Final Project
Performance Analysis of Ethernet Network

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Group 12

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1.0 Abstract

This project studies the viability of using different Ethernet specifications to implement local network attached storage in a post-production facility. Nine scenarios were executed in Riverbed Modeler 18.0 in which the feasibility of transferring AVCHD 1080p, ProRes 422 1080p, and ProRes 422 4K files over Fast Ethernet, Gigabit Ethernet, and 10 Gigabit Ethernet links. The simulation was analyzed and showed a significant impact depending on the Ethernet link implemented. Fast Ethernet was shown to underperform for even the least demanding modern video codec while Gigabit Ethernet is capable of handling all but the most cutting edge 4K video files. 10 Gigabit Ethernet, the next generation Ethernet standard, proved capable of handling even the most demanding shared storage scenario.

2.0 Introduction

This project simulated a video editing studio with eight workstations simultaneously accessing video footage from network-attached shared-storage over an FTP connection. The simulation consisted of nine scenarios in which ethernet links and video file formats were varied across the options detailed in Section 3 and 4. The objective of the project is to determine which Ethernet links are able to provide the workstations with on-demand access of the video footage (i.e. average throughput of each client greater than or equal to the video file data rate) as well as minimal delay.

3.0 Video File Formats

The project simulates the transfer of three video file formats: AVCHD 1080p, ProRes 422 1080p, and ProRes 422 4K. These file formats correspond to commonly used file formats in use by amateur videographers, typical video productions, and high-budget filmmaking, respectively.

3.1 AVCHD 1080p

AVCHD is a video encoding format jointly created by Sony and Panasonic and released in 2006 [1]. At the time, DVD storage was an attractive medium for video storage due to it's relatively low cost and ease of acquisition. According to the original press release, AVCHD was originally designed as "an HD1 digital video camera format for recording 1080i and 720p signals onto 8cm DVD media by using highly efficient codec technologies" [1].

Figure 1: AVCHD Logo [1]

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[1] "HD" (high definition) is a marketing term for digital video recordings with a resolution of 1280x720 (known as "720") or 1920x1080 (known as "1080". The "i" and "p" following the resolution indicate the method by which video frames are refreshed on-screen, but fall outside the scope of this report.

The technologies underlying the AVCHD file format are the now ubiquitous MPEG-4/H.264 codec which offer high data-compression of HD video files resulting in low data rates but at the sacrifice of colour information and low quantization bit rate [1].

Digital storage of an image involves encoding image information into three distinct channels known as Y'Cb'Cr (the Y channel records luminance information while the Cb and Cr channels record colour information) [2]. AVCHD follows a 4:2:0 colour sampling algorithm[2] which captures all luminance information while discarding half of the Cb channel information and all of the Cr channel information [2]. Data in each channel is quantized in 8 bit, a relatively low colour bit rate.

This compression scheme enables the impressively small file sizes. While image quality is noticeably reduced, the codec is aimed at consumer devices and offers an acceptable trade-off in file size and image quality.

The "DSLR video revolution" began in 2008 with the launch of the Canon EOS 5D Mark II, a traditional photography camera capable of capturing cinema-style video at consumer-friendly prices [3, 4]. In 2011 the AVCHD format was updated to version 2.0 with the addition of 1080p support, leading to the widespread adoption by many camera manufacturers. One such camera which employs the AVCHD video encoding format is the Canon 7D Mark II, released in September 2014 [5].

This project simulates the transfer of AVCHD video from the Canon 7D Mark II. As specified in the camera's instruction manual, 1080p video captured at 24 frames per second results in footage with an average bit rate of 30 Mbps or 225 MB/min of footage [6].

3.2 ProRes 422 1080p

While the compression ratio of AVCHD is impressive, the lossy compression algorithm results in a serious reduction in image data available during post-production and lesser image quality [7]. While this loss of information is acceptable to the average consumer, filmmakers, independent production companies, and avid consumers require an alternative data compression method capable of efficiently compressing video files while maintaining a higher level of image data integrity [7].

Apple Inc. responded to the industry need in 2007 with the release of the ProRes 422 codec [8]. In addition to providing efficient bit-rate compression while maintaining video quality, decompression of Apple ProRes requires minimal CPU processing, posing ProRes as an attractive codec to video editors and post-production teams [8].

Figure 2: Apple ProRes Logo

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[2] To read more regarding colour sampling theory, see [2]

ProRes 422 is named according to the 4:2:2 chroma subsampling used in the compression algorithm, offering twice the colour information as available in AVCHD. Figure 3 shows the effect of varying colour sampling techniques. Additionally, data is encoded in 10-bit which offers a 4x improvement in data quantization. The additional data captured in ProRes 422 is crucial to modern post-production including colour grading and animation [7].
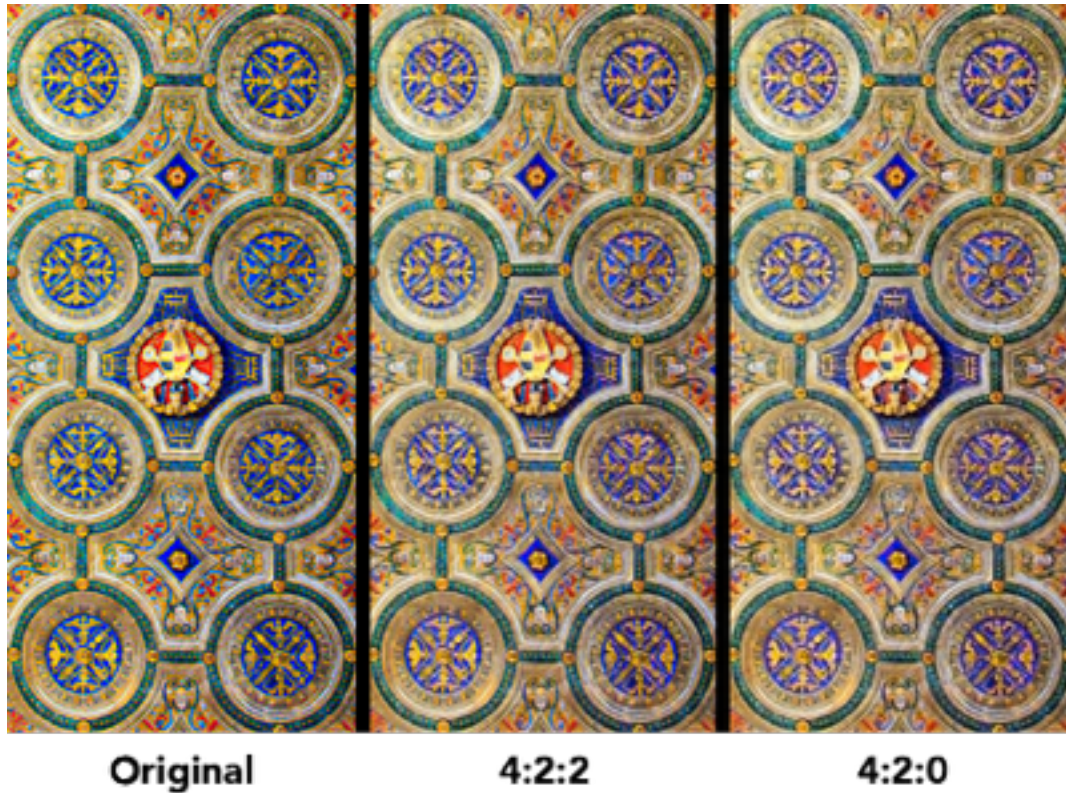

