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Compare the Performance of Dynamic Routing Protocols-Based Protocol Traffic Sent, Network Convergence Duration and CPU Utilization Using OPNET Modeler

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ABSTRACT This paper investigates the performance of three common dynamic routing protocols: RIP, OSPF, and EIGRP. The goal is to assist network administrators in choosing the most suitable protocol for their specific needs. Analyzes critical factors like network convergence time, scalability, memory and CPU requirements. Through a detailed simulation study using OPNET, the project compares the performance of each protocol across these parameters. The findings demonstrate that EIGRP offers faster network convergence, and better CPU and memory utilization compared to RIP and OSPF. This paper provides valuable insights for network professionals by evaluating these popular routing protocols and highlighting the key factors to consider when making implementation decisions.

KEYWORDS EIGRP, OSPF, RIP, Dynamic Routing Protocol, Network Convergence, CPU Utilization, OPNET.

I. INTRODUCTION

In extensive, real-world networks, internet service providers depend on dynamic routing protocols to maintain accurate and updated routing tables. Within TCP/IP-based environments, data packets are routed efficiently according to their destination IP addresses, with routers serving as the core infrastructure for traffic control and forwarding. In packet-switched communication, routing involves directing traffic across various networks; this requires routers to continuously identify the next optimal hop toward the ultimate destination. Consequently, selecting an appropriate routing protocol is vital for long-term network performance. Protocols are typically evaluated and distinguished based on key metrics, including convergence speed (how quickly they respond to topology shifts), route selection efficiency among multiple paths, and the volume of overhead traffic they generate. Furthermore, network administrators must consider resource utilization (CPU and memory), ease of management, and whether to deploy open-standard or proprietary protocols. [1]. This paper focuses on the implementation of dynamic routing protocols in computer networks and networking technology. The performance of three dynamic routing protocols, namely RIP, OSPF, and EIGRP, is compared and evaluated based on different parameters.

The objective of this project are as follows:

A. Conduct a comprehensive simulation study using OPNET Modeler to evaluate the performance of RIP, OSPF, and EIGRP.

B. Analyze various parameters and criteria, such as network convergence time, and waiting delay, to compare the performance of the routing protocols.

C. Draw conclusions and make recommendations based on the specific parameters and overall performance of each protocol.
D. Choose the most appropriate protocol for routing practical networks based on multiple criteria.

II. RESEARCH AND IMPLEMENTATION METHODOLOGY

The research and implementation methodology for this project includes the following steps:

1. Use the OPNET simulation tool to design six different types of networks in terms of size and type (Mesh , Ring , Tree):
   - Design 3 small networks, each consisting of 10 routers.
   - Design 3 large networks, each consisting of 40 routers.
2. Configure failure and recovery scenarios in each network To determine the strength of the routing protocols.
3. Implementing High-Definition Video Conferencing Applications across six network topologies to simulate real-world sessions. The aim is to test routing protocols under high-definition video traffic, assessing their performance under challenging conditions. This will help evaluate the strength and efficiency of the protocols in managing complex traffic and data transmission.
4. Identify the three performance metrics to be used in the research:
   - Protocol Traffic Sent.

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- Network Convergence Duration.
- CPU Utilization.

5. Configure the routing protocols RIP, OSPF, and EIGRP for all networks.
6. Start the simulation, collect and analyze the results, and provide recommendations.

By this methodology, we aim to provide insights into the performance of the dynamic routing protocols and facilitate the decision-making process for selecting the most suitable protocol.

III. ROUTING

Routing is the process of transferring data from one place to another, and it is done using a router that acts as an intermediary between different networks or parts of the same network. A router translates and forwards data information between different networks, allowing them to understand and communicate, thus forming a larger and efficient network.

The primary goal of routing is to ensure that data packets reach their intended destination in a timely and efficient manner.

A. Routing Table

Routers utilize routing tables to select the best paths for forwarding data packets. These tables contain essential network topology details, including IP networks and their linked interfaces, allowing the router to make smart forwarding choices. For accurate performance, routing tables are frequently updated as the network environment changes. This routing table operates as a data file kept in the router's RAM and tracks two main types of routes:

1. Directly connected networks: Routes that are automatically added as soon as a router interface is assigned an IP address and turned on.
2. Remote networks: Networks attached to other routers, which can be mapped out manually through static routing or learned automatically using dynamic protocols.

In short, these entries create associations between target destinations and the specific next-hop router or exit interface needed to get there efficiently.

B. Routing Protocols

Routing protocols are a set of rules that determine how routers communicate with each other to share information and update their routing tables.

A routing protocol is the language a router speaks with other routers in order to share information about the reachability and status of network.

configured. They define an explicit path between two networking devices. Unlike a dynamic routing protocol, static routes are not automatically updated and must be manually reconfigured if the network topology changes [2].

- The benefits of using static routes include improved security and resource efficiency. Static routes use less bandwidth than dynamic routing protocols, and no CPU cycles are used to calculate and communicate routes.
- The main disadvantage to using static routes is the lack of automatic reconfiguration if the network topology changes.

Table 1
Static Routing Advantages and Disadvantages

Advantages	Disadvantages
Easy to implement in a small network.	Suitable for simple topologies or for special purposes such as a default static route.
Very secure. No advertisements are sent, unlike with dynamic routing protocols.	Configuration complexity increases dramatically as the network grows. Managing the static configurations in large networks can become time consuming.
It is very predictable, as the route to the destination is always the same.	If a link fails, a static route cannot reroute traffic. Therefore, manual intervention is required to re-route traffic.
No routing algorithm or update mechanisms are required. Therefore, extra resources (CPU and memory) are not required.	

C. STATIC ROUTING

Even in modern environments, manual configuration remains highly relevant, with contemporary networks frequently implementing a hybrid approach that combines both static and dynamic routing methodologies. Within the routing table, static configurations generally fall into two primary categories:

- Network-Specific Static Routes: Manually defined paths targeting a explicit destination network.
- Default Static Routes: A catch-all route utilized when no specific path to a destination exists in the routing table.

D. DYNAMIC ROUTING

To dynamically exchange information regarding the accessibility and operational status of distant networks, routers utilize dynamic routing protocols. These protocols serve multiple critical functions, such as [2]:

- Remote Network Discovery: Automatically identifying and mapping unfamiliar, distant networks.
- Real-Time Table Maintenance: Keeping routing data continuously refreshed and accurate.
- Optimal Path Selection: Evaluating metrics to determine the most efficient route to a target destination.
- Dynamic Rerouting: Automatically calculating an alternative optimal path in the event of a primary link failure.

