ENSC 427: COMMUNICATION NETWORKS

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Performance Analysis of a Wireless Home Network

Group 4

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1. Abstract

Over the past decade, Wi-Fi networks have become commonplace in a typical home. Multiple users may be simultaneously streaming, torrenting, browsing the web, gaming, and using VoIP. This may be quite demanding on the network and may result in a loss of Quality of Service. For our project, we plan to model a multiple-user home wireless network using OPNET. We wish to observe and analyze the effect of various users' bandwidth demands on the latency, packet jitter, packet loss, and throughput on other users within the network. Furthermore, we plan to compare the effect of various wireless standards and environments in order to determine the standard that provides the best QoS.

2. Introduction

With the increasing popularity of smart phones and other wireless devices, wireless networks are experiencing tremendous traffic growth. At the same time, more and more users are experimenting with bandwidth intensive multimedia applications on their wireless devices. Thus, with increasing users and more demanding applications, the quality of service (QoS) over wireless local area networks (WLAN) can be difficult to maintain.

For this project, we analyze the performance of a wireless local area network consisting of 4 users. Each client of the network will perform certain tasks ranging from bandwidth intensive applications, such as streaming video, to less demanding tasks like browsing the web. The main objective is to compare the effect that each user has on the quality of service of the network. We want to determine which standard is the most appropriate to use and to propose a way to improve its performance in the future. All this will be done under the assumption that our Wi-Fi network operates according to the 802.11g standard at 18 Mbps. Other standards such as 802.11b and 802.11e will be simulated and compared to 802.11g in order determine the most effective standard. In order to fully illustrate the scope of this project, it is necessary to define and explain certain fundamental concepts such as Wi-Fi, the 802.11 standards and quality of service.

2.1 Fundamental Concepts

2.1.1. Wi-Fi and the 802.11 Standards

Wi-Fi is a technology that transfers data wirelessly through the radio frequency bands such as 2.4 GHz and 5 GHz [1]. Over the past few decades, Wi-Fi has been steadily growing in popularity and is now commonplace in home and office environments. Its ability to reduce the clutter of cables and wiring makes Wi-Fi desirable for small and restrictive areas. Wi-Fi has a plethora of applications and is implemented in almost all new electronic devices such as personal desktop/laptop computers, smart phones, video-game consoles and printers. Wi-Fi is commonly used in wireless local area networks (WLAN) and is based on the 802.11 standards defined by the Institute of Electrical and Electronic Engineers (IEEE).

The 802.11 standards family (802.11a, b, n, g, ac) each contain different protocols which define their general performance. For this project, we implement the 802.11g,b and e standard commonly used in modern routers. 802.11g works in the 2.4 GHz frequency band and uses orthogonal frequency-division multiplexing (OFDM) transmission scheme [2]. The standard has a max data rate of 54 Mbps and a range of approximately 40 meters, which satisfy our requirements when creating a small home network. 802.11b works on the same frequency band as 802.11g and it can transmit up to a maximum of 11 Mbps. It is based on Complementary Code Keying Modulation (CCK). CCK modulation is used because it provides a network with the possibility of transferring more data unit per time for a given signal bandwidth [3].

802.11e started developing as the need for delay-sensitive applications grew. 802.11 operates on two distinct modes: Distributed Coordinated Function (DCF) mode and Point Coordination Function (PCF) mode. DCF mode is based on Carrier Sense Multiple Access (CSMA). PCF facilitates the coordination of timing by making use of contention-free periods (CFP) and contention periods (CP) where a CFP is the moment information can be transmitted without disruption. A key point of 802.11 is that neither PCF nor DCF can differentiate between data types, which ultimately results in better QoS. Enhanced Distributed Control Function (EDCF) employs the usage of access categories that determine the channel access probability, according to information's hierarchy; it is set at different priority levels and then sent in the desired order. Another purpose of 802.11e is to extend the polling capability and to provide the station with a transmission opportunity time (TXOP).The QoS-enabled stations can request specific transmission parameters, hence the combination of these lead to an effective performance of the network for applications like voice and video. 802.11e uses Hybrid Coordinated Function (HCF) mode, which works like PCF, except that CFPs are able to be commence at anytime [4]

2.1.2. Quality of Service (QoS)

Quality of service defines the overall performance of the network. In order to provide proper service to the network, several parameters such as latency, packet loss and jitter must be considered. Latency refers to the delay in transmission of packets from source to destination. Jitter is the variation of the latency over time. Packet loss is when packets are dropped or corrupted during transmission. In some cases, these packets are retransmitted which adds further delay. In our project, the QoS will determine which applications are utilizing most of the provided service. We will observe how each client will compete with each other to utilize the network [5].

3. OPNET Implementation

The WLAN home environment was implemented using four fixed workstations, an Ethernet router as well as an Ethernet server. Task, application and profile configuration were also placed in the network as seen in Figure 1 below.

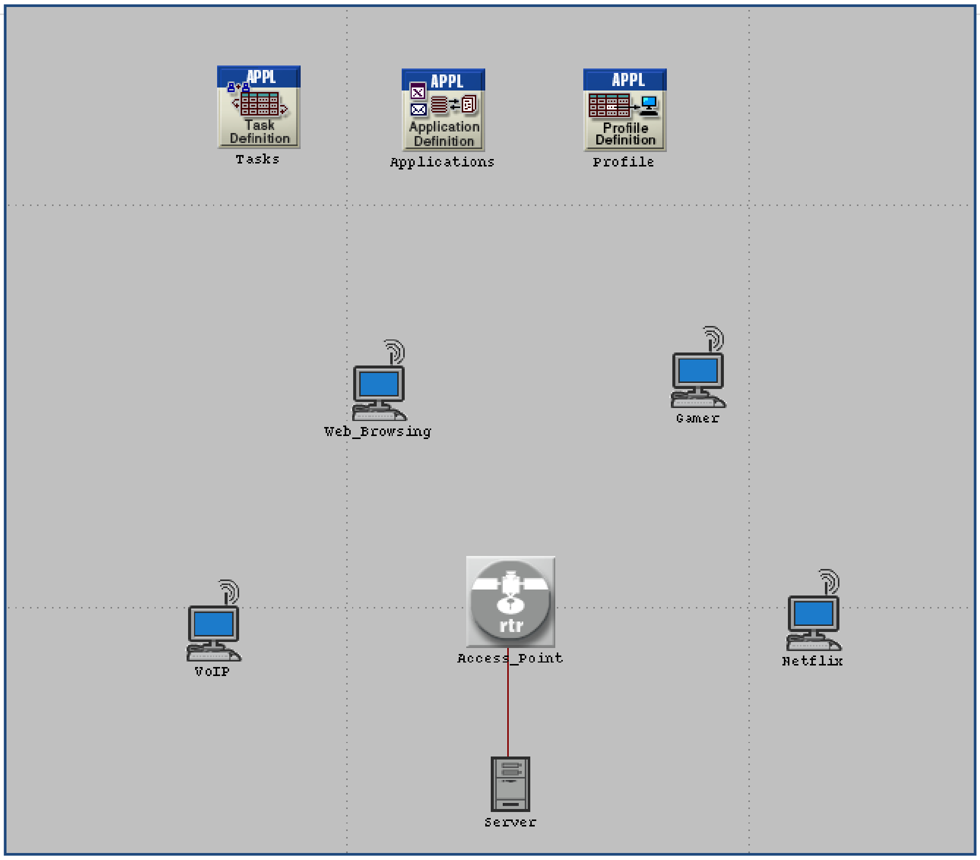


Figure 1 - Overall Network

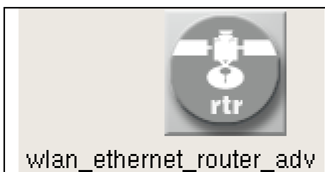
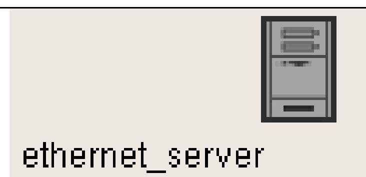
		
Access Point	Server	Workstations

Table 1- Object Palette

The function of the router was to act as an access point to the workstations, while receiving data from the server. The server supported the profiles and services for the workstations through a 100BaseT link Ethernet link. There are a total of 4 services supplied to the workstations, including VoIP, Heavy Web Browsing, Video Stream and Gaming applications.

