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# FINAL PROJECT: Analysis of RIP, OSPF, and EIGRP Routing Protocols using OPNET

**www.sfu.ca/~mtn9/Group5.html**


**Group #5**

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# Abstract

Routing protocols determine the best routes to transfer data from one node to another and specify how routers communicate between each other in order to complete this task. There are different classes of routing protocols, two of which are Exterior Gateway Protocol (EGP) and Interior Gateway Routing (IGR). A routing protocol can be dynamic or static, as well as distance-vector or link-state. In this project, we will focus on Routing Information Protocol (RIP), Open Shortest Path First (OSPF), and Enhanced Interior Gateway Routing Protocol (EIGRP). All three protocols are dynamic IGP's, meaning that these protocols route packets within one Autonomous System (AS). RIP is a distance-vector protocol; EIGRP is an enhanced distance vector protocol developed by Cisco and OSPF is a link-state routing protocol. Detailed descriptions of these routing protocols are provided later in this report. We will study characteristics such as convergence time and routing traffic sent within small and large topologies. Using OPNET, we will obtain simulation results for the specified routing protocols and compare performance in order to determine the best routing protocol for a given network topology.

# 1 Introduction

On the network layer, achieving routing convergence, the process in which routing tables are updated, is a crucial and complex process. At every topology change, including a link failure or recovery, the routing tables need to be updated at which time the convergence process takes place. The task of updating these tables is accomplished by routers that communicate according to a set of rules set by routing protocols. The main goals of any routing protocol are to achieve fast convergence, while remaining simple, flexible, accurate and robust. In this project, we analyze and compare the convergence times of three protocols: Routing Information Protocol (RIP), Open Shortest Path First (OSPF), and Enhanced Interior Gateway Routing Protocol (EIGRP).

We will consider different topologies or different sizes, each of which will be simulated on OPNET 16.0. We will simulate each topology with all three routing protocols and collect statistics such as convergence time and routing traffic sent. We will also analyze the routing tables of a simple network topology in order to study the metrics of each protocol and gain a better understanding of how routes are chosen. By examining the results (convergence times in particular), we will identify the routing protocol with the best performance for a large, realistic network.

Finally, we will discuss the limitations that exist within our project and network implementations of the routing protocols. Furthermore, we will provide possible modifications that could be explored for future work.

# 2 Background

Routing links together small networks to form huge internetworks that span vast regions. This cumbersome task makes the network layer the most complex in the OSI reference model. The network layer provides the transfer of packets across the network. Routing protocols define the path of each packet from source to destination. To complete this task, routers use routing tables, which contain information about possible destinations in the network and the metrics (distance, cost, bandwidth, etc.) to these destinations. Routers have information regarding the neighbor routers around them. The degree of a router's network knowledge and awareness depends on the routing protocol it uses. At every change in the network, including link failure and link recovery, routing tables must be updated. The efficiency of these updates determines the efficiency of the routing protocols.

There are two main types of routing protocols: static routing and dynamic routing. Static routing assumes that the network is fixed, meaning no nodes are added or removed and routing tables are therefore only manually updated. Dynamic or adaptive routing, more commonly used for internetworking, allows changes in the network topology by using routing tables that update with each network change. In this report we will only consider dynamic routing protocols. Within the class of dynamic protocols, we can have Interior or Exterior Gateway Protocols. EGP's deals with routing information between different autonomous. An example of an EGP is Border Gateway Protocol (BGP). The three routing protocols we chose to compare are IGP's, protocols that exchange routing information within an AS. These protocols can either use distance vector (such as RIP and EIGRP) or link-state algorithms (such as OSPF) to optimize convergence times. In this project we will compare the three dynamic routing protocols shown on the right of the hierarchy chart below: RIP, OSPF and EIGRP.

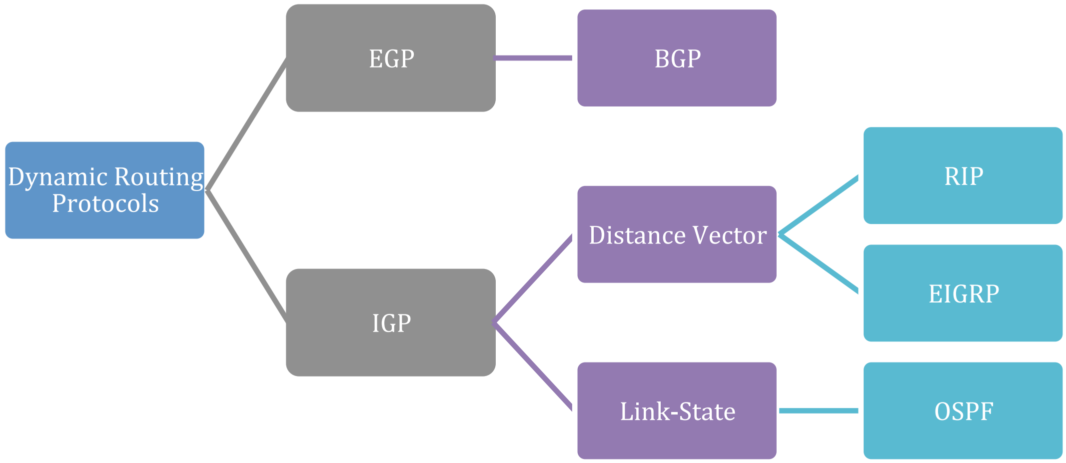


**Figure 1.1: Hierarchy Chart of Routing Protocols**

## 2.1 Routing Information Protocol (RIP):

The Routing Information Protocol (RIP), which is a distance-vector based algorithm, is one of the first routing protocols implemented on TCP/IP. Information is sent through the network using UDP. Each router that uses this protocol has limited knowledge of the network around it. This simple protocol uses a hop count mechanism to find an optimal path for packet routing. A maximum number of 16 hops are employed to avoid routing loops. However, this parameter limits the size of the networks that this protocol can support. The popularity of this protocol is largely due to its simplicity and its easy configurability. However, its disadvantages include slow convergence times, and its scalability limitations. Therefore, this protocol works best for small-scaled networks.

