EXPERIMENTAL ANALYSIS OF EFFECTS OF DIFFERENT NETWORK PARAMETERS ON TCP/IP NETWORKS

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SEPTEMBER 2025

ÇANKAYA UNIVERSITY

GRADUATE SCHOOL

ELECTRICAL-ELECTRONICS ENGINEERING DEPARTMENT
ELECTRICAL-ELECTRONICS ENGINEERING MASTER'S THESIS

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ABSTRACT

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Supervisor: Assoc. Prof. Dr. Barbaros PREVEZE

September 2025, 56 pages

Today, the Internet is actively used in almost every aspect of life and stands out as an indispensable component of the digital age. With Internet technologies, instant access to information is possible, and global communication processes are significantly simplified.

Computer networks are structured by using different topologies depending on their purpose and scale. In this thesis, the use of the preferred Mesh topology in complex and large-scale network structures has been deemed appropriate. Using mesh topology has been a logical choice due to its high connection level and reliability. However, in these mesh topologies it is important that the network performance must be in good condition to provide network security and high efficiency. Therefore, having better system performance is one of the fundamental rules to maintain proficient network management. In the thesis GNS3 simulation environment is used, which is frequently used by network engineers.

Thanks to this simulation environment we can investigate various network parameters' performance on TCP/IP based networks, and we are able to compare performances of each parameter with using different routing protocols. In network management, the most common routing protocols are used such as RIP (Routing Information Protocol), OSPF (Open Shortest Path First), EIGRP (Enhanced Interior Gateway Routing Protocol) and BGP (Border Gateway Protocol). These protocols are analyzed by comparing each one's throughput, packet data volume and their packet

loss performances. Statistical data which is acquired by graphs is designed in MATLAB environment.

In the conclusion of this thesis, it can be seen that routing algorithms perform differently with respect to consecutive packet data amount. Thus, we can conclude to a study that which routing protocol performs better in which environment and this enables us to make clear judgements for them as well.

The main purpose of this study is to monitor different routing protocols in simulation environments and understand differences of their performances. This study may be clarifying the way and can work as a guidebook for those who would like to create real network design.

Keywords: Throughput, BGP, RIP, OSPF, EIGRP, Mesh

ÖZET

FARKLI AĞ PARAMETRELERİNİN TCP/IP AĞLARI ÜZERİNDEKİ ETKİLERİNİN DENEYSEL ANALİZİ

SIRER, HİRA

ELEKTRİK-ELEKTRONİK MÜHENDİSLİĞİ YÜKSEK LİSANS TEZİ

Danışman: Doç. Dr. Barbaros Preveze

Eylül 2025, 56 sayfa

Günümüzde internet, yaşamımızın hemen her alanında yaygın olarak kullanılmaktadır. Dijital çağın önemli bir parçası olarak öne çıkmaktadır. İnternet teknolojileri, bilgiye kolay ve hızlı erişim sağlarken ayrıca dünya çapında iletişimi de önemli ölçüde kolaylaştırmıştır.

Bilgisayar ağları, amaçlarına ve büyüklüklerine göre farklı topolojilere sahiptirler. Mesh topolojisi, güvenilirliği ve bağlantı kapasitesi nedeniyle özellikle karmaşık ve büyük ölçekli sistemlerde tercih edilmektedir. Bununla birlikte, bu tür karmaşık yapılarda TCP/IP ağlarının düşük "Paket Kaybı" ve yüksek verimlilikle çalışması, ağ performansı için çok önemlidir. Bu nedenle, etkili bir ağ yönetimi için sistem performansının optimize edilmesi kaçınılmazdır.

Bu tez çalışması, TCP/IP tabanlı ağlarda farklı ağ parametrelerinin etkilerini benzetimsel olarak incelemekte ve GNS3 simülasyon programı kullanarak mesh topolojisi üzerinde uygulanan çeşitli yönlendirme algoritmalarının performanslarını karşılaştırmaktadır. Araştırma kapsamında RIP (Yönlendirme Bilgi Protokolü) , OSPF (Açık En Kısa Yol Öncelikli Protokolü), EIGRP (Gelişmiş İç Ağ Geçidi Yönlendirme Protokolü) ve BGP (Sınır Ağ Geçidi Protokolü) gibi yaygın kullanılan yönlendirme protokolleri ele alınmış; bu protokollerin veri iletim performansı (throughput), paket veri miktarı, paket kayıp oranı gibi ölçütler açısından karşılaştırmalı analizleri

gerçekleştirilmiştir. Simülasyon çalışmaları, belirlenen parametreler doğrultusunda yürütülmüş ve elde edilen sonuçlar istatistiksel olarak değerlendirilmiştir.

Elde edilen sonuçlar neticesinde, çeşitli yönlendirme algoritmalarının paket veri miktarına bağlı olarak ne kadar iyi çalıştığını bizlere göstermektedir. Böylece, somut veriler elde edilmiş ve hangi yönlendirme algoritmasının hangi koşullarda daha iyi sonuçlar verdiğini göstermiştir.

Elde edilen sonuçlar, çeşitli yönlendirme algoritmalarının paket veri miktarına bağlı olarak ne kadar iyi çalıştığını göstermektedir. Böylece, somut veriler, hangi yönlendirme algoritmasının hangi koşullarda daha iyi sonuçlar verdiğini göstermektedir.

Bu tezin nihai amacı, farklı yönlendirme algoritmalarının performanslarını ve davranışlarını simülasyon sürecinde nasıl etkilediğini öğrenmektir. Çalışma, hem akademik çalışmalar hem de uygulamalı ağ tasarımları için deneysel bir kılavuz olarak hizmet etmektedir.

Anahtar Kelimeler: Throughput, BGP, RIP, OSPF, EIGRP, Mesh

ACKNOWLEDGEMENT

I would like to thank lot to Assoc. Prof. Dr. Barbaros Preveze for his invaluable support in the preparation of this thesis. Due to his constructive feedback and professional approach, this thesis is prepared much easier. It has been an honor to be his student because his contributions to this thesis are beyond measure.

My beloved husband Uğur Sırer, his fabulous support and encouragement is priceless so I would also like to express my deepest gratitude to him. This thesis will not be completed without his both academic and emotional support.

Finally, I would like to express my deepest gratitude to my family. Their faith and sacrifice have been so crucial for completing this thesis. I will always be grateful for supporting me no matter what.

Moreover, I am very grateful to my thesis juries for their constructive comments and directions and finally I would like to thank you to all Electrical and Electronic engineering department staff for their outstanding efforts.

Finally, I would to thank all my friends, whose support and companionship made my study more enjoyable and productive.

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LIST OF ABBREVIATIONS

ACK	: Acknowledgment
BGP	: Border Gateway Protocol
CPU	: Central Processing Unit
EIGRP	: Enhanced Interior Gateway Routing Protocol
FTP	: File Transfer Protocol
HTTP	: HyperText Transfer Protocol
HTTPS	: HyperText Transfer Protocol Secure
IGP	: Interior Gateway Protocol
IP	: Internet Protocol
IS-IS	: Intermediate System to Intermediate System
LAN	: Local Area Network
LSAs	: Link State Advertisements
MTU	: Maximum Transmission Unit
OSPF	: Open Shortest Path First
POP3	: Post Office Protocol v3
RAM	: Random Access Memory
RIP	: Routing Information Protocol
SMTP	: Simple Mail Transfer Protocol
SSH	: Secure Shell
TCP	: Transmission Control Protocol
UDP	: User Datagram Protocol
WAN	: Wide Area Network

CHAPTER I
INTRODUCTION

1.1 INTRODUCTION

One of the most commonly used protocols on the Internet is the TCP/IP protocol. A network based on the TCP/IP protocol enables efficient routing of data packets according to their IP (Internet Protocol) addresses. In the network, data transmission and data control are ensured through the used routers. [1] Routers are not like any other network devices. To communicate with each other routing algorithm applications are required. Dynamic routing algorithms provide same work but considering situations like different network topology and traffic load their performances might differ. Due to undeniable inevitability of the Internet, infrastructure has been both expanded and varied. Thus, Internet performance has become one of the most essential needs in complex and vast network structure.

With the expansion and variety of network infrastructure, it has recently become more difficult to understand the performance effects of different network metrics on the network. Especially in the most used TCP/IP-based networks, throughput, packet loss, and the number of packets transmitted are performance metrics that directly affect the network's data transmission. However, considering the network's structure, topology, and routing algorithm, we can say that these parameters may vary. Therefore, in mesh topologies with multiple alternative paths, observing which dynamic routing algorithm performs better under which network conditions and drawing conclusions about this is of critical importance for future network research.

The main purpose of this thesis is to evaluate the performance of TCP/IP networks using different dynamic routing algorithms (RIP, OSPF, EIGRP, BGP) on routers within a mesh topology, to compare network parameters such as jitter, packet loss, transmitted data volume, and efficiency, and to analyze which dynamic routing algorithm performs better under specific conditions. This thesis presents an simulational reference especially for researchers and engineers who aim to model their own network topologies.

In the simulation, a network model with mesh topology are created using the GNS3 simulation software. Multiple routers are placed between two computers, and all routers are individually configured with one of the routing protocols (RIP, OSPF, EIGRP, and BGP). The two computers in the topology equipped with the Iperf3 tool, and packet transmissions are performed for specific durations. Each tests are conducted for 10 seconds, and the average values are calculated based on 10 repetitions. Afterwards, the packet sizes send per second are gradually increased, and the tests are repeated under these new conditions. All experimental results are visualized in a MATLAB environment and analyzed graphically.

In the established topology, the amount of successfully transmitted data are examined by increasing the amount of data sent per unit of time for each routing algorithm. When we investigate conclusions, we can observe very low packet loss at low data rates and many transmitted packets are delivered to the other side. For this reason, we can comment routing algorithms aren't important at low data loads. However, after passing threshold data, all the routing algorithms' data loss increased, and we observed the amount of transmitted data decreasing. In the same way, while we see increased throughput value at low data load, after the threshold, throughput decreases. After that we observe all the routing algorithms stabilizing. Additionally, it is found that the jitter parameter varied depending on the traffic load and the routing algorithm used.

This study aims to compare the performance of each routing algorithm in light of the mentioned parameters and to reveal their behavior under different network conditions. The results indicate that; there are no dramatic throughput performance differences between the routing algorithms; however, in certain network structures, specific algorithms perform more efficiently. In the small-scale mesh topology used in this study, the EIGRP routing algorithm is observed to see whether it delivers higher performance and provides the most efficient results compared to the others or not. The findings obtained from this study are intended to assist network engineers in selecting the most appropriate routing algorithm based on the network topology.

1.2 TCP/IP NETWORK FUNDAMENTALS

Nowadays internet and local area network communications are provided by TCP/IP (Transmission packet control / Internet protocol) suite . Owing to this protocol,

datas are transfered much more safely on network. Moreover TCP/IP protocol assure arriving target destination.

The TCP/IP protocol consist of two fundamental protocol . These are called as TCP (Trasnmision Control Protocol) and IP. These components provide transmission completely and accurately.

TCP , before data transfer , it separate data to packets. These packets dispatch on network .When these packets arrive on receiver , these packets are combined again with correct order. Tcp's another mission is also to implement protection mechanism in order to ensure reliability in data transmission.

IP provides appropriate network routing by specifying the path that data should follow. IP also provides an addressing capability each network.

