Analysis of Reliable and Scalable Video-On-Demand Networks

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***Abstract*-Various architectures have been proposed and implemented to handle the rapid growth in demand for video delivering technologies. This paper implements and thoroughly examines various Video-on-Demand (VoD) architectures using the NS2 simulation tool. The simulation tool used for the project provides an efficient platform to analyze different architectures and obtain performance metrics and plots. This article analyzes the VoD traffic, compares the performance of VoD architectures under different network conditions and suggests efficient network parameters required for VoD architectures to become more reliable and scalable.**

Keywords-Video On Demand; Interactive TV; Tele-conferencing; VoD Architecture.

I. INTRODUCTION

Video-on-demand (VoD) lso provides interactivity, large catalogue of content and flexibility to watch content at the user's leisure rather than being bound by time limits. Higher network bandwidth speeds, faster CPU's and mobile internet such as Wifi and 3G have fueled the advancement of video-on-demand technologies. Video-on-Demand has wide range of applications in the field of entertainment, education, and business. Some of the examples of the applications are Movies on demand, Interactive video games, Interactive news television, Distance learning, Catalogue browsing, Interactive advertising, Video-conferencing, etc [1]. Video-on-Demand systems are continuously evolving and there have been contributions from researchers and the industry to provide varied capabilities and improved architectures. We analyze some of the architectures behind the Video-on-Demand systems. We use multiple approaches to provide this analysis, measure various parameters and give graphical representation of the results.

Performance of the Video-on-Demand system can be measured by evaluating various metrics. The transport metrics [2] measured in this paper are *packet loss*, *packet delay*, and *jitter*.

Packet loss in VoD system can be caused due to various reasons like bandwidth limitations, network congestion, link failures, transmission errors, signal degradation over the network medium, corrupted packets and faulty hardware. With UDP based video streaming protocols, a loss of packets will affect the video streams as information cannot be recovered as no retransmissions occur unless the upper layer protocol has support for it. In case of TCP based protocols, retransmissions make sure that data is somehow sent to the client, but retransmissions can induce delays thereby causing frozen images.

Packet delays are very common in packet-based networks. The various possible routes the packet may have to travel and various factors like hardware, bandwidth speed and congestion in the different routes can cause a delay in the packet arrival. Usually video transmission protocols handle the arrival of delayed packets through buffering. When the delay of arriving packets exceeds the buffer size the packet is dropped. This drop can affect video quality.

Jitter is defined as a measure of the variability over time of the packet latency of a network. A short-term variation in the packet arrival time can be caused due to network congestion, difference in routes and hardware errors. Usually a small jitter buffer is present in the client side to smooth out the variations by collecting out of order frames and sequencing it in the correct order. With severe jitter, the buffer may overflow causing distorted video.

The remaining of this article focuses on the performance evaluation of the video-on-demand systems with centralized architectures examining various clients attached to the system.

II. PERFORMANCE EVALUATION

This paper implements VoD architectures in Network Simulator 2 [3]. Simulation environment used in the project is MyEvalvid_RTP Framework supported on Network Simulator 2 [4]. Data analysis implementation is done to calculate the delay, jitter, inter-packet delay. The implementation is done

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according to RFC3550 [5]. The delay of particular packet 'i' has been calculated using the formula provided below.

$$\text{Delay}(i) = \text{Receive\_time}(i) - \text{Send\_time}(i) \qquad (1)$$

Average delay has been calculated using:

$$\text{Average delay per client} = \left[\sum_{k=1}^{N} (\text{delay})_k\right] / N \qquad (2)$$

where N is the number of clients in the system. The interpacket delay between two successive packets 'i' and 'j' has been calculated using the formula provided below.

$$\text{Interpacket\_delay}(i,j) = [\text{Receive\_time}(j)-\text{Receive\_time}(i)]-[\text{Send\_time}(j)-\text{Send\_time}(i)] \qquad (3)$$

