

# **Network Modeling and Simulation**

By

Melinda Kelch

Submitted to  
the Faculty of the Information Technology Program  
in Partial Fulfillment of the Requirements for  
the Degree of Bachelor of Science  
in Information Technology

University of Cincinnati  
College of Applied Science

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Melinda Kelch

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Date

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John Nyland, Faculty Professor

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Date

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Patrick Kumpf, Department Head

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Date

## Acknowledgements

I would like to give a special thanks to Professors John Nyland and Mark Stockman. First of all, their instruction in the classroom is what sparked my interest in computer networking and thus initiated my work on this project. Professor Nyland has been there to support all aspects of this difficult and sometimes very frustrating endeavor and instead of giving me the answers I needed, pointed me in the right direction towards finding them for myself. Professor Stockman's networking classes have been unarguably valuable not only to my education but also to fostering the desire and knowledge needed to complete this project. I thank them both for the time and energy they have put forth to help me.

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Most of all I would like to thank God and my family. I've not known a more stressful period in my life than this last year which included Senior Design (even boot camp wasn't this draining). They have supported me and pulled me through when all I wanted to do was give up.

Lastly, I would like to thank all of the professors at OCAS. I believe the instruction and guidance at this college is top notch and I am proud to say I received my education from this school. The professors not only demonstrate excellent teaching skills, but mentoring and guidance skills as well. Thank you.

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## **Abstract**

Computer network availability and security are two of the most essential areas of network design in today's ever-increasing technical society. My network modeling and simulation senior design project is based on the computer network at University of Cincinnati's College of Applied Science (OCAS). At the time that I began this project, the OCAS network was suffering from several problems. These problems include a frequently slow or unavailable network including access to the main campus resources such as Internet and email. There was a bottleneck created when data left the OCAS network due to a 20 Mbps link to the main campus. Another issue the network was facing was security vulnerabilities. Because all of the nodes (computers, servers, printers, etc.) are located on one subnet, one exploited machine could affect or even take down the entire network. Some of these security threats include Denial of Service attacks, viruses, and worms.

I have designed a project that potentially solves these problems. Using OPNET IT Guru I built a simulated network model of the OCAS network. Using this model I then analyzed the network to determine the main sources of problems. I collected baseline statistics such as link utilizations and download response times for web pages, emails, etc. I then reconfigured several areas of the network to compare performance. I started by increasing the throughput on the link to main campus to determine the effect on traffic leaving and entering the OCAS network. I also set up a Virtual LAN schema that logically separated the network into smaller networks. This not only increased performance on the local network but also implemented containment for security threats on the network.

This project will be turned over to OCAS professors for use in the classroom as an example of live network analysis. The project will be more meaningful to students as it is a study of the network they are currently operating in. My network model and design project will also be available for UCIT if they choose to implement any of the concepts in the College's networks.

# Network Modeling and Simulation

## 1. STATEMENT OF PROBLEM

When dealing with the network at OCAS, one might notice some problems with performance and availability. The network is sometimes slow or not accessible at all. According to Mike Ames, an Information Technology Analyst at OCAS, there are a number of problems with the current network configuration.

The most widespread hindrance is network performance measured by speed and stability. The configuration and topology of our network are part of the problem although it is not known exactly where the problem lies. The college's current throughput is a 20 Mbps link that is routed to the Clifton campus. This creates a bottleneck when anyone on the OCAS network accesses information through main campus; this includes all Internet access as well as email on Exchange servers. The issue with increasing our bandwidth is largely related to money and if there is an immediate need to implement changes.

Another problem is that the OCAS campus is not subnetted<sup>A</sup> within itself (it is just one subnet of the Clifton campus). This creates major security issues within our network. Viruses, worms, and Denial of Service<sup>B</sup> (DoS) attacks cannot be easily quarantined once they have entered the network. If just one machine is infected with one of these, it can easily infiltrate the rest of the systems on the network. This can have a massive impact on network performance. Another issue mentioned by Ames is that when certain applications are run or multicasted<sup>C</sup> at OCAS, they inadvertently bog down other areas of UC's network (1).

Another issue deals with the stability of the network. According to Ames, it is not unusual for the network to go down (become inaccessible) several times a month. This downtime usually pertains to the link to the Clifton campus and the Internet. The downtime also sometimes includes access within the College's internal network. This problem is especially prevalent during fall quarter or around mid-terms and finals because of an increase in student usage during these peak times (1).

More problems will probably develop with technology upgrades. Wireless access has already been installed on campus but it is not known how the increase in students' usage of wireless access will affect network performance. There is not a mechanism to test what will happen to the bandwidth at OCAS and its performance once this is implemented. (1).

The College needs tools available to be able to analyze its current network configuration and topology to ascertain where problems lie and how to fix them. The College also needs a tactic that will allow it to simulate and test different scenarios and configurations so that it can make changes within the network to increase performance and stability. There are often minor changes that can be made (as related to protocols and topology) that can have a positive impact on the Quality of Service<sup>E</sup> (QoS) of the network.

Another concern is the availability of network training to networking students. As this is an educational institution, focus should be placed on the quality of training that students receive. Currently, the College's classrooms offer some live network training by using Virtual PC's and networks set up in laboratories. However, there is no network instruction presently available on a scale where students can see in practice what kind of

traffic goes on in a live network, security issues and risks, and how these affect network performance.

Network topologies can be studied from a book, but there is no simulation system in place to see the advantages and disadvantages of each topology, the differences small configuration changes make, and how to use this information to design a high quality network. We can only study from books and documentation the effects of using certain protocols, what happens when one adds systems and components to the network, and how to configure these components to achieve the most efficient network possible.

## **2. DESCRIPTION OF SOLUTION**

I propose to build a simulated network model that will mirror the OCAS network. My solution includes both networking and database components. The simulated network built will be used to study and analyze the network configuration and performance. This model was built using a simulation software program called OPNET IT Guru. A Microsoft Access database was built for storage of network inventory information, configuration data, and other data.

The network model I proposed is a simulated replica of the network at the College of Applied Science. The design stages began with infrastructure documentation to include researching the layout of cabling, equipment and telecommunication rooms, and equipment placement. The infrastructure matches the current topology of the OCAS network. I built simulated routers and switches and configure them in a topology modeling the current design as accurately. Basically, every component and node that is currently on the OCAS network was built into the simulation in order to emulate the live

traffic that occurs. Once the model was built, I then configured each component of the network to implement specified applications that are common to the office, lab, or room that the computer is located in. These applications included web browsing, email access, file transfer, database access, and printing.

My solution of building the simulated network model used technologies that offer the tools necessary to design, test, optimize, and research computer networking. I used these technologies to build a simulated model of the College's current network configuration and topology, construct a baseline of current performance, and detect where problems are occurring. Once detected, new settings can be tested and configured before implementation to ensure the desired speed and stability of the new network design. A new subnet or Virtual LAN (VLAN) will optimize performance and greatly increase the security on the College's network. A VLAN also allows quarantining of compromises to the area where it occurred versus allowing infiltration of the entire network.

In addition to building the network model, I built a Microsoft Access database to store all of the data that was collected. The database stores configuration data and documentation of each network model. Although the software technology I used has some storage capabilities of its own, this database will allow storage in a central location for easier access and simplification of the documentation process.

Another significant advantage of the project is the benefit to the networking students. Live network training is usually not available until one is on the job. The difficulties of visualizing network planning, network design, implementation, and testing will almost be eradicated. Students can use my network model and the related

technologies as an outstanding training tool that is more meaningful because it is a “picture” of the live network they are operating in—not just a textbook scenario. Students will have live, hands-on training building and troubleshooting networks, analyzing packet data, and understanding the prevailing need for effective network security.

## **2.1 User Profiles**

There are three categories of the intended users: Network Administrators (local and/or UCIT), Networking Professors and Networking Students.

