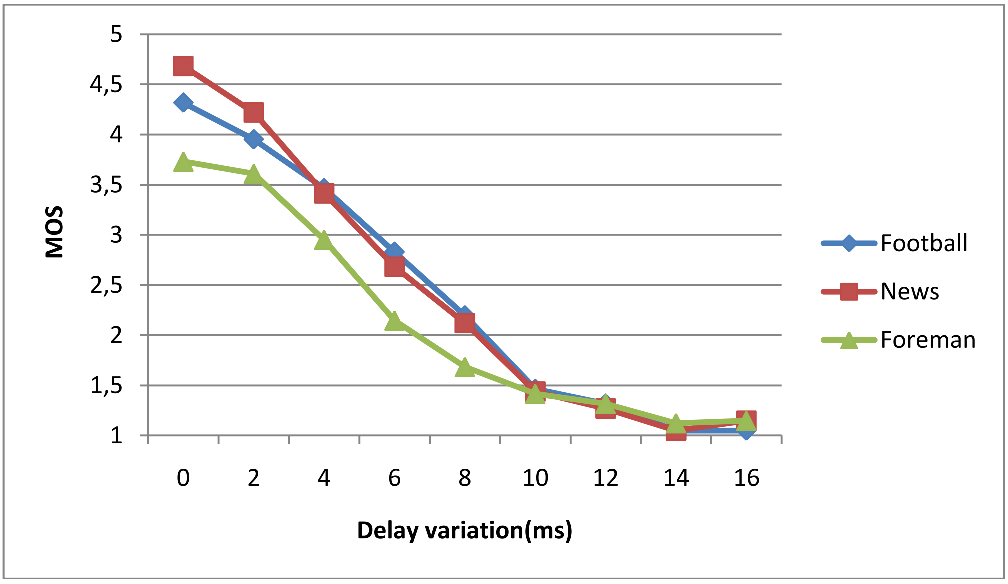

Fig. 4.4 Aggregated MOS ratings for the three videos

In Fig 4.4 the aggregated MOS ratings for three video clips; football, news and foreman are plotted in Y-axis and the delay variation is given in X-axis. It is clear from the figure 4.4 that MOS decreases as delay increases.

At 100ms and ±2ms delays the ratings are different for three videos, news has better rating when compared to football and foreman. The QoE for Foreman video abruptly decreases beyond ±2ms of delay variation and continues to degrade until ±16ms of delay variation. Football and news videos ratings are approximately equal beyond ±4ms delay. Foreman video is more affected with delay variation because foreman is a still video focusing on facial expression of a man with a static background, a small change in delay variation has a greater impact on the video. Football and news are less affected because football is a fast moving video focusing on distant objects and news has the dance frames at background so, the change in movements is easily perceivable even with larger delays.

However this is not the case, when an individual user is tested. It is quite interesting to observe the conflictions in the user perception. These conflictions rather caused difficulty to fall upon a conclusion. Certain threshold values might be acceptable to one user while same threshold values were not acceptable by another user. Which can be observed from the figure 4.4, when delay variation is ±16ms, video degrades more compared to the video with ±14ms variation but as stated one user may feel video clip with delay variation ±16ms is better than video clip with ±14ms.The differences in the graph for ±14ms and ±16ms delay variation is because of the differences between the user perceptions.

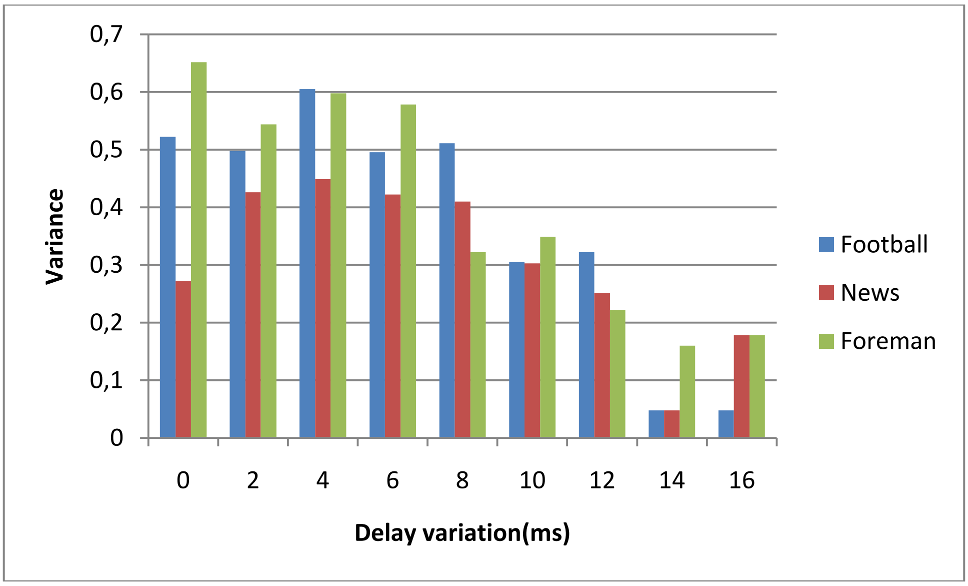

Fig 4.6 Variance of Different users

Figure 4.6 shows the variances of the users for each of the videos. In all the cases foreman has high variance compared to football and news. Between the range 0ms-8ms of delay variation, the variance is high for all the videos and low in the range 10-16ms of delay variation. This shows how difficult it is for the users to rate the videos in the range between 0ms-8ms.At delay variation of 14ms and 16ms, the variance of the people opinion on the football video is low which means many users agreed that football video which contains fast scenes has better video quality and is same with the news video which has low variance when compared to football and foreman.

So, the videos football and news which has the fast movements are satisfactory by all the users other than the videos with slow movements like foreman. At certain level of delay variation say 8ms the foreman video is accepted but beyond that the video quality is degraded completely. Football and news are good even at 10ms of delay variation but beyond that the video quality is degrading. So, the acceptable level for football and news videos is ±10ms.

5 DISCUSSION

The streaming of video will be influenced by several factors of which delay/delay variation is one. In our thesis we have figured that a constant delay on the video does not have a huge impact on the user's perception towards the video quality, whereas delay variation degrades the user's perception. Considering the survey, we analyzed that ±10ms is the threshold level of delay variation because beyond this, the MOS rating is degrading. The quality of experience as seen from the user perspective is evaluated using mean opinion score from each user. We have taken 3 videos of varying speeds and then we introduced constant and varying delay. The results are presented in section 4.2.

We have placed a network emulator in between the streaming server and the client. In this emulator we try to introduce delay for all the outgoing packets. At first we introduced a constant delay of 25ms, 50ms, 75ms and 100ms. There is no much difference in the QoE for the videos. Then we have introduced some delay variation which is nothing but jitter at the network emulator. Jitter degrades the quality of a video quite similar to the packet loss [28]. This is quite similar to the results that are obtained through the experiment. We try to vary the delay variable to find the threshold level of delay that is acceptable for the users. From the graphs in Section 4 it is quite clear that the acceptable threshold level of delay variation for Football and news is ±10ms and it is ±8ms for foreman video. Beyond this level of delay users rated the video quality as low. For this analysis, 41 human subjects were taken and were presented with the videos. The MOS scale is used to rate the quality of videos from 1 to 5 in which 1 is taken as poor and 5 is taken as excellent. A subjective assessment is made using mean opinion score taken from all the human subjects for all the three videos.

The video codec taken for the video streaming is MPEG which has different frames such as I (Intra), P (Predicted) and B (Bi-Directional) frames. The order of sending the frames is also important as one frame will depend on the other [30].

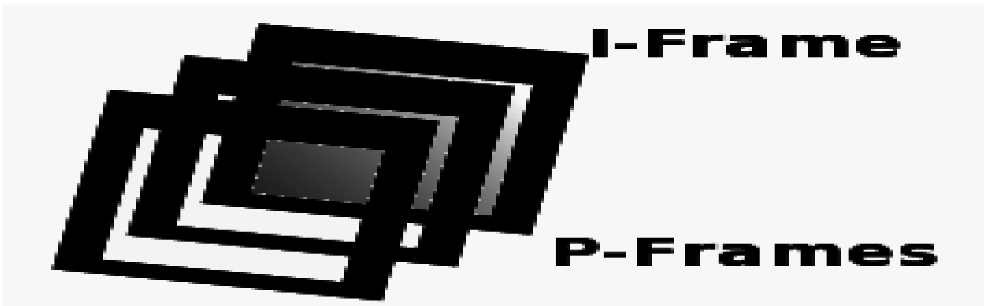

Fig 5.1 Illustration of frames in MPEG [31].

All these frames will increase the coding efficiency and decrease the coded frame size, thereby decreasing the overall size of the video at the receiver's end. The 'I' frame is referred to as a key frame and contains the information about all other frames, starting and destination point of the video etc. Moreover VLC does not support packet reordering and when the frame arrives late at the client it just drops the frame.

A graph is drawn for delay against the user rating for different delay values for the video football. From this it is quite clear that for all constant delay values the quality of the video is rather same. This is also similar for all the other videos. For varying delay the quality of the video is also varying as perceived from the user's point of view. A comparison graph for all the three videos is also drawn in which the delay variation can be clearly seen. These graphs are drawn by calculating the MOS values for each of the three videos. From all these graphs, the user's perceived quality of experience of watching a video can be analyzed.

6 CONCLUSION AND FUTURE WORK

Multimedia streaming has become a very prominent way to share audio and video over a network. Several factors affect the quality of video streaming of which some are network dependant while others are network independent. The quality of experience of the user is either directly or indirectly related to the quality of the streaming video. The effect of delay/delay variation on the quality of video streaming will correlate to the quality of experience of the user. In our thesis, the quality of experience of a video as perceived by the user is evaluated using MOS.

Regarding the research question "What is the effect of packet delay/delay variation on video QoE?", if the delay of the packet is kept constant the quality of experience of the user does not seem to alter much i.e., the variation of QoE is low. However if the delay variation is introduced for the streaming packets, even for small variation (±4ms) of delay, the quality of experience is degrading as shown in Fig 4.4.

Regarding our second research question "What is threshold level of delay/delay variation on video QoE in user's perspective?", we took a constant delay of 25ms, 50ms, 75ms and 100ms for all the three videos and there is not much variation in user's QoE (can be seen from the graph no. in Section 3). So we took a delay of 100ms and have added a delay variation ± {0, 2, 4, 6, 8, 10, 12, 14 and 16}ms. For a delay variation of ±10ms and above the QoE of the users is low and thus we consider the threshold level of delay variation as ±8ms for foreman and ±10ms for football and news videos.

To answer our last research question "What is the relation between MOS (Mean Opinion Score) and Delay/Delay Variation for the videos?" for an increasing delay/delay variation the mean opinion score is decreasing and vice versa as can be seen from the Table 4.1.

We considered three videos at three different rates (fast, alternating, slow) to analyze the QoE as perceived by users. We have taken a survey from 41 human subjects (users) and analyzed their rating for each video. We have shown the results of the survey in the form of graphs in Section 4.2. From the results we conclude that as the delay/delay variation increases above ±10ms the QoE decreased.

Lot of research has been done on the effect of packet loss on the quality of experience of the user as discussed in this paper. However there is no much work on the effect of delay/delay variation on QoE of user. So in our thesis we try to analyze the effect of delay variation on QoE using mean opinion score from the user.

Future Work

There are several areas of Research in the field of video streaming. Our future work include the comparison between the inter arrival times calculated at MP (Measurement Point) and the MOS taken from subjective tests and also we try to relate how they vary.

In our Thesis, the videos that are taken for the experiment are video encoded but are not audio encoded. So, our future work also includes testing the video with both video as well as audio encoders and analyzing the results. There are many more open areas to work on in the field of video streaming.

References

[1] Dapeng Wu; Hou, Y.T.; Wenwu Zhu; Ya-Qin Zhang; Peha, J.M.;" Streaming video over the Internet: approaches and directions", *IEEE Transactions on Circuits and Systems for Video Technology*, Volume: 11, Issue: 3, Publication Year: 2001, Page(s): 282 – 300.

[2] G. J. Conklin, G. S. Greenbaum, K. O. Lillevold, A. F. Lippman, and Y. A. Reznik, "Video coding for streaming media delivery on the Internet", *IEEE Trans. Circuits Syst. Video Technol., vol. 11, Mar. 2001*.

[3] W.R. Stevens, TCP/IP illustrated: The Protocols, *Addison-Wesley Longman Publishing Co., Inc.*, 1993.

[4] Yasuhiko Yoshimura and Masao Masugi, "A QoS Monitoring Method for Video Streaming Service Based on Presentation-Timeline Detection at User Clients", *The 2004 Joint Conference of the 10th Asia-Pacific Conference.*

[5] Venkataraman, M.; Sengupta, S.; Chatterjee, M.; Neogi, R.," Towards a Video QoE Definition in Converged Networks", *Second International Conference on Digital Telecommunications, 2007. ICDT '07,* Publication Year: 2007, Page(s): 16 – 16.

[6] Chi-Fai Wong; Wai-Lam Fung; Chi-Fai Jack Tang; Chan, S.-H.G.," TCP streaming for low-delay wireless video", *Second International Conference on Quality of Service in Heterogeneous Wired/Wireless Networks,* 2005, Publication Year: 2005, Page(s): 6 – 41.

[7] StreamingMedia.com, an Information Today Inc. company. 1998 - 2010, "configuring servers for streaming-part one" [online]. Available http://www.streamingmedia.com/article.asp?id=8226&page=1&c=11.%5b [Accessed: Feb 21, 2010].

[8] Venkataraman, M.; Chatterjee, M.; Chattopadhyay, S., "Evaluating Quality of Experience for Streaming Video in Real Time", *Global Telecommunications Conference, 2009. GLOBECOM 2009. IEEE,* Publication Year: 2009, Page(s): 1 – 6.

