Student Network Design Projects using OPNET

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Abstract

To provide students with a practical knowledge of networking, the K.U.Leuven organizes design projects, complementary to the theoretical courses. Master students in Electrical Engineering (Telecommunications option) design a network for a specific service in a specific environment. During the academic year 2000-2001, students worked on one of the following topics: voice traffic on leased lines, VoIP on an Ethernet, or file sharing on an office LAN. Every project consists of four different parts: traffic load measurements, analytic performance calculations, simulations, and a practical lab implementation. The simulations are performed with the OPNET Modeler and are discussed in this paper.

Introduction

Graduate education in the field of networking is far from evident in our present-day ICT society. New inventions and technologies are developed in rapid succession. Networks constantly grow in size and complexity. More and more people and companies connect to the information highway.

To offer students the opportunity to get acquainted with modern communication networks, the TELEMIC (Telecommunications and Microwaves) research group of the Electrical Engineering department (ESAT) organizes design projects. These projects are supplementary to the advanced lectures on networking, taught in the final Master's year. They provide students not only with a clear understanding of networking but also with practical design and project skills.

To make the projects as interesting as possible, real-life problems and challenges are presented to the students. The subjects dealt with during the academic year 2000-2001 are the following: voice traffic on leased lines between two remote campuses of the university, VoIP on a student dorm network, and file sharing on the LAN of our research group. Previous topics examined are the impact of videoconferencing on the university network, VoIP replacing the ISDN network of our research group, and cable access networks using the DOCSIS protocol.

The assignment consists of different parts. After a study of the problem, students determine the current network load statistics. This ranges from measuring packets on the specific network infrastructure to analyzing call records. Some precautions are taken to avoid violating users' privacy. The aim of the project is to predict whether a new service can be added to the existing infrastructure.

Both analytical calculations based on simplified models and simulations are used to determine the quality of service the network can offer. A comparison of both methods will indicate their respective strength and weakness. Finally, some practical experience is gained from a lab implementation.

The last year Master students in Electrical Engineering (Telecommunications option) are grouped in teams of two. Each team works on one of the three subjects. Teams, working on the same subject, have a slightly different assignment and are encouraged to cooperate where possible. The total project is credited a study load of 150 hours and should result in a report summarizing the major results. The students are coached by a team of assistants, each responsible for one part of the assignment.

In this paper, we will focus on the use of the OPNET Modeler for simulations in the projects. In [1] we comment on the other parts of the assignment.

This paper is organized as follows: for each subject we summarize the results of one team. We start with an outline of the problem followed by a description of the simulations. We go deeper into the simulated network topology and the definitions of the different tasks and applications. Possible problems and difficulties encountered are also mentioned. Finally we conclude with an evaluation of the projects and of the simulations in particular.

More information on the design projects, together with all reports, can be found on the homepage [2].

Voice traffic on leased lines

In this chapter we summarize the results obtained in [3]. The complete report can be found on the homepage [2] together with the reports of two other groups working on the same subject.

Problem outline

The University in Leuven (K.U.Leuven) has a smaller campus in Kortrijk (KULAK). Both sites are located more than a 100 km apart and are interconnected by a 2 Mbps full duplex leased line. Until now this line is only used for data traffic. The aim of this project was to examine whether the current phone traffic between the two campuses can go via this line instead of using the PSTN and paying a telecom operator for every call.

At the beginning of the project, Belgium was still divided in phone zones: phone calls to the same or a neighboring zone were charged at local rate while long distance calls were more expensive. By using the leased line, phone calls from the K.U.Leuven to the Kortrijk zone (outside KULAK) and surroundings are charged at local rate. Analogously, calls from the KULAK campus to the neighborhood of Leuven become zonal. In addition, students examined where to add other POPs (Points of Presence) to cover the complete Flemish part of Belgium and convert it into one big phone zone. Of course the cost saving opportunities should be weighed against the technological investments.

Solution
To cover the complete Flemish part of Belgium, two extra POPs are necessary, one in Gent and one in Tongeren. To minimize the leasing cost (distance), Gent is connected to Kortrijk while Tongeren is connected to Leuven. The resulting topology is the base for Figure 1.