Packet switching network provides to sending minimum lost with each combination of these protocols. Therefore, understanding the logic of TCP/IP is important in many areas, such as network design, network management, and network performance analysis.

1.2.1 What is TCP ?

TCP is an standart protocol which is used on the Internet[2]. It allows data transmission in a secured way on the devices on the network[2]. Data is transfered in a divided way during communication[2]. As the result of this divided tranmisssion , it guarantees full transmission and protects data integrity[2]. TCP also provides fundamental needs for not only application data transfer and also installisation of the network[2]. File transfer , email communication and loading time of the websites are based on this[2].

Plenty of common application protocols such as HTTP, HTTPS (HyperText Transfer Protocol Secure), FTP, SMTP, POP3 (Post Office Protocol v3) and SSH (Secure Shell) are worked on TCP/IP protocol which is a component of TCP[3]. In order to tranfer data securely TCP uses three-way handshake procedure[3]. Thus , more reliable and secure connections are set up due to this procedure[3].

Another important aspect of TCP is that packet loss prevention is accepted[4]. Furthermore, to improve security it senses mistakes and resends packets if needed[4].

In short, TCP is considered as one of the fundamental protocols which guarantees efficent , safe and flawless data transfer on the Internet. Thanks to the

features that TCP offers , it is considered as one of the most contemporary communication networks in modern era.

1.2.2 How Does TCP Work?

While we define TCP ,it has been said that it enables flawless and ordered data transmission. [5] TCP also presents variable techniques to provide data transmission. [5] Those techniques can be ordered in such way ;timers , retransmission algorithms and ACK (Acknowledgment) packets.[5]

Each sended data segments are approved by the receiver. If data is not approved within a specified time , this data is assumed as lost and thus it shall be resended. Especially, due to quick retransmit feature , it is being resent without any packet timeout.Provided that 3 ACK message are received , it is assumed that there is packet lost and afterwards related packet is resent to receiver.[5]

TCP gives a number to each packet so that it gets easier to detect the packets in the case of monitoring and loss.[5] Due to this method resend transmission and integrity of data is guaranteed.[5] Additonally, several packets can be sent due to pipelining technique simultaneously which increases the efficency of data transmission channel.[5]

Flow control and congestion control are two fundamental control systems that determine the level of data size when the data is sent.[6] It adjusts data size with respect to its data capacity.[6] Data size which is about to be sent without any approval is also determined by congestion window and advertised window.[6] Moreover, this value is also known as window size which is also a parameter accountable for network performance in a direct way.[6]

Packet switching technology is one of the fundamentals of data transfer structure. Thanks to this technology ,data is divided into managable pieces and sent via network. After that , they are united in target point. Due to this feature, more flexible and tolerant communication is provided. In order to comprehend relationship of TCP and packet switching stucture , it has critical value to analyze specified network parameters which are underperformed.

1.2.3 Layered Structure of TCP/IP

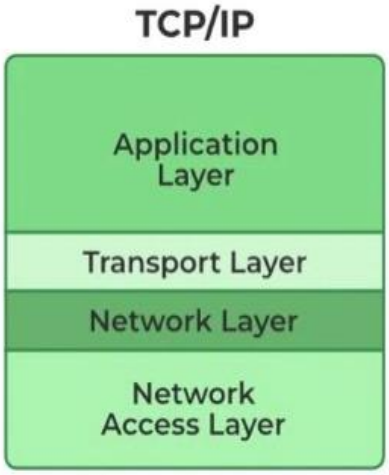


Figure 1: Layers of the TCP/IP Model [7]

As shown in Figure 1, the TCP/IP architecture consists of four basic layers: Application Layer, Transport Layer, Internet Layer, and Network Access Layer. These layers are designed to facilitate data communication. Each layer has its own specific tasks. In order to perform data exchange, the layers must cooperate with each other.

1. **Application Layer:** This layer is at the top. The application layer provides computer applications and communication between last users. The application layer carries out many actions, such as sending email, remote access, sending files, network management work, DNS interrogation etc. This layer takes part SMTP (Simple Mail Transfer Protocol), FTP (File Transfer Protocol), and HTTP (Hypertext Transfer Protocol) which are the most used protocols. Thanks to these data, various services are provided for the last users, and the data is presented clearly. [8]
2. **Transport Layer:** In this layer, large data are separated into segments in the receiver and then combined in the receiver. With this way, data are sent safely. TCP (Transmission Control Protocol) works at this layer. Furthermore, actions are provided such as data flow control, data sorting and error correction at this layer. [8]
3. **Internet Layer:** This layer assumes fundamental tasks such as addressing and redirection. Data sends correct addresses without any errors even if there are multiple networks. With this point Internet Protocol (IP) occupies an essential

role because it provides data sending at receiver and it also provides to identify device addresses. [8]

4. **Network Access Layer:** This layer provides physical connection and transferring data electrical, optical and radio signals. Network Access Layer is lowest layer. Technologies such as Ethernet, Wi-Fi, and Bluetooth can be set as examples of protocols operating at this layer. [8]

1.2.4 Performance Assessment of TCP/IP Networks

In this thesis study is investigated parameters at different routing algorithms. These parameters are throughput, jitter and packet loss ratio. Nowadays, as we do in this network structure, networks' purposes are increasing efficiency, low data latency and making minimum levels of packet loss. With this way, it is scoped, increasing data transferring performances.

The one of the critical network parameters is throughput. Throughput means the amount of data successfully transmitted within a specific time. Today, it is one of the first parameters users examine to understand the quality of an internet connection. Experimental results show us efficiency reaches maximum value at certain points; after that, it is observed to be stabilizing. This condition demonstrates to us that experiments work determinately and stable.

Packet loss means ratio of the number of undeliverable packets to the total number of packets. Parameters such as jitter, bandwidth and low transmission rate etc. effects packet loss ratio in a bad way. With ideal data packet amount and low data latency, a network's general efficiency can be increased.

Graph that summarizes the relationship between different network parameters and data performances is demonstrated in Figure 2.

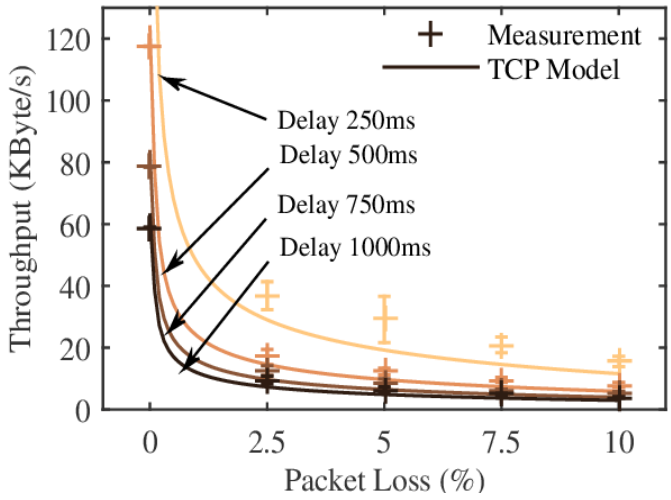


Figure 2: Impact of Delay and Packet Loss on TCP Throughput [9]

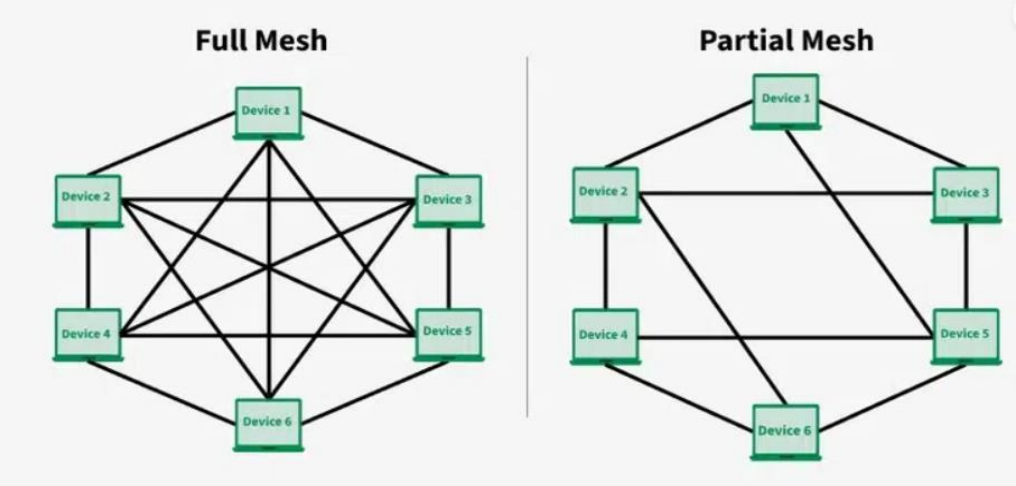
Figure 2 summarizes well the differences between latency and packet loss ratio on top of throughput effects. When this graph exceeds certain value, throughput increase along with packet loss decreases. Also, thesis experiments can be seen as having the same logic.

This works designed Mesh which is complicated topology. Experimental comparing is done using different routing algorithms (BGP, EIGRP, OSPF, RIP) in this network design. [9] As a result, there are performance differences depending on network size and the different routing protocols used. [9] As a conclusion to this experiment, the most idealist parameters are determined, and solutions are served to increase network efficiency. [9]

1.2.5 Concept of the Mesh Based Wireless Network

People who would like to design a network can design a network according to the network's needs and features. Mesh topology is one of the most used network topologies in the world. Mesh topology has more advantages than other topologies. Especially when one of the topology node has an error, this topology has to serve with other alternative nodes. Thanks to this feature, this type of topology is much more reliable than other topologies.

Mesh topology is a hybrid. That is, it contains topologies such as star, bus and ring in its constitution. Mesh topology ensures flexibility, multi-layered design and high error tolerance. This feature has made it the preferred choice for WAN (Wide Area Network) used in natural disaster zones.



(a) **(b)**

Figure 3: Full Mesh (a) and Partial Mesh (b) Topology [10]

As seen in Figure 3, it has two types of mesh topologies. These are full mesh topology and partial mesh topology.

- Full Mesh Topology: In a network, all nodes relate to each other. If there are n nodes in a network, each node must have n-1 connections.[10] A full mesh provides perfect redundancy; however, due to its high implementation cost, it is usually reserved for network backbones. [10] The total number of connections required for the network topology is [n(n-1)]/2. [10]
- Partial Mesh Topology: Partial mesh is more practical compared to full mesh. [10] In a partially connected network, not all nodes need to be connected to each other in the network path. Peripheral networks are connected using partial mesh topology. [10]

1.2.6 Routing Protocols

Routing protocols are essential to enable seamless data exchange between different networks. Routers are configured appropriately to guarantee that data packets are routed to the proper networks in order to facilitate this connection.

There are two fundamental ways to set up routing on a router: static routing and dynamic routing. The static routing algorithm is a manual technique in which IP addresses are defined one by one by network developers at a small network that is designed. However, it can be complicated on a large-scale network. The static routing

algorithm loses flexibility. Management costs increase. Additionally, the probability of making a mistake increases.

A dynamic routing algorithm's working principle is different than a static routing algorithm. Dynamic routing algorithm learns own neighborhoods. It updates tables automatically. It does not cause communication breakdowns by using an alternative node whenever any connection error happens. However, if the dynamic routing algorithm is misconfigured, it causes packet loss, delays, and data interruptions. Therefore, determining a routing algorithm suitable for the network size and usage scenario is a factor that affects the network's efficiency.