## 2.2 Open Shortest Path First (OSPF)

Open Shortest Path First (OSPF) is a very widely used link-state interior gateway protocols (IGP). This protocol routes Internet Protocol (IP) packets by gathering link-state information from neighboring routers and constructing a map of the network. OSPF routers send many message types including hello messages, link state requests and updates and database descriptions. Djisktra's algorithm is then used to find the shortest path to the destination. Shortest Path First (SPF) calculations are computed either periodically or upon a received Link State Advertisement (LSA), depending on the protocol implementation. Topology changes are detected very quickly using this protocol. Another advantage of OSPF is that its many configurable parameters make it a very flexible and robust protocol. Contrary to RIP, however, OSPF has the disadvantage of being too complicated.

## 2.3 Enhanced Interior Gateway Routing Protocol (EIGRP)

EIGRP is a Cisco-developed advanced distance-vector routing protocol. Routers using this protocol automatically distribute route information to all neighbors. The Diffusing Update Algorithm (DUA) is used for routing optimization, fast convergence, as well as to avoid routing loops. Full routing information is only exchanged once upon neighbor establishment, after which only partial updates are sent. When a router is unable to find a path through the network, it sends out a query to its neighbors, which propagates until a suitable route is found. This need-based update is an advantage over other protocols as it reduces traffic between routers and therefore saves bandwidth. The metric that is used to find an optimal path is calculated with variables bandwidth, load, delay and reliability. By incorporating many such variables, the protocol ensures that the best path is found. Also, compared to other distance-vector algorithms, EIGRP has a larger maximum hop limitation, which makes it compatible with large networks. The disadvantage of EIGRP is that it is a Cisco proprietary protocol, meaning it is only compatible with Cisco technology.

# 3 Implementation

In this section, we will discuss the breakdown of the project implementation from initiating the topologies to setting various protocol and simulation parameters. In the following sections, we will present the obtained simulation results and compare the performance of the three routing protocols.

In order to compare RIP, OSPF and EIGRP, we used OPNET 16.0 to implement four networks: two small topologies and two large topologies. These implementations were realized using Cisco routers connected by PPP_DS1. The small ring and mesh topologies that we implemented, though unrealistic, are simple examples that are easy to analyze and focus on routing protocol behavior and performance. In other words, the purpose of the two simple topologies is for validation of the routing protocols. We obtained routing tables from the small ring topology in order to better understand the routing system of each protocol. The large mesh and tree topologies implemented are more realistic and serve as better models for real-world communication networks.

## 3.1 Network Topologies

### 3.1.1 Small Ring Topology

We first implemented the simple ring topology shown in Figure 3.1 with 5 routers, each connected to 2 neighbor routers. The Rapid Configuration option on OPNET was used to achieve this network. We chose this topology because of its simplicity, and also because we wanted to analyze its behavior when a link failure is added between Router 1 and Router 2. When this failure occurs, routes will be changes and routing tables will be updated. For example, all packets from Router 1 will now have to flow through Router 5. We will analyze the routing tables from this topology after the link failure so as to ensure that this expected behavior is achieved.

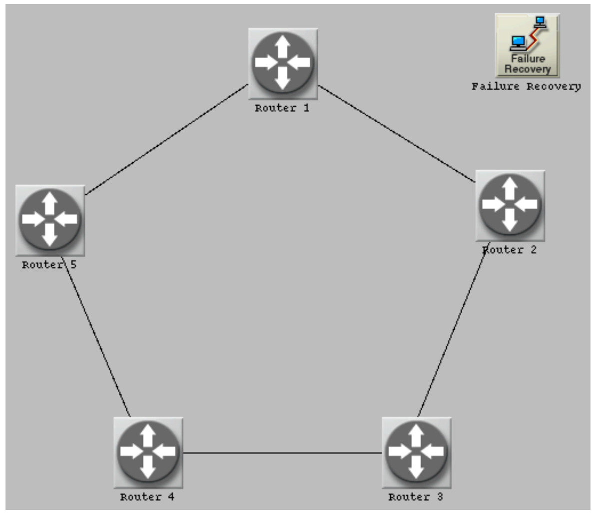


**Figure 3.1: Simple Ring Topology**

### 3.1.2 Small Mesh Topology

Our next topology, also attained by Rapid Configuration, is shown in Figure 3.2. This small mesh also consists of 5 routers; however, now each router is connected to the 4 other routers in the network. As in the ring topology, we implemented a link failure between Router 1 and Router 2. Unlike in the ring topology, now each destination in the network is only one hop away. Therefore, when a link fails, routers have more than one backup path. Also, we expect more routing traffic sent than in the ring topology because each router has more neighbors to communicate with. Though this topology is not realistic for most networks, it is simple and easy to understand.

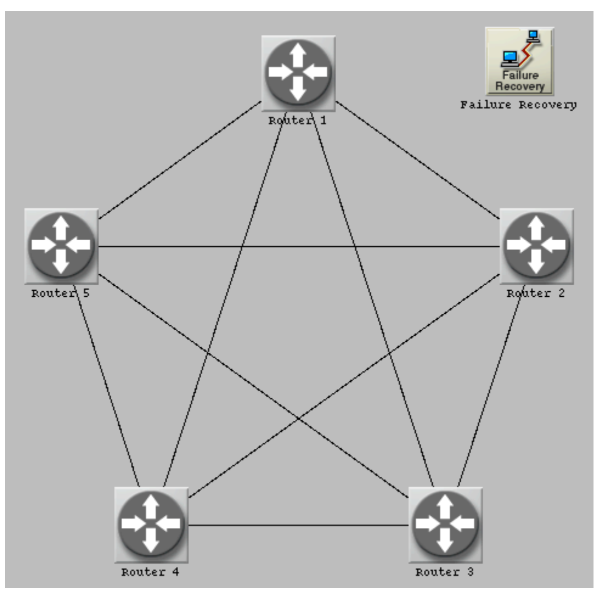


**Figure 3.2: Simple Mesh Topology**

### 3.1.3 Large Mesh Topology

Now we move on to our large network topologies. Figure 3.3 shows our large mesh topology. Though most large networks are not in a mesh topology, we wanted to analyze the result of scaling up one of our smaller topologies. This network consists of 100 routers, each of which is connected to 2 to 4 neighbor routers. The Rapid Configuration option on OPNET resulted in a large mesh arranged in a ring format, where routers were not visible. Therefore, for aesthetic purposes, we manually created the topology below. However, we did ensure that the results were comparable to those obtained by Rapid Configuration. Furthermore, we implemented a link failure on only one link in this network. Because of the size of this topology, the link failure will not affect all routes, but all routing tables will still be required to update.