### **2.1.1 Network Administrators**

Network administrators can use my optimized network model to implement changes in the current network architecture and configuration. Visual graphs of performance and stability reports of the current network can be used as proof to higher authorities that the changes are needed and thus funding should be made available. Administrators can also take the suggested changes from my model and implement them in other areas of UC’s network.

### **2.1.2 Networking Professors**

Networking professors can use my simulated network models in the classroom. Visual aids are essential to understanding computer networking and the use of pictures and graphs in the classroom will be an excellent learning tool for the students. Professors can use the model to emphasize the importance of well planned network design with the use of visuals in addition to the normal lecture. The “before and after” picture of the

OCAS network will provide live demonstration of what occurs on a network and how problems can be fixed, or mitigated and the network design can be optimized overall.

### **2.1.3 Networking Students**

Networking students can use my project as a learning tool. They will value from the network models by using them for visualizing network problems, troubleshooting and testing network issues, and performing labs involving network analysis and optimization.

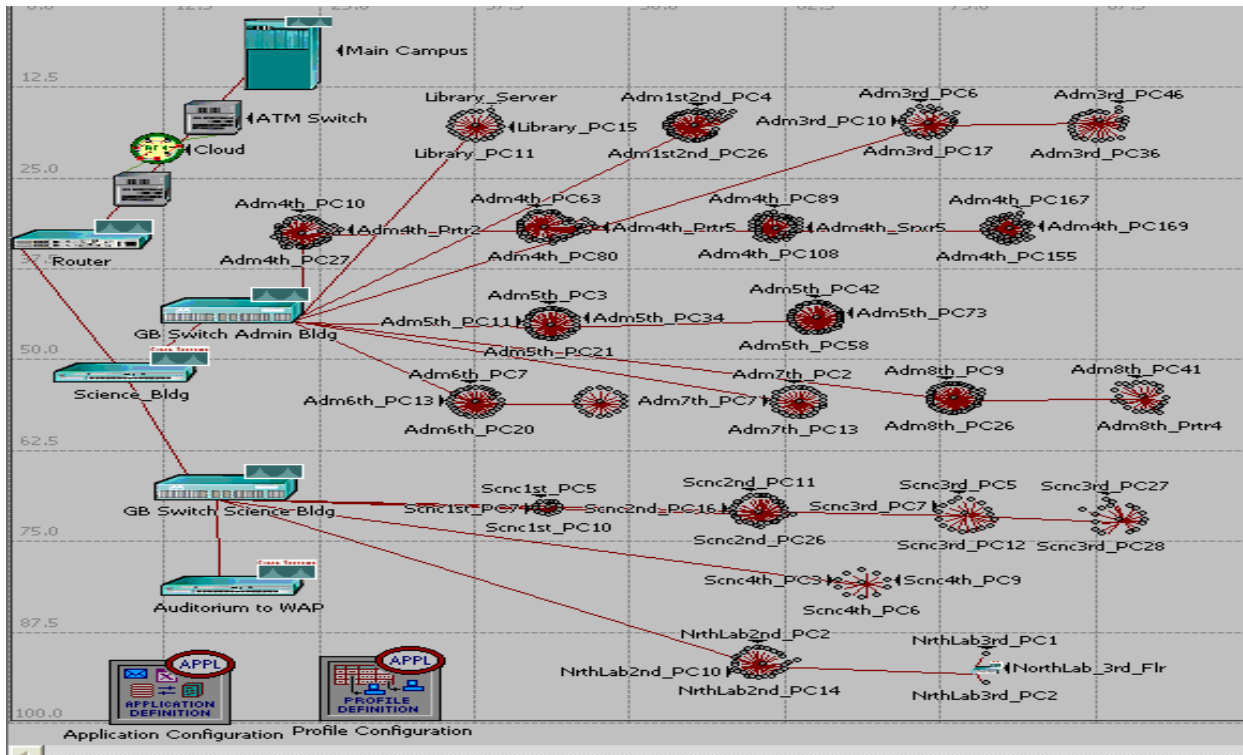
## **2.2 Design Protocols**

### **2.2.1 Project Design**

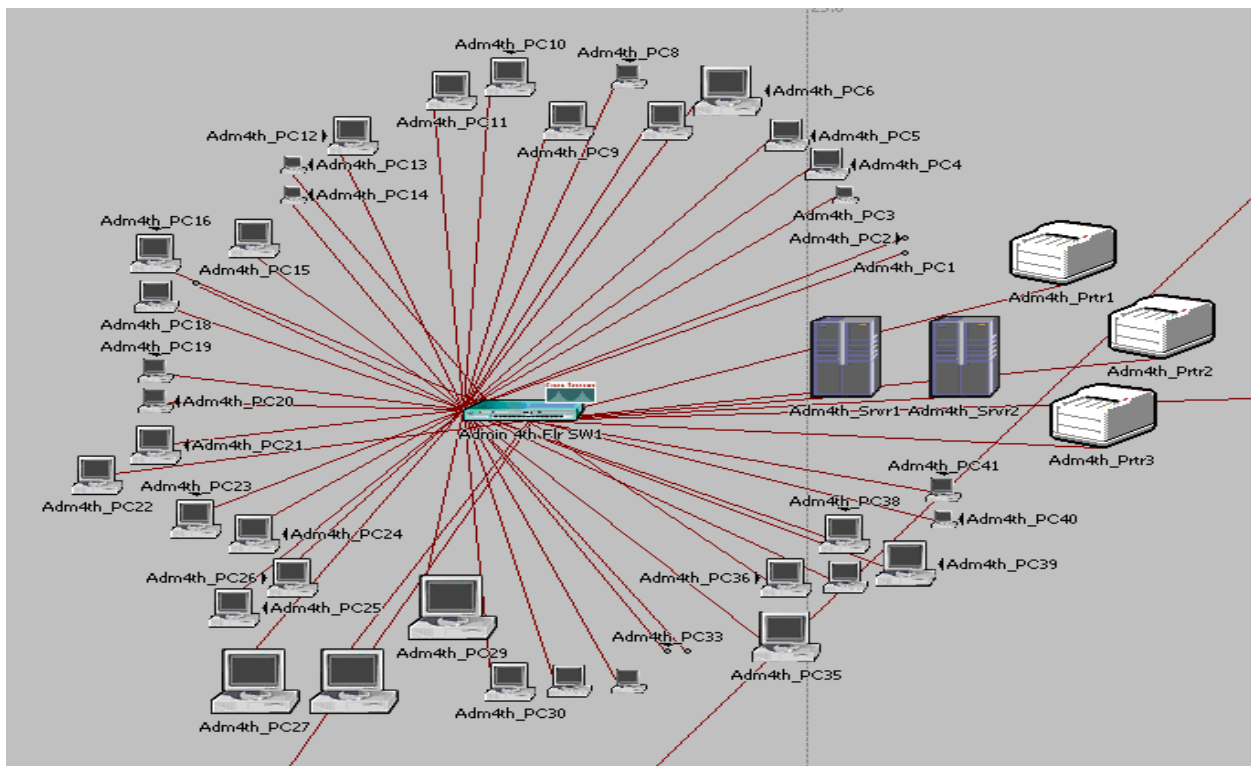
The project design includes both networking and database components. I am using OPNET IT Guru to build the model and simulate scenarios. Microsoft Access was used to build the database.

