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FINAL PROJECT

**Comparison of RIP, OSPF and EIGRP Routing
Protocols based on OPNET**

Project Group # 9

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Abstract

In a computer network, the transmission of data is based on the routing protocol which selects the best routes between any two nodes. Different types of routing protocols are applied to specific network environment. Three typical types of routing protocol are chosen as the simulation samples: RIP, OSPF and EIGRP. RIP (Routing Information Protocol) is one of the oldest routing protocols still in service. Hop count is the metric that RIP uses and the hop limit limits the network size that RIP can support. OSPF (Open Shortest Path First) is the most widely used IGP (Interior Gateway Protocol) large enterprise networks. OSPF is based on the Shortest Path First (SPF) algorithm which is used to calculate the shortest path to each node. EIGRP (Enhanced Interior Gateway Routing Protocol) is Cisco's proprietary routing protocol based on Diffusing Update Algorithm. EIGRP has the fastest router convergence among the three protocols we are testing.

More detailed description of these three routing protocols will be included later. We aim to analyze the performance of the three protocols such as their router convergence, convergence duration and end-to-end delay. In our project, we are going to use OPNET to simulate RIP, OSPF and EIGRP in order to compare their attributes and performance. According to the convergence we can find out which protocols are suitable for different sizes and types of network.

1. Introduction

1.1 Routing Protocol Basics

A routing protocol is the language a router speaks with other routers in order to share information about the reachability and status of network.(1) It includes a procedure to select the best path based on the reachability information it has and for recording this information in a route table. Regarding to select the best path, a routing metric will be applied and it is computed by a routing algorithm.

1.2 Routing Metric Basics

A metric is a variable assigned to routers as a means of ranking them from the best to worst or from most preferred to least preferred. (1) Different routing protocols have different metrics. When there is more than one route between two nodes, a router must determine a method of metrics by choose the routing protocol to calculate the best path.

1.3 Static Routing Dynamic Routing

Protocols can fall into two groups: static routing and dynamic routing. Static routing is simply the process of manually entering routes into a device's routing table via a configuration file that is loaded when the routing device starts up. In static routing, all the changes in the logical network layout need to be manually done by the system administrator. However, dynamic routing allows routers to select the best path when there is a real time logical network layout change. In our project, we will discuss the difference between the EIGRP, RIP and OSPF. All of them are belong to dynamic routing protocols.

1.4 Distance Vector and Link State

In addition, most routing protocols can be classified into two classes: distance vector and link state. Distance vector routing protocol is based on Bellman – Ford algorithm and Ford – Fulkerson algorithm to calculate paths. A distance vector routing protocol uses a distance calculation and a vector direction of next hop router as reported by neighboring routers to choose the best path. It requires that a router informs its neighbors of topology changes periodically.

Link state routing protocols build a complete topology of the entire network are and then calculating the best path from this topology of all the interconnected networks. It requires more processing power and memory because it has a complete picture of the network.

2. Three Routing Protocols

2.1 Routing Information Protocol (RIP)

RIP is a standardized vector distance routing protocol and uses a form of distance as hop count metric. It is a distance vector. Through limiting the number of hop counts allowed in paths between sources and destinations, RIP prevents routing loops. Typically, the maximum number of hops allowed for RIP is 15. However, by achieving this routing loop prevention, the size of supporting networks is sacrificed. Since the maximum number of hop counts allowed for RIP is 15, as long as the number goes beyond 15, the route will be considered as unreachable.

When first developed, RIP only transmitted full updates every 30 seconds. In the early distributions, traffic was not important because the routing tables were small enough. As networks become larger, massive traffic burst becomes more likely during the 30 seconds period, even if the routers had been initialized at different times. Because of this random initialization, it is commonly understood that the routing updates would spread out in time, but that is not the case in real practice.

RIP has four basic timers:

Update Timer (default 30 seconds): defines how often the router will send out a routing table update.

Invalid Timer (default 180 seconds): indicates how long a route will remain in a routing table before being marked as invalid, if no new updates are heard about this route. The invalid timer will be reset if an update is received for that particular route before the timer expires. A route marked as invalid is not immediately removed from the routing table. Instead, the route is marked with a metric of 16, which means the route is unreachable, and will be placed in a hold-down state.

Hold-down Timer (default 180 seconds): specifies how long RIP will keep a route from receiving updates when it is in a hold-down state. In a hold-down state, RIP will not receive any new updates for routes until the hold-down timer expires. A route will go into a hold-down state for the following reasons:

- The invalid timer has expired
- An update has been received from another router; route goes into a 16 metric (or unreachable).
- An update has been received from another router; route goes into a higher metric than what it is currently using.

Flush Timer (default 240 seconds): When no new updates are received about this route, flush timer indicates how long a route can remain in a routing table before getting flushed out. The flush timer operates simultaneously with the invalid timer, so every 60 seconds, after it has been marked invalid, the route will get flushed out. When RIP timer is not in sync with all routers on the RIP network, system instability occurs. This timer must be set to a higher value than the invalid timer.

2.2 Open Shortest Path First (OSPF)

OSPF is defined in RFC 2328 which is an interior Gateway Protocol used to distribute routing information within an AS (Autonomous System). Among all the three chosen samples, OSPF is the most widely used routing protocol in large enterprise networks. OSPF is based on link-state technology by using SPF algorithm which calculates the shortest path.

SPF calculation

Before running the calculation, it is required that all routers in the network to know about all the other routers in the same network and the links among them. The next step is to calculate the shortest path between each single router. For all the routers they exchange link-states which would be stored in the link-state database. Every time a router receives a link-state update, the information stores into the database and this router propagate the updated information to all the other routers. Below is a simple model of how the SPF algorithm works.