[9] Ramesh Jain, "Quality of Experience", *IEEE Multimedia*, Vol. 11(1), pp 95–96, March 2004.

[10] International Telecommunication Union, Subjective video quality assessment methods for multimedia applications, Rec. ITU-T P.910, Sept. 1999.

[11] Dapeng Wu; Hou, Y.T.; Wenwu Zhu; Ya-Qin Zhang; Peha, J.M., "Streaming video over the Internet: approaches and directions", *IEEE Transactions on Circuits and Systems for Video Technology*, Volume: 11, Issue: 3, Publication Year: 2001, Page(s): 282 – 300.

[12] Yoshimura, Y.; Masugi, M., "A QoS monitoring method for video streaming service based on presentation-timeline detection at user clients", *The 2004 Joint Conference of the 10th Asia-Pacific Conference on Communications, 2004 and the 5th International Symposium on Multi-Dimensional Mobile Communications Proceedings,* Volume: 2 Publication Year: 2004, Page(s): 681 - 685 vol.2.

[13] Stephen Hemminger, "Network Emulation with NetEm", Open Source Development Lab, April 2005.

[14] G. Rubino, M. Varela, and J.-M. Bonnin, "Controlling Multimedia QoS in the Future Home Network Using the PSQA Metric," *Computer Journal*, vol. 49, no. 2, pp. 137–155, 2006.

[15] H. Cancela, P. Rodriguez-Bocca, and G. Rubino, "Perceptual quality in p2p multi-source video streaming policies," *Global Telecommunications Conference, 2007. GLOBECOM '07*. IEEE, pp. 2780–2785, Nov. 2007.

[16] Piamrat, K.; Viho, C.; Bonnin, J.-M.; Ksentini, A., "Quality of Experience Measurements for Video Streaming over Wireless Networks", *Sixth International Conference on Information Technology: New Generations, 2009. ITNG '09*., Publication Year: 2009 , Page(s): 1184 – 1189.

[17] Online access of webpage, http://www.videolan.org/doc/vlc-user-guide/en/ch01.html, on 12^{th} March 2010.

[18] Giovanni Gualdi; Rita Cucchiara; Andrea Prati, “Low-Latency Live Video Streaming over Low-Capacity Networks”, *Eighth IEEE International Symposium on Multimedia, 2006. ISM'06*, Publication Year: 2006, Page(s): 449 – 456.
[19] Zhi-Gang Li; Zhao-Yang Zhang, “Real-time streaming and robust streaming H.264/AVC video”, *Third International Conference on Image and Graphics, 2004. Proceedings*, Publication Year: 2004, Page(s): 353 – 356.
[20] M. Liou, “Overview of the px64 kbit/s video coding standard,” *Commun. ACM,* vol. 34, 1991, pp. 59-63.
[21] R. Nicol and N. Mukawa, “Motion video coding in CCITT SG XV-the coded picture format,” *Global Telecommunications Conference, 1988, and Exhibition. 'Communications for the Information Age.' Conference Record, GLOBECOM '8, IEEE*, 1988, pp. 992-996 vol.2.
[22] Online access of webpage, http://media.xiph.org/video/derf/, on 16th March 2010.
[23] Weiguo Zheng; Ahmad, I.; Ming Lei Liou, “Benchmark the software based MPEG-4 video codec”, *The 8th IEEE International Conference on Electronics, Circuits and Systems, 2001. ICECS 2001.,* Volume: 1, Publication Year: 2001 , Page(s): 289 – 292.
[24] Van der Auwera, G.; David, P.T.; Reisslein, M., “Traffic and Quality Characterization of Single-Layer Video Streams Encoded with the H.264/MPEG-4 Advanced Video Coding Standard and Scalable Video Coding Extension”, *IEEE Transactions on Broadcasting,* Volume: 54, Issue: 3, Part: 2, Publication Year: 2008, Page(s): 698 – 718.
[25] Junaid Shaikl,Tahir Nawaz Minhas,patrik Arlos,Markus Fiedler,”Evaluation of Delay Performance of Traffic Shapers”, *2nd International Workshop on Security and Communication Networks*,Karlstad,Sweden,2010.
[26] ITU-R Recommendation BT.500-11: “Methodology for the subjective assessment of the quality of television pictures”, *International Telecommunication Union,* Geneva, Switzerland, 2002.
[27] ITU-T Recommendation P.910: “Subjective video quality assessment methods for multimedia applications”, *International telecommunication Union,* Geneva, Switzerland, 1996.
[28] Mark Claypool, Jonathan Tanner, “The Effects of Jitter on the Perceptual Quality of Video”, Computer Science Department, Worcester Polytechnic Institute.
[29] Nagarajesh Garapati, "Delay impact on gaming experience" Department of Telecommunication Systems, School of Engineering, Blekinge Institute of Technology, September 2009.
[30] Susie Wee, Wai-tian Tan, John Apostolopoulos, "Optimized Video Streaming for Networks with Varying Delay", Streaming Media Systems Group Hewlett-Packard Laboratories, USA.
[31] Nicole Driscoll, Joshua Liberman, Jason Novinger, Robert Williamson “Streaming MPEG4 Video Over Wired and Wireless Local area networks”.
[32] Panusopone, K.; Xue Fang; Limin Wang, "An Efficient Implementation of Motion Estimation with Weight Prediction for ITU-T H.264 MPEG-4 AVC ", *IEEE Transactions on Consumer Electronics*, Volume: 53, Issue: 3, Publication Year: 2007, Pages(s): 974-978.
[33] Xue-Wu Zhang, Bing Jiang, Zhu-wei Lu, Ping Yan; Zi-jiang Hu, "End-to-end delivery strategies for H.264 video streaming over 3G wireless networks", *2006 IET International Conference on Wireless, Mobile and Multimedia Networks,* Publication Year: 2006, Page(s): 1 – 6.
[34] Wu D.J.; Yang M.J.; Chen J.P.; Tham J.Y., "A real-time H.264 video streaming system on DSP/PC platform", *13th International Symposium on Consumer Electronics, 2009. ISCE '09. IEEE,* Publication Year: 2009, Page(s): 527 - 530.
[35] Patrik Arlos, “Measurements,” in: On the Quality of Computer Network Measurements, Karlskrona, 2005, pp. 113-119.
[36] Jian-Wen Chen; Chao-Yang Kao; Youn-Long Lin; "Introduction to H.264 advanced video coding ", *Conference on Automation Design, 2006*. Asia and South Pacific, Publication Year: 2006.
[37] Kalva, H., "Issues in H.264/MPEG-2 video transcoding", *First IEEE Consumer Communications and Networking Conference, 2004. CCNC* 2004., Publication Year: 2004 , Page(s): 657 - 659.

Appendix

A.1 Feed Back Form

when the MOS is calculated for D±ΔD=[{25,50,75,100}±{2,3,4,6,8,10,15}]ms

Name:
Occupation: 1. Student 2. Ph. D Student 3. Staff
4. Others
Gender: 1. Female 2. Male
Age:

Football 1

Table A.1 Feedback for football

Football -a	Football -b	Football -c	Football -d	Football -e	Football -f	Football -g	Football -h
5- Excellent	5- Excellent	5- Excellent	5- Excellent	5- Excellent	5- Excellent	5- Excellent	5- Excellent
4- Good	4- Good	4- Good	4- Good	4- Good	4- Good	4- Good	4- Good
3- Fair	3- Fair	3- Fair	3- Fair	3- Fair	3- Fair	3- Fair	3- Fair
2- Poor	2- Poor	2- Poor	2- Poor	2- Poor	2- Poor	2- Poor	2- Poor
1- Bad	1- Bad	1- Bad	1- Bad	1- Bad	1- Bad	1- Bad	1- Bad
RT:	RT:	RT:	RT:	RT:	RT:	RT:	RT:

Football 2

Table A.2 Feedback for football 2

Football -a	Football -b	Football -c	Football -d	Football -e	Football -f	Football -g	Football -h
5- Excellent	5- Excellent	5- Excellent	5- Excellent	5- Excellent	5- Excellent	5- Excellent	5- Excellent
4- Good	4- Good	4- Good	4- Good	4- Good	4- Good	4- Good	4- Good
3- Fair	3- Fair	3- Fair	3- Fair	3- Fair	3- Fair	3- Fair	3- Fair
2- Poor	2- Poor	2- Poor	2- Poor	2- Poor	2- Poor	2- Poor	2- Poor
1- Bad	1- Bad	1- Bad	1- Bad	1- Bad	1- Bad	1- Bad	1- Bad
RT:	RT:	RT:	RT:	RT:	RT:	RT:	RT:

Football 3

Table A.3 Feedback for football 3

Football -a	Football -b	Football -c	Football -d	Football -e	Football -f	Football -g	Football –h
5- Excellent	5- Excellent	5- Excellent	5- Excellent	5- Excellent	5- Excellent	5- Excellent	5- Excellent
4- Good	4- Good	4- Good	4- Good	4- Good	4- Good	4- Good	4- Good
3- Fair	3- Fair	3- Fair	3- Fair	3- Fair	3- Fair	3- Fair	3- Fair
2- Poor	2- Poor	2- Poor	2- Poor	2- Poor	2- Poor	2- Poor	2- Poor
1- Bad	1- Bad	1- Bad	1- Bad	1- Bad	1- Bad	1- Bad	1- Bad
RT:	RT:	RT:	RT:	RT:	RT:	RT:	RT:

Football4

Table A.4 Feedback for football 4

Football - a	Football -b	Football -c	Football -d	Football -e	Football -f	Football -g	Football –h
5- Excellent	5- Excellent	5- Excellent	5- Excellent	5- Excellent	5- Excellent	5- Excellent	5- Excellent
4- Good	4- Good	4- Good	4- Good	4- Good	4- Good	4- Good	4- Good
3- Fair	3- Fair	3- Fair	3- Fair	3- Fair	3- Fair	3- Fair	3- Fair
2- Poor	2- Poor	2- Poor	2- Poor	2- Poor	2- Poor	2- Poor	2- Poor
1- Bad	1- Bad	1- Bad	1- Bad	1- Bad	1- Bad	1- Bad	1- Bad
RT:	RT:	RT:	RT:	RT:	RT:	RT:	RT:

RT-Repeating Time

FEED BACK FORM

This is the second feedback taken from users only for values
$D \pm \Delta D = [\{100\} \pm \{0,4,6,8,10,12,14,16\}]$ms

Name:
Occupation: 1. Student 2. PhD Student 3. Staff
4. Others
Gender: 1. Female 2. Male
Age:

Video 1: Foreman

Table A.5 Feedback for foreman

Foreman-A	Foreman-F	Foreman-B	Foreman-G	Foreman-C	Foreman-H	Foreman-D
5-Excellent	5-Excellent	5-Excellent	5-Excellent	5-Excellent	5-Excellent	5-Excellent
4-Good	4-Good	4-Good	4-Good	4-Good	4-Good	4-Good
3-Fair	3-Fair	3-Fair	3-Fair	3-Fair	3-Fair	3-Fair
2-Poor	2-Poor	2-Poor	2-Poor	2-Poor	2-Poor	2-Poor
1-Bad	1-Bad	1-Bad	1-Bad	1-Bad	1-Bad	1-Bad
RT:	RT:	RT:	RT:	RT:	RT:	RT:

Foreman-I	Foreman-E
5-Excellent	5-Excellent
4-Good	4-Good
3-Fair	3-Fair
2-Poor	2-Poor
1-Bad	1-Bad
RT:	RT:

Video 2: News

Table A.6 Feedback for news

News-A	News-F	News-B	News-G	News-C	News-H	News-D
5-Excellent	5-Excellent	5-Excellent	5-Excellent	5-Excellent	5-Excellent	5-Excellent
4-Good	4-Good	4-Good	4-Good	4-Good	4-Good	4-Good
3-Fair	3-Fair	3-Fair	3-Fair	3-Fair	3-Fair	3-Fair
2-Poor	2-Poor	2-Poor	2-Poor	2-Poor	2-Poor	2-Poor
1-Bad	1-Bad	1-Bad	1-Bad	1-Bad	1-Bad	1-Bad
RT:	RT:	RT:	RT:	RT:	RT:	RT:

News-I	News-E
5-Excellent	5-Excellent
4-Good	4-Good
3-Fair	3-Fair
2-Poor	2-Poor
1-Bad	1-Bad
RT:	RT:

Video 3: Football

Table A.7 Feedback form for football

Football-A	Football-F	Football-B	Football-G	Football-C	Football-H	Football-D
5-Excellent	5-Excellent	5-Excellent	5-Excellent	5-Excellent	5-Excellent	5-Excellent
4-Good	4-Good	4-Good	4-Good	4-Good	4-Good	4-Good
3-Fair	3-Fair	3-Fair	3-Fair	3-Fair	3-Fair	3-Fair
2-Poor	2-Poor	2-Poor	2-Poor	2-Poor	2-Poor	2-Poor
1-Bad	1-Bad	1-Bad	1-Bad	1-Bad	1-Bad	1-Bad
RT:	RT:	RT:	RT:	RT:	RT:	RT:

Football-I	Football-E
5-Excellent	5-Excellent
4-Good	4-Good
3-Fair	3-Fair
2-Poor	2-Poor
1-Bad	1-Bad
RT:	RT:

RT: Repeating Time

B.1 Commands

1. Commands for converting .y4m to .avi
   ffmpeg –s 352X288 –r 25 –i /home/user/Desktop/filename.y4m –vcodec copy /home/user/Desktop/filename.avi

B.2 Experiment setup Commands

MArC: ./MArelayD
Consumer: pwd (i.,e present working Directory)
consumer –o /root/marc/consumers/src/v05/skmo09/filename/ -i eth0 01:00:00:00:00:04
MP: ./mp –i dag0 dag1 –s eth0
Shaper: Same as in B.1 2nd Bullet.