### **2.2.2 OPNET IT Guru**

The network model I built is a simulated replica of the network at OCAS. There are actually two models that were built. One model is the current configuration of the OCAS network and the other is the “new and improved” optimized model--which will include my configuration changes. The OPNET model I built provides a baseline for network performance and was used as a comparison for the optimized network. Once the baseline was established, I redesigned and reconfigured it for the optimized network model. The following diagrams are screen shots of the network models I have built (Figures 1 and 2, pg 14)



**Figure 1: First OPNET Network Model**



**Figure 2: OPNET Model Zoomed In Screenshot**

### 2.2.3 Microsoft Access Database

In addition to the network models, I built a Microsoft Access Database to hold the current network configuration such as locations of routers, switches, and nodes. I've also stored the network profile configurations as well as VLAN setup information in this database and generated reports based on these.

### 2.2.4 Microsoft Visio

I am using Microsoft Visio for the initial network topology plan. This is just part of my documentation and can be saved as an image for visual purposes. The Visio document served as a guide for my building my OPNET model. The following diagram is the current configuration diagram:

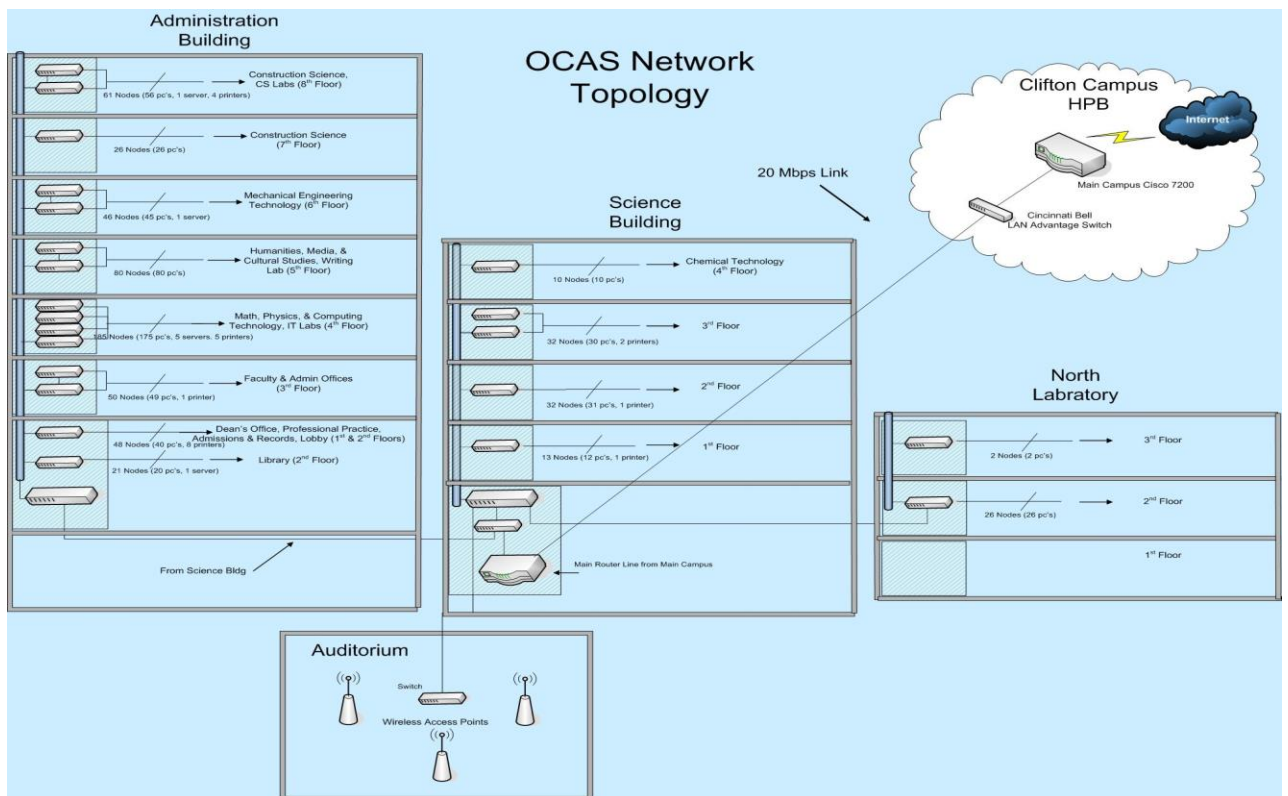


Figure 3: Microsoft Visio Network Diagram

### 3. DELIVERABLES

- Established baseline for the network's current typical performance
- Optimized network model
- Results and comparisons of the following tested scenarios:
  - Topology reconfiguration
  - Implementation of Virtual LANs
  - Results of increased bandwidth to main campus
  - Denial of Service attacks
  - Addition of users-wired and wireless
- Microsoft Access database including statistical analysis reports
- Microsoft Visio diagram of network topology
- Collection of all network models and analysis data available for professor and student use.
- Router and switch configuration files available to upload to live routers

## 4. DESIGN AND DEVELOPMENT

Below I've included the timeline, Senior Design accomplishments, and the overall budget.

### 4.1 Timeline

The timeline for my project is shown in the following Gantt chart:

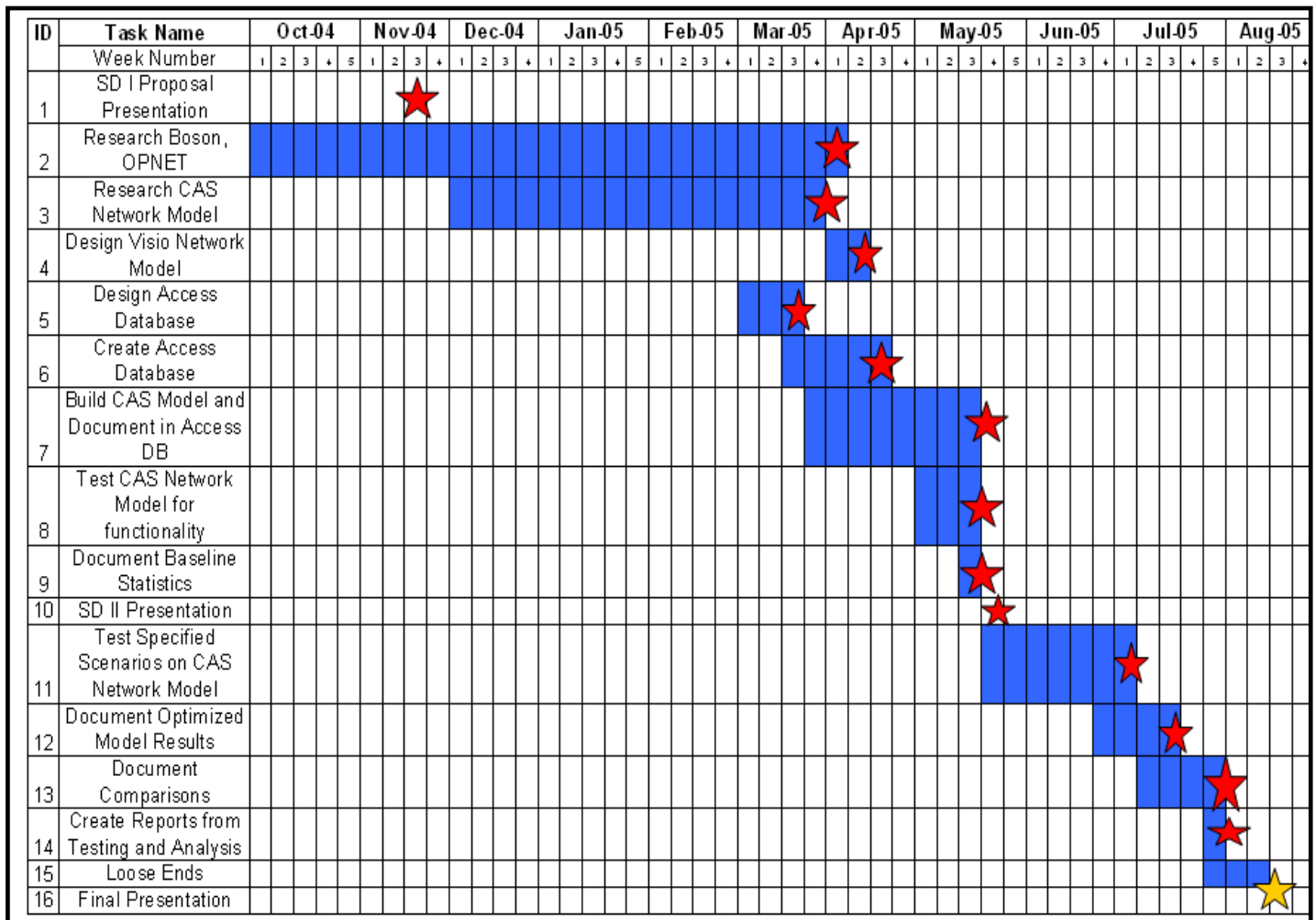


Figure 4: Timeline

### **4.1.1 Senior Design I Accomplishments—Fall 2004**

Week 1-5

- Research OPNET IT Guru
- Download and Installation of software
- Write Draft Proposal