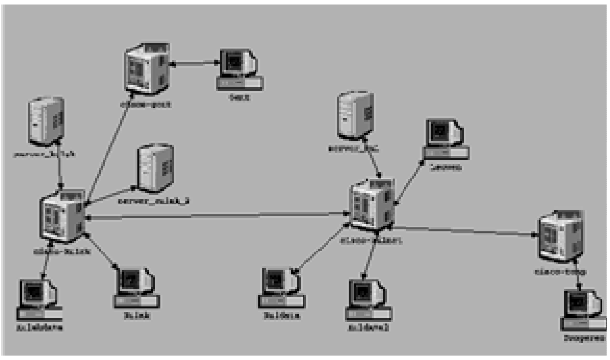

Figure 1: Simulation topology

A router is placed in each POP. Students picked the same router (Cisco 7000) out of the object palette for every POP because of the difficulty to find smaller routers with enough ports. The effective routing capacity of each router was adjusted in the attributes menu (100.000 p/s in Leuven, 40.000 in Kortrijk, 5000 p/s in Gent and Tongeren). The routers are linked by serial lines: 2 Mbps between Leuven and Kortrijk, 1 Mbps between Kortrijk and Gent, 128 Kbps between Leuven and Tongeren.

The aim of the project was to transport voice calls in a packetized way over this network infrastructure. To obtain a realistic load, students analyzed call traces from the university and filtered out the necessary statistics: the interarrival time between the calls (6.41 s) and the length of the calls (221.8 s) during busy hour. Both were taken to be exponentially distributed. In order to add voice traffic to the network, an Ethernet workstation was connected to each router. For simplicity, each POP is studied abstracting from the gateway and PABX.

Two voice profiles are defined, one for voice calls originating from Leuven and one for voice calls originating from Kortrijk. The weighing table in Figure 2 shows the destination preference for the voice profile in Leuven.

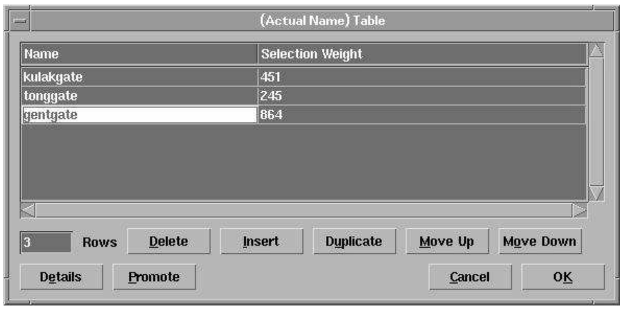

Figure 2: Weights for the Leuven voice profile

The predefined Voice over IP application was used to generate voice traffic. Figure 3 and 4 show respectively how the measured call duration and the interarrival time could be configured for use in simulations.

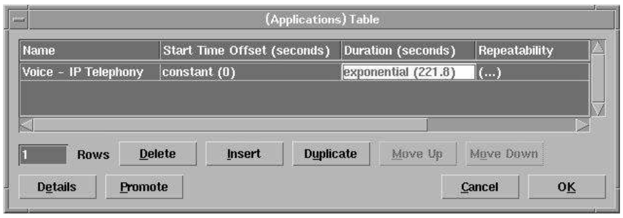

Figure 3: Configuration of the call duration

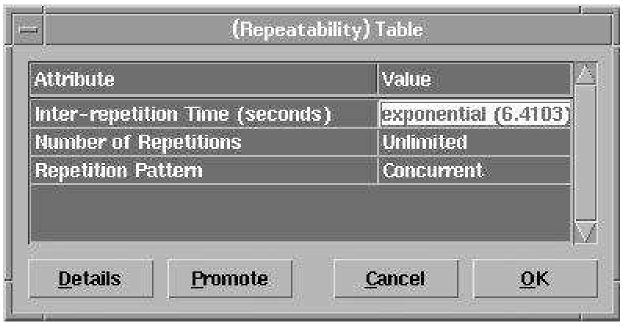

Figure 4: Configuration of the interarrival time

However , the network infrastructure also carries normal data traffic. Not only the load of the line but also the total load of the routers is necessary to determine the quality the network can deliver. Students used SNMP requests to measure the number of packets and bytes transmitted through each router port.