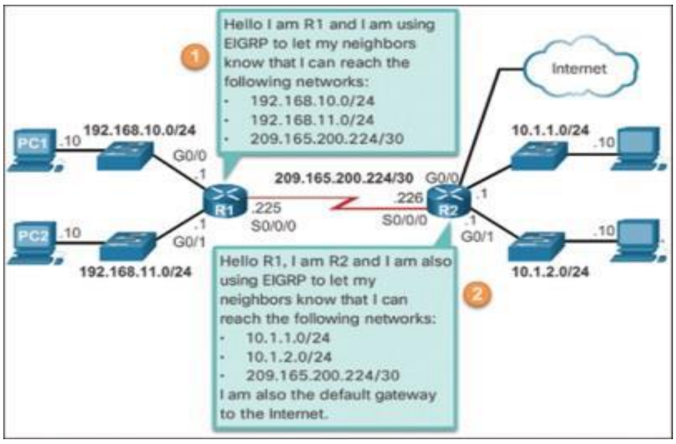

FIGURE 1: Dynamic Routing Scenario

Dynamic routing protocols work well in any type of network consisting of several routers. Dynamic routing is the best choice for large networks They are scalable and automatically determine better routes if there is a change in the topology.

Table 2
Dynamic routing Advantages and Disadvantages

Advantages	Disadvantages
Suitable in all topologies where multiple routers are required.	Can be more complex to initially implement.
Generally independent of the network size.	Less secure due to the broadcast and multicast routing updates. Additional configuration settings such as passive interfaces and routing protocol authentication are required to increase security.
Automatically adapts topology to reroute traffic if possible.	Route depends on the current topology.
	Requires additional resources such as CPU, memory, and link bandwidth.

E. CLASSIFYING ROUTING PROTOCOLS

Routing protocols are categorized into distinct classes based on their operational traits and architectural designs. Broadly, these protocols are differentiated according to three primary criteria [2]:

- Operational Scope (Purpose): Classified as either Interior Gateway Protocols (IGPs) for routing within a single autonomous system, or Exterior Gateway Protocols (EGPs) for routing between different autonomous systems.
- Algorithmic Operation: Divided into distance-vector, link-state, or path-vector protocols, depending on how they calculate routes and map the topology.
- Subnet Mask Behavior: Distinguished as legacy classful protocols, which do not include subnet mask information in updates, or modern classless protocols, which fully support variable-length subnet masking (VLSM).

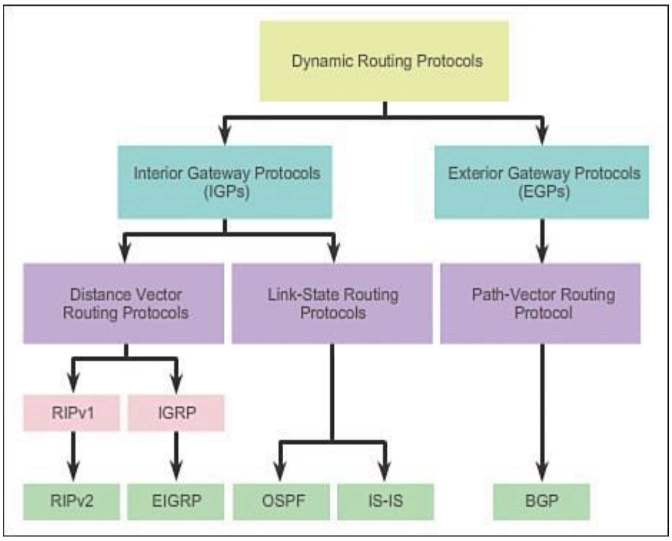

FIGURE 2: Routing Protocol Classification

1. IGP and EGP Routing Protocols

An Autonomous System (AS), alternative designated as a routing domain, represents an interconnected cluster of routers managed by a single administrative entity, such as a commercial enterprise or an organization. Familiar examples encompass corporate intranet works and internet service provider (ISP) infrastructures [2]. Because the foundational architecture of the global internet relies heavily on the AS framework, routing protocols are divided into two primary functional types [2]:

- Interior Gateway Protocols (IGPs): Implemented for intra-AS routing, these protocols manage traffic internally within a single administrative domain. Corporate entities, academic networks, and ISPs utilize IGPs—such as OSPF, EIGRP, RIP, and IS-IS—to maintain internal connectivity.
- Exterior Gateway Protocols (EGPs): Employed for inter-AS routing, these protocols facilitate communication across distinct autonomous boundaries. Large enterprises and service providers leverage EGPs to interconnect their environments, with the Border Gateway Protocol (BGP) serving as the definitive, industry-standard EGP powering modern internet infrastructure.

2. Distance Vector Routing Protocols

Under the distance-vector paradigm, routing information is propagated using two defining operational characteristics [2]:

- Distance: Quantifies the remote network's proximity through metric calculations such as link cost, bandwidth, end-to-end delay, or total hop count.
- Vector: Defines the structural direction by designating the exact exit interface or next-hop router required to forward traffic toward its destination.

3. Link-State Routing Protocols

a router configured with a link-state routing protocol can create a complete view or topology of the network by gathering information from all of the other routers.
using a link-state routing protocol is like having a complete map of the network topology. A link-state router uses the link-state information to create a topology map and to select the best path to all destination networks in the topology.
RIP-enabled routers send periodic updates of their routing information to their neighbors. Link-state routing protocols do not use periodic updates. After the network has converged, a link-state update is only sent when there is a change in the topology [**2**].

4. Classful and Classless Routing Protocols

Classful Routing Protocols [2]:

- Classful routing protocols, such as RIPv1 and IGRP, were developed when network addresses were allocated based on classes (A, B, or C).
- They do not include subnet mask information in their routing updates.
- The subnet mask can be determined based on the first octet of the network address.

- Classful routing protocols do not support variable-length subnet masks (VLSMs) and Classless Inter-Domain Routing (CIDR).
- Discontinuous networks, where subnets from the same major network address are separated by a different network address, pose problems for classful routing protocols.
- Classful addressing is not used in IPv6.

Classless Routing Protocols [2]:

- Modern networks use classless IP addressing, where subnet masks are not determined by the value of the first octet.
- Classless routing protocols, such as RIPv2, EIGRP, OSPF, and IS-IS, include subnet mask information in their routing updates.
- Classless routing protocols support variable-length subnet masks (VLSMs) and Classless Inter-Domain Routing (CIDR).
- In IPv6, all routing protocols are considered classless because they include the prefix-length with the IPv6 address.

5. Routing Protocol Metrics

When a routing protocol discovers multiple pathways to an identical destination, it must employ a standardized evaluation mechanism to differentiate between them and select the optimal route. This selection process is driven by routing metrics—quantifiable values assigned to paths based on their efficiency and viability.

The metric methodologies utilized by prominent dynamic protocols include:

- RIP: Relies exclusively on the shortest hop count.
- OSPF: Determines path cost based on cumulative link bandwidth.
- EIGRP: Employs a composite metric evaluating bandwidth, end-to-end delay, link load, and reliability.

6. Routing Information Protocol (RIP)

The Routing Information Protocol (RIP) was a first-generation routing protocol for IPv4. It is easy to configure, making it a good choice for small networks. RIPv1 has the following main characteristics [2]:

- Routing updates (255.255.255.255) are broadcast every 30 seconds.
- The number of hops is used as a metric for path selection, with a maximum of 15 hops allowed.