C.1 Individual User MOS Ratings:

The Table for three videos with individual MOS ratings is given below, where the delay settings for the videos are [100±{0,2,4,6,8,10,12,14,16}]ms

Table C.1 Individual MOS ratings for football video

Users	Football a	Football b	Football c	Football d	Football e	Football f	Football h	Football g	Football i
1	4	4	4	3	3	2	2	2	2
2	4	5	4	2	2	1	1	1	1
3	4	3	2	2	1	1	1	1	1
4	4	4	4	3	3	2	2	1	1
5	3	3	4	4	2	2	1	1	1
6	5	4	5	4	4	3	3	2	2
7	4	4	4	3	2	1	1	1	1
8	4	5	3	2	2	1	1	1	1
9	4	4	4	3	3	2	3	1	1
10	3	2	1	2	1	1	1	1	1
11	4	4	3	2	2	1	1	1	1
12	5	4	3	2	2	1	1	1	1
13	3	3	2	2	1	1	1	1	1
14	5	5	4	3	2	1	1	1	1
15	5	4	4	4	3	2	2	1	1
16	3	4	4	2	1	2	1	1	1
17	3	3	2	2	2	1	1	1	1
18	4	3	4	3	2	1	1	1	1
19	4	3	3	2	2	1	1	1	1
20	5	4	4	3	4	2	1	1	1
21	5	4	4	3	3	1	2	1	1
22	5	4	4	3	2	2	1	1	1
23	4	3	4	3	3	2	2	1	1
24	5	4	3	2	1	1	1	1	1
25	5	4	4	3	2	1	1	1	1
26	3	3	3	2	2	1	1	1	1
27	5	5	4	4	3	2	2	1	1
28	4	4	3	2	2	1	1	1	1
29	4	4	3	3	2	1	1	1	1
30	5	5	4	3	2	1	1	1	1
31	5	5	4	4	2	2	1	1	1
32	5	5	4	4	3	2	2	1	1
33	5	4	3	3	2	2	2	1	1
34	4	4	3	3	3	2	2	1	1
35	5	5	4	4	2	1	1	1	1
36	5	4	3	3	2	1	1	1	1
37	5	4	4	3	2	2	1	1	1
38	4	4	3	2	2	1	1	1	1
39	4	4	3	3	2	2	1	1	1
40	5	4	3	3	2	1	1	1	1
41	5	4	4	3	2	2	1	1	1

Table C.2 Individual MOS ratings for news video

users	news a	news b	news c	news d	news e	news f	news g	news h	news i
1	5	5	4	3	3	2	2	2	2
2	5	5	3	2	2	1	2	1	1
3	4	4	3	2	2	1	1	1	1
4	4	4	3	3	2	2	2	1	1
5	4	4	3	1	1	1	1	1	1
6	5	5	4	4	4	3	3	2	2
7	5	4	4	3	2	2	1	1	1
8	5	5	3	3	2	1	1	1	2
9	5	4	4	3	3	2	2	1	1
10	4	3	2	2	1	2	1	1	1
11	4	4	3	2	2	1	1	1	1
12	4	5	3	2	1	1	1	1	1
13	3	2	2	2	2	1	1	1	1
14	5	4	3	2	2	1	1	1	1
15	5	4	3	3	2	1	2	1	1
16	4	4	3	2	2	1	1	1	1
17	5	3	4	2	1	1	1	1	1
18	5	4	4	3	2	1	1	1	1
19	4	4	3	2	2	1	1	1	1
20	5	5	5	4	3	1	1	1	3
21	5	4	4	3	2	1	2	1	2
22	5	4	4	3	2	2	1	1	1
23	5	4	4	3	2	1	1	1	1
24	5	4	4	3	3	2	2	1	1
25	5	4	2	2	1	1	1	1	1
26	5	5	4	3	2	2	1	1	1
27	5	5	3	3	2	1	1	1	1
28	5	5	4	3	2	1	1	1	1
29	5	4	4	3	3	2	1	1	1
30	5	4	3	3	2	2	1	1	1
31	5	5	4	3	3	2	2	1	1
32	5	5	4	4	3	2	1	1	1
33	5	4	4	2	2	2	1	1	1
34	5	4	3	3	3	2	2	1	1
35	4	4	3	2	2	1	1	1	1
36	5	4	3	2	2	1	1	1	1
37	5	4	3	3	2	2	1	1	1
38	4	4	3	3	2	1	1	1	1
39	5	4	3	3	2	1	1	1	1
40	4	5	4	3	2	1	1	1	1
41	5	5	4	3	2	2	1	1	1

Table C.3 Individual user rating for foreman video

users	foreman a	foreman b	foreman c	foreman d	foreman e	foreman f	foreman g	foreman h	foreman i
1	4	3	3	2	2	2	2	1	2
2	3	4	3	2	1	2	2	1	1
3	3	4	3	2	2	1	1	1	1
4	4	4	3	2	1	1	1	1	1
5	2	3	2	2	1	2	1	1	1
6	5	4	3	4	2	3	2	3	3
7	2	4	2	2	1	1	1	1	1
8	3	4	4	2	2	2	2	1	1
9	4	4	4	3	3	2	2	1	1
10	3	3	1	1	1	1	1	1	1
11	3	2	2	2	2	1	1	1	1
12	4	3	3	2	1	1	1	1	1
13	2	2	1	1	1	1	1	1	1
14	5	5	4	2	2	2	2	1	1
15	4	4	4	3	2	3	2	2	2
16	3	4	4	2	1	2	1	1	1
17	4	2	2	1	1	1	1	1	2
18	4	3	4	2	2	1	1	1	1
19	4	3	3	1	2	1	2	1	1
20	5	3	4	1	2	1	2	1	1
21	3	4	3	2	2	1	2	1	1
22	4	4	3	2	2	2	2	2	1
23	4	3	3	3	3	2	2	2	2
24	3	3	2	1	1	1	1	1	1
25	4	4	3	2	2	1	1	1	1
26	3	3	2	1	1	1	1	1	1
27	4	4	3	2	1	1	1	1	1
28	4	4	3	3	2	1	1	1	1
29	3	3	3	2	2	1	1	1	1
30	4	4	3	2	2	1	1	1	1
31	4	4	3	3	2	2	1	1	1
32	4	4	3	2	1	2	1	1	1
33	4	4	3	2	1	1	1	1	1
34	5	5	4	3	2	2	1	1	1
35	5	5	4	4	2	1	2	1	1
36	3	3	3	2	2	1	1	1	1
37	4	4	3	2	2	1	1	1	1
38	4	4	3	3	2	1	1	1	1
39	4	4	3	3	2	2	1	1	1
40	5	4	3	3	2	1	1	1	1
41	4	3	2	2	1	1	1	1	1

Individual graphs for 40 users are as shown:

