Comparative Study of Routing Protocols in Ring Topologies using GNS3

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***Summary*— Routing is the function of seeking a path between all possible in a packet network topologies which have great connectivity. Because it comes to find the best possible route, the first step is to define what constitutes best route and consequently what is the metric to measure it. This parameter and the operation of the routing protocol itself give us the protocol performance. This work presents a comparative study of three of the most used routing protocols, i.e., Routing Information Protocol (RIP), Open Shortest Path First (OSPF) and Enhanced Interior Gateway Routing Protocol (EIGRP) in ring topologies. Through this study, the performance of each routing protocol is analyzed. To this purpose, we have used a network simulator known as GNS3 that allows simulating different network scenarios using real operating systems (IOS) of CISCO equipment. We have simulated a topology with these three protocols in order to observe and analyze the network behaviour, traffic flow, time of routes updating and network convergence. As results show, RIP presents the lowest time for initializing the network while OSPF is the protocol that presents highest time in initializing process of network. Finally, EIGRP shows the best convergence time after the first fault in the network.**

Keywords- Routing Protocol; Convergence time; RIP; OSPF; EIGRP; GNS3; Network Performance.

I. INTRODUCCIÓN

Routing is the process through which a router determines the best route of a data packet to reach a destination. This packet passes through several devices so that the network destination is different to the origin network. There are two types of routes, i.e., statics and dynamics routes. Static routes are those that are configured by hand or are specified by default and do not have any reaction to new routes or falling sections of the network routes. However, a router with dynamic routing is able to understand the network and pass routes between neighbouring routers. The network through routers with dynamic routing is responsible for specifying the access to new nodes on the network or adapts and modifies the access to certain parts of the network due to the fall of any link or node seeking an alternative optimal route [1].

Routing protocols are algorithms that allow to determine and to select the best route upon which the network traffic will be send from one network to another. To this end, these algorithms use different information associated to links, such as bandwidth, delay, load, reliability, number of hops or cost, among others [2]. In this way, the exchange of information between the equipment can generate the existing network topology and determine the best links to be used to reach a specific destination.

Routing protocols are subdivided in two types, distance vector and link state. On the one hand distance vector algorithms use the Bellman-Ford algorithm. It searches the path of lowest cost by the indirect method search. The distance vector associated to a network node is a control packet that contains the distance to the nodes of the network known so far. Each node sends its neighbours the distances that knows through this packet. The neighbouring nodes examine this information and compare it with the information they already have updating its routing table, if necessary. Some examples of distance-vector protocols are Routing Information Protocol (RIP) (version 1 and 2), Interior Gateway Routing Protocol (IGRP) and Enhanced Interior Gateway Routing Protocol (EIGRP). On the other hand, link status algorithms are based on each node gets to know the network topology and costs (delays) associated with the links. From these data, nodes can obtain the tree and the routing table after apply the minimum cost algorithm (Dijkstra algorithm). Open Shortest Path First (OSPF) and Intermediate system to intermediate system (IS-IS) protocols are examples of link state protocols.

Because of the complex operation of these algorithms, it is necessary understanding the protocols operation in order to select the more adequate protocol for the designed network. Additionally to the basic operation, researchers usually modify some of these features in order to provide improvements in energy consumption in the transmission of information [3] [4] and the own consumption of network devices [5].

On the other hand, it is important to know the most appropriate sort of topology that our network needs. We can find Simple topologies such as bus, star or ring topology and more complex structures as mesh networks. Besides these topologies, they can be combined for grouping nodes in clusters [6] or in groups [7].

Networks with ring topologies offer one grade of redundancy to a possible fail so that if one link fails, it is possible to maintain the communication between all network nodes. This fact is essential in backbone networks [8]. In a backbone network with ring topology where dynamic routing with default values is configured, every node of the ring, after the network has converged, has a data base with the information about the network routes toward every node,

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where there will be information about how to arrive to the destination for two routes with equal cost. It is known as redundancy.

The time that a routing protocol takes to calculate the route to achieve the destination, as well as the convergence time to start data transmission after a failure and recovery time are different depending on the protocol and the mode that it exchanges information about the network topology. For this reason, some protocols will have better performance than another.

Taking into account all of these issues, in this paper, we are going to perform a comparative analysis with three routing protocols, RIP, OSPF and EIGRP, in order to check which one offer the best performance when a ring topology is used. To do this, we are going to use a network simulator called GNS3 [9]. These protocols are used in a ring topology composed by 5 routers and a computer that monitors all events. The tests are performed in terms of convergence time when network begins to work, recovery time after a failure and network response when one or two links register a failure.