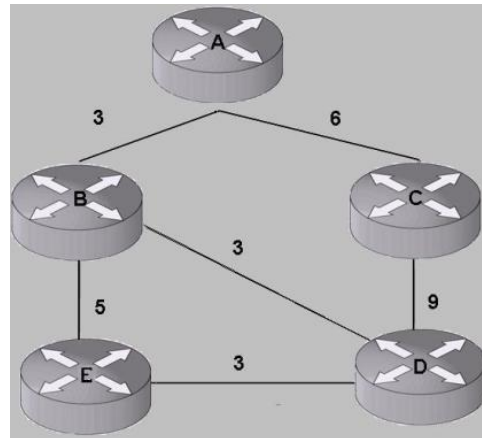


Figure 1: Simple structure of OSPF

A simple network formed by five routers; all the routers know about all the other routers and links. After all the paths are figured out, the path information are stored in the link database. The link database for the above model is : [A, B, 3], [A, C, 6], [B, A, 3], [B, D, 3], [B, E, 5], [C, A, 6], [C, D, 9], [D, C, 9], [D, B, 3], [D, E, 3], [E, B, 5] and [E, D, 3]. Each term is referred to the originating router, the router connected to and the cost of the link between the two routers. Once the database of each router is finished, the router determines the Shortest Path Tree to all the destinations. (The shortest path in the SPF algorithm is called the Shortest Path Tree). The Dijkstra Shortest Path First is then running to determine the shortest path from a specific router to all the other routers in the network. Each router is put at the root of the Shortest Path Tree and then the shortest path to each destination is calculated. The accumulated cost to reach the destination would be the shortest path.

The cost (metric) of OSPF is the cost of sending packets across a certain interface. The formula to calculate the cost is: $\text{cost} = \frac{100000000}{\text{bandwidth in bps}}$. If the bandwidth is wider, the cost would be lower.

Below is a diagram of the structure used to calculate the Shortest Path Tree.

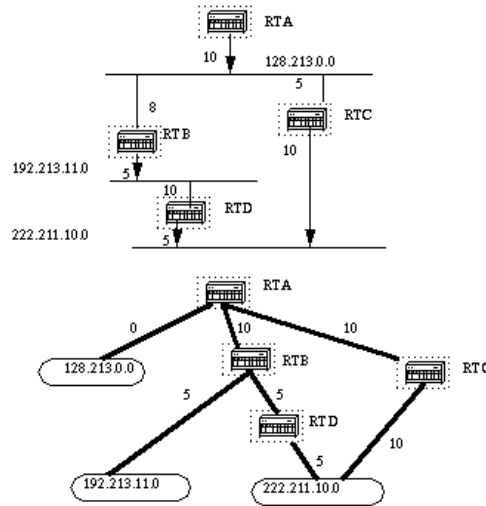


Figure 2: Shortest path tree

When the Shortest Path Tree is completed, the router will work on the routing table.

Areas and Border Routers

In OSPF protocol, an Autonomous System can be divided into sections. A section and a nearby router can form an AREA. Since each section calculate the Shortest Path using the same algorithm as above, each section has its own database and path tree and the information are invisible outside this section. By doing this, the size of the database can be dramatically reduced.

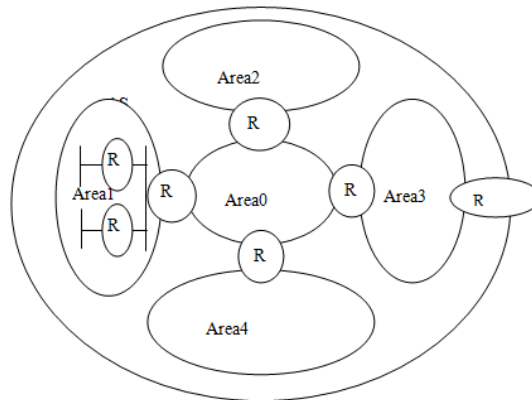


Figure 3: Area

In an autonomous, there is a backbone called Area 0 which is the pivot of this autonomous. Area 0 connected to other sections with ABR (Area Border Router) to exchange link-state. Stub Area, Not-So-Stubby Area, Totally Stubby Areas and Totally NSSA are other types of sections with specific functions.

Advantages

Compare to RIP, OSPF has no limitation due to hops (RIP has a limit of 15 hops so any network with more than 15 hops cannot be achieved by RIP). OSPF can handle Variable Length Subnet Masks (VLSM) but RIP cannot. The most important is that OSPF converges much faster than RIP due to its calculation algorithm. This might not be significant in a small size network but in large enterprise networks, this will be a time out.

2.3 Enhanced Interior Gateway Routing Protocol (EIGRP)

The Enhanced Interior Gateway Routing Protocol (EIGRP) is a hybrid routing protocol which provides significant improvements on IGRP. EIGRP replaced IGRP in 1993 since Internet Protocol is designed to support IPv4 addresses that IGRP could not support. Hybrid routing protocol incorporates advantages of both Link-state and Distance-Vector routing protocols, it was based on Distance-Vector protocol but contains more features of Link-State protocol. EIGRP saves all routes rather than the best route to ensure the faster convergence. EIGRP keeps neighboring routing tables and it only exchange information that it neighbor would not contain. EIGRP is commonly used in large networks, and it updates only when a topology changes but not periodically unlike old Distance-Vector protocols such as RIP.

Metric is used to determine whether the chosen route is optimized. EIGRP metric is based on its bandwidth, delay, reliability, load and MTU. A default expression for EIGRP metric is $Metric = (BandWidth + Delay) * 256$.

There are four basic components to operate EIGRP, which are

- Neighbour Discovery/Recovery
- Reliable Transport Protocol
- DUAL Finite State Machine
- Protocol Dependent Module

Since EIGRP updates are triggered when there is a change, it is important to have a process that routers dynamically learn of other routers on directly connected network. A router should discover once a neighbouring router is unreachable or inoperative. Neighbour Discovery and Recovery is accomplished by sending small Hello packets periodically at low cost. Once the hello packets are received, whether this neighbour is alive can be determined. The neighbouring router will start exchanging information when routers are functioning.

The default EIGRP algorithm DUAL requires guaranteed and ordered delivery of packets for transmission which reliable transport protocol manages. EIGRP sends a unicast data receiver

indicating the hello packet does not require the confirmation of the notification packet. When there is a packet sending, a sequence number is assigned which is incremented by the router sending a new packet. Reliable Transport Protocol insures fast transport when there are unacknowledged packets pending. That guarantees the low convergence time.

DUAL, the Diffusing Update Algorithm is the default convergence algorithm which is used in EIGRP to prevent routing loops from recalculating routes. DUAL tracks all routes and detect the optimal path in terms of efficiency and cost which will be added in the routing table. There also exist backup routes that can be used in case the optimal route is dropped.

Protocol Dependent Modules are used to encapsulate the IP packets for network layer. It determines if an additional route is necessary from sources such as routing table. PDMs make sure that EIGRP provides support for various routed protocols.