Figure 3: Color Sampling Image Comparison [2]

This project also simulates the transfer of an Apple ProRes 422 1080p video file. According to a white paper published by Apple in 2009, a 1080p video file captured at 24 frames per second has an approximate data rate of 117 Mbps or 904 MB/min of footage [9].

3.3 ProRes 422 4K

The same year the original ProRes codec was released, the Red Digital Camera Company continued to push camera industry forward with the 2007 release of the Red One [10]. This camera was first to offer capture of 4K video, video captured at a resolution of 4096x2304 (approximately 4.5x the resolution of 1080p). In the following years, other camera manufacturers began releasing similar offerings capable of capturing the ultra high resolution video [11]. Figure 4 shows a comparison of the image resolutions highlighting the vast increase in resolution offered by 4K video capture.
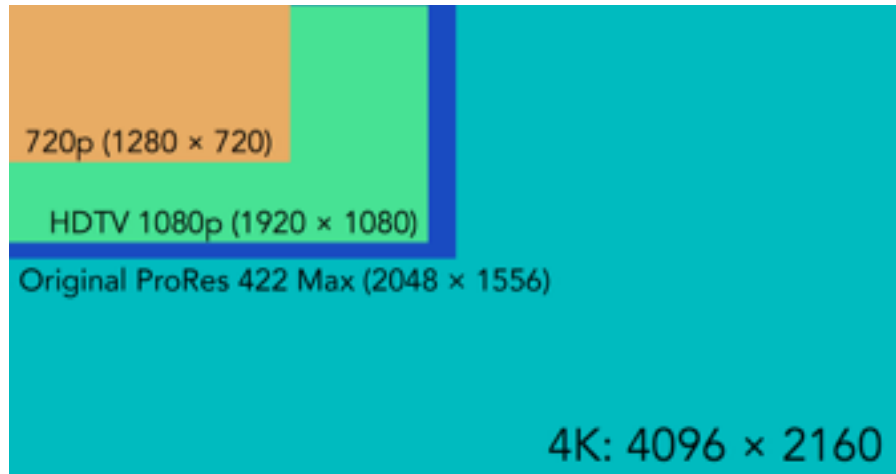
Figure 4: Video Capture Resolution Comparison

The ProRes 422 codec was limited to a maximum resolution of 2048x1556 until the release of Apple Final Cut Pro 10.1 in December 2013 which brought ProRes support for 4K and 5K resolutions [12]. Similar to ProRes 422 1080p, the higher resolution variants offer the same 4:2:2 colour sampling and 10-bit quantization.

This project simulates the transfer of ProRes 422 4K video captured at 24 frames per second. According to the 2014 ProRes White Paper, the approximate bit rate of ProRes 422 4K video files is 503 Mbps or 3.77 Gb/min of footage [13].

4.0 Ethernet

In 1973, while working at Xerox's Palo Alto Research Center (PARC), early Internet pioneer Robert Metcalfe invented the Ethernet protocol [14]. The first iteration of Ethernet created by Metcalfe consisted of a 2.94 Mbps CSMA/CD3 system over a 1 km cable connecting more than 100 workstation together [15]. Ethernet's place in the networking environment was solidified in 1983 when the IEEE Standards Association developed the local area network (LAN) 801.3 Ethernet standard.

Ethernet exists as a Physical Layer protocol in the OSI network model and provides communications between host machines via a shared medium. Ethernet has managed to remain one of the dominant networking technologies in use thanks to the continued development of the cost-effective protocol [14]. According to CISCO, Ethernet has "the highest number of installed ports and provides the greatest cost performance relative to Token Ring, Fiber Distributed Data Interface (FDDI), and Asynchronous Transfer Mode (ATM) for desktop connectivity" [14].

As Ethernet development has progressed, a unique naming scheme has been created to describe the specific implementations. The a standard name which follows the convention has three components which describe the specifics of the Ethernet implementation. One example of this

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3 For more information on Carrier Sense Multiple Access With Collision Detection (CSMA/CD), see http://www.linfo.org/csma_cd.html

naming scheme is 100BaseT. The 100 prefix of the name denotes the data transfer rate in Mbps. The "Base" component of the name indicates the data transfer rate is for a baseband transmission requiring no digital modulation. Finally, the suffix of the name indicates the physical medium. Of the many possible Ethernet name suffixes, T and F represent two examples indicating the standard operates over twisted copper wires or fibre optic cables, respectively [16].

4.1 Fast Ethernet (100BaseT)

One notable version of Ethernet, released in 1995 by the IEEE, is 100BaseT offering data transfer rates of 100 Mbps. As the name indicates, the standard operates over two unshielded twisted pairs (UTP) of copper wire. Twisted pairs come in unshielded (UTP) or shielded (STP) variants, the latter which offers additional protection from interference, speed improvements, and data security [18]. Similar to the original Ethernet protocol, the 100BaseT standard implements a CSMA/CD multiple access protocol to facilitate shared medium communication [17].
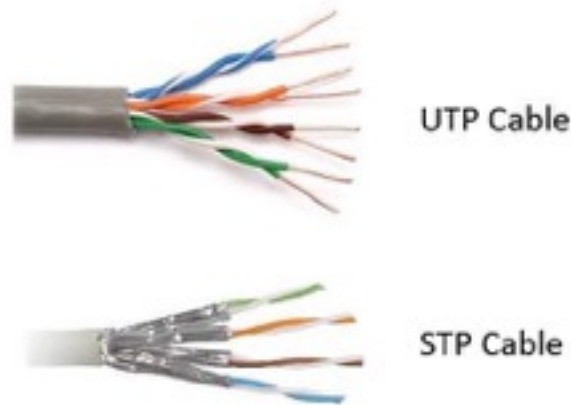

Figure 5: UTP vs. STP Ethernet Cable [18]

Prior to the release of 100BaseT, the 10BaseT Ethernet was in widespread use. The 10x increase in the data transfer rate resulted in the new standard being dubbed "Fast Ethernet" [17]. 100BaseT offered fast data transfer, high reliability, and low cost of implementation which led to the widespread adoption of the standard in backbone networks and server connectivity [17, 14].