The rest of this paper is structured as follows. Section 2 shows some previous studies where these protocols have been analyzed. Section 3 presents the protocols RIP, OSPF, and EIGRP that we have used in our test bench and simulations. The simulation scenario and some previous measurements are shown in Section 4. Section 5 shows the result of our study. Finally, Section 6 presents the conclusion and future work.

II. RELATED WORK

There is a big number of previous works where routing protocols are studied and evaluated using network simulators. There are several network simulators which are widely used in telecommunications such as OPNET, OMNET, NS-2 or NS-3, among others. Some of them are free and other ones can only be used under license. In any case, the most important thing is that these simulators should offer results as realistic as possible [10]. This Section shows some of these works.

G. S. Aujla and S. S. Kang [11] performed a study and analysis of several routing protocols over Mobile ad hoc networks (MANETs). Authors used OPNET simulation to test the operation of five well known routing protocols as Ad Hoc On-Demand Distance Vector (AODV), Dynamic Source Routing (DSR), Temporally-Ordered Routing Algorithm (TORA), Optimized Link State Routing (OLSR) and Geographic Routing Protocol (GRP). The protocols performance was measured on the basis of throughput, delay, load and data dropped metrics. In addition, the work was focussed on the e-mail and video conferencing traffic generating applications by increasing the number of nodes. As a result of this study, we can see that AODV is the one which present better results for video conferencing when a low number of nodes. However, OLSR protocol shows good results for email traffic

K. Yao et al. [12] presented a real-time testbed for routing network (ARTNet) in order to evaluate the requirements that routing protocols should present. As authors state ARTNet supports some of the most popular routing protocols used in typical applications in a cost-effective way. To test the good operation of ARTNet, authors have performed several simulations with two popular routing protocols, EIGRP and OSPF based on quantitative metrics, i.e., packet loss and delta time for standard application services. The results of this study demonstrate that EIGRP presents converge time faster for HTTP and FTP applications when the primary link for a subnet suffers a fault. This kind of simulators and proposal are a good tool that allows users to easily make different network configurations.

M. I. Ashraf et al. [13] presented a comparative analysis of OSPF and EIGRP. Authors study the network performance of these protocols in enterprise environments. The study was performed at simulation level using OPNET Modeler. Along the paper, authors explained the main features that a protocol should present in order to be used in big networks that manage the information in corporative and enterprise environments. The study evaluated OSPF and EIGRP performance in terms of convergence time, scalability and resources Utilization through the simulated network models. As results shows, EIGRP seems to be more scalable in terms of routing domain size. On the other hand, OSPF is more efficient in terms of router and CPU utilization, message processing, routing table size and the traffic load through the network. In terms of convergence time, EIGRP is faster than OSPF. This report can be understood as a user guide to use EIGRP, OSPF in certain circumstances.

There are several comparative studies where more complex topologies have been studied, but we have not found studies of routing protocols in ring topologies. However, there are interesting proposals based on ring topologies such as [14] where authors presented a set of test benches to study the TCP/IP interaction based on congestion price for evaluating the stability and optimality in ring topologies and [15] where X. Li describes a particle swarm optimization (PSO) algorithm using a ring neighborhood topology, which does not require any niching parameters. For this reason and because of the features of this kind of topologies, we have decided to perform this work.

III. ROUTING PROTOCOLS

This section presents some of the most widely used routing protocols. For each protocol, it is explained the main characteristics as well as default values of each parameter that these protocols use when they are running.

A. *RIP and RIP V2*

RIP [16] is an Interior Gateway Protocol (IGP) used by routers to exchange information about IP networks that are connected. This protocol is based on the distance vector algorithm and it uses the User Datagram Protocol (UDP) to send information through the network. The router that uses this protocol has a limited knowledge about the network information. This protocol uses the hops number mechanism to determine the best route. It supports up to 15 hops to avoid routing loops. A route with 16 hops is considered a route as unreachable or not desirable. This fact limits the network size. It is a popular protocol due its simplicity and easy configuration. However, the main problem lies in the convergence times and scalability limitations, so it has a better performance in small networks [17].