The image below, based on routing algorithm classifications and varieties, is shown.

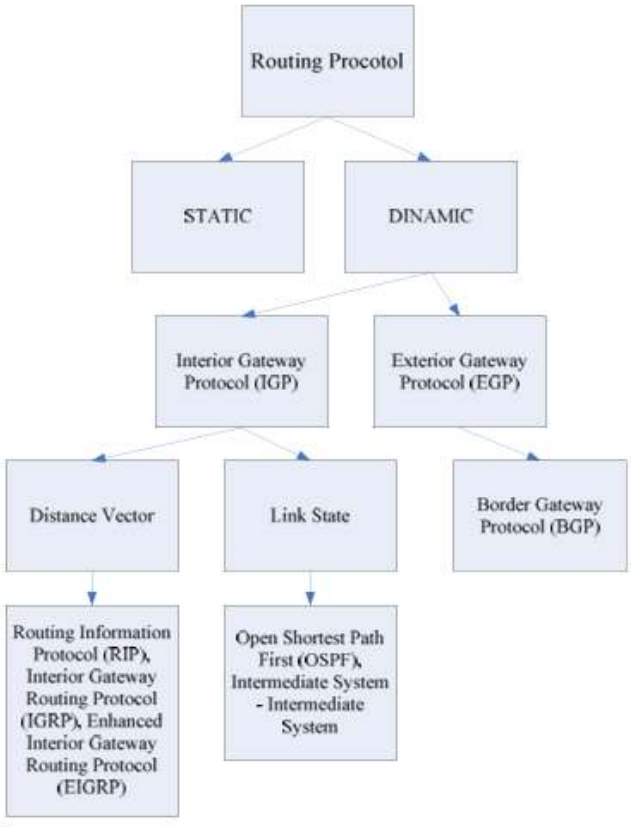


Figure 4: The classification of routing protocol [11]

As shown in figure 4, dynamic routing algorithm has two types. These are distance vector and link-state protocols. These protocols are used to transmit data in the fastest way possible with the least amount of data loss. These protocols, which investigated in this thesis, are RIP, OSPF, EIGRP and BGP. All of the protocols are

examined in detail, and also the performance of effects on the designed network is examined.

1.2.6.1 RIP

RIP is dynamic routing algorithm which protocol type is distance vector. It makes RIP routing decisions according to hop count. Hop count's maximum value is fifteen. This fact causes it to be useless at large-scale networks. This is why RIP is preferred at generally small-scale or medium-scale networks.

Routers continuously update their tables at specific intervals. While routers update, they use UDP (User Datagram Protocol) 520 port. [12] Thanks to these tables, fastest path is calculated in network. However, RIP may not always be the logical choice for reliable communication or fast data transmission in a network. [13] In some networks, when important parameters such as latency and bandwidth etc. are taken into consideration, the RIP protocol may result in insufficient communication. [13]

However, it can be said that RIP is an advantageous algorithm type for devices with insufficient RAM (Random Access Memory) and CPU (Central Processing Unit). [14] Delays in convergence time, however, can result in transmission delays and packet loss in complicated networks [14].

In conclusion, protocols like OSPF, EIGRP, or BGP offer more efficient solutions in bigger and more complicated contexts, whereas RIP's straightforward design and simplicity of use make it appropriate for small-scale networks.

1.2.6.2 OSPF

An IGP (Interior Gateway Protocol) that is link-state and hierarchical, OSPF was created specifically for intricate and sizable network architectures. Its high performance and quick convergence time allow it to function effectively in dynamic network conditions. OSPF is an effective internal routing technology because it reacts more quickly than RIP, but this also makes its architecture more complicated [15].

Every router may create a topological map of the entire network thanks to OSPF. In order to establish a shared network perspective, routers exchange link-state information. As a result, every router has the same information about the network architecture and uses it to inform its routing decisions. To keep the topology map current, network changes are broadcast to other routers using multicast.

A router sends Hello packets to surrounding routers when it joins the network, and depending on the replies it receives, it creates neighbor relationships [16]. After this stage, special messages known as LSAs (Link State Advertisements) are sent to every router in the network with link-state information. As a result, each router gains consistent knowledge about the network architecture as a whole.

Using the incoming topological information, each router constructs a shortest path tree, a mathematical structure that determines the shortest routes to destination addresses [17]. In the event of a link breakdown, this structure enables quick recalculation of alternative routes. OSPF uses various cost attributes such as bandwidth and also takes hop count information into account to make more accurate and efficient routing decisions.

One of the other OSPF's feature is separating area. Thanks to this feature, tables' sizes decrease. Complication of tables also decreases. Furthermore, OSPF is a reliable protocol type thanks to authentication support.

1.2.6.3 EIGRP

EIGRP is developed by Cisco. EIGRP has a hybrid structure. [18] Because EIGRP contains distance vector and link-state protocol. EIGRP uses autonomous system features for routers performing the same routing task. Other routers on the network learn this routing information after updates. However, the most fundamental difference from traditional distance vector protocols is its ability to store a partial network topology locally.

EIGRP uses three basic tables to make routing decisions: the Routing Table, the Neighbor Table, and the Topology Table. The two main parameters used to determine the best route are delay and bandwidth. The protocol also considers other factors such as load, reliability, and MTU (Maximum Transmission Unit) [19].

One of the main problems with traditional distance vector protocols is the use of broadcast for routing updates. Since these updates are also sent to hosts that do not need them, system resources and network bandwidth are wasted. In order to solve this problem, EIGRP ensures that only pertinent routers receive routing changes by sending them via multicast to the IP address 224.0.0.10 [20].

By sending only triggered updates, EIGRP lessens network demand while the network is up and running. Additionally, it checks the activity state of nearby routers using 1-byte Hello messages. On LAN (Local Area Network) and T1/E1 multipoint

lines, these packets are transmitted every 5 seconds; on other link types, they are sent every 60 seconds. The sender router deletes the pertinent neighbor from the routing database if it doesn't hear back within the allotted time (15 seconds for LANs, 180 seconds for other scenarios).

EIGRP is a powerful routing solution for large-scale network topologies because of its performance, reliability, and adaptability properties.

1.2.6.4 BGP

For inter-domain routing, BGP is the de facto external gateway protocol. A BGP router uses an algorithm to rate the pathways it has learned for a target IP prefix and chooses the best one [21].

Network managers can create their own routing policies using BGP to choose the best routes. This implies that different and autonomous routing strategies can be implemented by border routers.

Although BGP's policy-based routing offers flexibility, it can make routing decisions less predictable, particularly in situations where BGP parameters are not directly accessible.

BGP only chooses the optimal route to a destination by default. BGP uses criteria like the path's age or the identification of the nearby BGP router from which the path was learned to break the tie if two or more pathways have the same configurable BGP properties.

Nonetheless, the performance and reliability of the routing system may be improved by using several equally good paths.

Although BGP is essential for preserving stability in extremely big and intricate networks, errors or assaults (like BGP hijacking) can cause major issues for the entire Internet.

CHAPTER II
LITERATURE OVERVIEW

2.1 LITERATURE OVERVIEW

In order to assess the effectiveness (throughput) of routing algorithms and identify the best routing protocol based on network topology and conditions, numerous research have been carried out. These features have a direct impact on network performance since network architecture and settings differ. The purpose is to provide data transfer with minimum error percentage and delay. In the literature part there are overall investigations and network models.

[22] in this study routing algorithms such as BGP, RIP, OSPF and EIGRP are assessed by their performances on TCP. During the simulation process metric such as throughput, latency and packet loss are investigated by comparing. In the light of the outcomes, it can be seen significant changes in performances of the TCP network. Particularly, EIGRP protocol performs much more efficiently and has less packet loss.

[23] in this thesis, RIP, OSPF and EIGRP routing algorithms are examined. Thesis researchers test network topology by using simulation programs such as Cisco Packet Tracer and OPNET. Network metrics are assessed by their convergence time and traffic volume. In the result of simulation, the closest convergence can be observed even when there are errors in the EIGRP network connection. The reason is that OSPF is doing all the topology mapping. Furthermore, it can also be seen that EIGRP and OSPF are more efficient than RIP. In conclusion of the thesis, it can be understood that EIGRP has the fastest convergence and due to its efficient bandwidth usage, this is concluded that it is the most proficient protocol.

[24] in this thesis failover and load balancing metrics of routing algorithms based on BGP, OSPF and EIGRP are assessed on IPv6 based network. Parameters such as convergence time, packet loss, delay and jitter are measured by using GNS3, VMware, Wireshark and Iperf3 network tools. As the result of the simulation, it is concluded that even when EIGRP's connection malfunctions it provides fastest convergence and the lowest packet loss.

[25] in this thesis, route redistribution cases are investigated between OSPF, EIGRP and BGP protocols. These routing algorithms are compared by their efficiencies, packet loss and delay metrics. With this work, EIGRP and BGP combination provide better performance than OSPF and BGP combination by their lesser delay and more efficiency.

[26] in this thesis, convergence times of the routing algorithms such as OSPF, EIGRP, IS-IS (Intermediate System to Intermediate System) and BGP are compared. One of the most essential observations is that during the protocols' connection problems and their rerouting times they update the network such a fast way. These are the results of the study which is done on GNS3 platform: Although BGP generally has longer convergence time, inner routing protocols such as OSPF and EIGRP react faster than BGP. This study reveals that protocol selection does not only rely on topology but also metrics like network dynamics and convergence time.

[27] in this thesis, routing protocols such as RIP, EIGRP and OSPF are tested by their latency, efficiency, packet loss and convergence time parameters on OPNET environment. According to the result, while OSPF provides more stability on bigger networks, RIP performs much better in the smaller scale of networks. This study signifies the importance of performance requirement and network design while selecting routing algorithms.

In literature, similar studies can be seen but this thesis has different working methodology. No other thesis example has been found that analyzes RIP, OSPF, EIGRP, and BGP routing algorithms simultaneously on a mesh topology.

The primary difference between this thesis and earlier research is the thorough analysis of performance outcomes based on packet size, packet loss variations, and the graphical display of these results. Chapter 3 provides a detailed explanation of the analyses that were performed and the procedures that were used.

CHAPTER III
METHODOLOGY

3.1 SIMULATION ENVIRONMENT

GNS3 software is chosen for this study's network topology design and simulation. GNS3 has more sophisticated features than other simulation tools when it comes to simulating live packet transfer and realistic network activity. Despite being taken into consideration at first, Cisco Packet Tracer is determined to be inadequate for producing real-time traffic and carrying out thorough performance analysis.

The virtual working environment is set up once GNS3 is installed, and the system is combined with image files (library components) of the routers and client devices that would be utilized in the simulation. It is thought to be crucial that the virtual machine images support the Iperf3 program to carry out the simulation successfully. In order to enable network performance analysis, Iperf3 is installed on virtual machines using the command line.

Iperf3 is a popular, trustworthy, and open-source testing tool used to gauge and examine network data transmission performance. This program allowed for the measurement of important factors in the simulation environment, including bandwidth, packet loss, and latency.

3.2 NETWORK TOPOLOGY DESIGN

The network topology creates in the simulation environment consists of nine routers and two end-user computers. The network structure has been designed to comply with the mesh topology definition mentioned in the introduction. The routers are connected to each other in such a way that there will be multiple connections. But only computers are connected to one router and they are placed to the networks' endpoints.