3. OPNET Simulations

3.1 Topologies

Network topology is the arrangement of various elements of a computer network. It is typically described as either physical or logical. Different placements of network components such as device location and the shape of cabling layout are part of physical topology. On the other hand, Logical topology illustrates how the data passes through the network regardless of the physical design. In many cases, network topologies may be identical, but the distances between nodes, physical interconnections, transmission rates and signal types will still be different. We use two basic topologies in our project, which are mesh and tree topology.

3.1.1 Mesh Topology

In mesh topology, each node distributes data in the network, and the value of a fully meshed network is proportional to the exponent of the number of subscribers. This relationship is modeled by Reed's Law. In a fully connected network, each of the nodes is connected to each other, making a complete graph. Therefore a fully connected network does not require the usage of any switching nor broadcasting. Nonetheless, this network becomes particularly impractical in larger networks, as the numbers of connections grow quadratically with the

number of nodes, by the formula $c = \frac{n(n-1)}{2}$ and so it is extremely impractical for large networks. A two-node network is technically a fully connected network. Figure 4 represents the structure of Mesh topology we used in this project.

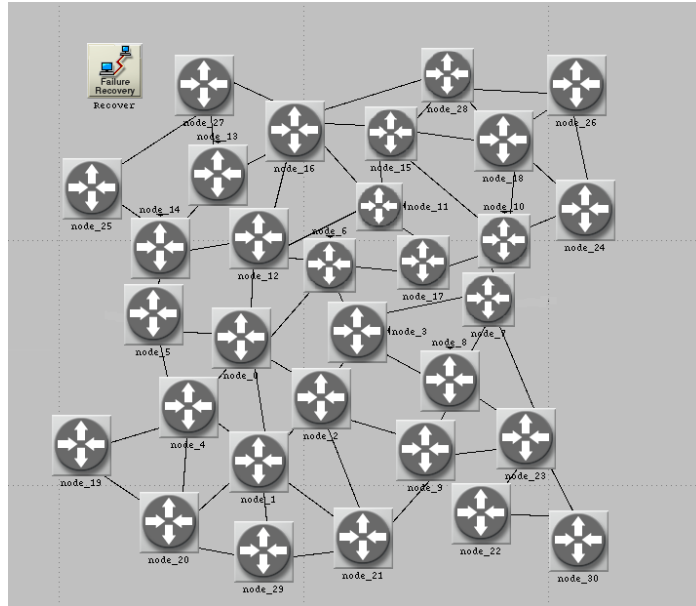


Figure 4: Basic structure of Mesh topology

3.1.2 Tree Topology

In a tree network topology, nodes are arranged in a form of hierarchy where the highest level consists of a single 'root node'. From this root node, it branches out through point-to-point links into single or multiple nodes in the next level. This process repeats at each level, and there are no limits to the number of levels within a network. Each node in the network has a specific number of nodes to connected, and this number is referred to as the 'branching factor'. On the other hand, as a bus network topology variant, tree topology is especially prone to crippling network failures. Figure 5 represents the structure of Tree topology we used in this project.

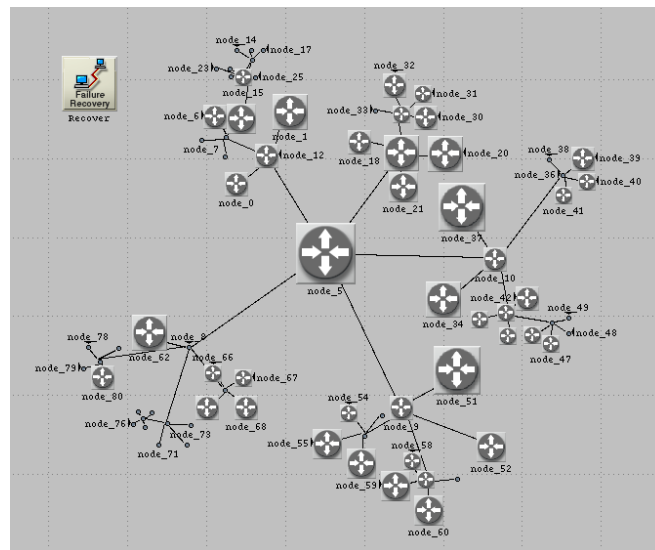


Figure 5: Basic structure of Tree topology

3.2 Simulation Setup

3.2.1 Simulation Setup for Failure/Recovery Configuration

Figure 6 below shows the setup for Recovery Configuration. The simulation is set to be 15 minutes, the first failure is set to be 5 minutes which is 300 second, and the recovery is set to be 600 seconds. Recovery configuration is set to be the same for all scenarios except the route would be dropped.

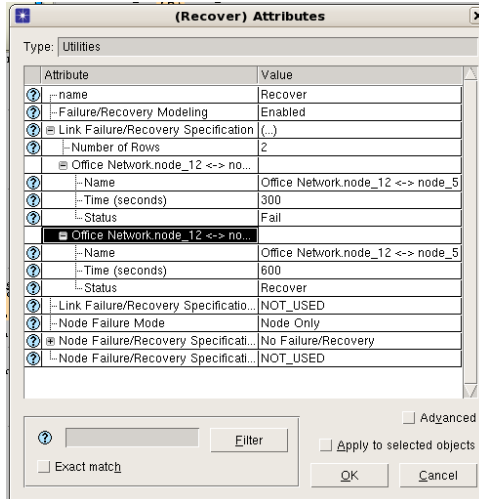


Figure 6: Failure/Recovery Configuration

3.2.2 Simulation Setup for Individual DES statics

Since three protocols will be examined, the individual statics will be set differently. It concludes the features will be compared in the project which are Convergence Activity, Convergence Duration and Traffic Sent (bits/sec).