The measured data traffic on the leased line between Leuven and Kortrijk is simulated by an interaction between an Ethernet workstation in Leuven (kuldata2) and an Ethernet server in Kortrijk (server_kulak_2). Each time the server receives 5 request packets, it answers with 2 response packets. This ratio represents the difference in amount of traffic in both directions. The average packet size can be calculated from the measurements: 444 bytes going from Leuven to Kortrijk and 194 the other way around. The students assumed an exponential distribution for both packet sizes. The average interrequest time is 0.1 s and is also assumed to be exponentially distributed. Figure 5 and 6 show the configuration of the client and the server respectively.

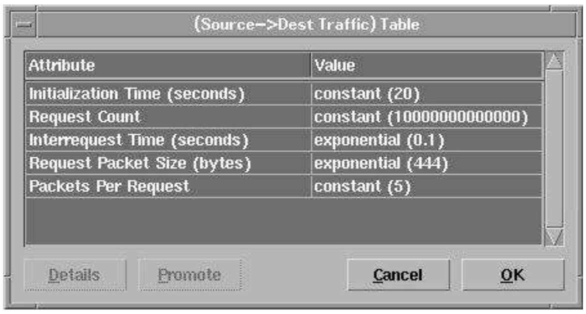

Figure 5: Configuration of the client

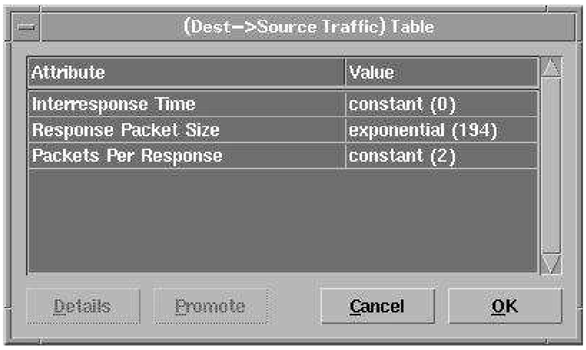

Figure 6: Configuration of the server

To simulate the other load of the routers in Leuven and Kortrijk, a workstation-server pair was added both in Leuven and Kortrijk. The total number of packets (requests and responds) equals the total load of the router measured with SNMP minus the number of packets that are transmitted on the 2 Mbps leased line.

Within the scope of this paper, we cannot discuss all simulation results, instead we will focus on the link between Leuven and Kortrijk. For the complete results we refer to the report made by the students [3].
Figure 7 and 8 show the traffic load (in packets/s and bits/s) and the delay in both directions respectively.