This project simulates the data transfer of AVCHD 1080p, ProRes 422 1080p, and ProRes 422 4K video files over 100BaseT network links as described in Section 5.

4.2 Gigabit Ethernet (1000BaseX)

As the nature of the Internet and interconnected networks has developed and new higher bandwidth applications were developed, the need for a faster Ethernet standard quickly became evident [19].

One of the first steps to improving Ethernet technology beyond Fast Ethernet began with the creation of the 802.3z Gigabit Ethernet Standardization Project by the IEEE 802.3 Committee in March 1996 [20]. The task of creating the next generation of Ethernet was undertaken by a consortium of as many as 95 companies which formed the Gigabit Ethernet Alliance (GEA) with

the intention of creating a protocol with 1000 Mbps data transfer speed, a 10x improvement over Fast Ethernet [20].

The GEA had a number of objectives while creating the updated standard [21]:

- Create an update to the standard which allows half-and full-duplex operation at 1000 Mbps
- Maintain backwards compatibility with the existing 802.3 frame format
- Maintain use of CSMA/CD access method

The work of the GEA was completed a mere two years after inception with the publication of Gigabit Ethernet in 1998 [21]. Gigabit Ethernet accomplished the above objectives through the combination of existing Ethernet technology with the ANSI X3T11 Fibre Channel Specification and is available in both UTP copper wire and fibre channel, known as 1000BaseT and 1000BaseX, respectively [20]. Like the standards before it, Gigabit Ethernet was quickly adopted and has become the dominant LAN link in use today.

This project makes use of the 1000BaseX link format provided in Riverbed Modeller 18.0 to simulate the transfer of AVCHD 1080p, ProRes 422 1080p, and ProRes 422 4K video files as outlined in Section 5.

4.3 10 Gigabit Ethernet (10Gbps_Ethernet)

In today's network-connected world, local area networks are used for and ever growing number of applications. While Gigabit Ethernet is still the most commonly found wired LAN link in use by consumers, the need for further development continued. In particular, higher bandwidth links are necessary in scenarios such as [22]:

- Aggregating multiple Gigabit Ethernet segments into higher bandwidth downlinks
- Providing backbone links for metro and WAN connections
- Providing Storage Area Network (SAN) connections between interconnected server clusters

10 Gigabit Ethernet was standardized in 2002 as 802.3ae by the IEEE [23]. The introduction of 10 Gigabit Ethernet brought a notable and fundamental changes to the Ethernet protocol. More specifically, the updated standard offers support for full-duplex mode only and does not implement CSMA/CD [23]. Beyond this change, however, most all other aspects of 10 Gigabit Ethernet remain consistent with previous iterations of the standard. Unlike Gigabit Ethernet, however, the cost of 10 Gigabit Ethernet is still relatively high and has not yet seen widespread adoption [23].

The use of 10 Gigabit Ethernet in a Storage Area Network was the inspiration from which this project is based. The project simulation includes transfer of AVCHD 1080p, ProRes 422 1080p, and ProRes 422 4K video files over 10 Gigabit Ethernet links.

5.0 Simulation Setup and Implementation

5.1 Scenario Overview

As mentioned in section 4.3, locally connected network attached storage has emerged as a new use for high bandwidth network links. One common application of shared storage is in video post-production studios where multiple editors access video footage stored on a shared server in or nearby an editing studio. A variety of transfer protocols are used in real-world implementations of such a scenario including AFP, SMB, and FTP. This project simulates an FTP file transfer to study how effective different Ethernet standards are at providing on-demand, network access to a variety of file formats.

To study the effects of transferring high quality video file formats over Ethernet, nine different scenarios were created with varying file sizes were used to simulate the high definition video transfers. Each scenario consists of a network of eight workstations connected to a server via an Ethernet link. As shown in Figure 6 below, the Ethernet links used include 10 Gigabit Ethernet, Gigabit Ethernet, and Fast Ethernet connected to a central server. The analysis will then be conducted base on the point-to-point and FTP statistics collected from the Ethernet links.
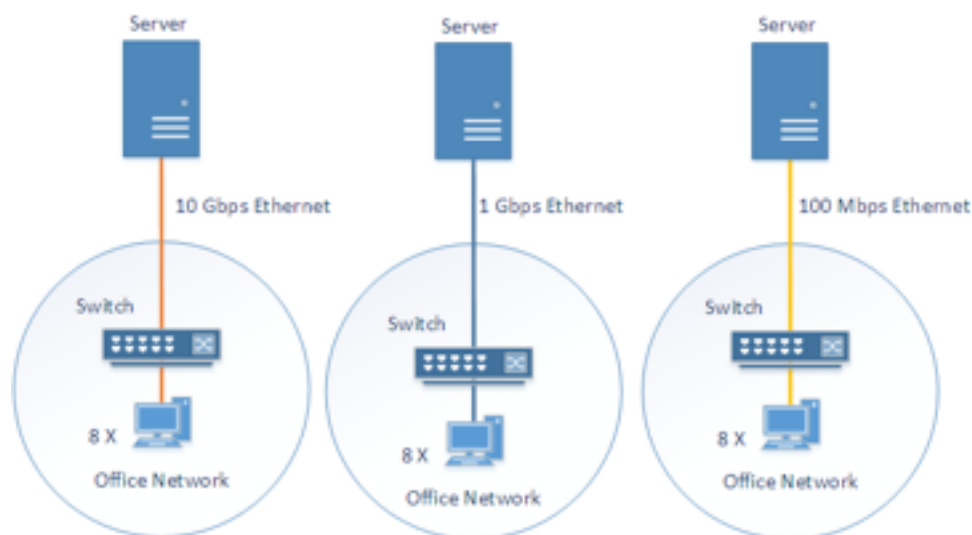