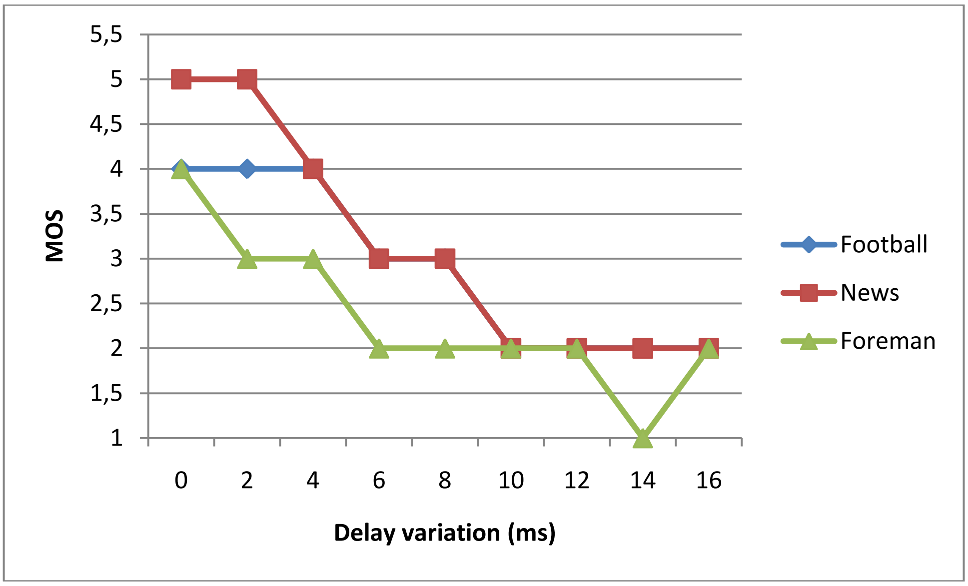

Fig. C.1 User1

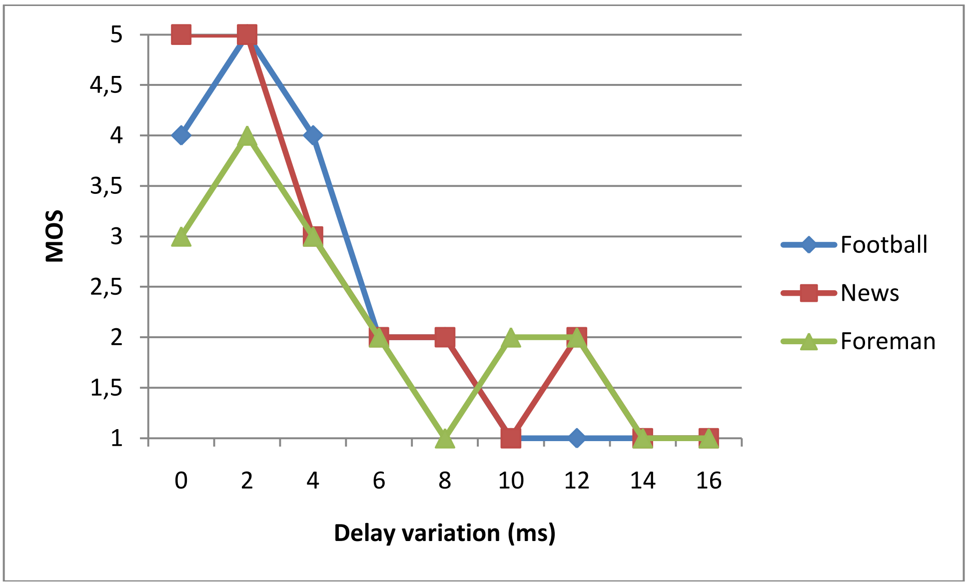

Fig C.2 User 2

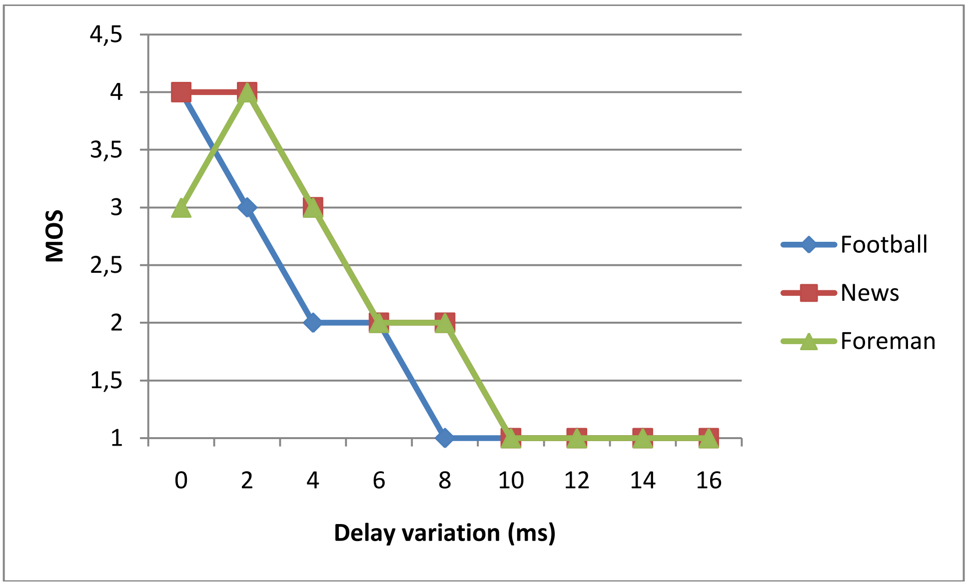

Fig C.3 User 3

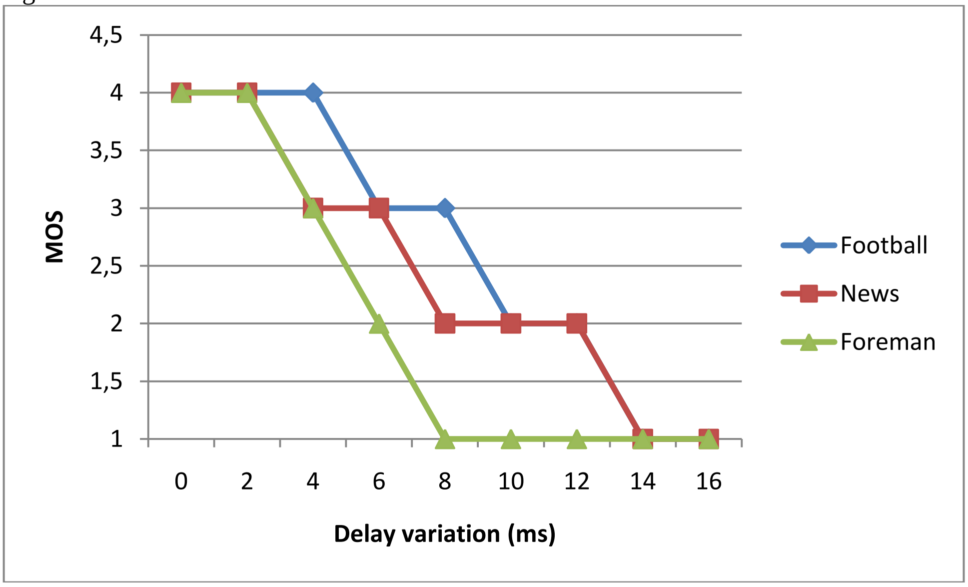

Fig C.4 User 4

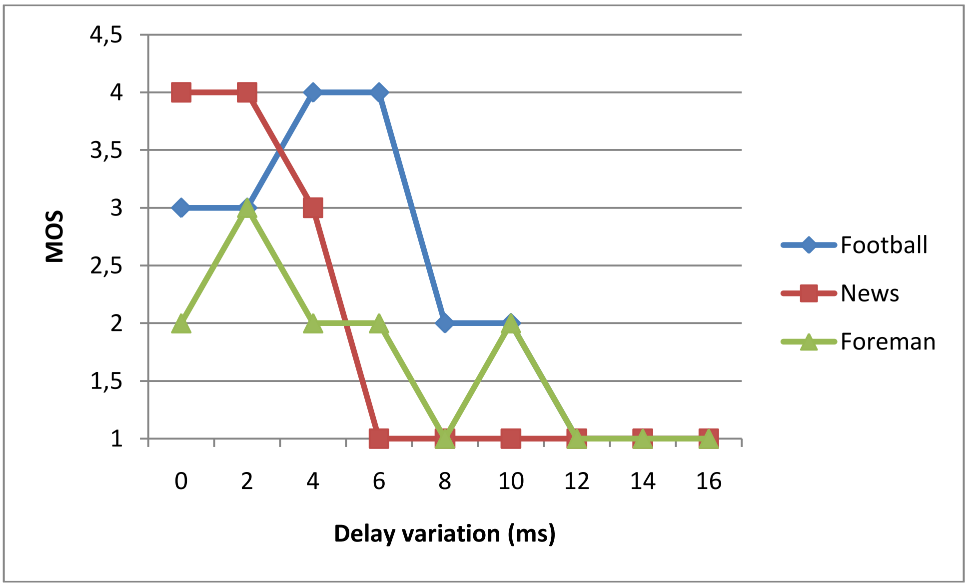

Fig C.5 User 5

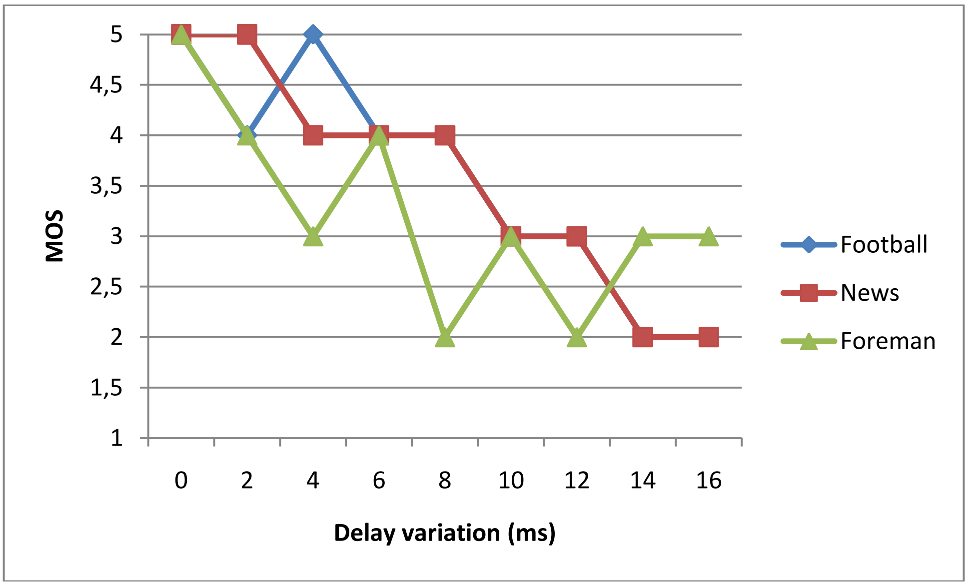

Fig C.6 User 6

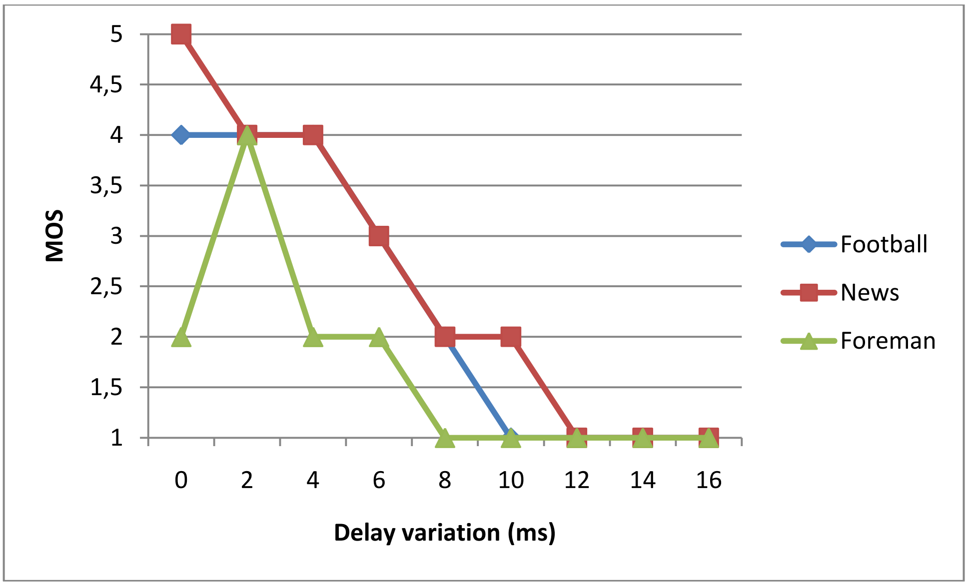

Fig C.7 User 7

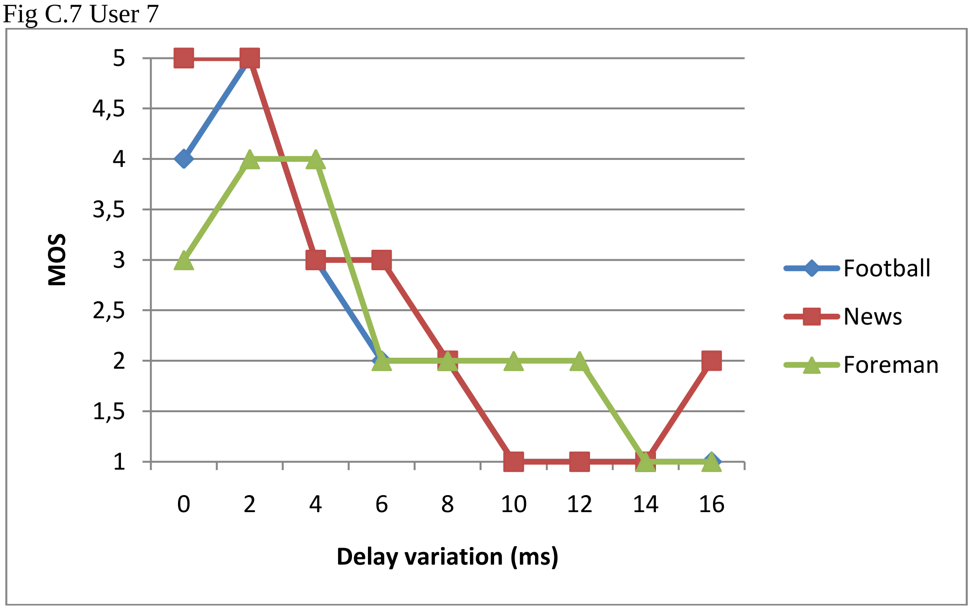

Fig C.8 User 8

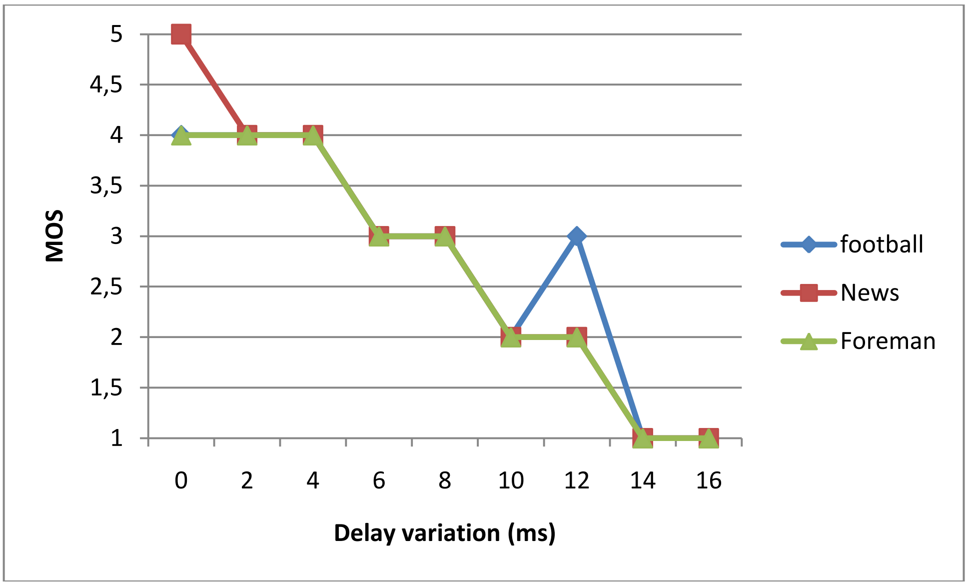