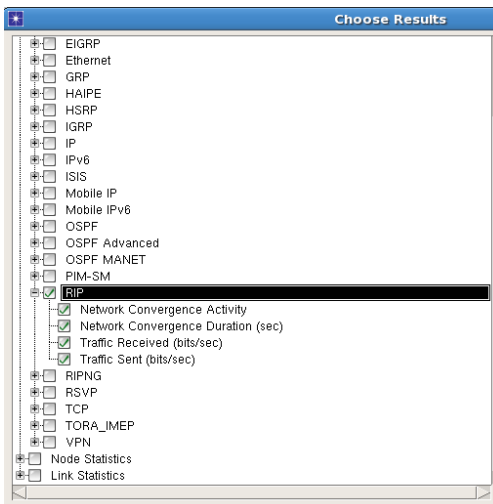


Figure 7: RIP DES statics

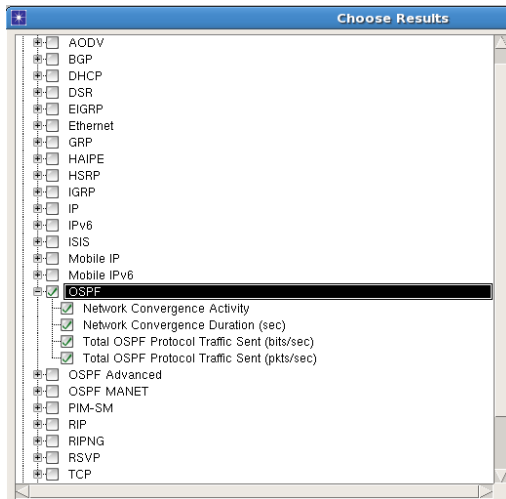


Figure 8: OSPF DES statics

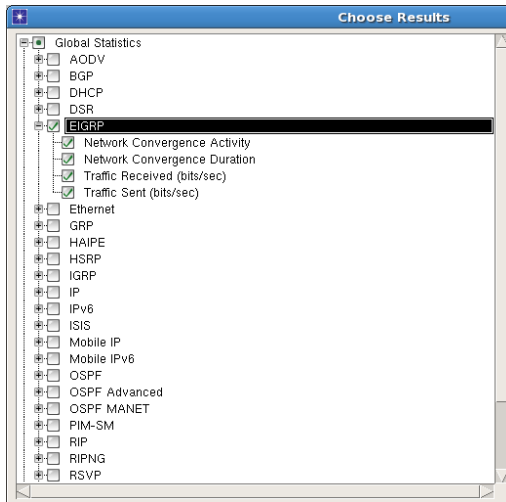


Figure 9: EIGRP DES statics

3.2.3 Simulation Setup for Simulation Global Attributes

IP dynamic Routing Protocol is set to be RIP, OSPF and EIGRP respectively. And it exports routing table once the simulation is completed. Simulation efficiency for three protocols are disabled and stop time has been set to longer than the simulation time, it guarantees the protocols continue throughput until the end of the simulation.

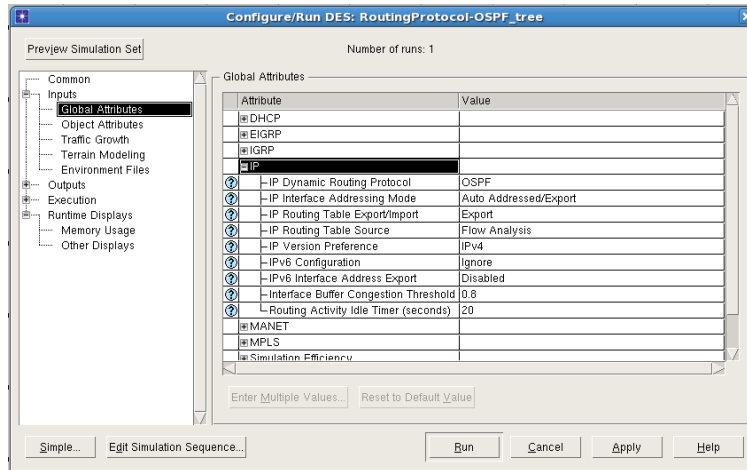


Figure 10: Simulation Global Attributes

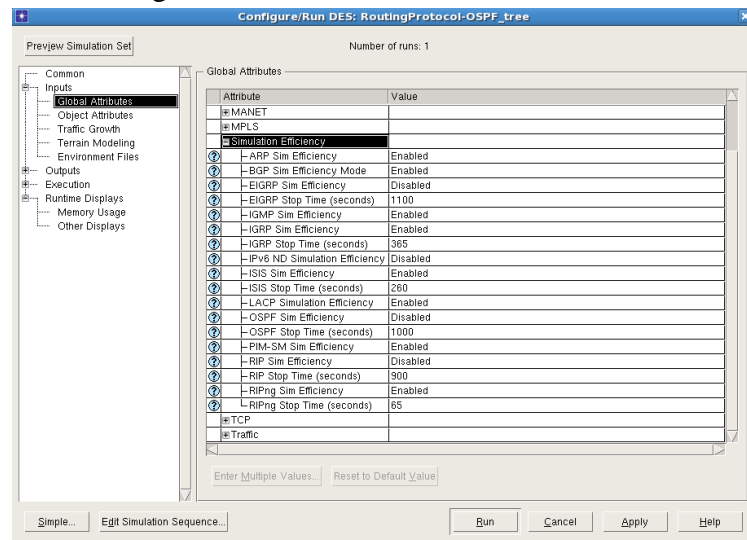


Figure 11: Simulation Efficiency setup

3.2.4 Model Attributes

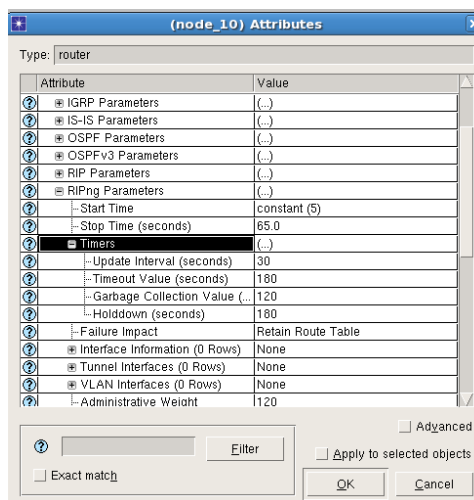


Figure 12: RIP parameters

- The RIP routing tables are initialized with the local gateway's IP addresses. The cost for these routes is set to 0.
- Silent RIP processes are modeled with a parameter that can be controlled by the user. Silent RIP processes do not send out routing update messages, and are normally used for hosts that do not act as network gateways.
- The start time at which the first regular routing updates are generated is a parameter that can be controlled by the user.
- Split Horizon with Poisoned Reverse is implemented to avoid including routes in updates sent to the gateway from which they were learned. Such routes are included in updates, but their metrics are set to infinity.
- Regular and Triggered Updates
- Garbage Collection (Flush) and Timeout (Route Invalid) timers