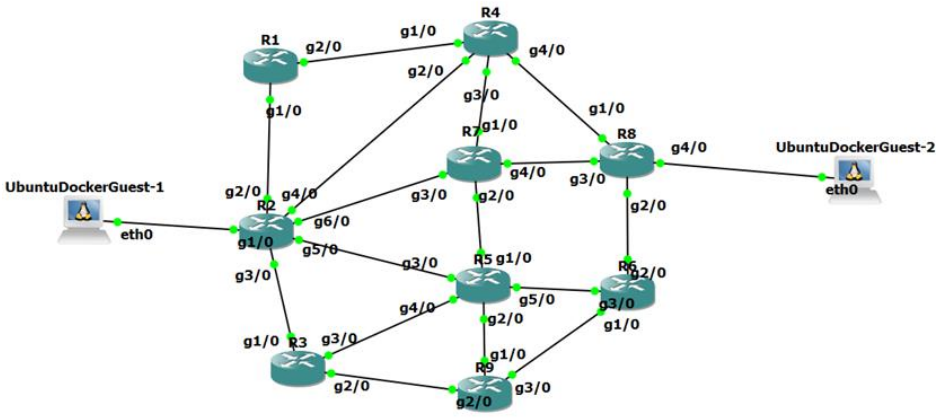


Figure 5: Mesh topology in GNS3 simulation

Figure 5 shows the network topology we designed in the GNS3 simulation environment. In this figure, the routers are labeled with numbers. The port type for the routers is set to Gigabit Ethernet. In the image, the ports are abbreviated as G2/0, and each router's port is also numbered.

Gigabit Ethernet ports are often used in network topologies that require high bandwidth. These ports are preferred for communication between routers in complex topologies such as star and mesh. Computers, on the other hand, have Ethernet ports labeled eth0 that provide wired network connections to routers.

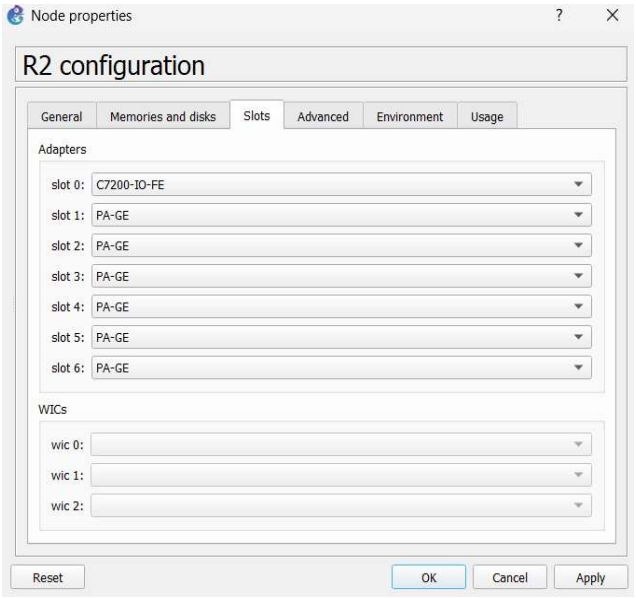


Figure 6: Router Port Configuration in Mesh Topology (GNS3)

Figure 6 demonstrates routers' port configurations. These settings are necessary to create a sufficient number of ports in the network topology. For example, the structure shown on Router 2 clearly demonstrates this requirement.

As a result, for the network simulation to operate smoothly and to avoid delay or data loss during packet transmission, it is critically important to prefer high-speed and stable connection methods.

3.3 IP ADDRESSING AND CONFIGURATION PROCESS

In accordance with the prepared topology, a unique IP address was assigned to each router and end device. There are some important points to consider during this process. First, routers that are directly connected to each other must be located within the same subnet. However, the interfaces (ports) of each router should be configured to belong to different networks. This ensures that routing operations can be performed correctly.

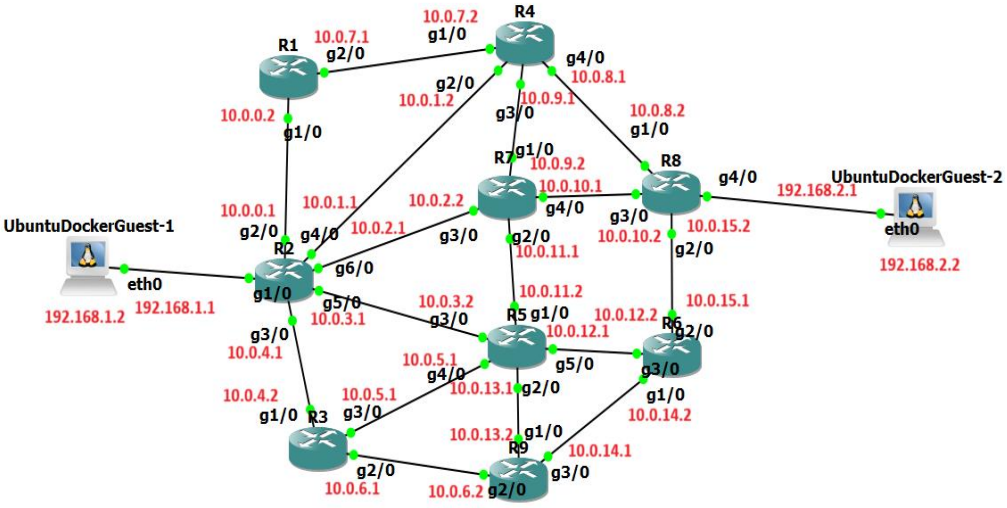


Figure 7: IP Information of Routers and Computers in Mesh Topology

Figure 7 schematically presents the IP address information of the routers and computers in the mesh topology. Based on this IP plan, the dynamic routing protocols (RIP, OSPF, EIGRP, and BGP) to be used in the simulation have been configured individually on each router.

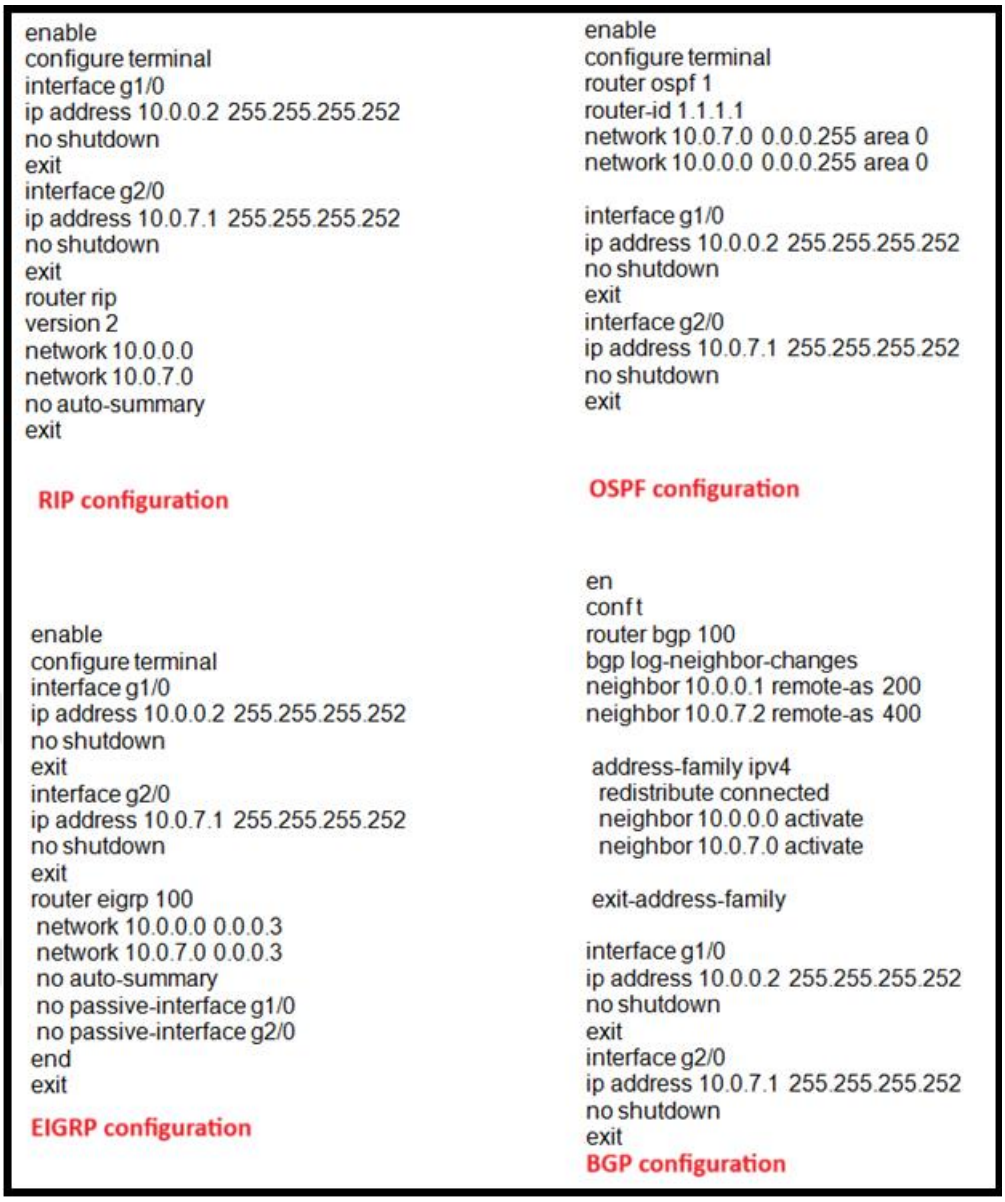


Figure 8: Configuration of Dynamic Protocols on Router 1

Figure 8 shows an example of the dynamic protocol configuration for Router 1. Similarly, configurations for other routers were completed using appropriate commands according to their connected ports and neighboring routers. Necessary protocol settings were made through each router's interfaces, enabling the creation of routing tables.

After the router configurations, the IP addresses and default gateway information for the end devices were defined.

3.4 DATA COLLECTION METHOD

After applying the dynamic routing protocol to all network routers, ping tests were performed on each port to evaluate the status of the connections in the network. If the ping operation was successful, the Iperf3 tool was used to measure data transmission. In the initial phase, the UbuntuDockerGuest-1 computer was configured in server mode. Similarly, the UbuntuDockerGuest-2 computer was configured in client mode to carry out data transmission. These procedures are visually represented in Figures 9 and 10, respectively.