The workstations as well as the access point were also configured to utilize either 802.11b,g or e, whilst changing the data rates of the respective standard. Our simulations were run using 802.11g at 18 Mbps for 30 minutes duration. Figure 2 shows the screen at which these WLAN properties are changed. Note that these properties must be changed in the Access Point, and each of the workstations for full effect.

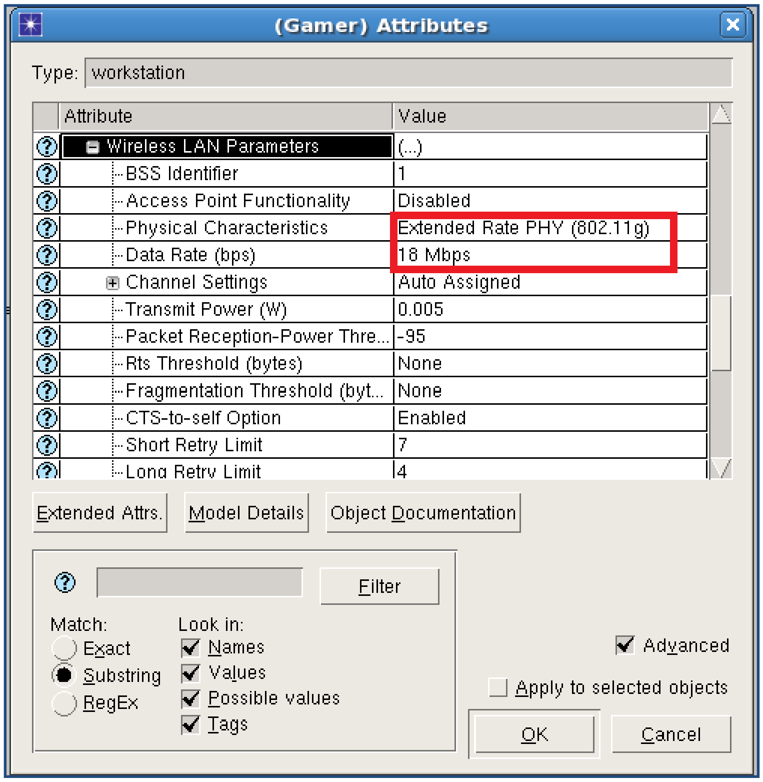


Figure 2 - WLAN Parameters

3.1 Applications

3.1.1 VoIP and Web Browsing

The first application used in the network is Voice over Internet Protocol (VoIP). VoIP is a common protocol used in many applications such as Skype. Due to its popularity, it seemed appropriate to add to our network. In order to implement a workstation using VoIP, the default application for Voice over IP (GSM) was used. Heavy Web Browsing also seemed to be a good addition to our network because it could accurately represent a casual user in the network. Web Browsing is not affected by delay and jitter as much as the other applications of our network, but at the same time, will not add much delay for the other users. Both VoIP and Web Browsing application set up was very self explanatory because they utilize pre-defined OPNET applications. All that was needed was to create profiles for each so the workstations could utilize the respective applications.

3.1.2 Video Stream

In order to incorporate an accurate representation of a user streaming video, the video conferencing application was utilized. Since video conferencing involves multiple users sending and receiving video packets, our definitions had to be changed to simulate an accurate video stream. The incoming frame inter-arrival time was set to a constant 0.0333 seconds. This corresponds to a video running at 30 frames per second. The outgoing packet stream was set to "none" to simulate a video stream where information will only be received by the client. Below is Figure 3, which shows the incoming and outgoing packet interarrival times.

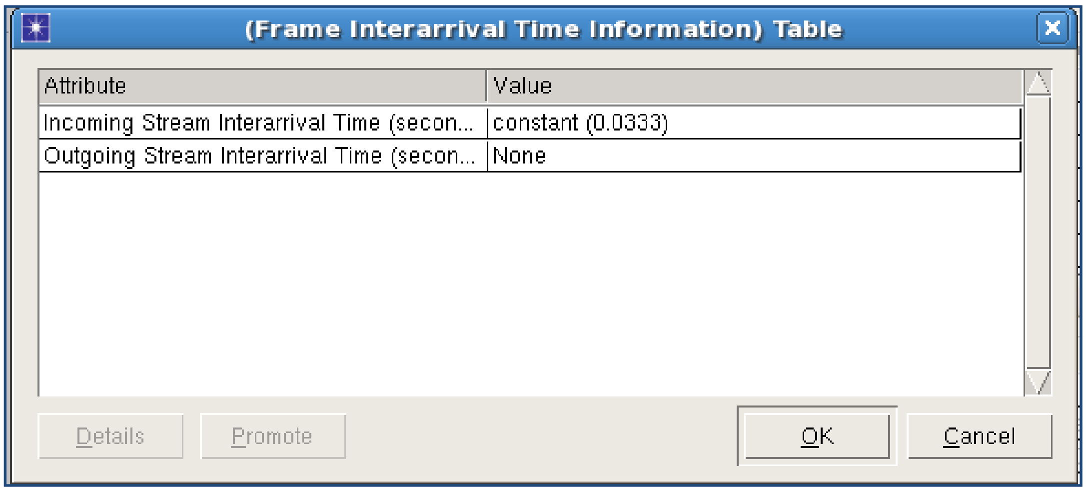


Figure 3 - Video Conferencing to Video Stream

Now that a unilateral design had been put in place, the next objective was to incorporate realistic packet size information. Normally, it is difficult to create an accurate representation of a video as they will vary in frame size depending on the information used in a particular scene of the movie. OPNET provides an option to add a video trace, rather than utilizing their various distribution functions. Martin Reisslein along with the University of Arizona, has provided an archive of video traces of several different compression schemes [6]. For our project, we chose to use his video trace for silence of the lambs with MPEG-4 compression. This trace lasts for approximately 30 minutes and contains over 50000 frames, with a mean frame size of 15531 bytes. Below is Figure 4, which shows a section of the video trace table and where the script was put into OPNET. Later, in the simulation, we also change the priority of the video by accessing the ToS option.

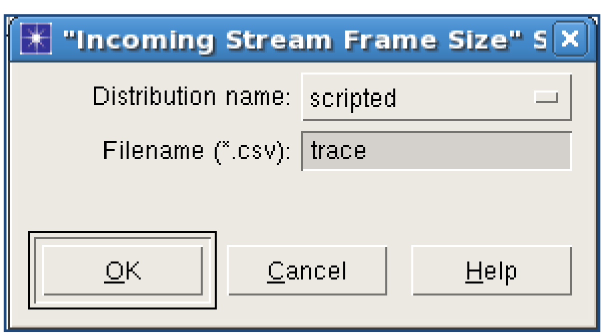
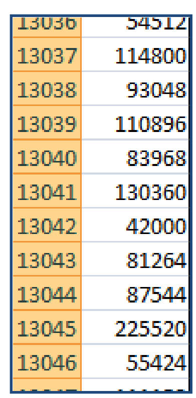


Figure 5 - Custom Trace



13036	54512
13037	114800
13038	93048
13039	110896
13040	83968
13041	130360
13042	42000
13043	81264
13044	87544
13045	225520
13046	55424

Figure 4 - Video Trace Packet Sizes (Right Column)

3.1.3 Gaming

Over the past few decades, online gaming has become an increasingly popular application in the home, and generates some of the largest revenue in the entertainment industry. Due to its popularity and our general interest, it seemed worthwhile to analyze the effects typical WLAN users had on the QoS of the gamer. The genre of gaming we chose to model was First Person Shooters (FPS). FPS games are known for their high skill-cap and require quick decision making and even faster reflexes. This makes FPS games very sensitive to delay and jitter. Johannes Farber study, *Network Game Traffic Modeling,* analyzed a gaming environment consisting of 50 participants for a total of 36 hours [7]. Farber mentioned several key factors about FPS games which are important to implement into OPNET. First of all, server to client traffic is very "bursty" in nature. The server sends each client data in cycles to update the status of the other players in the game. The frequency at which this information is updated is known as the tickrate. FPS game developer, Valve, explains tickrate as "During each tick, the server processes incoming user commands, runs a physical simulation step, checks the game rules, and updates all object states... A higher tickrate increases the simulation precision, but also requires more CPU power and available bandwidth on both server and client."[8] The server sends critical information to each individual player in the game at the specified tickrate. This means the traffic flow heavily depends on the amount of active players in the game. On the other hand, the client to server traffic has been observed to be relatively constant.