Figure 6: Overview of Scenarios implemented

5.2 Riverbed Modeler Implementation

Using Riverbed Modeler 18.0, a campus sized network with a parameter of 5 km × 5 km was configured to analyze the effects of the nine scenarios. A rapid configuration tool was used to create a star topology with an Ethernet_16 switch as the centre node, 8 Ethernet workstations as the periphery nodes, and 10 Gbps Ethernet links as the link model. The Ethernet_16 switch is responsible for connecting the 8 clients to the central server for file access. The load of the 8 channels are forwarded to the FTP server using different Ethernet links for comparison.
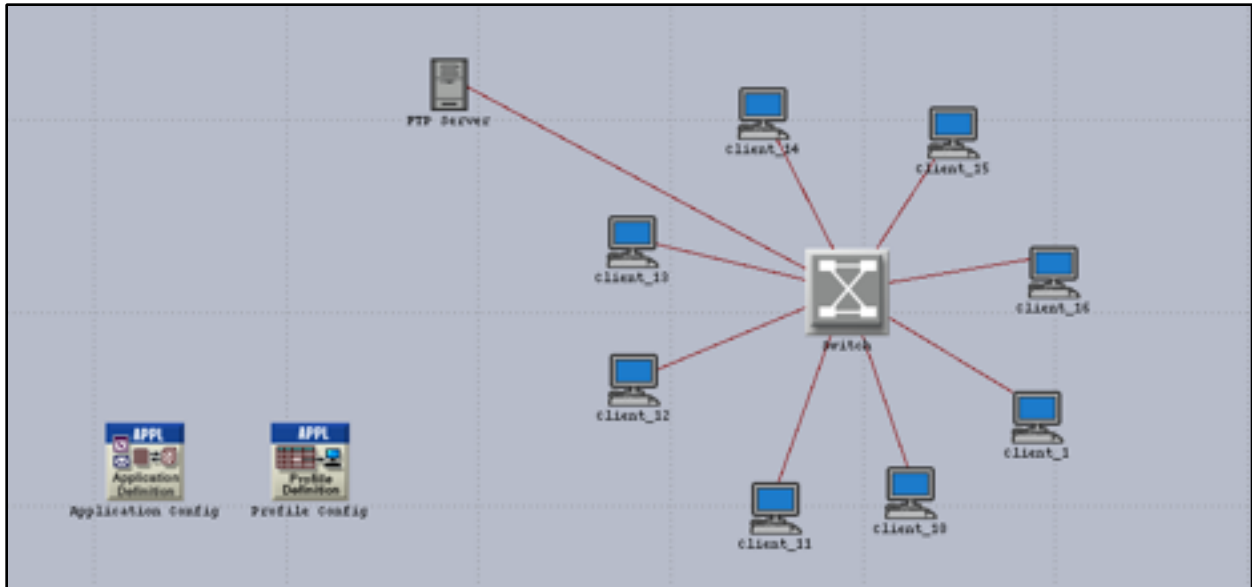
Figure 7: Network Topology for Simulation

The project was duplicated after the initial setup from a rapid configuration in Riverbed Modeler. Ethernet links were placed from the eight Ethernet workstations to the switch and from the switch to the local server. The scenario was then duplicated and configured using different link models and varying file sizes shown in Figure 8.

#	Scenario Name	Saved	Results	Sim Duration	Time Units
1	10Gb_net_50MB	saved	up to date	5.0	minute(s)
2	1Gb_net_50MB	saved	up to date	5.0	minute(s)
3	100Mb_net_50MB	saved	up to date	5.0	minute(s)
4	100Mb_net_500MB	unsaved	out of date	5.0	minute(s)
5	1Gb_net_500MB	saved	up to date	5.0	minute(s)
6	10Gb_net_500MB	saved	up to date	5.0	minute(s)
7	10Gb_net_5GB	saved	up to date	5.0	minute(s)
8	1Gb_net_5GB	saved	up to date	5.0	minute(s)
9	100Mb_net_5GB	saved	up to date	5.0	minute(s)

Figure 8: Scenario Management in Riverbed Modeler

5.2 FTP Application

Next, an Application and Profile Configuration model was then placed inside the network to configure the File Transfer Protocol (FTP) application between the clients and the central server. The purpose of the Application and Profile Configuration is to specify the different application(s) used in the network as well as the execution timing.

In order to simulate a large file transfer through the Ethernet channel from the switch to the server, an FTP application, FTP High Load, was manually configured in the application profile. The parameters are modified to send varying file sizes ranging from 50 MB, 500 MB, and 5 GB in order to simulate simultaneous large file transfer through the Ethernet channel. These file sizes approximately correspond to a 13 second AVCHD 1080p video file, a 33 second ProRes 422 1080p file, and an 80 second ProRes 422 4K video file, respectively.
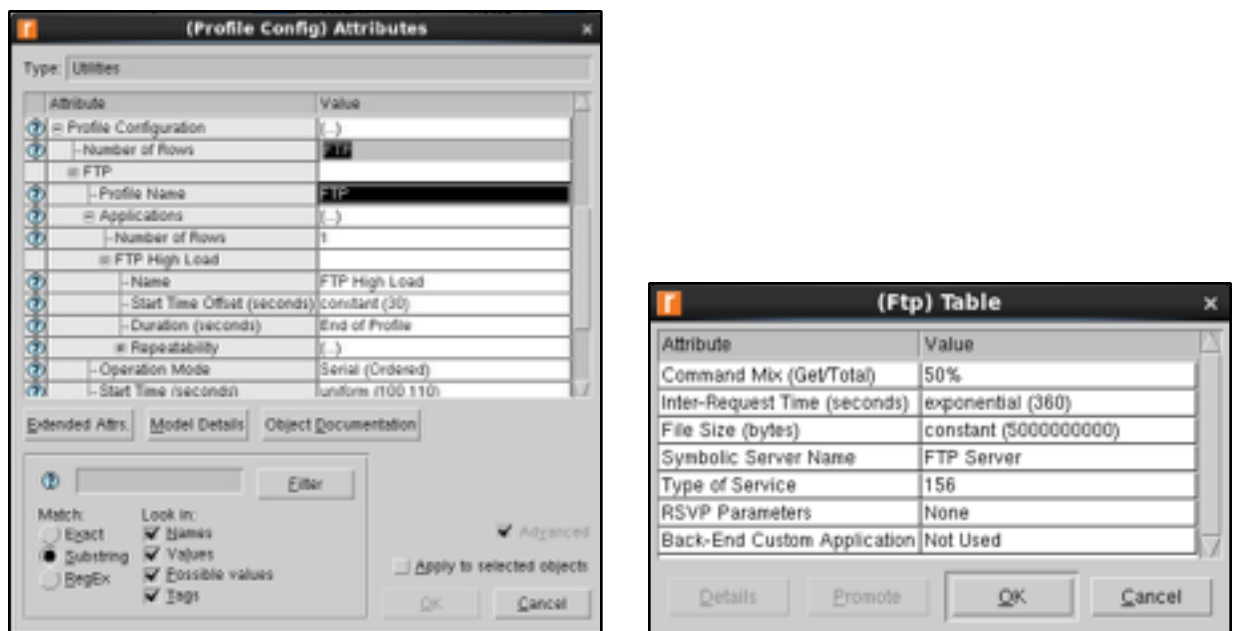

Figure 9: Profile and Application Configuration

A single profile was then created for the application and a thirty second offset was used as a buffer before the application is deployed on all the clients. The Ethernet workstations and the local server were then configured to support the application created. Next, using the Deploy Applications tool, the FTP profile was applied to network. Lastly, the 8 Ethernet workstations were selected as the source and the FTP server as the destination in the application.

