

Performance Evaluation of IMAP and POP3 Protocols Using Optimized Network Engineering Tool (OPNET)

by

Shahbaz Ali

B.Sc., University of Sindh, Pakistan, 2014

A Report Submitted in Partial Fulfilment of the Requirements

for the Degree of

MASTER OF ENGINEERING

in the Department of Electrical and Computer Engineering

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University of Victoria

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Abstract

The volume of email traffic is growing rapidly over time. Recent years have seen an increase in not only personal and business email accounts, but also in the number of emails sent daily. According to the latest data, there was an approximately 6% annual increase in worldwide email accounts during the period of 2015 to 2019. In 2018, approximately 250 billion emails were sent daily worldwide and researchers are predicting this number to reach 347 billion emails daily in the next 5 years. These increases highlight the importance of email protocols. Email protocols have been evaluated extensively and various ways have been used to analyze their performance. In this project, two well-known email protocols, Post Office Protocol version 3 (POP3) and Internet Message Access Protocol (IMAP) are evaluated using Optimized Network Engineering Tool (OPNET). The performance of these protocols is evaluated for two different network scenarios with different link bandwidths, packet loss ratios, and packet latencies. The performance metrics are average TCP delay, average TCP load, average TCP retransmissions count, and average traffic received. The results obtained show that POP3 performs better than IMAP. The complex process of retrieving emails and synchronization which requires many TCP connections for IMAP results in a higher average TCP delay compared to POP3. POP3 also has higher average traffic received than IMAP. Further, the TCP load for IMAP and POP3 is similar.

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Glossary

CPU	Central Processing Unit
DS	Digital Signal
FTP	File Transfer Protocol
HTTP	Hypertext Transfer Protocol
IMAP	Internet Message Access Protocol
LAN	Local Area Network
MAN	Metropolitan Area Network
OPNET	Optimized Network Engineering Tool
PAN	Personal Area Network
POP	Post Office Protocol
PPP	Point to Point Protocol
SMTP	Simple Mail Transfer Protocol
TCP	Transmission Control Protocol
UI	User Interface
WAN	Wide Area Network
WLAN	Wireless Local Area Network
WWAN	Wireless Wide Area Network

Acknowledgements

I would like to thank **Dr. T. Aaron Gulliver** for his support throughout my degree.

I would also like to thank **Assad Raza** and **Sultan Salahudin Jokhio** for their input on my Master of Engineering project.

My Spouse and Siblings for their love and motivation.

Invention is not the product of logical thought, even though the final product is tied to a logical structure.

(Albert Einstein)

Dedication

I dedicate this work to my lovely parents for their moral and financial support and everything they have given to me my entire life.

Chapter 1

Introduction

A network is a connection of two or more devices that transmit, receive, and exchange information such as data, voice, and video traffic [7]. The devices in a network employ communication media such as cables, telephone lines, and satellites. Some of the common types of networks include Local Area Networks (LAN), Wide Area Networks (WAN), Personal Area Networks (PAN), Metropolitan Area Networks (MAN), Wireless LANS (WLAN), and Wireless WANS (WWAN). The internet is a self-contained network of many individual networks and devices such as routers that connect many millions of people around the globe.

In order for communications to take place between users, each user must adhere to a defined set of rules, commonly known as protocols. Protocols which are used to exchange information between email clients and email servers are known as email protocols. These protocols play an important role in the modern world since the number of email users and daily email traffic is growing every year. According to a survey by Radicati (a market research firm), there was an approximately 5% increase in worldwide email accounts and 3% increase in worldwide email users every year from 2015 to 2019 as shown in Table 1 [8].

Statista, a German research and statistics portal provider, reported that in 2018 approximately 250 billion emails were sent daily worldwide. They also predicted an increase in this number to over 347 billion emails daily in 2023 [9]. Radicati also provided figures for daily email traffic which show an increase of approximately 5% every year from 2015 to 2019 as shown in Table 1.2. The average number of daily emails per business user increased from 122 in 2015 to 126 in 2019 as shown in Table 3 [8].

	2015	2016	2017	2018	2019
Worldwide Email Accounts (Millions)	4,353	4,626	4,920	5,243	5,594
Percentage Growth		6%	6%	7%	7%
Worldwide Email Users (Millions)	2,586	2,672	2,760	2,849	2,943
Percentage Growth		3%	3%	3%	3%
Average Accounts Per User	1.7	1.7	1.8	1.8	1.9

Table 1: Worldwide email users and accounts from 2015 to 2019 [8].

	2015	2016	2017	2018	2019
Total Worldwide Emails Sent/Received Per Day (Billion)	205.6	215.3	225.3	235.6	246.5
Percentage Growth		5%	5%	5%	5%
Business Emails Sent/Received Per Day (Billion)	112.5	116.4	120.4	124.5	128.8
Percentage Growth		3%	3%	3%	3%
Consumer Emails Sent/Received Per Day (Billion)	93.1	98.9	104.9	111.1	117.7
Percentage Growth		6%	6%	6%	6%

Table 2: Worldwide email traffic (daily) from 2015 to 2019 [8].

Business Email	2015	2016	2017	2018	2019
Average Number of Emails Sent/Received Per Day	122	123	124	125	126
Average Number of Emails Received	88	90	92	94	96
Average Number of Legitimate Emails	76	76	76	76	77
Average Number of Spam Emails	12	14	16	18	19
Average Number of Emails Sent	34	33	32	31	30

Table 3: Business email exchanges per user daily from 2015 to 2019 [8].

Email communication from a network perspective is a three-step process, sender to sender mail server, sender mail server to receiver mail server, and receiver mail server to receiver. The network utilizes different protocols for each of these steps. Transmission Control Protocol (TCP) enables clients and servers to establish a connection and exchange packets. TCP guarantees delivery of data and also guarantees that packets will be delivered in the same order in which they were sent.

TCP connections utilize a three-way handshake. Before a client attempts to connect with a server, the server must first bind to and listen at a port to open it up for connections.

TCP delay is the delay (s) of packets received by a client/server for all TCP connections. It is the time for an application data packet sent from the source to be completely received by the destination.

TCP load is the rate of traffic (bytes/s) sent or received at the TCP layer from the application layer by a client or server. It is the total load for all managed TCP connections between clients and servers.

Simple Mail Transfer Protocol (SMTP) is a protocol used for communications between the sender and sender mail user. SMTP is also used for communication between sender mail server and receiver mail server. Email protocols used for receiving emails from a mail server are Post Office Protocol version 3 (POP3) and Internet Message Access Protocol (IMAP) as shown in Figure 1. POP3 and IMAP enable receiving clients to retrieve emails from the email server. POP3 and IMAP will be discussed in detail later in this report.

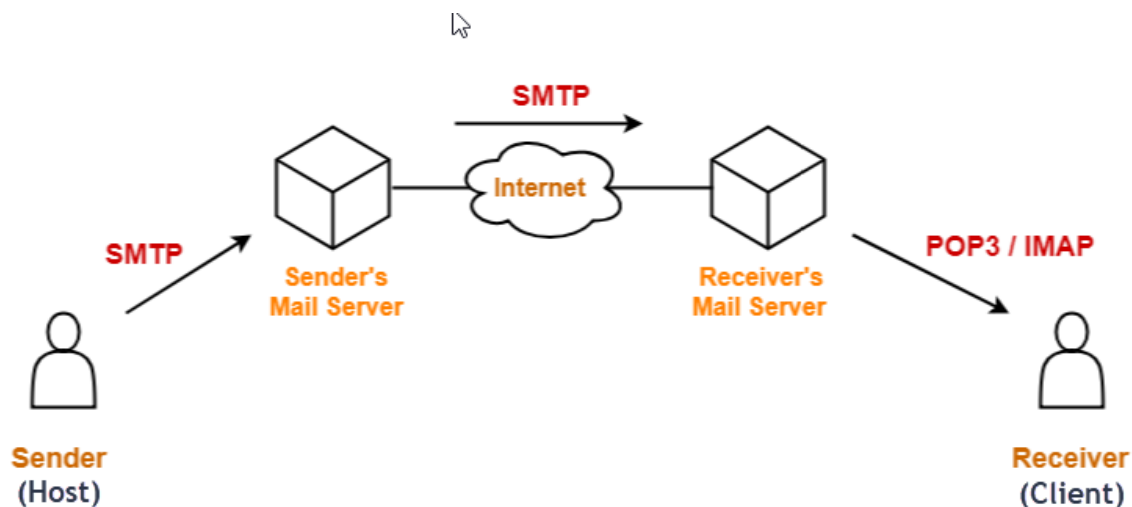


Figure 1: An overview of email communications [10].

The growing number of emails makes email protocols the most commonly used protocols in internet communications. One example of the different functionalities provided by POP3 and IMAP is that a POP3 user can only access emails after downloading them from the email server using the POP3 client, while an

IMAP user can access emails anytime and from different devices without having to download them to local storage using an email client.

1.1 Problem Statement

Email protocols play a vital role in network communications. IMAP and POP3 both offer email retrieval functionalities and differ in how they are carried out. Each protocol has advantages over the other such as privacy, bandwidth utilization, storage utilization, multi-device support, and data synchronization. Further, protocol behavior in a network and supported features and functionalities need to be considered when implementing a protocol. It is important for network architects to determine the most suitable email protocol for their network environment.

This work evaluates the performance of IMAP and POP3 using Optimized Network Engineering Tool (OPNET) network modeler 17.5A to simulate real-time network environments. This provides a simulation platform to evaluate email protocols using metrics such as delay, latency, data rate, and load. Results are obtained for the IMAP and POP3 protocols with different link bandwidths and packet latencies. These results can be used by network designers, architects, and administrators to compare the protocols. Understanding the benefits and limitations of each protocol will help determine the right protocol for an environment according to user needs.

1.1.1 Aim and Objectives

The aim and objectives of this project are as follows.

- Evaluate the behavior of the email protocols IMAP and POP3.
- Determine which protocol performs better in a given network environment.

1.2 Related Work

Several researchers have examined email systems and related protocols. In [1], the performance of 5 clients utilizing HTTP and FTP application layer protocols was analyzed. A new active monitoring algorithm was proposed in [2] which improves current email protocol functions and detects protocol failures during the sending and retrieving of email messages. In [3], a detailed characterization of IMAP email traffic on

a large campus network was given. The focus was on commercial cloud-based email services for the campus. The throughput was analyzed and the effect of data transfer size was determined.

In [4], a campus scaled characterization of IMAP was evaluated based on the workload of Outlook email traffic. Active and passive network traffic measurements were used to evaluate application components such as authentication used in the email delivery infrastructure. Email traffic was characterized using network data collected over a month. The focus was on the complexity of modern email services, daily human-driven email activity patterns, and the low throughput achieved for large email attachments.

In [5], the performance of the SMTP, POP3, and X.400 protocols was compared in terms of end-to-end delay, volume of traffic, number of frames generated at the data link layer, and frame length distribution. Upper and lower bounds were derived for the volume generated by SMTP and these were extended to POP3. In [6], a new email client based on an un-hosted web application architecture was developed which runs on a browser and hence is independent of the Operating System (OS). This client connects to any standard mail server directly from the browser using IMAP and SMTP protocols.

1.3 Report Organization

This report is organized as follows.

Chapter 1 introduced the significance of email protocols in the internet. The problem statement and objectives of the project were given. Related research in the area was also discussed.

Chapter 2 introduces and discusses the features of the email protocols that are evaluated in this work.

Chapter 3 provides details of the simulation environment and the simulation tool used for this work is discussed. The simulation scenarios used to evaluate the performance of email protocols and the performance evaluation metrics are presented. The simulation network topology and configuration parameters are also given.

Chapter 4 presents the simulation results for the IMAP and POP3 protocols. The results for each evaluation metric are discussed.

Chapter 5 concludes the report and discusses some topics for future work.

Chapter 2

Email Protocols

The email protocols POP3 and IMAP are discussed in this chapter. Email clients employ email protocols to send or retrieve emails from a mail server. POP3 and IMAP are used by clients to retrieve emails from the mail server. Simple Message Transfer Protocol (SMTP) is used for sending emails from a client to an email server and between two email servers. An overview of SMTP will be given later in the chapter.

2.1 Post Office Protocol Version 3 (POP3)

POP version 3 (POP3) is the most commonly used email protocol. It is used to retrieve emails from an email server. POP3 is based on a client-server paradigm where the client has to download emails from the server. Emails once downloaded are deleted if the default configuration is used. This protocol does not allow a user to organize emails on the server because it does not support email folders. Further, a user cannot check the contents of emails before downloading them because this is not supported.

POP3 simply contacts the mail server and retrieves the emails. POP3 allows users to access mailboxes and quickly download emails to their devices. The main advantage of POP3 is reduced dependency over the internet as the email client does not periodically check for updates on the mail server. A user can also download and access emails when offline (without connecting to the internet) if the POP3 mail server is present in the same local area network (LAN). Email applications such as Microsoft Outlook provide optional functionality to change the default behavior of the POP3 mail server to allow it to keep emails after they are retrieved by a client. The default ports for POP3 are port 110 and port 995. Port 110 is the default non-encrypted port while Port 995 is the default port for secure (encrypted) connections.

2.1.1 Workflow of the POP3 Protocol

POP3 has the following workflow when retrieving emails from the email server using an email client.

- Email client
- Connection to mail server
- Retrieve emails
- Store locally (as new emails)
- Delete (emails) from mail server

Typically, POP3 deletes emails from the server after retrieval, but most POP3 clients allow a copy of the retrieved emails to remain on the server. Figure 2.1 presents the POP3 email retrieval workflow and Table 5 presents the POP3 protocol commands [11].

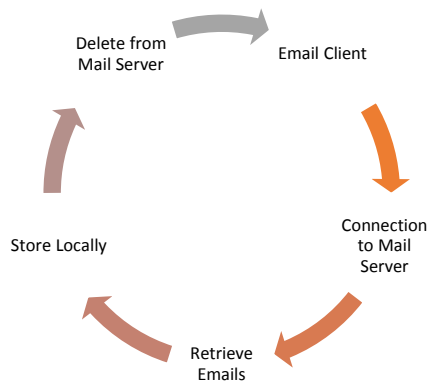


Figure 2: POP3 email retrieval workflow.

Command	Description
LOGIN	Open the connection.
STAT	Display the number of messages currently in the mailbox.
LIST	Get a summary of each message currently in the mailbox.
RETR	Select a mailbox to access the messages.
DELE	Delete a message.
RSET	Reset the connection to its initial state.
QUIT	Terminate the connection.

Table 4: The POP3 commands [11].

2.2 Internet Message Access Protocol (IMAP)

The Internet Message Access Protocol (IMAP) allows a user to access email messages through the internet, typically using a web browser. A client using an IMAP based email service can read an email from the mail server without downloading or storing it on a user machine. As a result, it is possible to check email from anywhere using multiple devices such as a desktop computer, laptop, or smartphone. This protocol also allows users to access, organize, and sort emails on the server. IMAP is more complex to implement and consumes more CPU and memory than POP3, especially when it performs synchronization, hence IMAP is more expensive [10]. Synchronization occurs when IMAP compares the folders on the email client with folders on the email server. It then moves or deletes messages as required. In fact, IMAP consumes more memory than POP3 at both the client and server ends. IMAP allows a user to download an email partially in the case of limited bandwidth. IMAP has advantages over POP3 such as accessing emails from multiple devices. POP3 can only be used with a single device at a time, while IMAP can be used with multiple devices simultaneously. A major difference between POP3 and IMAP is email synchronization. IMAP accesses mail servers using ports 143 and 993. Port 143 is the default non-encrypted port while port 993 supports encryption and is the default port for secure connections [12].

2.2.1 Workflow of the IMAP Protocol

IMAP has the following workflow when retrieving emails from the email server using an email client.

- Email client
- Connection to remote server
- Retrieve emails
- Cache locally
- Disconnect from mail server

The IMAP workflow is different from that of POP3. In IMAP, folders and emails are stored on the email server and only copies of emails are stored locally. IMAP does not delete the retrieved emails from the email server. By default, copies of the emails are stored temporarily on local devices. However, the configuration can be changed to store local copies of emails. Figure 3 presents the IMAP email retrieval workflow and Table 6 presents the IMAP protocol commands [11].