For our project, we will model gaming traffic in a similar fashion to graduate student S. Chiu's and Group 3 from Spring 2010, who worked on gaming traffic over WiMax [9][10]. Farber shows the server to client and client to server traffic approximations in the following table.

	Server	Client
Interarrival Time (ms)	Extreme (55,6)	Constant (40)
Packet Size (bytes)	Extreme (120,36)	Extreme (80,5.7)

Table 2 - Game Traffic Model

To implement this model into OPNET, a custom application and task were created. First, in the application configuration, an application called "game" was added with default settings shown in the Figure 6 below. Note that the Type of Service settings is later edited to change the priority of the game application. This will be used to analyze the effect of 802.11e standard on the gaming application.

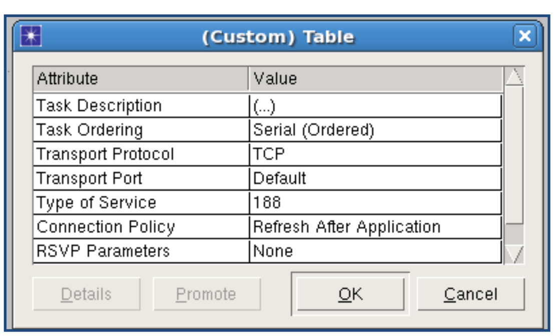
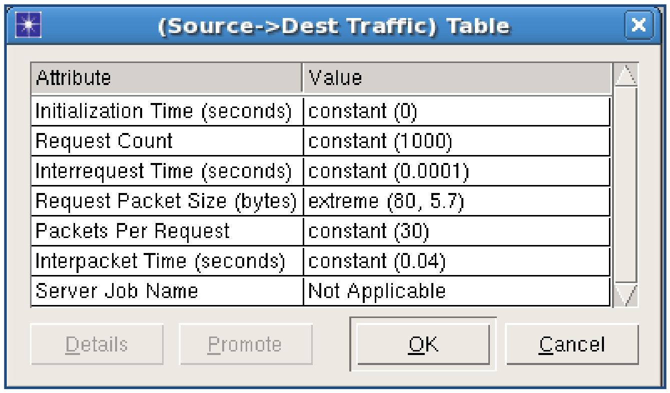


Figure 6 - Custom Game Application Configuration

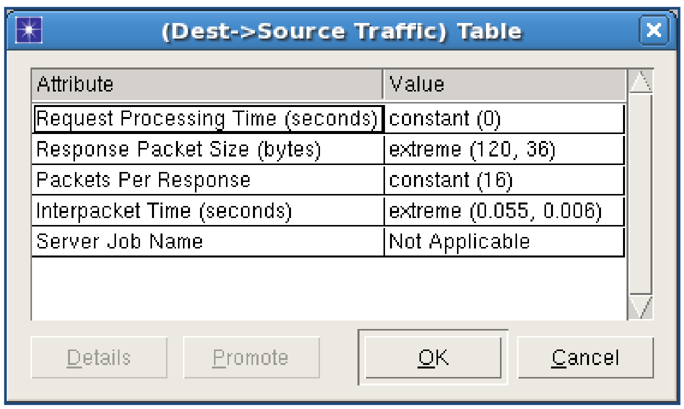
Next, a task was created in order to properly define gaming traffic within the application configuration. The task was configured manually in order to apply Farber's FPS game traffic model. Below are figures of the Server to Client and Client to Server parameters.



(Source->Dest Traffic) Table

Attribute	Value
Initialization Time (seconds)	constant (0)
Request Count	constant (1000)
Interrequest Time (seconds)	constant (0.0001)
Request Packet Size (bytes)	extreme (80, 5.7)
Packets Per Request	constant (30)
Interpacket Time (seconds)	constant (0.04)
Server Job Name	Not Applicable

Figure 7 - Client to Server Traffic



(Dest->Source Traffic) Table

Attribute	Value
Request Processing Time (seconds)	constant (0)
Response Packet Size (bytes)	extreme (120, 36)
Packets Per Response	constant (16)
Interpacket Time (seconds)	extreme (0.055, 0.006)
Server Job Name	Not Applicable

Figure 8 - Server to Client Traffic

The Server to Client parameters include Farber's model for packet size and interpacket arrival time. The extreme(*a*,*b*) function specifies the peak value, *a,* as well as the scale, *b.*

Next, a profile called Game_Profile was created to allow the gaming workstation to generate the traffic model. The profile was set to use the game application configuration and was set to begin at the start of the simulation and continue until the completion of the simulation. Figure 9 shows the profile configuration window.

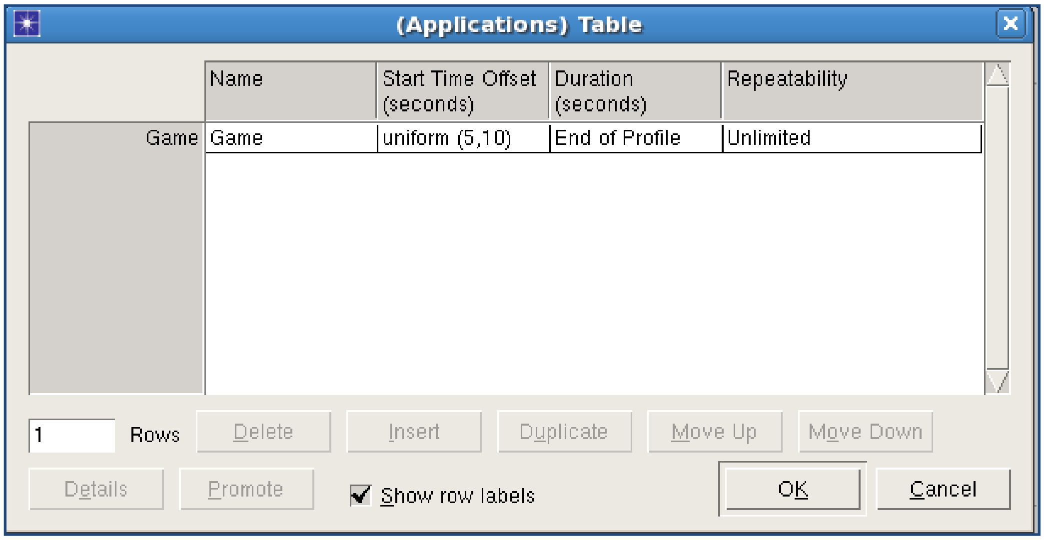


Figure 9 - Game Profile

The Game_Profile was then applied to the gamer workstation and the server was set to support the created game profile.

3.2 Adding QoS

Since the gamer experiences very high delay due to the video streaming application, his gaming experience could be ruined due to the delay and jitter induced by high throughput applications. To effectively "fix" the gamers delay, the HCF parameters of the workstations is supported as shown in Figure 10.

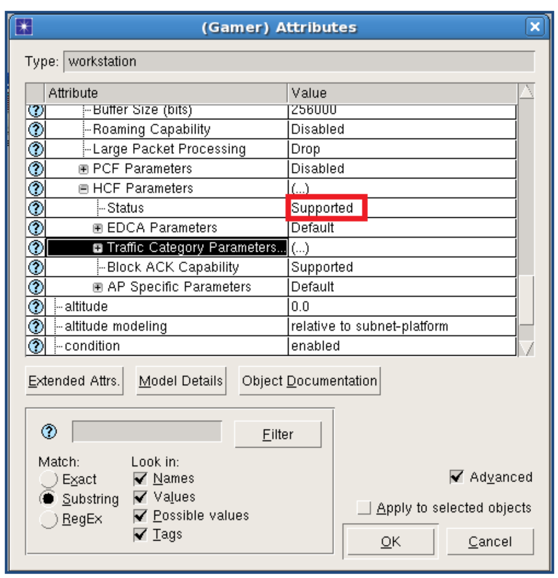


Figure 10 - Supporting HCF Parameters

Also in the gamer and video stream application, the Type of Service (ToS) was changed such that the gamer received a higher priority than the video streamer. There are several different "priority levels" that individual applications can be at. The ToS for both the gamer and video streamer are shown in the figures below.