In 1993, RIPv1 evolved into a classless routing protocol known as RIP version 2 (RIPv2).

TABLE 3
RIPv1 versus RIPv2

Characteristics and Features	RIPv1	RIPv2
Metric	Both use hop count as a simple metric. The maximum number of hops is 15.	
Updates Forwarded to Address	255.255.255.255	224.0.0.9
Supports VLSM	No	Yes
Supports CIDR	No	Yes
Supports Summarization	No	Yes
Supports Authentication	No	Yes

7. Enhanced Interior Gateway Routing Protocol (EIGRP)

Introduced by Cisco in 1984, the Interior Gateway Routing Protocol (IGRP) represented the initial proprietary IPv4 routing solution, utilizing specific architectural design principles [3]:

- Composite Metric Calculation: Path evaluation was derived from a combination of link bandwidth, transmission delay, interface load, and channel reliability.
- Periodic Broadcasts: By default, complete routing tables were broadcasted at 90-second intervals.

To overcome its limitations, Cisco replaced IGRP with Enhanced IGRP (EIGRP) in 1992. Mirroring the advancements found in RIPv2, EIGRP incorporated full compatibility with Variable-Length Subnet Masking (VLSM) and Classless Inter-Domain Routing (CIDR). This evolution significantly optimized resource consumption, minimized routing update overhead, and integrated cryptographic mechanisms for secure protocol communication.

TABLE 4
IGRP versus EIGRP

Characteristics and Features	IGRP	EIGRP
Metric	Both use a composite metric based on bandwidth and delay. Reliability and load can also be included in the metric calculation if configured.	
Updates Forwarded to Address	255.255.255.255	224.0.0.10
Supports VLSM	No	Yes
Supports CIDR	No	Yes
Supports Summarization	No	Yes
Supports Authentication	No	Yes

8. Link-State Routing Protocol : Open Shortest Path First (OSPF)

Engineered by the Internet Engineering Task Force (IETF), Open Shortest Path First (OSPF) was designed to address and mitigate the inherent constraints of distance-vector mechanisms. A primary driver behind its widespread adoption across modern enterprise infrastructures is its open-standard nature, which ensures freedom from proprietary limitations [4]. As an Interior Gateway Protocol (IGP), OSPF utilizes a link-state architecture rather than distance vectors for path calculation. Instead of broadcasting full routing tables, it propagates Link-State Advertisements (LSAs), a mechanism that drastically optimizes network overhead [4]. Consequently, OSPF provides exceptional scalability and rapid convergence times; however, while its deployment remains straightforward in small-to-medium topologies, configuring and troubleshooting OSPF within massive enterprise networks can introduce significant operational challenges [3].

8.1 OSPF Operation Overview

To construct and sustain accurate routing data, OSPF-configured routers execute a standardized, multi-stage link-state routing process [5]:

- Establishment of Neighbor Adjacencies: Prior to exchanging any data, OSPF routers must form formal relationships with adjacent nodes. This is achieved by transmitting Hello packets across all active OSPF interfaces to detect nearby routers. Upon discovering a peer, the router initiates the adjacency establishment process.
- Propagation of Link-State Advertisements (LSAs): Once adjacencies are secured, routers begin exchanging LSAs, which document the operational status and metric cost of every directly connected link. These advertisements are flooded to immediate neighbors, who sequentially propagate them throughout the network segment until an identical database is achieved across the entire area.
- Compilation of the Topology Table: Utilizing the aggregated LSAs, routers assemble a local Link-State Database (LSDB). This database functions as a comprehensive and unified map of the entire network architecture [6].
- Execution of the Shortest Path First (SPF) Algorithm: Each router runs Dijkstra's SPF algorithm independently against the LSDB. This computational process generates a loop-free SPF tree topology, positioning the local router as the root.

Construction of the Routing Table: The optimal, lowest-cost paths derived from the SPF tree are subsequently populated into the routing table, which serves as the primary data file for making packet-forwarding decisions.

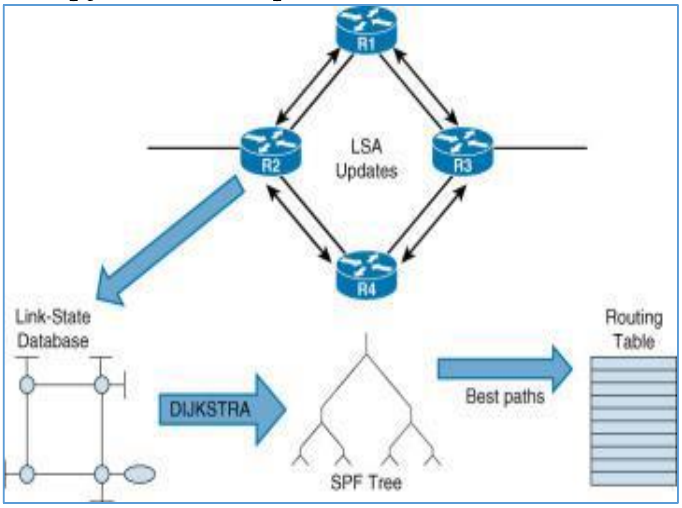

FIGURE 3: OSPF Operation

IV. THE PROPOSED MODEL

In this paper, design and implementation of the simulation environment used to analyze the performance of the dynamic routing protocols EIGRP, OSPF, and RIP. The simulation environment was built using OPNET Modeler it is the main scenario.

i. Protocol Traffic Sent: Measures the total amount of data (in bits) sent per second by the routing protocol for communication between routers. Includes hello messages and updates used to establish neighbor relationships and exchange routing information.[7].

ii. Network Convergence duration: The time it takes for the routing protocol to converge, meaning all routers have updated their routing tables. Shorter convergence time is preferred.[7]

iii. CPU Utilization: The percentage of the router's CPU resources used by the routing protocol. High CPU utilization can negatively impact network performance.

1. Scenario

1.1 Small Topologies

1.1.1 Small Mesh

In a small mesh topology, each node directly connects to approximately three others. This topology is ideal for simulating small, interconnected networks

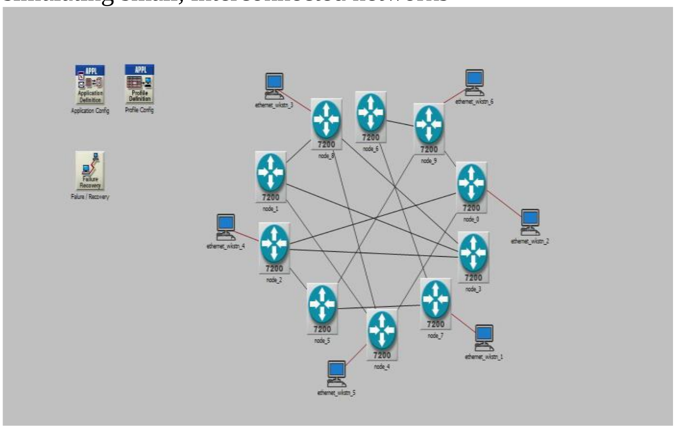

FIGURE 4: Small Mesh Topology

1.1.2 Small Ring

A small ring topology consists of a circle of nodes, each connected to its two immediate neighbors This simple, closed-loop structure is suitable for facilitating communication among a small, interconnected set of entities.