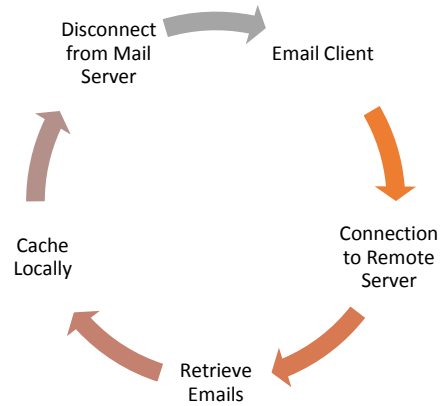


Figure 3: IMAP email retrieval workflow.

Command	Description
IMAP_LOGIN	Open the connection.
CAPABILITY	Request the capabilities that the server supports.
NOOP	Used as a periodic poll for new messages or message status updates during a period of inactivity.
SELECT	Select a mailbox to access the messages.
EXAMINE	Same as SELECT except no change to the mailbox is permitted.
CREATE	Used to create a mailbox with a specified name.
DELETE	Used to permanently delete a mailbox with a given name.
RENAME	Used to change the name of a mailbox.
LOGOUT	Inform the server that the client is done with the session. The server sends a BYE response followed by OK and termination of the network connection.

Table 5: The IMAP commands [11].

2.3 Simple Mail Transfer Protocol (SMTP)

SMTP uses three ports for sending and receiving email. Default port 25 is non-encrypted and ports 465 and 587 are the default ports supporting encryption for secure connections. This protocol is used by a Mail Transfer Agent (MTA) to deliver emails to an email server. The MTA is responsible for transferring and routing messages from the email sender to email receiver. It provides functionality for sending emails and cannot be used to receive emails. SMTP is the most commonly used protocol for email transfer between servers. Unlike POP3 and IMAP, SMTP does not require authentication on the default ports. Certain Internet Service Providers (ISPs) block port 25 which is an SMTP port, in which case the mail server provides an alternate port.

Chapter 3

Simulation and Evaluation Environment

This chapter discusses the simulation environment and tools used to evaluate the POP3 and IMAP email protocols. OPNET modeler is used since it provides different wired and wireless network components. It is a very good tool for network design and simulation. With OPNET, different models can be created for simulation and analysis. An overview and the features of OPNET are presented in this chapter. The evaluation metrics are discussed later in the chapter.

The test bench was set up on a high-performance Dell XPS laptop using the Microsoft Windows 7 professional edition OS. The network was modeled using the network protocol analyzer tool known as OPNET which is also referred to as Riverbed Modeler. Table 7 provides the technical specifications of the test bench.

Parameter	Specifications
Manufacturer	Dell Corporation Inc.
Model	XPS 15
Processor	2.8 GHz Intel Core i7-700HQ CPU
Memory	16 Gigabytes (GB) Double Data Rate (DDR4)
Graphical Processing Unit	GeForce GTX 1050 GPU, Integrated Graphics Unit Intel HD 620
Operating System	Microsoft Windows 7
Network Modeler and Simulator	OPNET (Riverbed) Modeler Version 17.5A (Academic Version)

Table 6: Technical specifications of the test bench.

3.1 Optimized Network Engineering Tool (OPNET) Network Modeler

OPNET is a simulation tool used for network simulation and modeling. It can provide performance results for application management, network planning, and network engineering. OPNET offers built-in functions and objects to create simulation environments for different network topologies [15]. It also provides a large number of built-in network scenarios. OPNET consists of a high-level User Interface (UI) and uses C language source code blocks and a library of functions [13].

The functionalities and capabilities of OPNET to model and simulate network environments are as follows.

- It can assist in network planning, prediction, analysis, and network optimization.
- It provides an integrated network modelling environment.
- It provides tools to build network models such as LAN, WAN, Wired, Wireless, Mobile, and Satellite.
- It provides the ability to construct, execute, and debug simulations.
- It has enhanced tools to collect, analyze, and present results.
- It has an interactive debugging engine.
- It is comprised of built-in and contributed model libraries.
- Tutorials and online documentation are available.

3.1.1 Structure, Tools, and Features of OPNET

The hierarchical structure and modeling in OPNET are divided into three domains.

Network Domain where the network and sub-networks are designed using different network topologies.

Node Domain where single network nodes (mobile, server, router, workstation, and other node devices), are used.

Process Domain which contains blocks of C code and OPNET function libraries to create and implement process models.

The features of OPNET are as follows [14].

- Hierarchical network models.
- Finite state machine modeling.
- Integrated analysis tools.
- A comprehensive library of detailed protocol and application models and network devices.
- Wireless, point-to-point, and multipoint links.
- Geographical and mobility modeling.
- Integrated debugger.

OPNET has the following tools which are commonly used for network modelling and simulation [14].

Project Editor (Network Editor) to drag nodes from the object palette and drop them to the desired places. It can also be used to connect nodes.

Node Editor to select modules and connect them.

Process Editor to add states and edit processes as well as C language functions.

Simulation Tool to specify simulation parameters and run simulations.

3.2 Performance Evaluation Metrics

The following performance metrics are used to evaluate the performance of the email protocols as in [1].

- **Average TCP Delay**

This is the delay (s) of packets received by a client/server for all TCP connections. It is the average time for an application data packet sent from the source to be completely received by the destination.

- **Average TCP Load**

This is the average rate of traffic (bytes/s) sent or received at the TCP layer from the application layer by a client or server. It is the total load for all managed TCP connections between clients and servers.

- **Average TCP Retransmission Count**

This is the average number of TCP retransmissions for a particular connection. A packet is retransmitted if it is dropped or not acknowledged by the destination.

- **Average Traffic Received**

This is the average amount of data (bytes/s) forwarded to the application layer by the TCP layer for a client or an email server for all TCP connections. It is obtained by dividing the number of bytes forwarded by the simulation time.

3.3 Evaluation Scenarios

Two scenarios were created to evaluate the POP3 and IMAP protocols. Both were simulated on the test bench with the same number of clients, email server configuration, application and profile configurations, custom configurations and settings, and a simulation period of 24 hours. However, they differ in terms of the network configuration. Simulation parameters used in this work are kept as in {1}.

In Scenario 1, a 56 kbps link is used to connect clients to the internet with a Point to Point Protocol Digital Signal 3 (PPP_DS3) link for the email server. The PPP_DS3 link has a bandwidth of 45 Mbps. In Scenario 2, a 33 kbps link is used to connect clients to the internet with a Point to Point Protocol Digital Signal 0 (PPP_DS0) link for the email server. The PPP_DS0 link has a bandwidth of 64 kbps. Thus, DS3 has a much higher bandwidth than DS0. The packet loss ratio for the internet is 0.1% and 0.5% for Scenarios 1 and 2, respectively. The packet latency is 200 ms for Scenario 1 and 100 ms for Scenario 2. The simulation period for both scenarios is 24 hours.

Figure 4 shows the attributes for communications between a POP3 server and the internet in Scenario 1. Figure 5 shows the attributes for communications between an IMAP server and the internet in Scenario 1. Figure 6 shows the attributes for communications between a POP3 server and the internet in Scenario 2. Figure 7 shows the attributes for communications between an IMAP server and the internet in Scenario 2. Figure 8 shows the attributes of the internet in Scenario 1. The packet loss ratio is 0.1% in this scenario. Figure 9 shows the attributes of the internet in Scenario 2. The packet loss ratio is increased in this scenario from 0.1% to 0.5%.

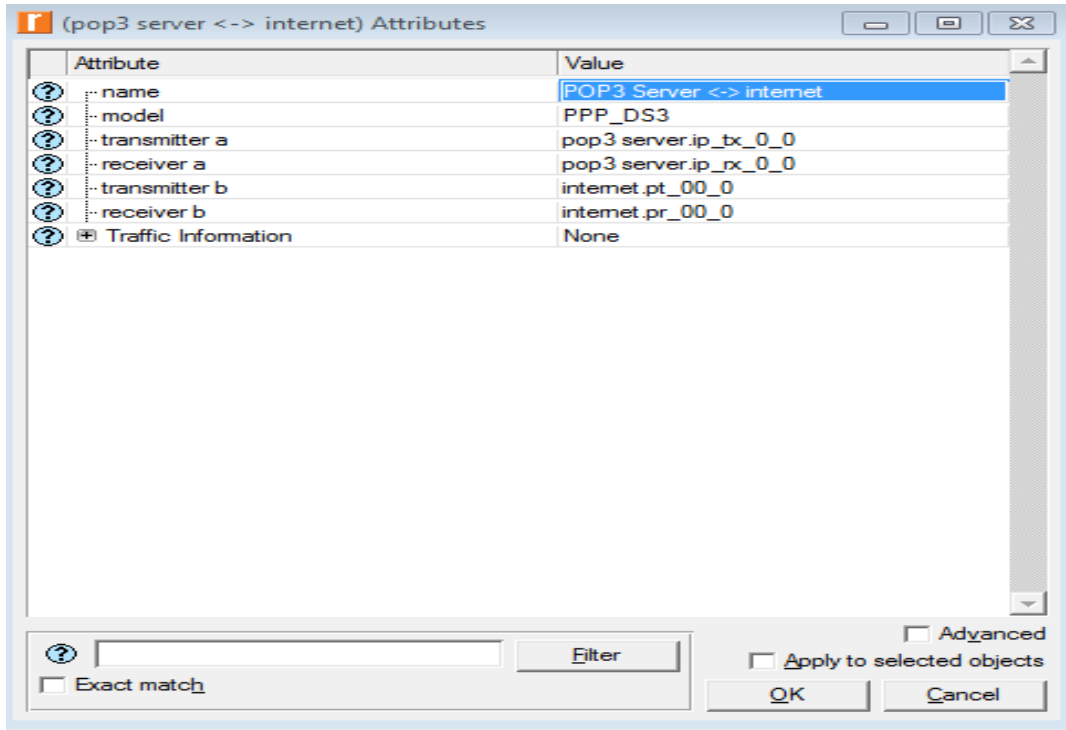


Figure 4: Attributes of POP3 server to internet communications in Scenario 1.

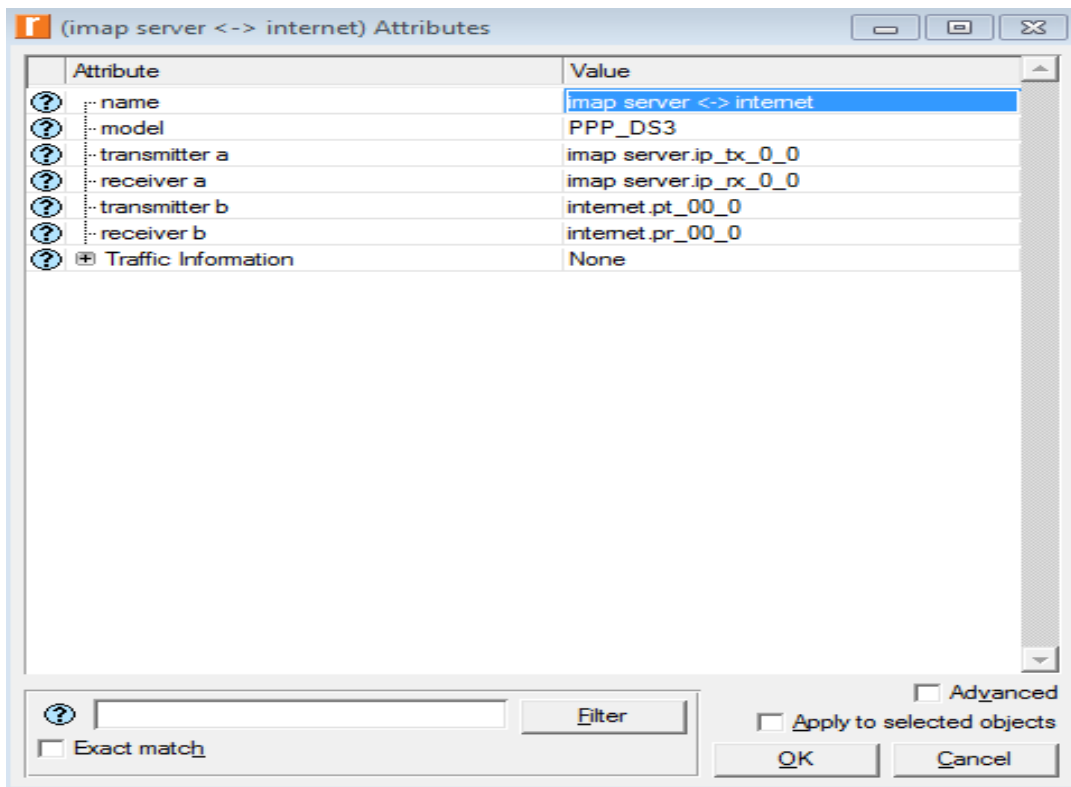


Figure 5: Attributes of IMAP server to internet communications in Scenario 1.

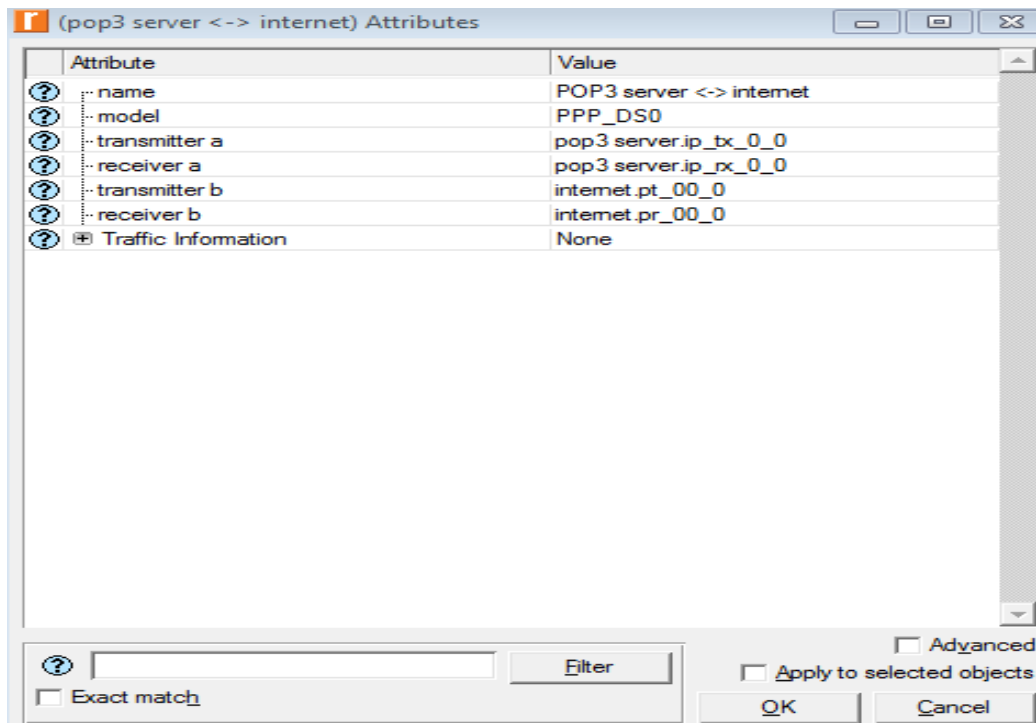


Figure 6: Attributes of POP3 server to internet communications in Scenario 2.