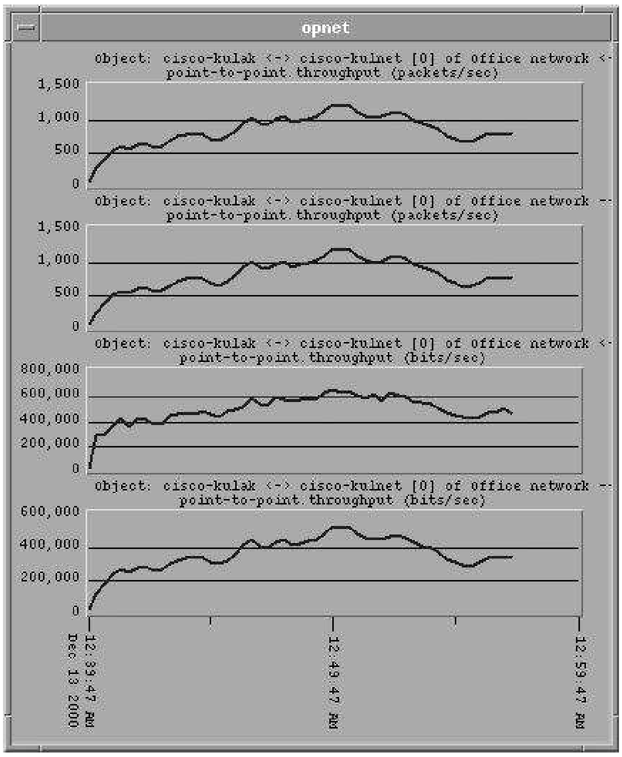

Figure 7: Traffic load between Leuven and Kortrijk

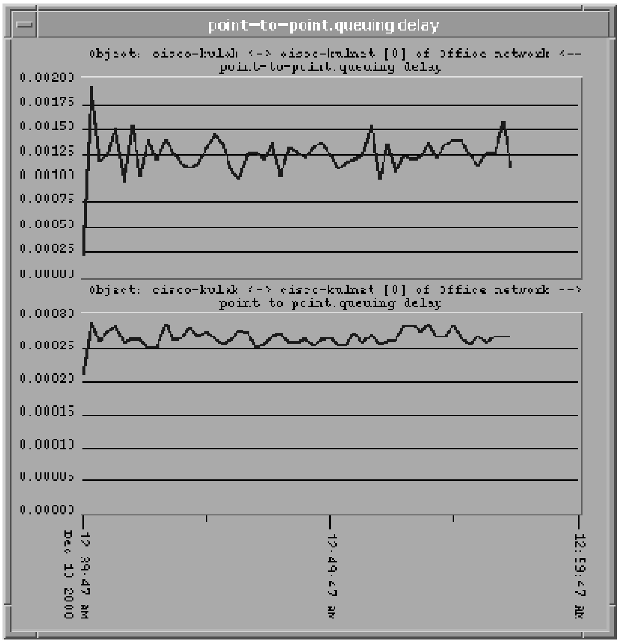

Figure 8: Delay between Leuven and Kortrijk

The difference in delay between the two directions is caused by an asymmetry in data traffic load.

The delay values permit a good voice quality. The network is not overloaded. It can carry the additional voice traffic.

VoIP on a shared Ethernet

This chapter gives an overview of the results obtained in [4]. The complete report can be found on the homepage [2] together with the reports of three other groups working on the same subject.

Problem outline

Students living in a university dorm can access *'Kotnet'* (the student network infrastructure) from their room via a shared Ethernet connection. On each floor of a student dorm there is one public telephone students can use to make external calls or receive calls. During busy hour this single phone is clearly not enough to serve 11 students per floor. Adding more telephone lines is an expensive operation. Therefore, the university wants to use the computer network to offer VoIP services to each student room.

For management and security reasons the university wants to place the necessary servers and gateway in a central place called *'Ludit'*. In this project, students tried to figure out whether these VoIP services can be offered to the students of the *'Blok5'* dorm. Figure 9 shows the way the voice traffic of *Blok5* has to follow to reach the gateway at *Ludit*.

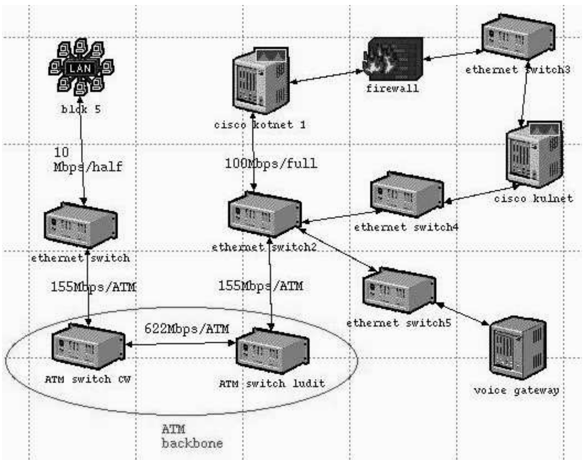

Figure 9: From *Blok5* to the voice gateway

Solution

The delay introduced by the different switches can be neglected compared with the one introduced by the routers. They were omitted in the simulations. Also the gateway could be disregarded because it adds a constant delay.
About 50 PCs are connected to the hub in *Blok5*. To reduce simulation time, only 3 PCs and a server are used to generate the complete traffic load. One PC represents the internal data traffic, another the external data traffic, while the third is used for voice traffic.

The simulated topology is depicted in Figure 10.