Week 6-10

- Interviews with Mike Ames and UCIT
- Research and Analysis of OCAS network
- Write Senior Design Proposal
- Present proposal to Information Technology Faculty

### **4.1.2 Senior Design II Accomplishments—Spring 2005**

Week 1-5

- Design network model in Microsoft Visio
- Perform OPNET tutorials and research to learn software
- Build Microsoft Access Database
- Write Draft Design Freeze

Week 6-10

- Build simulated model of current network configuration in OPNET IT Guru
- Start collection of Baseline Statistics
- Write SDII Design Freeze
- Present Model and Project Demo to Information Technology Faculty

### **4.1.3 Senior Design III Accomplishments—Summer 2005**

#### Week 1-5

- Troubleshoot OPNET model issues with application performance
- Configure OPNET model for application design
- Completion of Baseline Statistics
- Document in Access Database
- Write Draft of Final Report

#### Week 6-10

- Testing
  - Reconfigure network topology in problem areas
  - Increase of throughput of link to main campus
  - Design and Implement Virtual LAN
  - Simulate Denial of Service attack
  - Documentation of all results
- Prepare analysis reports
- Finish Senior Design Final Report
- Present proof of design to Information Technology Faculty

## 4.2 Budget

The budget for my project is shown in the following chart:

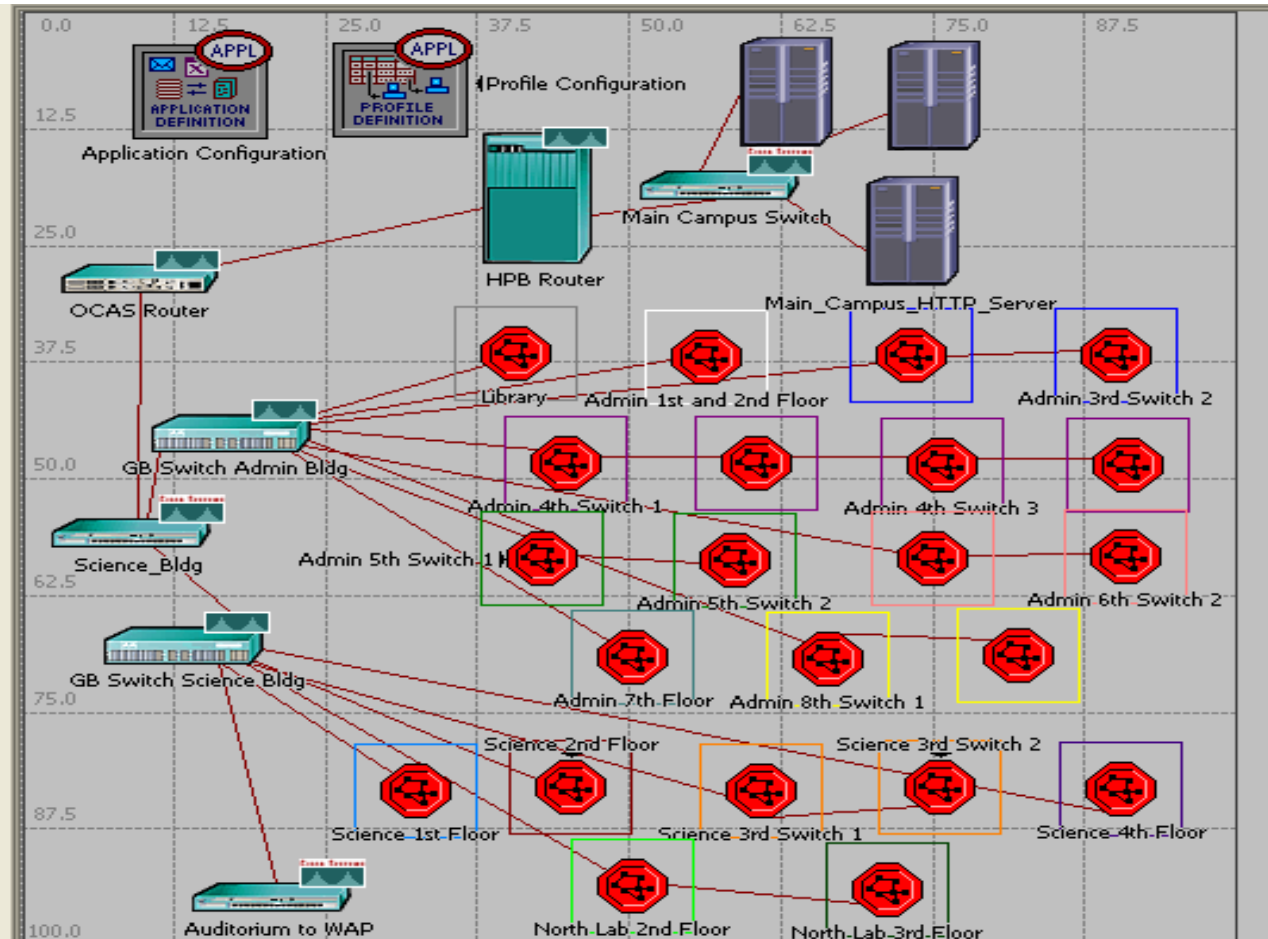
<b>Item</b>	<b>Price</b>	<b>Actual Cost</b>
OPNET IT Guru Academic Edition	0	0
Microsoft Access	199	7
Microsoft Visio	499	0
1 Computer System	1200	0
<b>Total</b>	<b>\$2,047.95</b>	<b>\$7.00</b>

**Figure 5: Budget**

## **5. PROOF OF DESIGN**

In order to meet the deliverables from Senior Design II, I first had to learn how to use the OPNET IT Guru software. This product is an extremely advanced network design tool used for enterprise application performance management, network configuration analysis, and IT capacity modeling/planning. Because it is so advanced, and because I am a novice network designer, a good part of my effort on this project dealt with learning how to use this tool.

Once I researched the OCAS network and documented all of the equipment and layout, I created a Visio diagram to model the network. This diagram served as a guide for creating my simulated network model. Some of the problems I encountered during this process included determining the correct equipment items to use in the software that would accurately represent what is present on the OCAS network. Once that was determined I was able to build the simulated model which included one router, twenty-seven switches, six hundred and four workstations, eleven servers, and twenty-five printers for a total of six hundred and sixty nine nodes. I grouped each floor into its own segment for aesthetic purposes. Below is an illustration of the OPNET simulated network model and although each floor appears to be a separate subnet, all nodes are actually in the same network with no logical separation (Figures 6, page 22).