The average interpacket delay of VoD network has been calculated using the equation provided below.

$$\text{Average interpacket delay per client} = \left[\sum_{k=1}^{N} (\text{interpacket delay})_k\right] / N \qquad (4)$$

Jitter is defined as packet delay variation. In particular, inter-arrival jitter is defined as mean deviation of interpacket-delay and has been implemented according to RFC3550 [10].

$$\text{Jitter}(i) = \text{Jitter}(i-1) + [\,|\text{Interpacket\_delay}(i-1,i)| - \text{Jitter}(i-1)\,] / 16 \qquad (5)$$

Average jitter has been calculated using the equation provided below.

$$\text{Average jitter per client} = \left[\sum_{k=1}^{N} (\text{jitter})_k\right] / N \qquad (6)$$

Now, we compare two architectures: Centralized and Content-based networks.

III. CENTRALIZED ARCHITECTURES

Centralized architecture is one in which the central video-on-demand server's are placed in the core of the network. The various Internet service providers (ISPs) are connected to the core network through access networks which may take multiple router hops to reach the VOD server. Figure 1 shows the simulated centralized architecture with 5 clients. Figure 2 shows the flow diagram for the centralized architecture. The clients in turn are connected to the ISPs. To better understand the various factors affecting video quality at client side, a network as shown below was chosen. The VOD server is connected to the router with a 30Mbps link and a delay of 10ms. The rest of the routers from 1 to 16 are connected with a constant bandwidth of 10Mbps and varying delays.

The clients were in-turn connected to their respective ISP's with different link speeds to simulate the currently popularly available client bandwidth rates. Clients 1-5 were connected at the rates of 768 Kbps, 1024 Kbps, 2 Mbps, 4 Mbps, and 6 Mbps respectively. All clients were simulated to request a same video of length 750 frames. Various factors such as delay, inter-packet delay and jitter have been studied

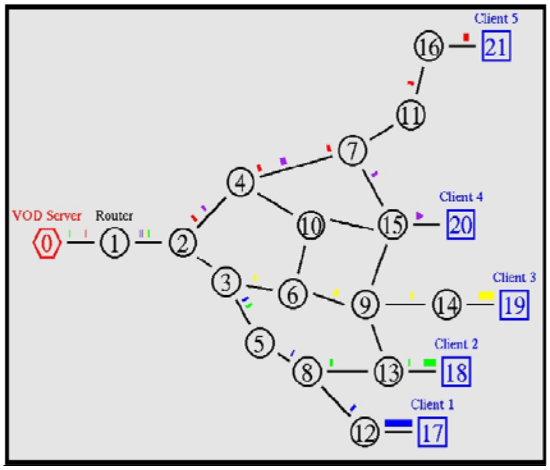

Figure 1. Simulated Centralized Architecture with 5 clients

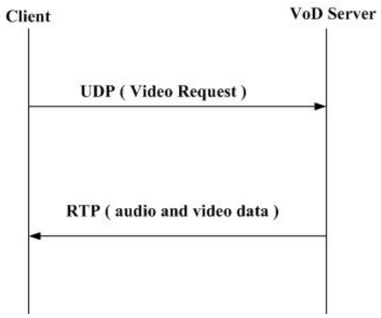

Figure 2. Flow diagram for Centralized Architecture

Client 1, which was connected at 768 Kbps had the most varying data for delay. Large variance in delay can affect the video quality badly. In case of client 2 connected at 1024 Kbps the delay values are significantly stable. The reason for such a variance between client-1 and client-2 is the bit rate at which the video was encoded, which is 1024 Kbps. Clients 3, 4 and 5 show a constant delay data.

An interesting thing to note about clients 3, 4 and 5 is that even with better bandwidth client 5 has higher delay than client 4 and client 3. This is due to the delay between the different routers and the higher number of hops that a frame takes to reach client 5, when compared to client 4. Client 3 has same number of hops as client 5, but the delay on a per hop basis has been configured to be less for client 3 which has actually boosted its performance.