On the other hand, RIPV2 [18] was created due to the necessity of supporting variable length subnet masks (VLSM) and other requirements enhanced in respect to its first version. In addition to including VLSM, RIPV2 supports the process of routes authentication and it incorporates the routes updating making use of multicast packets, classless inter-domain routing (CIDR) and the updating by trigger. It keeps the sending of updating packets each 30 seconds and a limit of 15 hops. It uses the same port UDP, i.e., the port 520, and it uses the strategies of inverse poisoning and counting to infinite to prevent loops, as the first version of RIP [19].

Unlike other protocols, RIP is a free protocol to be used by different routers and not only by a single one owner such as EIGRP which was developed by Cisco Systems. Table I [20] shows a summary of the default parameters of RIP protocol.

TABLE I. PARAMETERS OF RIP

Parameter	**Default values of RIP Parameters**	
	Description	***Value***
Updating interval	Time period to sending actualizations, to its neighbours.	30 s.
Invalid route	It is a initialized timer when a route is inserted in the routing table. When this time expires the route is invalid.	180 s.
Flush	It marks that a route must be removed of routing table. This value must be bigger that the value to the invalid route.	240 s.
Holddown	It is used to avoid that one route has been marked as valid immediately after of it had marked as invalid. During this time the actualizations respect to the invalid route are ignored.	180 s.
Announcing's methods	It specifies the mechanisms that the router uses to communicate with its neighbours. 1- No filtering: Announce the routes for all its neighbours. 2- Split horizon: Do not announce a route to one neighbour from which it was learned. 3- Split horizon with poison reverse: Announce the route to the neighbour of which it was learned with a metric to infinite or 16 maximum.	3

B. OSPF

OSPF [21] is a link state routing protocol that uses the algorithm short path first (SPF) to calculate the best route to the destination node. It is one of the most widely used hierarchical protocols due to its significant scalability.

OSPF keeps all network information in its routing table. For this reason, it requires a major level of processing and memory. The header of OSPF packets includes the source and destination address. OSPF uses multicast as destination address and sends many message types including hello messages, link state requests and updates and database descriptions. Djisktra's algorithm is used to specify the shortest path to the destination. SPF calculations are computed either periodically or upon a received Link State Advertisement (LSA). This fact depends on the protocol implementation. The protocol operation is based on 5 different types of link states packets (LSP's). These packets help the protocol to distinguish between its neighbours and update the routing information of link states. The routers of a network that runs OSPF can have different roles as a function of its position. These roles are internal router, backbone router, edge area router and autonomous systems (AS) router. OSPF uses the accumulated bandwidth as metric from the source interface to destination interface to calculate the cost. Finally, it is important to know that OSPF supports VLSM [17]. Contrary to RIP, however, OSPF has the disadvantage of being too complicated. Table II shows a summary of the main parameters of OSPF protocol [20].

TABLE II. PARAMETERS OF OSPF

Parameter	**Default values of OSPF parameters**	
	Description	***Value***
Cost Interface	The cost of each interface can be specified, this parameter is used to use the short path first.	1
Hello's messages interval	Time period to send Hello's messages to its neighbours. If this parameter is too small, result in more traffic to the router, that it increments the risk of that the packets are discarded, so it could producing false alarms. If the value is too big, the change detection times in the topology are majors, the router dead timer could be expire.	10 s.
Router dead timer	Timer used, to declare to its neighbours as down, when the Hello messages didn't have been received. Its value must be multiple of the Hello interval.	40 s.
Transmissi on delay	It is the estimated time to transmit notification packets about link state LSA.	1 s.
Retransmis sion interval	Retransmission time LSA. It must be major that the round trip time estimated between any couple routers in the network.	5 s.
Parameters to the calculate SFP	It specifies how often it calculates the short path first: 1- Periodic: It recalculated in each specified interval, unless it hasn't occurred any change. 2- LSA delivered: It recalculated after of each LSA has been received.	2

C. EIGRP

EIGRP [22] is an advanced routing protocol based on distance vector, owned by Cisco Systems, which offers the best characteristics of both distance vector and link state algorithms. This protocol can only be used in Cisco routers. It is a fast convergence routing protocol and extremely scalable for medium and big networks. In addition, EIGRP implements CIDR and VLSM. It is considered an advanced protocol because it is based on features commonly associated with link-state protocols and although it may serve as it, the fact is that EIGRP is a distance vector routing protocol. EIGRP uses some of the best features of OSPF, such as partial updates and neighbor discovery.