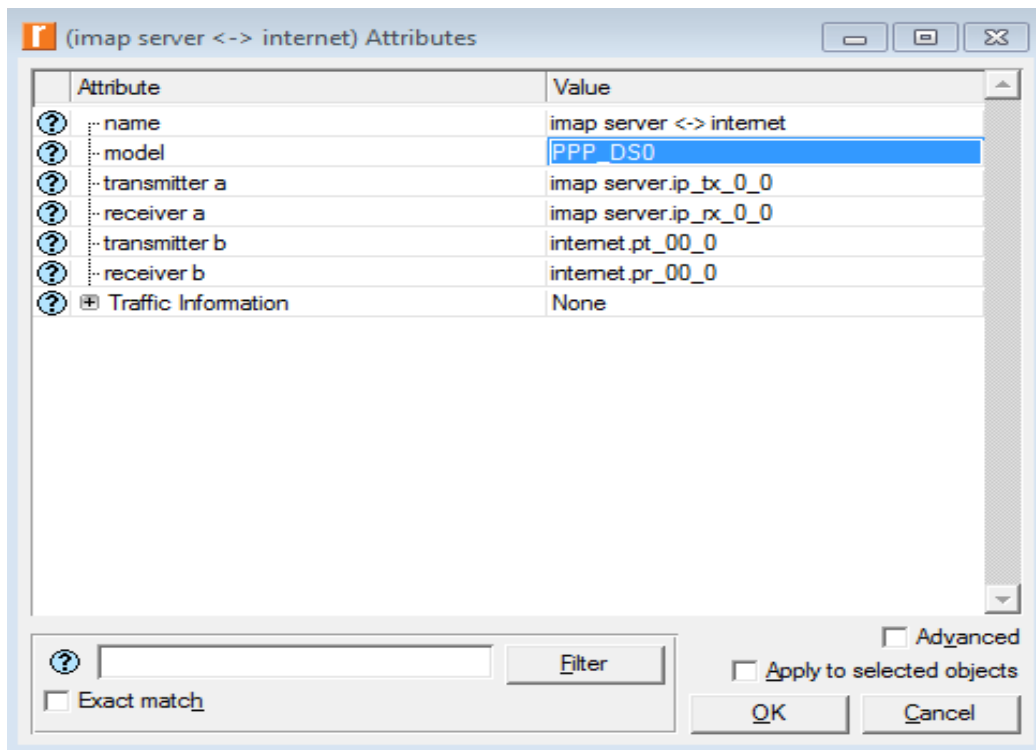


Figure 7: Attributes of IMAP server to internet communications in Scenario 2.

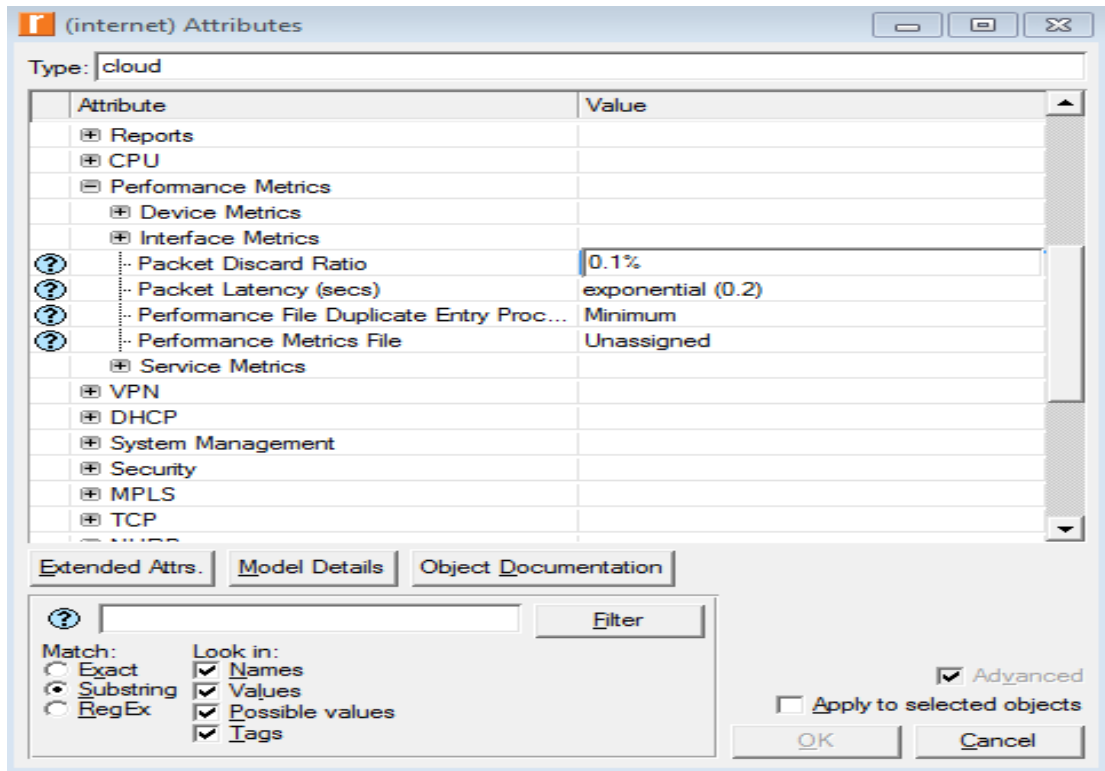


Figure 8: Attributes of the internet in Scenario 1.

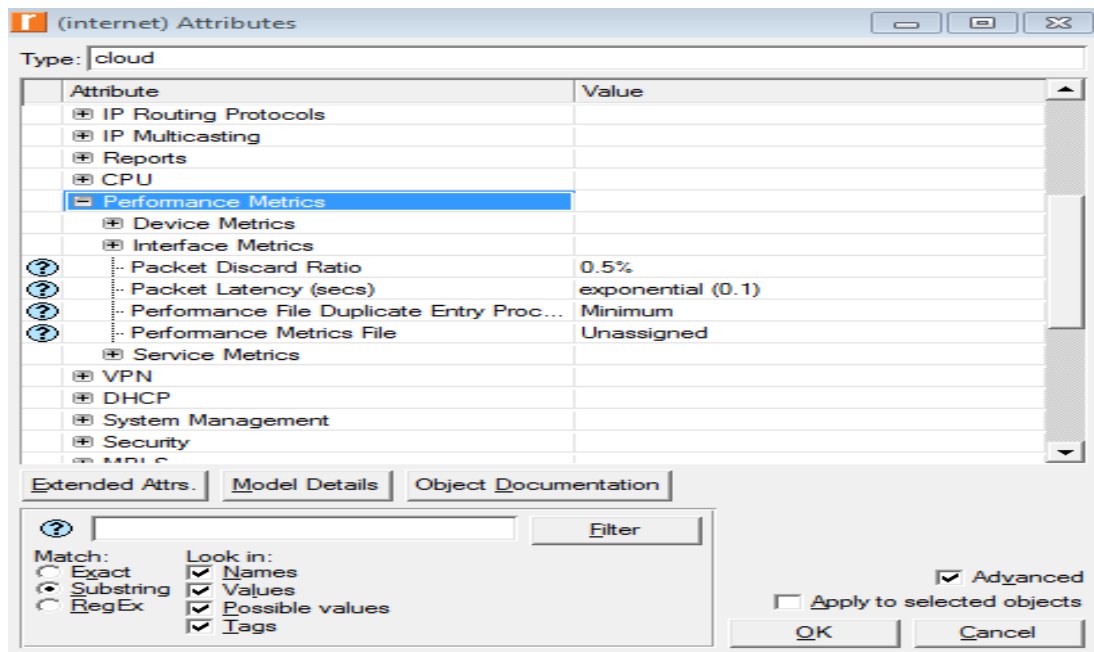


Figure 9: Attributes of the internet in Scenario 2.

3.4 Network Topology and Parameters

The simulation environment has 5 clients and an email server connected via the internet for both POP3 and IMAP protocols. Figure 10 shows the network topology for the POP3 email server and email clients. Figure 11 shows the network topology for the IMAP email server and email clients. The number of clients is the same for Scenarios 1 and 2. Table 8 gives the network configuration parameters for Scenario 1 and Table 9 gives the network configuration parameters for Scenario 2.

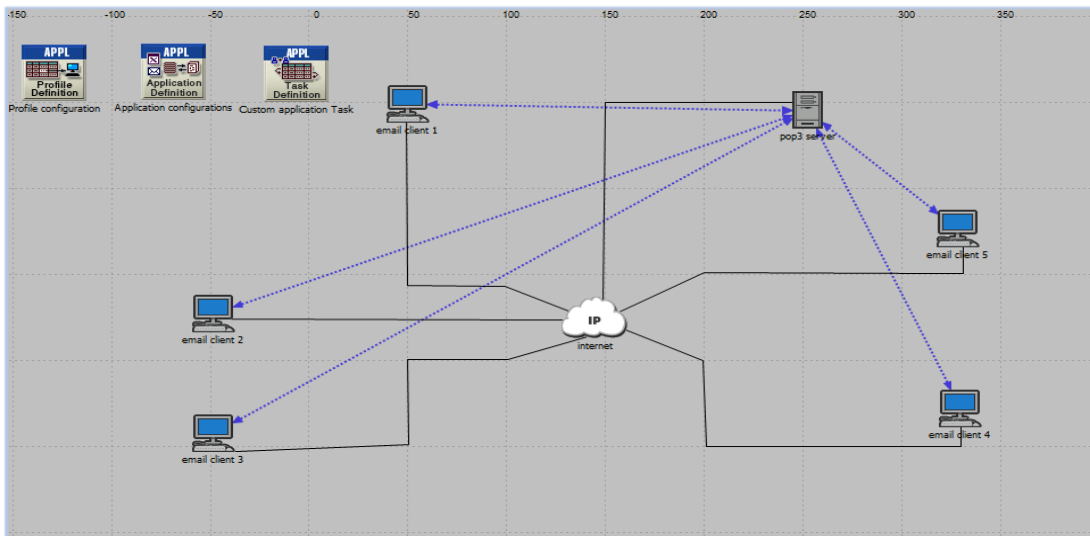


Figure 10: Network topology for the POP3 email server and clients.

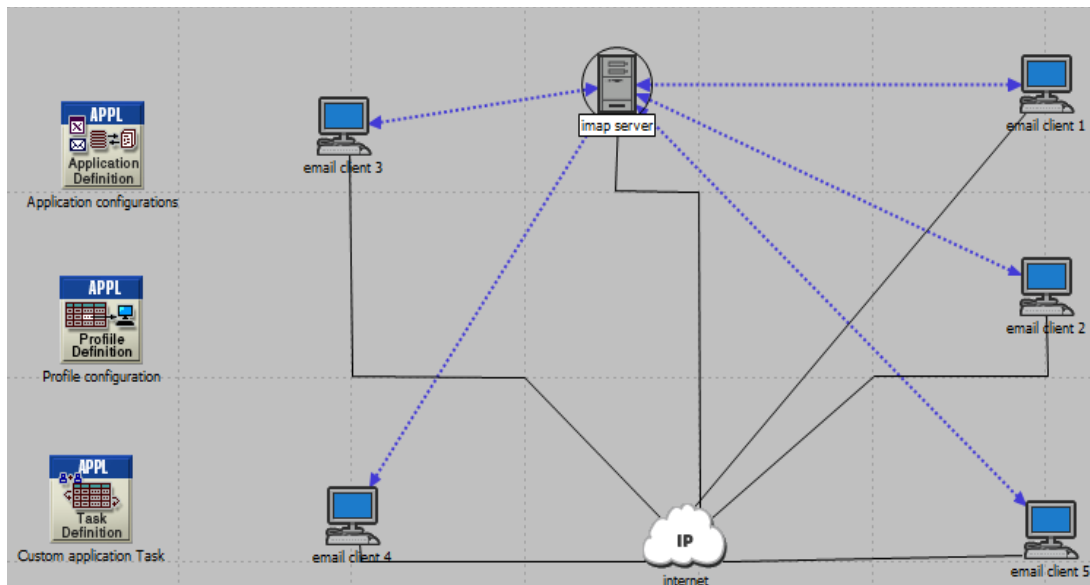


Figure 11: Network topology for the IMAP email server and clients.

Email Server	No. of Clients	Link Type	Communication Link	Bandwidth	Packet Loss Ratio	Packet Latency	Simulation Period
POP3	5	PPP_DS3	Server to Internet	44.73 Mbps	0.1%	200 ms	24 h
		PPP	Internet to Client	56 kbps	-	-	
IMAP	5	PPP_DS3	Server to Internet	44.73 Mbps	0.1%	200 ms	24 h
		PPP	Internet to Client	56 kbps	-	-	

Table 8: Network configuration parameters for Scenario 1.

Email Protocol	No. of Clients	Link Type	Communication Link	Bandwidth	Packet Loss Ratio	Packet Latency	Simulation Period
POP3	5	PPP_DS0	Server to Internet	64 kbps	0.5%	100 ms	24 h
		PPP	Internet to Client	33 kbps	-	-	
IMAP	5	PPP_DS0	Server to Internet	64 kbps	0.5%	100 ms	24 h
		PPP	Internet to Client	33 kbps	-	-	

Table 9: Network configuration parameters for Scenario 2.

Chapter 4

Simulation Results and Discussion

This chapter provides the simulation results and discussion for the POP3 and IMAP protocols obtained using the OPNET 17.5A modeler. The average TCP delay, average TCP load, average TCP retransmission count, and average traffic received are discussed in the following sections.

4.1 Average TCP Delay

The POP3 and IMAP TCP delay statistics for Scenarios 1 and 2 are given in this section.

Figure 12 shows the average TCP delay of the POP3 clients for Scenario 1. The highest average TCP delay is 3.4 s for client 2 at about 1.5 h while client 5 had the lowest average TCP delay of 0.5 s. The peak in TCP delay indicates multiple clients trying to establish TCP connections with the server at the same time. Figure 13 shows the average TCP delay of the POP3 clients in Scenario 2. The highest average TCP delay is 1.5 s for client 3. The average TCP delay for all clients in Scenario 2 is lower than in Scenario 1 due to the lower packet latency.

Figure 14 presents the average TCP delay of IMAP clients for Scenario 1. The peak average TCP delay is for client 3 at about 6.8 s. Client 1 had the lowest average TCP delay of 0.1 s during the 24 h simulation. Figure 15 shows the average TCP delay of IMAP clients for Scenario 2. The average TCP delay is much smaller in Scenario 2 as the peak is 2.4 s for client 2.

Figure 16 shows the average TCP delay for the POP3 and IMAP email servers in Scenario 1. The average TCP delay for the POP3 email server is greater than for the IMAP email server. The peak average TCP delay for the POP3 server is about 0.39 s at about 8 h. The peak average TCP delay for the IMAP server is 0.28 s at about 1 h. Figure 17 shows the average TCP delay of the POP3 and IMAP email servers in Scenario 2. The average TCP delay for the POP3 and IMAP email servers is 0.17 s and 0.19 s, respectively, during the 24 h simulation period.

Reducing the average packet latency from 200 ms in Scenario 1 to 100 ms in Scenario 2 improved the average TCP delay of email clients and servers for both the POP3 and IMAP email protocols. Overall, POP3 provides better performance than IMAP in terms of the average TCP delay. This may be due to the fact that IMAP has a more complex process for retrieving emails. Further, IMAP requires synchronization which

results in a higher number of connections compared to POP3. This is because POP3 does not periodically check for updates from the email server.

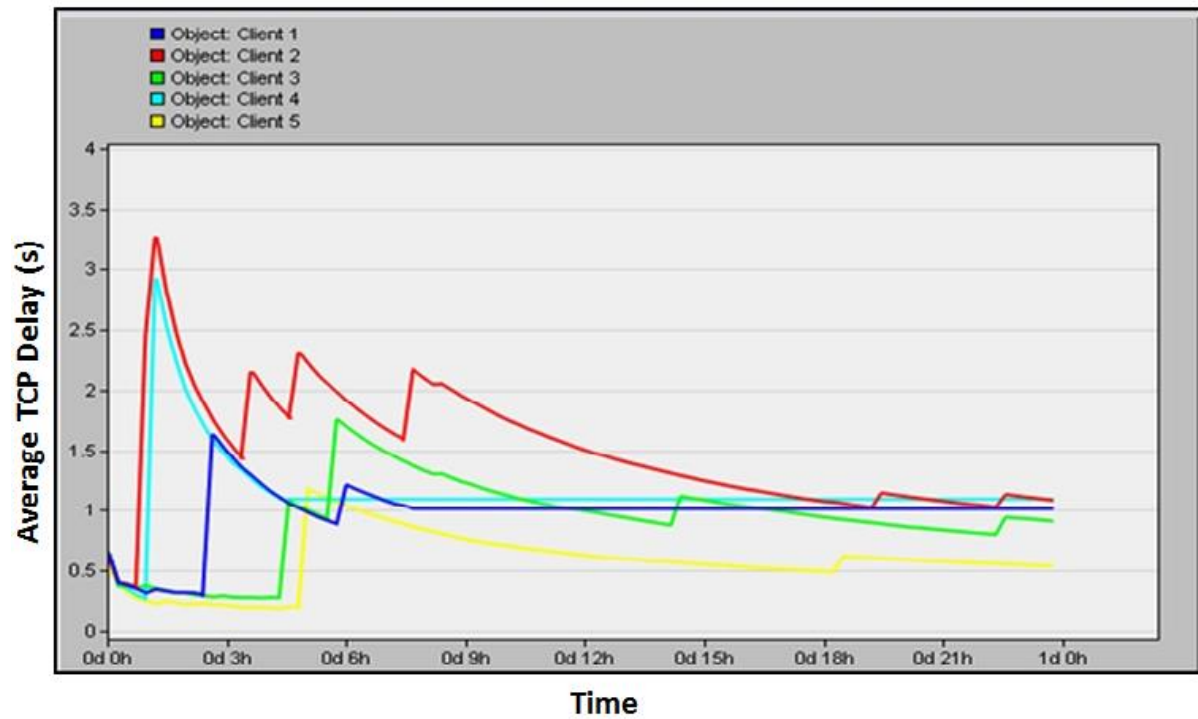


Figure 12: Average TCP delay (s) for POP3 clients in Scenario 1.