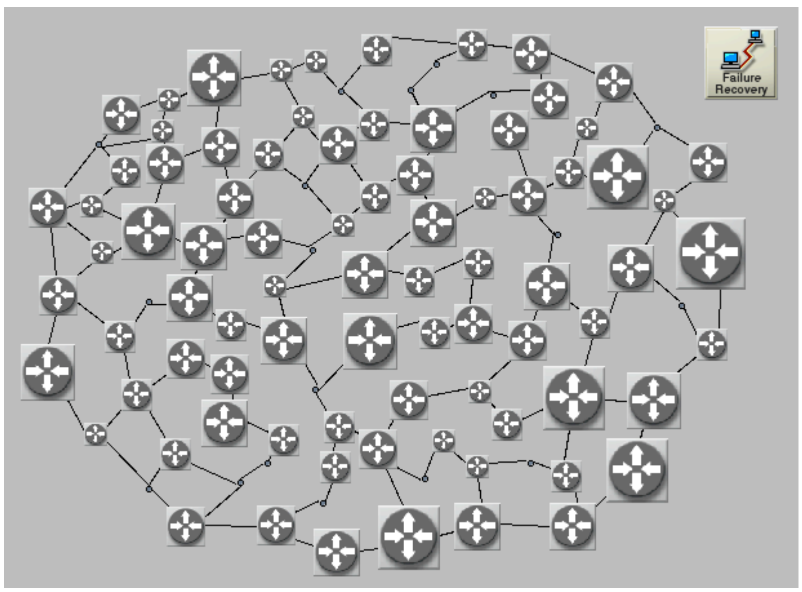


**Figure 3.3: Large Mesh Topology**

### 3.1.4 Large Tree Topology

Our last topology is shown in Figure 3.4. This large tree topology was generated by use of Rapid Configuration. It consists of 156 routers, with one central router, 4 levels and 5 splits per level. Being our most realistic topology, we expect the results to be most accurate. Again, we implemented a link failure between the central router and a level 2 router. Unlike in the large mesh topology, this link failure will have the distinct consequence of rendering 31 routers inaccessible to the rest of the network.

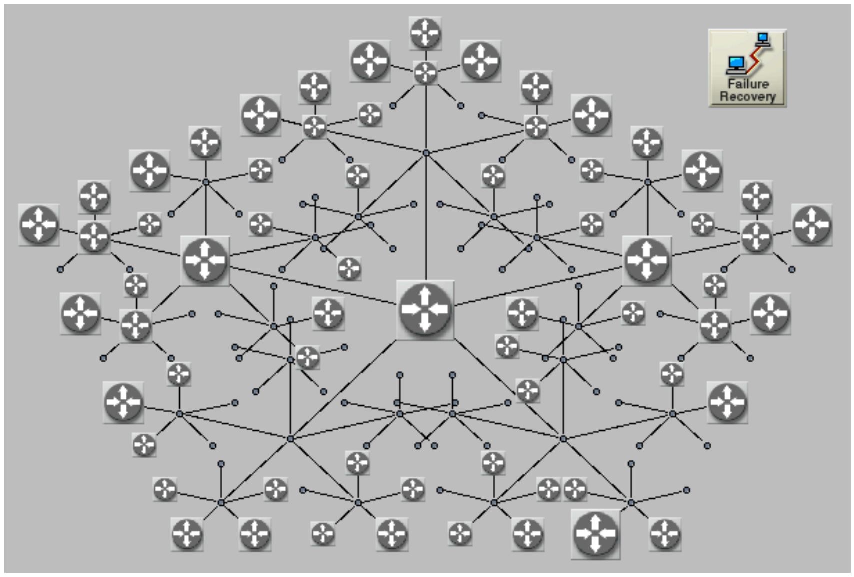


**Figure 3.4: Large Tree Topology**

## 3.2 Simulation Parameters & Collected Statistics

We chose to collect three sets of statistics. First, for the small ring topology we exported the routing tables of each protocol after the link failure. These tables serve to give us a better understanding of each protocol. Next, for all scenarios we collected Convergence Activity, Convergence Duration (sec) and Traffic Sent (bits/sec). It should be noted that the traffic sent only includes routing traffic, as we have not implemented user applications.

Here we mention the simulation parameters that are common to all network topologies and all protocols implementations. First, we simulate each scenario for 10 minutes, with a random seed of 128. Also, the link failure occurs at 300 seconds, and recover occurs at 480 seconds. Each protocol starts with a constant distribution and a mean outcome of 5. In OPNET's Discrete Event Simulation (DES) preferences window, we disabled RIP, OSPF, and EIGRP simulation efficiency to ensure that these protocols continue throughout the entire simulation.

## 3.3 Routing Protocol Parameters

### 3.3.1 RIP Parameters

The following table lists and describes the RIP protocol parameters. It should be noted that the parameters that define RIP are the maximum hop count and the update interval. Unlike the other protocols we are analyzing, RIP routers send their full routing information periodically, according to the update interval parameter in the first row. The default OPNET values for these and other parameters are also shown below.

**Table 3.1 RIP Parameters**

| | Description | Default |
|---|---|---|
| **Update Interval (seconds)** | How often a router sends updates to its neighbors | 30 seconds |
| **Route Invalid (seconds)** | Used to indicate an invalid route. This timer is initialized when the route is inserted into the routing table. When it expires, the route is removed. | 180 seconds |
| **Flush (seconds)** | Indicates that a route should be removed from the routing table. This value should be greater than the "Route Invalid" parameter. | 240 seconds |
| **Holddown (seconds)** | Used to avoid route flapping. This timer starts when "Route Invalid" expires. During holddown time, updates regarding invalid routes are ignored. | 180 seconds |
| **Maximum hops** | Maximum number of packet supported by RIP. Implemented in order to prevent endless loops. If this value is too low, network size is limited. If this value is too high, packets may get stuck in loops. | 16 hops |
| **Advertisement Mode** | Specified how a router advertises to its neighbors. Three options on OPNET:<br>1. No Filtering: Advertises routes to all neighbors<br>2. Split Horizon: Does not advertise route to the neighbor from which route was learned.<br>3. Split Horizon with Poison Reverse: Advertises route to neighbor from which route was learned with a metric of infinity (or max 16). | Split Horizon with Poison Reverse |

### 3.3.2 OSPF Parameters

The table below presents various OSPF parameters. These parameters differ greatly from those of RIP because OSPF is a link-state algorithm, which means it maps out the network before choosing the best routing path. This protocol has many more parameters with much more complexity than RIP.