Fig C.9 User 9

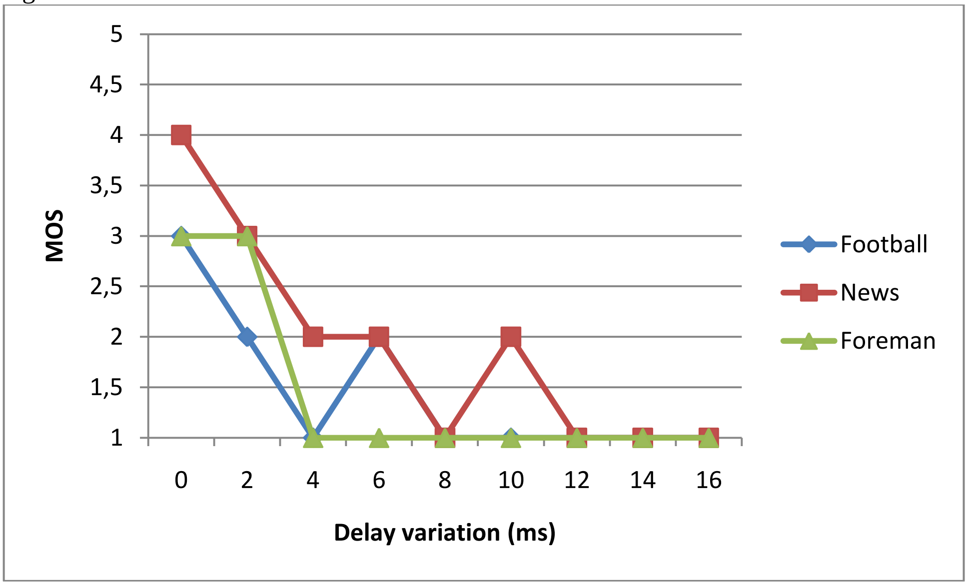

Fig C.10 User 10

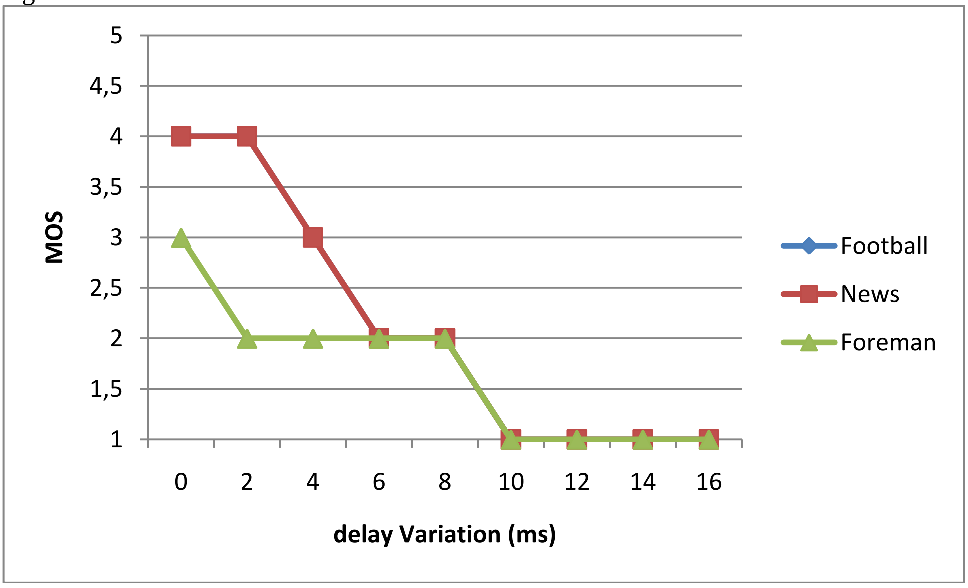

Fig C.11 User 11

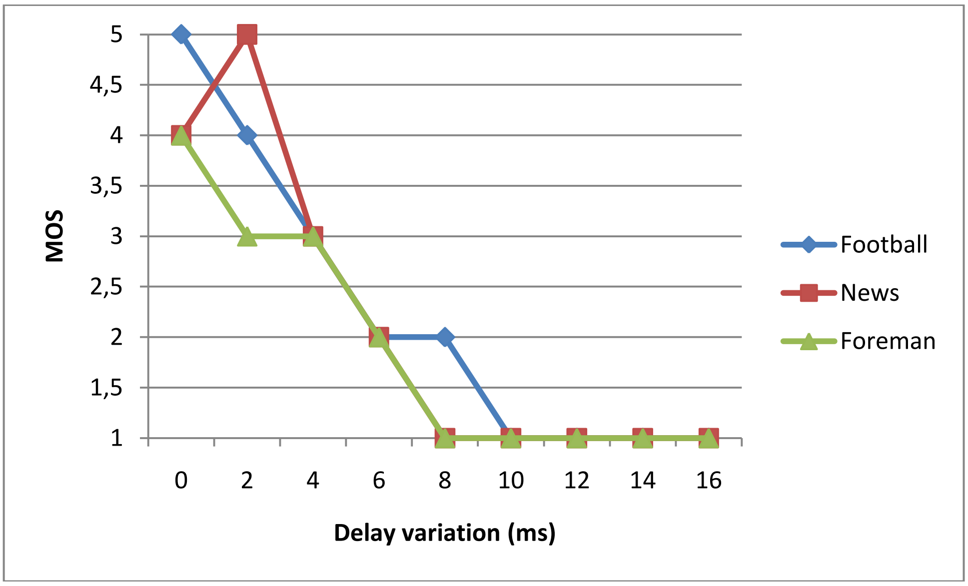

Fig C.12 User 12

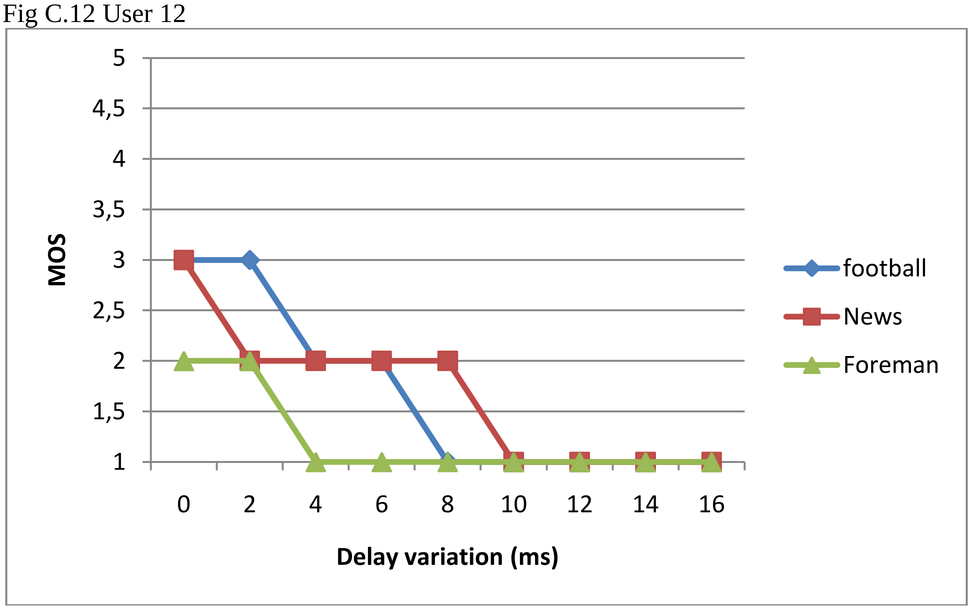

Fig C.13 User 13

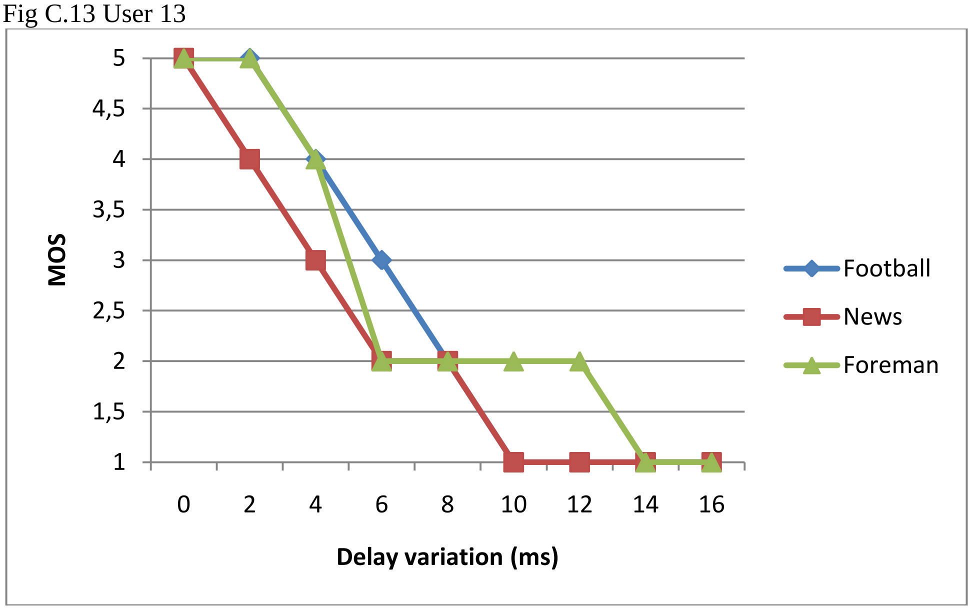

Fig C.14 User 14

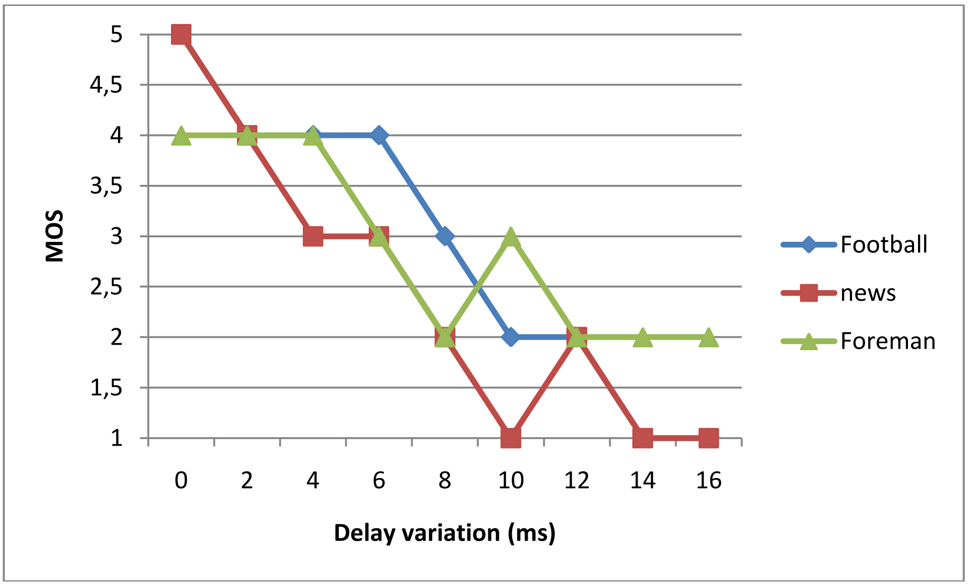

Fig C.15 User 15

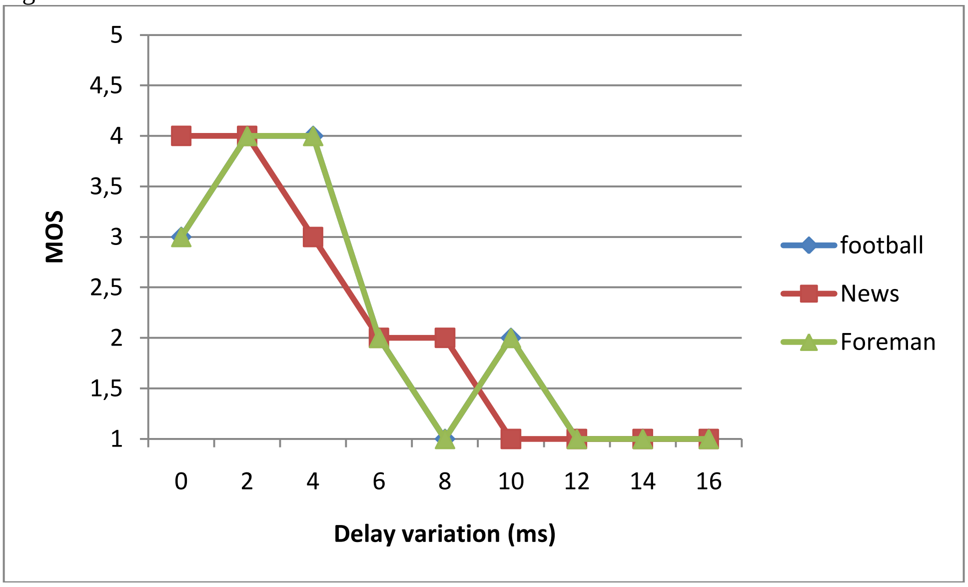

Fig C.16 User 16

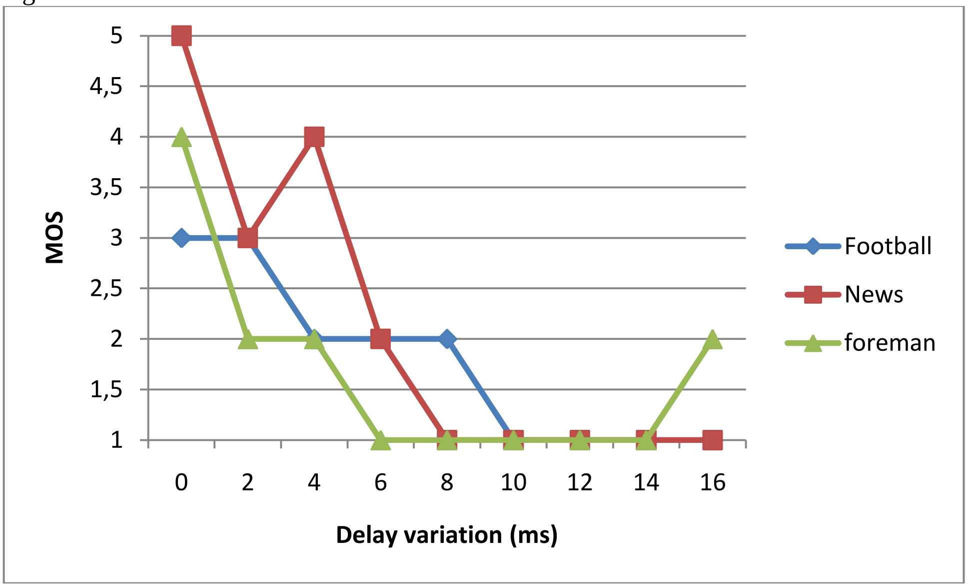