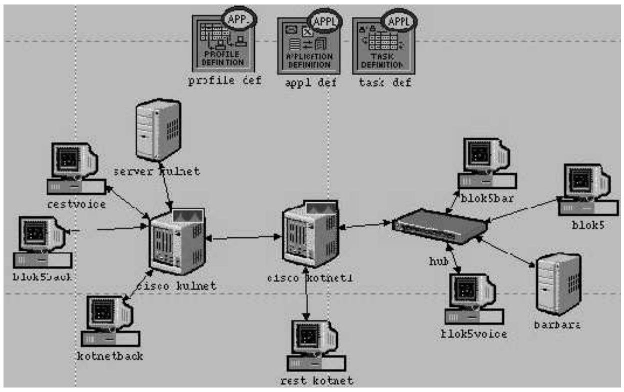

Figure 10: Simplified topology for simulations

For each traffic stream, a different task was defined. Because of memory limitations, no distinction in packet size classes could be made for a specific stream. Table 1 gives an overview of the different tasks.

	source	destination	interreq. time (s)	size (bytes)
1	*blok5*	*server kulnet*	5.5e-3	1116
2	*blok5bar*	*barbara*	1.07 e-3	1307
3	*rest kotnet*	*server kulnet*	2.38e-4	1116
4	*blok5back*	*blok5*	5.5e-3	1116
5	*kotnetback*	*rest kotnet*	1.35e-4	1116

Table 1: Task definitions

Two profiles were defined: one for data traffic and one for voice traffic. The voice application settings are listed in table 2.

Codec	G 723.1
Frames per packet	4
Frame size	30 ms
Lookahead size	7 ms
DSP processing	1
Coding rate	6.3 Kbps

Table 2: Voice application settings

The students started simulations without voice to examine the current situation. The traffic sent and received by the *blok5bar* PC is plotted in Figure 11. On the application level 930 p/s while on the IP level only 182 p/s were sent to *barbara*. This discrepancy is caused by a saturated Ethernet: the application sends more packets than the network can transport. *Blok5bar* was not configured to receive traffic. The values in Figure 11 are caused by TCP acknowledgements, each time a packet is transmitted successfully.

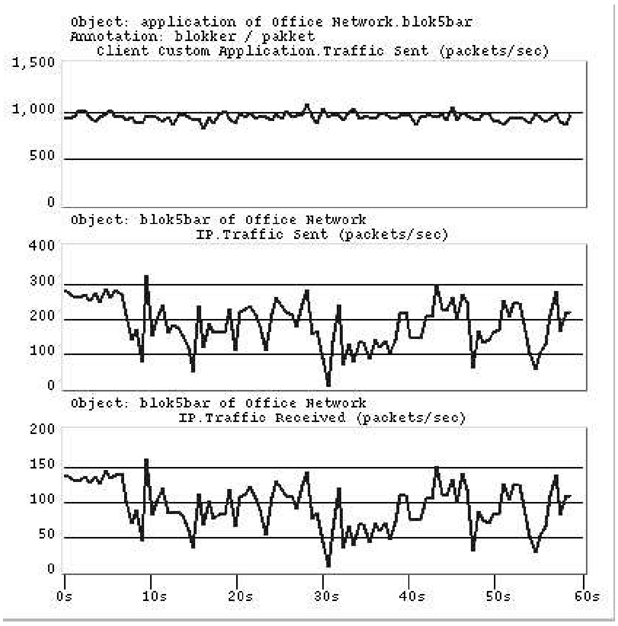

Figure 11: Traffic sent and received by *blok5bar*

Figure 12 shows Ethernet delay, collision count and utilization respectively. The Ethernet is clearly overloaded. Adding voice traffic is obviously not a good idea during peak moments in traffic load.

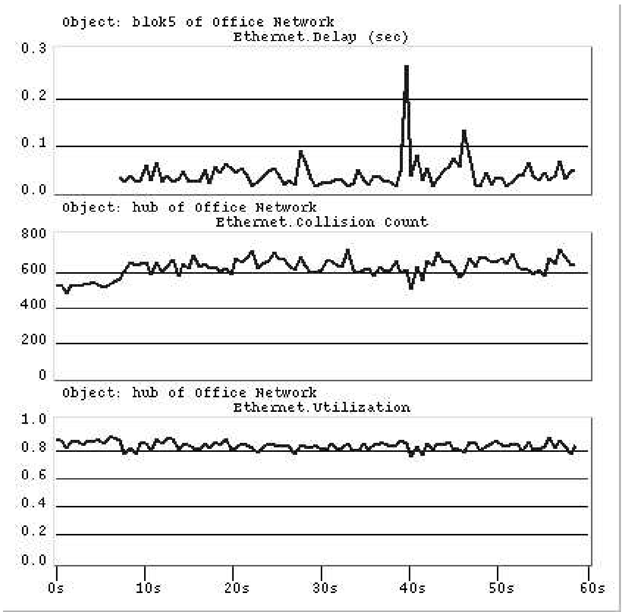

Figure 12: Ethernet performance parameters without voice traffic

Students performed simulations in two other cases: one with a single active voice call and one with three simulataneous calls.