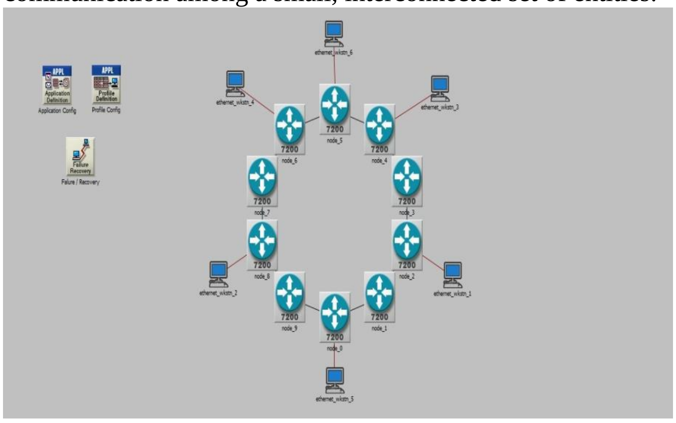

FIGURE 5: Small Ring Topology

1.1.3 Small Tree

A small tree topology resembles a hierarchical structure where nodes branch out from a central hub, resembling a tree This topology efficiently manages data flow in smaller networks.

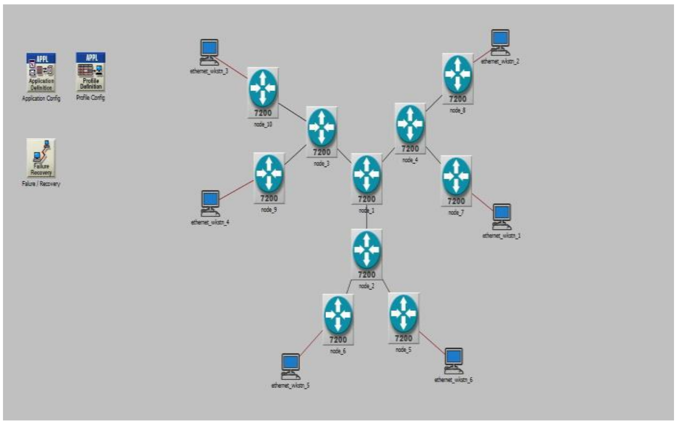

FIGURE 6: Small Tree Topology

1.2 Large Topologies

1.2.1 Large Mesh

In a large mesh topology, each node connects to roughly five others, creating a complex, interconnected mesh.

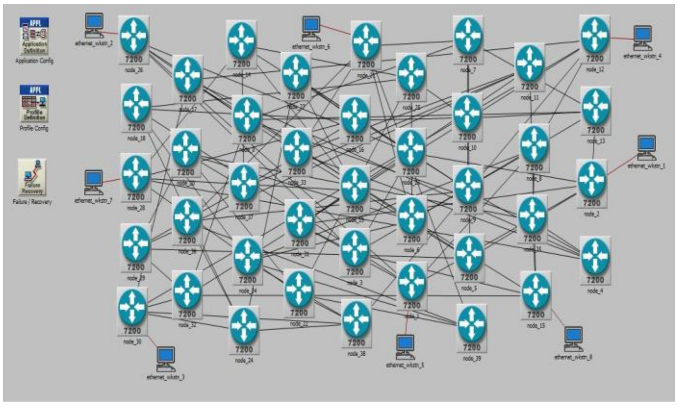

FIGURE 7 : Large Mesh Topology

1.2.2 Large Ring

A large ring topology consists of a ring with a significantly larger number of nodes.

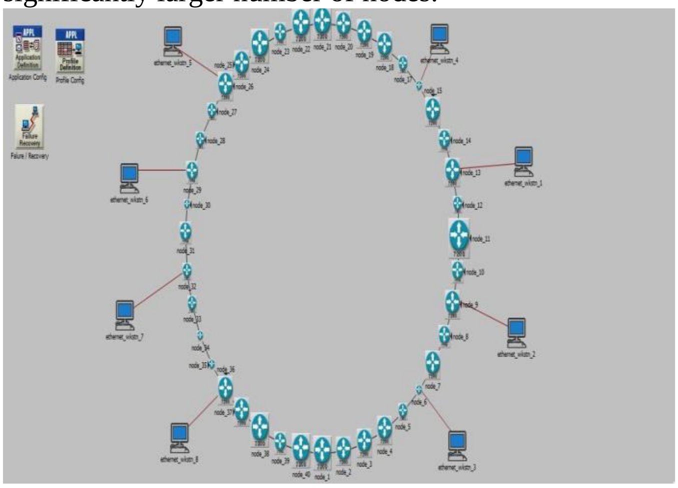

FIGURE 8: Large Ring Topology

1.2.3 Large Tree

A large tree topology resembles a massive hierarchical structure with numerous branches extending from a central hub, resembling a giant tree This topology efficiently manages data flow in extensive networks.

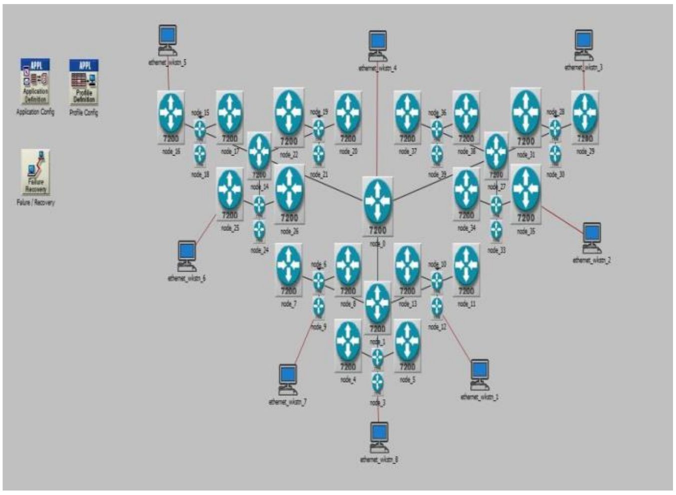

FIGURE 9: Large Tree Topology

To evaluate the performance of the routing protocols, a set of statistics were collected for comparison. The metrics were collected by right-clicking on an empty space in the OPNET Modeler interface and selecting "choose Individual DES statistics." The following metrics were selected :

- Protocol Traffic Sent (bits Per sec) .
- Network Convergence Duration (sec) .
- CPU Utilization .(%)

V. EXPERIMENTAL RESULTS

analyze the simulation results for the six different networks using OPNET Modeler. The purpose of this chapter is to evaluate and compare routing protocols through the results obtained from scenario simulations for the dynamic routing protocols EIGRP, OSPF, and RIP for each topology. These results will be presented in the form of graphs and numerical values. Finally, we will analyze the data extracted from these graphs to draw conclusions about the performance of each routing protocol within different network topologies.