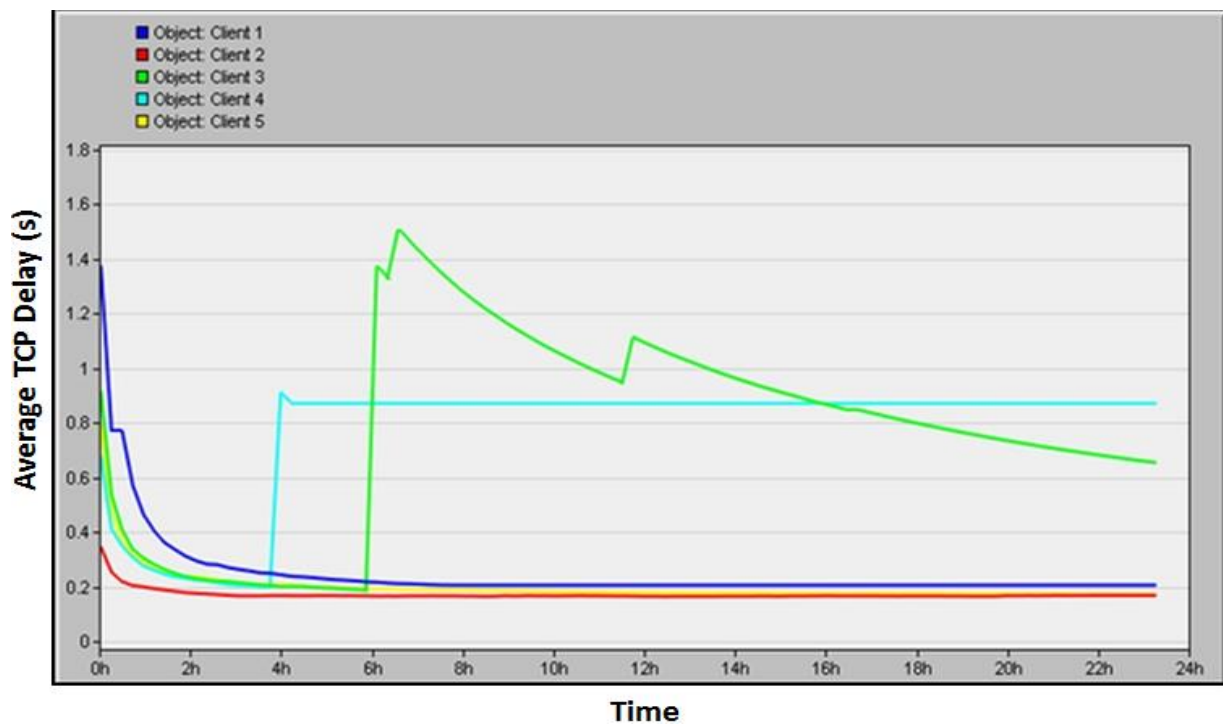


Figure 13: Average TCP delay (s) for POP3 clients in Scenario 2.

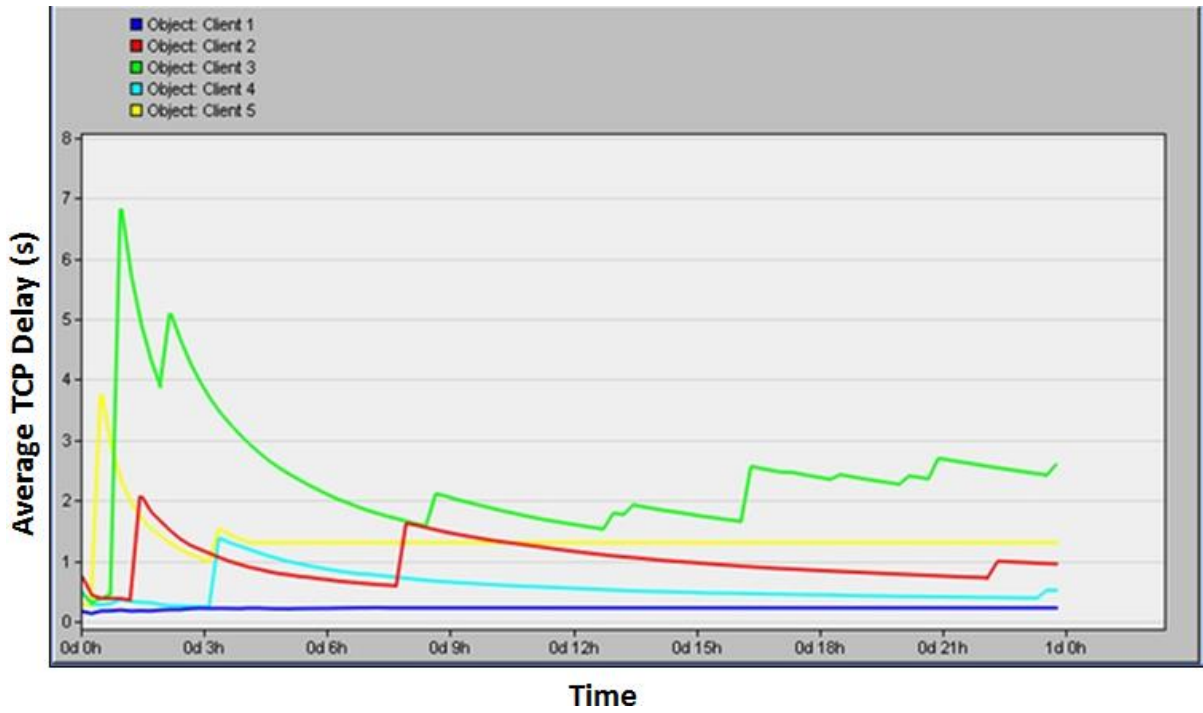


Figure 14: Average TCP delay (s) for IMAP clients in Scenario 1.

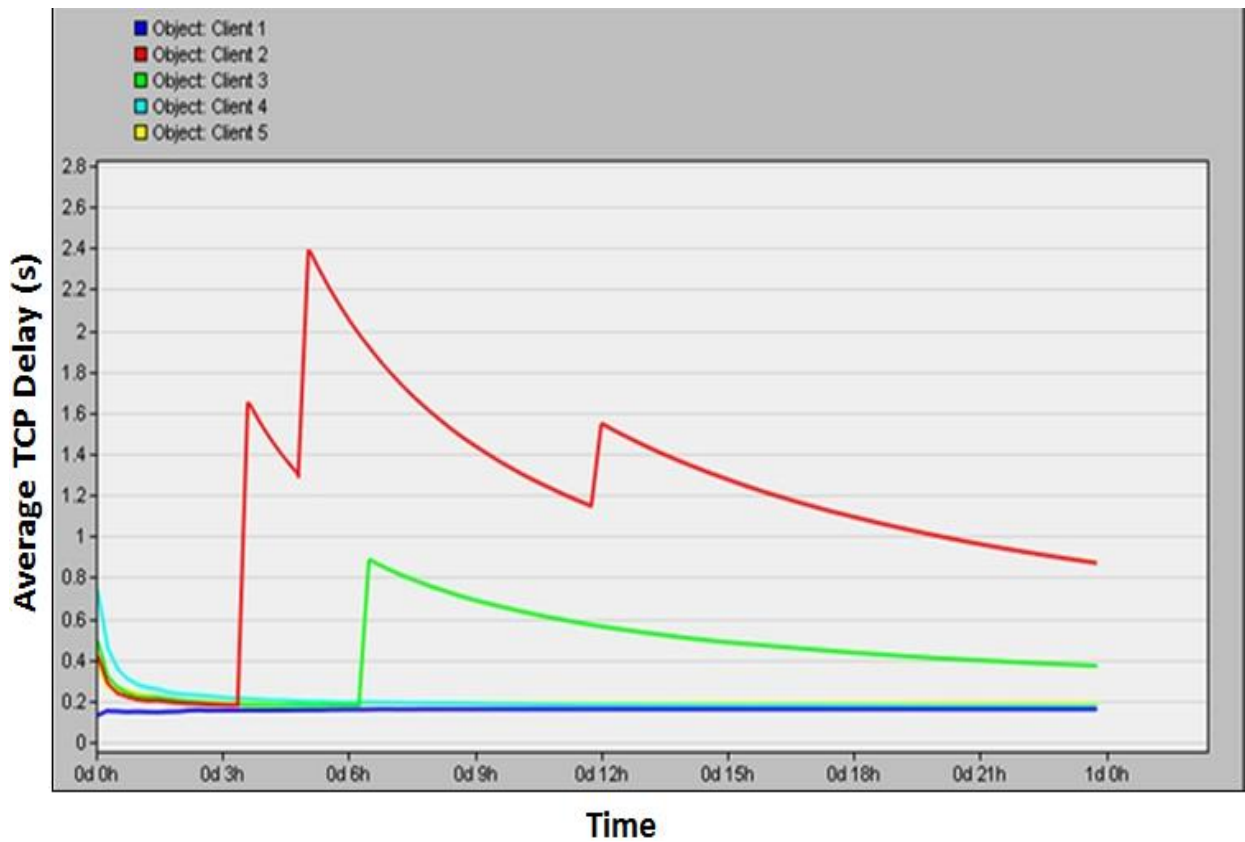


Figure 15: Average TCP delay (s) for IMAP clients in Scenario 2.

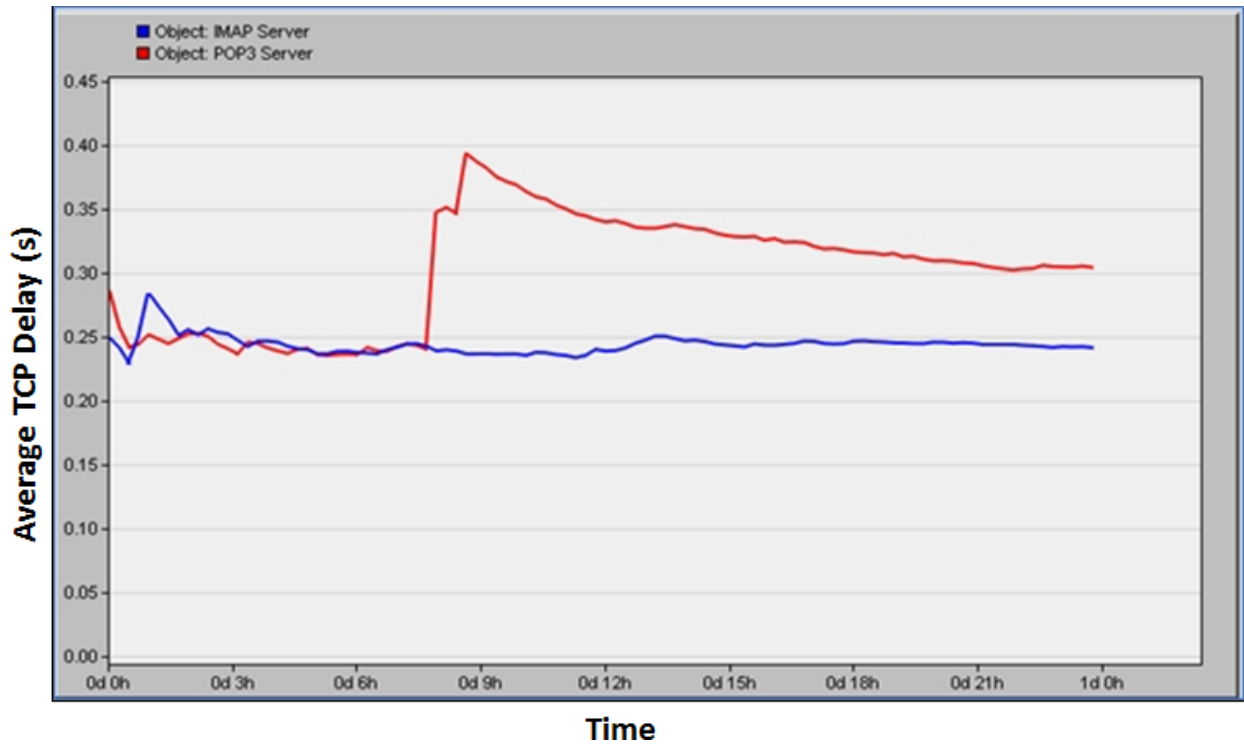


Figure 16: Average TCP delay (s) for POP3 and IMAP email servers in Scenario 1.

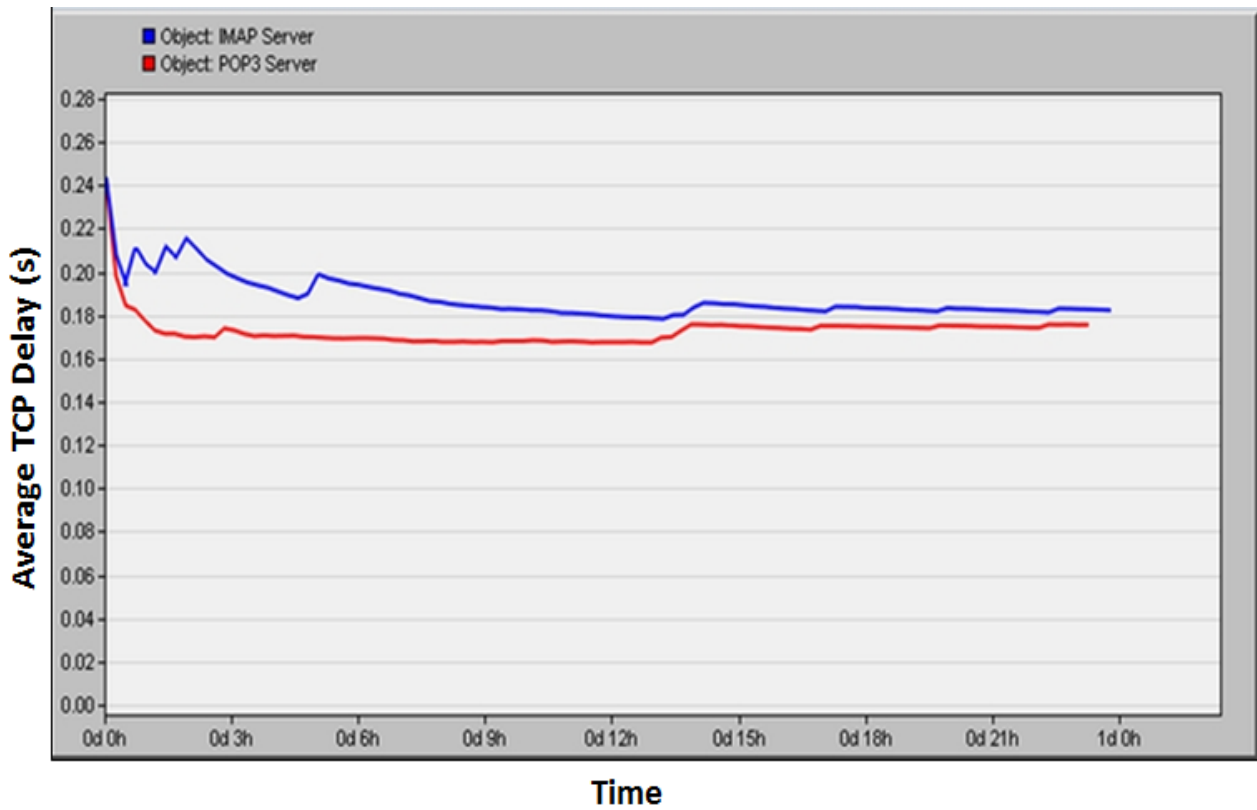


Figure 17: Average TCP delay (s) for POP3 and IMAP email servers in Scenario 2.