Figure 13 gives the end-to-end delay and the variation on this delay for one active call. The Ethernet collision count and the utilization in this case can be found in Figure 14.

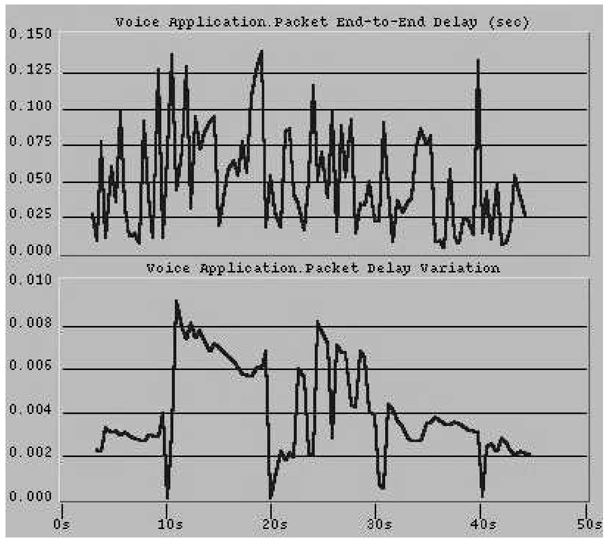

Figure 13: Voice end-to-end delay and variation on this delay for one active call

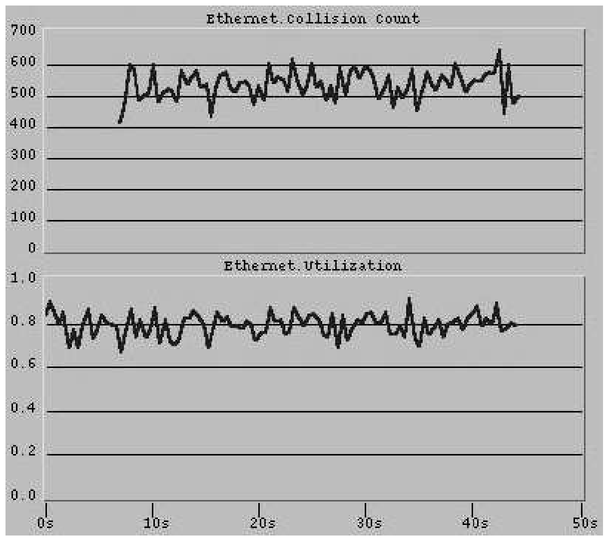

Figure 14: Ethernet performance parameters for one active call

The voice application end-to-end delay does not include the delay of the gateway, the codecs and the soundcards. These still have to be added to the average end-to-end delay of 53 ms. This gives a total delay of more or less 150 ms. To know the delay of the voice stream, a latency of 120 ms between two packets has to be taken into account. This brings the delay to 270 ms, which is above the maximum allowed 253 ms.

Due to the high Ethernet utilization, a large number of voice (UDP) packets will get lost, resulting in a very poor quality. Clearly a number of technical interventions (e.g. an upgrade to switched Ethernet) are needed to provide VoIP services to students in their student room.

File sharing on an Office LAN

In this chapter we summarize how the students in [5] dealt with the office network optimization problem. Their complete report can be found on the homepage [2], together with the reports of five other groups who worked out a different solution to the problem.

Problem outline

The aim of this project is to optimize file sharing on the network of the TELEMIC research group. File sharing enables users to access files and directories located on remote computers and use those files and directories as if they were local.

The central component of the network is an Ethernet switch. Seven workstations are attached to this switch: *Loebas*, *Zulte* and *Kastaar* act as file server, *Duchesse* as application server, while *Toine*, *Blondine* and *Hercule* are combined servers. Also three hubs with respectively 9, 11 and 19 PCs are connected to the switch.

The students had to examine a dedicated server configuration. A specific server can only be used for a specific task: file serving or application serving. The Network File Serving (NFS) protocol version 2 is used. Other groups focussed on NFS version 3, or the Server Message Block (SaMBa) protocol.