**Figure 6: OPNET Model-Original Network**

Next I had to configure the applications that this network should model. These applications include web browsing, email, file transfer, database access, and file printing. Each workstation was configured to what could be “assumed” its purpose was and these assumptions were based on interviews with Mike Ames and Dave Dessauer. After each PC was set up with an application configuration, I also had to specify the destination where this application would be served. Consequently, each server was configured to support the specified applications. Below I’ve included screen shots of the profile configuration as well as one of the application configurations (Figures 7 and 8, pg 23).

**(Profile Configuration) Table**

Profile Name	Applications	Operation Mode	Start Time (seconds)	Duration (seconds)	Repeatability
Library	[...]	Simultaneous	constant (100)	End of Simulation	Once at Start Time
Administrative	[...]	Simultaneous	constant (100)	End of Simulation	Once at Start Time
Student	[...]	Simultaneous	constant (100)	End of Simulation	Once at Start Time
Professor	[...]	Simultaneous	constant (100)	End of Simulation	Once at Start Time
LabPC	[...]	Simultaneous	constant (100)	End of Simulation	Once at Start Time
ClassroomLecture	[...]	Simultaneous	constant (100)	End of Simulation	Once at Start Time

6 Rows

**Figure 7: Profile Configurations**

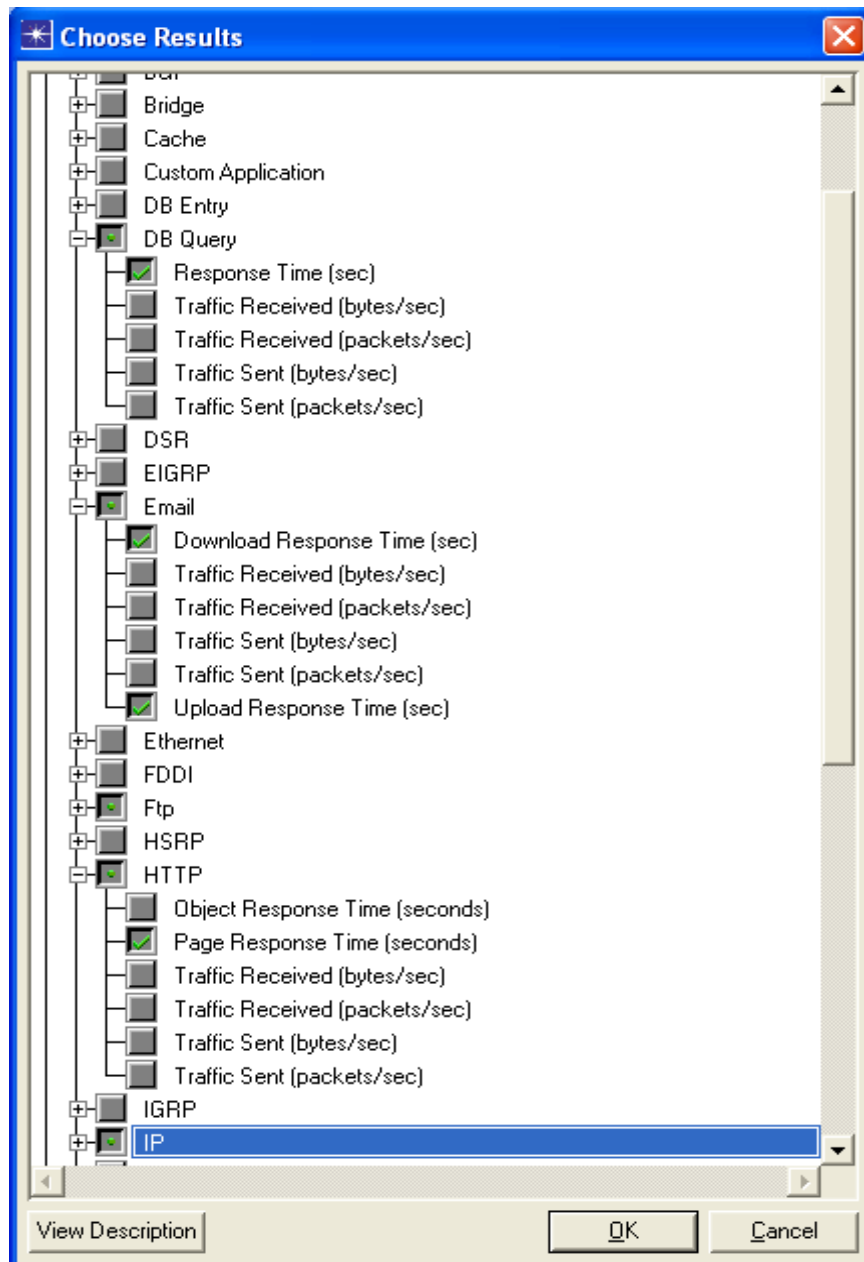
**(Applications) Table**

Name	Start Time Offset (se...	Duration (seconds)	Repeatability
Web Browsing (Light HTTP1.1)	uniform (0, 300)	End of Profile	Unlimited
Email (Light)	uniform (0, 300)	End of Profile	Unlimited
Database Access (Heavy)	uniform (0, 300)	End of Profile	Unlimited
File Transfer (Light)	uniform (0, 300)	End of Profile	Unlimited
File Print (Light)	uniform (0, 300)	End of Profile	Unlimited

5 Rows

**Figure 8: Application Configurations**

Once the applications were configured and each workstation was set up with the appropriate profile and destination server, I was ready to conduct the Discrete Event Simulation. This is where I determined which statistics I wanted to collect. I've included a screen shot of some of the statistics I included for this project:



**Figure 9: Discrete Event Simulator Settings**

Running the Discrete Event Simulator produced the results I needed to generate the baseline statistics needed to outline the current network performance at the College of Applied Science. Now that the baseline was established, I began testing of various scenarios.

The first scenario that I tested was to cable each switch on every floor directly to the main Gigabyte switch in that building. The current network setup is designed so that if there are multiple switches on a floor, the other switches are just daisy chained off of the first one. When I tried to implement this in the network, I found that the Gigabyte switches don't have enough Gigabyte ports to support a link to each switch, so I kept the original configuration.

Next I tested a scenario in which the throughput of the link to main campus was increased from 20 Mbps to 1Gbps. This modification practically eliminated the bottleneck effect that the current network design was facing. A 1 Gbps link was more than enough throughput to allow for efficient traffic flow between OCAS and main campus. The results of this scenario are shown in the following figures (Figure 10, pg 26):