4.2 Average TCP Load

This section provides the average TCP load results for the POP3 and IMAP email protocols in Scenarios 1 and 2.

Figure 18 shows the average TCP load in bytes/s of the POP3 clients in Scenario 1. Clients 2, 3, and 5 have the highest average TCP load of around 0.65 bytes/s. Clients 1 and 4 have the lowest average TCP load of about 0.35 bytes/s. Figure 19 shows the average TCP load in bytes/s of the POP3 clients in Scenario 2. Clients 1 and 4 have the lowest average TCP loads of about 0.35 bytes/s. This shows that reducing the link bandwidth and packet latency does not affect the performance of the POP3 clients in terms of average TCP load.

Figure 20 shows the average TCP load of IMAP clients in Scenario 1. All clients have an average TCP load of about 0.51 bytes/s. Figure 21 shows the average TCP load of IMAP clients in Scenario 2. Clients 1 and 5 have an average TCP load of 0.35 bytes/s as compared to 0.61 bytes/s for clients 2, 3, and 4. Similar to the results for the POP3 clients, reducing the link bandwidth in Scenario 2 did not have a noticeable impact on the average TCP load of IMAP clients as the lowest loads were for clients 1 and 5 at 0.35 bytes/s and for clients 2, 3, and 4 it was 0.61 bytes/s.

Figure 22 shows the average TCP load of the POP3 and IMAP email servers in Scenario 1. The POP3 server has a slightly higher average TCP load in comparison to the IMAP server. The initial load at the start of the simulation was 80 bytes/s and 28 bytes/s for the POP3 and IMAP servers, respectively, due to the high number of TCP packets transmitted to establish connections. Figure 23 shows the average TCP load for the POP3 and IMAP email servers in Scenario 2. The results in Scenario 2 are similar to those in Scenario 1. In both scenarios, the average TCP loads of the POP3 and IMAP servers are approximately 4.5 bytes/s as shown in Figures 22 and 23.

The average TCP loads of the POP3 and IMAP email servers are as expected. This is because instead of sending message headers first and giving clients the choice to select the messages, POP3 sends all email contents to the clients resulting in a high TCP load at the start of the simulation. However, the IMAP email server first sends only message headers which results in a significantly lower TCP load initially as compared to the POP3 server. The average TCP loads of the POP3 and IMAP email servers are similar for the remainder of the simulations.

The average TCP loads for the POP3 and IMAP email servers were approximately 5 bytes/s for the simulation period 1 h to 24 h. The average TCP load for the clients at the start of simulations was about 2.5 bytes/s. These numbers are low compared to the link bandwidths. The reason for this is as follows. OPNET breaks the 24 h simulation period into 101 equal time simulation periods so each period is approximately 864 seconds. Thus, each simulation point corresponds to 864 seconds, and the TCP load values are the average within this period. These values are small because a client is not retrieving data continuously within a period. The observed AS-IS results showed that the TCP load is high when a client is retrieving emails from an email server. Further, an average email is approximately 50 to 70 kilobytes which is small compared to video, voice, web, and file transfers, so it does not require a large bandwidth.

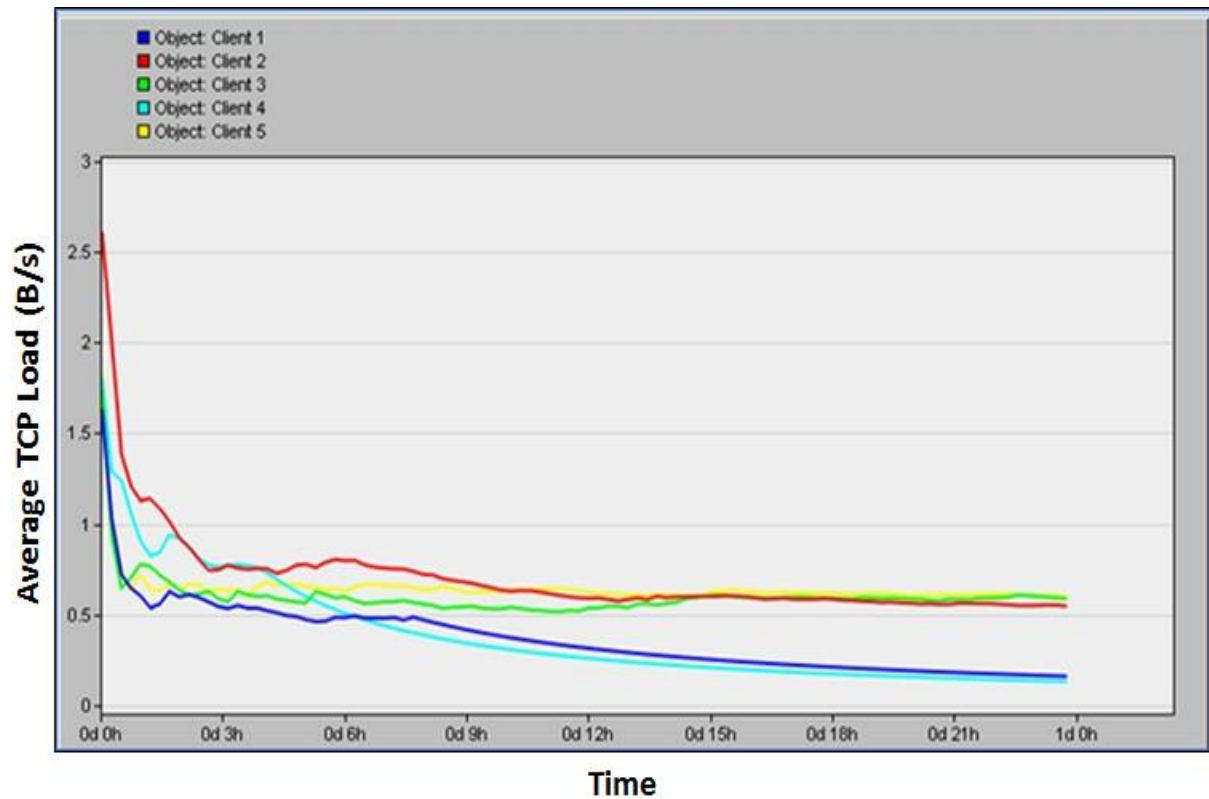


Figure 18: Average TCP load (bytes/s) for POP3 clients in Scenario 1.

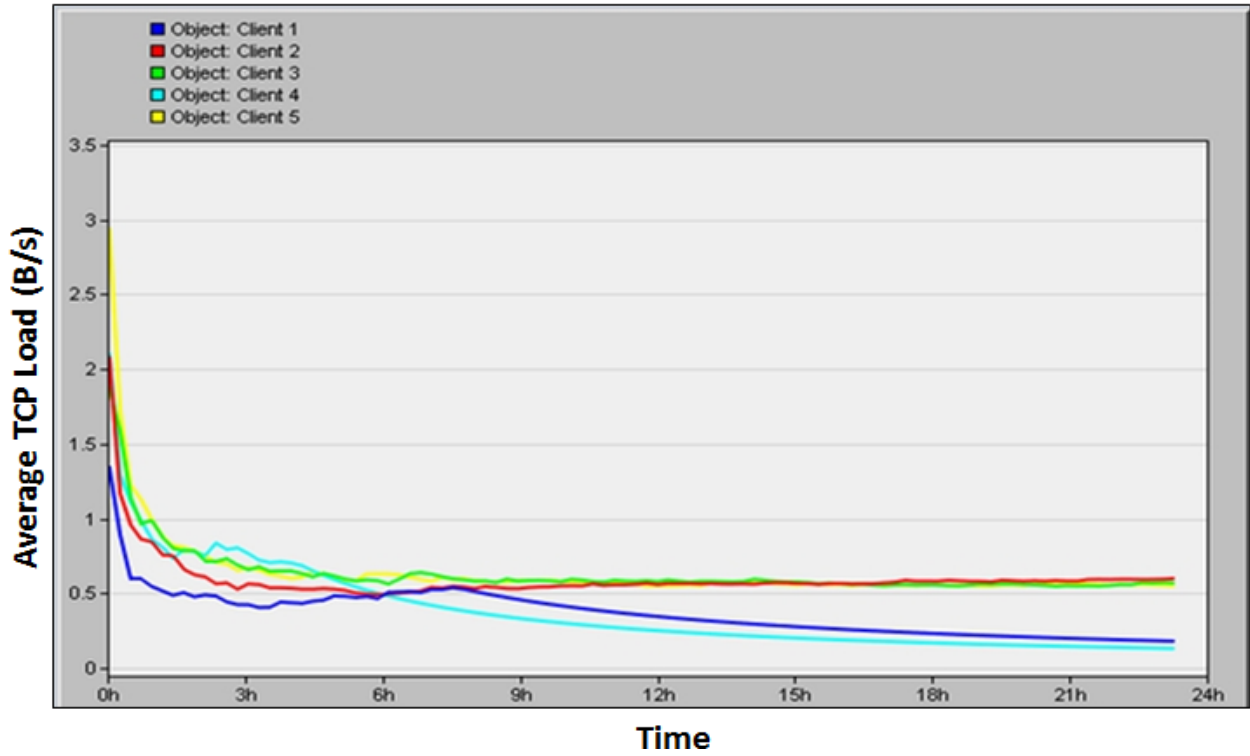


Figure 19: Average TCP load (bytes/s) for POP3 clients in Scenario 2.

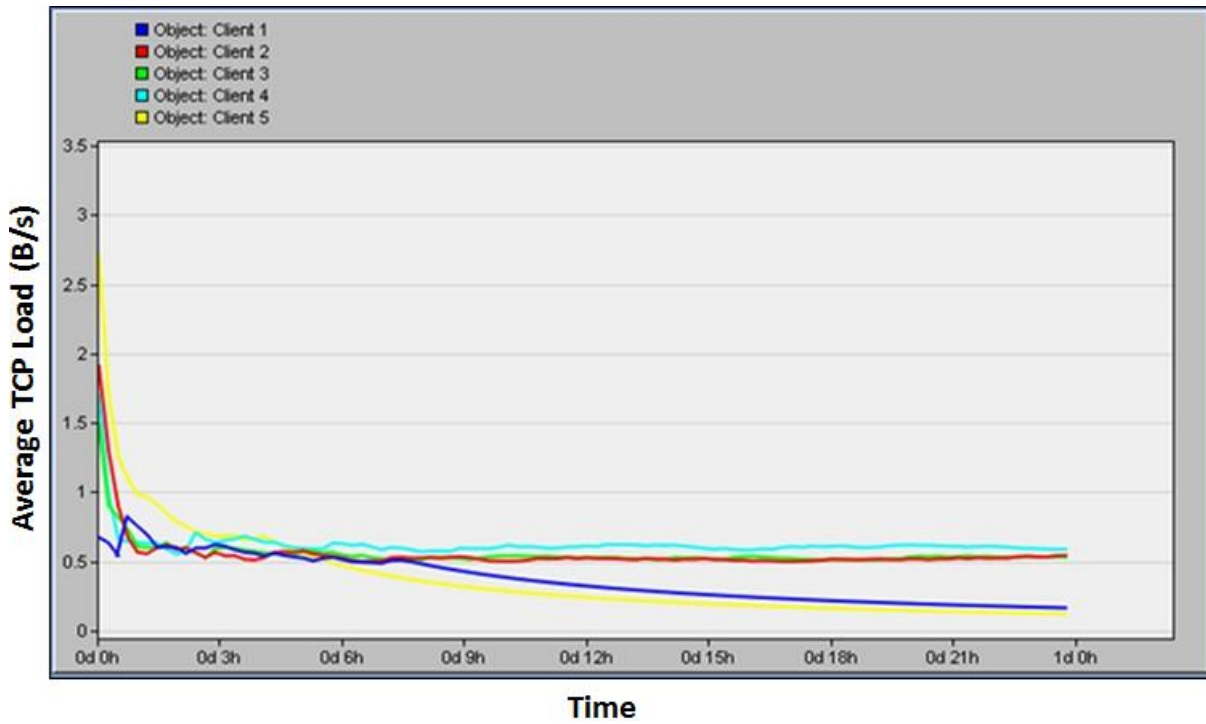


Figure 20: Average TCP load (bytes/s) for IMAP clients in Scenario 1.

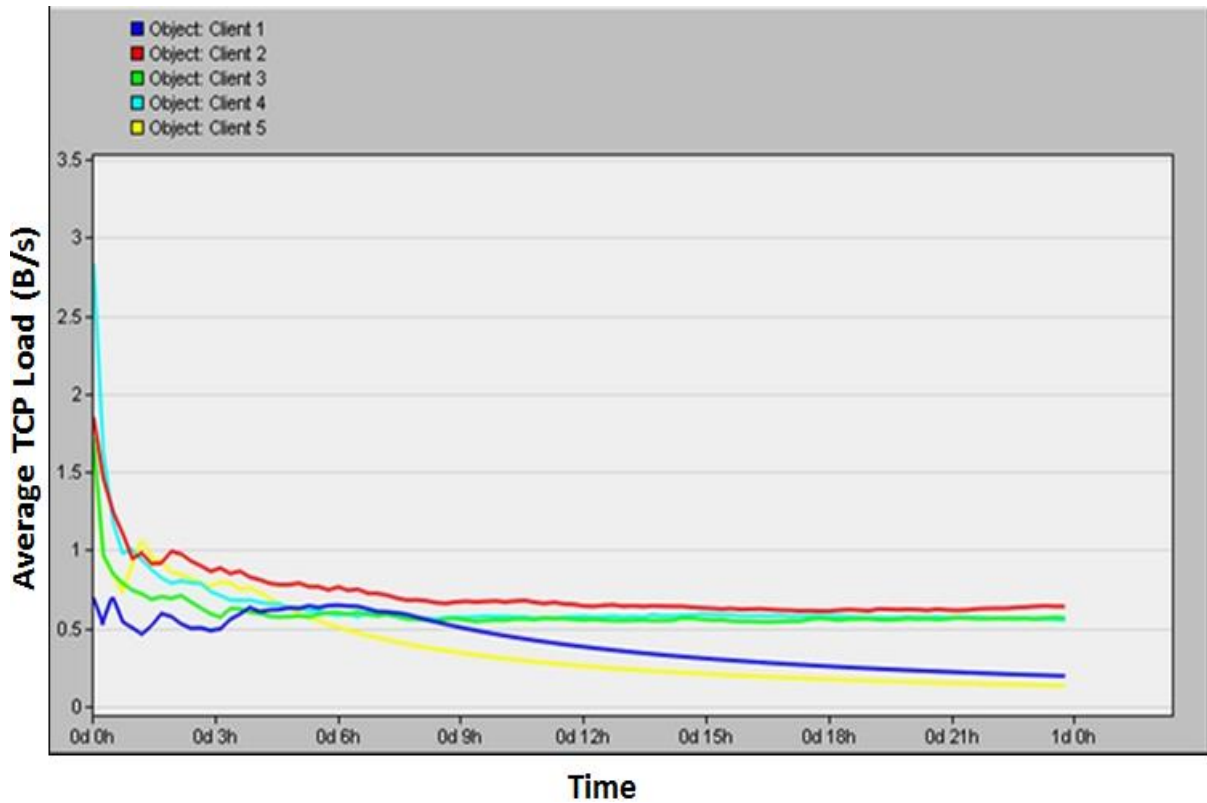


Figure 21: Average TCP load (bytes/s) for IMAP clients in Scenario 2.