The smoothened absolute value of inter frame delay gives the final jitter. Large variance in inter frame delay depicts out of order frames, which can lead to very bad video quality. The client bandwidth plays a major role in the inter frame delay. From the above simulation, client 1 and client 2 which have the least bandwidth connectivity's to their respective ISPs have the most variance in inter frame delay. With higher bandwidth connectivity clients 3, 4 and 5 have very less variance. The inter frame delay plays a major role in the final inter frame jitter values. With a large variance in delay, the jitter effect is more pronounced in clients 1 and 2. Jitter corresponds to choppiness in the video and with high jitter values, video quality is drastically affected. Figures 3, shows the delay for video transmission from VoD Server to Client.

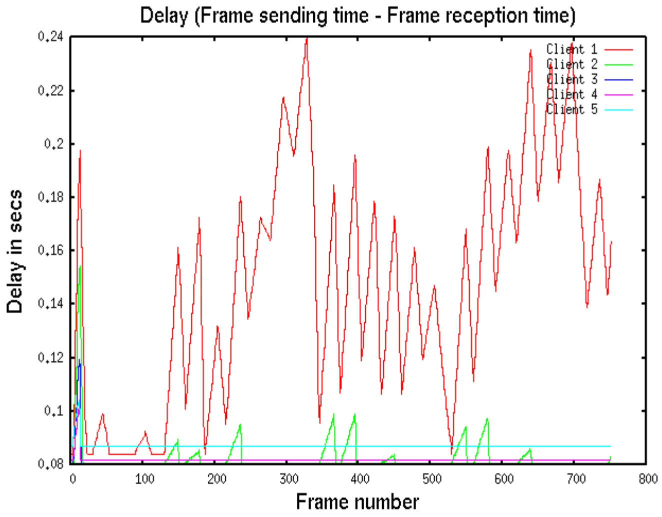

Figure 3. Delay for video transmission from VoD Server to Client

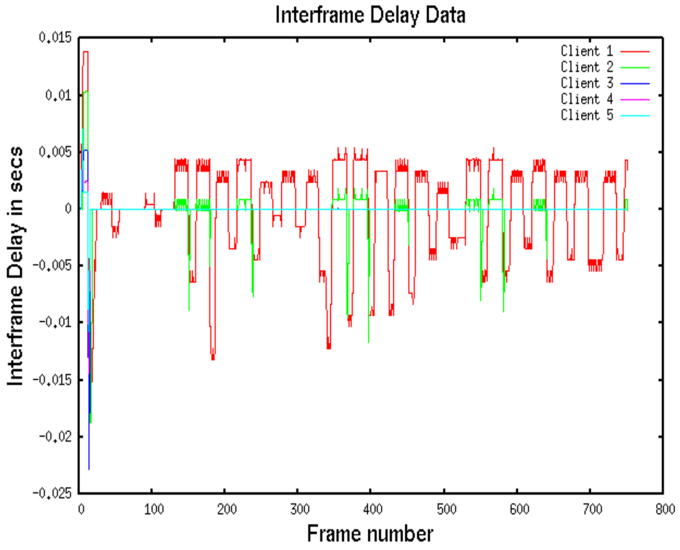

Figure 4. Centralized Architecture Interpacket delay plot

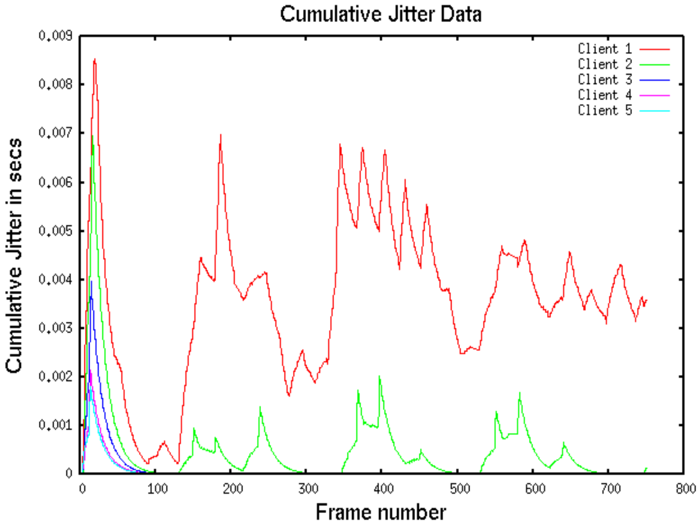

Figure 5. Centralized Architecture Jitter plot

A. Case 1

The effect of increasing number of clients in centralized architecture is provided below. Video on demand is currently in a high growth spurt. Scalability of architecture plays a vital role in its selection for widespread use. To