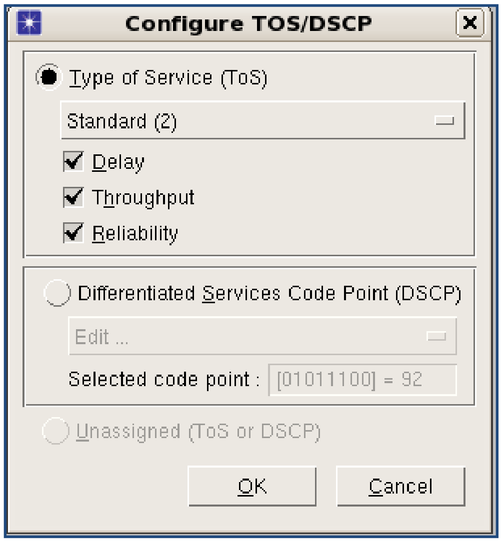


Figure 12 - Type of Service for Video Streamer

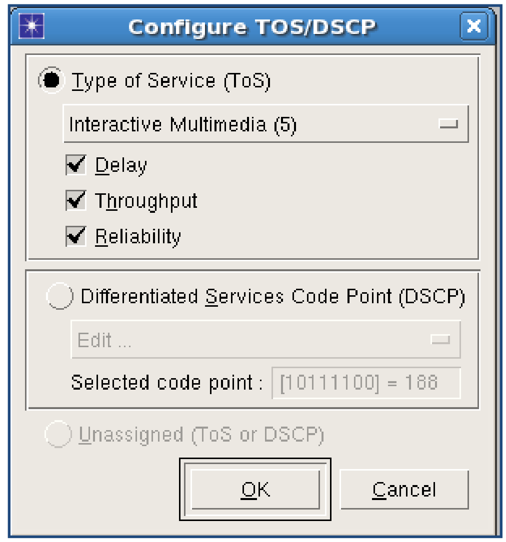


Figure 11 - Type of Service for Gamer

Table 3 shows the options for ToS provided by OPNET.

OPNET Type of Service	
Priority	Description
0 (Lowest)	Best Effort
1	Background
2	Standard
3	Excellent Effort
4	Streaming Multimedia
5	Interactive Multimedia
6	Interactive Voice
7 (Highest)	Reserved

Table 3 - OPNET ToS Options

4. Results and Discussion

4.0.1 Application Traffic

Figures 13 through 16 graph the throughput of our 4 applications. The Video Stream experiences large variations in throughput due to the nature of a typical movie. There are scenes with little visual information and there are scenes with great visual information; thus, there will be small video frames and there will be large video frames. The throughput of the web browsing user, as provided by OPNET, models a series of “clicks” and “page reads”. The Gamer throughput fits our Game Traffic Model as it is bursty in nature. The VoIP Throughput, again provided by OPNET, has a constant throughput level.