6.0 Results and Analysis

6.1 Ethernet Delay

The Ethernet delay or latency is a measure of the duration between the sending of a packet from the source to the reception by the destination host [24]. Ethernet delay can be caused by two main factors, physical layout of the network architecture and the network traffic used [25]. As more components are used in the network architecture, each component will contribute a fixed amount of delay to the network [25].

The Ethernet delay shown in Figures 10 through 12 illustrates the effect of the different Ethernet links in transferring 50 MB, 500 MB, and 5 GB of data. The 100 Mbps link in green has the highest delay in all three figures with a maximum value of 1.6 ms while transferring the 50 MB file. Gigabit and 10 Gigabit Ethernet exhibited minimal delay during the simulation. As the same physical layout and components were used in all simulations, the substantially lower delay seen in Gigabit and 10 Gigabit Ethernet appears to be a result of using fibre network instead of twisted pair in 100BaseT link.

Figure 11 shows the delay statistics gathered during the 500 MB file transfer simulation. Similar to the previous scenario, the delay experienced by Fast Ethernet is significantly greater than Gigabit or 10 Gigabit ethernet. The delay experienced by Fast Ethernet reaches a maximum of approximately 0.8 ms, however. This represents an apparent improvement, however this conclusion is likely erroneous. The improvement may be a result of the 5 minute simulation not being executed for long enough to complete the transfer. The Gigabit Ethernet link showed an increase in delay to approximately 0.06 ms while the 10 Gigabit Ethernet showed no noticeable delay.
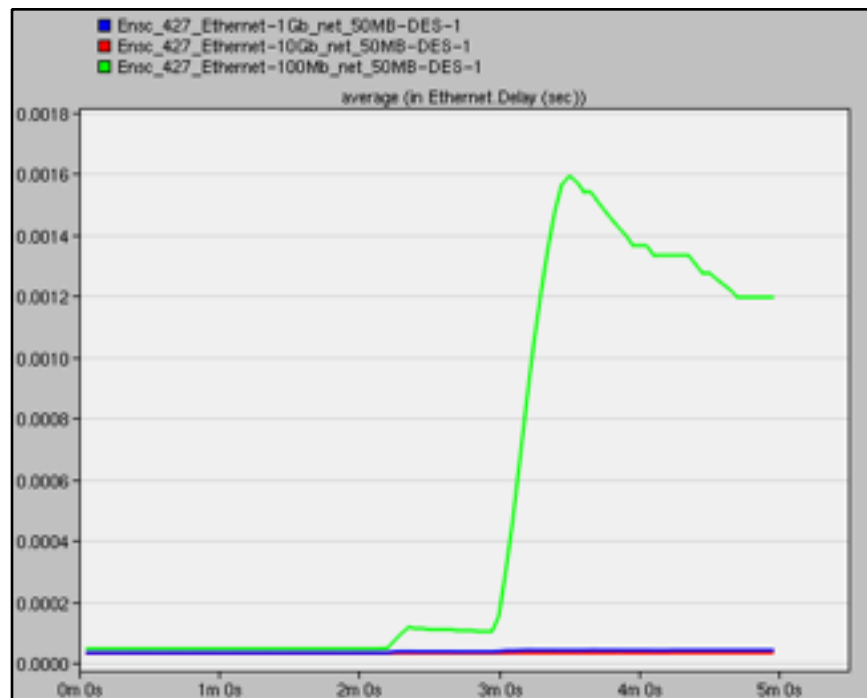

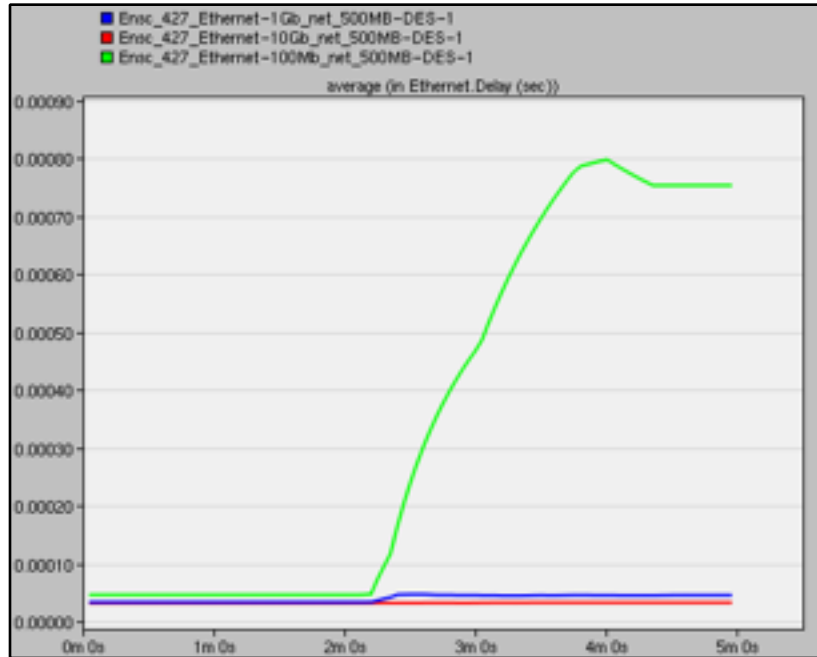Figure 10: Ethernet Delay of 50 MB File Transfer