- **Protocol Traffic Sent**
- **Small Networks Results**
- **Small Mesh:** EIGRP (14,848), OSPF (14,933.333), RIP .(6,085.333)

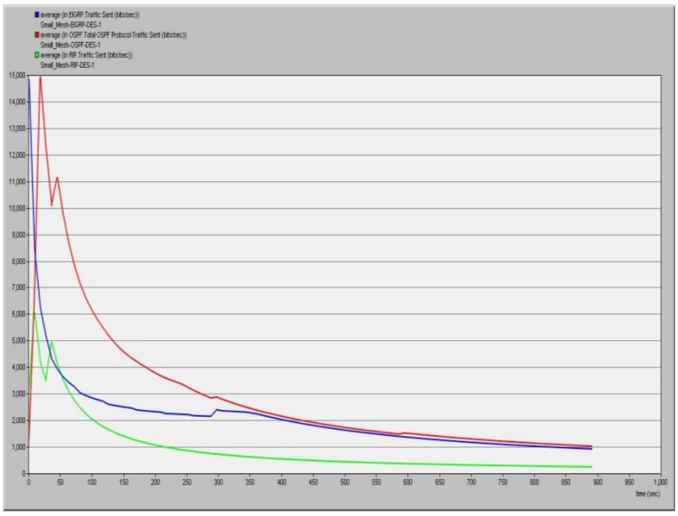

FIGURE 10 : Small Mesh - Protocol Traffic Sent (bits per second)

- **Small Ring :** EIGRP (7,8222.222), OSPF (8,904.296296), RIP (3,208.888889).

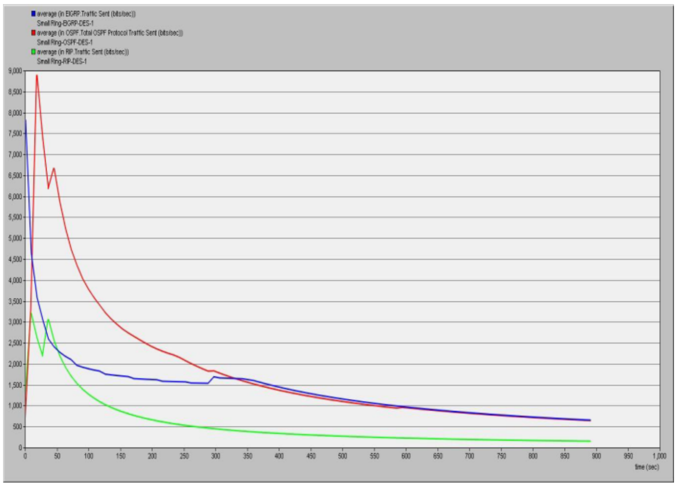

FIGURE 11 : Small Ring - Protocol Traffic Sent (bits per second)

- **Small Tree:** EIGRP (6,378.6667), OSPF (7,790.222), RIP (3,198.222).

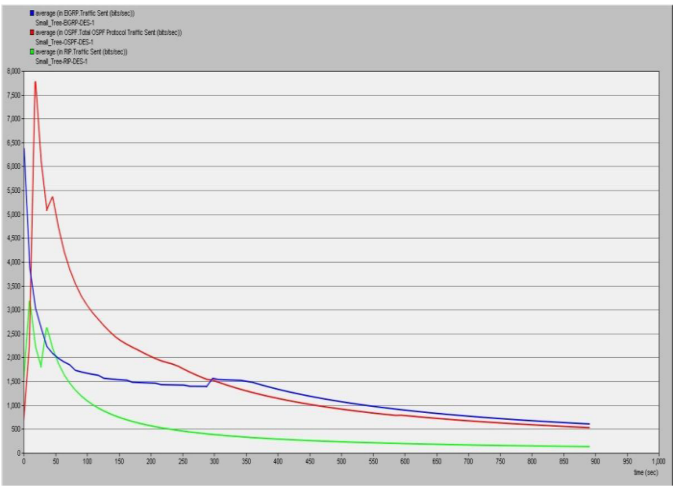

FIGURE 12 : Small Tree - Protocol Traffic Sent (bits per second

- **Small Networks Analysis**

TABLE 5
Protocol Traffic Sent Analysis - Small Networks Comparison

Network Topology	EIGRP (bits/sec)	OSPF (bits/sec)	RIP (bits/sec)	Analysis
Small Mesh	14,848	14,933.333	6,085.333	OSPF and EIGRP generate substantially more protocol traffic than RIP.
Small Ring	7,8222.222	8,904.296296	3,208.888889	Similar to the mesh topology, OSPF and EIGRP generate more protocol traffic than RIP.
Small Tree	6,378.6667	7,790.222	3,198.222	Again, Both OSPF and EIGRP have higher protocol traffic compared to RIP.

- **Large Networks Results**
- **Large Mesh :** EIGRP (546,499.5556), OSPF (631,002.074074), RIP (219,541.3333).

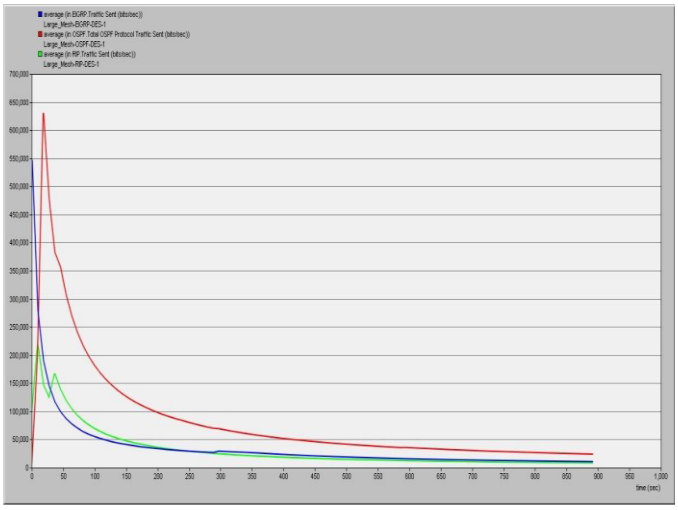

FIGURE 13 : Large Mesh - Protocol Traffic Sent (bits per second)

- **Large Ring :** EIGRP (84,238.22222), OSPF (106,237.62963), RIP (20,352.2).