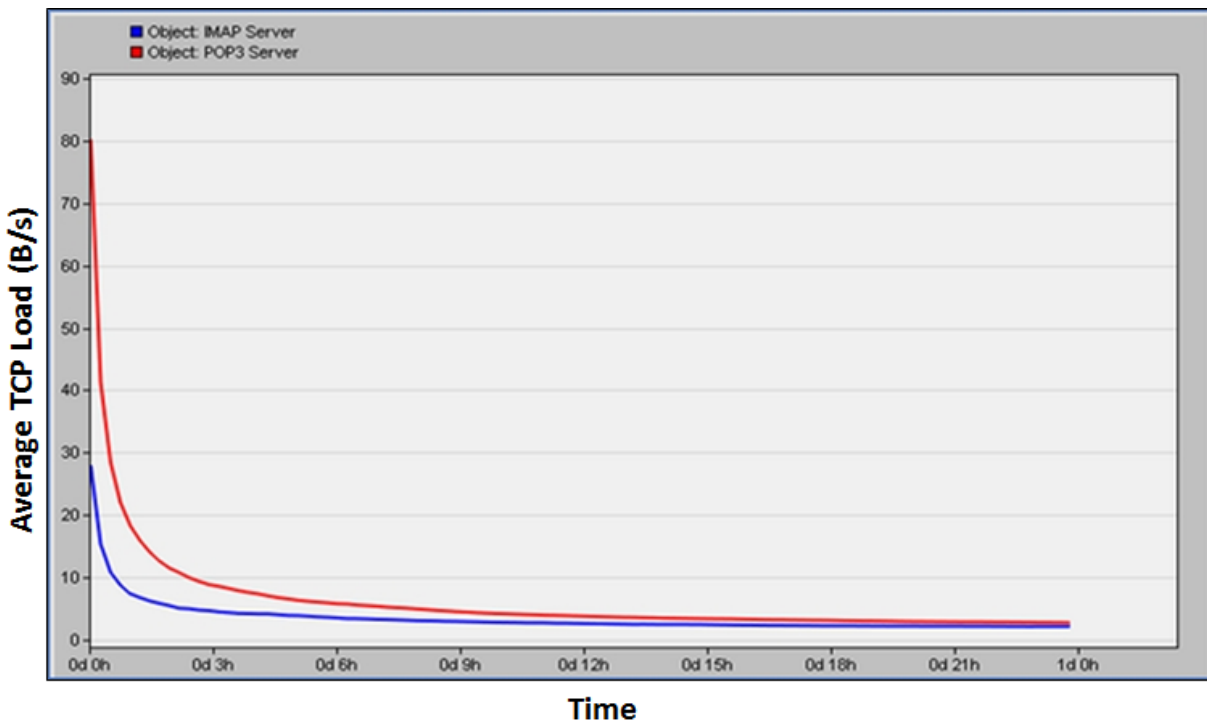


Figure 22: Average TCP load (bytes/s) for POP3 and IMAP email servers in Scenario 1.

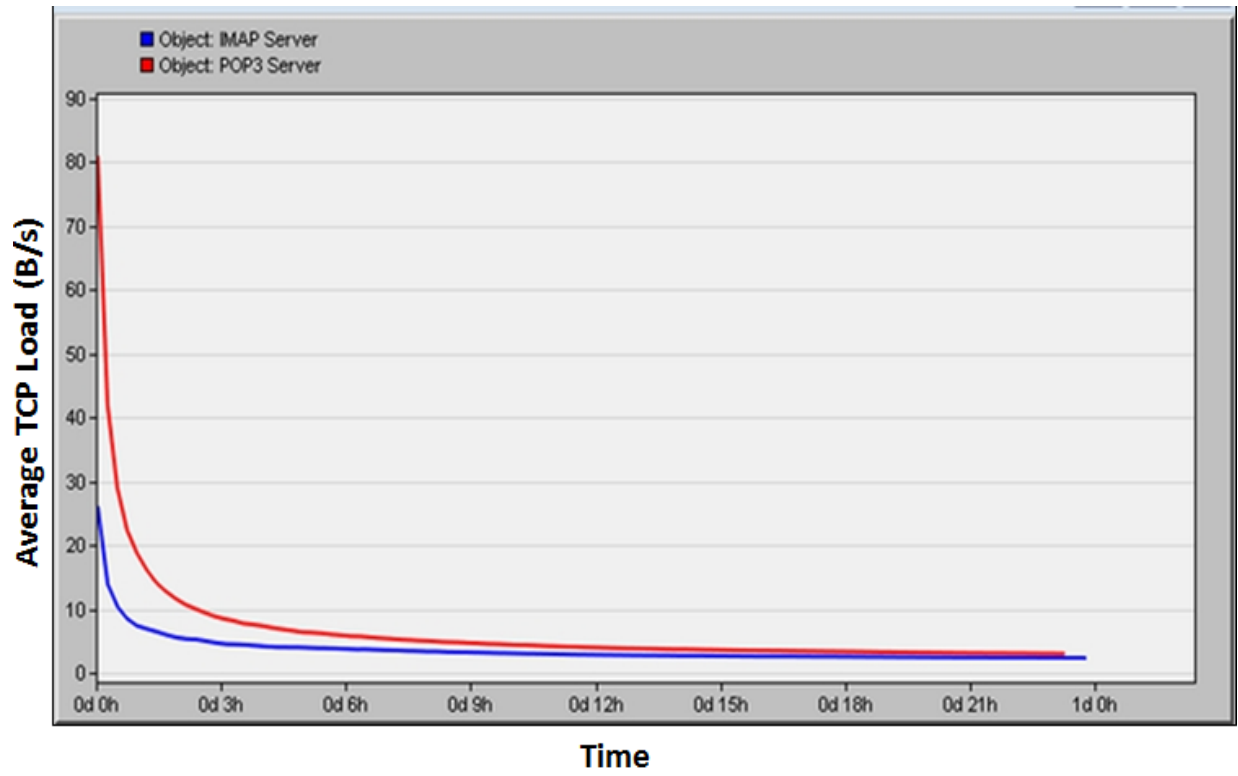


Figure 23: Average TCP load (bytes/s) for POP3 and IMAP email servers in Scenario 2.

4.3 Average TCP Retransmission Count

This section provides the average TCP retransmission counts for the POP3 and IMAP email protocols.

Figure 24 shows the average TCP retransmission counts for POP3 clients in Scenario 1. The retransmission counts for clients 3 and 5 are higher than for the other clients. The peak in retransmission count for client 3 (1.3), at about 3 h reflects a busy communication channel either due to buffer overflow or packet queuing. Figure 25 shows the average TCP retransmission counts for POP3 clients in Scenario 2. The high average TCP retransmission count of 2 for client 4 appears to be due to a busy POP3 server at 5 h. When the server is busy, packets are dropped and these packets are retransmitted by the sender. There were no retransmissions for about the first 3 h of the simulation. This indicates that a lower packet latency has a positive effect at the start since no clients had TCP retransmissions.

Figure 26 shows the average TCP retransmission counts for IMAP clients in Scenario 1. Client 3 has the highest average TCP retransmission count of 2 at approximately 2 h. Clients 1, 4, and 5 have average TCP retransmission counts of 1. Figure 27 shows the average TCP retransmission counts for IMAP clients in Scenario 2. The reduced packet latency in Scenario 2 lowered the counts as clients 3, 4, and 5 did not have any TCP retransmissions. The highest average TCP retransmission count was 1.5 for client 2.

Figure 28 shows the average TCP retransmission counts for the POP3 and IMAP email servers in Scenario 1. The POP3 email server has an average TCP retransmissions count of 4 at the start of the simulation. These retransmissions may occur because of dropped packets. Throughout the 24 h simulation, the IMAP email server performed slightly better than the POP3 email server and retransmitted fewer TCP packets. Figure 29 shows the average TCP retransmission counts for the POP3 and IMAP email servers in Scenario 2. The IMAP email server had a constant average count of 1 but the POP3 email server had varying average TCP retransmission counts. In comparison with Scenario 1, the POP3 email server had fewer average TCP retransmissions.

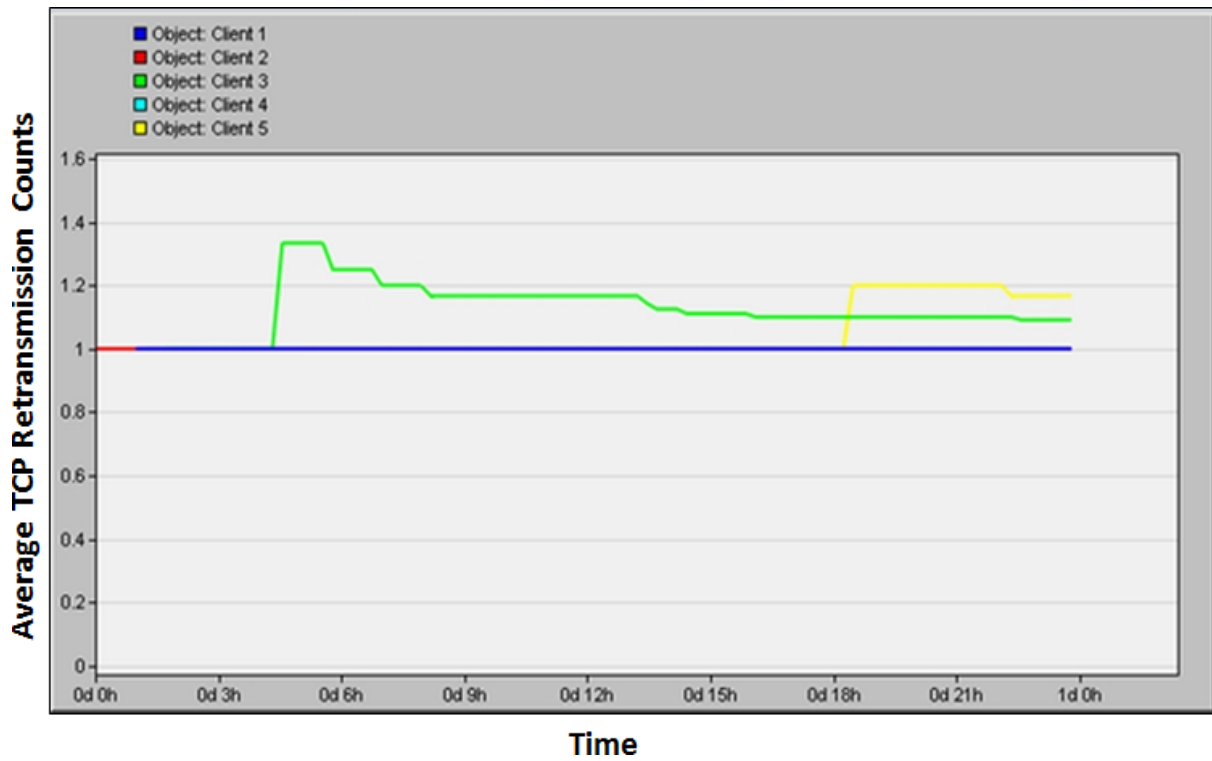


Figure 24: Average TCP retransmission counts for POP3 clients in Scenario 1.

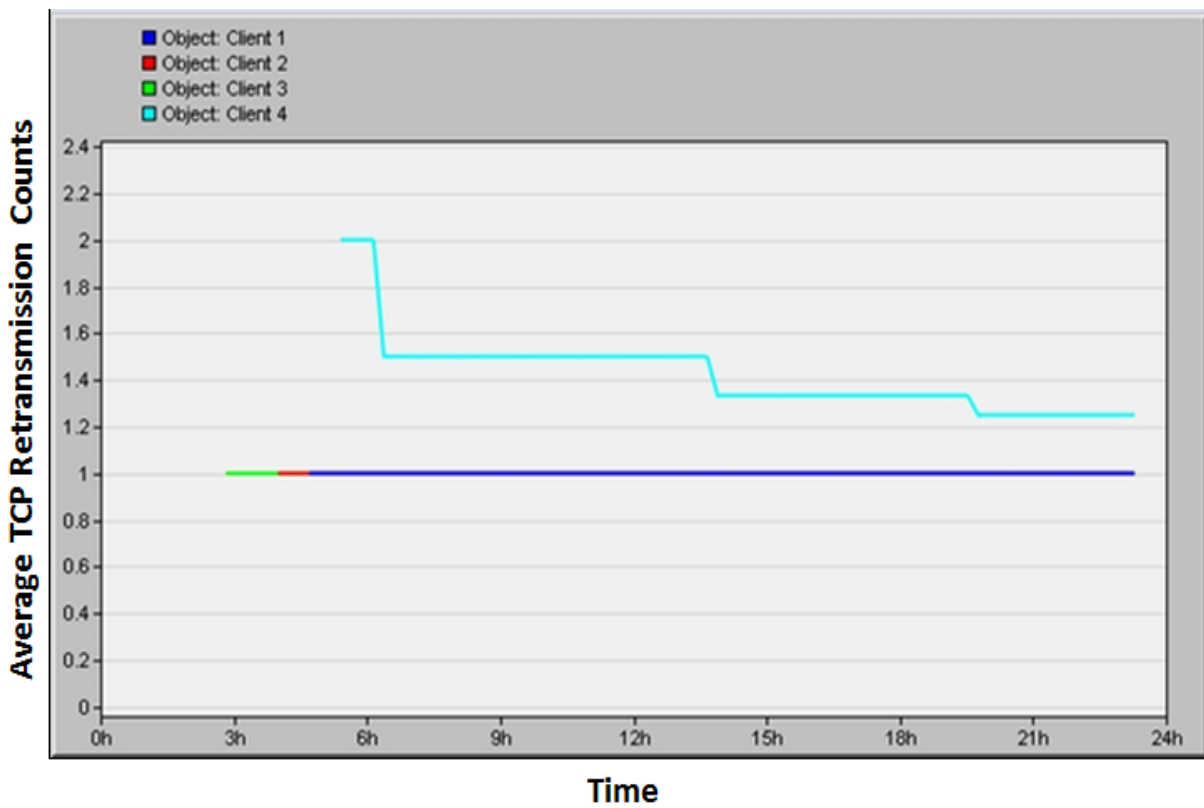


Figure 25: Average TCP retransmission counts for POP3 clients in Scenario 2.

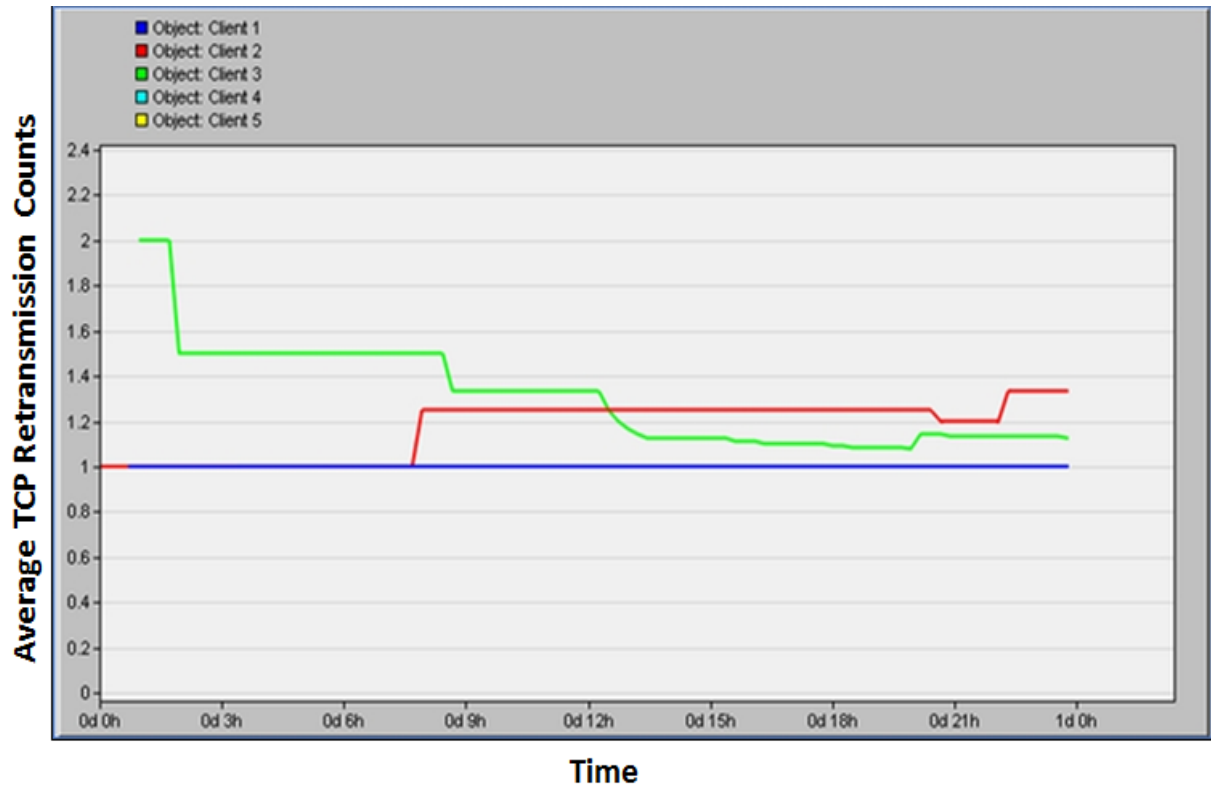


Figure 26: Average TCP retransmission counts for IMAP clients in Scenario 1.

