

The City College of New York

Computer Networks (EE F6000)

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OPNET Project Report

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Introduction

OPNET is very large and powerful software with wide a variety of libraries. It has enabled the possibilities to simulate entire heterogeneous network with various protocols. Originally, OPNET was developed for military usage. Nowadays, it is used for a variety of simulations and is therefore one of the leading network simulation tools in the world. OPNET is a high-level event-based network level simulation tool. Simulation operates at “packet level”. OPNET contains a huge library of accurate models of commercially available fixed network hardware and protocols. Nowadays, the possibilities for wireless network simulations are also very wide. The simulator has a lot of potentialities, but there exists typically a lack of the recent wireless systems. Much of the work considering new technologies are usually done individually. OPNET can be used as a research tool or as a network design/analysis tool.

Abstract

In this project, we needed to construct a network with 7 nodes. We simulated and analyzed how data travels from node to node and gathered different statistics both at the “object level” as well as at the “global level”. Finally, we provided step by step procedure of using the OPNET software to simulate a 7-node network system. We used two different protocols to simulate: RIP protocol and OSPF protocol. The next section explains the difference between these two protocols. In addition, we also compared simulated values using RIP with simulated values using OSPF.

RIP vs OSPF

RIP (Routing Information Protocol) is a widely used protocol for managing router information within a self-contained network such as a corporate local area network (LAN) or an interconnected group such as LANs. RIP is classified by the Internet Engineering Task Force

(IETF) as one of several internal gateway protocols (Interior Gateway Protocol). The **Routing Information Protocol** ('RIP') is one of the oldest distance-vector routing protocols which employ the hop count as a routing metric. RIP prevents routing loops by implementing a limit on the number of hops allowed in a path from source to destination. The largest number of hops allowed for RIP is 15, which limits the size of networks that RIP can support.

The major alternative to RIP is the Open Shortest Path First Protocol (OSPF). OSPF is a router protocol used within larger autonomous system networks in preference to the Routing Information Protocol (RIP) because of its features, an older routing protocol that is installed in many of today's corporate networks. Like RIP, OSPF is designated by the Internet Engineering Task Force (IETF) as one of several Interior Gateway Protocols (IGPs).

Using RIP, a gateway host (with a router) sends its entire routing table to its closest neighbor host every 30 seconds. The neighbor host in turn will pass the information on to its next neighbor and so on until all hosts within the network have the same knowledge of routing paths, a state known as network convergence. RIP uses a hop count to determine network distance. (Other protocols use more sophisticated algorithms that include timing as well). Each host with a router in the network uses the routing table information to determine the next host to route a packet to for a specified destination.

Using OSPF, a host that gathers a change to a routing table or detects a change in the network immediately sends the information to all other hosts in the network so that all will have the same routing table information. Unlike RIP in which the entire routing table is sent, the host using OSPF sends only the part that has changed. With RIP, the routing table is sent to a neighbor host every 30 seconds. OSPF sends the updated information only when a change has taken place.

Rather than simply counting the number of hops, OSPF bases its path descriptions on "link states" that take into consideration additional network information. OSPF also lets the user assign cost metrics to a given host router so that some paths are given preference. OSPF supports a variable network subnet mask so that a network can be subdivided. RIP is supported within OSPF for router to end station communication. Since many networks using RIP are already in use, router manufacturers include RIP support within a router designed primarily for OSPF.

OPNET Simulations

The following are the steps that describe the process of building the 7-node network using OPNET software:

1. We started off by creating the project (File > New > Project > OK)



Figure 1: Creating a project using OPNET software.

2. Then, we type in the project name and the scenario name as shown in the following figure:

- Project name: Samuel_Youssef_CompNetworksProject
- Scenario name: ProjectScenario

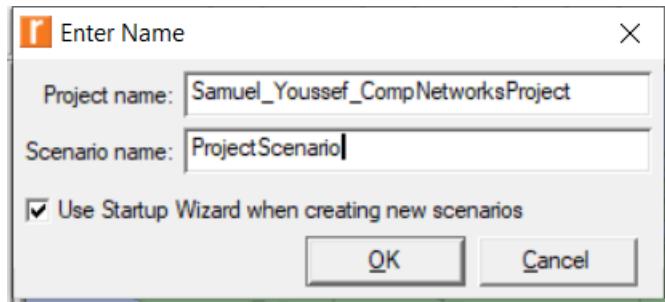


Figure 2: inputting the project name and scenario name.

3. Then, we start putting our 7-node network and its connections using Object Palette Tree shown in the following figure:

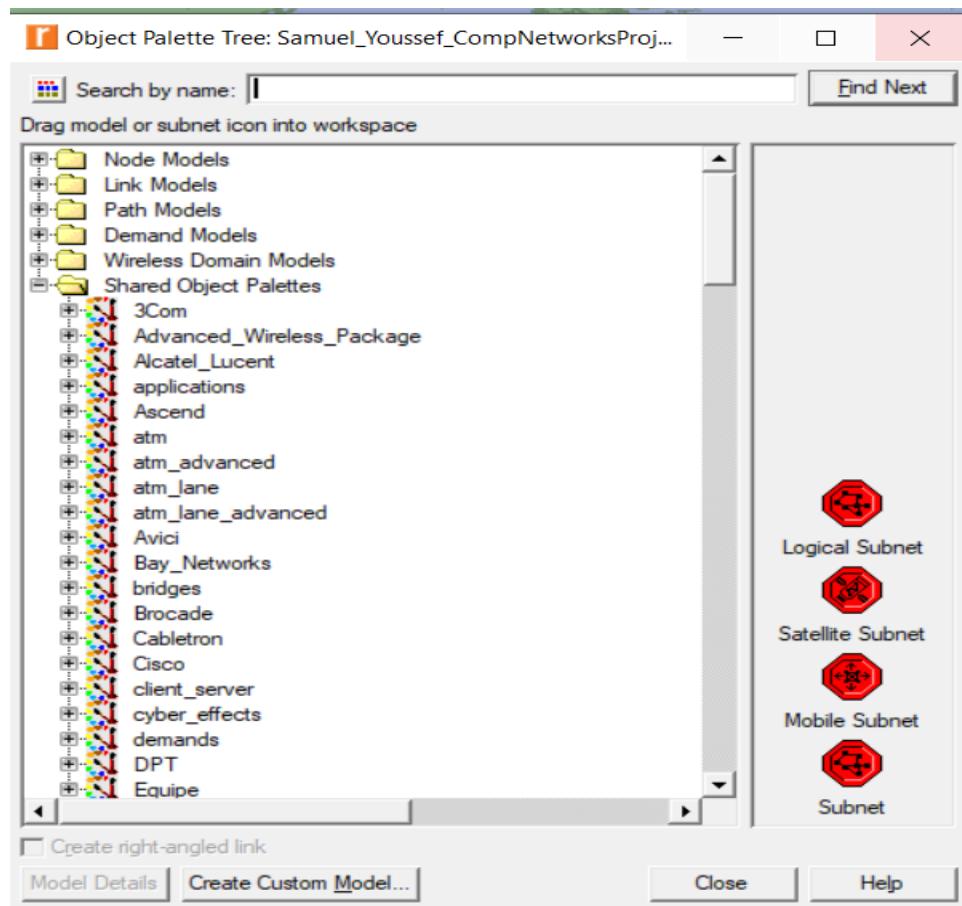


Figure 3: Object Platte Tree.

4. Using the Object Platte Tree, we started importing relevant components by which the 7-node network is constructed. These components are:

- Router (Ethernet4_slip8_gtwy): Ethernet4_slip8_gtwy represents an IP based gateway that supports 4 Ethernet hub interfaces and 8 serial line interfaces. IP packets that arrive on any interface are routed to appropriate output interface based on the packets' destination IP address. Routing Information Protocol (RIP in short) or Open Shortest Path First (OSPF in short) can be used to create gateway's routing tables and select routes accordingly. This component can be found directly from Object Platte Tree popup window. We placed 7 instances of this component in our workspace.
- 10Gbps Link: 10Gbps link represents a Duplex Ethernet link with a capacity of 10 Giga Bits per Second. In industry, network specialists use Cat5, Cat5e, Cat6 cables to connect routers/switches and workstations. Cat6 is faster and has higher bandwidth. This component can be found in the Object Platte Tree using the following steps: Link Models > Duplex Link Models > By Name > 10Gbps > 10Gbps_Ethernet. We connected our 7-node network using 10Gbps links as given in the following figure:

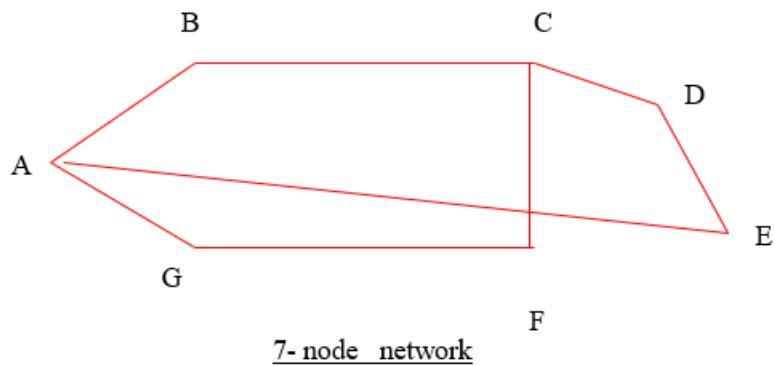


Figure 4: 7-node network design (given)

- IP_traffic_flow: IP_traffic_flow represents the IP layer traffic flow between source and destination. We needed to configure this flow using values from Traffic Matrix table (Symmetric). This component can be found in the Object Platte Tree using the following steps Demand Model > By Name > IP > IP_traffic_flow. We connected every node to every other node using IP_traffic_flow Demand Model.

The final design of our 7-node network is shown in the figure below:

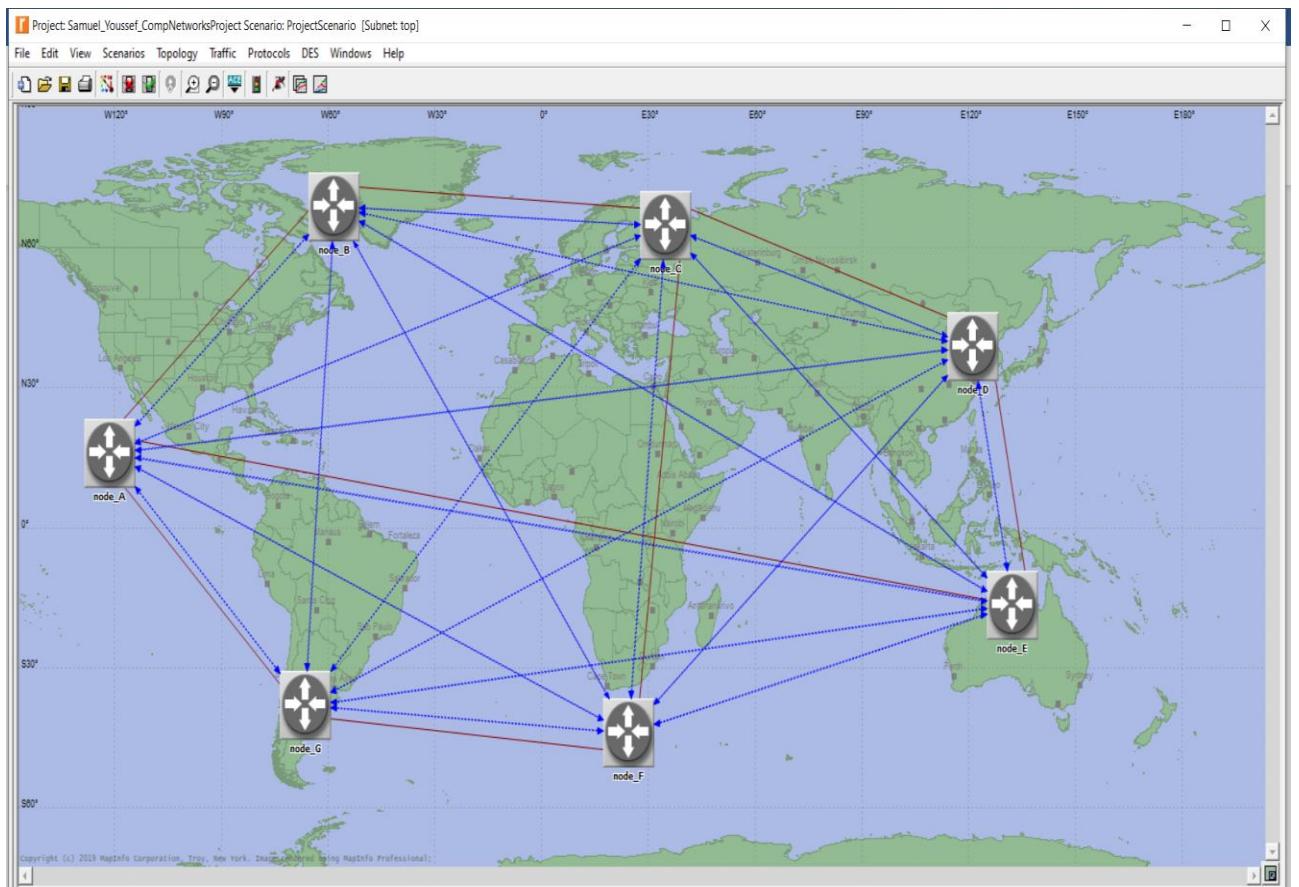


Figure 5: 7-node Network Design.