Figure 11: Ethernet Delay of 500 MB File Transfer

Figure 12 depicts the delay experienced during the 5 GB file transfer simulation. Compared with the 500 MB transfer, Fast Ethernet shows a 20% increase in delay while Gigabit Ethernet increased at a more drastic rate from ~0.06 ms to ~0.18 ms. 10 Gigabit Ethernet proved impervious to increased network delay with no noticeable change between any of the simulations.
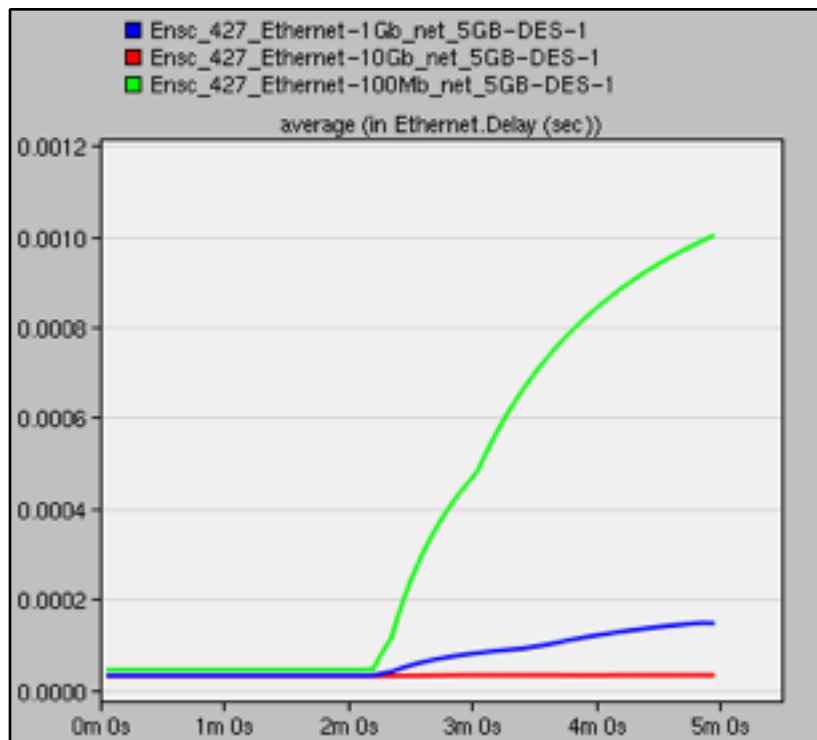

Figure 12: Ethernet Delay of 5 GB File Transfer

6.2 Utilization Rate

Link utilization is defined as the ratio between the current network traffic to the maximum traffic that the link can handle [25]. A network is considered idle when the utilization rate is at 0% and increases as the traffic requires more bandwidth.

In Figure 13, 14, and 15, the utilization of each link is illustrated showing the amount of bandwidth used while transferring the AVCHD 1080p, ProRes 422 1080p, and ProRes 422 4K video files.

Figure 13 shows the link utilization as a result of the 50 MB file transfer. Fast Ethernet exhibits 100% utilization while Gigabit Ethernet reached a maximum of ~35% utilization while 10 Gigabit Ethernet easily handled the load with utilization less than 5%.

The simulated scenario confirms anticipated network usage. The 50 MB file is equivalent to 50 MB × 8 Mb/MB = 400 Mb. With eight clients transferring identical files, the eight clients require the 3200 Mb to be transferred. With a theoretical maximum transfer rate of 100 Mbps, Fast Ethernet therefore requires 32 seconds to complete the file transfer. Figure 13 shows the Fast Ethernet link reached 100% utilization for approximately 35 seconds, roughly confirming the theoretical value. While the exact cause of the blimps shown in Figure 13 are unknown, one likely cause is due to delayed transmissions resulting from detected collisions in the CSMA/CD method.
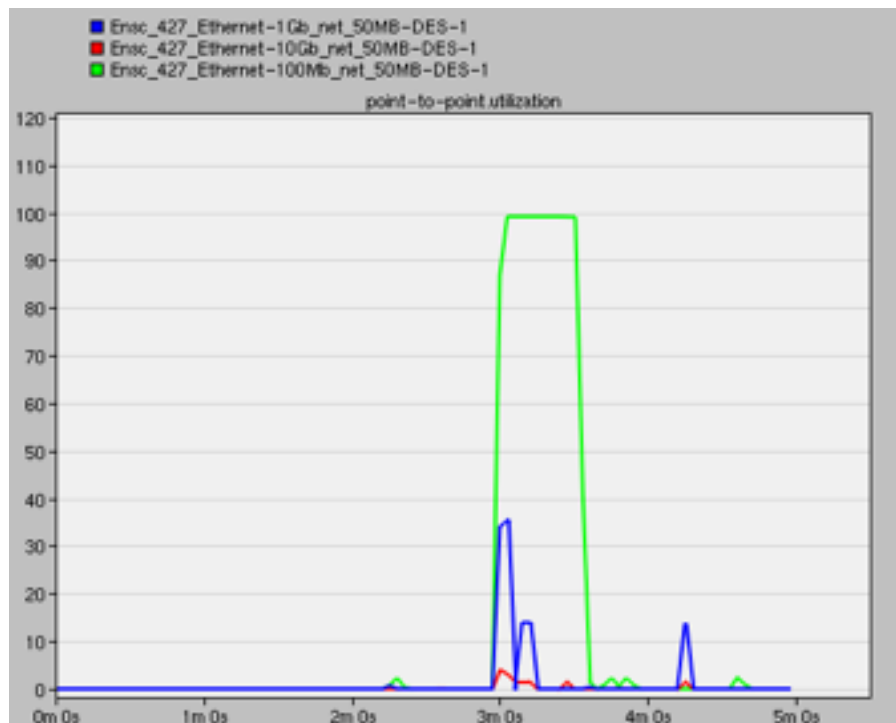

Figure 13: Point-to-Point Utilization for 50 MB File Transfer

Figure 14 shows a very similar utilization graph, however with the Fast Ethernet link holding 100% utilization for approximately two minutes prior to returning to 0% and Gigabit Ethernet reaching 100% utilization amidst the pulsing utilization rate. While this seems to indicate the Fast

Ethernet link was able to complete the file transfer, theoretical calculation show that a 100 Mbps link requires a minimum of 320 seconds to complete a 500 MB file transfer. The return to 0% utilization at the 4.5 minute mark is likely only temporary and a result of collision detection. Similar calculation and approximation appear to indicate that the Gigabit link successfully completed the file transfer.
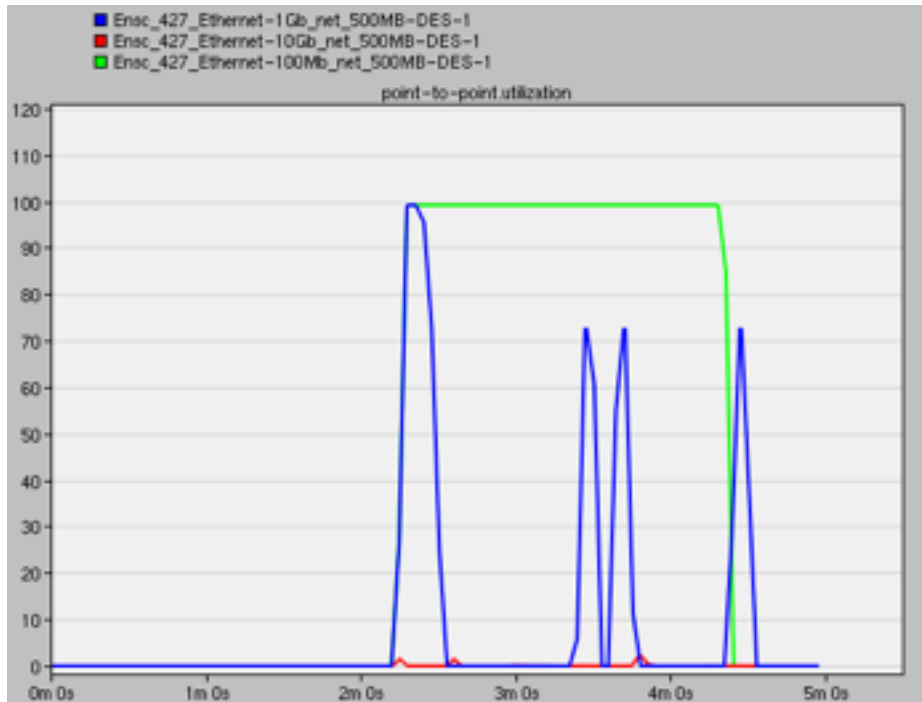