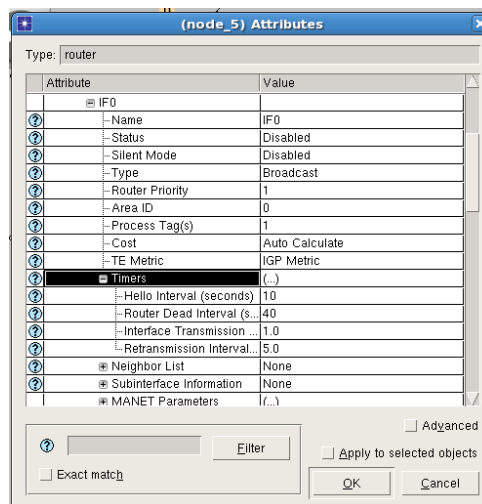


Figure 13: OSPF parameters

- Hello interval: Time between Hello packets sent by the router on this interface. This value should be same for all interfaces connected to common network. The default value is 10 seconds.
- Router Dead Interval: Time after which, if a neighboring router's Hello messages are not seen, it is considered inactive. It should typically be set to some multiple of the Hello Interval, and should be the same for all interfaces attached to a common network. The default value is 40 seconds.
- Interface Transmission Delay: The estimated time it takes to transmit a link state advertisement (LSA) packet over this interface. This value is used to age an LSA prior to transmission on an interface. The default value is 1 second.
- Retransmission Interval: Time (in seconds) between LSA retransmissions for adjacencies belonging to this interface. The default value is 5 seconds.

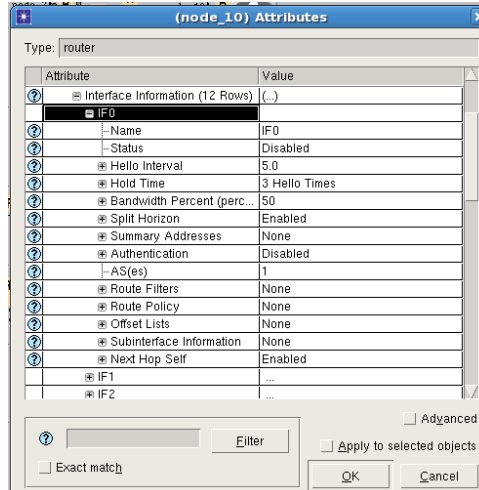


Figure 14: EIGRP parameters

- Hello Interval. Determines the time interval between hello messages. A high value lowers the EIGRP traffic in steady state, and a low value enables node failures to be detected more quickly.
- Hold Time. Specifies the value of hold time, which is advertised in the hello message sent over the corresponding IP interface. The hold time value defines the amount of time a neighbor should wait for another hello message from this process model before marking its node as down. A high hold time value delays the detection of node failures, and a low value may cause misjudging the status of a neighbor as down because of a few delayed or dropped hello packets.
- Split Horizon. Enables or disables split horizon on the interface. The default configuration enables this feature on all interfaces.
- Route Filters. Specifies the prefix/distribute lists used to filter routes received on or sent from this interface. Prefix/distribute lists are defined in the IP > IP Routing Parameters > Prefix Filter Configuration attribute.

4. Result and Analysis

Based on our three topologies, we simulated the performance of each routing protocol on all three topologies.

Firstly we ran the simulation on small mesh topology for RIP, OSPF and EIGRP.

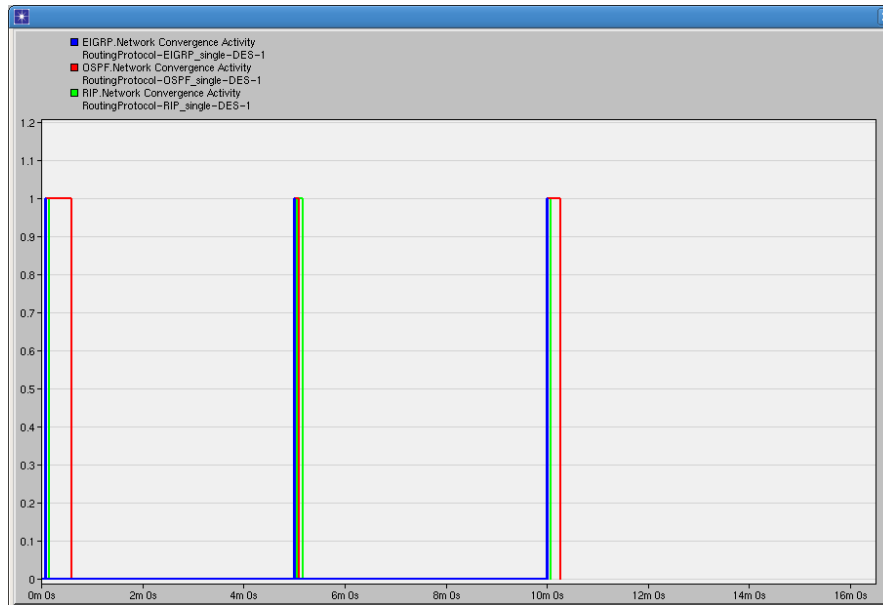


Figure 15: Overlaid Convergence Activity on small mesh

The three peaks from left to right in the graph represent: initialization, failure, recover. The width of the peak stands for the convergence time of the protocol. If the peak is wider, the protocol converges slower. In small mesh topology, EIGRP is the fastest protocol among the three. RIP is a little bit slower than EIGRP. It is clear to see from the graph that OSPF converges most slowly.

Next we simulated the data transmission of three protocols on large mesh topology.