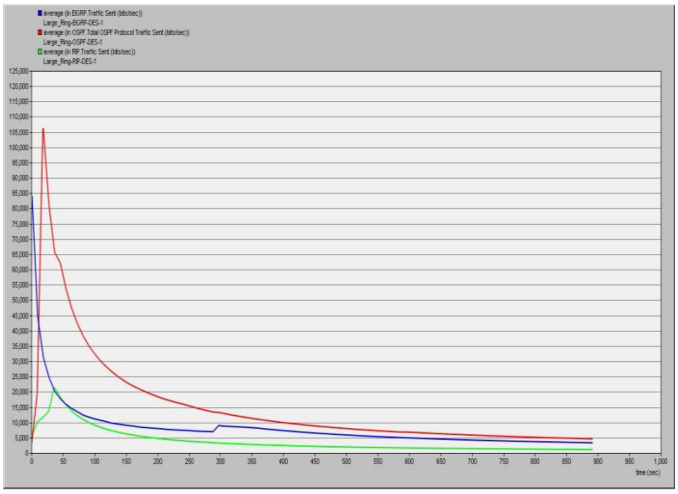

FIGURE 14 : Large Ring - Protocol Traffic Sent (bits per second)

- **Large Tree:** EIGRP (65,479.11111), OSPF (94,832.592593), RIP (29,100.44444).

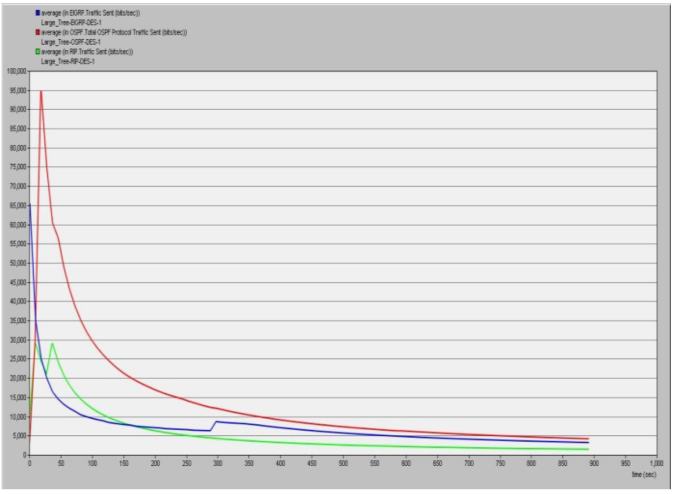

FIGURE 15 : Large Tree - Protocol Traffic Sent (bits per second)

- **Large Networks Analysis**

TABLE 6
Protocol Traffic Sent Analysis - Large Networks Comparison

Network Topology	EIGRP (bits/sec)	OSPF (bits/sec)	RIP (bits/sec)	Analysis
Large Mesh	546,499.5556	631,002.074074	219,541.3333	OSPF and EIGRP generate substantially more protocol traffic than RIP. but the difference is even more pronounced in large networks.
Large Ring	84,238.2222	106,237.62963	20,352.2	Similar to the small ring, OSPF and EIGRP generate more protocol traffic than RIP.
Large Tree	65,479.11111	94,832.592593	29,100.44444	Again, Both OSPF and EIGRP have higher protocol traffic compared to RIP.

- **Network Convergence Duration**
- **Small Networks Results**
- **Small Mesh :** EIGRP (0.000192), OSPF (45.300901), RIP (9.08896).

FIGURE 16 : Small Mesh - Network Convergence Duration(second)

- **Small Ring :** EIGRP (0.000128), OSPF (45.241699), RIP (14.352036).

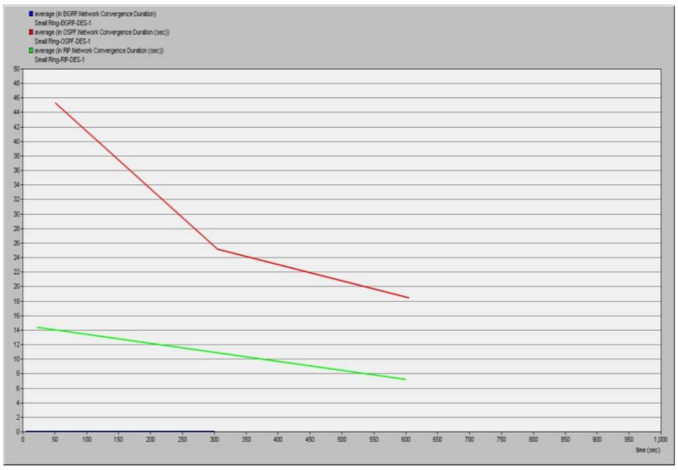

FIGURE 17 : Small Ring - Network Convergence Duration(second)

- **Small Tree:** EIGRP (0.000168414), OSPF (45.69381562), RIP (11.49594).

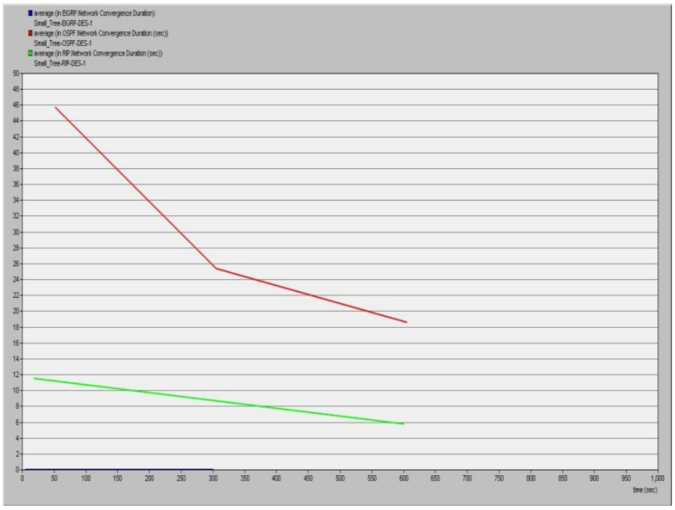

FIGURE 18 : Small Tree - Network Convergence Duration(second)

- **Small Networks Analysis**

Table 7
Queuing Delay Analysis - Small Networks Comparison

Network Topology	EIGRP (sec)	OSPF (sec)	RIP (sec)	Analysis
Small Mesh	0.000192	45.300901	9.08896	EIGRP converges much faster than OSPF and RIP. OSPF has a very long convergence time.
Small Ring	0.000128	45.241699	14.352036	EIGRP also converges much faster than OSPF and RIP.
Small Tree	0.000168414	45.69381562	11.49594	EIGRP again shows superior convergence speed compared to OSPF and RIP.

- **Large Networks Results**
- **Large Mesh :** EIGRP (0.000736), OSPF (45.973618), RIP (12.243451)**.**

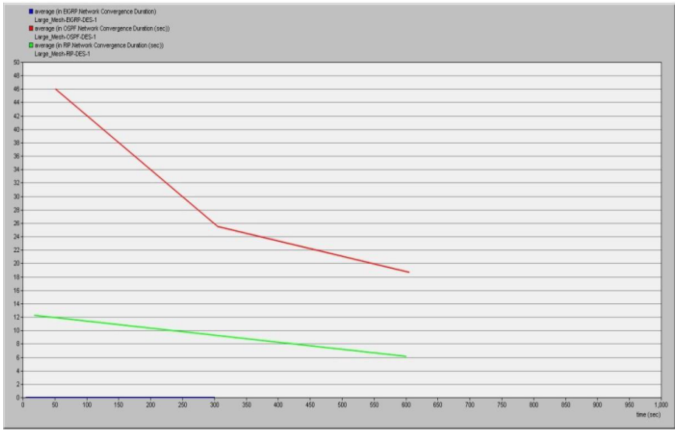

FIGURE 19 : Large Mesh - Network Convergence Duration(second)

- **Large Ring :** EIGRP (0.000434), OSPF (45.982241), RIP (49.686168).