# OCAS to Main Campus Link Utilization

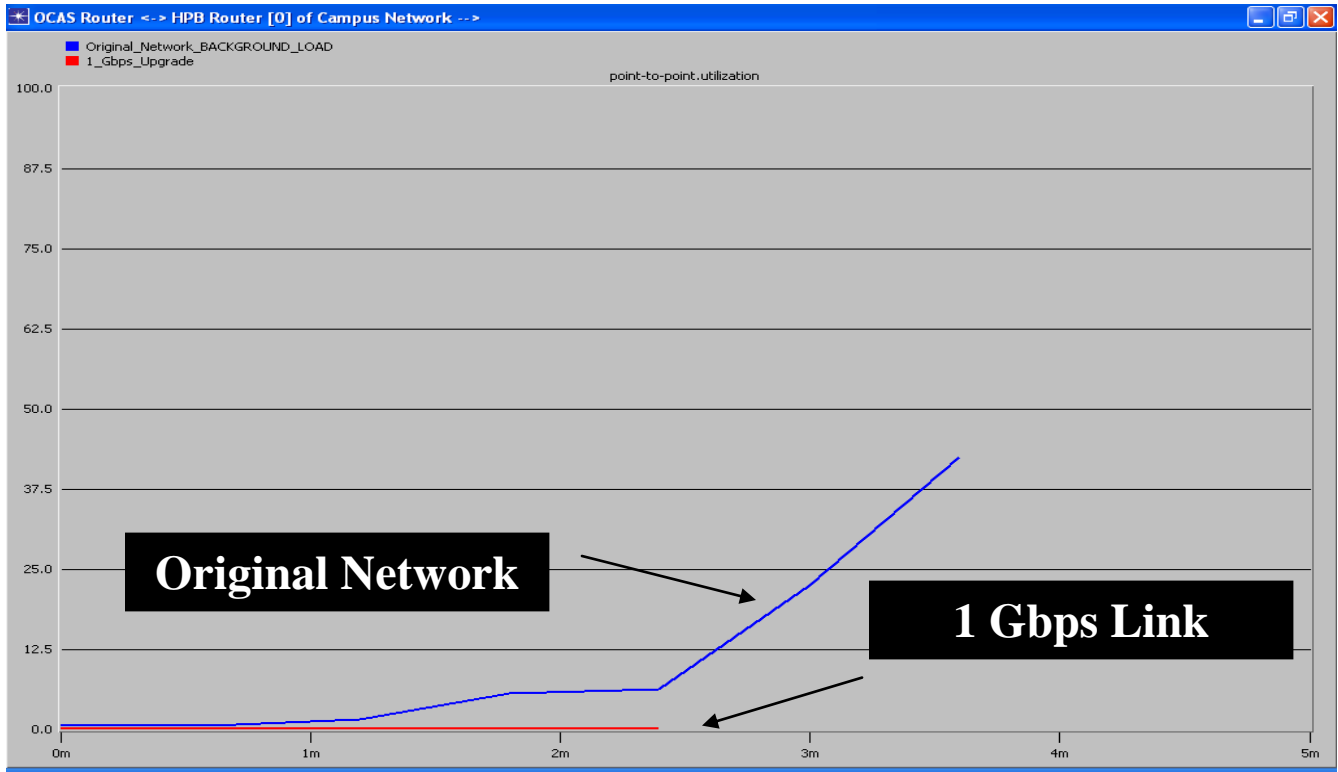


Figure 10: 1 Gbps Link to Main Campus Upgrade

Now that I tested some of the proposed topology changes, I was ready to tackle the problem of network security (or lack thereof on the current network). The first point I wanted to illustrate was how vulnerable the current network design is. Because all of the nodes are on one subnet, if a virus or worm infiltrates even one system, it can easily propagate to all other computers on the network because there is no quarantining in the form of subnets. My solution to this problem was to implement a Virtual LAN<sup>E</sup> design.

The goal of implementing a large switched campus with few routers (such as the OCAS network), is to keep costs down by using switches instead of routers, and to provide good performance because presumably switches are faster than routers. However,

because routers provide the capability of containing broadcast traffic within each subnet, the only way to obtain a logical separation is through VLANs.

By implementing a VLAN, you can see an immense impact on network performance. This is mostly due to the fact that broadcast traffic is only routed to the small VLAN that the node is connected to, versus broadcasting across the entire network. Performance is also enhanced because a VLAN introduces a much more secure network environment. For example, a Denial of Service attack would only affect the VLAN where it was introduced; it can't propagate to the entire network because of the logical separation. I simulated a Denial of Service attack by increasing the background traffic load to a point where the original network becomes unusable. With the same amount of background traffic on each, I ran the simulator on the original network and the VLAN network. I've included graphs below illustrating some comparisons of the current network performance versus the network including the Virtual LAN implementation while undergoing a denial of service attack (Figures 11 and 12, pg 27):