Figure 14: Point-to-Point Utilization for 500 MB File Transfer

Figure 15 shows the corresponding delay graph for the 5 GB file transfer. As expected, the Fast Ethernet and Gigabit Ethernet links show 100% utilization throughout the simulation. 10 Gigabit Ethernet exhibited the first signs of stress reaching a maximum of 40% utilization.
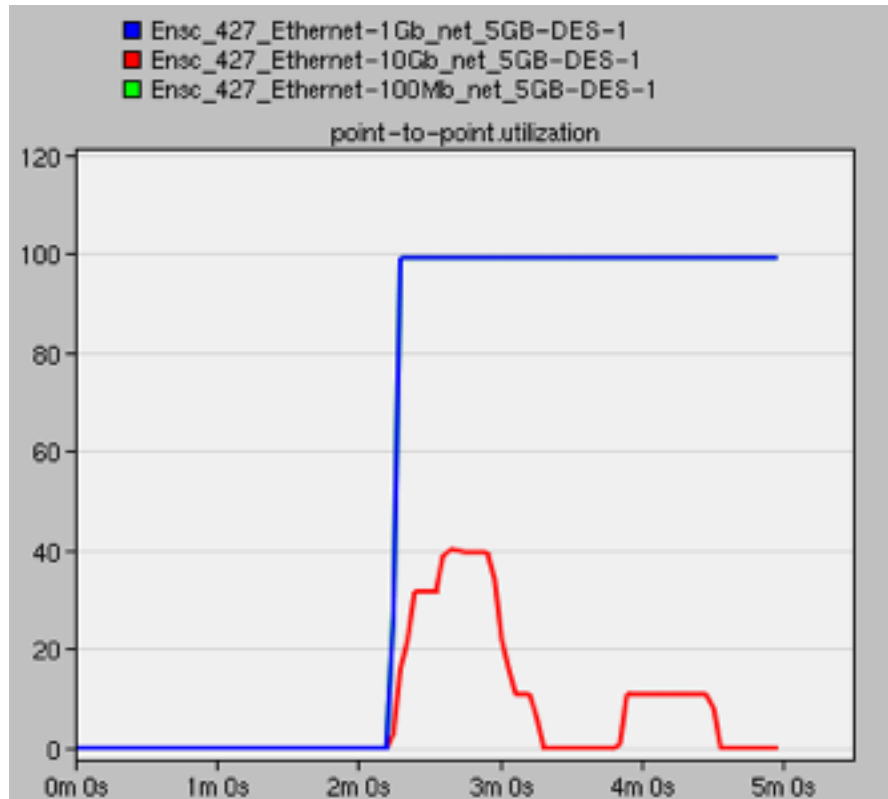
Figure 15: Point-to-Point Utilization for 5 GB File Transfer

6.3 Throughput

Throughput is defined as the maximum bandwidth transferred via a given link [25]. Measured in bits/second, the maximum throughput of each Ethernet link is indicated from the technology used:

- Fast Ethernet (100BaseT): 100 Mbps
- Gigabit Ethernet (1000BaseX): 1 Gbps
- 10 Gigabit Ethernet (10Gbps_Ethernet): 10 Gbps

Figure 16 shows the link throughput for the 50 MB file transfer. As expected, the Fast Ethernet link showed 100,000,000 bits/second (100 Mbps) while at 100% utilization (as shown in Figure 13). Meanwhile, the Gigabit and 10 Gigabit links showed peaks of high throughput approximately corresponding to the spikes seen in Figure 13. Also of note is that the amplitudes of these spikes again have a direct relationship to the utilization shown in Figure 13. For example, The Gigabit link shows a peak utilization of approximately 350 Mbps while experiencing ~35% utilization.

Figure 17 and 18 show similar results for the 500 MB and 5 Gb file transfers with throughput peaks corresponding to the utilization peaks seen in Figure 14 and 15.

Overall, the throughput analysis did not reveal any new insights regarding the simulation, however it did substantiated the listed throughput specifications of the different Ethernet standards.
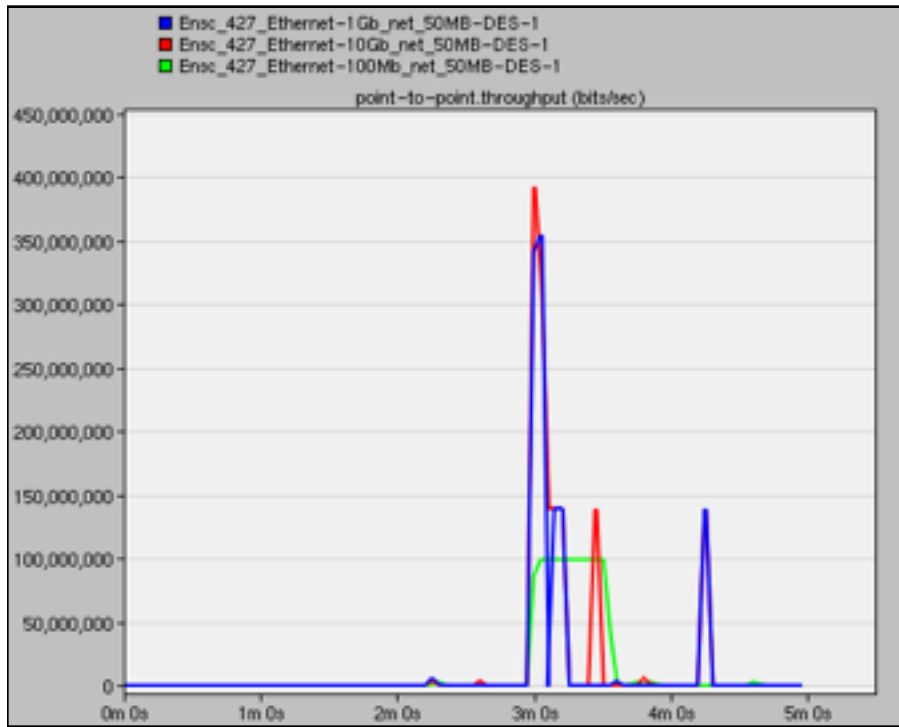