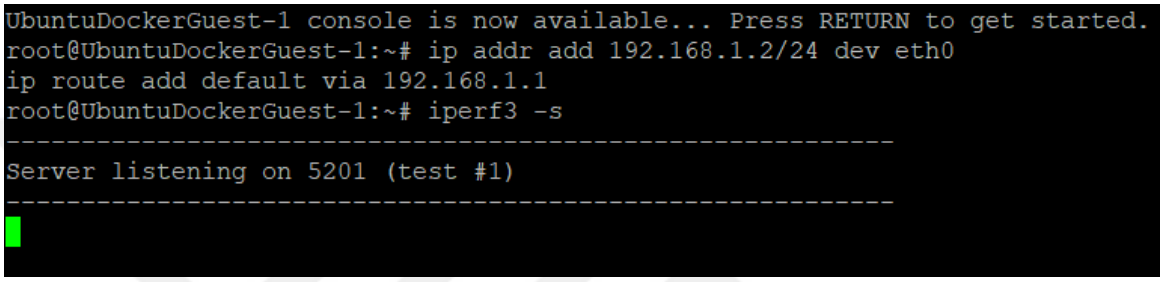


Figure 9: Iperf3 Server Command on UbuntuDockerGuest-1 (GNS3)

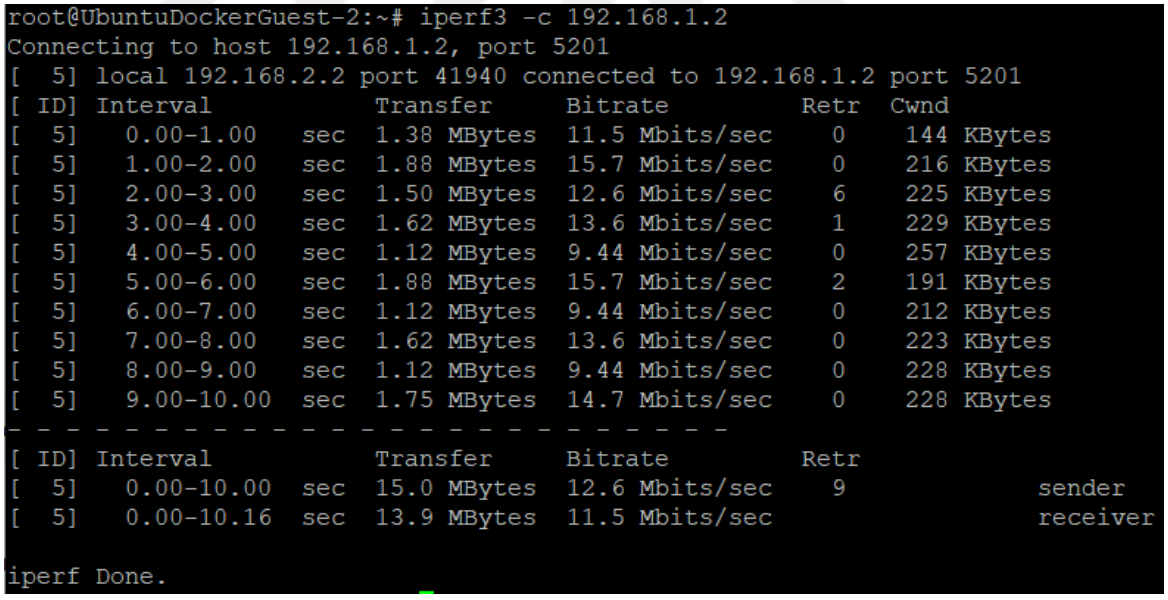


Figure 10: Iperf3 Server Command on UbuntuDockerGuest-2 (GNS3)

As shown in Figures 9 and 10, using the command written with the Iperf3 tool, data transfer was carried out from the UbuntuDockerGuest-2 computer to theUbuntuDockerGuest-1 computer in the topology shown in Figure 5, with specific packet sizes. As a result of this experiment, different performance results and metrics were obtained by changing the packet sizes.

3.5 APPLICATION PROCESS

When the UbuntuDockerGuest-2 computer sends data to the UbuntuDockerGuest-1 computers, the simulation duration is set to 10 seconds.

```
root@UbuntuDockerGuest-2:~# iperf3 -c 192.168.1.2 -u -b 10M
Connecting to host 192.168.1.2, port 5201
[  5] local 192.168.2.2 port 49228 connected to 192.168.1.2 port 5201
[ ID] Interval           Transfer     Bitrate         Total Datagrams
[  5]   0.00-1.00   sec  1.19 MBytes  10.0 Mbits/sec  863
[  5]   1.00-2.00   sec  1.19 MBytes  10.0 Mbits/sec  863
[  5]   2.00-3.00   sec  1.19 MBytes  10.0 Mbits/sec  863
[  5]   3.00-4.00   sec  1.19 MBytes  10.0 Mbits/sec  864
[  5]   4.00-5.00   sec  1.19 MBytes  10.0 Mbits/sec  863
[  5]   5.00-6.00   sec  1.19 MBytes  10.0 Mbits/sec  863
[  5]   6.00-7.00   sec  1.19 MBytes  10.0 Mbits/sec  864
[  5]   7.00-8.00   sec  1.19 MBytes  10.0 Mbits/sec  863
[  5]   8.00-9.00   sec  1.19 MBytes  10.0 Mbits/sec  863
[  5]   9.00-10.00  sec  1.19 MBytes  9.98 Mbits/sec  863
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bitrate         Jitter    Lost/Total Datagrams
[  5]   0.00-10.00  sec  11.9 MBytes  10.0 Mbits/sec  0.000 ms  0/8632 (0%)  sender
[  5]   0.00-10.09  sec  11.9 MBytes  9.91 Mbits/sec  1.864 ms  0/8632 (0%)  receiver

iperf Done.
```

Figure 11: UbuntuDockerGuest-2 Iperf3 Client Command

As seen in Figure 11, the Iperf3 tool is used while these actions are being done. According to obtained results, performance analyses are conducted. Firstly UbuntuDockerGuest-2, initially configured as a client, begins sending data to the server device UbuntuDockerGuest-1. As seen as command output, the value of 10 Mbit/s indicates the bit rate, which shows the amount of data transmitted per second.

The simulation conducted to evaluate the performance of increasing data packet sizes continued with increasing bit rate values. The bit rate values used in this context are listed below:

5 Mbit/s, 10 Mbit/s, 11 Mbit/s, 12 Mbit/s, 13 Mbit/s, 14 Mbit/s, 15 Mbit/s, 20 Mbit/s, 25 Mbit/s, 30 Mbit/s, 35 Mbit/s, 40 Mbit/s, 45 Mbit/s, 50 Mbit/s, 55 Mbit/s, 60 Mbit/s, 65 Mbit/s, 70 Mbit/s, 75 Mbit/s, 80 Mbit/s, 85 Mbit/s, 90 Mbit/s, 95 Mbit/s, 100 Mbit/s.

After the data is sent to the receiver, the parameters obtained in the simulation are as follows: Transfer (Sender) (MBytes/sec), Transfer (Receiver) (MBytes/sec), Throughput (MBytes/10sec), Jitter (Sender) (ms), Jitter (Receiver) (ms), Packet Loss (%) (Receiver), Lost/Total Datagram (Sender), and Lost/Total Datagram (Receiver). Let us briefly explain what these parameters represent.

Transfer (Sender): Amount of data sent by UbuntuDockerGuest-2 (MBytes/sec)
Transfer (Receiver): Amount of data received on the UbuntuDockerGuest-1 computer (MBytes/sec)
Throughput: Amount of data successfully transmitted within ten seconds (MBytes/10sec)
Jitter (Sender): Latency variation on the UbuntuDockerGuest-2 side (ms)
Jitter (Receiver): Latency variation on the UbuntuDockerGuest-1 side (ms)
Packet Loss (%) (Receiver): Packet loss percentage on UbuntuDockerGuest-1 (%)
Lost/Total Datagram (Sender): Ratio of lost packets to total packets sent by UbuntuDockerGuest-2
Lost/Total Datagram (Receiver): Ratio of packets lost before delivery by UbuntuDockerGuest-1 to total packets

The BGP, EIGRP, RIP, and OSPF protocols were examined independently on the built mesh topology in light of the results that were obtained. The arithmetic means of the data gathered were computed after ten repetitions of each dynamic routing protocol were carried out at each designated bit rate level. By lowering measurement errors, this technique made guaranteed that protocol comparisons were more accurate and consistent.

Methodologically:

1. Within the mesh topology, analyses of the BGP, EIGRP, RIP, and OSPF protocols were carried out.
2. The bit rate has been regularly increased in topologies where routing algorithms are applied.
3. Ten measurements are repeated for each bitrate . These values are added and their average is calculated.
4. This reduces the impact of measurement errors and deviations. This technique is used in other studies.

This approach is called the “multiple measurements for each parameter – averaging” strategy in literature [28].

CHAPTER IV
RESULTS AND DISCUSSION

The results of the parameters mentioned in the Methods section are obtained. Tables are created according to experiment results. These tables are examined in detail and compared with each other. As seen in the Implementation Process section, results are obtained from network metrics such as throughput, packet size, transmitted packet size, and total data units. Reasons for the resulting analyses are investigated. Obtained data has emerged as graphs in the MATLAB environment. Thanks to graphs, differences are clearly observed.

At the start of the simulation, performance analyses of the BGP, EIGRP, RIP, and OSPF routing protocols are conducted on a mesh topology at bit rates of 5 Mbit/s, 10 Mbit/s, 11 Mbit/s, and 12 Mbit/s. The results are presented in Tables 1 through 4 below.

Table 1: Results of Routing Protocols for 5 Mbit/s Bit rate

Routing Protocol	Transfer (Sender) (MBytes/sec)	Bit rate (Sender) (Mbits/sec)	Throughput (Receiver) (MBytes/sec)	Throughput (MBytes/10sec)	Jitter (Sender) (ms)	Jitter (Receiver) (ms)	Packet Loss (%)	Lost / Total Datagram (Sender)	Lost / Total Datagram (Receiver)
BGP	6,25	5	6,19	0,619	0	3,278	0	0\4316	0\4316
EIGRP	6,25	5	6,19	0,619	0	3,477	0	0\4316	0\4316
RIP	6,25	5	6,19	0,619	0	3,477	0	0\4316	0\4316
OSPF	6,25	5	6,19	0,619	0	3,506	0	0\4316	0\4316

Table 2: Results of Routing Protocols for 10 Mbit/s Bit rate

Routing Protocol	Transfer (Sender) (MBytes/sec)	Bit rate (Sender) (Mbits/sec)	Throughput (Receiver) (MBytes/sec)	Throughput (MBytes/10sec)	Jitter (Sender) (ms)	Jitter (Receiver) (ms)	Packet Loss (%)	Lost / Total Datagram (Sender)	Lost / Total Datagram (Receiver)
BGP	12,5	10	12,38	1,238	0	1,958	0	0\8632	0\8632
EIGRP	12,5	10	12,38	1,238	0	1,963	0	0\8632	0\8632
RIP	12,5	10	12,39	1,239	0	1,864	0	0\8632	0\8632
OSPF	12,5	10	12,39	1,239	0	1,866	0	0\8632	0\8632

Table 3: Results of Routing Protocols for 11 Mbit/s Bit rate

Routing Protocol	Transfer (Sender) (MBytes/sec)	Bit rate (Sender) (Mbits/sec)	Throughput (Receiver) (MBytes/sec)	Throughput (MBytes/10sec)	Jitter (Sender) (ms)	Jitter (Receiver) (ms)	Packet Loss (%)	Lost / Total Datagram (Sender)	Lost / Total Datagram (Receiver)
BGP	13,75	11	13,63	1,363	0	2,215	0	0\9495	0\9495
EIGRP	13,75	11	13,63	1,363	0	1,667	0	0\9495	0\9495
RIP	13,75	11	13,63	1,363	0	1,738	0	0\9495	0\9495
OSPF	13,75	11	13,63	1,363	0	2,085	0	0\9495	0\9495

Table 4: Results of Routing Protocols for 12 Mbit/s Bit rate

Routing Protocol	Transfer (Sender) (MBytes/sec)	Bit rate (Sender) (Mbits/sec)	Throughput (Receiver) (MBytes/sec)	Throughput (MBytes/10sec)	Jitter (Sender) (ms)	Jitter (Receiver) (ms)	Packet Loss (%)	Lost / Total Datagram (Sender)	Lost / Total Datagram (Receiver)
BGP	15	12	14,75	1,475	0	1,733	0	0\10359	0\10359
EIGRP	15	12	14,3	1,43	0	1,385	0	0\10359	0\10356
RIP	15	12	14,3	1,43	0	1,68	0	0\10359	0\10355
OSPF	15	12	14,75	1,475	0	1,631	0	0\10359	0\10359

Upon examining the tables above, it was observed that packet loss was zero in all routing algorithms. This situation demonstrates providing high reliability at low bit rate values.