**Table 3.2 OSPF Parameters**

| | Description | Default |
|---|---|---|
| **Interface cost** | Cost of each interface can be specified. These values are used to calculate the shortest path. | 1 |

| | | |
|---|---|---|
| **Hello interval (seconds)** | How often a router sends hello messages to its neighbors. If this parameter is too small, more router traffic results. This increases the risk of dropped packets, which could result in false alarms. If interval is too big, topology changes will take longer to be detected, and router dead interval may expire. | 10 seconds |
| **Router dead interval (seconds)** | Used to declare neighbor routers dead when no Hello messages have been received. This interval should be a multiple of the "Hello interval". | 40 seconds |
| **Transmission delay (seconds)** | Estimated time to transmit a Link State Advertisement (LSA) packet. | 1.0 seconds |
| **Retransmission interval (seconds)** | Time between LSA retransmissions. Must be greater than the expected round-trip time between any two routers in the network. | 5.0 seconds |
| **SPF Calculation Parameters** | Specifies how often shortest paths are recalculated. Two Options:<br>1. Periodic: Recalculate at each specified interval, unless no change has occurred.<br>2. LSA driven: Recalculate after every LSA has been received. | LSA Driven |

### 3.3.3 EIGRP Parameters

The table below shows the EIGRP parameters. The maximum hop parameter of 100 allows for larger network sizes than RIP's 16 hops. EIGRP also uses hello messages and a hold time timer similar to OSPF in order to detect topology changes. As we can see, EIGRP does not have many configurable parameters because it is a proprietary protocol.

**Table 3.3 EIGRP Parameters**

| | **Description** | **Default** |
|---|---|---|
| **Maximum Hops** | (As described for RIP) | 100 hops |
| **Hello Interval (seconds)** | (As described for OSPF) | 5 seconds |
| **Hold Time (seconds)** | Same function as "Router dead interval" for OSPF | 3 Hello Times |
| **Split Horizon** | When enabled, Split Horizon does not advertise route to the neighbor from which route was learned. | Enabled |

# 4 Results

## 4.1 Routing Tables

Routing tables lists the routes from a node to other nodes in the network and includes the metric (e.g. hop count, cost, or delay) and the next hop towards the destination. Once a topology change is detected, the routing tables are updated in order to reach convergence. Each router has its individual routing table and the number of entries in this table is dependent on the number of nodes in the network. For the purpose of our project, we analyzed the routing tables of our ring topology, where every router has 2 neighbors.

We obtained the routing tables for each routing protocol in order to compare their outputs at 350 seconds, when the link between Router 1 and Router 2 is still in a failed state. The routing table for Router 1 using RIP is shown below. The metric used for RIP is the hop count shown in the third column. The first row shows the metric of IF10 link from Router 1 to Router 2 as 16, which is the maximum hop value in RIP, because the link has failed.

**Table 4.1: RIP Routing Table**

| Destination | Destination Node | Metric | Next Hop Address | Next Hop Node | Outgoing Interface |
|---|---|---|---|---|---|
| 192.0.0.0/24 | Router 2 | 16 | 192.0.0.1 | Router 1 | IF10 |
| 192.0.1.0/24 | Router 1 | 0 | 192.0.1.1 | Router 1 | IF11 |
| 192.0.2.0/24 | Router 4 | 3 | 192.0.1.2 | Router 5 | IF11 |
| 192.0.3.0/24 | Router 5 | 1 | 192.0.1.2 | Router 5 | IF11 |
| 192.0.4.0/24 | Router 3 | 2 | 192.0.1.2 | Router 5 | IF11 |

We used OSPF's interface cost parameters to change the cost of each interface in order to investigate the effects on the routing table.

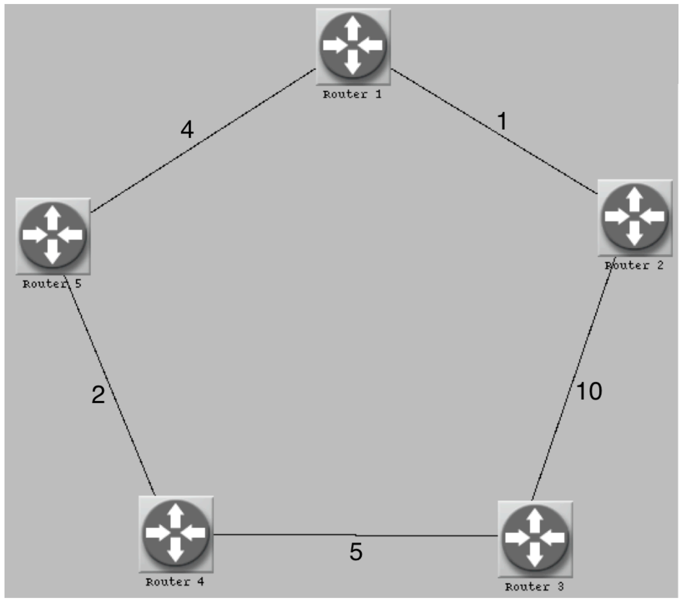

**Figure 4.1: Simple Ring Topology including link costs**

Below is Router 1's routing table at 350 seconds using OSPF. The metric displayed in the third column is the interface cost we implemented. As expected, when the link from Router 1 to Router 2 fails, packets are all routed to their destination through Router 5.