The key of its good performance is use of the Diffusing Update ALgorithm (DUAL) for updating routes. Through it, this protocol achieves an exceptional and rapid network convergence. The metrics takes into account the bandwidth, load, feasibility and delay. It keeps the routes' information and topology's network details in three different tables called neighbour table, topology table and routing table [4]. This algorithm uses the neighbour table and the topology table to develop the routing table in the EIGRP router. The topology table is created by the finite states machine of DUAL using the collected information of its routers neighbours. With the available information of the topology table, DUAL calculates the best route to the router destination and it makes that link as successor. DUAL also calculates the feasible successor (second best link free of loops) if it is available. Although EIGRP does not guarantee the use of the best route, this protocol is rather used because it is easier to configure than OSPF.

Table III shows the main parameters used by EIGRP protocol [20].

TABLE III. PARAMETERS OF EIGRP

Parameter	**Default values of EIGRP parameters**	
	Description	***Value***
Hello interval messages	Period of time to send Hello messages to its neighbours. If this parameter is too small, the result is more traffic to the router, so it increases the risk of that packets are discarded, so it could producing false alarms. If the value is too big, the changes detection time in the topology will be major, the router dead timer could expire.	5 s.
Hold Time	Timer used to declare to the neighbours as down, when the Hello messages has not been received. Its value must be multiple of Hello interval.	15 s.
Split Horizon	When it is enabled, it does not notifies the routes to the neighbours of which were learned.	Enable

As we can see, the EIGRP is simpler in terms of the number of different types of packets generated by the protocol.

IV. SIMULATION ENVIROMENT

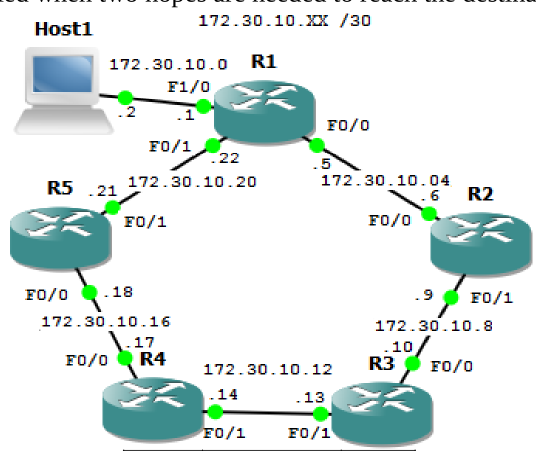
In order to evaluate the performance of each protocol, we have implemented a basic ring topology. This topology and response times of each router are shown in this Section.

As Figure 1 shows, the topology is composed by 5 routers linked by Fast Ethernet interfaces. In this case, the devices used are Cisco routers with the Cisco IOS Release 12.4(13b) for 2691 service Platform with IP Base. To perform the simulations, a personal computer (PC) is connected to the ring topology. Each router has, at least, 2 network interfaces except the router R1 which needs one more interface to connect the PC. This PC is in charge of monitoring all network events making use of the management software. Figure 1 also shows the subnet network and the physical interfaces that connects each router.

To design the network addressing, we have used VLSM. We have defined 5 subnets with subnet mask /30 starting from the class B address 172.30.10.0/16.

In order to see the initial performance of this network, we have configured static routes in each router. After that, a ping is transmitted from Host 1 to each router following the route with lowest cost. Figure 2 shows the Round Trip Time (RTT) in ms. where routers are configured with static routes. With the value of RTT, it is easy to measure the time during which part of the network does not have connectivity. We can also compare the times for symmetric routes.

From these results, we can calculate the average response time to reach each router (See Figure 3). Figure 3 also shows the percentage of packet loss. In this case, because we are working static routes and a very simple network, we do not register packet losses. If results are analyzed, we can observe that the biggest response time is registered by the farthest network to R1, i.e., the route up to network 172.30.10.12/30 through the interface F0/1 of router R3. We can observe that the minimum response time is established to reach the router R1 in 21 ms, and the maximum time is 64 ms to reach the node R3. In addition, it is important to see that this value is doubled when two hopes are needed to reach the destination.



Device	Subnet	Device
PC	172.30.10.0/30	R1
R1	172.30.10.4/30	R2
R2	172.30.10.8/30	R3
R3	172.30.10.12/30	R4
R4	172.30.10.16/30	R5
R5	172.30.10.20/30	R1

Figure 1. Network in ring topology used in our simulations.