better understand the effect of increasing number of clients on centralized architecture, all clients are connected with a constant bandwidth link of 2 Mbps. All router nodes are interconnected with a 10 Mbps link. The number of clients is continuously varied and various factors like average delay, jitter and packet loss are studied.

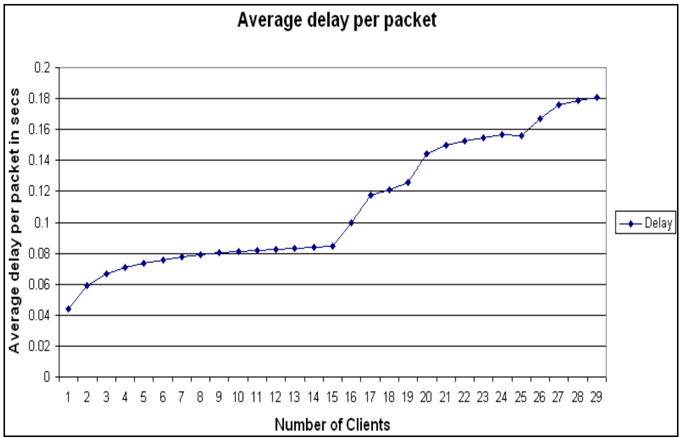

Figure 6. Average delay with the increase in the number of clients

All clients are configured to request the same video in our analysis, which gives consistent values for the graphs. As we can see in Figure 6, with increasing number of clients choking the bandwidth, the average delay per packet increases. In the scaled down network we can clearly see that till 16 simultaneous clients, the variance in delay is very smooth and levels down. When the 16 client threshold is reached a drastic increase in delay is seen.

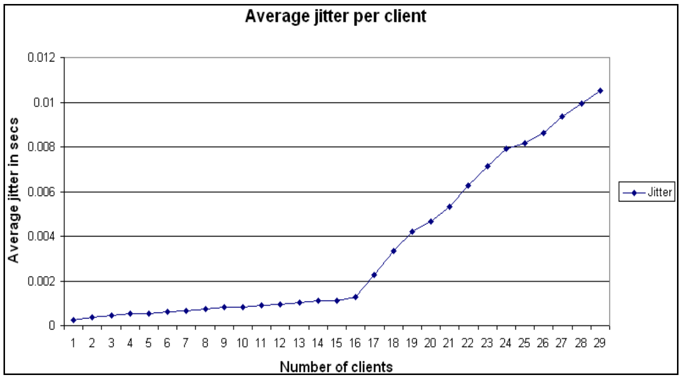

Figure 7. Average jitter with increase in the number of clients

The average jitter per client shown in Figure 7 is calculated by averaging the inter frame jitter on a per client basis. The effect of delay on Jitter is clearly seen in the above graph. When the delay was constant and under 0.1 seconds till 16 clients, the jitter was varying in a constant manner. Once the sweet spot of 16 clients is exceeded a drastic change in jitter is seen.