Fig C.17 User 17

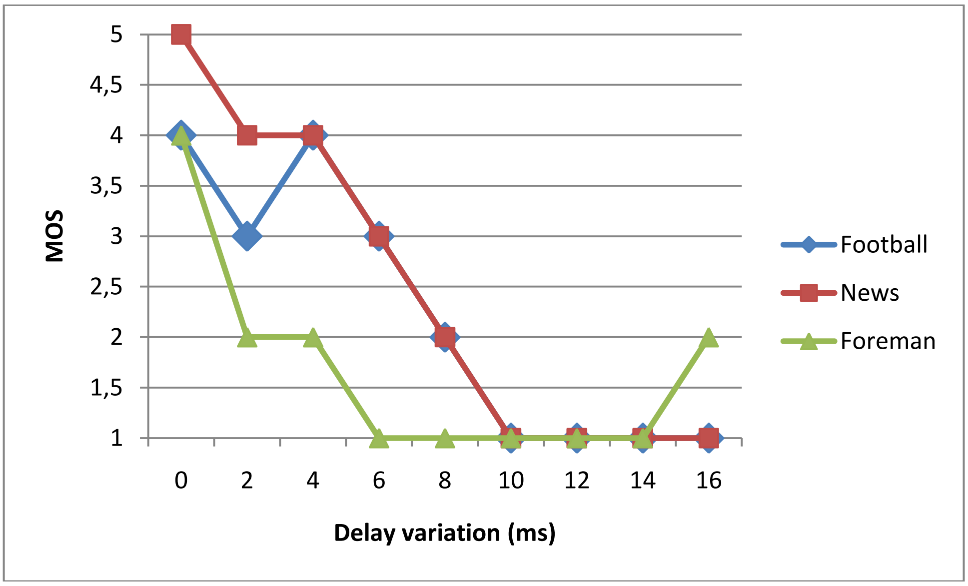

Fig C.18 User 18

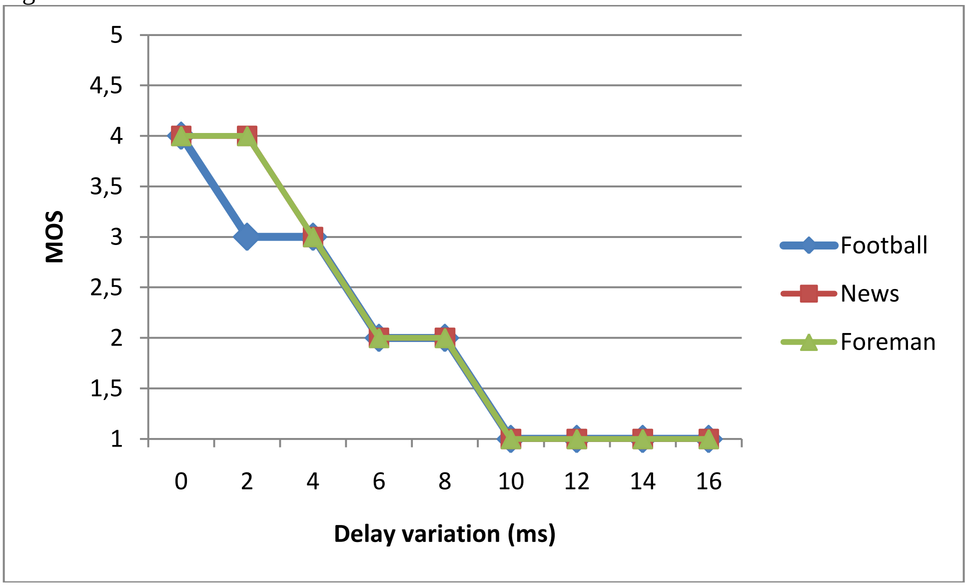

Fig C.19 User 19

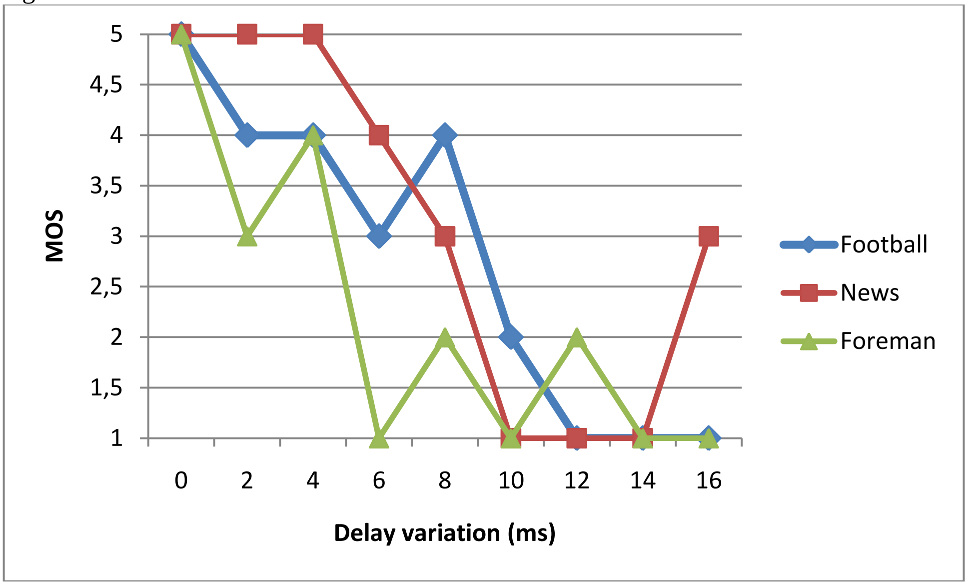

Fig C.20 User 20

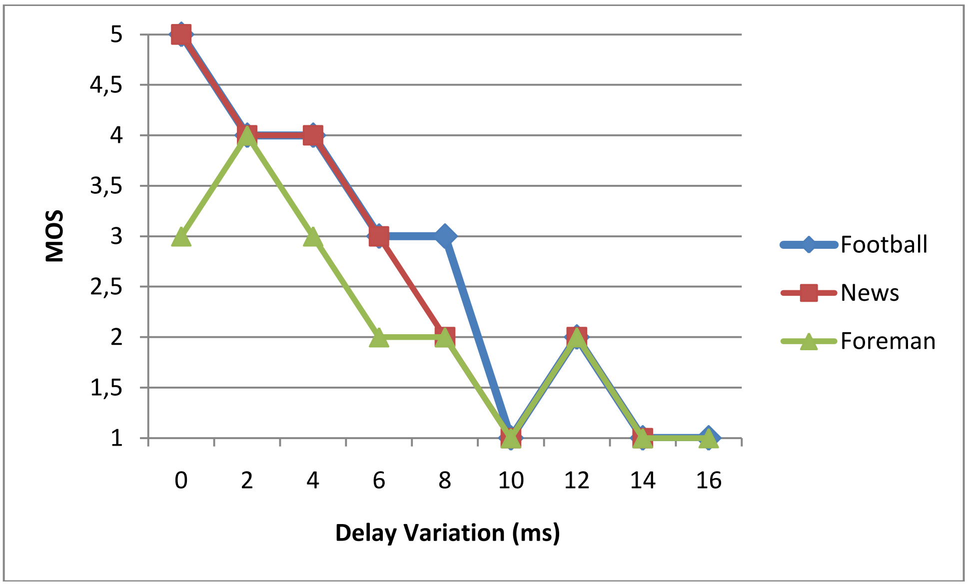

Fig C.21 User 21

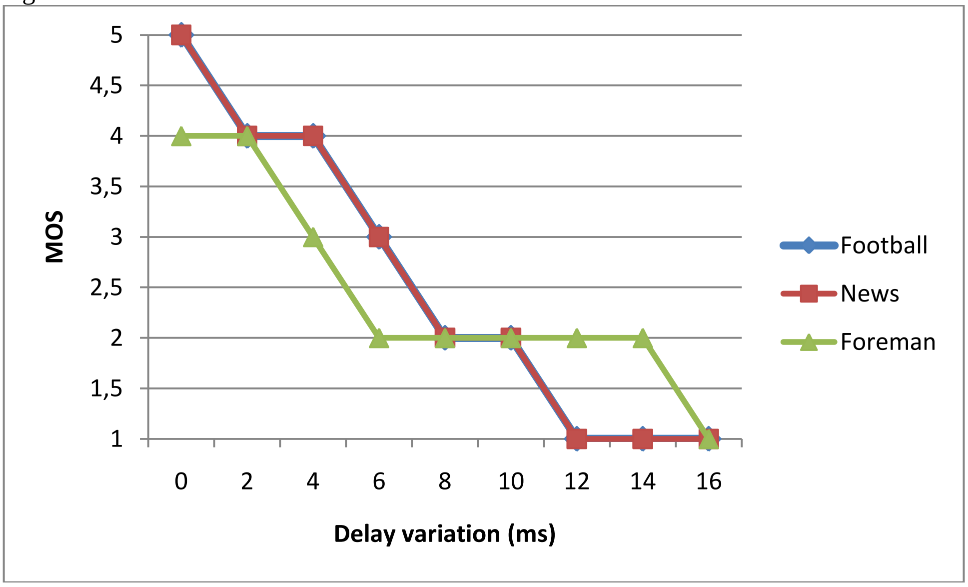

Fig C.22 user 22

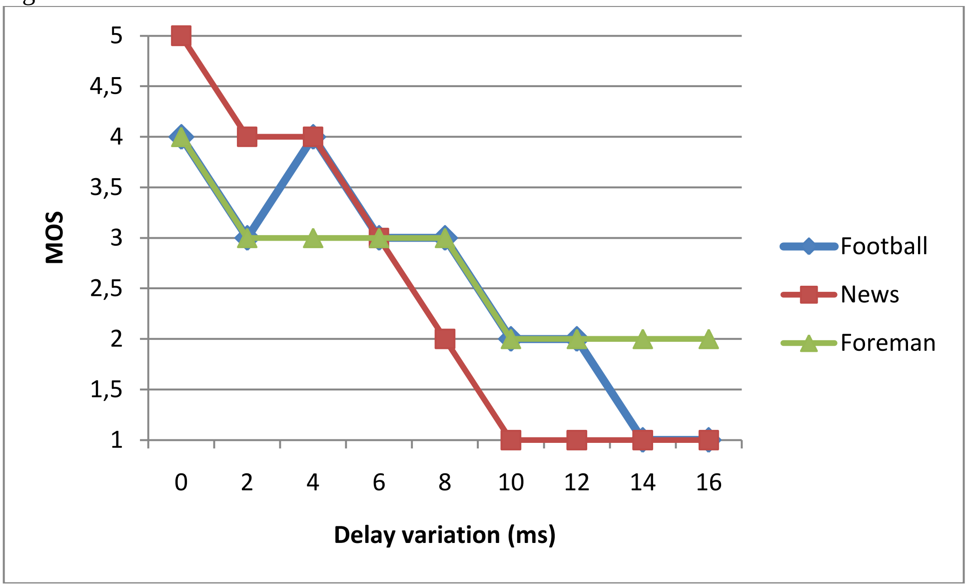

Fig C.23 User 23

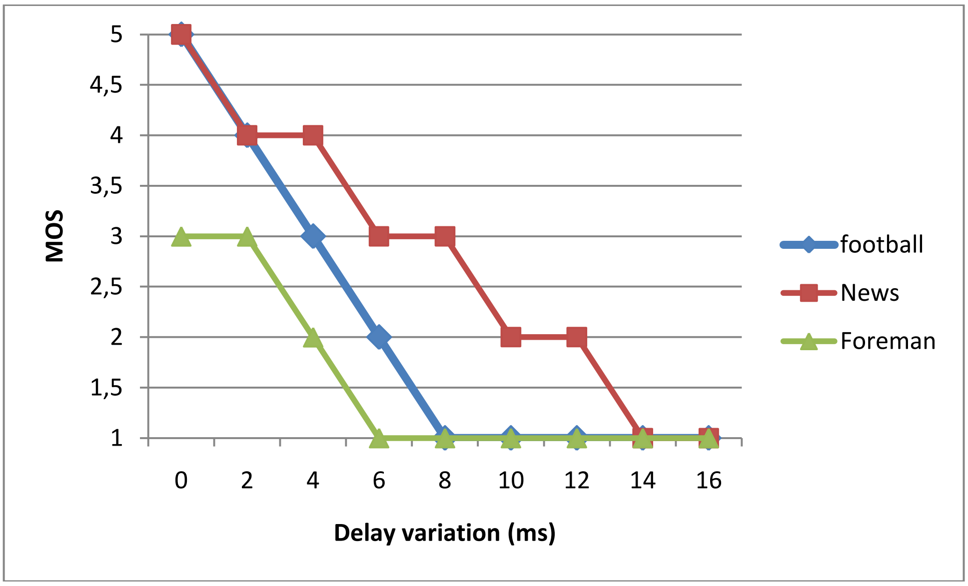

Fig C.24 User 24

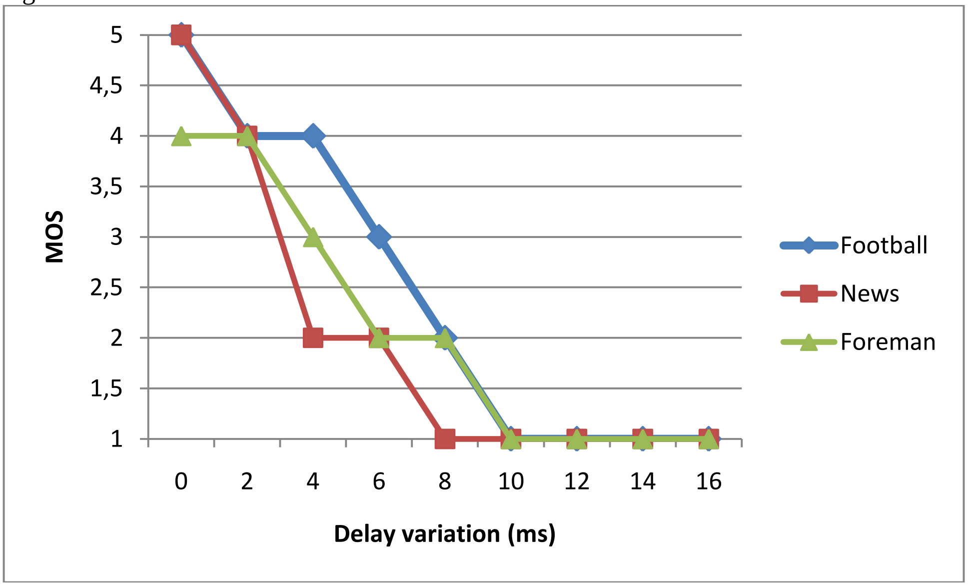