5. We were given the following traffic matrix (in Megabits per Second) as follows:

A	B	C	D	E	F	G
A	900	600	500	700	800	200
B	900	300	200	900	500	300
C	600	300	700	100	400	500
D	500	200	700	400	700	900
E	700	900	100	400	500	400
F	800	500	400	700	500	200
G	200	300	500	900	400	200

Figure 6: TRAFFIC (Megabits / sec) <SYMMETRIC>

And we had to generate the corresponding Traffic Matrix (in Packets per Second) as follows:

A	B	C	D	E	F	G
A	1.125	0.750	0.625	0.875	1	0.250
B	1.125	0.375	0.250	1.125	0.625	0.375
C	0.750	0.375	0.875	0.125	0.500	0.625
D	0.625	0.250	0.875	0.500	0.875	1.125
E	0.875	1.125	0.125	0.500	0.625	0.500
F	1	0.625	0.500	0.875	0.625	0.250
G	0.250	0.375	0.625	1.125	0.500	0.250

Figure 7: Traffic (Packets / sec) (in Millions) <SYMMETRIC>

The values in Traffic (Packets / sec) table were determined by the following formula:

$$\text{Given: Mean Packet size} = 1/u = 800 \text{ bits/packet}$$

$$\text{So, Capacity (Packets/second)} = (\text{bits/second}) / (\text{bits/packet})$$

For Example: A → B: Capacity (Packets/second) = 900,000,000 (bits/second) / 800 (bits/packet)
= 1,125,000 packets/sec = (1.125 M) as shown in the table (Figure 7).

6. Next, we applied the values from the above two tables to the respective attributes of each IP_traffic_flow line (blue lines in Figure 5). An example of this process is shown in the following figure:

(node_E --> node_G) Attributes

Attribute	Value
... name	node_E --> node_G
... model	ip_traffic_flow
Socket Information	
Associated VPN	None
Deployment Data	Not Set
Description	Represents IP Traffic
Autonomous System Information	
Destination Business Group	<Not Set>
Destination IP Address	Auto Assigned
Flow Type	Aggregate
Overhead/Segmentation	None
Probe Locations	None
SLA Parameters	(...)
Source Business Group	<Not Set>
Source IP Address	Auto Assigned
Traffic (bits/second)	41
Traffic (packets/second)	42
Traffic Characteristics	Best Effort
Traffic Duration	End Of Simulation
Traffic Mix	All Background
Traffic Start Time	Same As Global Setting

Filter Advanced Apply to selected objects
 Exact match OK Cancel

Figure 8: Attributes of the IP traffic flow line (node E To node G)

Specifically, we created “profiles” for the following attributes:

- Traffic(packets/second)
- Traffic(bits/second)

An example of setting profile for the above two attributes is shown in the two figures below:

NOTE: we chose the “Uniform X interval” to be 600 seconds / step in setting up the profiles for both above attributes.

NOTE: we carried out this step for all the IP_traffic_flow lines (Blue Lines in Figure 5).

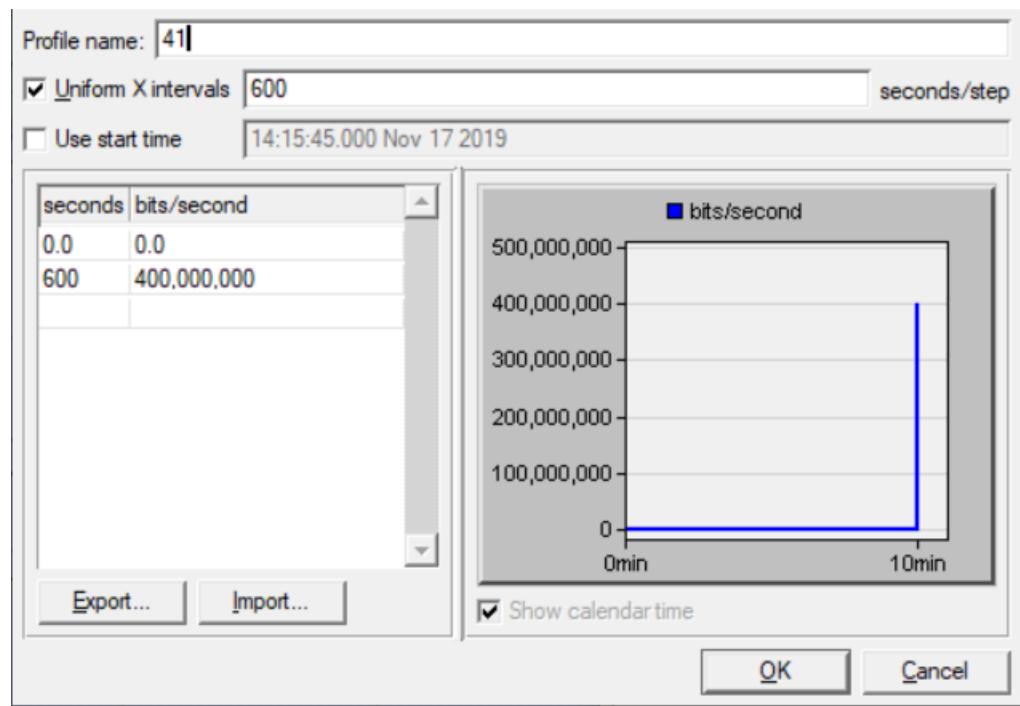


Figure 9: Profile of “Traffic (bits per second)” Attribute (node E To node G).

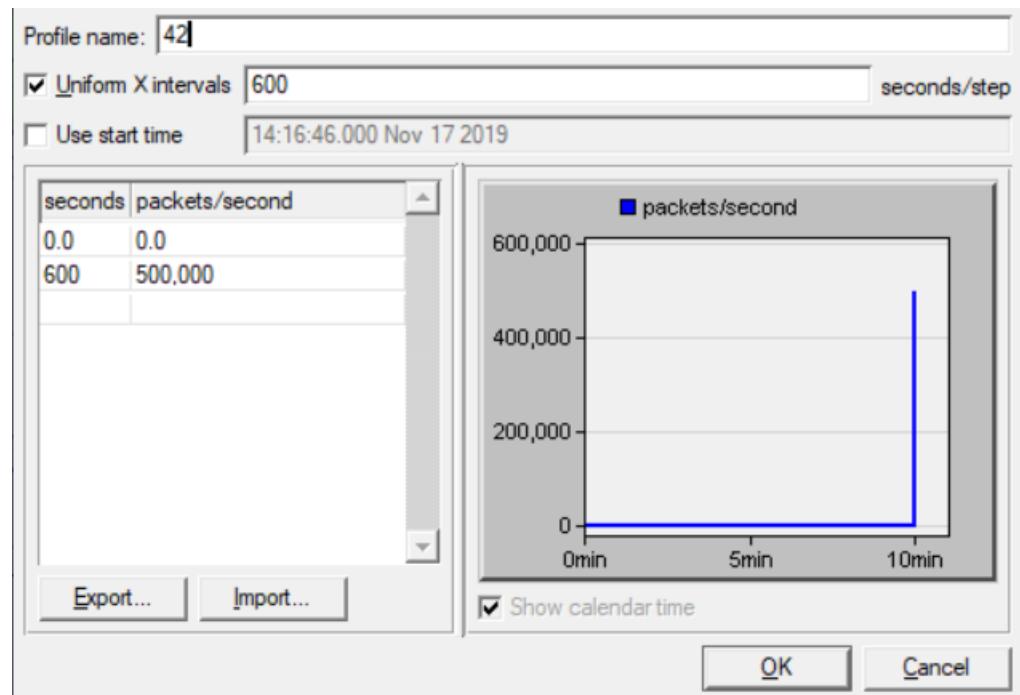


Figure 10: Profile of “Traffic (Packets per second)” Attribute (node E To node G).

7. Finally, we were able to run the simulations. But first, we needed to set the IP Routing Protocol to be used throughout the network. We started by setting the routing protocol to RIP by the following these steps:

- Protocols > IP > Routing > Configure Routing Protocols..., and then we choose RIP as shown in the following figure:

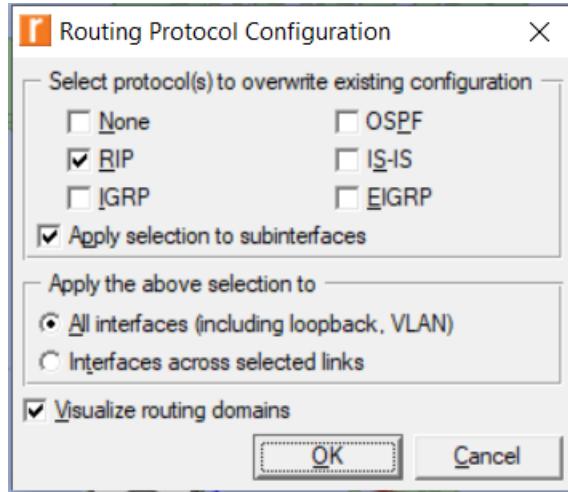


Figure 11: Choosing RIP to be the Routing Protocol of the Network.

Next, we needed to probe individual statistics before we run the simulations. This is done simply by following these steps (for the following example, we probe point-to-point statistics):

- DES > Choose Individual Statistics > Link Statistics > Point-to-point > Utilization

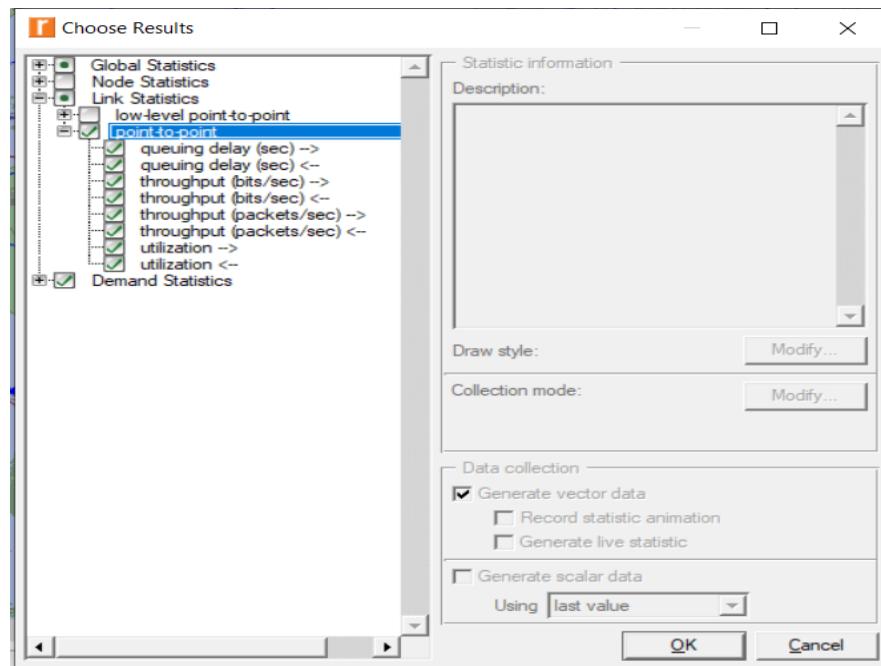


Figure 12: Probing Link Statistics (including point-to-point utilization).

The last step before running the simulation were to disable the simulation efficiency mode for RIP and OSPF as shown in the following figure:

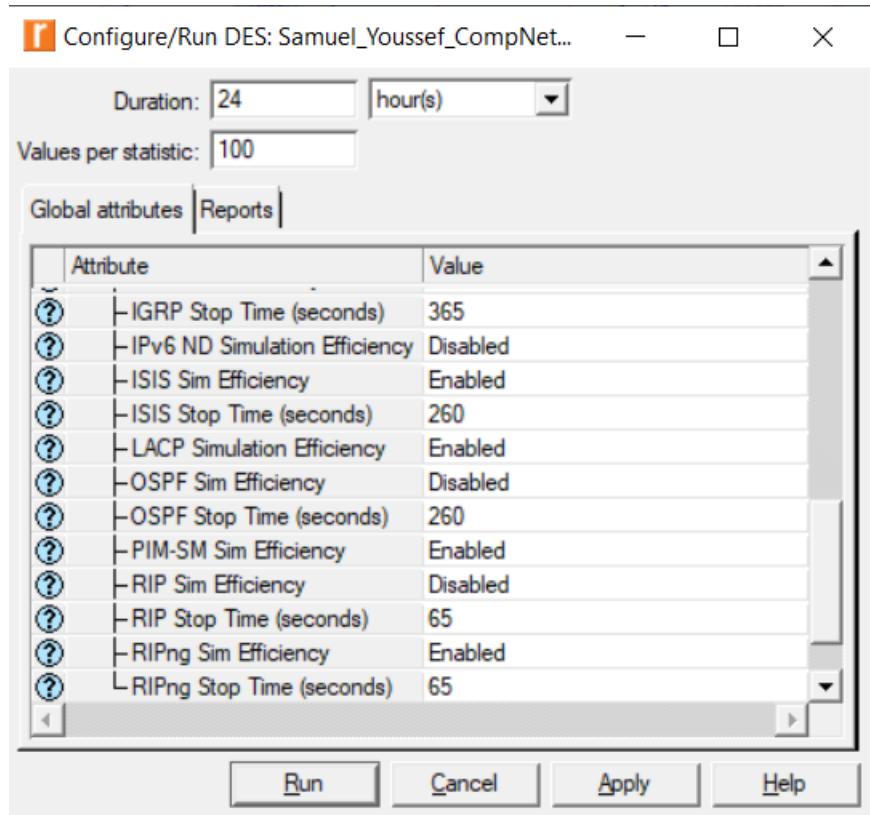


Figure 13: Disabling simulation efficiency option for RIP and OSPF.