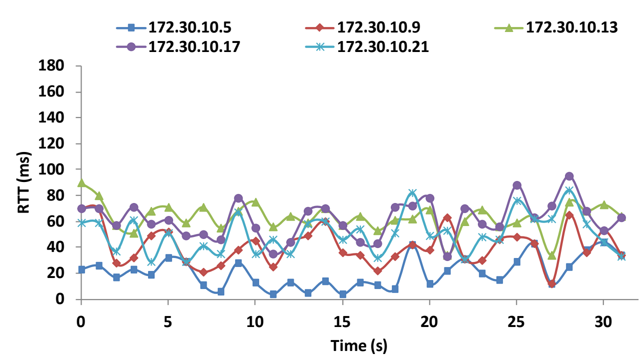


Figure 2. Response times from Host 1 to all routers

It is easy to see that symmetric routes, such as PC to R5 and PC to R2, present a difference of average response time of 10ms. If we analyze both, route from PC to R3 and route from PC to R4 this difference between the average response times is lower.

V. PROTOCOLS' EVALUATION

This Section presents several tests where RIP, OSPF and EIGRP are evaluated. Protocols are evaluated in terms of recovery time after a network failure. This Section also analyzes the different states that a network running a routing protocol can suffer, i.e., event of updating messages, event of network initialization, network failure and network recovery.

When configuring the routing protocols with its default parameters, routers calculate 4 optimal routes to reach the no adjacent networks from each router. Because we have a ring topology, each router only has two optimal routes to reach the farthest network to each node. To evaluate the performance of each routing protocol, we need to determine the learning and route publication time and the ring network convergence, in three different stages: (1) at the beginning of network operation, (2) when a dropped link is registered and (3) when this link is restored. The failure point has been established in the link between router R1 and R5. When the network starts, routers have to calculate and learn the two optimal routes to reach the two non adjacent networks in both directions through the interfaces of each router with a same cost. To determine the recalculating times of routes and the network convergence as a result of a dropped link, the monitoring point is established in the farthest network from router R5, i.e., Host 1 is used to monitor the network activity. The failure point is established in the fast Ethernet interface 0/1 (F0/1) of router R5. After generating the failure, the link is reconnected and restored. The time elapsed between the failure generation and the communication re-establishment will give us the time of network inactivity time which will consider the convergence time and some additions milliseconds that the devices will need to route the packets. As packets, we have used pings with the parameters by default.

A. Evaluation of RIP

In order to evaluate the network performance when RIP is running, we have generated a failure in the link between the R1 and R5. After that, the link is restored. To evaluate the restoring time of this protocol, we have sent a continuous ping between Host 1 and each router. Figure 4 shows the RTT in ms. of each ping between Host 1 and each router. As we showed in Figure 1, R4 and R5 are reached through the shortest path, i.e., R4 is reached through R5. As Fig. 4 shows, the disconnection and restoration of link is generated at 25th second. From this moment, the network needs around 475 s to recover the communication with R4 and R5. We can also observe that R1, R2 and R3 have not lost the connectivity with Host 1 although the RTT of their ping has slightly increased. This is because the protocol needs to inform to the rest of routers about the new path to reach R4 and R5. The RTT for R4 and R5 has increased about 110 milliseconds.

Table IV shows the response times evaluated for this protocol, in the different phases of its operation.

TABLE IV. RESULTS OF RIP

Event	RIP Results	
	Action	*Time (s)*
Updating messages	--	29.601
Network start	Learning and publishing routes	7.515
	Ring network convergence	13.823
Failure	Learning and publishing routes	27.931
	Ring network convergence	298.129
Recovery	Learning and publishing routes	2.269
	Ring network convergence	30.888

B. Evaluation of OSPF

In order to evaluate the restoring time of OSPF, we have sent a continuous ping between Host 1 and each router. In this case we have generated 2 failures in the same link. The second one is generated after restoring the network communication of the first failure. Fig. 5 shows the RTT in ms. of each ping between Host 1 and each router after the first failure. Figure 5 shows that the disconnection and restoration of link is generated at 7th second. From this moment, the network needs around 50 s to recover the communication with R5 and around 10 s to recover the communication with R4. We can also observe that R1, R2 and R3 have not lost the connectivity with Host 1. However, the RTT of their ping has increased around 10-15 ms. After restoring the communications with R4 and R5, the RTT is around 110 ms for R4 and 140 ms for R5.