**Table 4.2: OSPF Routing Table**

| Destination | Destination Node | Metric | Next Hop Address | Next Hop Node | Outgoing Interface |
|---|---|---|---|---|---|
| 192.0.1.0/24 | Router 5 | 4 | 192.0.1.0 | Router 1 | IF11 |
| 192.0.2.0/24 | Router 2 | 21 | 192.0.1.2 | Router 5 | IF11 |
| 192.0.3.0/24 | Router 4 | 6 | 192.0.1.2 | Router 5 | IF11 |
| 192.0.4.0/24 | Router 3 | 11 | 192.0.1.2 | Router 5 | IF11 |

Below is the equivalent EIGRP routing table. The metric in the third column is calculated by the protocol. It is calculated using the following formula which is valid when coefficient K5=0:

$$\text{Metric} = \text{K1} * \text{bandwidth} + \frac{K2 * bandwidth}{256 - load} + \text{K3} * \text{delay}$$

Our default values are K1=K3=1, K2=K4=K5=0 and bandwidth = 1.544 Mbps. This simplifies to

$$\text{Metric} = 256 \times \left[\frac{10^7}{Minimum\ Bandwidth} + \sum delays\right]$$

where minimum bandwidth is in Kbps and delay is in $\mu sec$. The metric from Router 1 to Router 5 is calculated as follows:

$$\text{Metric} = 256 \times \left[ \frac{10^7}{1544\ (Kbps)} + \sum 2000\ (\mu sec) \right] = 2170031$$

This value is approximately equal to the metric in the table below. Additionally, the table includes successor's metric, which is the metric from the router's neighbor closest to the destination.

**Table 4.3: EIGRP Routing Table**

| Destination | Destination Node | Metric/Successor's Metric | Next Hop Address | Next Hop Node | Outgoing Interface | Delay (msec) |
|---|---|---|---|---|---|---|
| 192.0.1.0/24 | Router 5 | 2169856/0 | 192.0.1.1 | Router 1 | IF11 | 20.00 |
| 192.0.2.0/24 | Router 2 | 3705856/3193856 | 192.0.1.2 | Router 5 | IF11 | 80.00 |
| 192.0.3.0/24 | Router 4 | 2681856/2169856 | 192.0.1.2 | Router 5 | IF11 | 40.00 |
| 192.0.4.0/24 | Router 3 | 3193856/2681856 | 192.0.1.2 | Router 5 | IF11 | 60.00 |

## 4.2 Performance Results

### 4.2.1 Small Ring Topology

Figure 4.2 shows the router traffic sent in bits/sec of the three protocols in a small ring network. From the graph of routing traffic sent we observe that EIGRP has the highest bandwidth efficiency while RIP has the lowest. It should be noted that OSPF has better bandwidth efficiency than EIGRP when there are no new routers added. OSPF has the highest initial peak because the routers must first map out the network before choosing a path. This requires routers to distribute a significant amount of information initially.

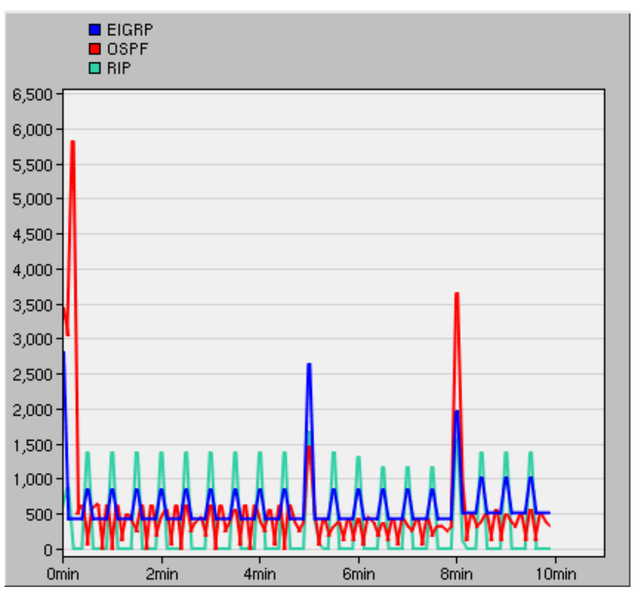


**Figure 4.2: Routing Traffic Sent in bits/sec for Small Ring**

The figure below shows the convergence activity of each protocol. The first, second, and third peaks represents the initial setup, the link failure at 300 seconds, and link recovery at 480 seconds. The width of each peak represents the convergence duration. The longer a protocol takes to converge, the wider the peak will be. From these results we observe that EIGRP has the fastest convergence in all the stages while OSPF has a faster convergence time than RIP during a link-failure.

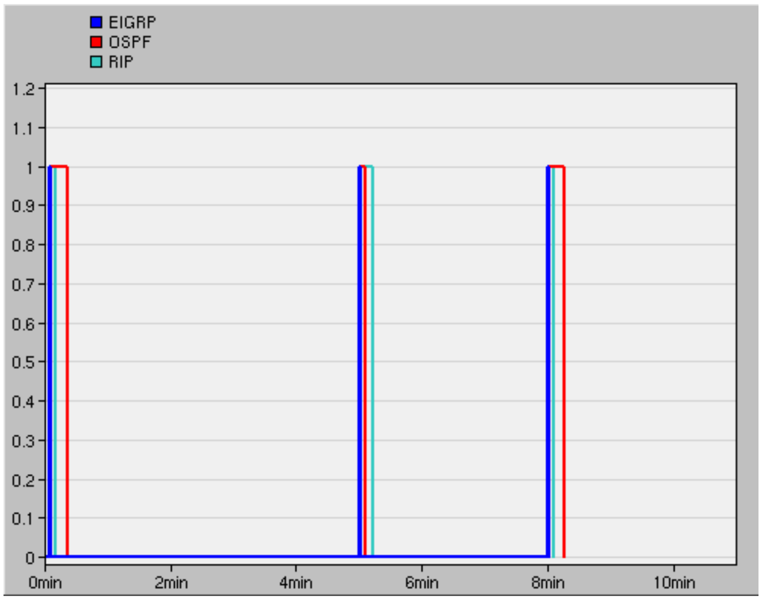

**Figure 4.3: Convergence Activity for Small Ring**

The table below displays the approximate convergence durations, including initial convergence, convergence after link failure and convergence after link recovery. From this table it is clear that OSPF is much quicker at detecting and recovering from a link failure than it is at realizing convergence initially and after link recovery.

**Table 4.4: Convergence durations (seconds) of small ring topology**

| | RIP | OSPF | EIGRP |
|---|---|---|---|
| **Initial Convergence** | 4 | 15 | < 1 |
| **Link Failure** | 10 | 5 | <1 |
| **Link Recovery** | 5 | 15 | <1 |

### 4.2.2 Small Mesh Topology

The traffic sent and convergence results of the small mesh are shown in figures 4.4 and 4.5 respectively. Similarly to the results in the small ring topology, the first, second, and third peak represents the initial setup, link-failure, and link recovery in the network. Looking at the traffic sent results we can see the throughput has increased for each protocol due to the increase of neighbor routers, but in comparison to the small ring the bandwidth efficiency (the amount of routing traffic sent within the network topology) has not changed.