At this point, we were able to run the simulations by following the steps below:

- DES > Configure/Run Discrete Event Simulation.
- We set the duration of the simulation to 24 hours and the values per statistic to be 100.
- Then, we clicked “Run”. Running the simulations takes some time.
- After the simulations had completed, we were able to view the results as shown in the following figure:

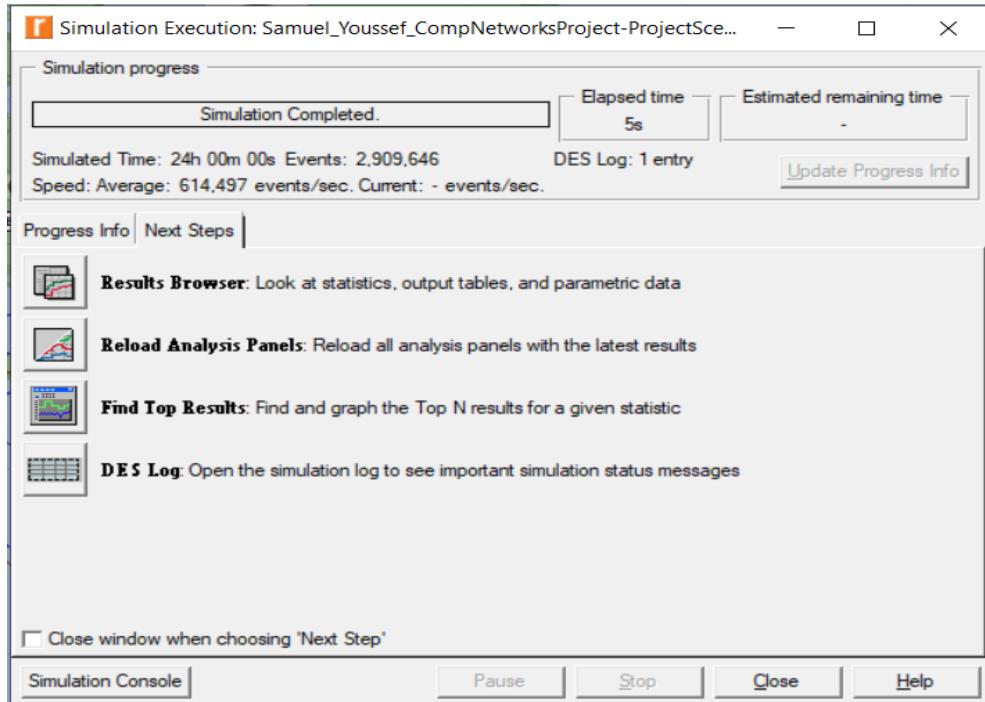


Figure 14: Simulations had completed, and Results are viewable by clicking “Results Browser”.

NOTE: To Avoid exceeding the Forwarding Rate of the IP Routers, the following step had to be taken:

- Increasing the “Datagram Forwarding Rate” of each of the 7 nodes from 500,000 pkts/sec (default value) to 20,000,000 pkts/sec as shown in the following figure:

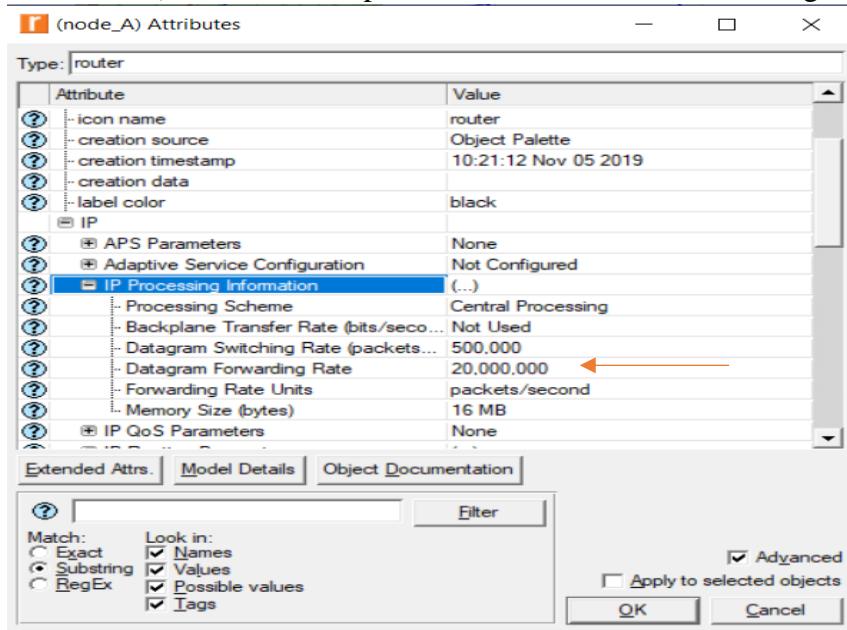


Figure 15: Increasing the Datagram Forwarding Rate of each IP Router.

Simulation Results (RIP)

- Point-to-point Utilization of the link (As is):

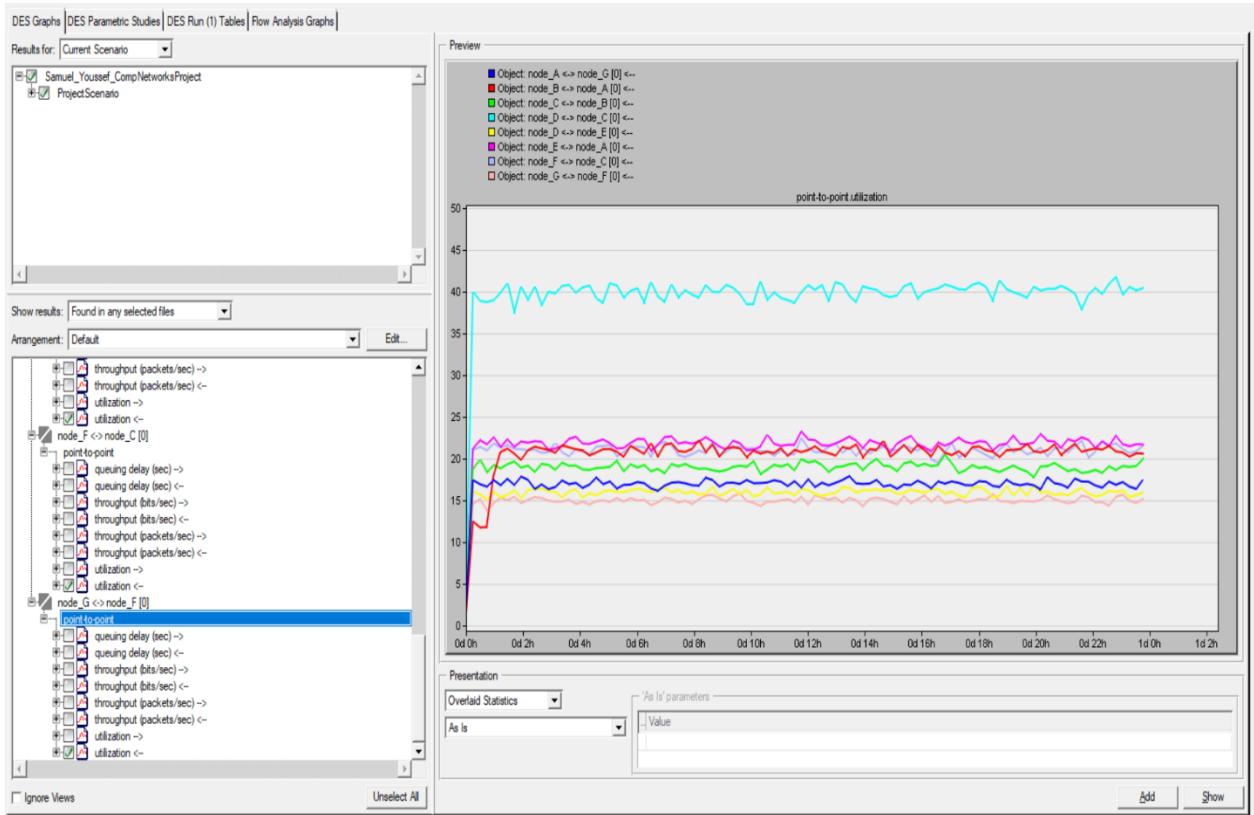


Figure 16: Point-to-point Utilization of the links (As is) using RIP.

NOTE: As we can see from the above figure, the utilization of the links does NOT exceed 40 percent.

- Point-to-point Utilization of the links (Average):

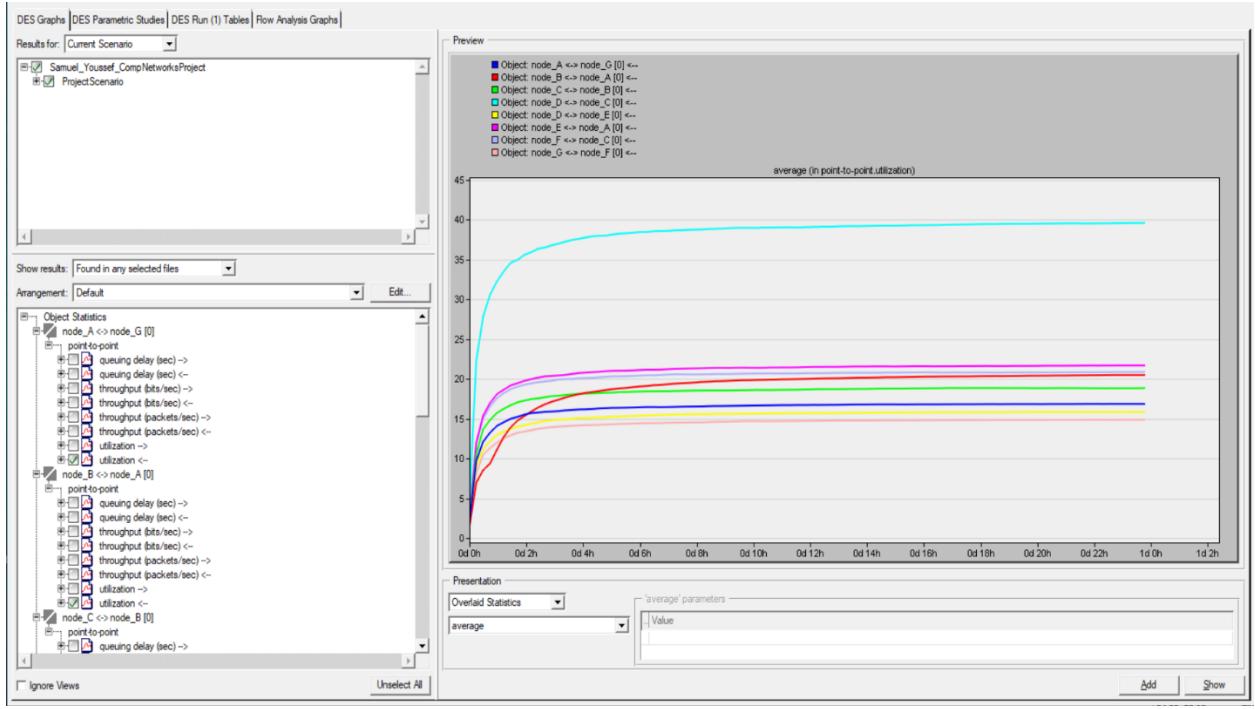


Figure 17: Point-to-point utilization of the links (Average) using RIP.

NOTE: The average point-to-point utilization of the links does not exceed 40 percent.

- Link Delay Histogram for 2 links and the average delay:
 - The 2 links are:
 - Node B to Node A
 - Node C to Node B
 - First, we had to probe the statistics for packet ETE (end-to-end) delay. We did that by following the steps below:
 - DES > Choose Individual DES Statistics > Demand Statistics > Packet End to End Delay.
 - Second, we had to change attribute “Traffic Mix” of the IP_traffic_flow line (Blue Lines in Figure 5) of the chosen links from “All Background” to “0.1% Explicit”.
 - The reason we did NOT change the value of “Traffic Mix” to be “All Explicit” is that the traffic between any two nodes in this 7-node network is heavy, and it would take a significant amount of time to simulate if we set the value of “Traffic Mix” to “All Explicit”.

- The following figure illustrates the change of “Traffic Mix” attribute to “0.1 % Explicit” of IP_traffic_flow link from node B to node A:

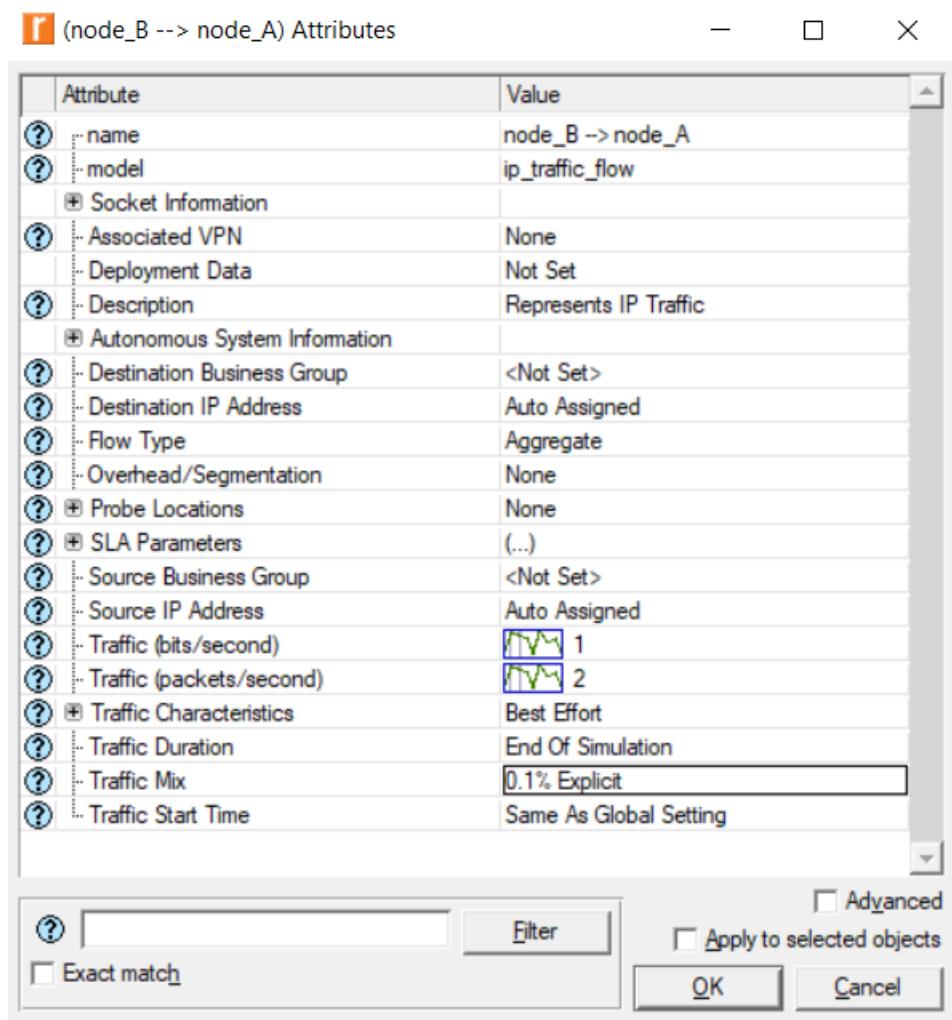


Figure 18: Setting “Traffic Mix” Attribute to “0.1% Explicit” (node B to node A).