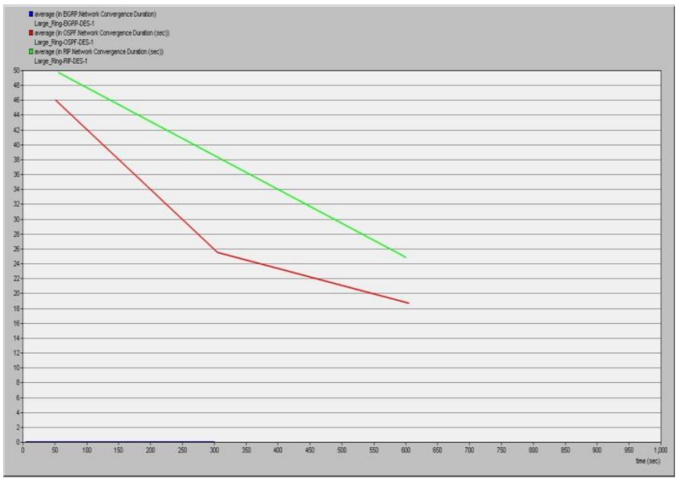

FIGURE 20 : Large Ring - Network Convergence Duration(second)

- **Large Tree:** EIGRP (0.000436), OSPF (55.309467), RIP (18.398567)**.**

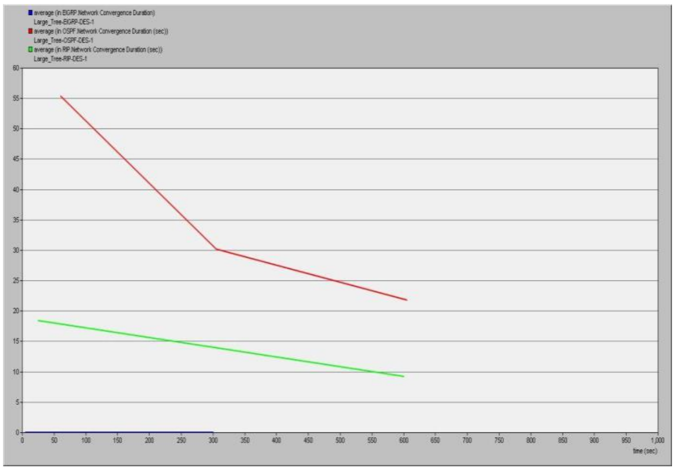

FIGURE 21 : Large Tree - Network Convergence Duration(second)

TABLE 8
Network Convergence Duration Analysis - Large Networks Comparison

Network Topology	EIGRP (sec)	OSPF (sec)	RIP (sec)	Analysis
Large Mesh	0.000736	45.973618	12.243451	EIGRP has the fastest convergence time compared to OSPF and RIP, while OSPF is the slowest.
Large Ring	0.000434	45.982241	49.686168	EIGRP has the fastest convergence time compared to OSPF and RIP, while RIP is the slowest.
Large Tree	0.000436	55.309467	18.398567	EIGRP again has the fastest convergence time, while OSPF is the slowest.

- **CPU Utilization**
- **Small Networks Results**
- **Small Mesh :** EIGRP (0.0005444), OSPF (0.0004333), RIP (0.0001000)**.**

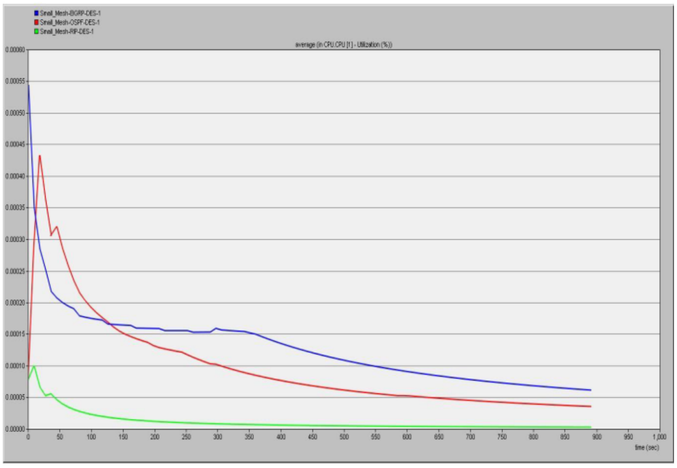

FIGURE 22 : Small Mesh - CPU Utilization (%)

- **Small Ring :** EIGRP (0.0003556), OSPF (0.000233), RIP (0.0000722).

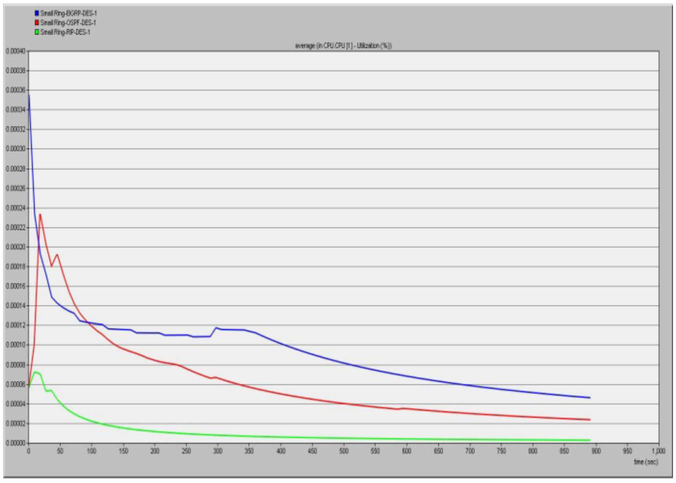

FIGURE 23 : Small Ring - CPU Utilization (%)

Small Tree: EIGRP (0.0004667), OSPF (0.0003481), RIP (0.0001056).