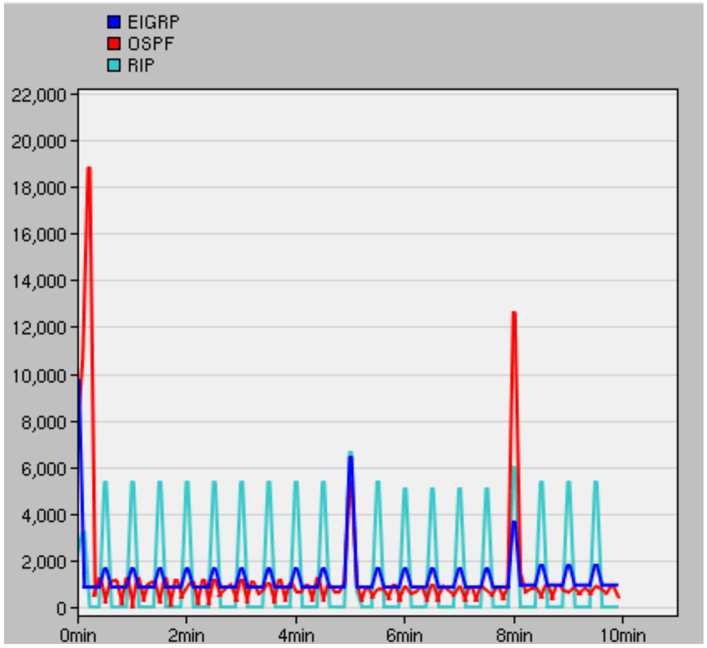

**Figure 4.4: Routing Traffic Sent in bits/sec for Small Mesh**

However, the convergence results shown below are different; while EIGRP is still the fastest, RIP now has faster convergence times than OSPF at all three peaks. RIP is unseen in this graph as it overlaps with EIGRP during the first and third peak, and OSPF during the second peak.

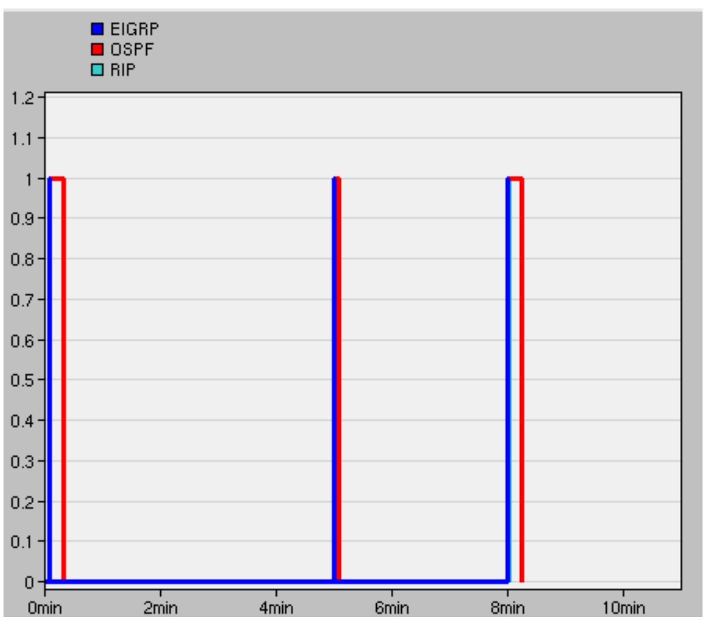

**Figure 4.5: Convergence Activity for Small Mesh**

The table below confirms that RIP has surprisingly fast convergence times. This behavior is contradictory to that we expected, as OSPF should be significantly faster than RIP. We attribute this discrepancy to the unrealistic network topology, and that the OSPF parameters have not been set to optimal for the protocol to perform at its "best". Because each destination in this topology is only one hop away, RIP is able to easily find its destination. In contrast, OSPF must first map out the entire network even though for this topology, it suffices to only having knowledge of neighbor routers.

**Table 4.5: Convergence durations (seconds) of small mesh topology**

| | RIP | OSPF | EIGRP |
|---|---|---|---|
| **Initial Convergence** | <1 | 15 | < 1 |
| **Link Failure** | 4 | 5 | <1 |
| **Link Recovery** | 1.5 | 15 | <1 |

### 4.2.3 Large Mesh Topology

Figure 4.6 and Figure 4.7 shows the traffic sent and convergence results of the large mesh network. The traffic sent results show that the traffic of all the protocols increasing substantially; however, EIGRP's and OSPF's bandwidth efficiency is significantly superior to that of RIP, with peaks of 1Mbps every 30 seconds.

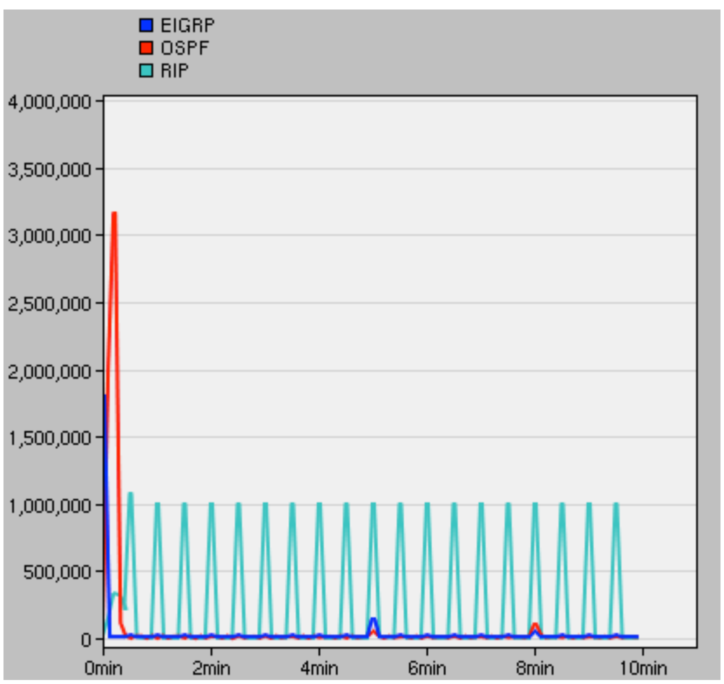


**Figure 4.6: Routing Traffic Sent in bits/sec for Large Mesh**

Looking at the convergence results we can see OSPF's and RIP's convergence time increase while EIGRP remains the fastest. It should also be noted that OSPF's convergence time is faster than RIP, as expected in a realistic topology.