Packet loss percentage is calculated as

100 x (1 – Packets seen / Packets expected)

Packet loss shown in Figure 8 shows the most drastic effect on video quality. When frames of video data are lost, video starts stuttering and become distorted. The drastic effect of packet loss with increasing number of clients once it reaches a particular count shows one of the major disadvantages of the centralized architecture. The video quality has a very high dependency on the access network links.

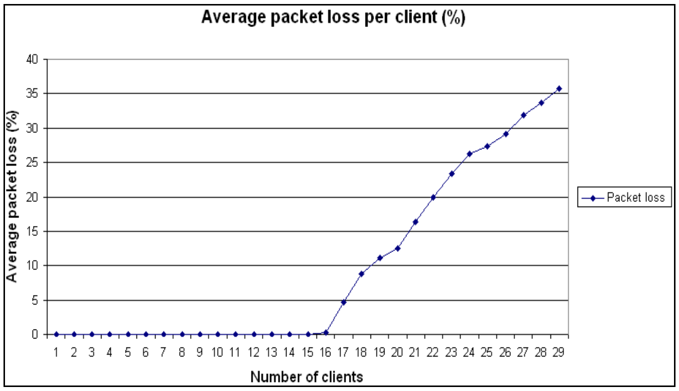

Figure 8. Average packet loss with increase in the number of clients

B. Case 2

The effect of increasing access network bandwidth is provided below. From the previous analysis with 5 clients, factors such as client bandwidth, router bandwidth and delay were shown as major factors affecting video transmission. In this current experiment the client bandwidth is taken to be constant value of 2 Mbps, which is sufficient to transmit a 1024 Kbps encoded video. The major effect on quality of video transmission in case of centralized architecture is due to the bandwidth between the access links connecting the core of the network to the edge of the network.

As access network bandwidth plays a major role in the video quality transmitted to the client, the same test as above has been conducted with a constant number of clients but varying bandwidth. The number of clients connected to the centralized video on demand server is kept at a constant value of 20. The bandwidth across the access network between each node is constantly varied from 5 Mbps to 20 Mbps and the effect of varying bandwidth is studied.

The average delay per packet has only been calculated for the packets that have been successfully received on the client end. With this data it is clear that increasing bandwidth reduces delay considerably. Once we reach 16 Mbps, the delay becomes constant and is now dependent on the delay between links of the access network. A reduction in average delay corresponds to reduction in jitter. Similar to delay, when sufficient bandwidth is present, the variation in delay becomes minimal. Figures 9, 10 and 11 are the results for this case.