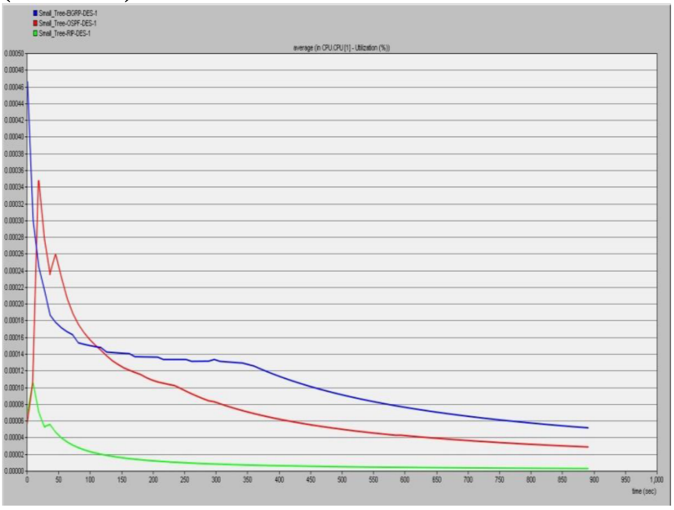

FIGURE 24 : Small Tree - CPU Utilization (%)

- **Small Networks Analysis**

TABLE 9
CPU Utilization Analysis - Small Networks Comparison

Network Topology	EIGRP (%)	OSPF (%)	RIP (%)	Analysis
Small Mesh	0.0005444	0.0004333	0.0001000	CPU utilization is generally low for all protocols, with EIGRP slightly higher than OSPF and RIP has the lowest percent utilization.
Small Ring	0.0003556	0.0002333	0.0000722	Also EIGRP slightly higher than OSPF and RIP has the lowest percent utilization.
Small Tree	0.0004667	0.0003481	0.0001056	The same, As previous mesh and ring analysis

- **Large Networks Results**
- **Large Mesh :** EIGRP (0.003633), OSPF (0.002093), RIP (0.0003222).

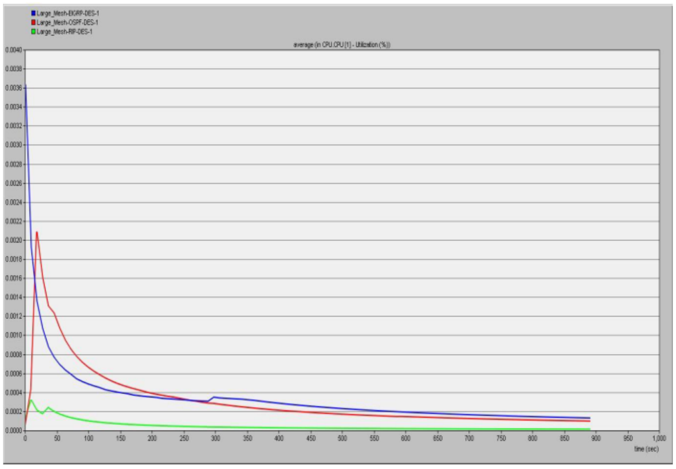

Figure 25 : Large Mesh - CPU Utilization (%)

- **Large Ring :** EIGRP (0.000989), OSPF (0.000437), RIP (0.000073).

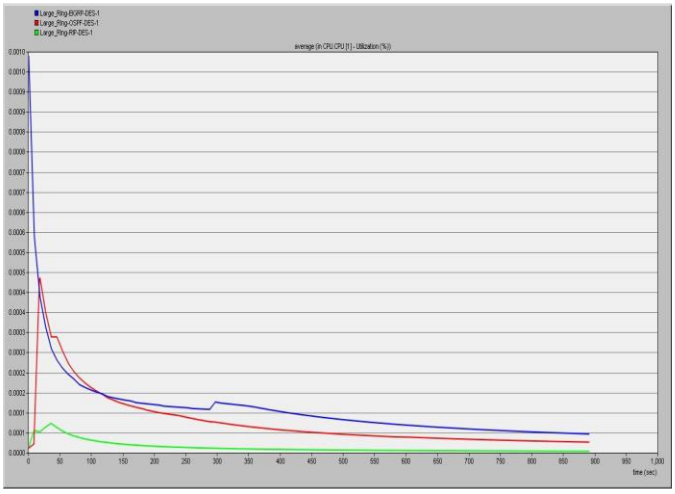

Figure 26 : Large Ring - CPU Utilization (%)

- **Large Tree:** EIGRP (0.0008111), OSPF (0.0007037), RIP (0.0001556).

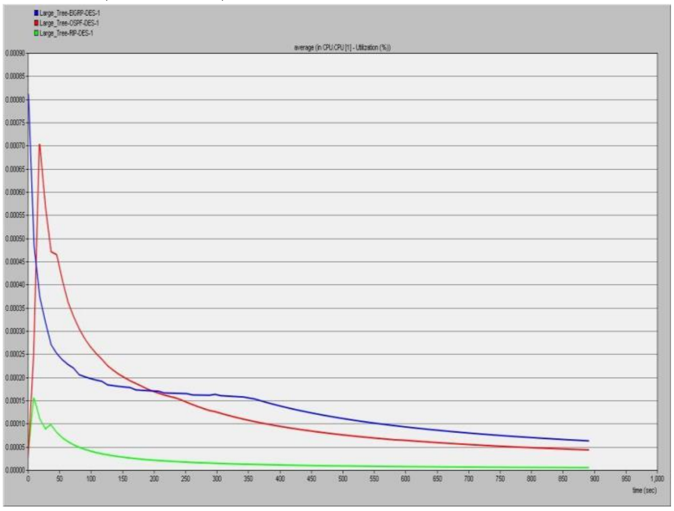

Figure 27 : Large Tree - CPU Utilization (%)

- **Large Networks Analysis**

TABLE 10
CPU Utilization Analysis - Large Networks Comparison

Network Topology	EIGRP (%)	OSPF (%)	RIP (%)	Analysis
Large Mesh	0.3633	0.2093	0.03222	CPU utilization is relatively low for all protocols. EIGRP slightly higher than OSPF and RIP has the lowest percent utilization.
Large Ring	0.0989	0.0437	0.0073	EIGRP has the highest CPU utilization in this topology. RIP has the lowest.
Large Tree	0.08111	0.07037	0.01556	The same, As previous mesh and ring analysis

VI. CONCLUSIONS

OSPF generates more protocol traffic than EIGRP and RIP across all networks, while RIP generates less traffic. We explain that by saying that OSPF uses a more complex algorithm based on link state advertisements (LSAs), which create a detailed map of the network. This requires routers to send more traffic than simpler protocols like RIP and EIGRP.

Routing protocols in Mesh networks generate more routing traffic than other types of networks. We can explain this by saying that each router in a mesh network is directly connected to a large number of neighbors, which increases the level of interconnection and complexity, forcing routing protocols to have higher traffic to exchange neighbor messages and achieve convergence. In contrast, tree and ring networks have a more organized structure, which helps reduce the traffic required.

EIGRP has the fastest convergence times in all networks, while OSPF is the slowest in all networks. Except for the large ring network where RIP is the slowest. The reason for EIGRP's superiority is due to its rapid information update mechanism, which allows it to quickly adapt its routing tables when changes occur in the network. OSPF, on the other hand, relies on exchanging comprehensive information about the entire network, which may lead to an increase in convergence time in some cases.

Also can conclude that in the case of the large ring network, RIP faced challenges due to the limited number of hops allowed (15 hops). This limitation made it difficult to reach convergence in a large network consisting of 40 devices connected in a ring. While RIP convergence times in the mesh network were slower than RIP convergence times in other types of networks. This is because each router connected to a neighbor needs less number of hops to reach convergence.

CPU utilization is generally low for all protocols, but EIGRP CPU usage is slightly higher than OSPF in all networks. RIP has the lowest CPU usage due to its simple algorithm.

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