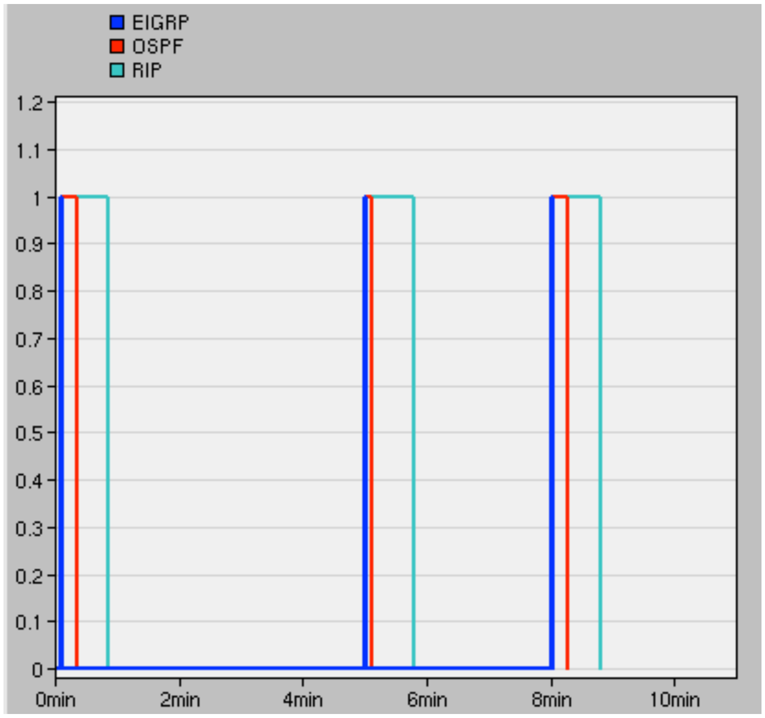


**Figure 4.7: Convergence Activity for Large Mesh**

Table 4.6 shows that RIP has very slow convergence of around 45 seconds in a large network. Also, note that OSPF converges 3 times faster upon link failure than it does upon initial convergence and link recovery. This is due to the prompt LSA's and the LSA driven SPF calculations. It should also be noted that even though the network size has significantly increased, EIGRP has convergence times approximately equal to those of smaller topologies.

**Table 4.6: Convergence durations (seconds) of large mesh topology**

| | RIP | OSPF | EIGRP |
|---|---|---|---|
| **Initial Convergence** | 45 | 15 | < 1 |
| **Link Failure** | 45 | 5 | <1 |
| **Link Recovery** | 47 | 15 | <1 |

### 4.2.4 Large Tree Topology

Routing traffic sent for the large tree topology is shown in Figure 4.8. Again, we observe that RIP wastes bandwidth with 1.3 Mbps peaks of traffic every 30 seconds. Both OSPF and EIGRP utilize the bandwidth more efficiently. However, OSPF has a much larger initial peak of traffic than EIGRP, at approximately 3.5 Mbps compared to 1 Mbps. This is due to OSPF being a link-state algorithm, which requires it to map out the entire network.

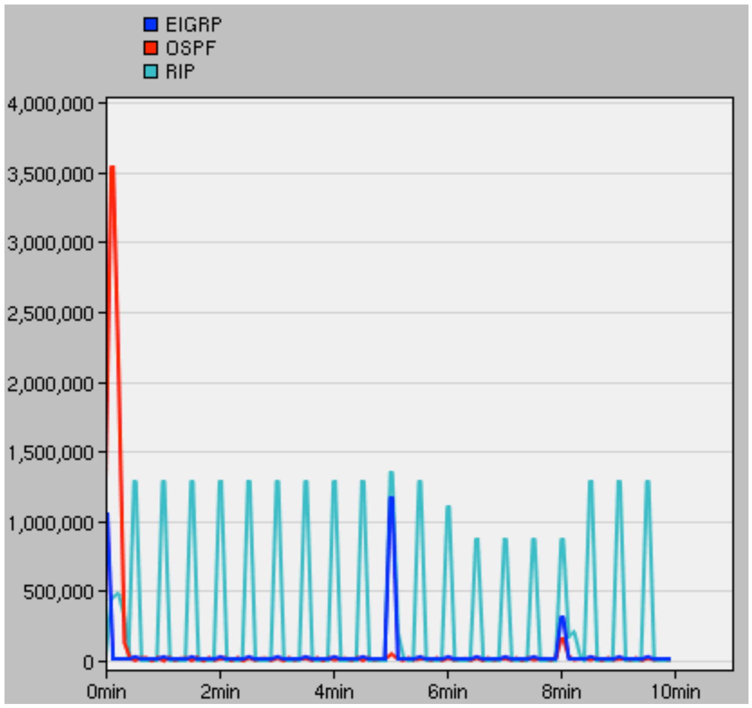


**Figure 4.8: Routing Traffic Sent in bits/sec for Large Tree**

Below we see the convergence activity of each protocol in the large tree configuration. In comparison with the large mesh topology, convergence occurs more quickly in this topology with the exception of EIGRP, whose convergence is fairly constant.