We ran the simulations and obtained the following:

Link Delay Histogram for the following links:

- Node B to Node A
- Node C to Node B

NOTE: we ran the simulations for 55 minutes, and we set the “values per statistics” to 1000.

Link Delay Histogram (Node B to Node A):

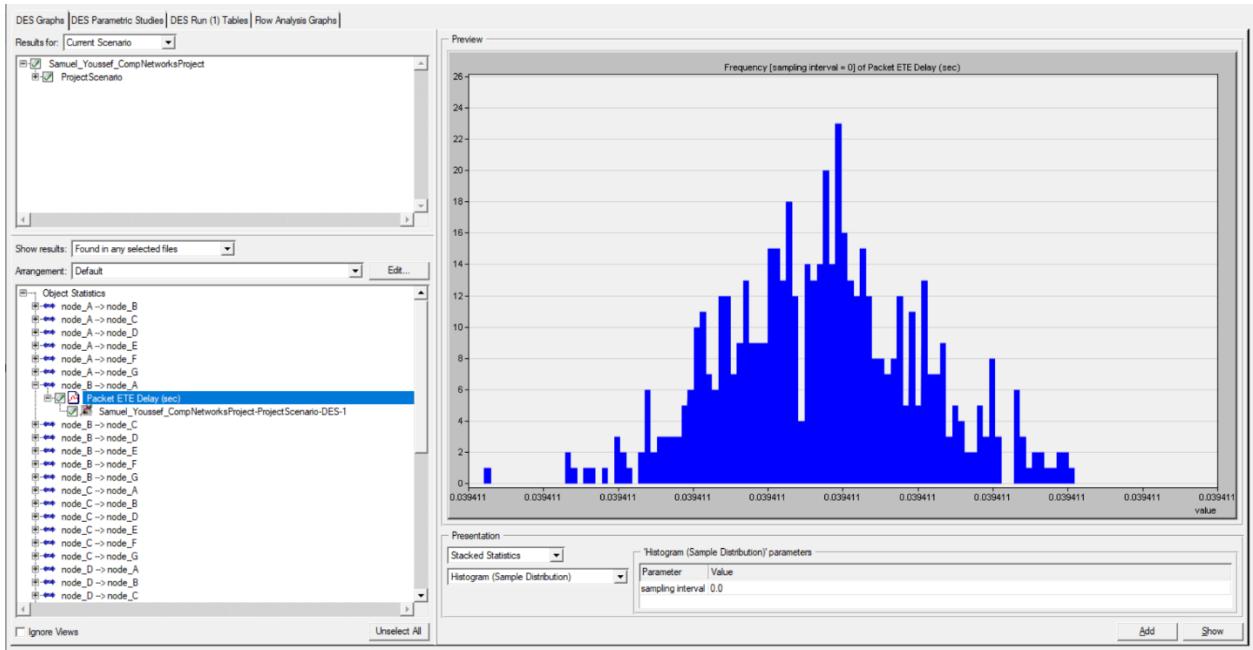


Figure 19: Link Delay Histogram (Node B to Node A)

Link Delay time-average (Node B to Node A):

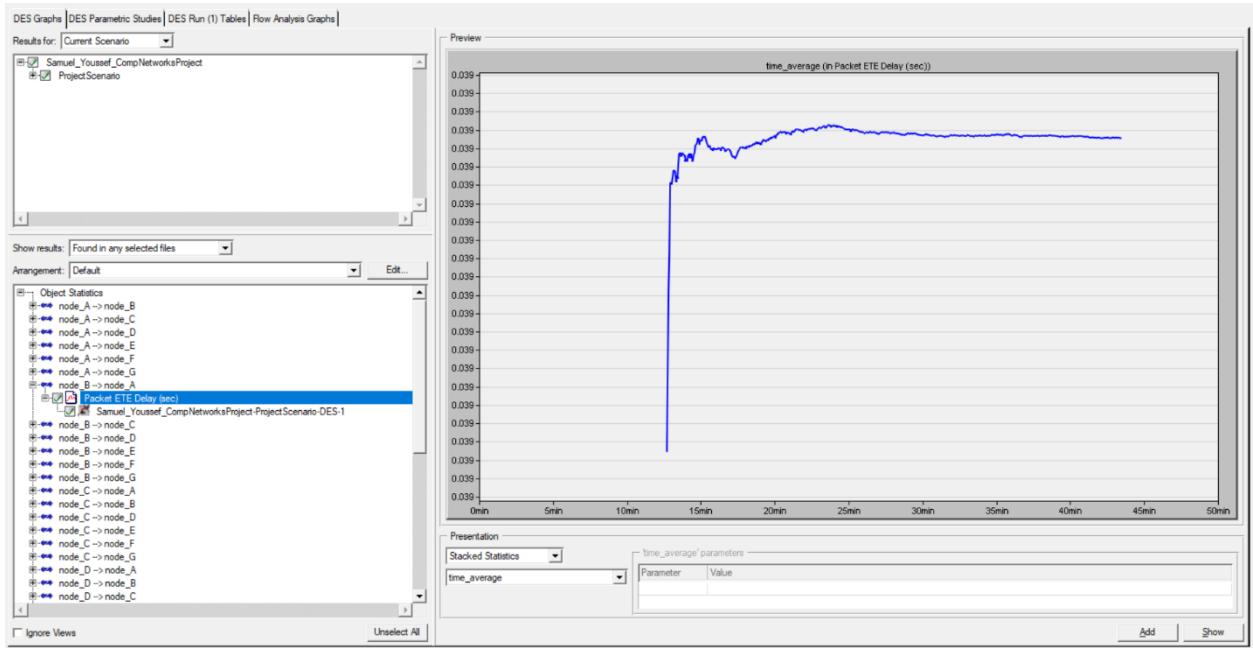


Figure 20: Time-Average graph of the link delay (Node B to Node A)

As we can see from the above figure, the time-average of the link delay from Node B to Node A is only 0.039 seconds.

Link Delay Histogram (Node C to Node B):

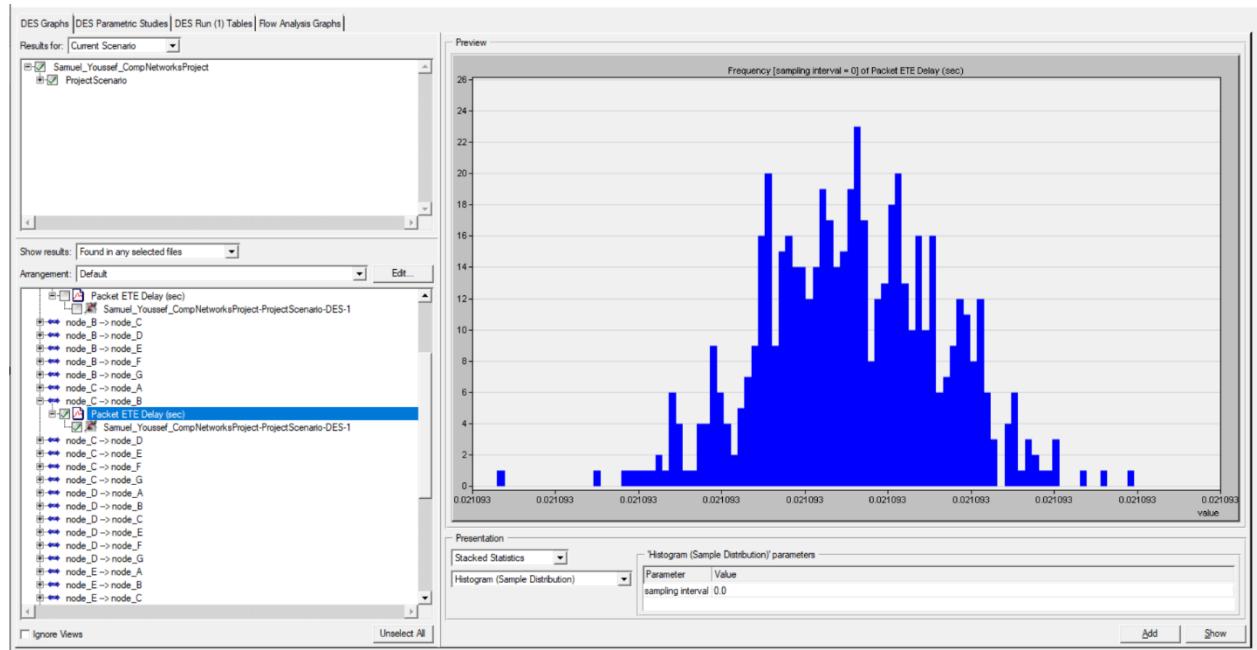


Figure 21: Link Delay Histogram (Node C to Node B)

Link Delay time-average (Node C to Node B):

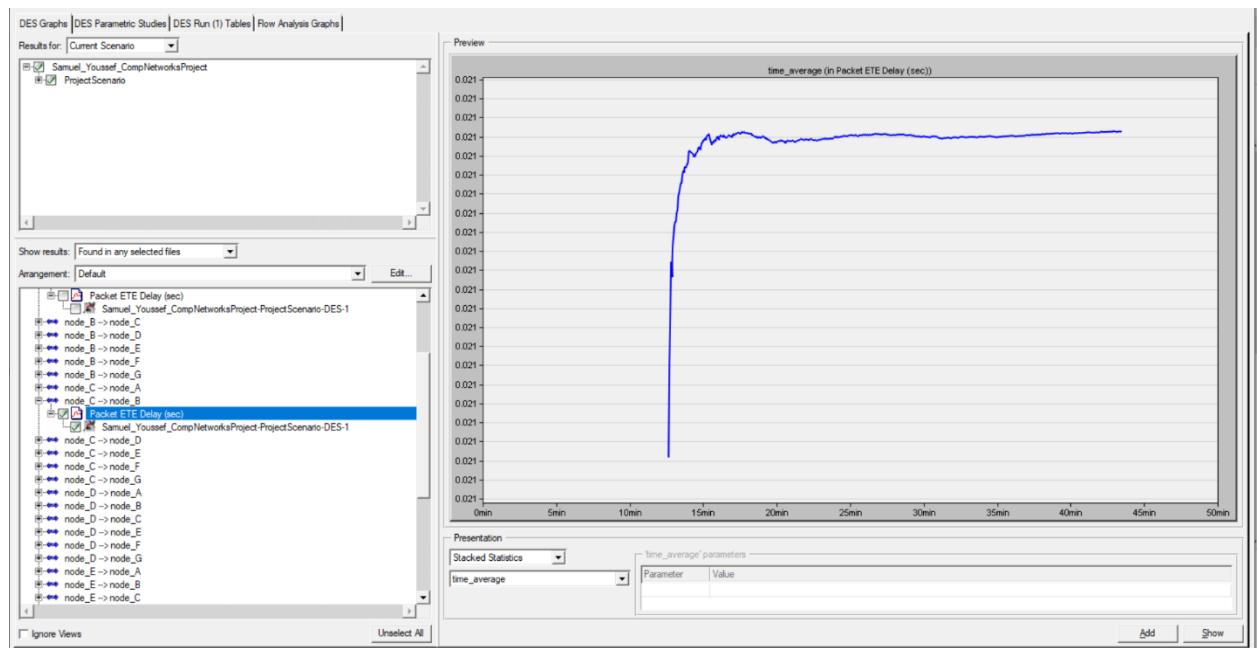


Figure 22: Time-Average graph of the link delay (Node C to Node B)

As we can see from the above figure, the time-average of the link Delay from Node C to Node B is only 0.021 seconds

- The histogram for the link flows for 2 other links you choose and each average:
 - The 2 links are:
 - Node A <-> Node D
 - Node D <-> Node F
 - we had to change attribute “Traffic Mix” of the IP_traffic_flow line (Blue Lines in Figure 5) of the chosen links from “All Background” to “0.1% Explicit”.
 - The reason we did NOT change the value of “Traffic Mix” to be “All Explicit” is that the traffic between any two nodes in this 7-node network is heavy, and it would take a significant amount of time to simulate if we set the value of “Traffic Mix” to “All Explicit”.
 - we had to probe the statistics for packet ETE (end-to-end) delay. We did that by following the steps below:
 - DES > Choose Individual DES Statistics > Demand Statistics > Traffic Sent (packets/sec).