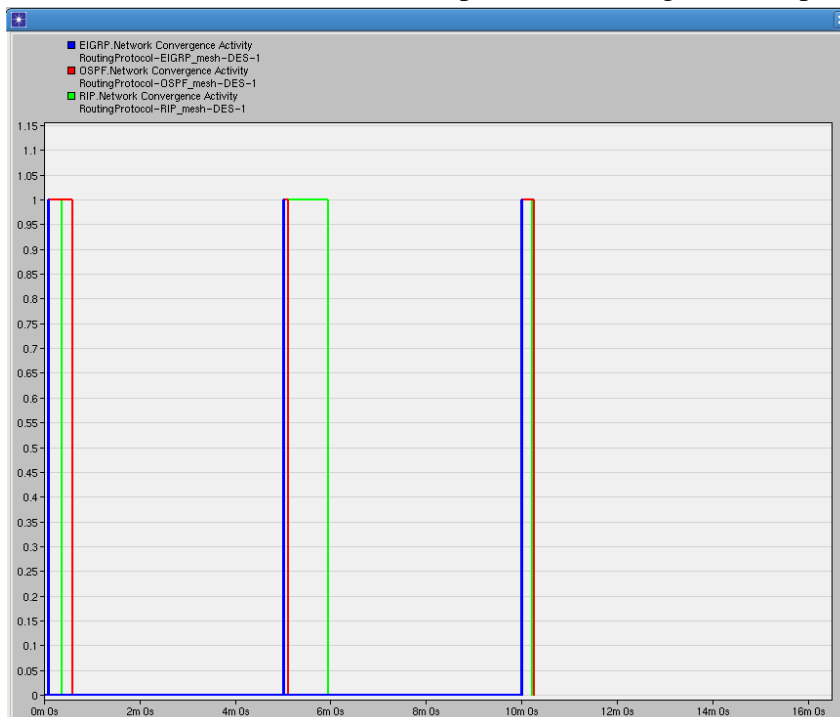


Figure 16: Overlaid Convergence Activity on mesh

This time the fastest protocol is still EIGRP. OSPF has longer initialization and recover time than the other two protocols. The difference in peak duration for OSPF is not significant in small and large topologies. RIP is the slowest one in large mesh especially when the link is failed; its initialization duration is half of OSPF. RIP has very long fail convergence compare to the other two. Our assumption was RIP is limited by its hop count which is only 15.

Then we simulated the data transmission of large tree topology.

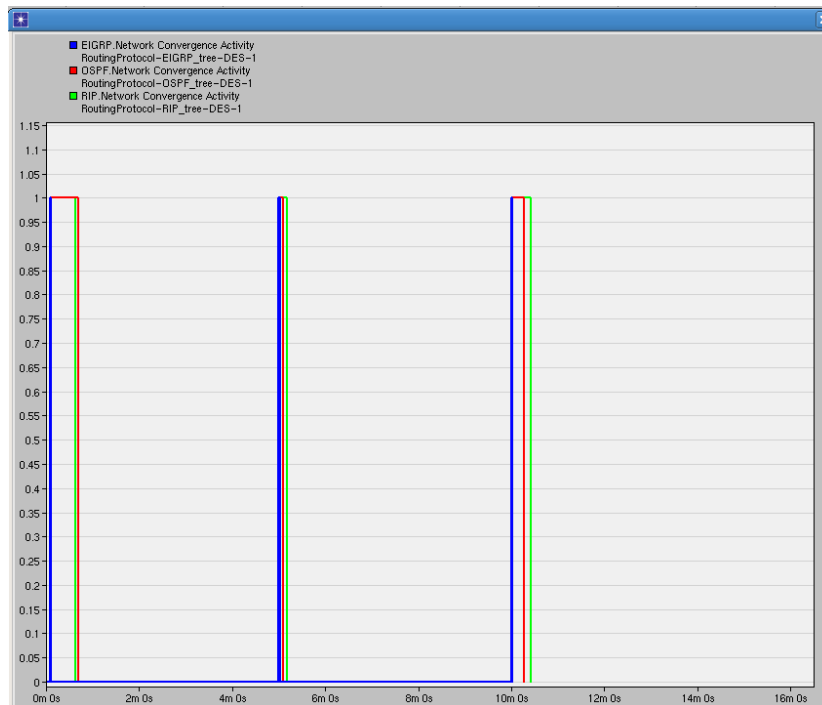


Figure 17: Overlaid Convergence Activity on tree

EIGRP is still the fastest protocol among all three. OSPF has a slightly longer initialization time compare to RIP and both OSPF and RIP has much longer initialization time than EIGRP. The fail convergence time is different from the mesh topology where $EIGRP > OSPF > RIP$, but the difference is not significant. RIP has the longest recover time and OSPF is a bit faster.

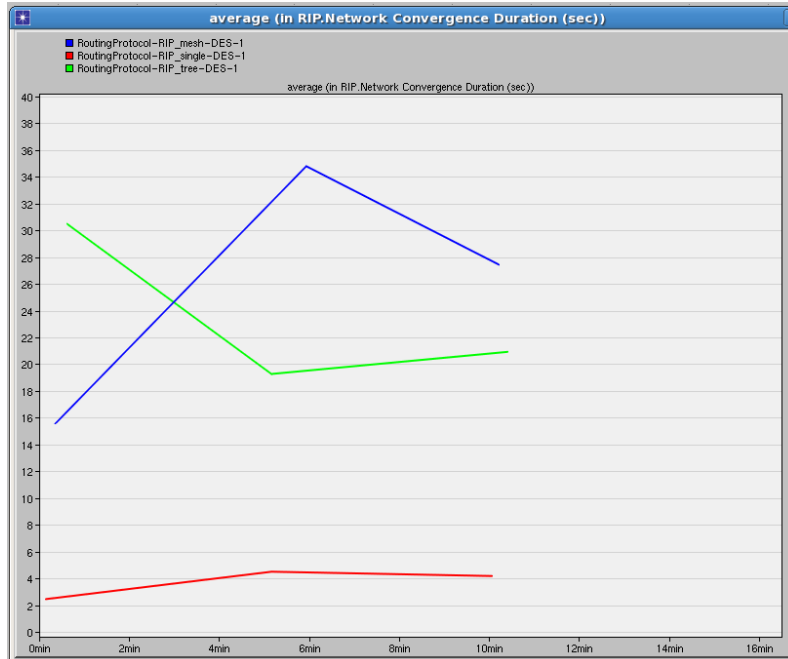


Figure 18: RIP Average Convergence Duration over different topologies

It is clear to tell that RIP has best performance on small network comparing to large tree and mesh. Since RIP has to update every 30 seconds, it will take more time on large networks.