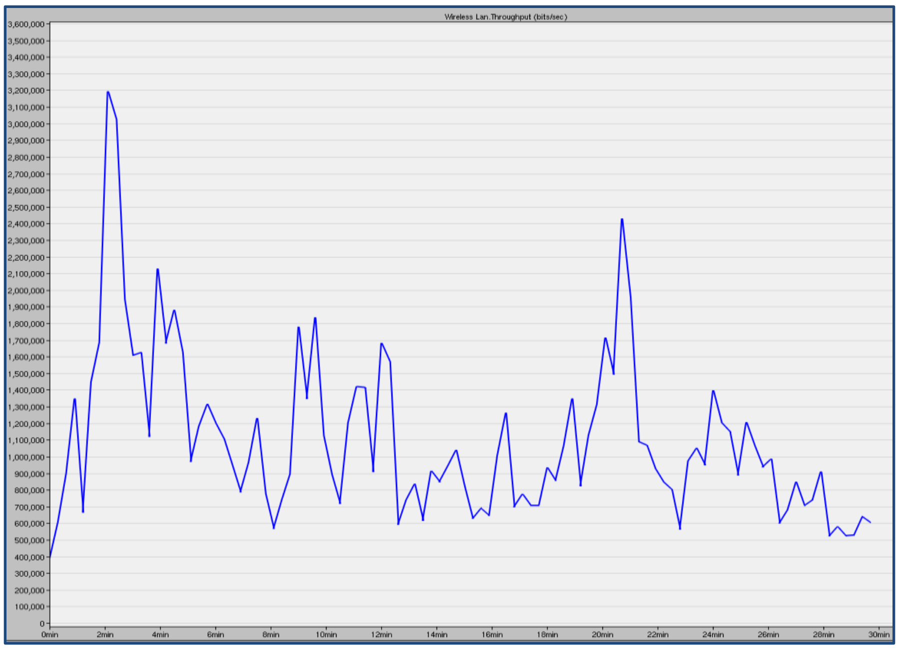


Figure 13 - Video Throughput

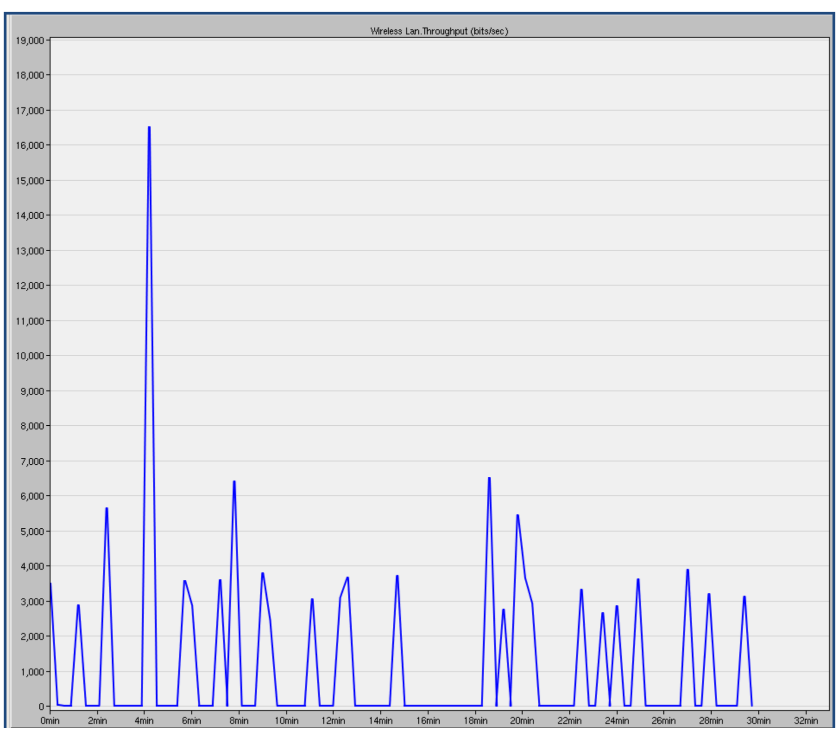


Figure 14 - Web Browsing Throughput

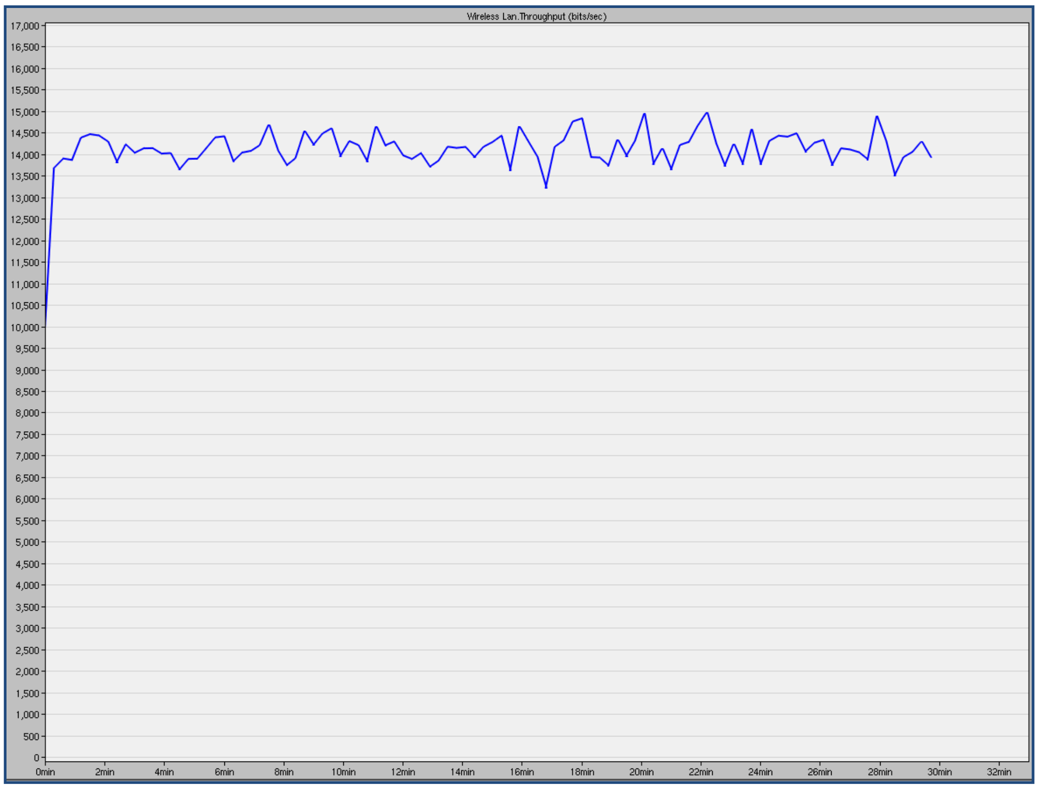


Figure 15 - Gamer Throughput

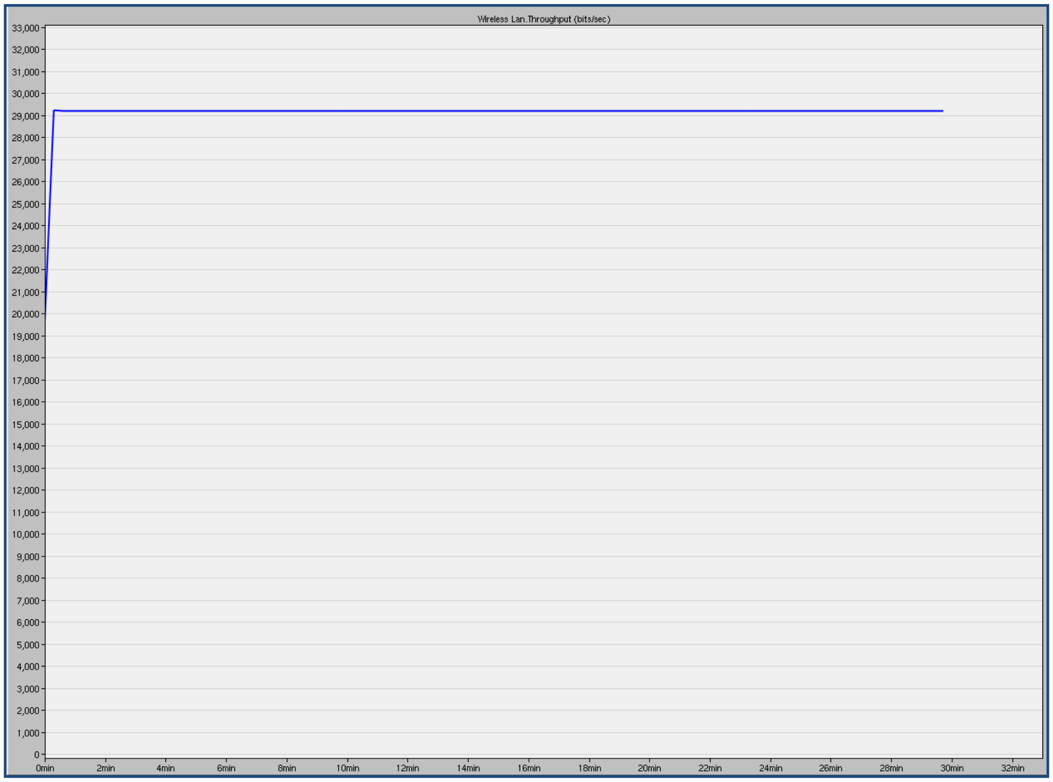


Figure 16 - VoIP Throughput

4.0.2 Global Delay

Our first set of simulation scenarios intended to test the capabilities of the 802.11 standards and data rates. Our network consisted of all 4 of the applications, and we varied the data rates provided by the Access Point, as well as switching between the 802.11 b and g standards, which in turn changed the modulation schemes between CCK and OFDM. Table 4 shows the scenarios used, and Figure 17 shows the global delay of each scenario. As expected, an increase in data rate capability by the Access Point results in a decrease in Delay. In addition, the OFDM modulation scheme outperformed the CCK modulation scheme when the data rate is held constant.

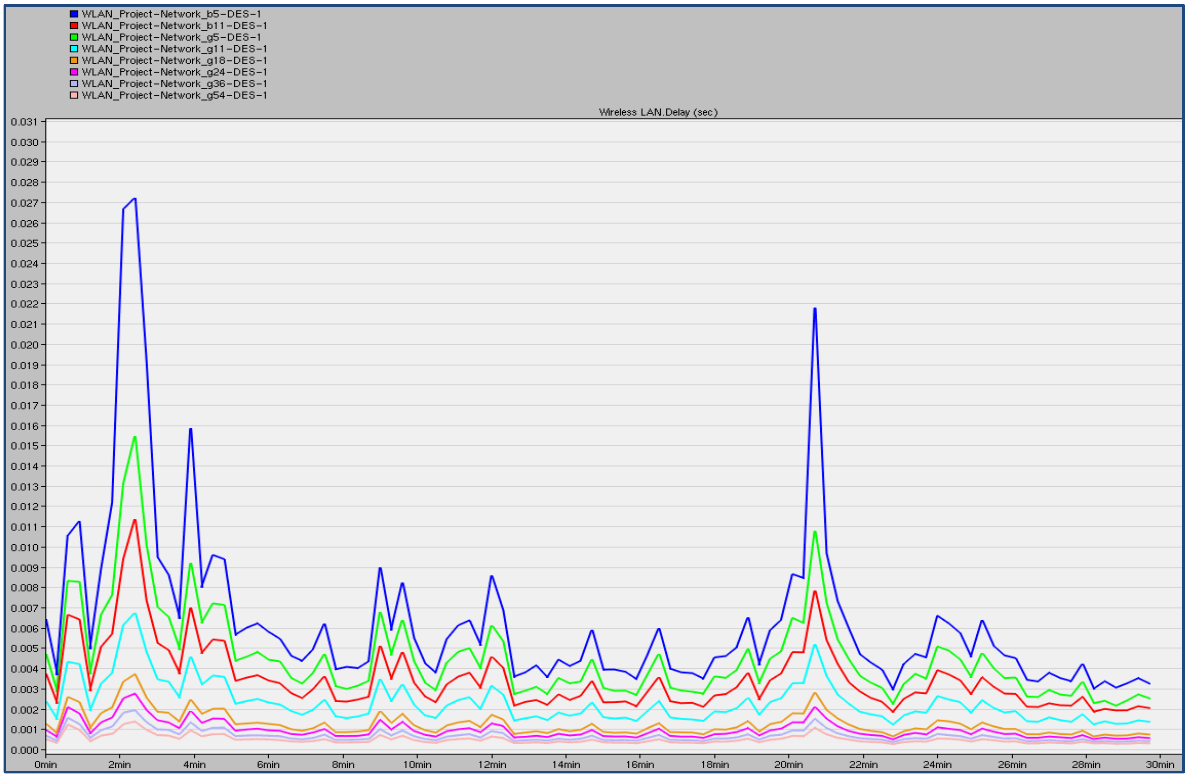


Figure 17 - Global Delay

Global Delay Scenarios	
IEEE Standard	Data Rate
802.11b	5.5 Mbps
	11 Mbps
802.11g	5.5 Mbps
	11 Mbps
	18 Mbps
	24 Mbps
	36 Mbps
	54 Mbps

Table 4 - Global Delay Scenarios

Note that the Global Delay Plot mirrors the Video Stream Throughput Plot. This shows that the application with the largest throughput will have the largest contribution to the delay. Keep this in mind for the upcoming results.