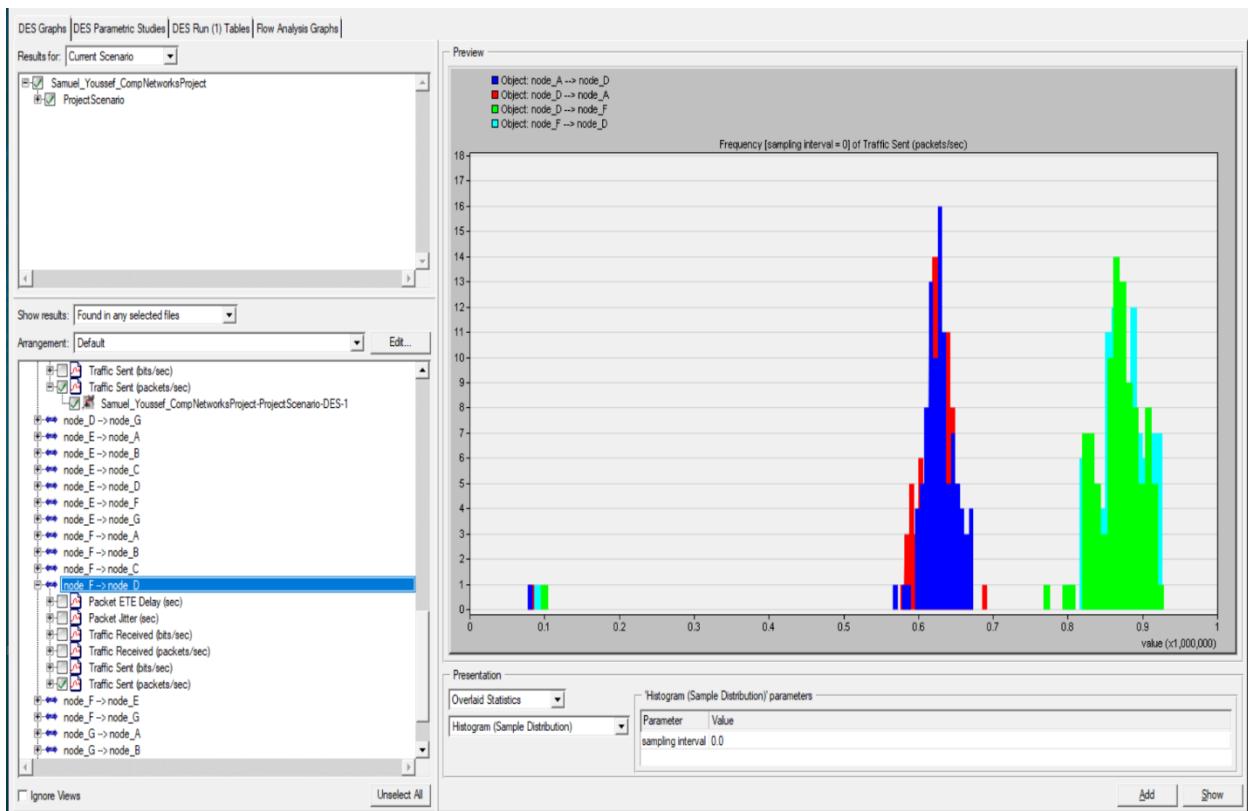


Figure 23: Link Flow Histogram (Node A <-> Node D, Node D <-> Node F).

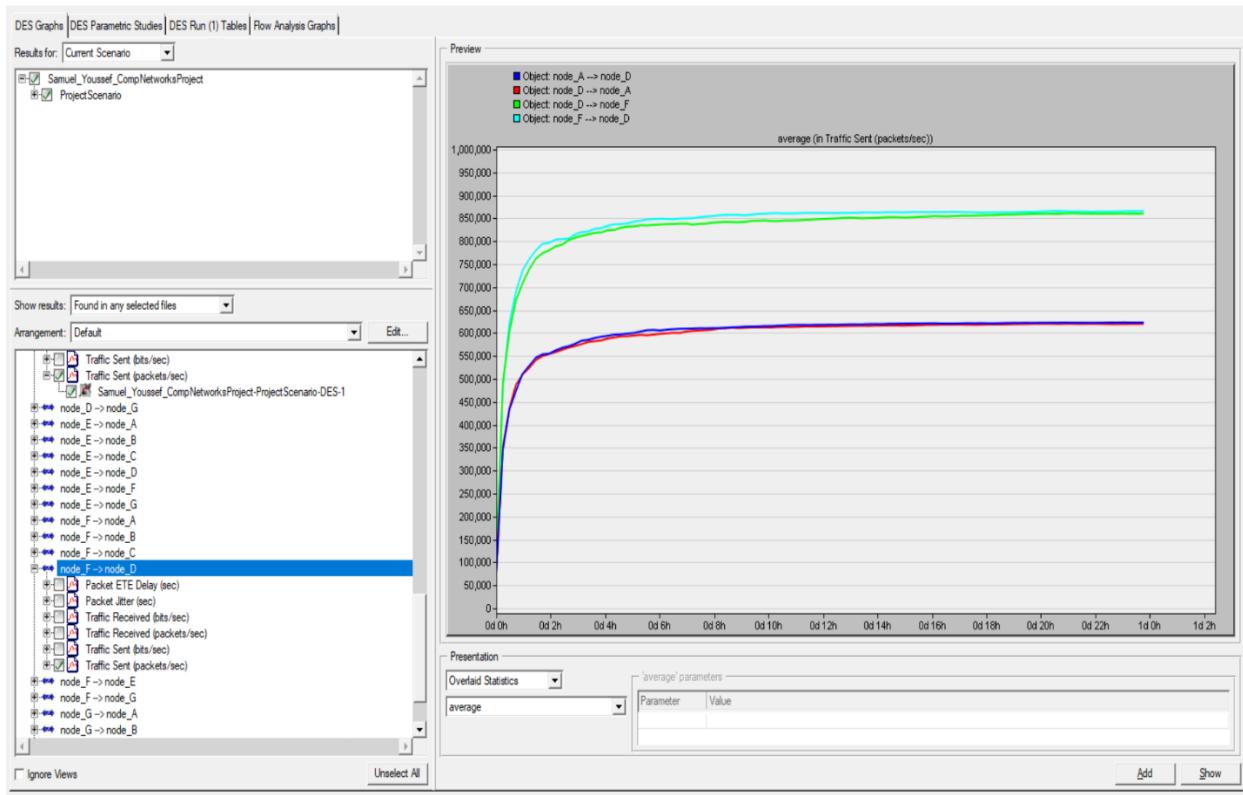


Figure 24: Average Link Flow (Node A <-> Node D, Node D <-> Node F)

As we can see from the above figure:

- The average link flow between Node A and Node D is 625,000 packets per second which confirms the values we have in the traffic matrix table (packets/second) in Figure 7.
- The Average link flow between Node D and Node F is 875,000 packets per second which confirms the values we have in the traffic matrix table (packets per second) in Figure 7.
- Average end to end delay and average number of hops for this network:
 - We followed the below steps to get the average end-to-end Delay and the average number of hops in the network:
 - DES > Choose Individual Statistics > Global Statistics > Ethernet > Delay.
 - DES > Choose Individual Statistics > Global Statistics > IP >Number of Hops.

Below is the ETE Ethernet Delay (As is):

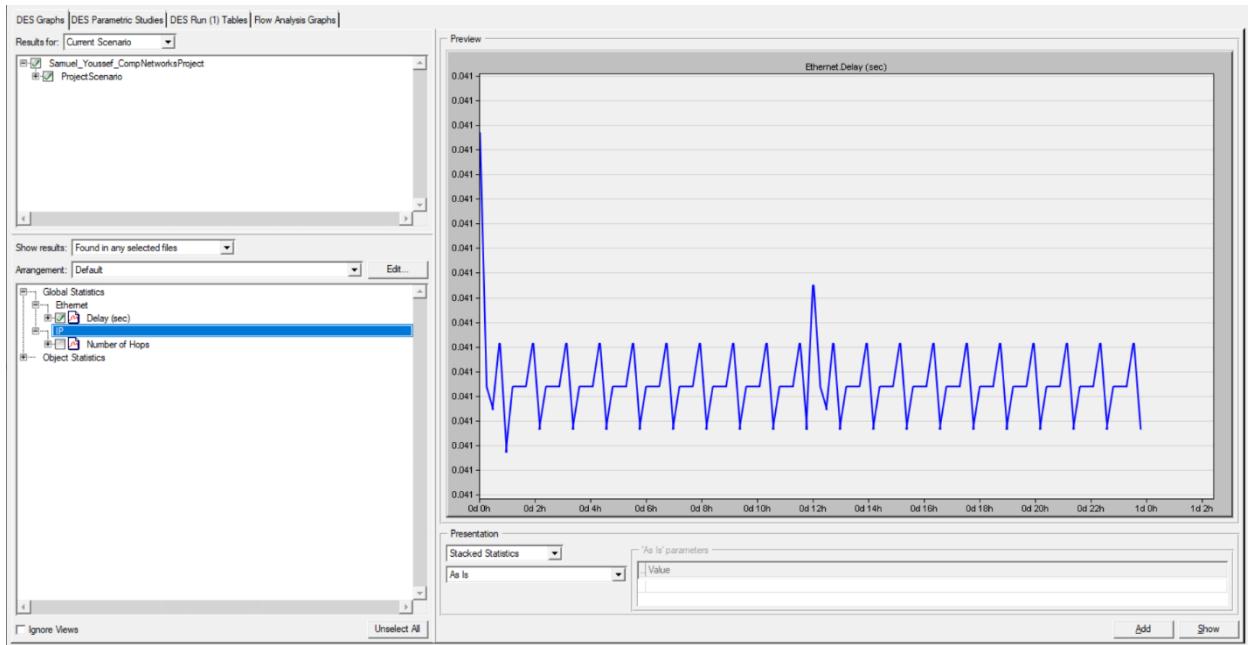


Figure 25: ETE Ethernet Delay (as is)

Blow is the Ethernet ETE Delay (Average):

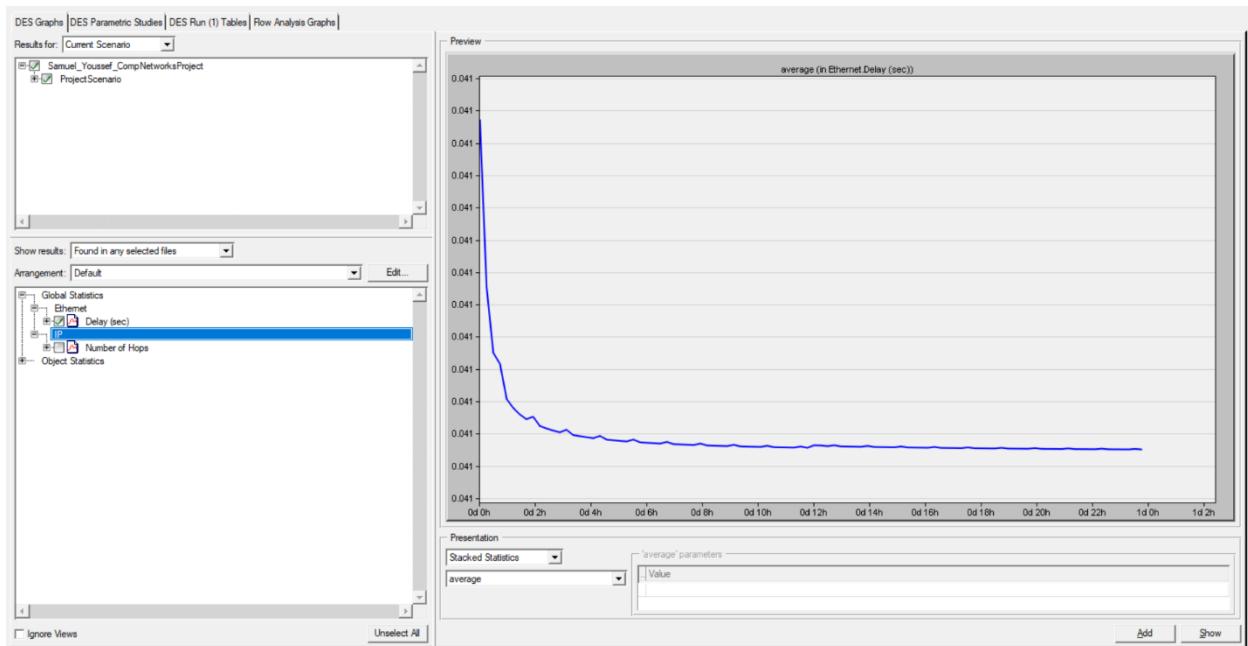


Figure 26: ETE Ethernet Delay (Average).

NOTE: The average ETE Ethernet Delay is 0.041 seconds

Below is the Average number of Hops:

NOTE: we ran the simulation for 24 hours, and the values per statistics were set to 10,000.