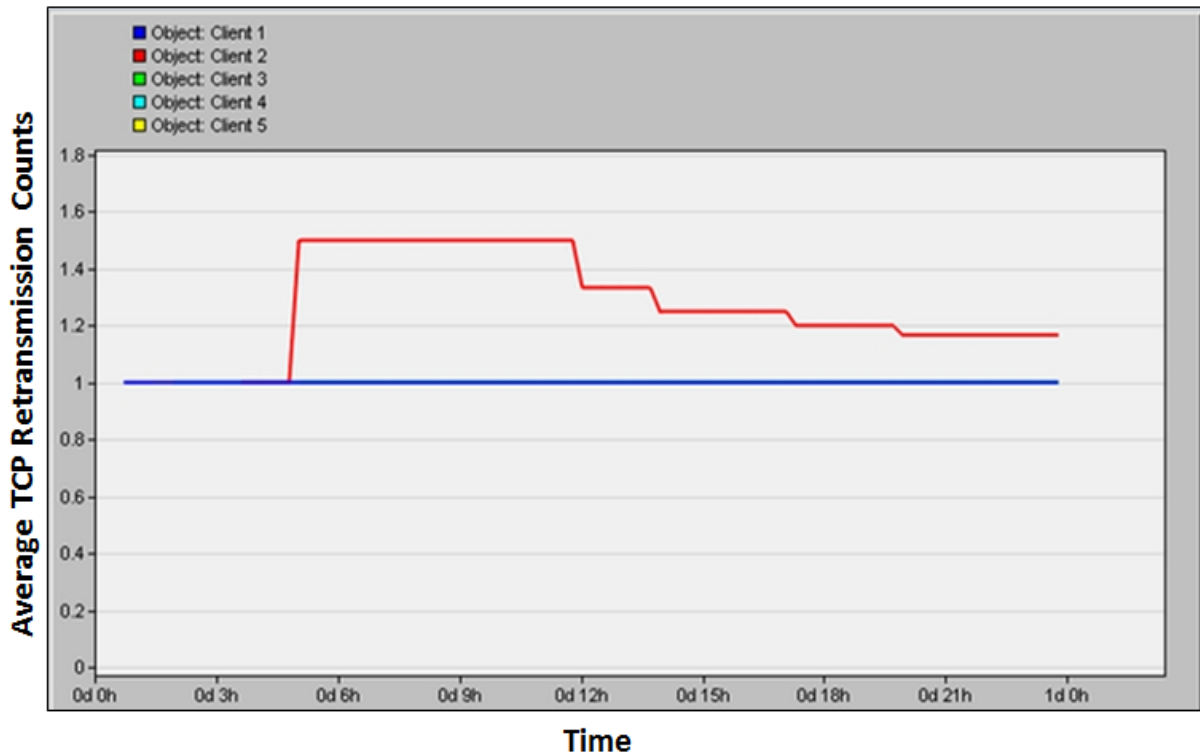


Figure 27: Average TCP retransmission counts for IMAP clients in Scenario 2.

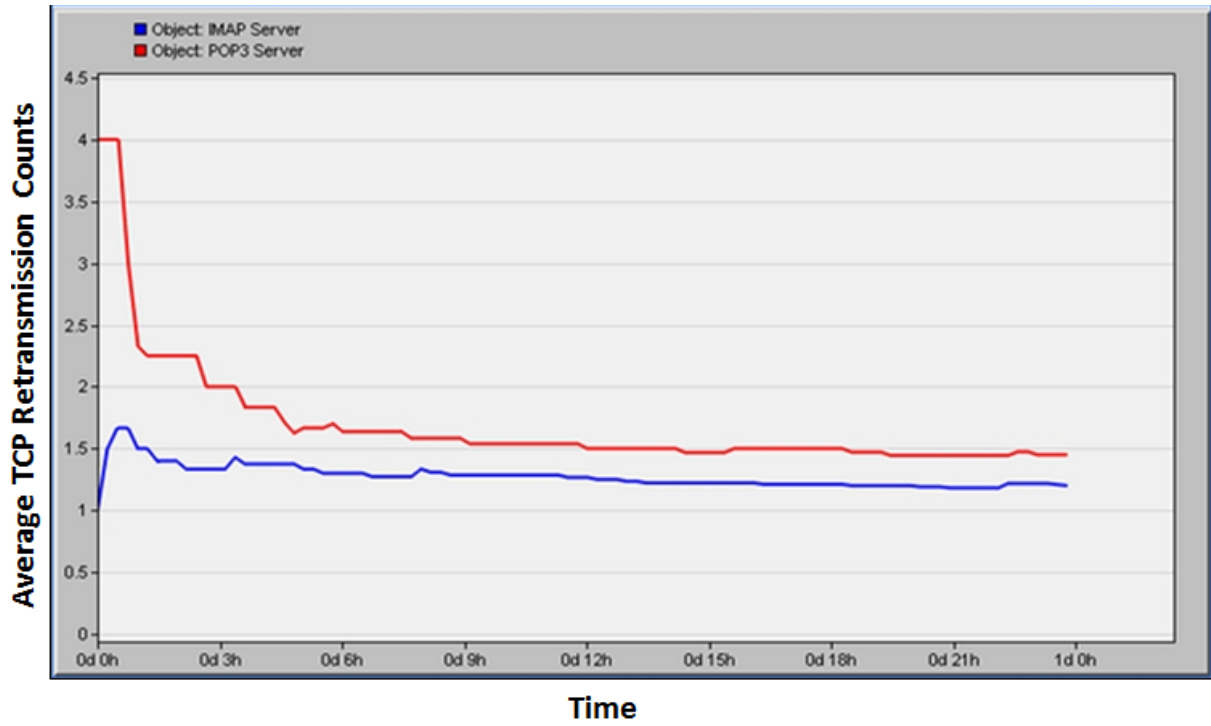


Figure 28: Average TCP retransmission counts for POP3 and IMAP email servers in Scenario 1.

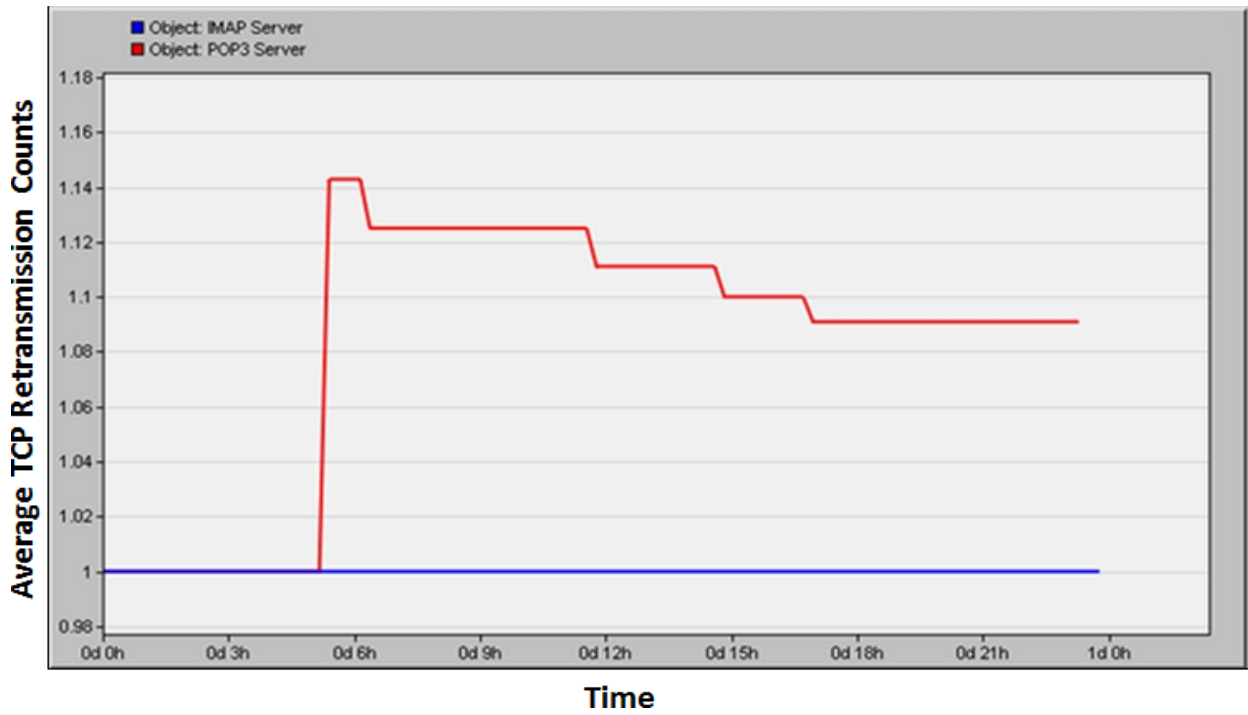


Figure 29: Average TCP retransmission counts for POP3 and IMAP email servers in Scenario 2.

4.4 Average Traffic Received

This section provides the average traffic received (bytes/s) by the POP3 and IMAP email protocols.

Figure 30 shows the average traffic received by POP3 clients in Scenario 1. The received traffic rate for all clients was much higher rate at the start of the simulation with the highest for client 3 at 19 bytes/s. During the rest of the simulation, all clients had similar average traffic received of approximately 1 byte/s. Figure 31 shows the average traffic received by POP3 clients in Scenario 2. The received traffic rate for most clients was 19 bytes/s at the start of the simulation, and subsequently all clients had an average traffic received of approximately 1 byte/s. The average traffic received for the POP3 clients in Scenario 2 is similar to the average traffic received in Scenario 1.

Figure 32 presents the average traffic received for IMAP clients in Scenario 1. The average traffic received by IMAP clients at the start of the simulation was high for clients 2, 3, 4, and 5 at about 7 bytes/s. The average traffic received by client 1 was initially 0.5 bytes/s. Figure 33 shows the average traffic received by the IMAP clients in Scenario 2. Similar to Scenario 1, clients 2, 3, 4, and 5 received traffic at about 7 bytes/s initially while client 1 received traffic at 0.5 byte/s. During the rest of the simulation, all clients had an average of less than 1 byte/s. Thus, the average traffic received by IMAP clients in Scenario 2 is similar to that for Scenario 1.

Figure 34 shows the average traffic received by the POP3 and IMAP email servers in Scenario 1. The POP3 email server had a slightly higher average traffic received than the IMAP email server, especially at the start of the simulation at rates of 9.5 bytes/s and 8.5 bytes/s, respectively. Figure 35 shows the average traffic received by the POP3 and IMAP email servers in Scenario 2. Initially, both email servers received traffic at rates of 9.5 bytes/s and 8.5 bytes/s, respectively. During the rest of the simulation, they received traffic at rates of 2.5 bytes/s. Reducing the packet latency and the link bandwidth (Scenario 2), had minimal effect on the average traffic received. However, unlike in Scenario 1, The IMAP email server had slightly higher average traffic received than the POP3 email server at about 2.1 bytes/s compared to 2.0 bytes/s.

The average traffic received results reflect the low average TCP loads obtained previously. They also show that IMAP clients have lower average traffic received than POP3 clients at the start of the simulations in both scenarios. However, later in the simulations most IMAP clients have the same average traffic

received as the POP3 clients at approximately 1 byte/s. Thus, The POP3 and IMAP email servers have similar average traffic received.

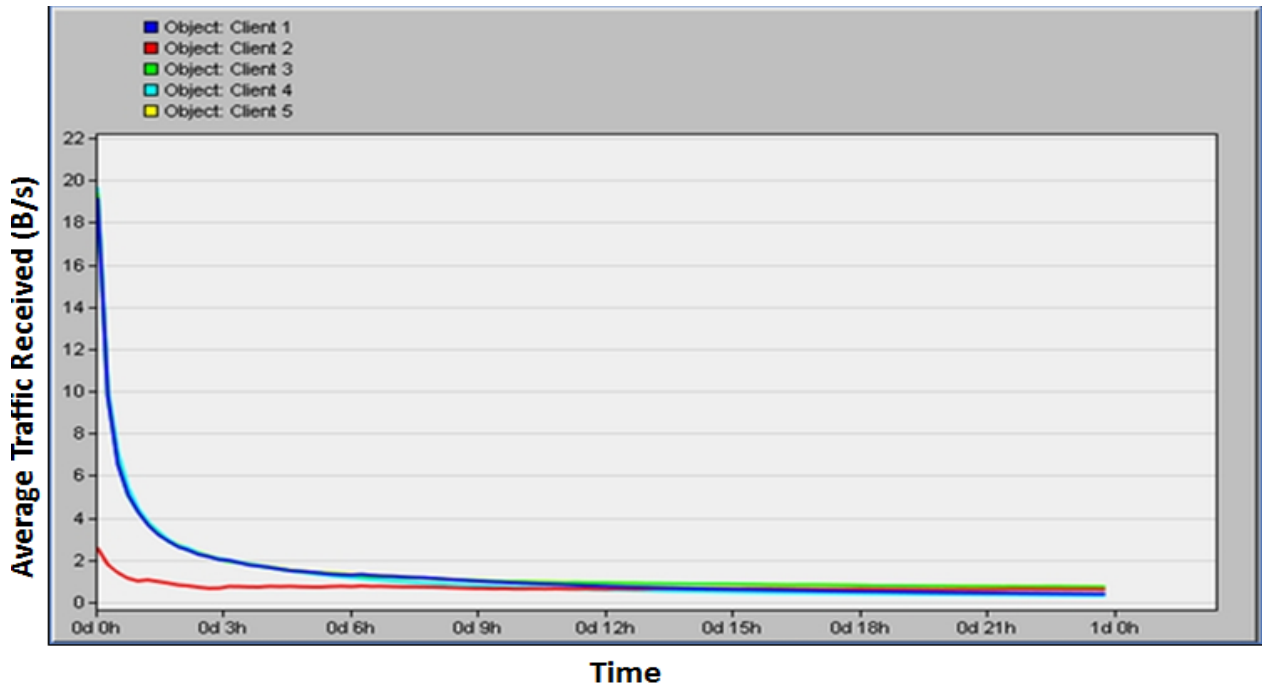


Figure 30: Average traffic received (bytes/s) from POP3 clients in Scenario 1.