Fig C.25 User 25

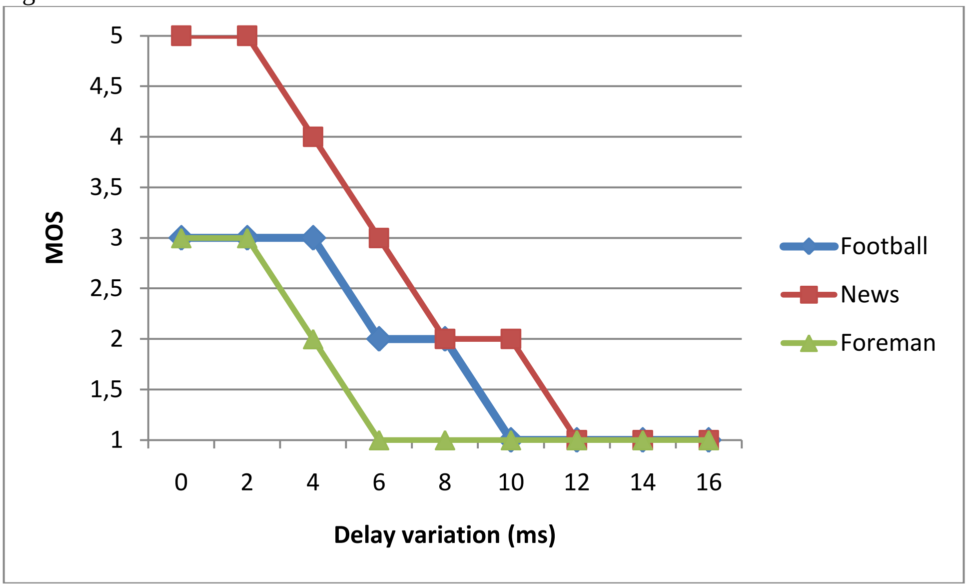

Fig C.26 user 26

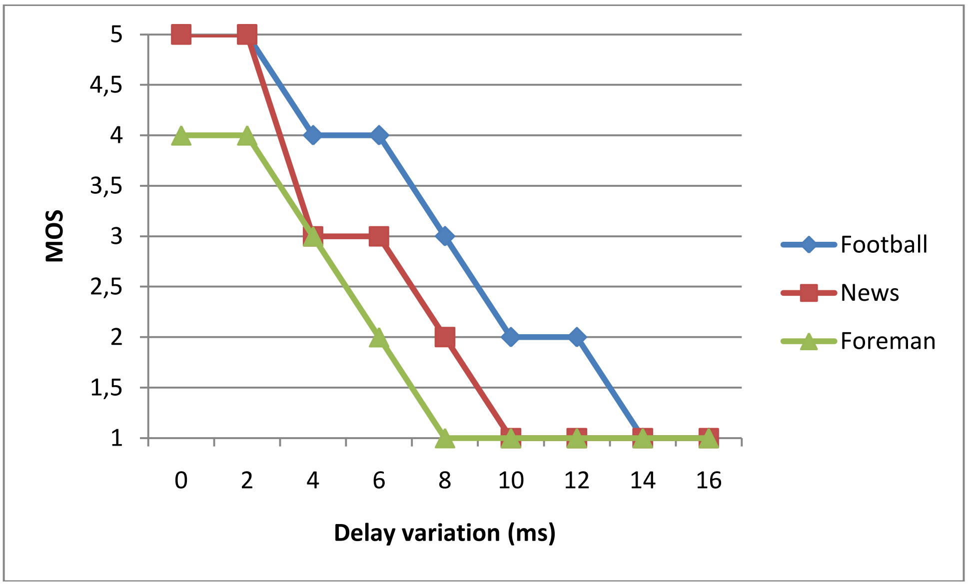

Fig C.27 user 27

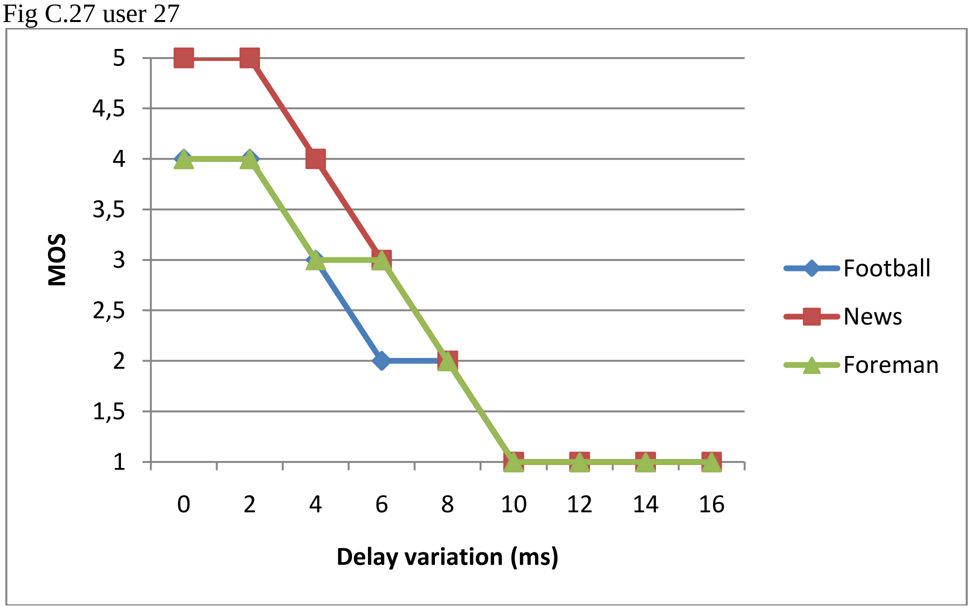

Fig C.28 User 28

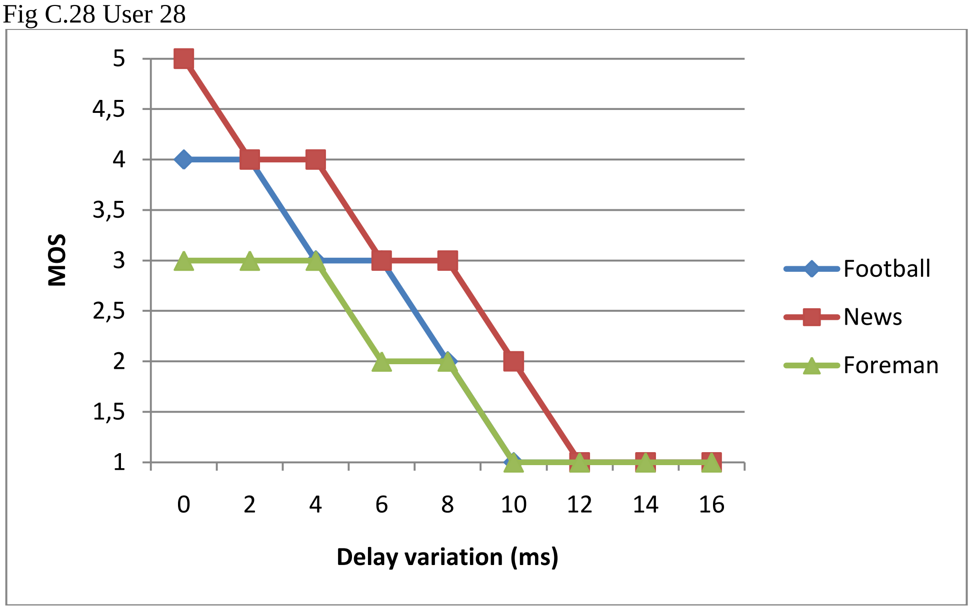

Fig C.29 user 29

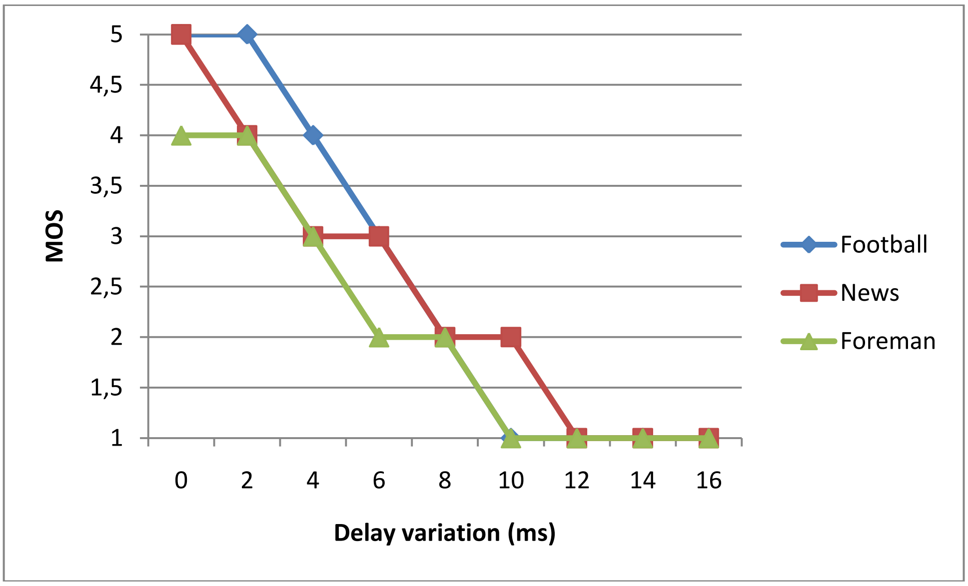

Fig C.30 user 30

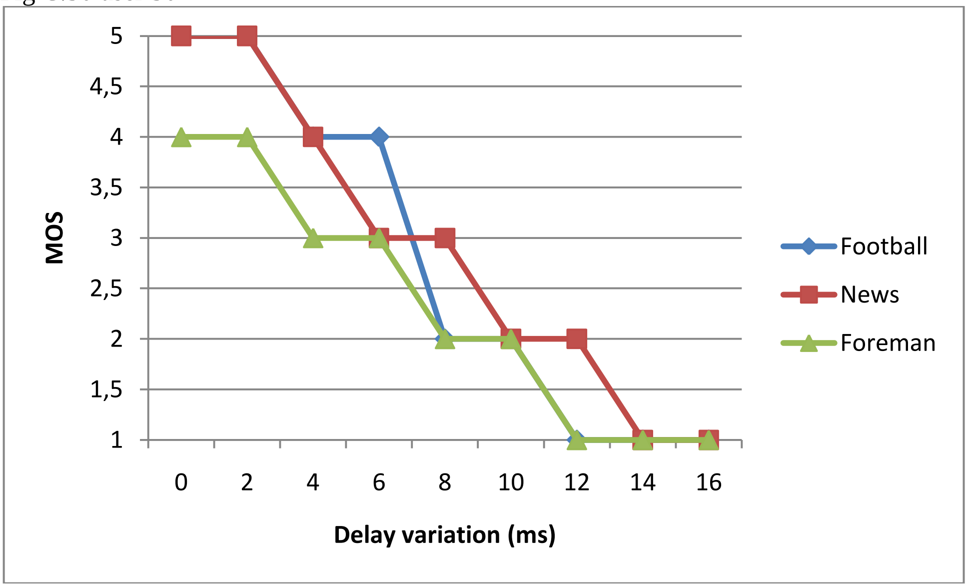

Fig C.31 User 31

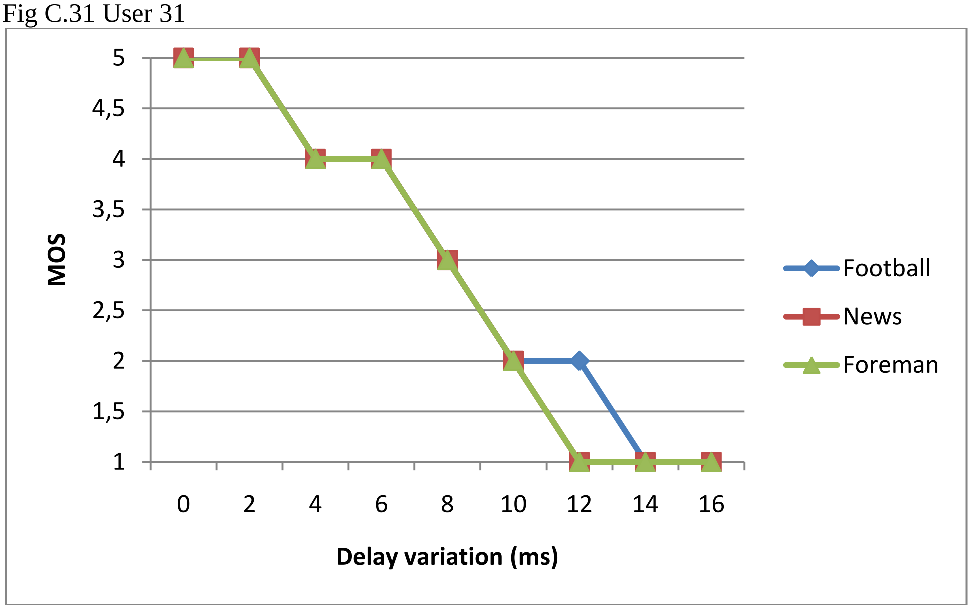

Fig C.32 User 32

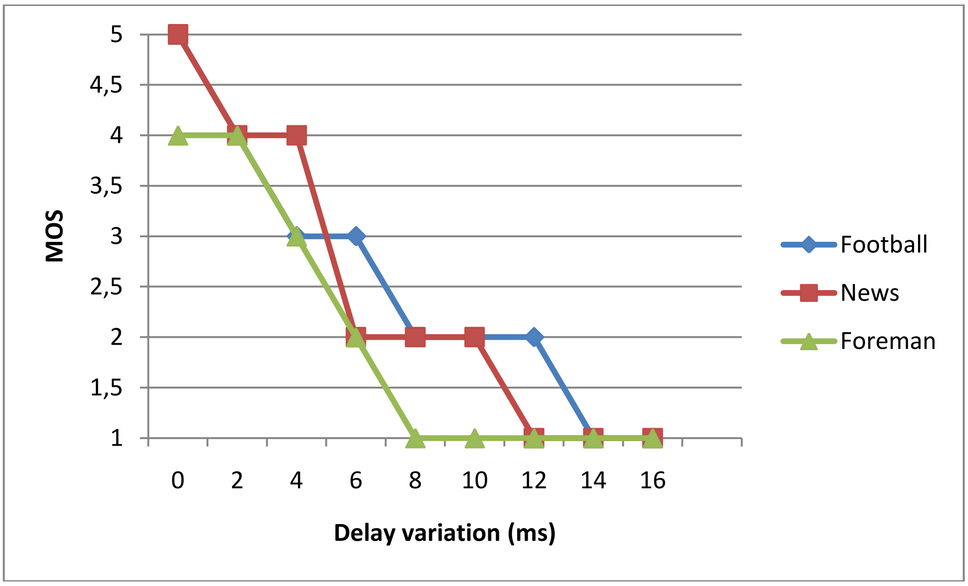