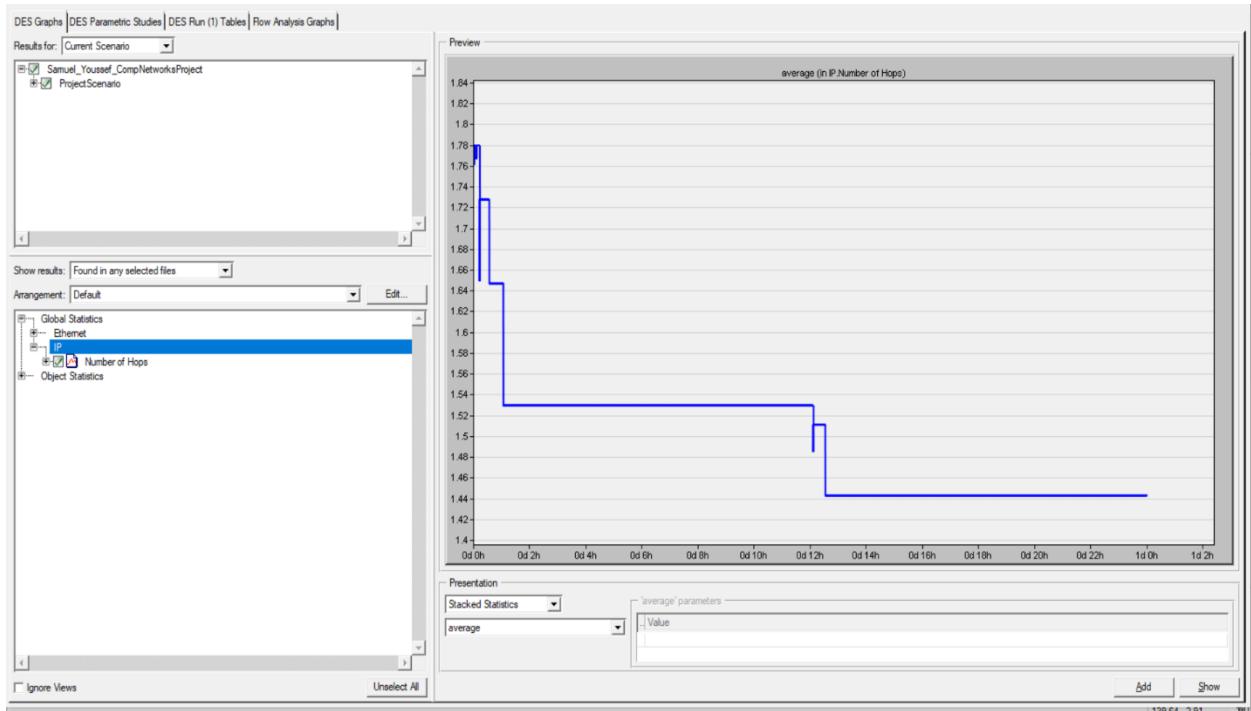


Figure 27: Average number of hops in the network.

From Figure 27, we can see that the average number of hops stabilizes at 1.46

Simulation Results (OSPF)

- First, we needed to change the protocol to OSPF and run the same simulations again.
- Protocols > IP > Routing > Configure Routing Protocols..., and then we choose RIP as shown in the following figure:

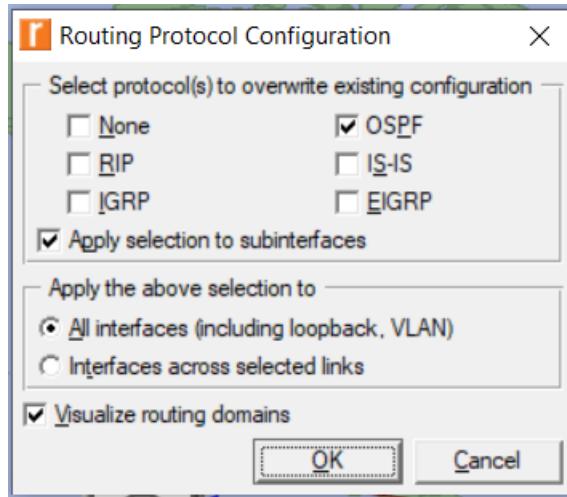


Figure 28: Choosing OSPF to be the Routing Protocol of the Network.

Next, we ran the same simulations to analyze the statistics of the network, and to compare OSPF simulations results with RIP simulation results.

- Point-to-point Utilization of the link (As is):

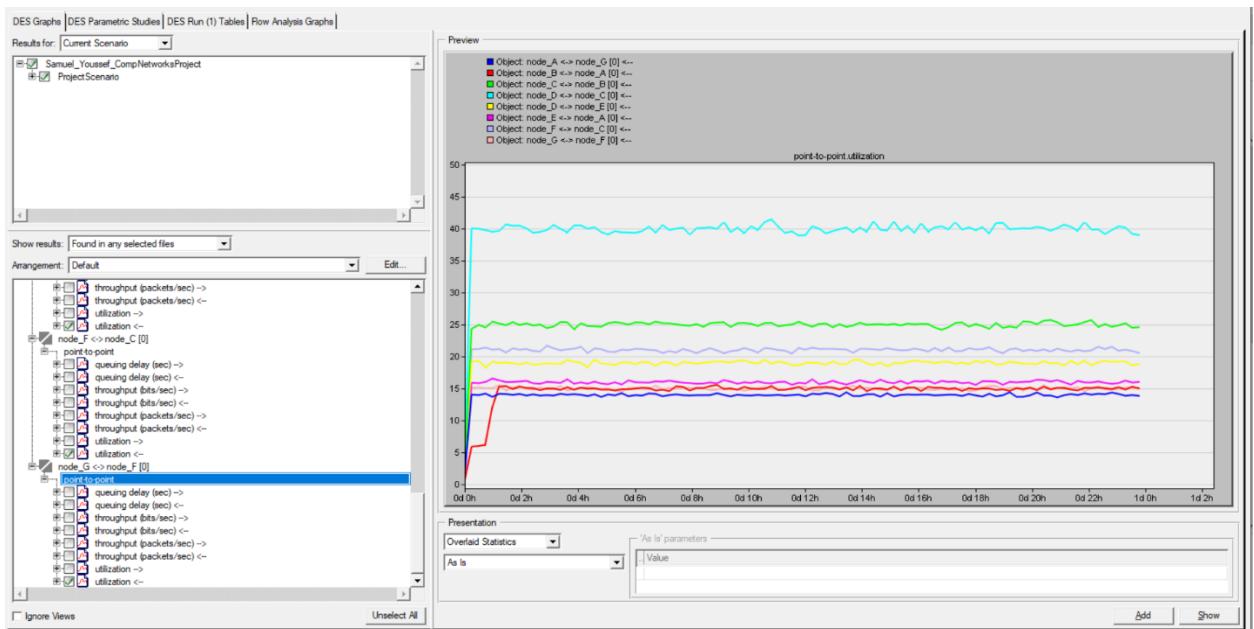


Figure 29: Point-to-point Utilization of the links (As is) using OSPF.

NOTE: As we can see from the above figure, the utilization of the links does NOT exceed 40 percent. However, compared to the utilization of the links using RIP, we can see that OSPF links are utilized **MORE** than RIP links which is also illustrated in the following figure of the average utilization of links when OSPF is in place.

- Point-to-point Utilization of the links (Average):

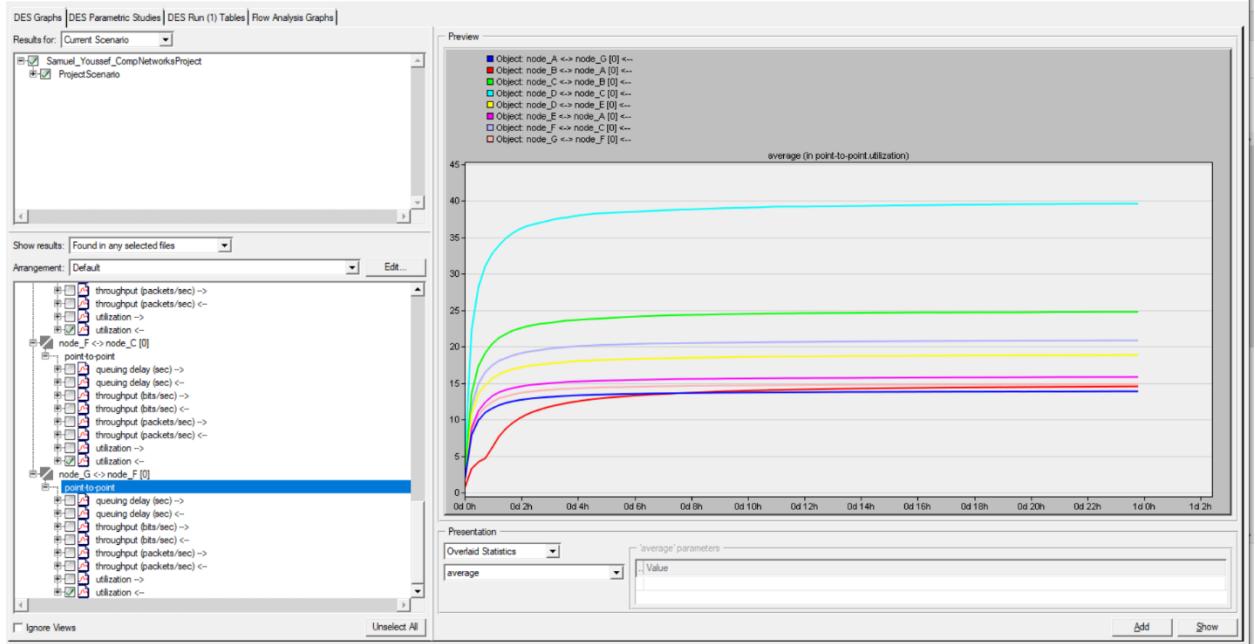


Figure 30: Point-to-point utilization of the links (Average) using OSPF.

NOTE: The average point-to-point utilization of the links does not exceed 40 percent. However, compared to the average utilization of the links (while using RIP), OSPF average utilization is **MORE** than that of RIP links.

- Link Delay Histogram for 2 links and the average delay:

- The 2 links are:
 - Node B to Node A
 - Node C to Node B
- First, we had to probe the statistics for packet ETE (end-to-end) delay. We did that by following the steps below:
 - DES > Choose Individual DES Statistics > Demand Statistics > Packet End to End Delay.

- Second, we had to change attribute “Traffic Mix” of the IP_traffic_flow line (Blue Lines in Figure 5) of the chosen links from “All Background” to “0.1% Explicit”.
 - The reason we did NOT change the value of “Traffic Mix” to be “All Explicit” is that the traffic between any two nodes in this 7-node network is heavy, and it would take a significant amount of time to simulate if we set the value of “Traffic Mix” to “All Explicit”.
 - The following figure illustrates the change of “Traffic Mix” attribute to “0.1 % Explicit” of IP_traffic_flow link from node B to node A:

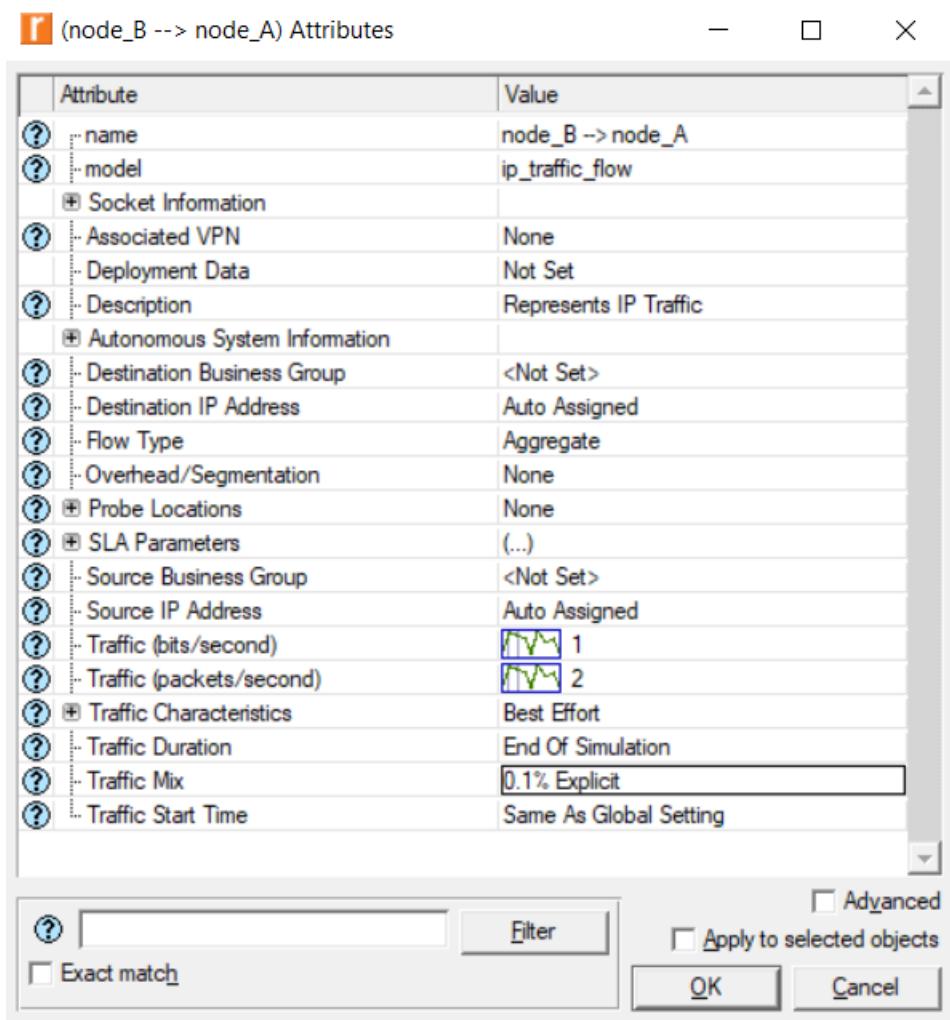


Figure 31: Setting “Traffic Mix” Attribute to “0.1% Explicit” (node B to node A).

We ran the simulations and obtained the following:

Link Delay Histogram for the following links:

- Node B to Node A
- Node C to Node B

NOTE: we ran the simulations for 55 minutes, and we set the “values per statistics” to 1000.