Solution

The students chose the slower machines (*Loebas*, *Zulte* and *Kastaar*) as file servers and the faster machines (*Toine*, *Blondine* and *Hercule*) as application servers.

The PCs on the hubs communicate with the application servers or with machines outside TELEMIC, not with each other. Most of the internal traffic originates from X11 application interactions. The delay on a hub domain is assumed to be negligible compared to the delay induced by the servers. Therefore three PCs were configured to simulate the total traffic from and to the three hubs. Figure 15 shows the simulated network topology. All links are 10 Mbps half duplex Ethernet connections, except for the link between the switch and Hercule which is a 100 Mbps half duplex Ethernet connection.

The X11 traffic was modeled using the predefined 'remote login' application. Two applications were defined with request packets of 64 bytes and response packets of 300 and 1518 bytes respectively. The necessary parameters were adjusted to obtain the right ratio of occurrence.

A profile was configured to obtain the correct distribution of traffic among the application servers and the *sink PC*. The latter represents the machines outside TELEMIC. Based on the assumption that each hub caused the same traffic load, one profile was enough for the three PCs.

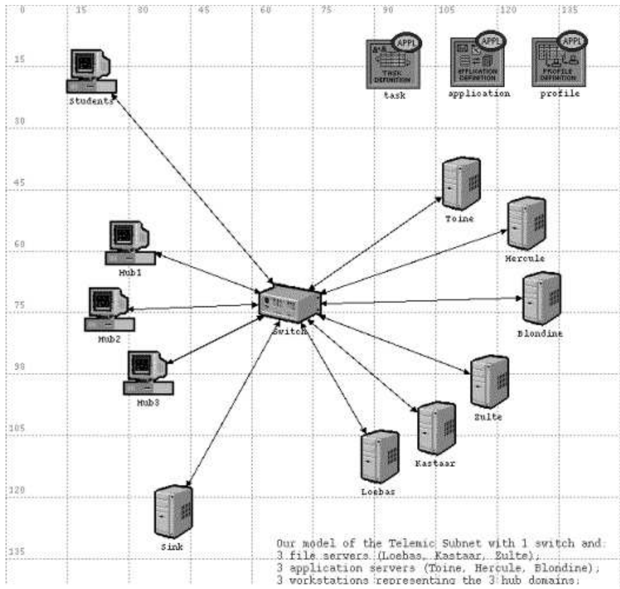

Figure 15: Simulated office LAN topology

Traffic from outside TELEMIC is caused by students and is modeled the same way. Only one remote login application is needed since only two packet sizes were measured: requests of 64 bytes and responses of 1200 bytes.

NFS traffic between the file servers and the application servers was modeled by defining a task that transmits a file of 900 Kbytes. This task lets the client send a request packet of 216 bytes. After a processing time for reading from the hard disk, the server answers with a response packet of 4096 bytes (which is divided into smaller packets for transmission over the Ethernet). This process of request – reading from hard disk – response is repeated 220 times to get a total file size of 900 Kbytes. The time between the requests and the time between a request and a response depends from the power of the application server and file server respectively. The NFS application is used by the 3 application servers by defining 3 profiles. The interrepetition time between two file transfers is assumed to be exponentially distributed and is different for the 3 servers because they request a different amount of NFS data. Also the destination preference differs.

The highest delay caused by the network itself is located at the hub. Figure 16 shows that the average delay is only 320 µs, which is small compared to the delay induced by the file servers.

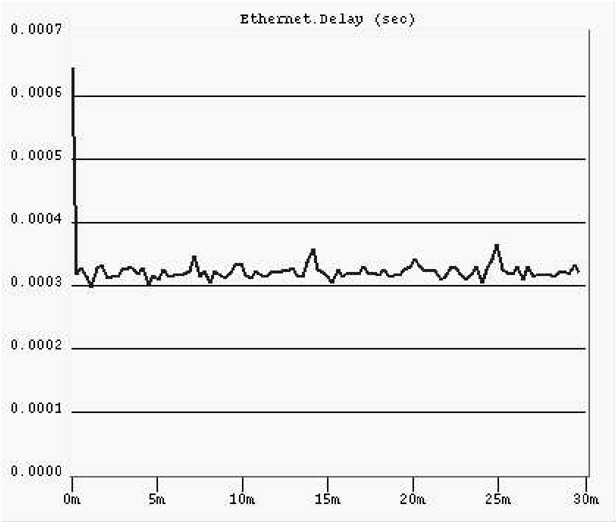

Figure 16: Ethernet delay on a hub

The average traffic the application servers receive from the file servers is plotted in Figure 17. The load of *Hercule* is about 7 times higher than that of *Blondine* and about 3 times higher than that of *Toine*.