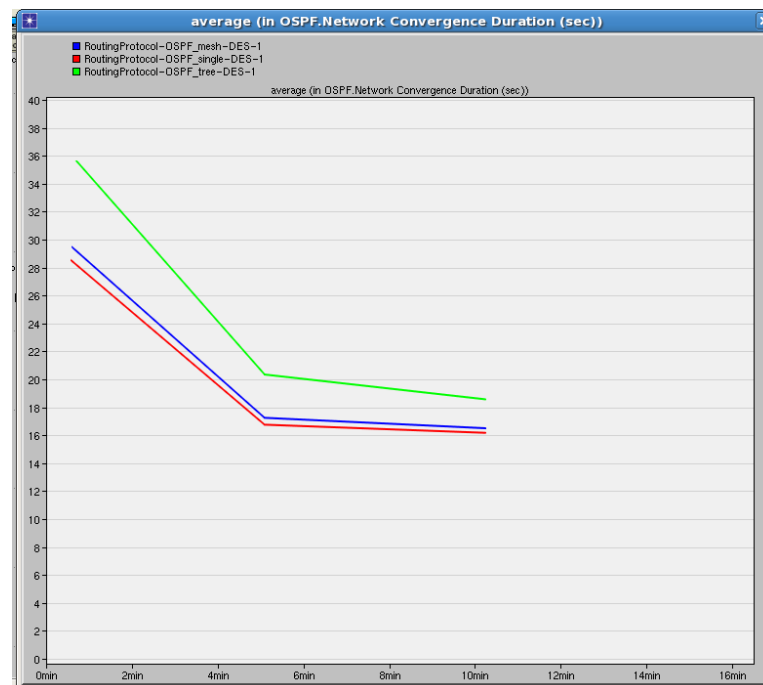


Figure 19: OSPF Average Convergence Duration over different topologies

The performance of OSPF is quite similar in three topologies. The initialization time in single mesh is a slightly faster than that in large mesh and large tree.

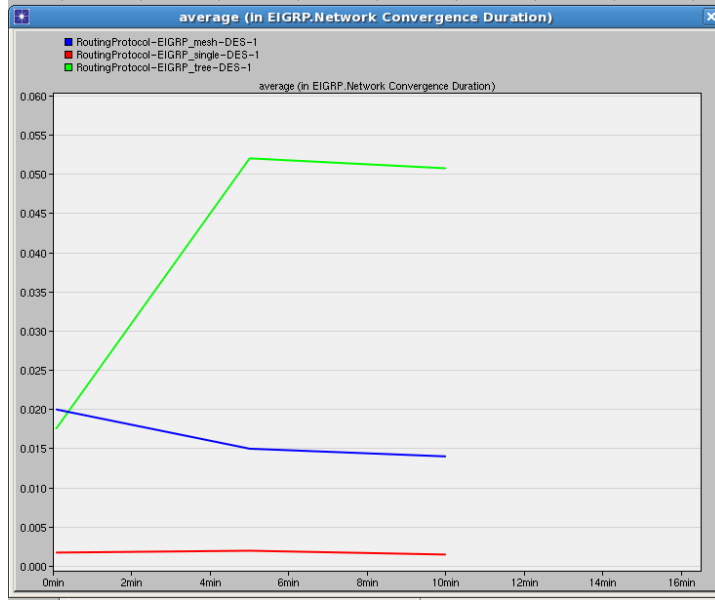


Figure 20: EIGRP Average Convergence Duration over different topologies

From figure 20, it looks like a huge difference over topologies but in details, the difference is only around 0.02 second which is really tiny. Therefore, the convergence of EIGRP in different topologies did not have radical improvement.

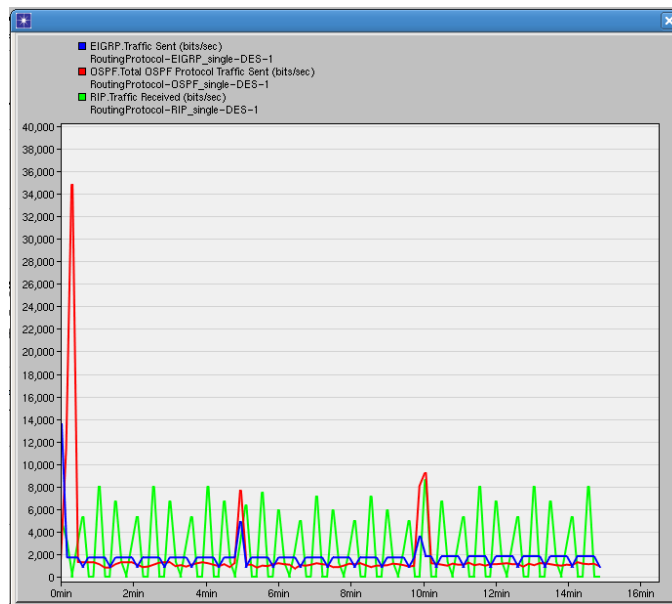


Figure 21: Traffic sent comparison on small mesh topology

The figure above shows the router traffic sent in bits/sec in three protocols using single mesh topology. From the graph, the first peak is the initial traffic, the next peak is link failure and the last peak is the link recovery in the network. We can tell OSPF generates the highest initial traffic since the OSPF will map out the network which requires routers to distribute a

large amount of information then choosing a path. In addition, we note that EIGRP has the highest bandwidth efficiency, and the second one is OSPF. However, the RIP has the lowest bandwidth efficiency. In this graph, the RIP shows a little difference from OSPF and EIGRP because RIP will update the routing table every 30 seconds, which is the same as our result.