Link Delay Histogram (Node B to Node A):

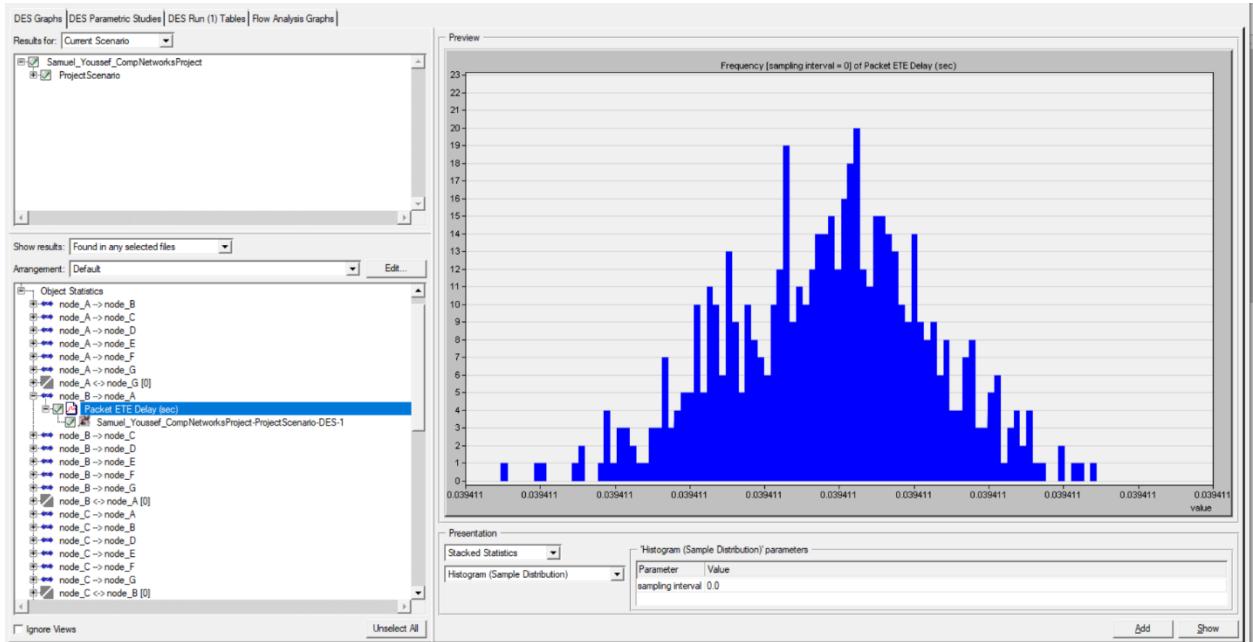


Figure 32: Link Delay Histogram (Node B to Node A) using OSPF

Link Delay time-average (Node B to Node A):

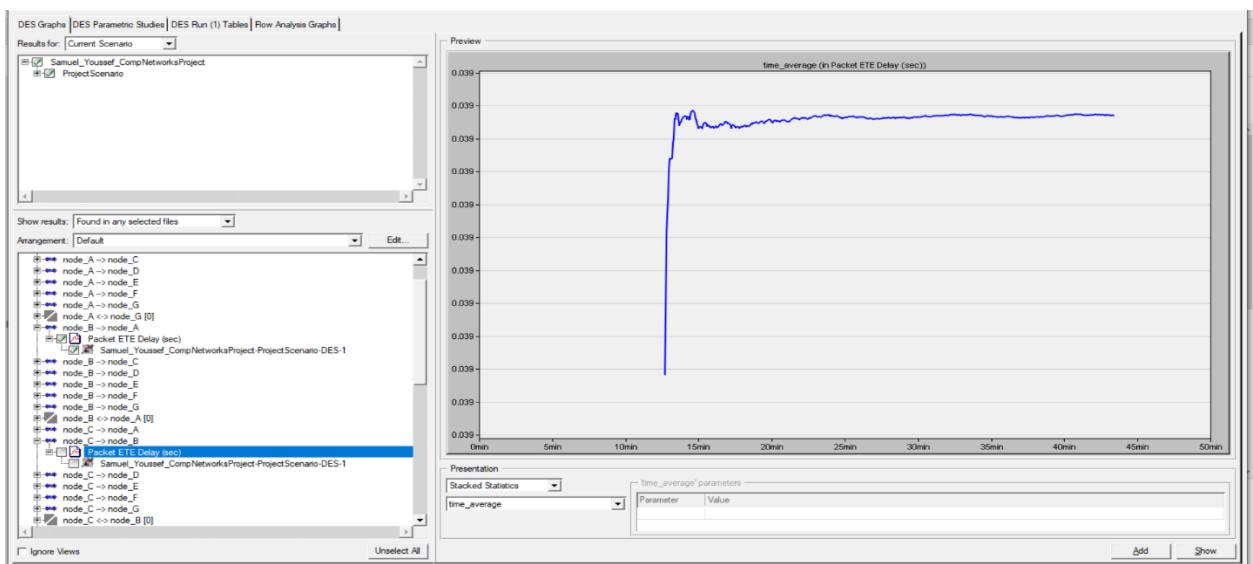


Figure 33: Time-Average graph of the link delay (Node B to Node A) using OSPF

As we can see from the above figure, the time-average of the link delay from Node B to Node A is only 0.039 seconds. While the average link delay is very similar, if not identical to that of RIP, we observe that the frequency of packet ETE delay while using OSPF is LESS than it is while using RIP.

Link Delay Histogram (Node C to Node B):

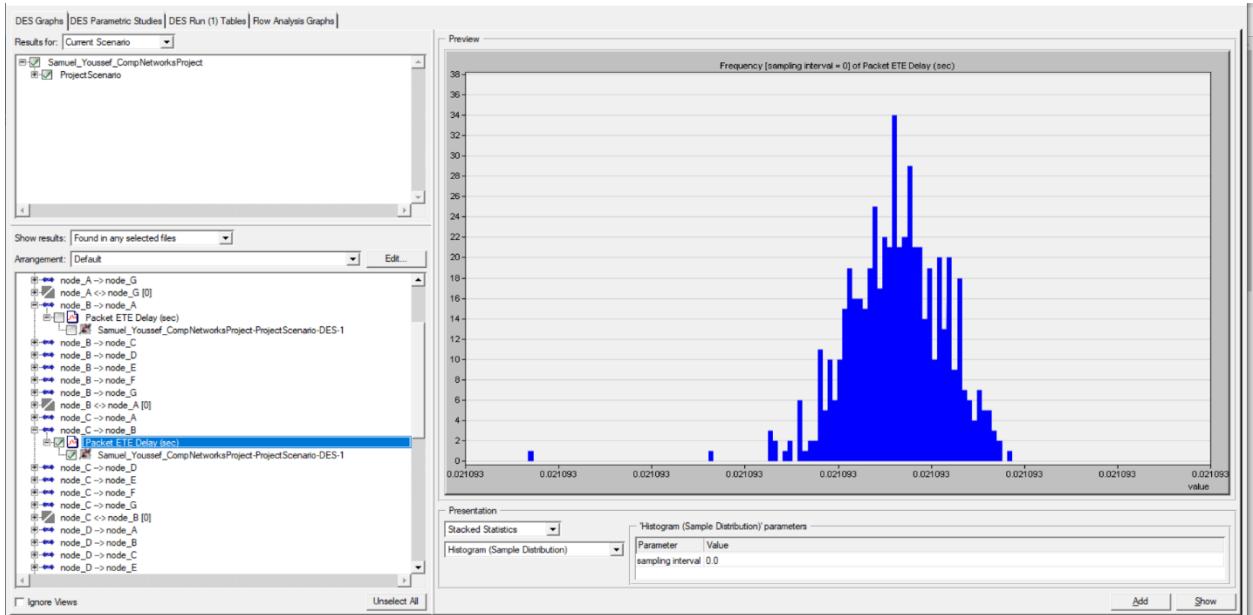


Figure 34: Link Delay Histogram (Node C to Node B) using OSPF

Link Delay time-average (Node C to Node B):

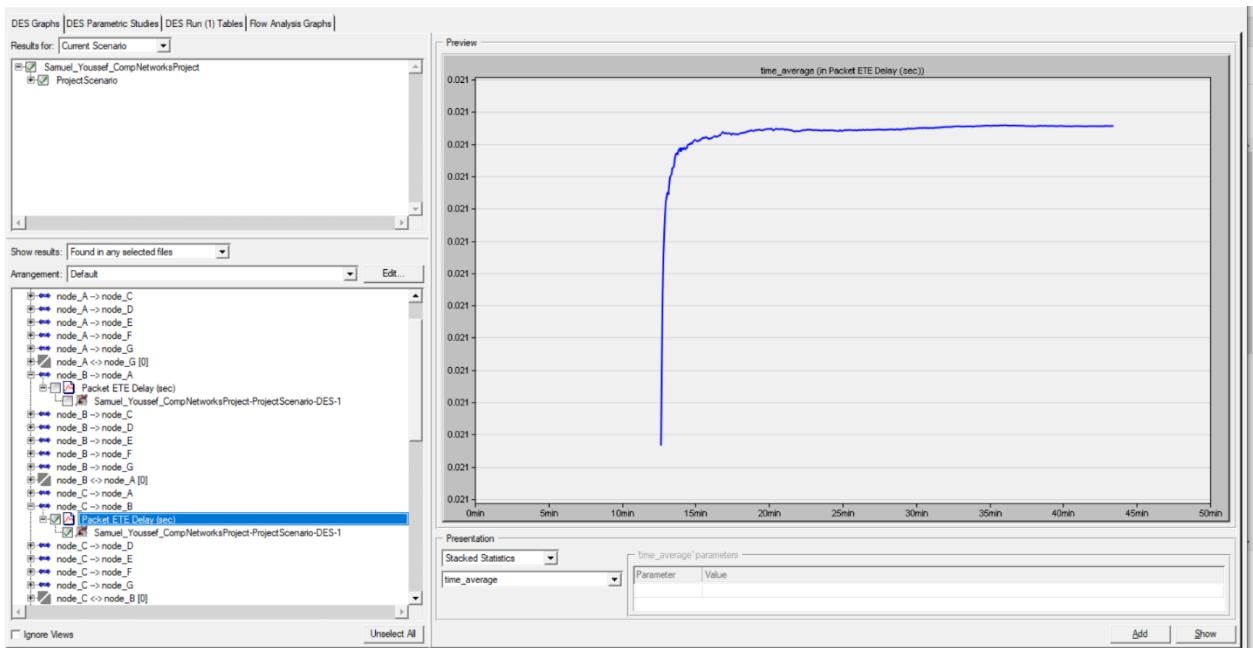


Figure 35: Time-Average graph of the link delay (Node C to Node B)

As we can see from the above figure, the time-average of the link Delay from Node C to Node B is only 0.021 seconds which is identical to results obtained when using RIP. In this instance, we observe that the frequency of packet ETE delay while using OSPF is MORE than it is while using RIP.

- The histogram for the link flows for 2 other links you choose and each average:
 - The 2 links are:
 - Node A <-> Node D
 - Node D <-> Node F
 - we had to change attribute “Traffic Mix” of the IP_traffic_flow line (Blue Lines in Figure 5) of the chosen links from “All Background” to “0.1% Explicit”.
 - The reason we did NOT change the value of “Traffic Mix” to be “All Explicit” is that the traffic between any two nodes in this 7-node network is heavy, and it would take a significant amount of time to simulate if we set the value of “Traffic Mix” to “All Explicit”.
 - we had to probe the statistics for packet ETE (end-to-end) delay. We did that by following the steps below:
 - DES > Choose Individual DES Statistics > Demand Statistics > Traffic Sent (packets/sec).

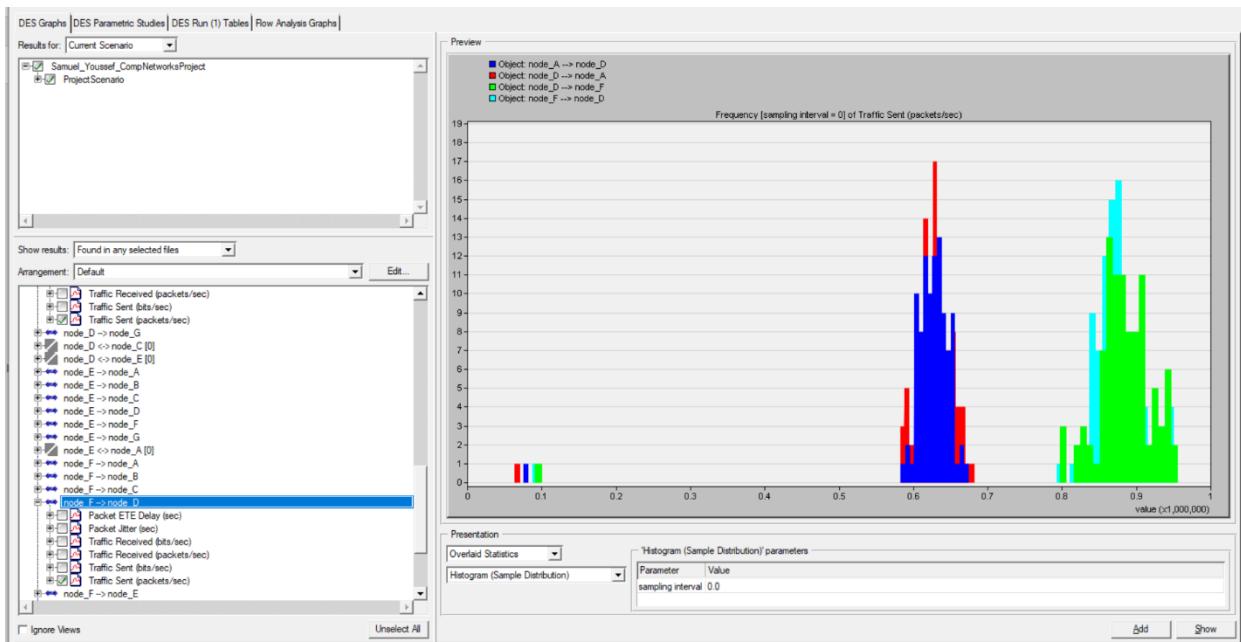


Figure 36: Link Flow Histogram (Node A <-> Node D, Node D <-> Node F) using OSPF.