It can be seen that as the bit rate increases, the amount of data transmitted by the sender (Transfer - Sender) also increases. Almost all the packages are delivered. The amount of data received by the receiver (Transfer - Sender) is very close to the sender's value.

Throughput increased in direct proportion to the bit rate. Jitter shows difference when it compares with other parameters. This difference is not merely an increase or decrease. This is why jitters have not been a decisive metric.

No significant loss is observed in the datagram either. The number of datagrams sent and delivered to the other side is almost identical. This situation can be considered an indicator that the system is operating efficiently.

As a result, all routing protocols evaluated within the 5–12 Mbit/sec range (BGP, EIGRP, RIP, OSPF) demonstrated similar throughput and packet transmission performance, with no significant performance differences observed between them. However, this situation changed in subsequent simulations starting with Table 5. When the bit rate value increased, noticeable differences occurred particularly in packet loss rates, and these changes are presented in detail in the following tables.

Table 5: Results of Routing Protocols for 13 Mbit/s Bit rate

Routing Protocol	Transfer (Sender) (MBytes/sec)	Bit rate (Sender) (Mbits/sec)	Throughput (Receiver) (MBytes/sec)	Throughput (MBytes/10sec)	Jitter (Sender) (ms)	Jitter (Receiver) (ms)	Packet Loss (%)	Lost / Total Datagram (Sender)	Lost / Total Datagram (Receiver)
BGP	16,25	13	13,68	1,368	0	1,711	10,1	0/11222	1135/11222
EIGRP	16,25	13	14,24	1,424	0	1,638	7,35	0/11222	818/11128
RIP	16,25	13	12,1	1,21	0	1,692	21,66	0/11222	2423/11184
OSPF	16,25	13	13,45	1,345	0	1,873	13,24	0/11222	1486/11222

Table 6: Results of Routing Protocols for 14 Mbit/s Bit rate

Routing Protocol	Transfer (Sender) (MBytes/sec)	Bit rate (Sender) (Mbits/sec)	Throughput (Receiver) (MBytes/sec)	Throughput (MBytes/10sec)	Jitter (Sender) (ms)	Jitter (Receiver) (ms)	Packet Loss (%)	Lost / Total Datagram (Sender)	Lost / Total Datagram (Receiver)
BGP	17,5	14	12,85	1,285	0	1,618	23,74	0\12085	2869/12085
EIGRP	17,5	14	13,48	1,348	0	1,759	19,2	0\12085	2318/12085
RIP	17,5	14	11,8	1,18	0	1,833	25,01	0\12085	2853/11403
OSPF	17,5	14	11,64	1,164	0	1,664	30,33	0\12085	3666/12085

Table 7: Results of Routing Protocols for 15 Mbit/s Bit rate

Routing Protocol	Transfer (Sender) (MBytes/sec)	Bit rate (Sender) (Mbits/sec)	Throughput (Receiver) (MBytes/sec)	Throughput (MBytes/10sec)	Jitter (Sender) (ms)	Jitter (Receiver) (ms)	Packet Loss (%)	Lost / Total Datagram (Sender)	Lost / Total Datagram (Receiver)
BGP	18,75	15	12,02	1,202	0	1,745	32,93	0\12948	4262 / 12945
EIGRP	18,75	15	13,13	1,313	0	1,8	25,82	0\12948	3313/12830
RIP	18,75	15	11,76	1,176	0	1,9913	34,3	0\12948	4435/ 12947
OSPF	18,75	15	10,95	1,095	0	1,763	37,73	0\12948	4811/12749

Table 8: Results of Routing Protocols for 20 Mbit/s Bit rate

Routing Protocol	Transfer (Sender) (MBytes/sec)	Bit rate (Sender) (Mbits/sec)	Throughput (Receiver) (MBytes/sec)	Throughput (MBytes/10sec)	Jitter (Sender) (ms)	Jitter (Receiver) (ms)	Packet Loss (%)	Lost / Total Datagram (Sender)	Lost / Total Datagram (Receiver)
BGP	25	20	11,14	1,114	0	1,643	53,34	0\17264	9192/17240
EIGRP	25	20	13,13	1,313	0	1,8	25,82	0\17264	3312/12830
RIP	25	20	10,66	1,066	0	1,658	52,35	0\17264	8479/16197
OSPF	25	20	9,73	0,973	0	1,827	59,18	0\17264	10214/17257

Table 9: Results of Routing Protocols for 25 Mbit/s Bit rate

Routing Protocol	Transfer (Sender) (MBytes/sec)	Bit rate (Sender) (Mbits/sec)	Throughput (Receiver) (MBytes/sec)	Throughput (MBytes/10sec)	Jitter (Sender) (ms)	Jitter (Receiver) (ms)	Packet Loss (%)	Lost / Total Datagram (Sender)	Lost / Total Datagram (Receiver)
BGP	31,25	25	11,44	1,144	0	1,83	60,23	0/21580	12470/20702
EIGRP	31,25	25	12,85	1,285	0	1,756	56,59	0/21580	12117/21410
RIP	31,25	25	10,11	1,011	0	1,715	65,54	0/21580	13917/21235
OSPF	31,25	25	9,85	0,985	0	1,739	65,76	0/21580	13715/20855

Table 10: Results of Routing Protocols for 30 Mbit/s Bit rate

Routing Protocol	Transfer (Sender) (MBytes/sec)	Bit rate (Sender) (Mbits/sec)	Throughput (Receiver) (MBytes/sec)	Throughput (MBytes/10sec)	Jitter (Sender) (ms)	Jitter (Receiver) (ms)	Packet Loss (%)	Lost / Total Datagram (Sender)	Lost / Total Datagram (Receiver)
BGP	37,5	30	11,16	1,116	0	1,478	67,85	0/25896	17226/25384
EIGRP	37,5	30	12,03	1,203	0	1,696	65,83	0/25896	16763/25464
RIP	37,5	30	8,21	0,821	0	2,152	76,06	0/25896	18892/24837
OSPF	37,5	30	9,85	0,985	0	1,793	70,96	0/25896	17436/24570

Table 11: Results of Routing Protocols for 35 Mbit/s Bit rate

Routing Protocol	Transfer (Sender) (MBytes/sec)	Bit rate (Sender) (Mbits/sec)	Throughput (Receiver) (MBytes/sec)	Throughput (MBytes/10sec)	Jitter (Sender) (ms)	Jitter (Receiver) (ms)	Packet Loss (%)	Lost / Total Datagram (Sender)	Lost / Total Datagram (Receiver)
BGP	43,75	35	11,24	1,124	0	1,684	72,06	0/30212	20585/28562
EIGRP	43,75	35	12,85	1,285	0	1,919	67,34	0/30212	19186/28493
RIP	43,75	35	8,85	0,885	0	1,838	76,79	0/30212	21214/27624
OSPF	43,75	35	9,32	0,932	0	1,726	76,72	0/30212	22247/28997

Table 12: Results of Routing Protocols for 40 Mbit/s Bit rate

Routing Protocol	Transfer (Sender) (MBytes/sec)	Bit rate (Sender) (Mbits/sec)	Throughput (Receiver) (MBytes/sec)	Throughput (MBytes/10sec)	Jitter (Sender) (ms)	Jitter (Receiver) (ms)	Packet Loss (%)	Lost / Total Datagram (Sender)	Lost / Total Datagram (Receiver)
BGP	50	40	11,12	1,112	0	1,744	76,42	0/34528	26293/34407
EIGRP	50	40	12,09	1,209	0	1,741	74,4	0/34528	25243/34000
RIP	50	40	8,37	0,837	0	2,042	81,24	0/34528	26268/32335
OSPF	50	40	9,46	0,946	0	1,455	79,57	0/34528	26694/33545

Table 13: Results of Routing Protocols for 45 Mbit/s Bit rate

Routing Protocol	Transfer (Sender) (MBytes/sec)	Bit rate (Sender) (Mbits/sec)	Throughput (Receiver) (MBytes/sec)	Throughput (MBytes/10sec)	Jitter (Sender) (ms)	Jitter (Receiver) (ms)	Packet Loss (%)	Lost / Total Datagram (Sender)	Lost / Total Datagram (Receiver)
BGP	56,25	45	11,16	1,116	0	1,841	78,89	0/38844	30164/38277
EIGRP	56,25	45	12,2	1,22	0	1,91	76,2	0/38844	28709/37555
RIP	56,25	45	8,45	0,845	0	2,071	83,1	0/38844	30084/36202
OSPF	56,25	45	9,29	0,929	0	1,748	82,44	0/38844	31580/38307

Table 14: Results of Routing Protocols for 50 Mbit/s Bit rate

Routing Protocol	Transfer (Sender) (MBytes/sec)	Bit rate (Sender) (Mbits/sec)	Throughput (Receiver) (MBytes/sec)	Throughput (MBytes/10sec)	Jitter (Sender) (ms)	Jitter (Receiver) (ms)	Packet Loss (%)	Lost / Total Datagram (Sender)	Lost / Total Datagram (Receiver)
BGP	62,5	50	11,88	1,188	0	1,573	80	0/43161	34433/43088
EIGRP	62,5	50	12,55	1,255	0	1,673	78,73	0/43161	33637/42723
RIP	62,5	50	8,13	0,813	0	1,785	86,12	0/43161	36538/42428
OSPF	62,5	50	9,27	0,927	0	2,061	83,73	0/43161	34576/41294

Table 15: Results of Routing Protocols for 55 Mbit/s Bit rate

Routing Protocol	Transfer (Sender) (MBytes/sec)	Bit rate (Sender) (Mbits/sec)	Throughput (Receiver) (MBytes/sec)	Throughput (MBytes/10sec)	Jitter (Sender) (ms)	Jitter (Receiver) (ms)	Packet Loss (%)	Lost / Total Datagram (Sender)	Lost / Total Datagram (Receiver)
BGP	68,75	55	11,76	1,176	0	1,88	80,98	0/47476	36286/44814
EIGRP	68,75	55	12,13	1,213	0	1,492	81,49	0/47476	38672/47453
RIP	68,75	55	8,36	0,836	0	1,717	87,06	0/47476	40734/46786
OSPF	68,75	55	9,2	0,92	0	2,098	85,5	0/47476	39307/45972

Table 16: Results of Routing Protocols for 60 Mbit/s Bit rate

Routing Protocol	Transfer (Sender) (MBytes/sec)	Bit rate (Sender) (Mbits/sec)	Throughput (Receiver) (MBytes/sec)	Throughput (MBytes/10sec)	Jitter (Sender) (ms)	Jitter (Receiver) (ms)	Packet Loss (%)	Lost / Total Datagram (Sender)	Lost / Total Datagram (Receiver)
BGP	75	60	11,43	1,143	0	1,553	84	0/51793	43508/51778
EIGRP	75	60	12,12	1,212	0	1,724	82,67	0/51793	41854/50626
RIP	75	60	8,4	0,84	0	3,53	87,42	0/51793	42284/48366
OSPF	75	60	9,05	0,905	0	1,747	86,84	0/51793	43232/49783