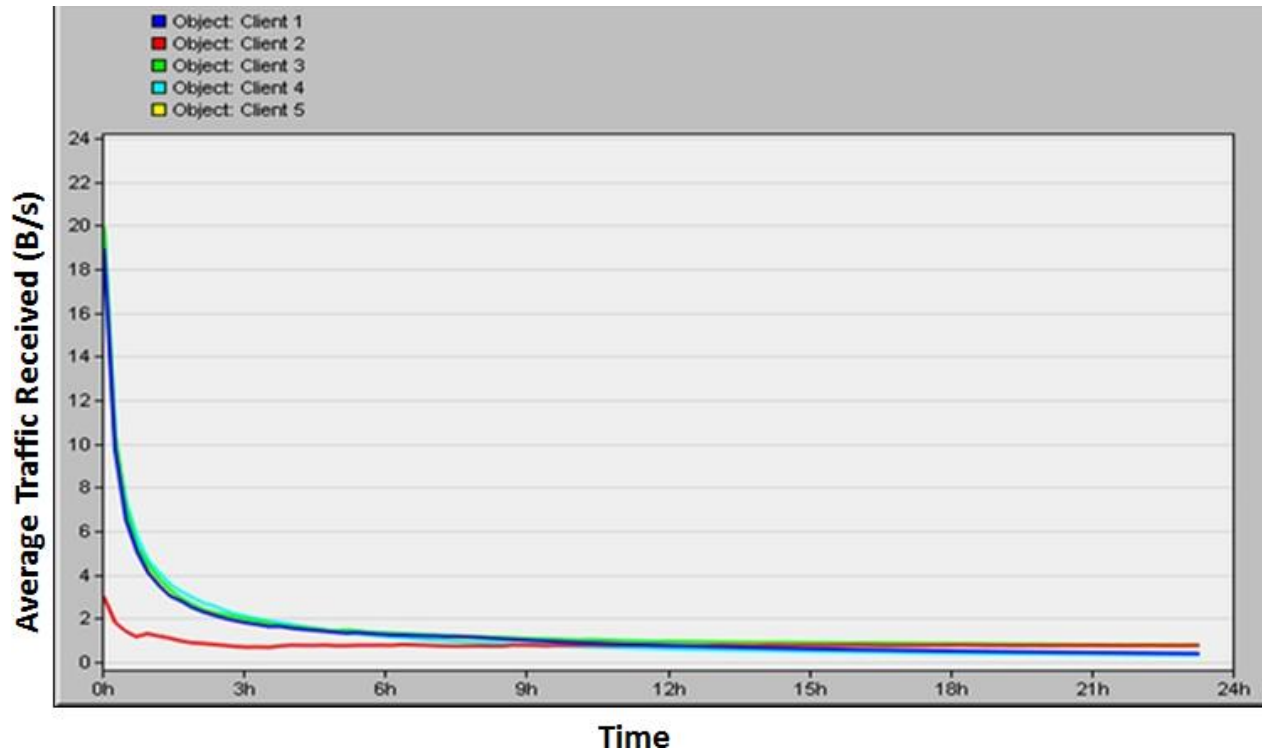


Figure 31: Average traffic received (bytes/s) from POP3 clients in Scenario 2.

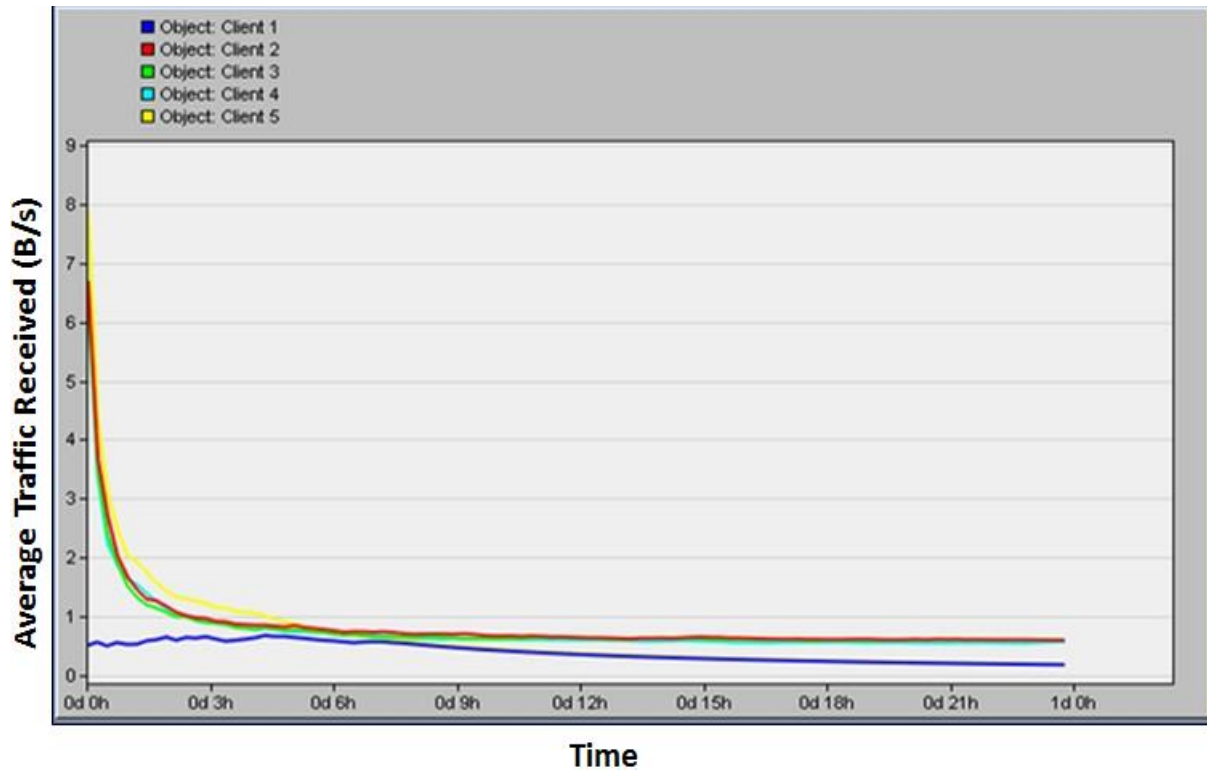


Figure 32: Average traffic received (bytes/s) for IMAP clients in Scenario 1.

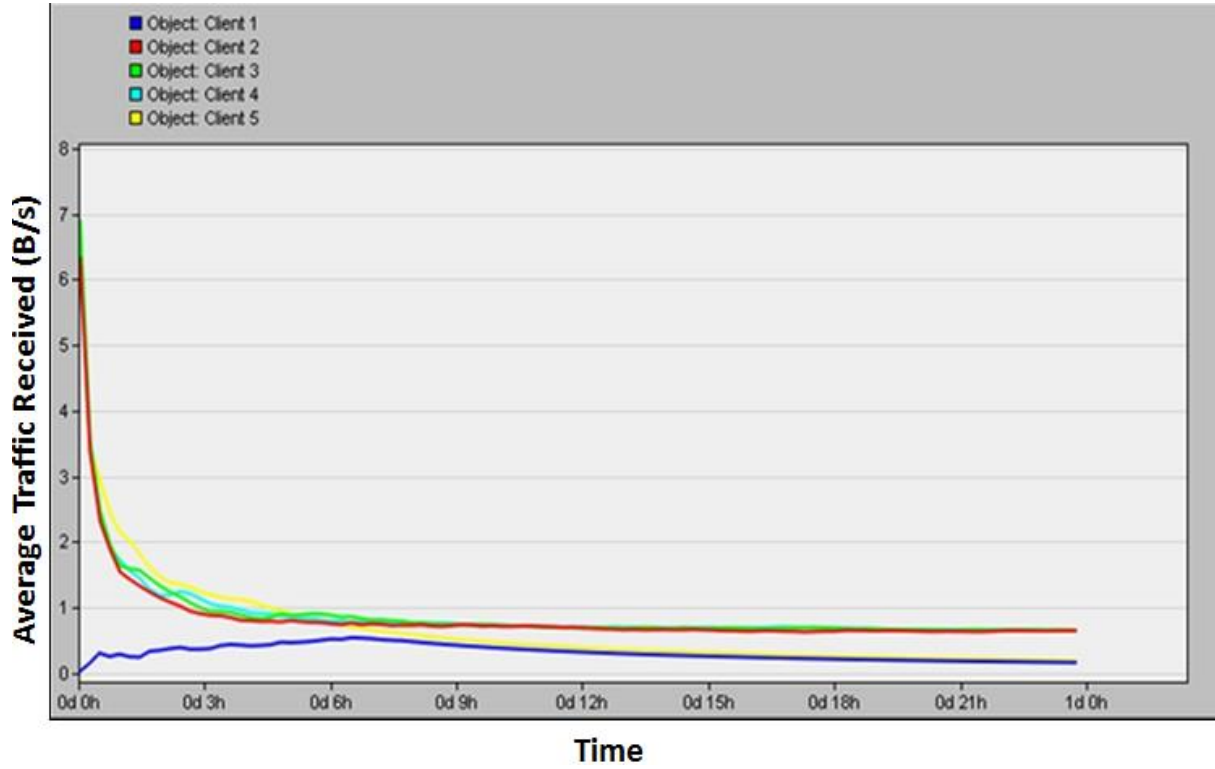


Figure 33: Average traffic received (bytes/s) for IMAP clients in Scenario 2.

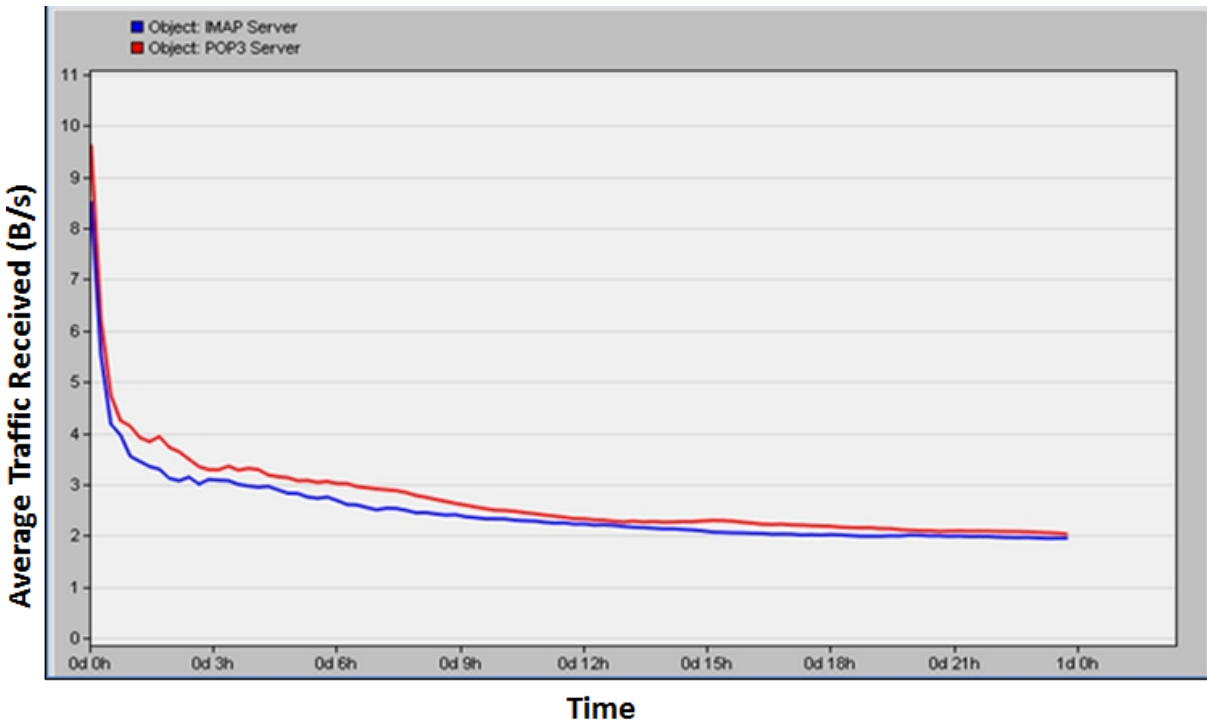


Figure 34: Average traffic received (bytes/s) for POP3 and IMAP email servers in Scenario 1.

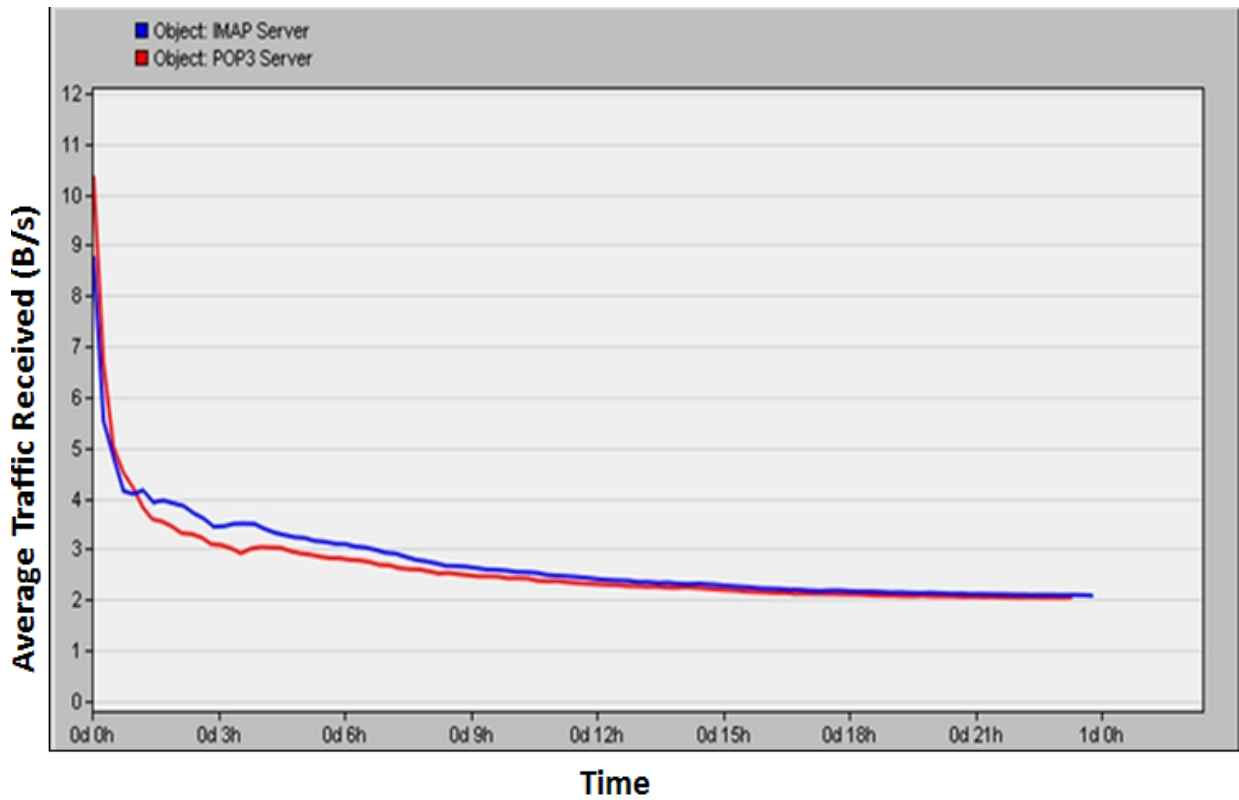


Figure 35: Average traffic received (bytes/s) for POP3 and IMAP email servers in Scenario 2.

Chapter 5

Conclusion

The number of email users and email accounts is increasing every day. This increase has resulted in a significant number of emails being sent and received daily. With the rapid increase in email usage and network traffic associated with emails, understanding the benefits and limitations of email protocols is important. Thus, there is interest in analyzing the performance of email protocols. Furthermore, there is a need for network architects to know more about email protocols to help them determine the right protocol for a network according to user needs.

Previous work compared the performance of the SMTP, POP3, and X400 protocols in terms of end-to-end delay, volume of traffic, and number of frames generated at the data link layer [5]. In this project, two common email protocols, Post-Office Protocol version 3 (POP3) and Internet Message Access Protocol (IMAP) were evaluated using the Optimized Network Engineering Tool (OPNET) to simulate the network environment. The performance of these email protocols was evaluated in two different network scenarios with different bandwidths and packet latencies.

The performance metrics used for evaluation examined were average TCP delay, average TCP load, average TCP retransmission count, and average traffic received. The results obtained show that the complex process of retrieving emails and synchronization with IMAP produces a higher number of TCP connections and a higher average TCP delay compared to POP3. The IMAP email server has a slightly better average TCP retransmission count than POP3. Conversely, POP3 has better average TCP traffic received than IMAP. Furthermore, both protocols have similar average TCP loads. The average TCP load was observed very low. Overall, the performance of POP3 is better than IMAP. Similar to previous studies [5], the efficiency of the POP3 email protocol is higher due to its simplicity. IMAP provides the ability to access emails with multiple devices and receive email updates from email servers, but the cost to provide these functionalities is a higher average TCP delay.

Future Work

In the future, a large network with several email clients and servers can be used to evaluate the performance of the POP3 and IMAP email protocols. They can also be evaluated in scenarios with limited bandwidth by using a bottleneck topology. Moreover, the performance of IMAP email applications such as Outlook, Thunderbird, and Gmail can be evaluated. The security and vulnerability of IMAP and POP3 protocols can also be assessed.

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