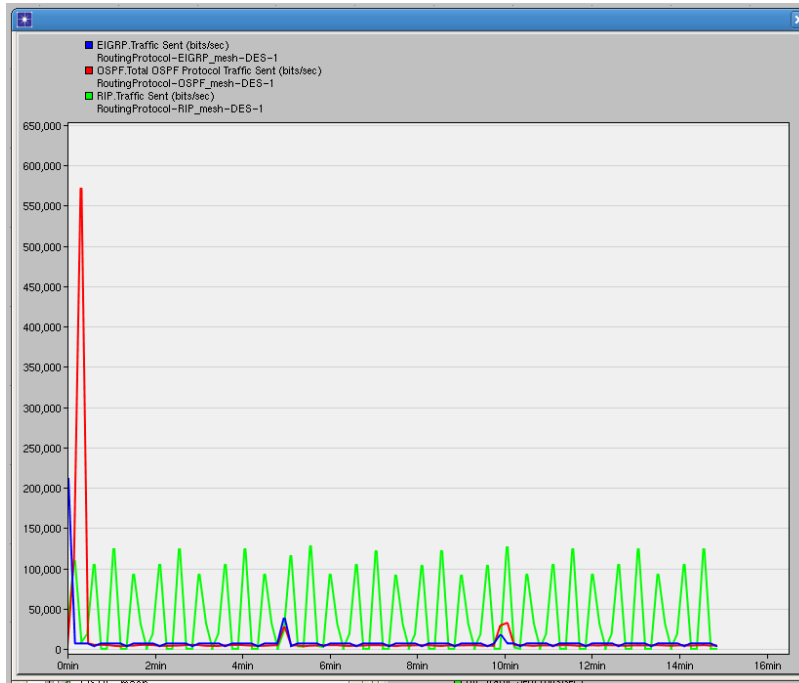


Figure 22: Traffic sent comparison on mesh topology

When we use large mesh topology, we can clearly tell that the throughput for each protocol has increased. It is just because the number of routers used in this topology is increased. At the beginning, OSPF has a throughput of 0.52Mbps, but EIGRP only has 0.2 Mbps. As we mentioned that OSPF using link state and EIGRP using hybrid in the introduction, link state requires to map out the whole network at the beginning. Also, we note that when failure occurs the EIGRP has higher throughput than OSPF. However, when recovery occurs the throughput is higher than EIGRP, which is the same situation as the initial. As for bandwidth efficiency, OSPF and EIGRP has a much higher bandwidth efficiency than RIP. In every 30 seconds, RIP wastes about 0.11Mbps, so we think RIP is only suitable for small network.

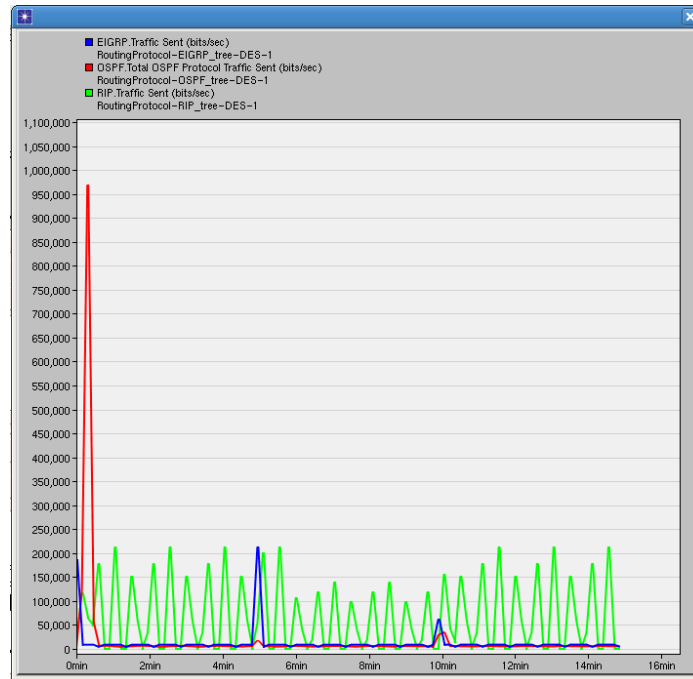


Figure 23: Traffic sent comparison on mesh topology

When we use large tree topology, we can clearly tell that at the beginning, OSPF has a throughput of 0.95Mbps, but EIGRP only has 0.18 Mbps. As we mentioned that OSPF using link state and EIGRP using hybrid in the introduction, link state requires to map out the whole network at the beginning. However, when failure and recovery occurs the EIGRP has higher throughput than OSPF. As for bandwidth efficiency, OSPF and EIGRP has a much higher bandwidth efficiency than RIP. In every 30 seconds, RIP wastes about 0.19 Mbps, so again we prove that RIP is not suitable for large network.

5. Conclusion

We analyzed the performance of three major types of routing protocols: RIP, OSPF and EIGRP using OPNET. Three different topologies had been built and the simulation of each routing protocol in all three topologies had been performed. Firstly we implemented the three routing protocols into a small mesh network and recorded the convergence activity, convergence duration and traffic sent (bytes/sec) to compare the difference in their performance. Then we implement the three protocols into large mesh and large tree topologies and recorded the same three graphs as we did in small mesh network.

We first compare the simulation result of convergence activity of three protocols. We did both horizontal and vertical comparisons. According to the convergence activity results, it is obviously that EIGRP is the fastest routing protocol among all the tree protocols when

initializing, failing and recovering. OSPF is the slowest (OSPF has to let all the routers to know each other) when initializing which matches our research. In small network, RIP's performance is close to EIGRP but when we changed to large network, RIP's convergence speed is the slowest. According to the traffic send (bytes/sec) we can conclude that OSPF and EIGRP benefit from the bandwidth while RIP sends complete information to flood the network which wasted bandwidth.

Refer to our analysis of all simulation results, we can conclude that EIGRP is the best choice for both large and small networks since it has the fastest convergence and EIGRP uses the bandwidth efficiently. But our research showed that EIGRP had just been implemented to companies other than CISCO (2013), and the structure is complicated. Based on EIGRP's attributes, OSPF will be the second choice for large networks. RIP has the worst performance in large networks so it is suitable for small, simple networks.

5.1 Future work and difficulties

In the future, we should do some security analysis for RIP, OSPF and EIGRP. In addition, we can implement different topologies in terms of the number of routers and links, distance and topology type. In our project, we just analyzed for OSPFv2 and EIGRP in the IPv4 environment based on OPNET. We should also compare OSPFv3 and EIGRP in the IPv6 environment using OPNET.

The first plan of the project was about VPN, but the topic has been changed since the expected result could not be achieved. Therefore, the whole process of research, simulation setups and report have to be started over. After reading a lot of paper and tutorial on OPNET, we decided to change the topic to the routing protocols which are widely used nowadays. It turns out that the parameter setups are easy to understand and doable with significant comparison of performance. However, setups are still the most challenging part we faced. For example, how do we predict the result? How do we determine if the result online is reliable as a reference? How does this parameter setup impact on simulation? What features should we compare over these protocols? Once the simulation is completed, analysis of all the graph we obtained became another challenge.

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