## Utilization of 20MB link to Main Campus (HPB) Simulated Denial of Service Attack

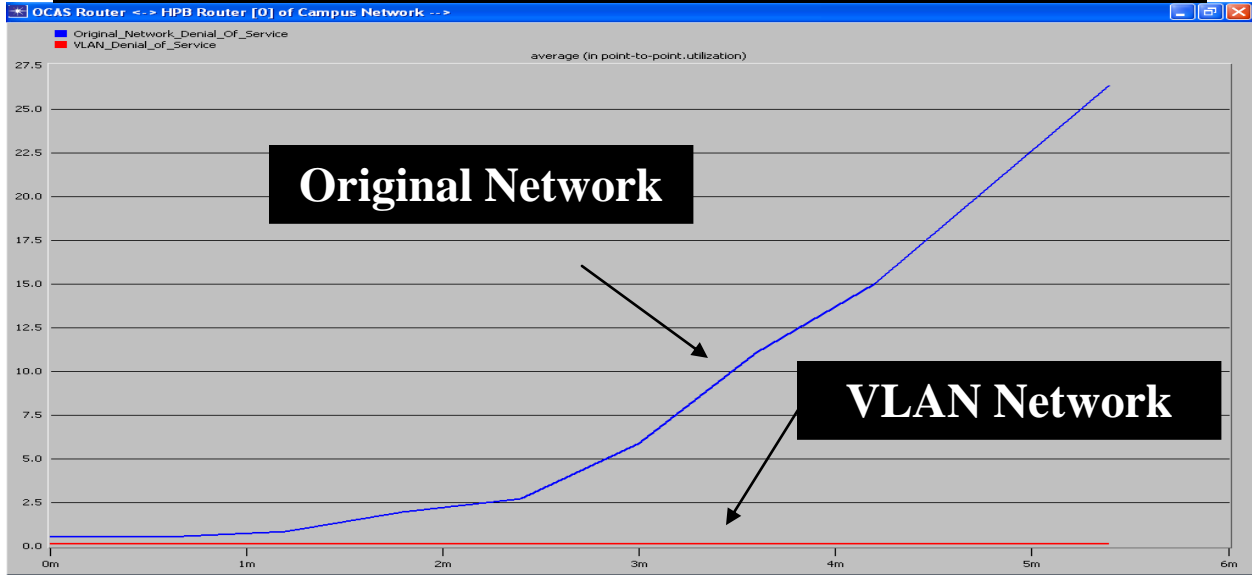


Figure 11: Denial of Service-Link Utilization Comparison

## File Transfer Download Time Simulated Denial of Service Attack

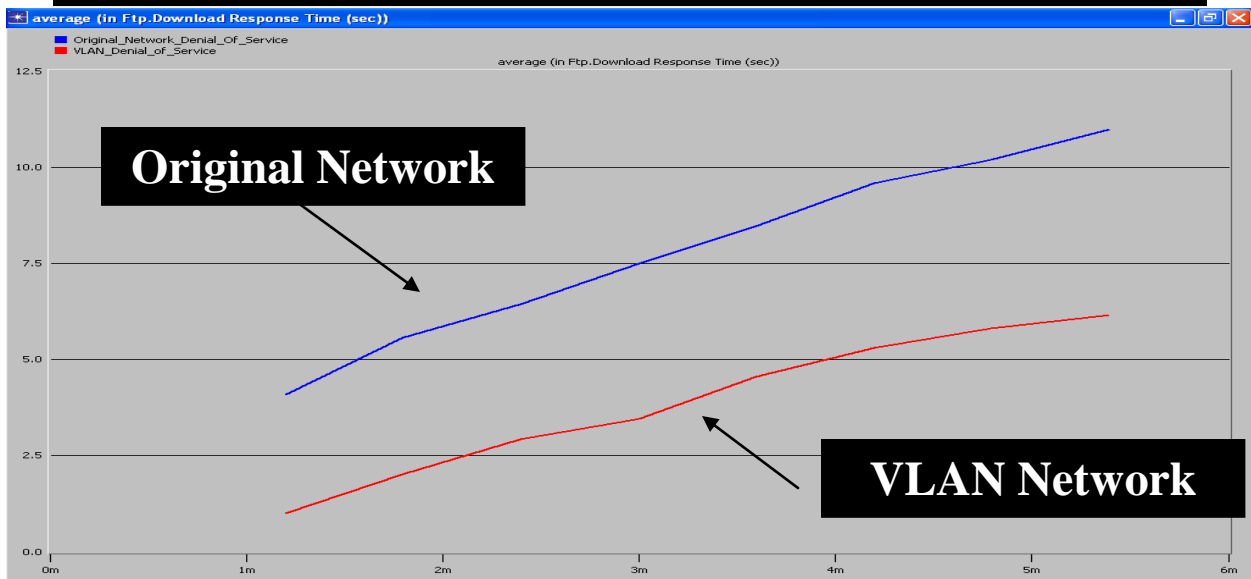
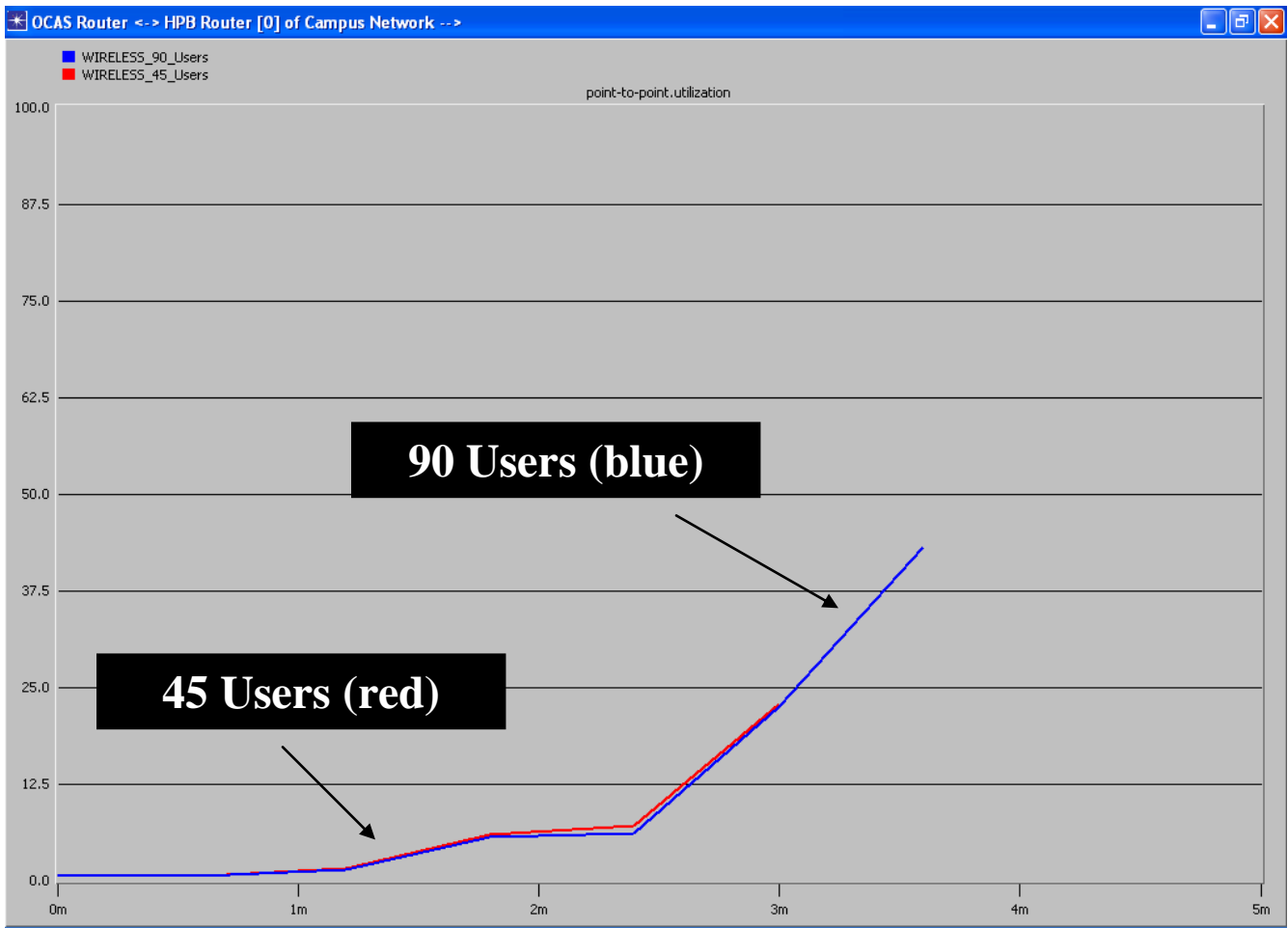


Figure 12: DOS-File Transfer Download Time Comparison

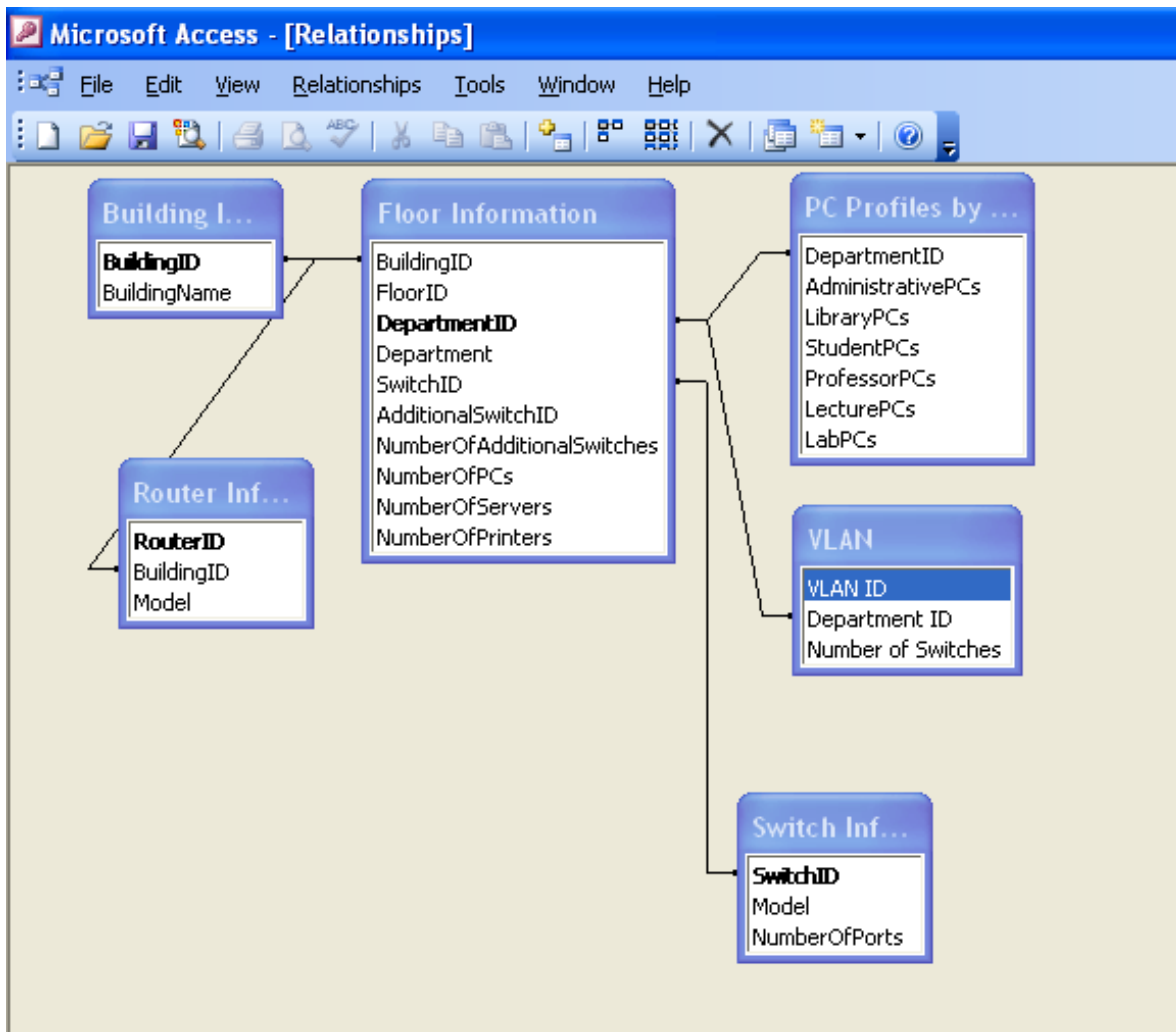
One last scenario I tested was the effect of adding wireless users to the network. I took a simulation with 45 users and then another one with 90 users. I've included the graph below but there was not a significant difference in network performance. Therefore, I believe our current infrastructure would be able to handle additional wireless users. This tool could easily be used to test more or less users on our infrastructure.