4.1 Variation of Users

Next, we decided to simulate the network experience through the perspective of each user. The first scenario is the network with just simply the lone user, and the next 3 three are with the other users added in independently.

4.1.1 Web Browser

Figure 18 graphs the delay for the scenarios through the perspective of the Web Browsing User. The scenario with the Video Stream User introduces the most delay to the Web Browsing User. Even though the Video Stream User costs the Web Browser User a 50% increase in delay, the QoS of the Web Browser remains relatively unchanged due to the nature of Web Browsing. The throughput of the web browser is shown in Figure 14. As expected, the throughput is a series of spikes and gaps. By intuition, the spikes represent the "clicks" made by the user, and the gaps represent the time the user takes to read the webpage. The QoS required by the Web Browsing User is low, because there is little bandwidth required and it relatively insensitive to delay and jitter.

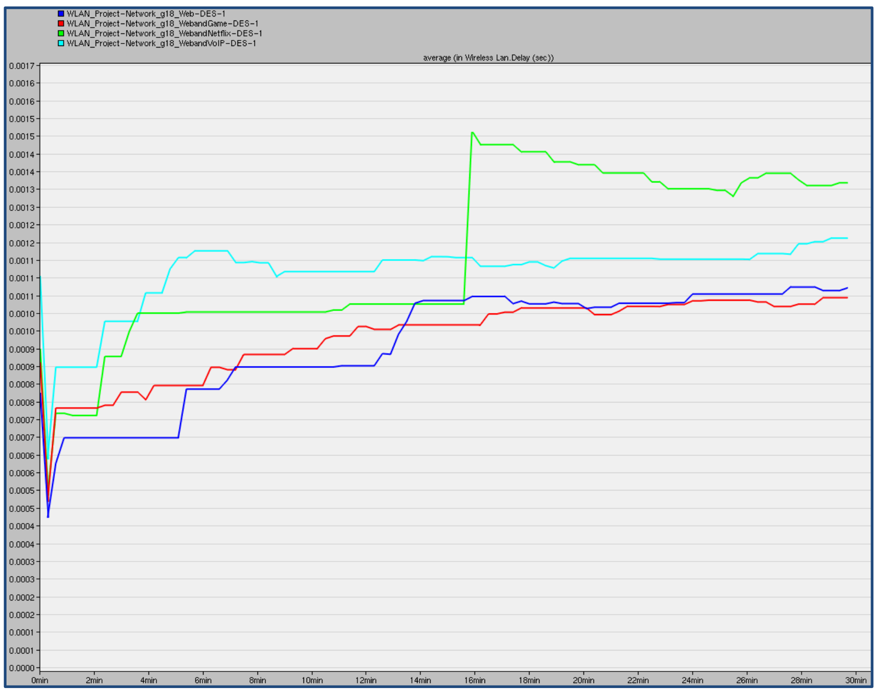


Figure 18 - Web Browser Delay

4.1.2 Gamer

Figure 19 graphs the delay for the scenarios through the perspective of the Gamer. The scenario with the Video Stream User introduces the most delay to the Gamer, with peak delay increases reaching 900%. The delay introduced by the Web Browsing User and VoIP User are negligible. Online gaming is a real-time application whose entertainment value depends on low delay and jitter. These huge increases in delay introduced by the Video Streamer, as well as large variations, severely hinder the QoS of the Gamer.

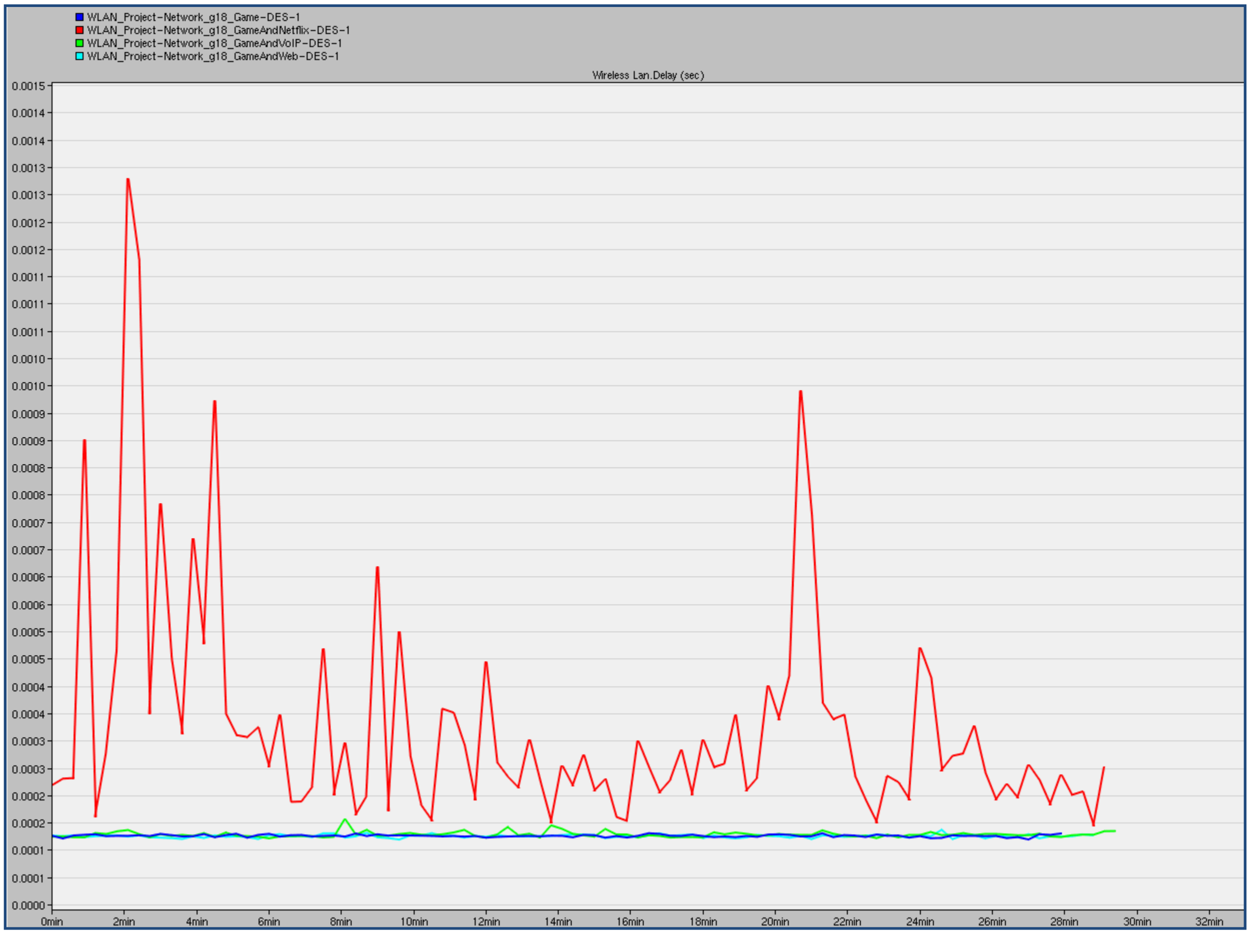


Figure 19 - Gamer Delay

4.1.3 VoIP

Figure 20 graphs the delay for the scenarios through the perspective of the VoIP User. The scenario with the Video Stream User introduces the most delay to the VoIP User, with peak delay increases reaching 680%. The delay introduced by the Web Browsing User and Gamer are negligible. VoIP is a real-time application whose performance critically depends on low delay and jitter. These huge increases in delay introduced by the Video Streamer, as well as large variations, severely hinder the QoS of the VoIP User.