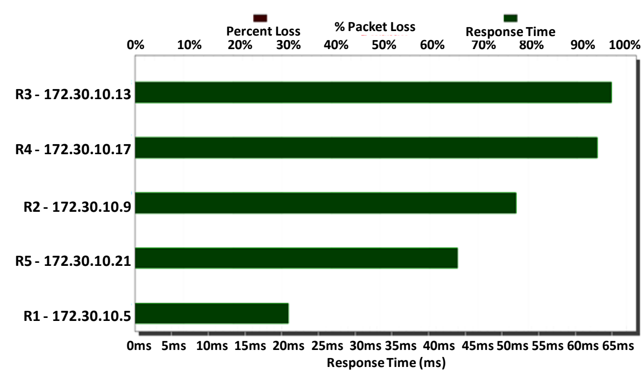


Figure 3. Average response time

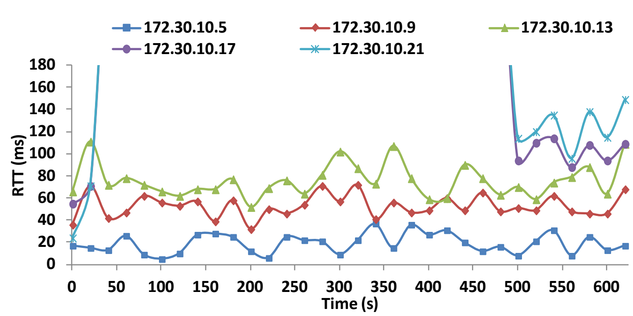


Figure 4. RTT and communication restoring time for RIP after a failure

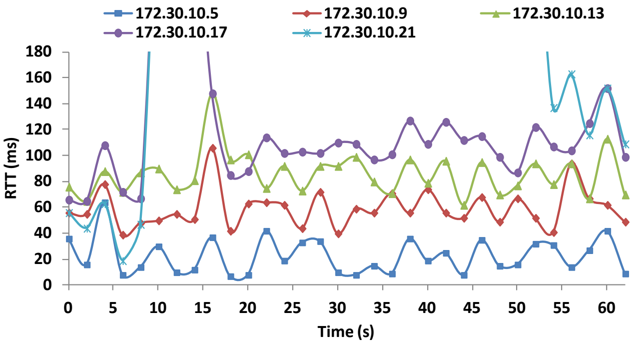


Figure 5. RTT and communication restoring time for OSPF after the first failure

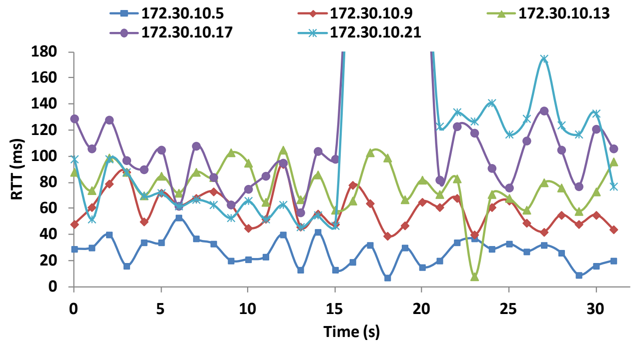


Figure 6. RTT and communication restoring time for OSPF after the second failure

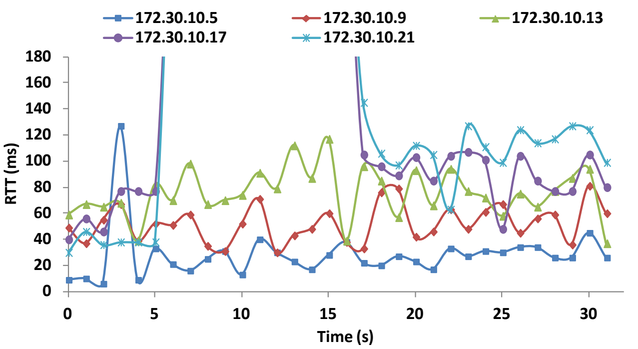


Figure 7. EIGRP data convergence before the failure

After generating the second fault and restoring it in the same link (in 15th second), we have observed that the network only needs 7 seconds to establish the connectivity (See Figure 6). This is because the routing tables already contain the alternative route to reach R4 and R5. The RTT values are similar to Figure 5.

Table V shows the response times registered for OSPF protocol, in the different stages.