Fig C.33 User 33

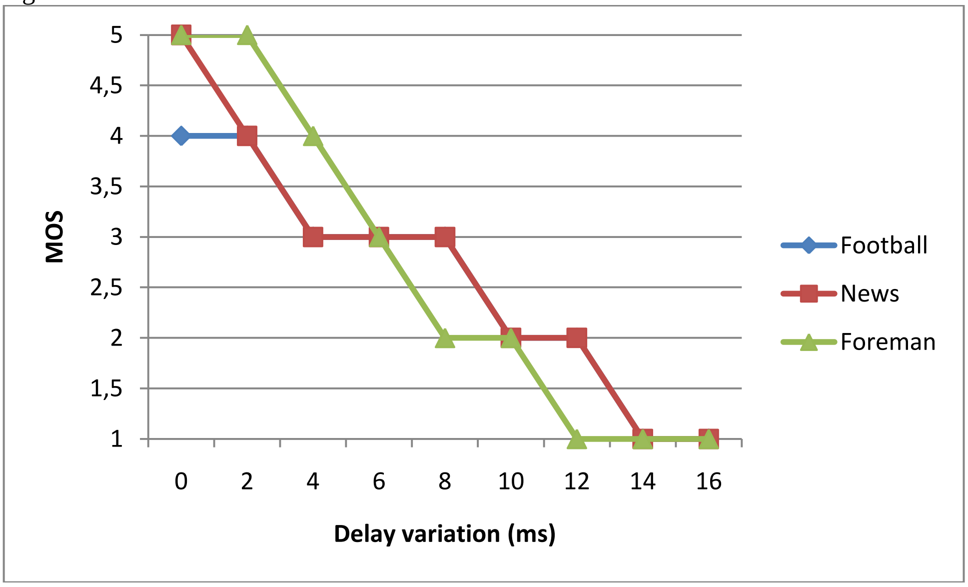

Fig C.34 user 34

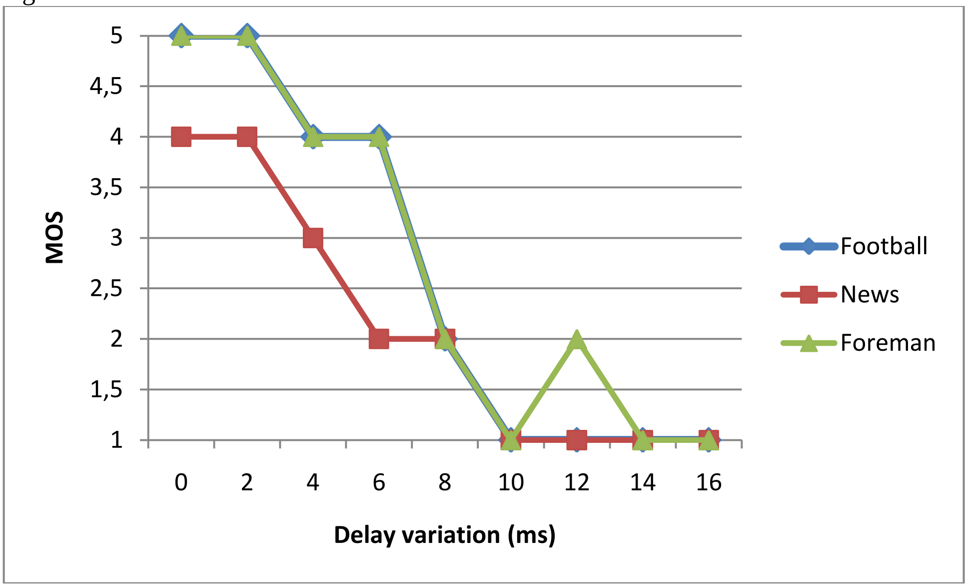

Fig C.35 User 35

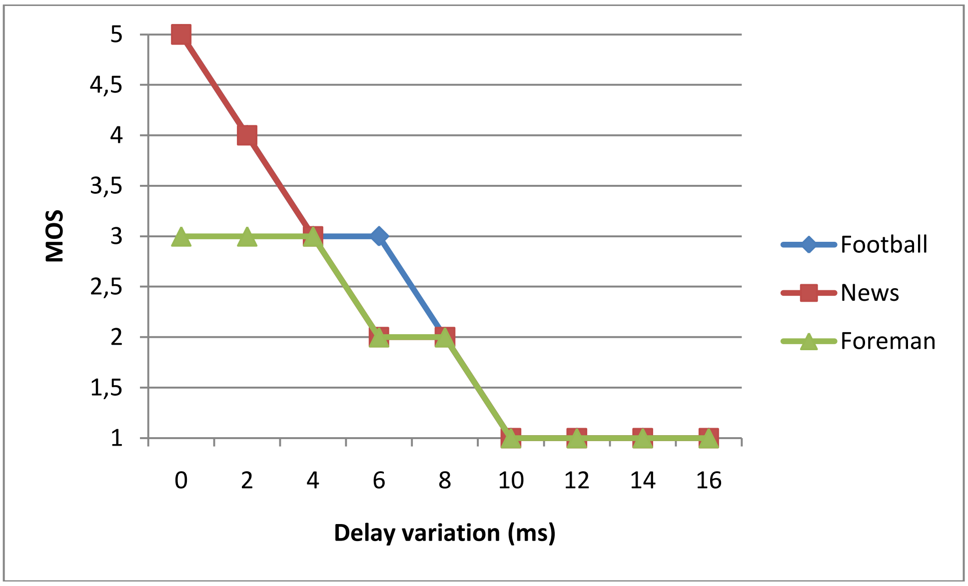

Fig C.36 User 36

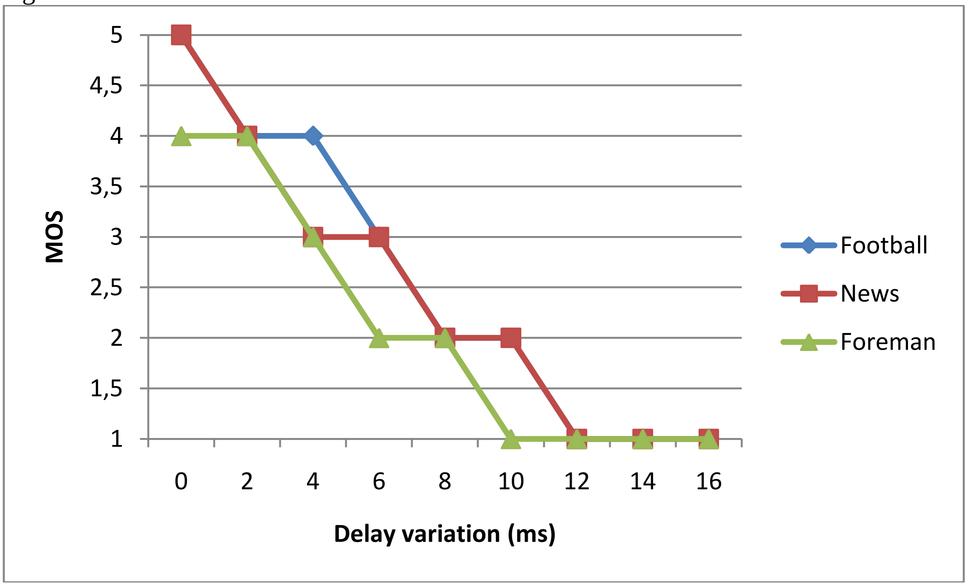

Fig C.37 User 37

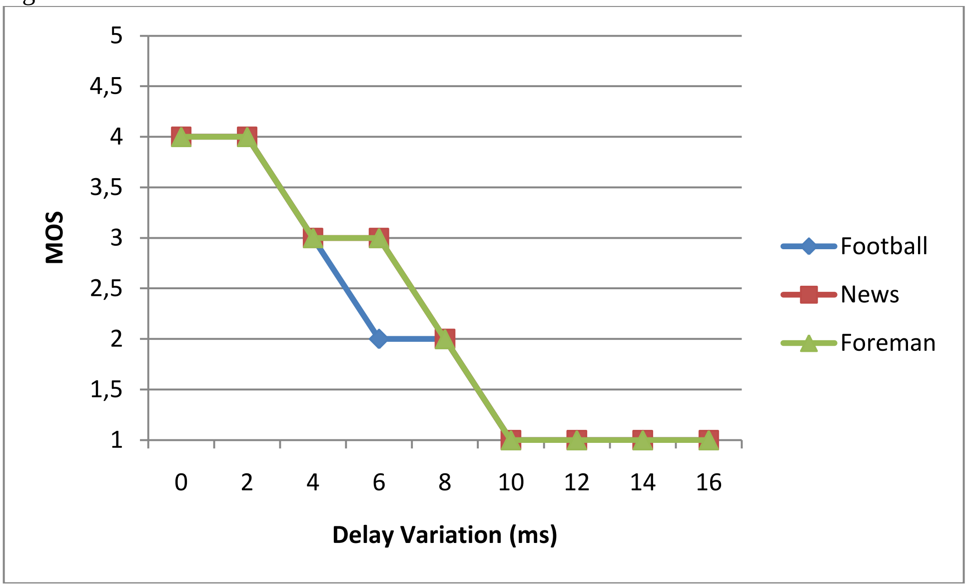

Fig C.38 User 38

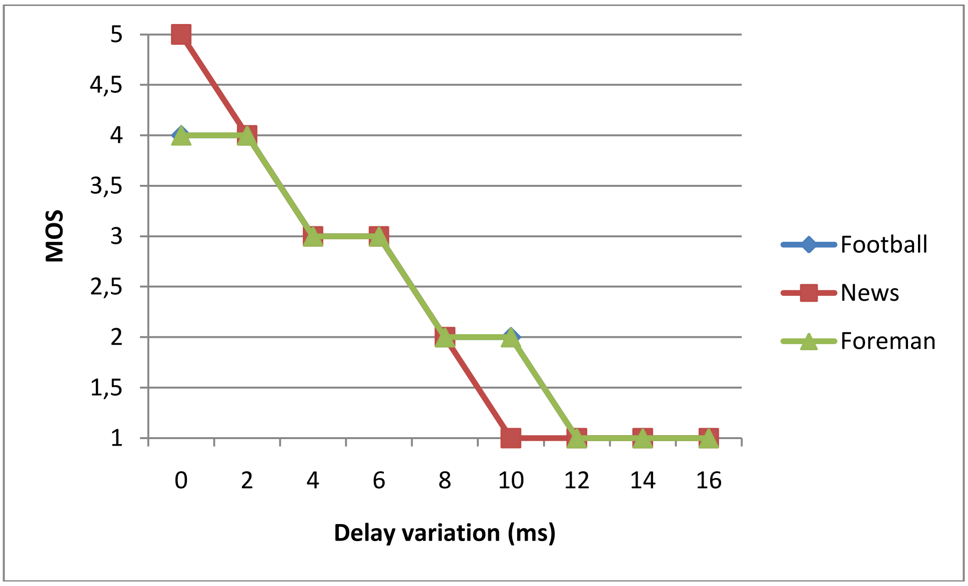

Fig C.39 User 39

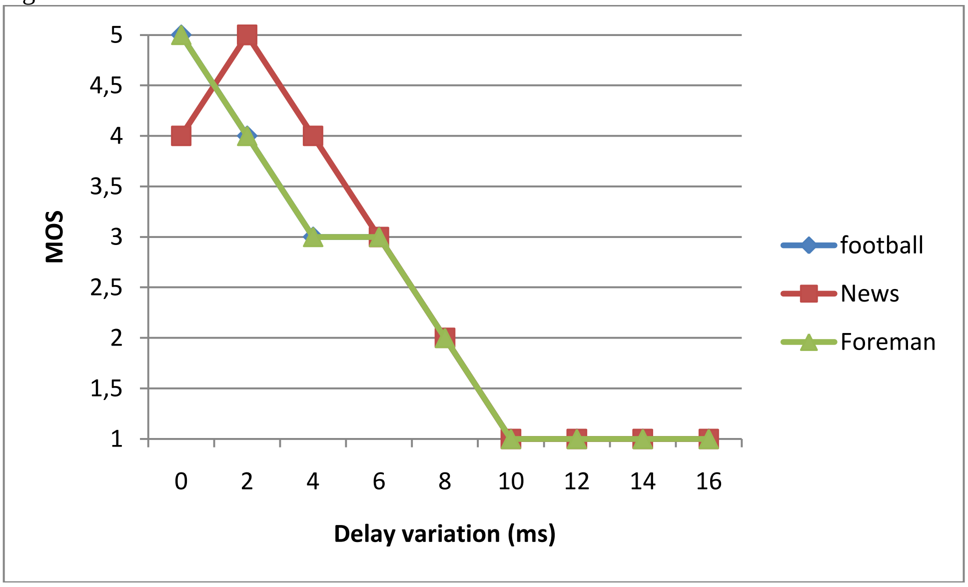

Fig C.40 User 40

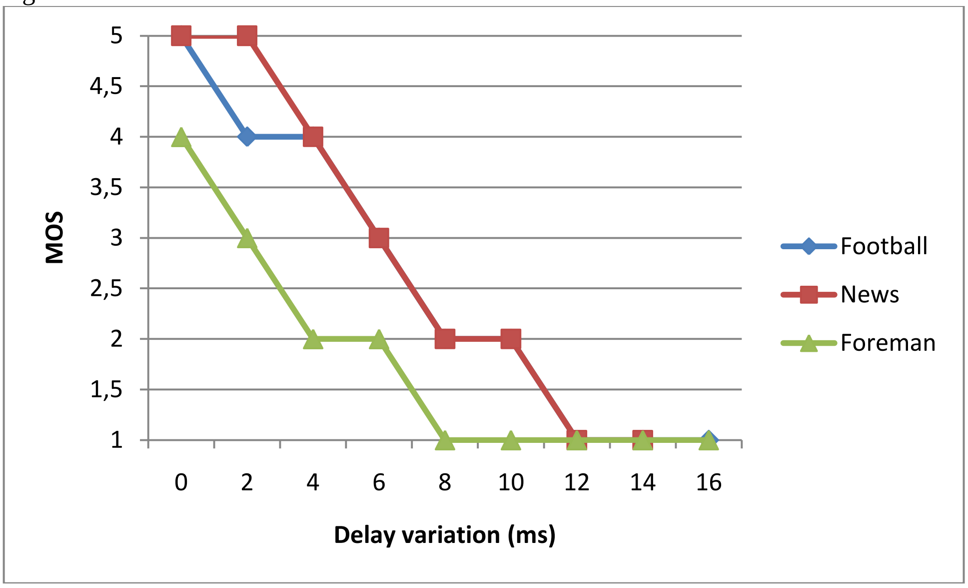

Fig C.41 User 41