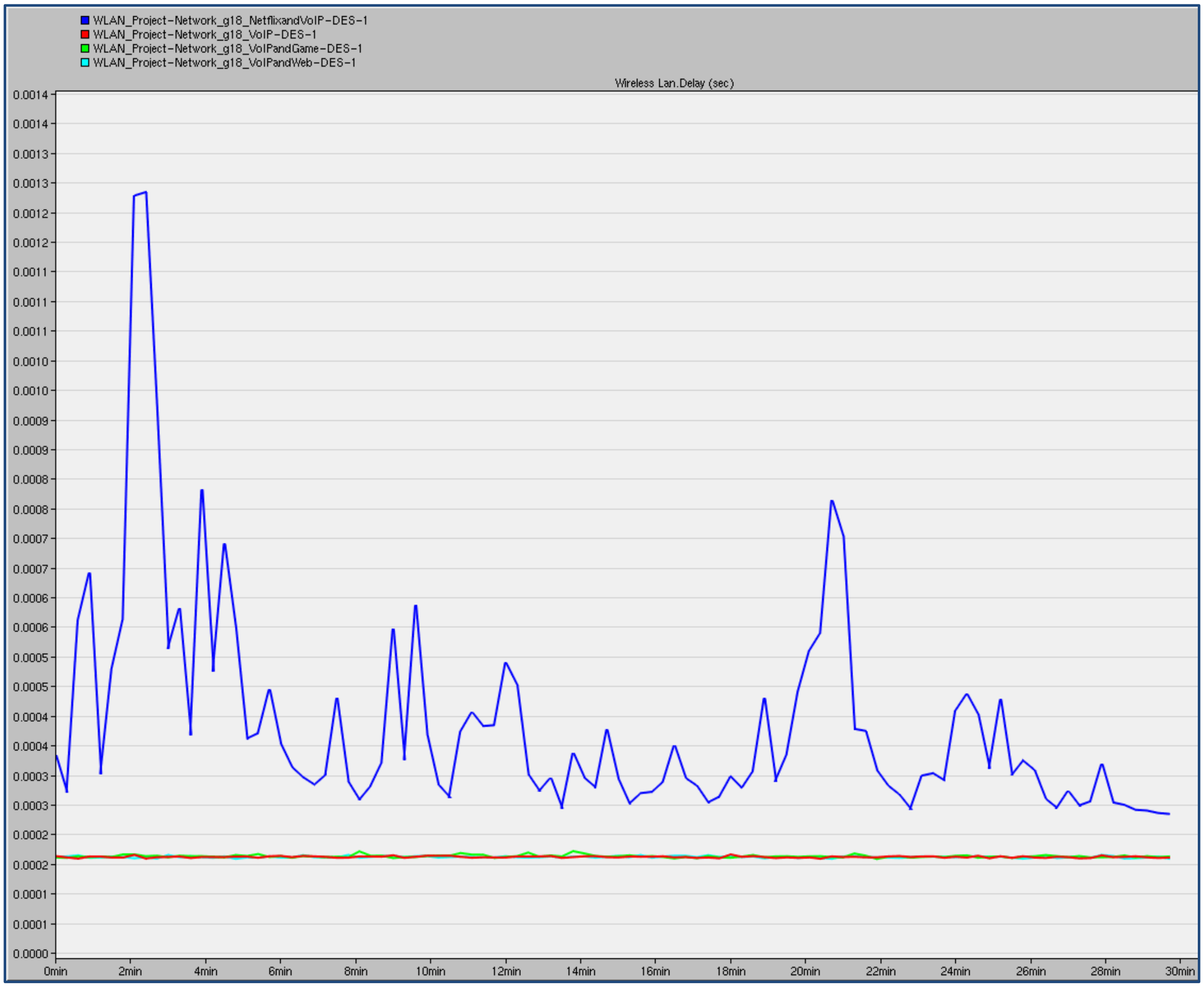


Figure 20 - VoIP Delay

4.1.4 Video Stream

Figure 21 graphs the delay for scenarios through the perspective of the Video Stream User. The increases in delay by the other, small-throughput users are nearly negligible. This shows that the users with the largest throughput hog the network resources and feel little impact from the other users.

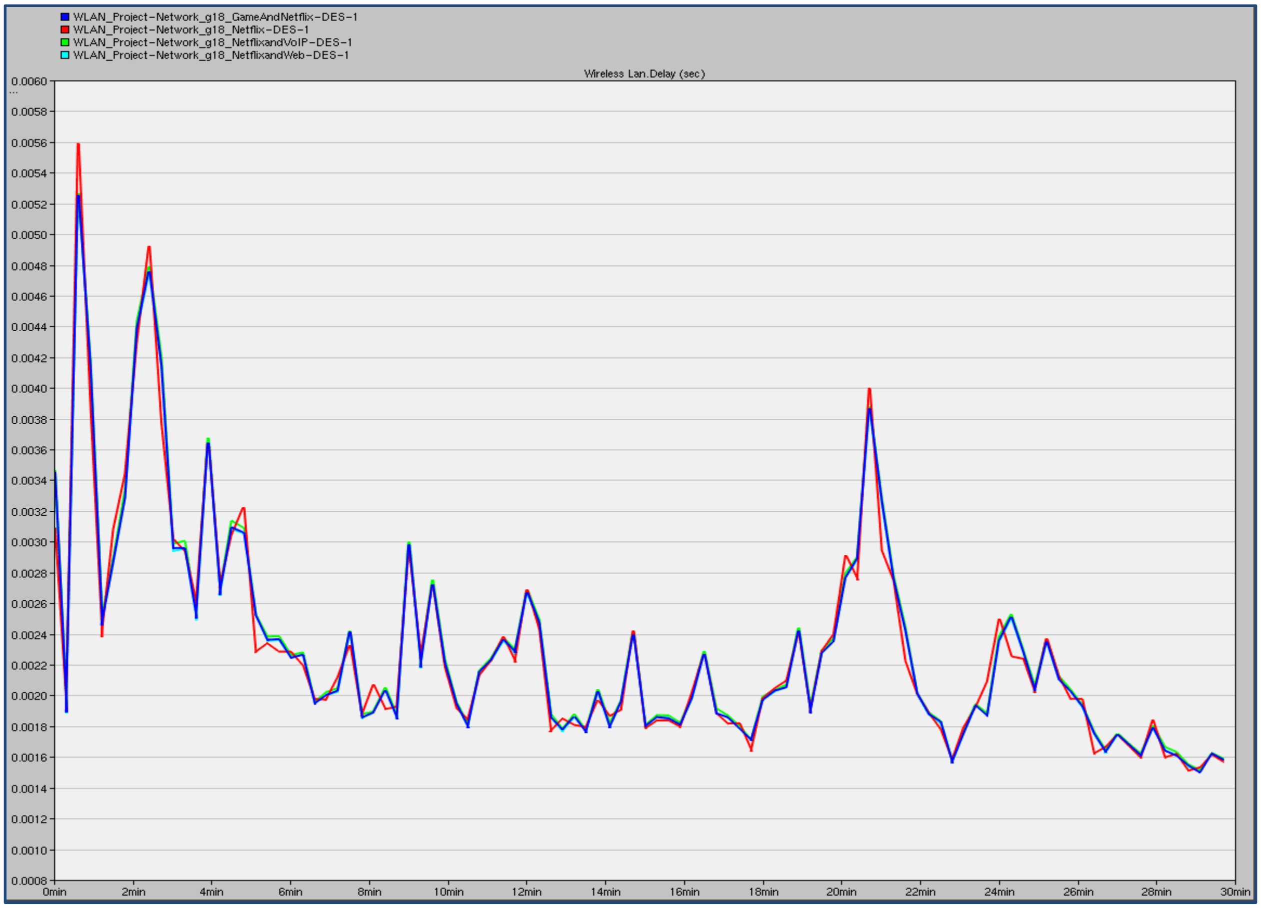


Figure 21 - Video Stream Delay

Video Streaming and other applications with large throughput are unable to coexist on the same 802.11g network with small throughput applications that require a low delay and jitter.