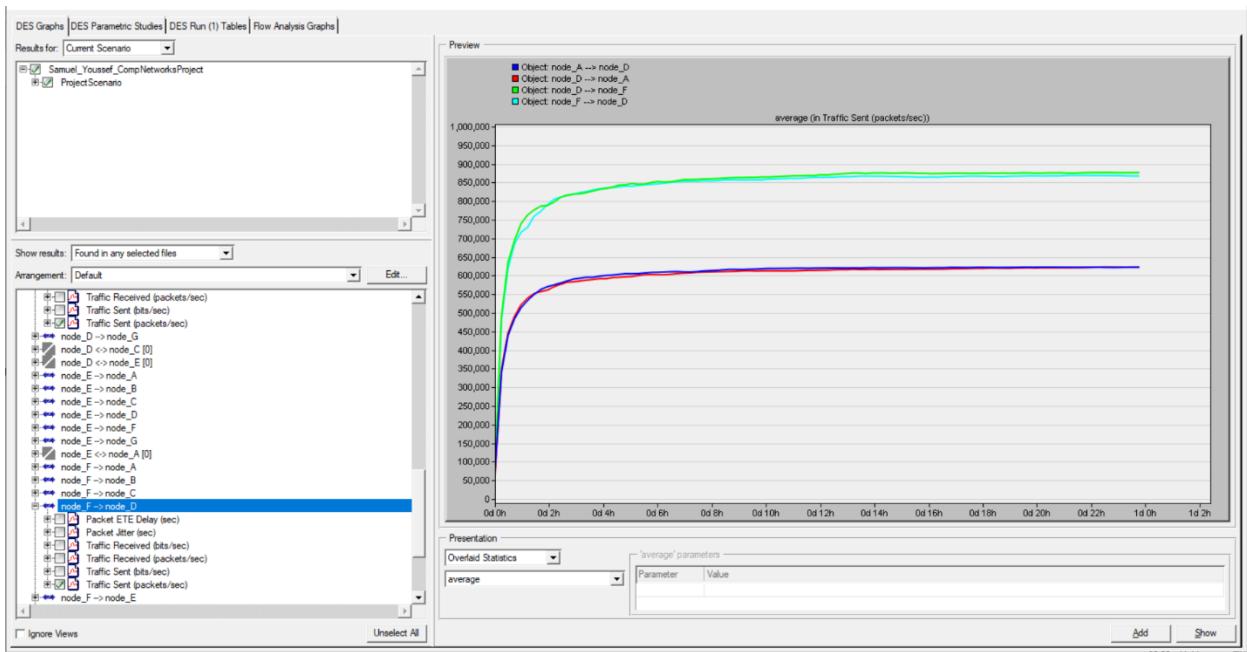


Figure 37: Average Link Flow (Node A <-> Node D, Node D <-> Node F) using OSPF.

As we can see from the above figure:

- The average link flow between Node A and Node D is 625,000 packets per second which confirms the values we have in the traffic matrix table (packets/second) in Figure 7.
- The Average link flow between Node D and Node F is 875,000 packets per second which confirms the values we have in the traffic matrix table (packets per second) in Figure 7.
- Average end to end delay and average number of hops for this network:
 - We followed the below steps to get the average end-to-end Delay and the average number of hops in the network:
 - DES > Choose Individual Statistics > Global Statistics > Ethernet > Delay.
 - DES > Choose Individual Statistics > Global Statistics > IP > Number of Hops.

Below is the ETE Ethernet Delay (As is):

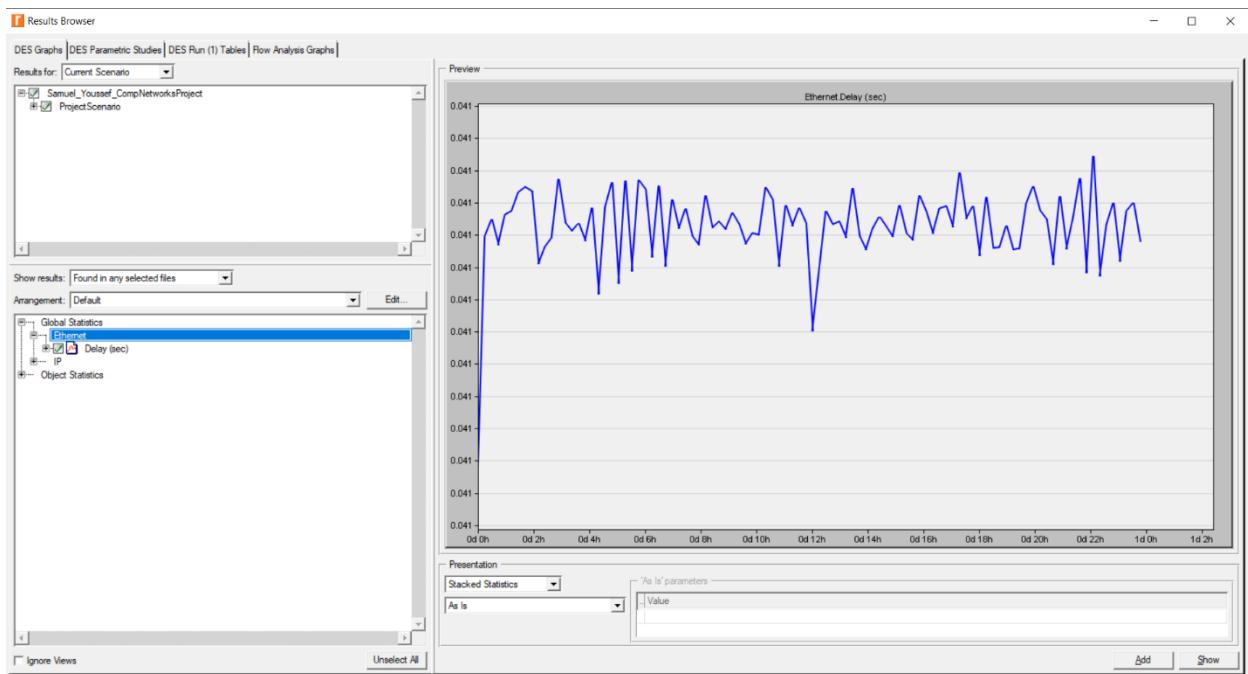


Figure 38: ETE Ethernet Delay (As is) using OSPF.

Blow is the Ethernet ETE Delay (Average):

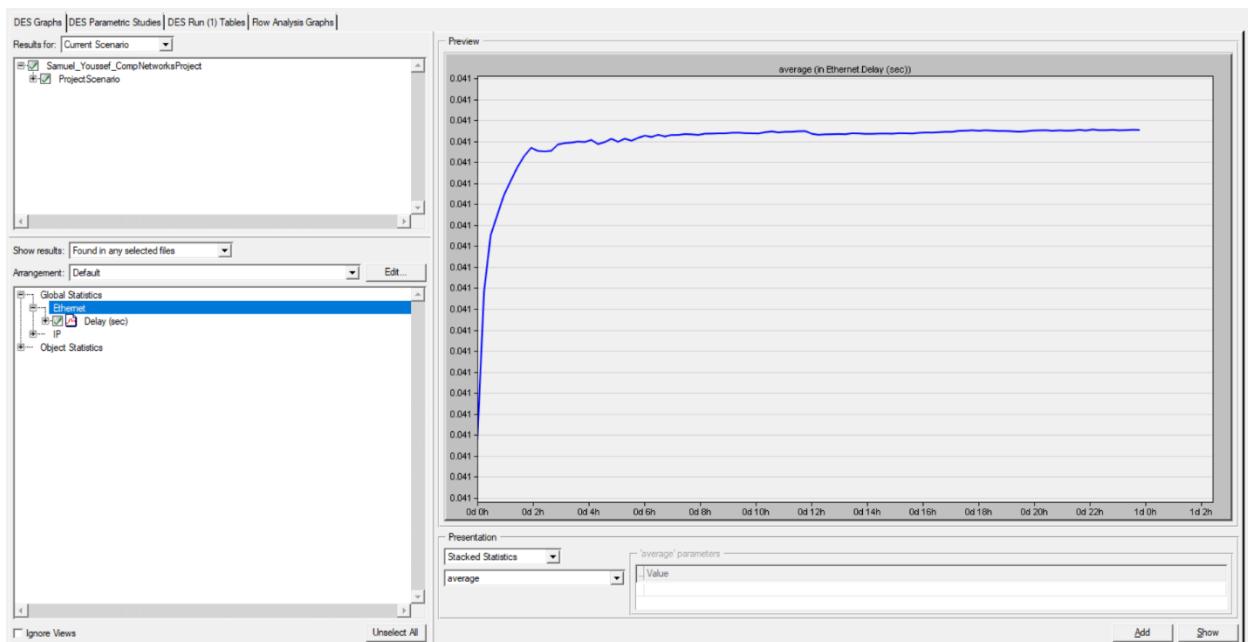


Figure 39: ETE Ethernet Delay (Average) using OSPF.

NOTE: The average ETE Ethernet Delay is 0.041 seconds. While the average ETE ethernet delay using OSPF is mostly identical to that using RIP, the graph trend shows that using OSPF may increase the average ETE ethernet delay.

Below is the Average number of Hops:

NOTE: we ran the simulation for 24 hours, and the values per statistics were set to 10,000.

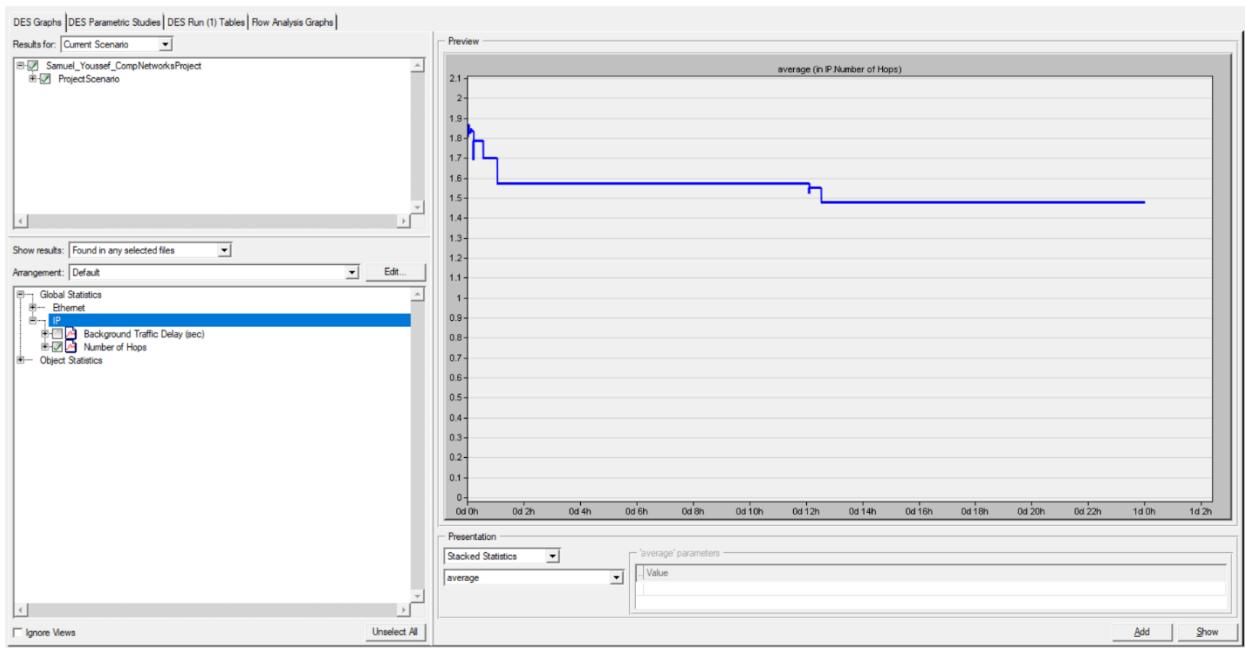


Figure 40: Average number of hops in the network.

From Figure 40, we can see that the average number of hops stabilizes at 1.5 which is MORE than the average number of hops when using RIP

Conclusion

Using OPNET software, we were able to observe the simulation results and compared two different routing algorithms. We observed that OSPF protocol had lower convergence time than that of RIP protocol, and the theory says that OSPF provides the shortest path with minimum link overhead. The following table summarizes the comparison between the two routing algorithms:

Attribute	RIP	OSPF
Convergence	Slow	Fast
Network Size	For small to medium networks	For large and small networks
Need of Device Resources	Much less memory and CPU intensive than OSPF	Memory and CPU intensive
Need of Network Resources	Bandwidth consuming; whole routing table is sent	Less than RIP; only small updates are sent
Metric	Based on hop count	Based on bandwidth
Design	Flat network	Hierarchical network possible

Figure 41: Comparison between RIP and OSPF routing algorithms.

This project was very helpful in visualizing a real-life network design situation. Before taking to construct any network, one must simulate the network design, and OPNET is a great tool to do so.