## Utilization of 20MB link to Main Campus (HPB) Additional Wireless Users



**Figure 13: Addition of Wireless Users**

I've documented all of switch placement as well as locations of all the other components of the OCAS network in my Microsoft Access Database. Included in the database are the profile and application configurations for the OPNET network model that I built as well as the Virtual LAN setup. Below are some diagrams that show the Access database table setup and relationships:



**Figure 14: Microsoft Access Database Relationships**

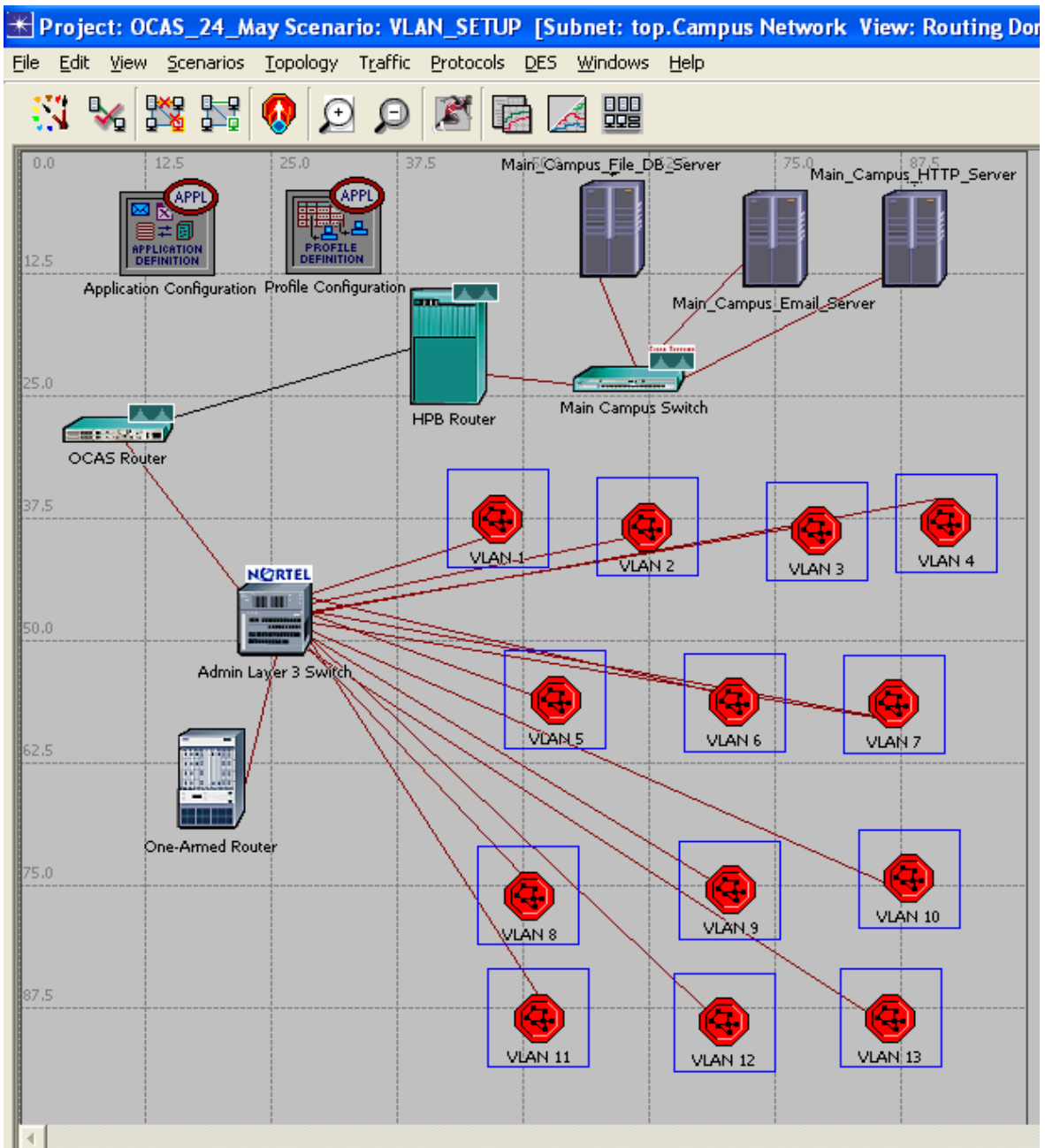
## 6. RECOMMENDATIONS

During the course of my senior design project, UCIT went ahead and made some upgrades. From what I've been told by Dave Dessauer, UCIT spent about \$70,000 to upgrade our campus router to a Cisco 6500 and to run a fiber to the auditorium. They bought the layer 4 switch in order to implement subnets but then set up VLANs on top of that.

Number one, the router replacement wasn't necessary because we are only connected to one other router. Routing demands aren't very high in our situation so the only reason this was purchased was so we could subnet the network. They did, additionally, implement Virtual LANs on top of this.

This was definitely not necessary because VLANs and subnets serve the same purpose, to segment the network and as discussed earlier, VLANs offer more flexibility, are faster and are usually much cheaper than subnetting through a router.

My recommendation (as seen in my optimized network model) would be for us to purchase Layer 3 switches instead of upgrading the router. I've looked at several Nortel products and found an appropriate Layer 3 Switch for around \$5000. This would integrate with the Cisco equipment and handle the Virtual LAN processing. Due to the low cost of this, we could even purchase 2 switches, stack them together and provide load balancing and redundancy throughout the network. I've included the diagram of my optimized OPNET network model (Figure 15, pg 32):



**Figure 15: Optimized VLAN Network Model**

We could utilize the leftover Gigabyte switches that we currently own in areas where there is a lot of traffic, such as the 4th floor IT labs. We could also spend the left over money on either implementing more Wireless Access Points, running more fibers to

some of the switches that are daisy chained off others on each floor, or implementing better security measures such as firewalls or intrusion detection.

Basically we could have greatly enhanced the performance, stability and security on the OCAS network for around \$10,000 and spent the other \$60,000 upgrading other equally important areas.

## Notes

- A. Subnet-** the process of logically dividing the network IP address into segments, called subnetworks (4, pg 132).
- B. Denial of Service-** a type of attack on a network that is designed to bring the network to its knees by flooding it with useless traffic (8, pg 1).
- C. Multicast-** to transmit a single message to a select group of recipients. A simple example of multicasting is sending an e-mail message to a mailing list.  
Teleconferencing and videoconferencing also use multicasting, but they require more robust protocols and networks (9, pg 1).
- D. Quality of Service-** on the Internet and in other networks, QoS is the idea that transmission rates, error rates, and other characteristics can be measured, improved and, to some extent, guaranteed in advance. QoS is of particular concern for the continuous transmission of high-bandwidth video and multimedia information (12, pg 1).
- E. Virtual LAN (VLAN) -** an emulation of a standard LAN that allows data transfer to take place without the traditional physical restraints placed on a network. Users can be grouped into a VLAN so they can communicate as if attached to the same wire, when in fact they are located on different physical LAN segments. (7, 137).

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