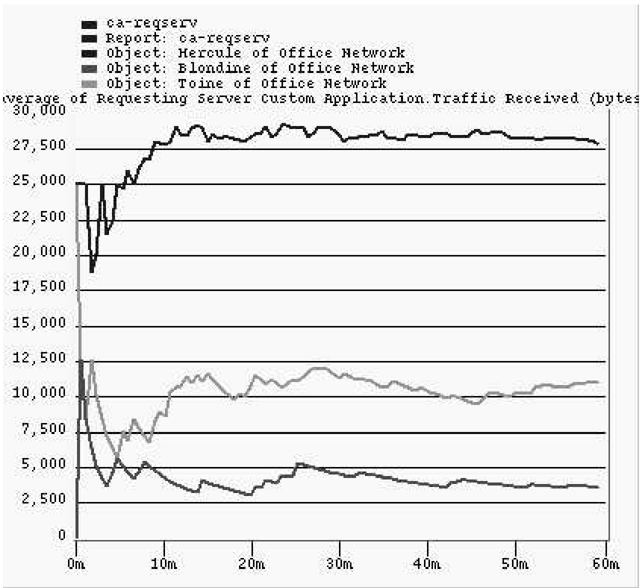

Figure 17: Average traffic application servers receive from file servers

Figure 18 shows the amount of time it takes to receive a file of 900 Kbytes. Since a file transfer is defined as one task, it is the task response time.

The average delay is 14.1 s with a peak of 23.7 s. The difference with the Ethernet delay clearly indicates that the file servers are the bottleneck in the system.

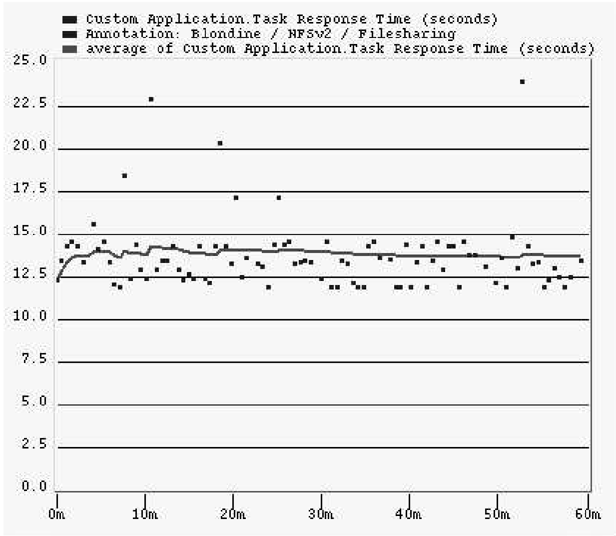

Figure 18: Time needed to send a file of 900 Kbytes.

Conclusion

In this paper we presented the simulations students performed in the framework of a design project. Getting acquainted with OPNET Modeler asked a lot of time and effort from the students. A lot of creativity was needed to overcome problems and difficulties but the results are quite satisfactory. Students gained a lot of insight in networking by using the OPNET tool.

TELEMIC participates in the OPNET University Program for research and educational projects.

References

[1] J. Theunis, J. Potemans, M. Teughels, A. Van de Capelle and E. Van Lil, “Project Driven Graduate Network Education,” will appear in the *Proceedings of the International Conference on Networking ICN'01*, Colmar, France, 2001.

[2] Homepage of the network design projects: http://www.esat.kuleuven.ac.be/~3irtele/H239/

[3] F. Dupont, G. Castermans and P. Leys, “Point to point connections: Voice over IP as an alternative for interzonal calls,” internal student report (can be downloaded from [2]), 2000.

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[5] P. Jonckheere and H. Vanhaute, “OFFICE LAN”, internal student report (can be downloaded from [2]), 2000.