4.1.5 QoS

Figure 22 shows the delay for the Gamer and Video Stream User in two scenarios : the full network using 802.11g, and the full network using 802.11e (where the QoS is ensured using the HCF Parameters). The top pair of plots represent the delay of the Video Stream User, and the bottom pair represent the delay of the Gamer. There are two neat things about the 802.11e configuration that catch our eye

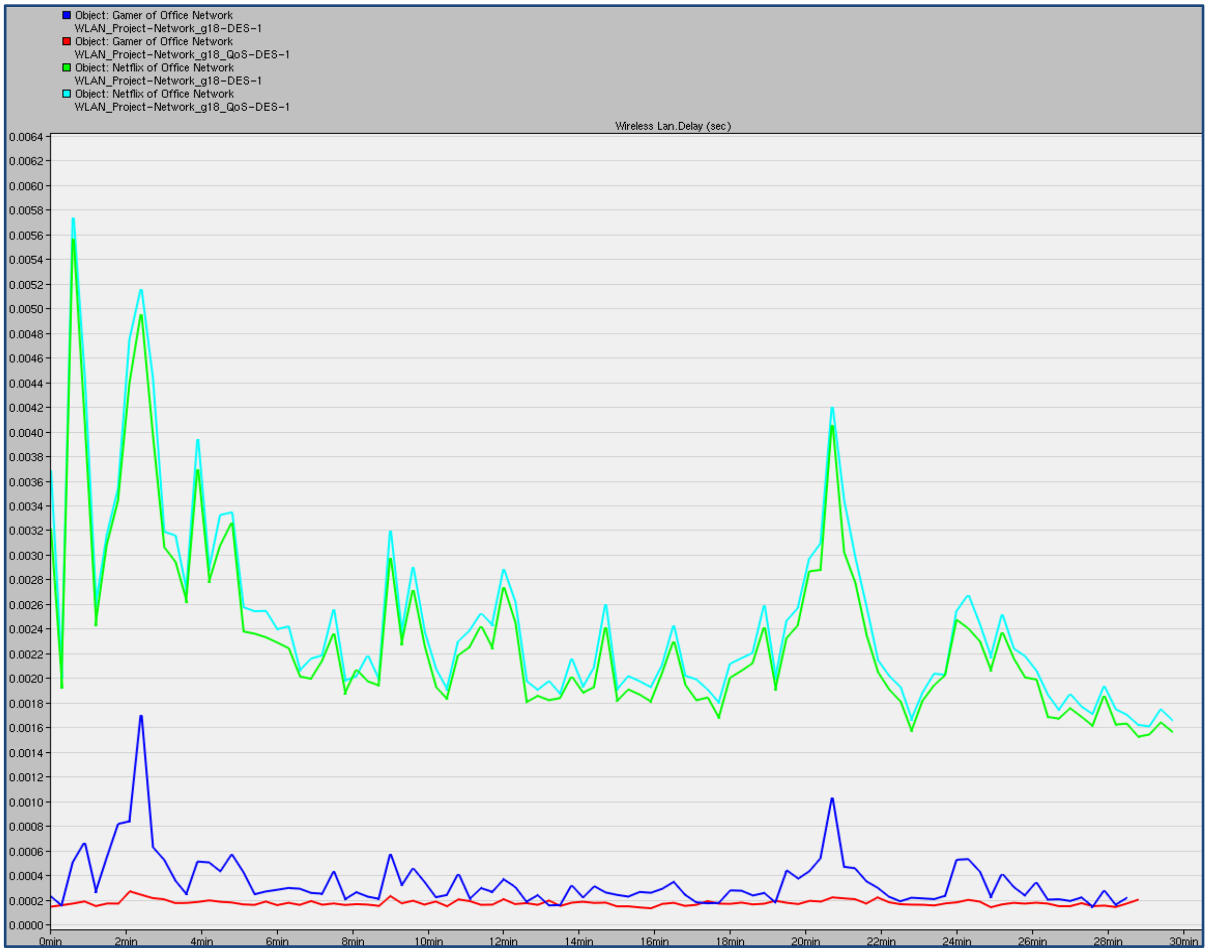


Figure 22 - 802.11g and e Delay

1) The decrease in delay of the Gamer is much larger than the increase in delay of the Video Stream User, indicating that we have made a trade-off that results in a *net* decrease in delay

2) The delay plot for the gamer has improved substantially, nearly removing all jitter, while the Video Stream User's delay plot remains relatively unchanged.

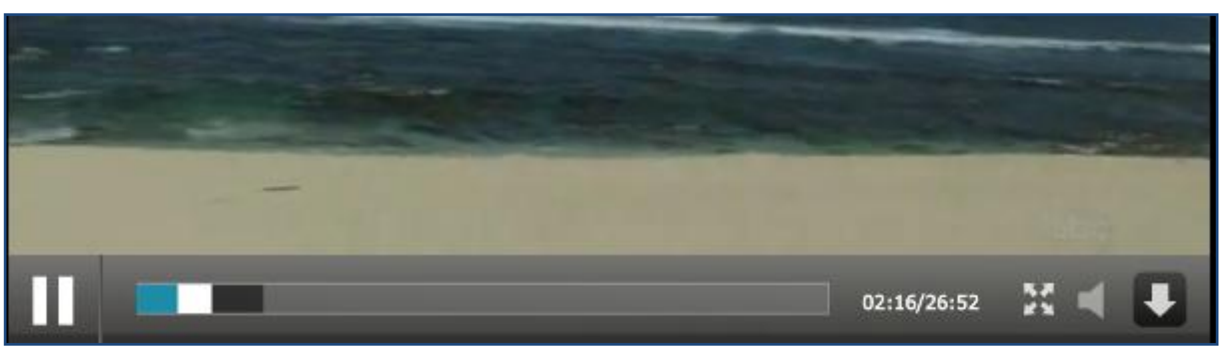


Figure 23 - Video Player with Buffer

When we compare the QoS required for both the Gamer and the Video Stream User, we need to keep in mind the real-time nature of gaming, as well as the buffering capabilities of a Video Player. If the network data rate is sufficient, we are able to preload the video faster than we are able to play a video. Figure 23 shows the progress bar of a typical video stream. The White Marker indicates the current playing time of the video, while the Dark Grey indicates how much future video has been preloaded. This means that once the video player starts preloading future video, the delay is only experienced by the *buffer*, not the video stream. The video will play seamlessly, and the user will experience a perfect QoS. The luxury of a buffer to preload data cannot be used by a Gamer, as online gaming is a real-time application. Thus, the only way to boost the QoS of a Gamer is to reduce delay and jitter. 802.11e, specifically the HCF Parameters, achieves this.

5. Conclusion and Future Work

5.1 Conclusion

Through our in depth analysis of our network, it has been determined that the applications with the highest throughput (i.e. the video stream), has the greatest impact on the QoS of the network. This means that all other users in the network will experience delay and jitter which follows the high-throughput application. In a home network, some applications are very sensitive to a low QoS such as gamers and VoIP users. To improve the QoS of these users, two different methods can be deployed. First of all, data rates can be increased to reduce the overall delay of the network. However, this does not eliminate spikes in throughput, which was introduced by the video stream user. Also, increasing data rates may be difficult, as some protocols such as 802.11b can only support up to 11 Mbps. This could mean users would have to purchase new and better routers to obtain higher data rates and access certain QoS parameters. By upgrading to 802.11e, both the delay and the delay spikes can be effectively negated, by setting higher priorities to applications which are more sensitive to low QoS. It might be thought that 802.11e would increase the delay to the lower priority application, however from our results, it has been shown that increases in delay to the low priority application (in this case the Video Streamer) are negligible.

5.2 Future work

In the future, we would like to include mobile users to the network. It is highly common to have mobile devices involved in most home wireless networks, such as smart phones or laptops. Another aspect that we would like to explore is the distance between server and access point, experimenting with various ranges to realistically model the delay values for certain applications. In addition, we would like to include the new 802.11 standards, particularly 802.11ac. This new standard is expected to be the norm in the near future, and would be interesting to model. Finally, we would be interested in determining the optimal amount of users per access point. It would be useful to provide a maximum allowable number of users to have a performance that satisfies a certain QoS, particularly in (W)LAN Parties!

6. References

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