Table 17: Results of Routing Protocols for 65 Mbit/s Bit rate

Routing Protocol	Transfer (Sender) (MBytes/sec)	Bit rate (Sender) (Mbits/sec)	Throughput (Receiver) (MBytes/sec)	Throughput (MBytes/10sec)	Jitter (Sender) (ms)	Jitter (Receiver) (ms)	Packet Loss (%)	Lost / Total Datagram (Sender)	Lost / Total Datagram (Receiver)
BGP	81,25	65	11,08	1,108	0	1,761	85,59	0/56107	47962/56065
EIGRP	81,25	65	12,25	1,225	0	1,717	84,1	0/56107	47085/55948
RIP	81,25	65	8,51	0,851	0	1,868	88,71	0/56107	48436/54598
OSPF	81,25	65	9,16	0,916	0	1,992	87,79	0/56107	47754/54395

Table 18: Results of Routing Protocols for 70 Mbit/s Bit rate

Routing Protocol	Transfer (Sender) (MBytes/sec)	Bit rate (Sender) (Mbits/sec)	Throughput (Receiver) (MBytes/sec)	Throughput (MBytes/10sec)	Jitter (Sender) (ms)	Jitter (Receiver) (ms)	Packet Loss (%)	Lost / Total Datagram (Sender)	Lost / Total Datagram (Receiver)
BGP	87,5	70	11,73	1,173	0	1,635	85,86	0/60424	51743/60305
EIGRP	87,5	70	12,29	1,229	0	1,617	85,07	0/60424	50692/59585
RIP	87,5	70	8,33	0,833	0	1,787	89,22	0/60424	49958/55994
OSPF	87,5	70	9,3	0,93	0	1,786	88,39	0/60424	51264/57999

Table 19: Results of Routing Protocols for 75 Mbit/s Bit rate

Routing Protocol	Transfer (Sender) (MBytes/sec)	Bit rate (Sender) (Mbits/sec)	Throughput (Receiver) (MBytes/sec)	Throughput (MBytes/10sec)	Jitter (Sender) (ms)	Jitter (Receiver) (ms)	Packet Loss (%)	Lost / Total Datagram (Sender)	Lost / Total Datagram (Receiver)
BGP	93,75	75	11,64	1,164	0	1,736	86,56	0/64739	54229/62689
EIGRP	93,75	75	12,6	1,26	0	1,4523	85,6	0/64739	53935/ 63068
RIP	93,75	75	8,49	0,849	0	1,694	90,24	0/64739	56795/62937
OSPF	93,75	75	9,17	0,917	0	2,005	89,65	0/64739	57524/64164

Table 20: Results of Routing Protocols for 80 Mbit/s Bit rate

Routing Protocol	Transfer (Sender) (MBytes/sec)	Bit rate (Sender) (Mbits/sec)	Throughput (Receiver) (MBytes/sec)	Throughput (MBytes/10sec)	Jitter (Sender) (ms)	Jitter (Receiver) (ms)	Packet Loss (%)	Lost / Total Datagram (Sender)	Lost / Total Datagram (Receiver)
BGP	100	80	11,61	1,161	0	1,662	88,24	0/69057	60887/69022
EIGRP	100	80	12,42	1,242	0	1,703	86,72	0/69057	58853/67864
RIP	100	80	8,48	0,848	0	1,714	90,52	0/69057	58714/64859
OSPF	100	80	9,51	0,951	0	2,127	89,92	0/69057	61398/68282

Table 21: Results of Routing Protocols for 85 Mbit/s Bit rate

Routing Protocol	Transfer (Sender) (MBytes/sec)	Bit rate (Sender) (Mbits/sec)	Throughput (Receiver) (MBytes/sec)	Throughput (MBytes/10sec)	Jitter (Sender) (ms)	Jitter (Receiver) (ms)	Packet Loss (%)	Lost / Total Datagram (Sender)	Lost / Total Datagram (Receiver)
BGP	106,25	85	11,19	1,119	0	1,461	88,88	0/73371	63600/71596
EIGRP	106,25	85	12,15	1,215	0	1,625	87,99	0/73371	64504/73307
RIP	106,25	85	8,12	0,812	0	1,755	91,52	0/73371	63477/69359
OSPF	106,25	85	9,65	0,965	0	1,815	90,13	0/73371	63731/70712

Table 22: Results of Routing Protocols for 90 Mbit/s Bit rate

Routing Protocol	Transfer (Sender) (MBytes/sec)	Bit rate (Sender) (Mbits/sec)	Throughput (Receiver) (MBytes/sec)	Throughput (MBytes/10sec)	Jitter (Sender) (ms)	Jitter (Receiver) (ms)	Packet Loss (%)	Lost / Total Datagram (Sender)	Lost / Total Datagram (Receiver)
BGP	112,5	90	11,44	1,144	0	2,02	89,02	0/77687	67159/75387
EIGRP	112,5	90	12,22	1,222	0	1,635	88,5	0/77687	68015/76850
RIP	112,5	90	8,73	0,873	0	1,922	91,42	0/77687	67345/73661
OSPF	112,5	90	9,6	0,96	0	1,9	90,8	0/77687	68595/75545

Table 23: Results of Routing Protocols for 95 Mbit/s Bit rate

Routing Protocol	Transfer (Sender) (MBytes/sec)	Bit rate (Sender) (Mbits/sec)	Throughput (Receiver) (MBytes/sec)	Throughput (MBytes/10sec)	Jitter (Sender) (ms)	Jitter (Receiver) (ms)	Packet Loss (%)	Lost / Total Datagram (Sender)	Lost / Total Datagram (Receiver)
BGP	118,75	95	11,2	1,12	0	1,812	89,74	0/81994	71690/79863
EIGRP	118,75	95	12,76	1,276	0	1,766	88,45	0/81994	70773/80014
RIP	118,75	95	8,14	0,814	0	1,687	92,44	0/81994	72117/78015
OSPF	118,75	95	9,49	0,949	0	2,246	91,48	0/81994	73684/80549

Table 24: Results of Routing Protocols for 100 Mbit/s Bit rate

Routing Protocol	Transfer (Sender) (MBytes/sec)	Bit rate (Sender) (Mbits/sec)	Throughput (Receiver) (MBytes/sec)	Throughput (MBytes/10sec)	Jitter (Sender) (ms)	Jitter (Receiver) (ms)	Packet Loss (%)	Lost / Total Datagram (Sender)	Lost / Total Datagram (Receiver)
BGP	125	100	11,64	1,164	0	1,728	90,23	0/86310	77820/86251
EIGRP	125	100	12,22	1,222	0	2,01	89,18	0/86310	73007/81861
RIP	125	100	8,54	0,854	0	1,748	92,39	0/86310	75023/81202
OSPF	125	100	9,47	0,947	0	1,715	91,97	0/86310	78542/85397

In the analyses from Table 5 to Table 24, it was observed that the amount of data transmitted by the sender consistently increased with rising bit rate values. The main reason for this increase is the gradual increment of the bit rate during the simulation. Initially in this experiment, data loss doesn't occur at low bit rates. All of the packets are transmitted to the receiver. However, after a certain threshold (breakpoint), although the amount of transmitted data continued to increase, packet loss rates started to rise and decreases in the received data amount began.

The throughput amount reaching the receiver in 1 second is fixed in each routing algorithm. These values are approximately 1 MByte/s for BGP, 12 MByte/s for EIGRP, 8 MByte/s for RIP, and 9 MByte/s for OSPF. Although the sender continuously increases the amount of data, the maximum amount of data the receiver can receive remains constant. This is related to packet loss in the network. Consequently, network efficiency has also decreased.

As seen in Table 1–4 at the beginning, throughput is increased proportionally to the bit rate. Throughput of routing algorithms is increased to a certain level. This peak value is approximately 1.4 MByte/10 seconds. However, the throughput has stabilized after a bit rate of 12 Mbit/s. There are decreases in the amount of data reaching the receiver. This situation may be caused by network congestion and overload.

When jitter values is investigated, inconsistent deviations are observed. It is not possible to make a comment when these values are investigated. The jitter level is observed to remain at the millisecond level. In summary, jitters are not a decisive performance parameter in this simulation environment.

To summarize by comparing the protocols:

- RIP is a protocol that experiences the highest packet loss at increasing bit rates. It is the protocol with the lowest throughput int this experiment. Consequently, RIP is a protocol that has the lowest performance at high data load.
- Although OSPF performs well compared to RIP, it has experienced performance degradation under high data loads. It has been unable to maintain its stability.
- BGP demonstrated better performance compared to OSPF. It is experienced low packet loss when compared with OSPF. Throughput of BGP is more acceptable than throughput of OSPF.
- EIGRP demonstrates the best performance. It has experienced the lowest packet loss and the highest throughput in simulation. This routing algorithm provides the most efficient communication in this experiment.

As a result, although the EIGRP protocol is more efficient than others, a stabilization in performance levels has been observed beyond a certain point, like other protocols. The simulation shows that the mesh topology created does not exhibit a significant difference in network efficiency across different routing algorithms.

The obtained tables have been graphically visualized in the MATLAB environment.

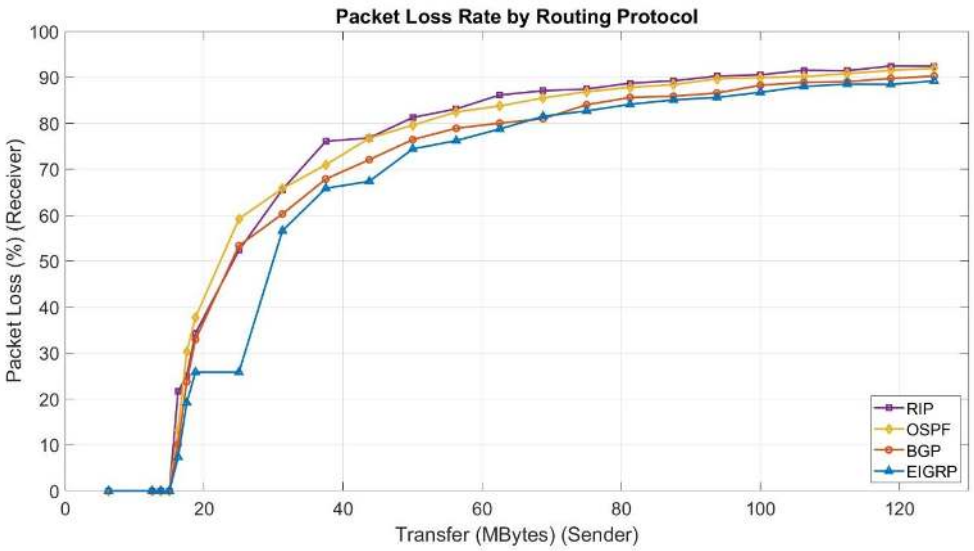


Figure 12: Transfer vs. Packet Loss Rate (%) Graph in MATLAB

Figure 12 shows the relationship between Transfer (MByte) (Sender) and Packet Loss Rate (%).