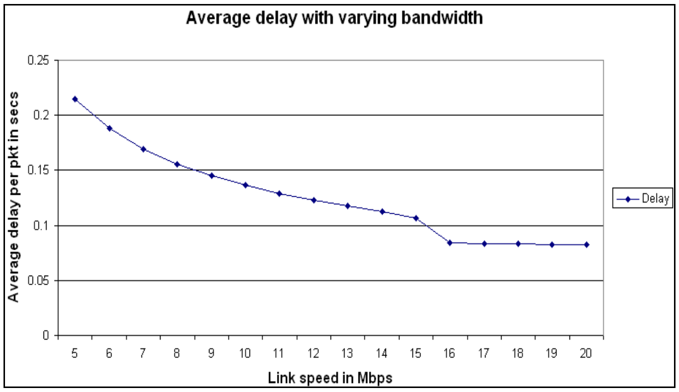

Figure 9. Average delay with increase in bandwidth

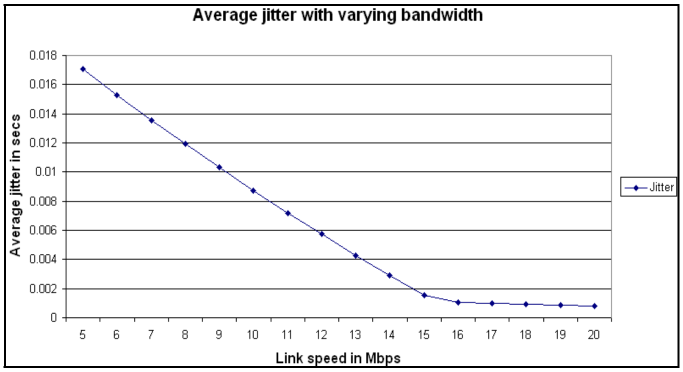

Figure 10. Average jitter with increase in bandwidth

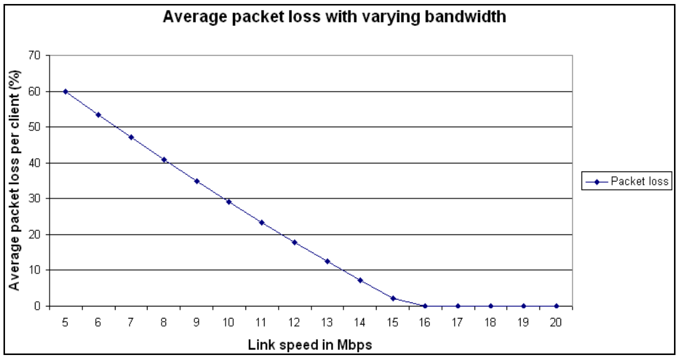

Figure 11. Average packet loss with increase in bandwidth

Bandwidth has a very profound effect on packet loss percentage, which in turn plays a major role in video quality. Factors like delay and jitter can be handled by the client with enough buffering. Packet loss on the other hand cannot be handled by the client without distortion or loss of video quality. With increasing bandwidth, packet loss is drastically reduced.

From the above analysis we can see that for 20 clients downloading a video of 1024Kbps at the same time, a minimum access network bandwidth of 16Mbps is required for optimal performance. The video on demand service provider is totally dependent on the access network which connects the VOD server to the client. Access networks can scale across multiple routers and may even cross multiple countries. It is thus very difficult on the part of the VOD service provider to ensure and guarantee video quality across the access network as the service provider has less to no control over the internet.

IV. CONTENT DELIVERY NETWORKS

The major factor that was found to affect video quality in centralized architecture is the access network link. This is totally removed out of picture when it comes to video delivery to the client in the CDN architecture. Figures 12 and 13 show an overview and the flow diagram of content delivery networks proxy video-on-Demand servers, denoted by red hexagons are placed close to the edge of the network. By placing the VoD proxies close to or at the ISP's infrastructure, the massive delays and losses incurred due to access network links can be avoided. The access network links are used only for replicating video content from the central VoD server to the VoD proxies.

In the below simulation, similar to centralized architecture, the clients are connected to the respective ISP's with different link speeds to simulate the current popularly available client bandwidth rates. Clients 1-5 were connected at the rates of 768 Kbps, 1024 Kbps, 2 Mbps, 4 Mbps, and 6 Mbps respectively. All clients were simulated to request a same video of length 750 frames. Various factors such as delay, inter-frame delay and jitter have been studied.

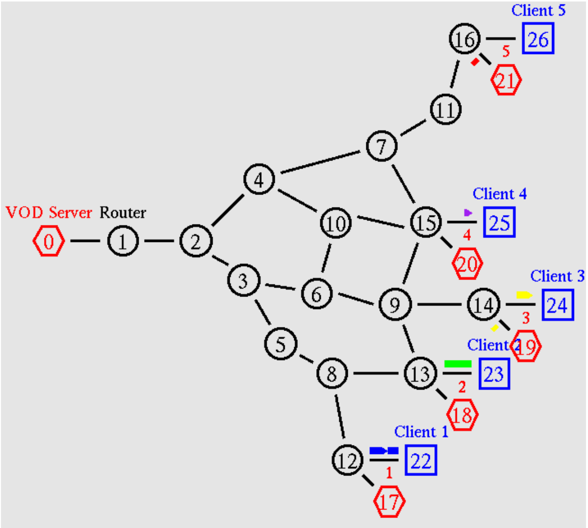

Figure 12. Simulated CDN (Hexagons labeled 1,2,3,4 & 5 are the proxy servers at the edge of the network)