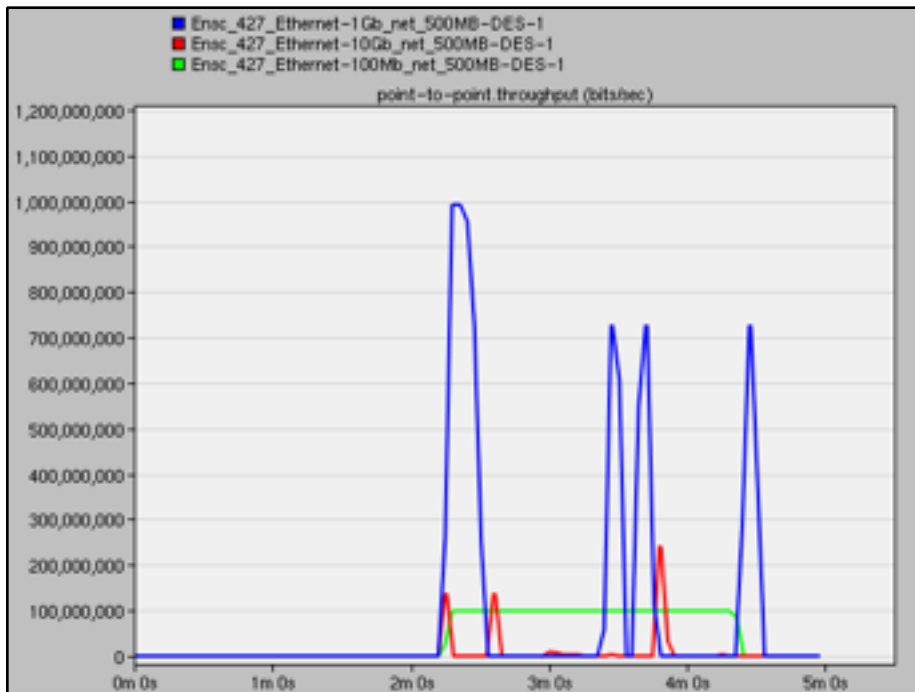Figure 16: Throughput in bits/second for 50 MB File Transfer

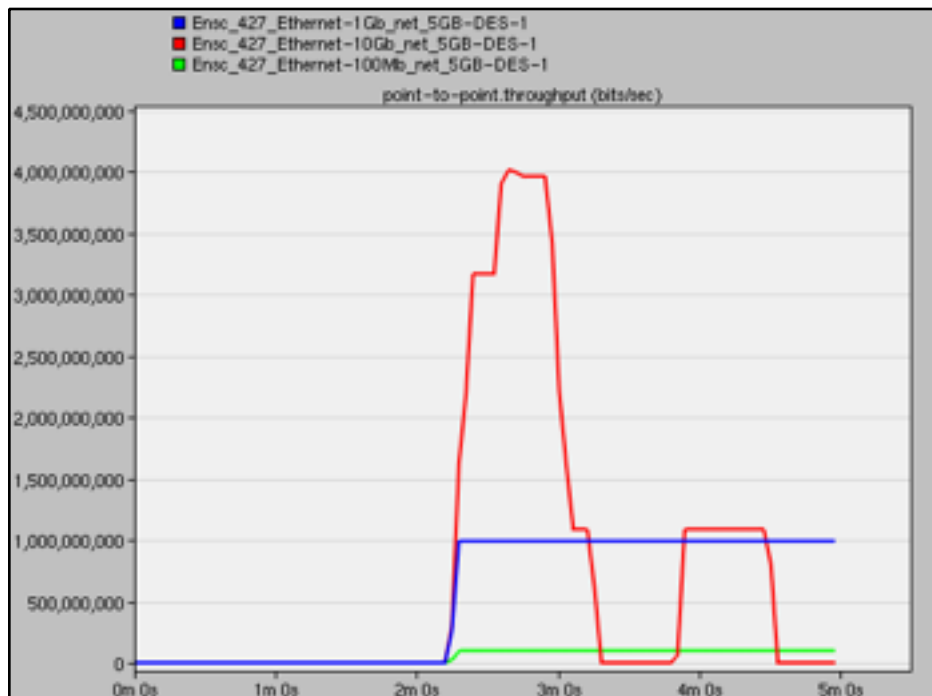Figure 17: Throughput in bits/second for 500 MB File Transfer

Figure 18: Throughput in bits/second for 5 GB File Transfer

7.0 Conclusion

Ethernet is a long-standing network standard which has undergone numerous advancements since it's induction, continually increasing maximum throughput with every iteration. Likewise, network usage has continued to harness the capabilities of the existing standards to perform networking feats unimaginable in previous years. Shared video storage is one example of a modern application testing the limits of networking technology.

This project studied the viability of using Fast Ethernet, Gigabit Ethernet, and 10 Gigabit Ethernet in an editing studio environment transferring different file types to eight LAN connected workstations.

As seen in Figure 10 and 13, Fast Ethernet experiences relatively high latency with 100% during the transfer of the smallest of the three video files transferred, AVCHD 1080p. This seems to indicate the network latency and file transfer delay would prove burdensome for any of the files over the Fast Ethernet standard, accurately reflecting it's age and inability to meet modest shared storage needs in a shared storage environment.

Gigabit Ethernet, however, appears to be able to accomplish AVCHD 1080p and ProRes 422 1080p video files in a shared storage environment. Figure 11 shows Gigabit Ethernet exhibits negligible latency and while Figure 14 shows Gigabit Ethernet reaching 100% utilization, it is only briefly and unlikely to result in significant transfer delay. Figure 15, however, shows Gigabit Ethernet maintaining 100% utilization throughout the transfer and would result in costly delays in a 4K post-production studio environment.

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Lastly, 10 Gigabit Ethernet excelled in all simulations, as seen in Figure 15 and is therefore suitable for on-demand access to 4K video files in a shared storage environment.

Overall, this project clearly show the significant impacts of the advancements in Ethernet technology over the last 20 years. These improvements have not only led to innovative new uses of Ethernet, such as transferring more detail rich multimedia files, but also played a vital role in interconnecting the network known as the Internet today.

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