TABLE V. RESULTS OF OSPF

Event	**OSPF Results**		
	Action	***Time (s)***	
Hello messages	--	9.99	
Network start	Learning and publishing routes	53.84	
	Ring network convergence	66.78	
Failure	Number of failure of the same link	1st	2nd
	Learning and publishing routes	42.14	2.51
	Ring network convergence	45.00	5.62
Recovery	Learning and publishing routes	7.76	
	Ring network convergence	14.80	

As Table V shows, the response times improve after the second failure. This is because the routing tables maintain the information about how to reach R4 and R5. The calculation of alternative routes is faster than the previous situation. The elapsed time without communication is the time that routers need to switch to the alternative route.

C. *Evaluation of EIGRP*

To evaluate the network performance when EIGRP is running, we have generated an only failure in the link between the R1 and R5. Figure 7 shows the RTT in ms. of each ping between Host 1 and each router. The disconnection and restoration of link is generated at 5th second. From this moment, the network needs around 12 s to recover the communication from Host 1 to R4 and R5. R1, R2 and R3 have not lost the connectivity with Host 1. The RTT of pings for R1, R2 and R3 are around 28 ms, 52 ms. and 75 ms, respectively. The average value of RTT for R4 is about 91 ms and for R5 is 111ms.

Finally, Table VI shows the different response times for EIGRP protocol in its different stages it needs to correctly work.

TABLE VI. RESULTS OF EIGRP

Event	**EIGRP Results**	
	Action	***Time (s)***
Hello messages	--	4.939
Network start	Learning and publishing routes	6.677
	Ring network convergence	15.241
Failure	Learning and publishing routes	0.9547
	Ring network convergence	12.573
Recovery	Learning and publishing routes	1.492
	Ring network convergence	1.965

As observed, EiGRP presents the lowest times compared to RIP and OSPF.

VI. CONCLUSION AND FUTURE WORK

In this paper, we have analyzed the network performance of ring topology when RIP, OSPF and EIGRP protocols are executed.

After evaluating these routing protocols, we should highlight several aspects of ring topologies as a function of the routing protocol it runs. On the one hand, RIP presents a good response time at the beginning of the network activity while its performance decreases after a failure. RIP requires higher time in the network establishing, when the network is recovered from the failure.

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On the hand, OSPF has a higher time in the network starting, but unlike of RIP, its performance improves after the first failure. It also improves its convergence time, even when a second failure is registered in the same link. OSPF registers better times response that the ones registered by EIGRP.

The simulations shows that after a failure the ring routers converge in an asynchronous form, i.e., the connectivity with the other routers is restoring according to time that each router needs to calculate the new optimal route.

EIGRP recorded the best convergence times of the ring after a failure and it also presents the best RTT when it is restored.

As future work, we would like to extend the comparative analysis of routing protocols for mesh topologies [23] in order to check their behaviour after a failure and the impact of this fact over the network efficiency. In addition, we have also found interesting approaches related to genetic algorithms based on ring topologies [24] and we would like to explore this possibility to improve the efficiency of sensor networks.

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REFERENCES

[1] S. Sendra, P. Fernández, M. Quilez, and J. Lloret, “Study and Performance of Interior Gateway IP Routing Protocols”, Integrated Management Coastal Research Institute, Polytechnic University of Valencia, Network Protocols and Algorithms, 2010, Vol. 2, No. 4, pp. 88-117.

[2] J. Deng, S. Wu, and K. Sun, “Comparison of RIP, OSPF and EIGRP Routing Protocols based on OPNET,” Simon Fraser University School of Engineering Science. ENSC 427: Communication Networks, 2014.

[3] Q. Ling, J. Yan, and H. Deng, “A Novel Energy-Aware Routing Algorithm for Wireless Sensor Networks Based on CDMA and TDMA,” Ad Hoc & Sensor Wireless Networks, 2015, Vol. 26, No. 1-4, pp. 21-41.

[4] M. Eslaminejad, S. A. Razak, and M. Sookhak, “Classification of Energy-Efficient Routing Protocols for Wireless Sensor Networks,” Ad Hoc & Sensor Wireless Networks, 2013, Vol. 17, No, 1-2, pp. 103-129

[5] S.Andrade, S. Sendra, E. Granell, and J. Lloret, “Towards green networks using optimized network devices.” (Ch. 15), Green Networking and Communications: ICT for Sustainability,2013, CRC Press, Taylor & Francis Group, pp. 355-376.