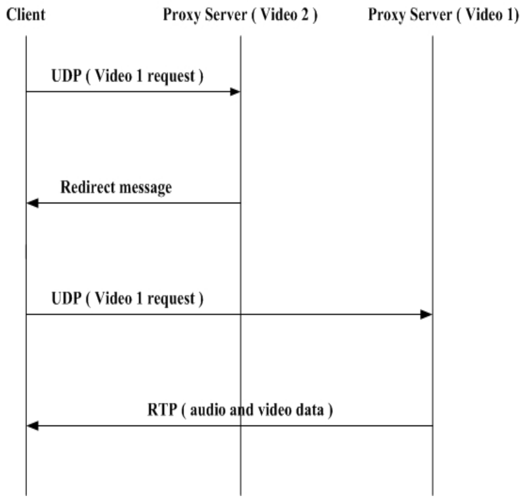

Figure 13. Flow diagram of Content Delivery Networks

In contrast to the centralized architecture, where the access network bandwidth and the client bandwidth both played a role in the delay noted, here only the client bandwidth affects the delay. This can be seen by comparison on data of clients 3, 4 and 5. In case of centralized architecture, due to better access link speed and delay client 3 connected at 2 Mbps was performing better than client 5 connected at 6 Mbps. In case of centralized architecture, the delay decreases with increasing client bandwidth rates.

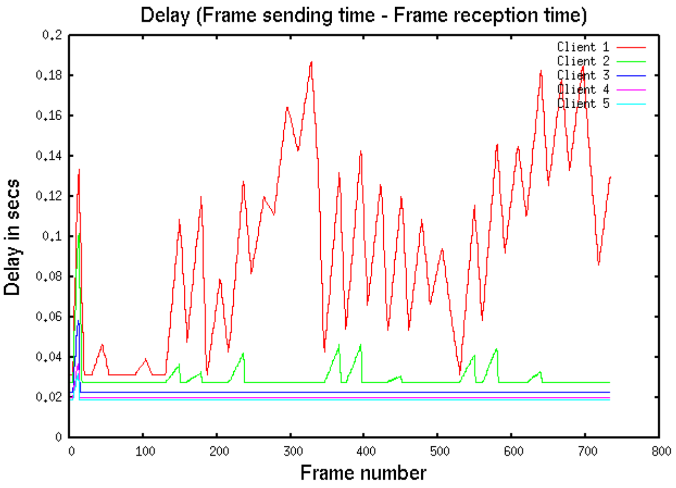

Figure 14. Delay for video transmission from proxy server to clients

The plots of Figure 14 clearly show the advantages of a distributed architecture as content delivery networks. Centralized architecture has a single point of failure and leads to heavy network congestion at the core of the network, which drastically affects the video quality. By distributing proxy servers towards the edge of the network, CDN no longer has a single point of failure. As the number of hops between the client and server are reduced - jitter, delay and packet loss are comparatively lesser and better video performance is achieved. Hence the deployment of proxy servers near to the clients makes the VoD systems more reliable and scalable.

V. CONCLUSION AND FUTURE WORK

In this article we analyzed the VoD traffic, and compared the performance of VoD architectures under different network conditions. We suggested efficient network parameters required for VoD architectures to become more reliable and scalable. With the best possible video on demand infrastructure, if the client does not make wise use of the existing bandwidth limits, video quality would be poor. Heavy network usage, computer virus, old versions of operating systems and unprotected network on the client end can have adverse effect on video on demand quality. Cable modems and wireless routers generally used at homes these days have good firewalling and quality of service configuration support. Bandwidth can be reserved in these devices for video on demand traffic. This ensures that even when in times of excessive network usage, minimum required bandwidth for video on demand traffic is available. The research in this article can be extended to non-centralized architecture in future.

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