When examining the EIGRP protocol, it is observed that packet loss stabilizes at 25.82% during data transmission between 15 and 20 Mbit/s. This situation may have occurred because the bottleneck link reached its maximum capacity within the transmission range. However, when the transmission speed exceeds 20 Mbit/s, the devices on the network exceed their capacity limits. This can lead to multiple simultaneous bottleneck link situations. Subsequently, bottleneck link overflows occur. Packet losses begin to increase. This causes higher memory usage in routers, which extends the processing time of these packets. The extended processing time ultimately leads to increased latency, which indirectly increases packet loss.

When comparing RIP and OSPF packet loss levels, significant differences are observed. Up to a bit rate of 13 Mbit/s, RIP exhibits the highest packet loss rates. However, at the 14 Mbit/s level, the RIP packet loss rate is 25.01%, while the OSPF packet loss rate rise to 30.33%. Subsequently, between 15 Mbit/s and 20 Mbit/s, OSPF shows the highest packet loss. At 25 Mbit/s, both protocols show a level of around 65%. After this point, RIP shows the highest packet loss. This indicates that 25 Mbit/s is the tipping point for the RIP protocol under high packet loads.

These variations are explained by the basic structural features of the procedures. Because of its frequent updates and cheap processing overhead, RIP, which is based on a straightforward distance vector technique, can preserve relative stability up to a specific traffic threshold. Update delays, on the other hand, could happen when the demand grows, increasing packet loss. On the other hand, OSPF offers more consistent performance and less packet loss under medium-load circumstances because to its link-state algorithm and quick convergence features. However, OSPF's higher CPU and message overhead may cause performance deterioration and increased packet loss in high-load situations. Furthermore, in high-traffic scenarios, RIP is more vulnerable to packet loss than OSPF due to its limited topological adaptability, such as the 15-hop maximum.

As seen in the graph, the lowest packet loss is observed in EIGRP (89.18%). The packet loss levels of the others are observed as RIP (92.39%), OSPF (91.97%), and BGP (90.23%). The reason EIGRP exhibits the lowest packet loss is that it uses a hybrid routing architecture that guarantees quick convergence through the Diffusing Update Algorithm (DUAL) mechanism. EIGRP only sends updates for changed routes. This reduces network traffic. Thanks to this feature, EIGRP performs better than other protocols.

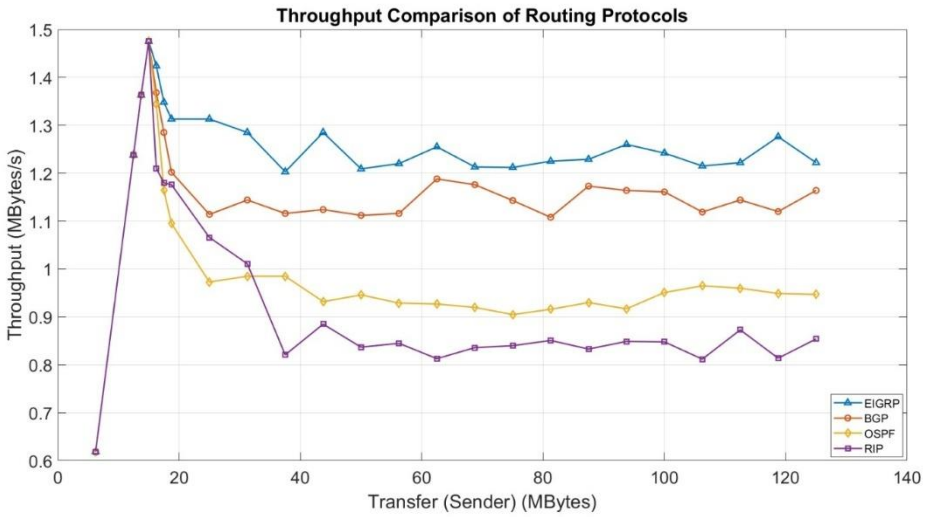


Figure 13: Transfer - Throughput Graph in MATLAB

Figure 13 is a graph created in the MATLAB environment that clearly summarizes the relationship between Transfer (MBytes) (Sender) and Throughput (MBytes/s). To summarize, an increase in throughput is observed as bitrates increase. Significant fluctuations are also noteworthy.

When examining the range between 10 Mbit/s and 15 Mbit/s in particular, throughput has increased across all protocols. However, a decrease was observed in the RIP protocol after 13 Mbit/s. This decline increased further to 14 and 15 Mbit/s levels. The reason for this change may be related to the 15-hop limit, the periodic update mechanism, and the increasing traffic control as the network size grows. Starting at 20 Mbit/s, RIP's throughput falls below 1.0 MByte/10s. It has been observed that it exhibits low performance even when the bit rate increases. This situation may be due to RIP's lack of scalability in high-traffic environments.

However, EIGRP is the highest efficiency protocol from 13 Mbit/s. For instance, At a bit rate of 20 Mbit/s, EIGRP achieves a throughput of 1.313 MByte/10s, while BGP and OSPF achieve 1.114 and 0.973 MByte/10s, respectively.

Initially, OSPF exhibits a high value of 1.475 MByte/10s at 12 Mbit/s, but a decrease is observed as the bit rate increases. For example, at 100 Mbit/s, it drops to only 0.947 MByte/10s. This decrease may be related to the calculation technique of the SPF (Shortest Path First) algorithm. This algorithm frequently recalculates in large-scale topologies, which increases processor load and slows down speed.

BGP generally exhibits average performance. BGP exhibits much better performance than OSPF at some of the bit rate levels. After 25 Mbit/s, BGP’s

efficiency values fixed in the range of 1.1–1.2 MByte/10s. This situation shows this routing algorithm is suitable for large-scale network environments designed to deliver consistent performance.

Generally, it can be concluded that an increase in bit rate alone is not sufficient to improve efficiency based on the simulation results. Such as efficiency performance, routing protocol architecture, control message load etc., factors must also be considered.

EIGRP provides the highest average throughput at approximately 1.2 MByte/10s. RIP provides the lowest performance at an average of 0.8 MByte/10s. BGP and OSPF demonstrate performance with average values of approximately 1.1 and 0.9 MByte/10s, respectively.

Consequently, all protocols show high efficiency at low bitrates. But bit rates are observed decreasing efficiency after a certain level. Despite this decline, EIGRP, which provides the best performance, continues to be effective under high network loads.

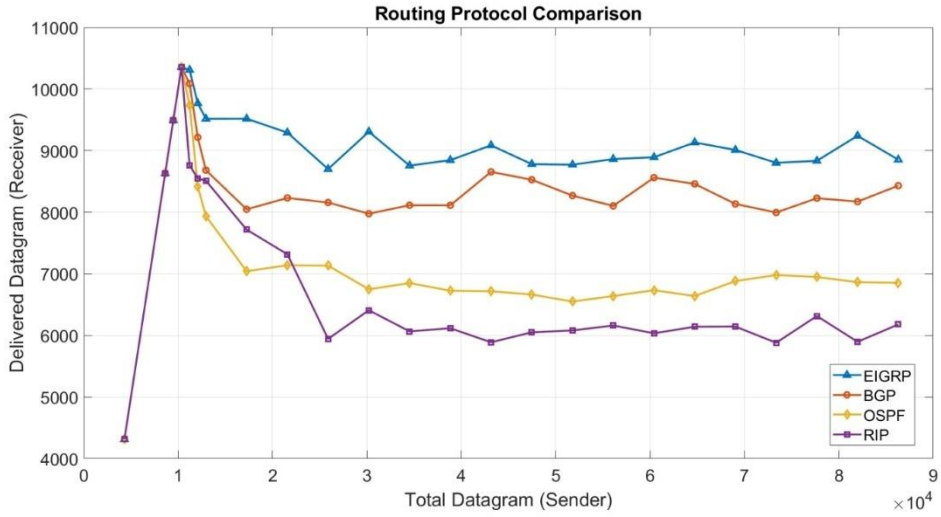


Figure 14: Total Datagram -Delivered Datagram Graph in MATLAB

Figure 14 shows a graph illustrating the relationship between the Total Datagram (Sender) and the Delivered Datagram (Receiver) according to routing protocols. In this graph, all routing algorithms reach the other side with minimal loss at low bit rates. However, with increasing bit rate, a drop of approximately 10,000–11,000 datagrams are observed after a certain point. When this threshold value is exceeded, all protocols are observed to stabilize at a certain level.

As in other graphs, EIGRP showed the best performance in this process, while RIP showed the worst. A similar trend to this graph was also observed in the Transfer (MByte) (Sender) – Throughput (MByte/10s) graph mentioned above.

CHAPTER V
CONCLUSION

In this thesis study, the bitrates of four different routing algorithms (BGP, EIGRP, OSPF, and RIP) are modified in a network environment with a mesh network topology, and the metrics are compared and analyzed according to this change. Throughout the simulation, performance parameters such as throughput, transfer volume, packet loss rate, jitter, and total datagram count are observed. The tables created as a result of these findings are graphically visualized in the MATLAB environment. This makes it easier to visualize the changing parameters under increasing traffic loads.

At the start of the simulation, all routing algorithms perform successfully at low bit rates. There was almost no packet loss. When network traffic density is low, these routing algorithms prove to be reliable and stable. However, differences between protocols begin to emerge at a bit rate of 12 Mbit/s. These differences are clearly visible in the graphs.

In particular, the Transfer – Packet Loss Ratio (%) graph in Figure 12 shows that bottlenecks occur for EIGRP at bit rates of 15 Mbit/s and above. These bottlenecks can mean many things, such as the router reaching its capacity limit and increased packet processing time. As a result, packet losses have been fixed at certain rates. This has led to a decrease in network efficiency.

Another noteworthy finding is the variability observed between OSPF and RIP protocols at different bit rates. When examining the Transfer–Throughput and Transfer–Packet Loss Ratio graphs, fluctuations are observed between the two protocols. Table 5 (13 Mbit/s) shows that the highest packet loss occurs in the RIP protocol. However, in the 14–25 Mbit/s range, OSPF experiences the highest packet loss (as seen in Tables 6–9). After 25 Mbit/s, as shown in Tables 10–24, RIP again reaches the highest packet loss rates.

The fundamental reason for this fluctuation is provided by the structural differences between protocols. RIP uses basic distance vector algorithm. This protocol

can only identify maximum 15 hop count. However, when traffic load expends updates slow down and hop count limit diminishes. This can also cause packet losses.

Another reason is that OSPF provides fast data transmission due to its link-state feature. However, control message traffic that expends between 14–25 Mbit/s and SPF algorithm can create losses due to overload which is on the processor and that leads to efficiency losses. This puts OSPF into disadvantaged position.

To sum up:

EIGRP shows the least packet loss and the best throughput performance. It provides stability in load traffic.

BGP performs more stable especially 25 Mbit/s and over. It is more suitable for larger-scale network protocols.

OSPF can work better in medium-scale network. However, when its bit rates expend its efficiency decreases.

RIP is not an efficient protocol in larger-scale networks. It can be used under low network conditions.

This study provides a foundation for different routing algorithms. This study can be enriched in the future by using different parameters.

Some suggestions for the future are as follows:

1. Network topologies (for instance star, tree and hybrid) can be changed.
2. Larger bit rate gap can be investigated.
3. Protocols can be assessed by using mobile network scenarios.
4. Performances of the network can be observed by using artificial intelligence supported mechanism.

This thesis is not only to enlighten the path of network engineers who would like to develop themself but also can act like a guidebook which might be used to create real life network structures and to create subtle designs into reality.

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