[6] M, Atto and C. Guy, “Routing Protocols for Structural Health Monitoring of Bridges Using Wireless Sensor Networks,” Network protocols and Algorithms, 2015, Vol 7, No 1, pp.1-23.

[7] J. Lloret, S. Sendra, M. Garcia, and G. Lloret, "Group-based underwater wireless sensor network for marine fish farms," 2011 IEEE GLOBECOM Workshops, Houston, Texas, USA, December 5-9, 2011. pp.115,119.

[8] B. Meador. “A Survey of Computer Network Topology and Analysis Examples,” Academic Report. In Washington University website. Available at http://www.cse.wustl.edu/~jain/cse567-08/ftp/topology/#ring_network_topology [Last Access: January 25, 2016]

[9] C. Welsh, “GNS3 Network Simulation Guide,” Packt Publishing, ISBN 13 9781782160809, October 2013

[10] A. Basu et al., “The state of peer-to-peer network simulators,” ACM Computing Surveys (CSUR), 2013, Vol. 45, No. 4, pp. 1-25.

[11] G. S. Aujla and S. S. Kang, “Comprehensive Evaluation of AODV, DSR, GRP, OLSR and TORA Routing Protocols with varying number of nodes and traffic applications over MANETs,” IOSR Journal of Computer Engineering (IOSR-JCE), 2013, Vol. 9, No. 3, pp 54 -61.

[12] K. Yao, W. Sun, M. Alam, M. Xu, and V. Devabhaktuni, “A Real-Time Testbed for Routing Network,” In proceedings of the 8th International ICST Conference on Testbeds and Research Infrastructures for the Development of Networks and Communities (TRIDENTCOM 2012), Thessaloniki, Greece, June 11-13, 2012. pp. 256-270.

[13] I. Ashraf, S. Iftikhar, U. Sarwar, and A. Latif, “Comparative Analysis of Link State and Hybrid Routing Protocols,” International Journal of Computer Science and Management Research, 2013, Vol. 2, No. 4, pp. 2244-2255.

[14] J. He, M. Chiang and,J. Rexford, "TCP/IP interaction based on congestion price: Stability and optimality." In proceedings of the IEEE 2006 International Conference on Communications (ICC 2006). June 11-15, 2006, Istanbul, Turkey. pp. 1032-1039.

[15] X. Li, "Niching without niching parameters: particle swarm optimization using a ring topology," IEEE Transactions on Evolutionary Computation, 2010, Vol. 14, No. 1, pp. 150-169.

[16] RIP Features. In IETF Website. Available at: https://tools.ietf.org/html/rfc1058 [Last Access: January 25, 2016]

[17] D. Sankar and D. Lancaster, “Routing Protocol Convergence Comparison using Simulation and Real Equipment,” Advances in Communications, Computing, Networks and Security Volume 10, ISBN: 978-1-84102-358-8, pp186-194, 2013.

[18] RIP V2 Features. In IETF Website. Available at: http://tools.ietf.org/html/rfc1723[Last Access: January 25, 2016]

[19] A. Bruno and J. Kim., “CCDA Self-Study: RIP, IGRP, and EIGRP Characteristics and Design,” Cisco Press , Pearson Education 2015.

[20] M. Nguyen, K. Mirzahossein, and S. Elmasry, “Analysis of RIP, OSPF, and EIGRP Routing Protocols using OPNET,” Simon Fraser University School of Engineering Science ENSC 427: Communication Networks, 2013.

[21] OSPF Features. In IETF Website. Available at: https://tools.ietf.org/html/rfc1247 [Last Access: January 25, 2016]

[22] EIGRP Features. In IETF Website. Available at: http://tools.ietf.org/html/draft-savage-eigrp-02 [Last Access: January 25, 2016]

[23] D. Lee, K. Lee, S. Yoo and, J.-K. K. Rhee, "Efficient Ethernet Ring Mesh Network Design", Journal of Lightwave Technology, 2011, Vol. 29, No. 18, pp. 2677-2683.

[24] N. Tian, J. Sun, W. Xu and, C.-H. Lai, “Quantum-Behaved Particle Swarm Optimization with Ring Topology and Its Application in Estimating Temperature-Dependent Thermal Conductivity,” Numerical Heat Transfer, Part B: Fundamentals, 2011, Vol. 60, No. 2, pp. 73-95.