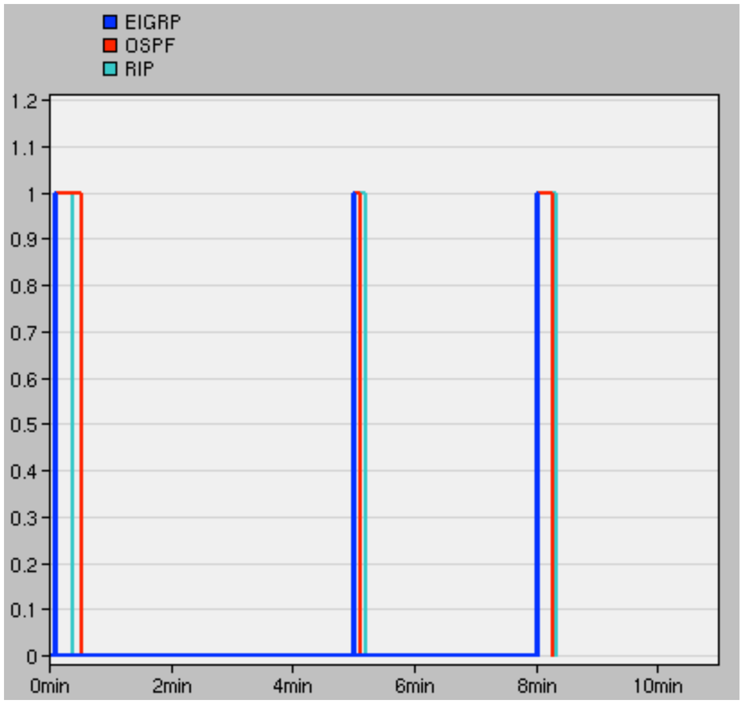

**Figure 4.9: Convergence Activity for Large Tree**

The table below displays the approximate convergence durations of each protocol. The difference between RIP and OSPF are not as radical as those of the large mesh topology. We expect OSPF to be much faster than RIP in a large topology at each convergence event. For this reason, we believe that our large mesh results are more accurate than the results shown here.

**Table 4.7: Convergence durations (seconds) of large tree topology**

| | RIP | OSPF | EIGRP |
|---|---|---|---|
| **Initial Convergence** | 17 | 25 | < 1 |
| **Link Failure** | 7.5 | 5 | <1 |
| **Link Recovery** | 18 | 15 | <1 |

# 5 Discussion

## 5.1 Analysis

Based on our results, EIGRP had the best convergence time and bandwidth efficiency for all scenarios. As for RIP, its initial convergence performance was better than OSPF for small topologies, but its bandwidth efficiency was the lowest for all scenarios. We expected RIP to have the lowest bandwidth efficiency, as it requires full periodic updates while OSPF and EIGRP do not. It should also be noted that OSPF had a better convergence time for small ring topologies after a link failure. This result makes sense, because like EIGRP, OSPF has an early detection mechanism for changes in the network. OSPF's overall convergence time and bandwidth efficiency, they stayed constant for both small topologies.

Our results for the large mesh were most accurate according to our expected results. In this scenario, EIGRP remained the fastest while OSPF converged sooner than RIP at each convergence event. In comparison, our large tree topologies resulted in much smaller convergence durations. Furthermore, RIP and OSPF had very similar convergence times, which is not accurate in a large topology.

In conclusion, EIGRP is the best routing protocol because it has the best convergence and bandwidth efficiency in all the scenarios. Comparing OSPF and RIP, the former is better for large topologies as confirmed by our large mesh topology, while the latter is only suitable for small networks.

## 5.2 Improvements and Future Work

The only varying parameter in our analysis, other than routing protocol of course, was the size of the network topology. Improvement or future works for this project can include adding metrics on interfaces such as cost, bandwidth, distance, Bit Error Rate (BER), and delay. Furthermore, various network topologies (in terms of size, routers and links used) can be implemented for comparison of performance between these routing protocols. Since OSPF is the most complex routing protocol, more time could be spent on analyzing it to find the value of parameters that need to be set in order for it to perform optimally. Another possibility is to implement real network topologies used, perhaps in a university campus a company office, or a larger network size while also modifying the network parameters, such as interfaces, to those of the actual scenario being analyzed.

## 5.3 Difficulties and Solutions

We initially started our project with a topic on LTE technology, so a lot of time and research was spent into its development. However, due to the uncertainty of obtaining an OPNET LTE license we changed our project's topic to routing protocols. Since routing protocols have been popular areas of research for some time, implementation of the routing protocols on OPNET was straightforward. The main challenge of this project lied in understanding the protocol parameters, and how they affected the simulation results. Another challenge was in understanding the routing tables we obtained, as well as the convergence times and how they were influenced by the network topology.

## 6. Conclusion

In this project, we used OPNET as our tool to analyze and compare the performance of three routing protocols commonly used in today's networks: RIP, OSPF, and EIGRP. We initially implemented a simple ring topology and a simple mesh topology to examine the performance of each routing protocol in simple scenarios, as well as the routing tables of the small ring. Next, we implemented a large mesh topology and a large tree topology, while holding all other protocol and simulation parameters the equal to those of previous simulations in order to compare the routing performances in a larger and more complicated network.

We first examined the routing tables of the small ring topology to gain a better understanding of each routing protocol's metric calculations and path routing systems. In order to be able to compare the performance of the protocols, we collected convergence and routing traffic sent statistics. Our simulation results confirmed that EIGRP has the fastest convergence for all network topologies. We also observed that EIGRP and OSPF both efficiently utilize the bandwidth, as we expected from our research. On the other hand, RIP sends full routing information through periodic updates, which floods the network and unnecessarily wastes bandwidth. Our large mesh topology also proved that RIP converges very slowly and is therefore only suitable for small networks.

In conclusion, our simulations confirmed that EIGRP is the best choice for all network topologies implemented as it has a fast convergence, while also efficiently utilizing bandwidth. OSPF is the second choice for large networks, as established by our large mesh results. RIP performs poorly in large networks and is therefore limited to small, simple networks.

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# Appendix A: List of Acronyms

AS: Autonomous System

BER: Bit Error Rate

BGP: Border Gateway Protocol

DES: Discrete Event Simulation

DUA: Diffusing Update Algorithm

EGP: Exterior Gateway Protocol

EIGRP: Interior Gateway Routing Protocol

IGP: Interior Gateway Protocol

IP: Internet Protocol

LSA: Link State Advertisement

OSPF: Open Shortest Path First

RIP: Routing Information Protocol

SPF: Shortest Path First

UDP: User Datagram Protocol

# Appendix B: Work on LTE

## Analysis of Quality of Service of Video Streaming over LTE

### Abstract

Long Term Evolution (LTE) is an IP based technology that has quickly become a leading global standard for 4G cellular networks. In order to keep up with traffic growth demands, the 3GPP (Third Generation Partnership Project) developed LTE technology with the goal of increasing capabilities and system performance, while reducing network complexity and minimizing costs. This technology improves quality of service and minimizes latency using a packet-switched approach. LTE's increased data rate makes high-resolution video streaming possible. The focus of this project will be to simulate LTE video traffic patterns using Opnet. Furthermore, we will analyze the simulation results, evaluate Quality of Service (QoS) and compare performance with current industry standards.

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