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Performance analysis and evaluation of distance vector and link state routing protocols over a large area networks

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ABSTRACT

Routing protocols are extremely important incredibly significant in data communication and computer networks. The high performance, reliability, stability, and security of the networks depend primarily on choosing the best type of dynamic routing protocol. In this paper, we evaluate and investigate the network performance for routing information protocol (RIP), enhanced interior gateway routing protocol (EIGRP), open shortest path first (OSPF), and intermediate system-to-intermediate system (IS-IS) routing protocols with three different scenarios of routes failure using the optimized network engineering tools (OPNET) simulator to determine which of the protocols is the most appropriate and effective in achieving high network performance. The results show that for large area networks, the EIGRP routing protocol gives the best network performance when all network routers are working with no failing, but when some network routers were failing to work and path failure is happening, the IS-IS link-state routing protocol works efficiently and gives the best performance. The obtained results for IS-IS protocol when failing seven routers is as: the hypertext transfer protocol (HTTP) page response time is (247.8 msec), voice delay variation is (4.19 µsec), video delay variation is (8.83 µsec) and ping request and response time is (115 msec).

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1. INTRODUCTION

In networking, routing protocols are considered the most important and the main key that contributes to and affects the performance of the network, whether this network small or big. Therefore, the network administrator should have high knowledge of the characteristics of routing protocols to decide which type should use based on the application and purpose design of that network. It is still one challenge for a computer network administrator to decide and choose which is a more suitable routing protocols are chosen based on the size of the network and the applications that run on it.

Two types of dynamic routing protocols, one is the link status protocols included; intermediate system-to-intermediate system (IS-IS), and open shortest path first (OSPF), and the second is the distance vector protocols included; routing information protocol (RIP), interior gateway routing protocol (IGRP) [1], [2]. In addition, there is another routing protocol that is considered a hybrid protocol due it is work based on both distance vector and link-state algorithms characteristics, called enhanced interior gateway routing protocol (EIGRP) [3], [4]. All the routing protocols have the same main aim that is to find and select the best route in the network to forward and deliver the packets to a correct destination. Every protocol has its own metrics such as the number of hop counts in the path, bandwidth, delay, and load that is used to evaluate a route quality.

For a more detailed explanation overview of different dynamic routing protocols based on various metrics, readers might refer to [5]-[8]. The main objective of this paper is to analyze, evaluates, test the suitability, and comparison the network performance of four types of routing protocols included RIP, EIGRP, OSPF, and IS-IS using three different scenarios in the larger network size and path failure is presents using optimized network engineering tools (OPNET) simulator to investigated which routing protocols are the best and more appropriate. The metrics that used to evaluate and investigate the network performance included, the response time of the hypertext transfer protocol (HTTP) page, voice and video packet delay variation, speed of network convergence, and ping request and response time.

This paper is organized as: section 2 discusses the related work. Section 3 demonstrates the methodology of the work. Simulation metrics are displayed in section 4. Simulation results analysis is discussed in section 5, and section 6 concludes the paper.

2. RELATED WORK

Routing protocols and enterprise networking have been carried out with a large range of research and surveys. Ibrahim [9] have evaluated and studied the network performance of two dynamic routing protocols OSPF and EIGRP using the OPNET simulation program. Two different scenarios with four parameters, database, file transfer protocol (FTP), HTTP, and e-mail are used in this paper. The results show that the OSPF provides better performance than EIGRP for the HTTP and FTP applications (web browsing and downloading/uploading process). However, for e-mail and database applications, EIGRP is better than OSPF. Wai [10] used the packet tracer simulation program to simulate and analyze OSPF, RIP, and EIGRP. The results show the EIGRP is better for fast convergence, the RIP protocol is appropriate for a small network, and the OSPF protocol is more appropriate for a large network.

Thin *et al.* [11] present the performance evaluation of three routing protocols, RIP and OSPF, and EIGRP using the OPNET simulation program for three different topologies. End-to-end delay, convergence duration, and router convergence are the three parameters being investigated. The results show that EIGRP has a faster convergence rate than RIP and OSPF. In large networks the RIP has the worst performance compared with other protocols, however, it is appropriate for small network size. In [12] investigated and compared the performance of OSPF and EIGRP using the network simulator graphical network simulator-3 (GNS3). Okonkwo and Emmanuel [12] simulate and implement star and mesh network topologies, and the results are validated in the laboratory using cisco hardware. Furthermore, the wire shark program is used to capture and analyze network packets. The results show that EIGRP outperforms OSPF in terms of convergence in the event of a link failure or the expansion of an existing link to the network.

Hadi [13], investigates the performance of e-mail traffic using the OPNET simulation program by applying EIGRP, IGRP, OSPF, and RIP. The evaluation is based on different criteria, including traffic sent and received, upload and download response time, and convergence duration time. The results show to select the fastest and shortest path subject on the application that is used since each protocol provides a method for transferring datagrams from the source to the destination that is the most efficient. Manzoor *et al.* [14] evaluated border gateway protocol (BGP), EIGRP, and OSPF using the GNS3 program . Manzoor *et al.* [14] used five routers that are directly connected via serial links. To analyze the packet delay, throughput, and network convergence, the network generates and transmits various types of data traffic. The results demonstrate the OSPF is better in packet delay, whereas EIGRP is better in throughput and convergence.

Dey *et al.* [15] investigate the performance of, EIGRP, OSPF, and routing information protocol version 2 (RIPv2). The topology for simulation has been developed on eight routers and one switch using the software GNS3. The results show that in small networks RIPv2 is better and OSPF is better in large networks. The EIGRP performs better compared to RIPv2 and OSPF. Hossain *et al*. [16], present the performance analytical for EIGRP, OSPF, and RIP using the OPNET simulator and Packet Tracer program. The performance of routing protocols was evaluated based on the delay, network convergence, bandwidth requirement, and security. The EIGRP routing protocol, according to the authors, has the best link utilization followed by OSPF, and RIP.

Three network models were designed in [17] and configured with EIGRP, OSPF, and with both EIGRP and OPSF routing protocols. The performance evaluation used the metrics of end-to-end delay, packet loss, throughput, latency, and convergence time. When video is the primary traffic on the network, the results show that combining OSPF and EIGRP is more reliable in providing quality of service (QoS) than using only OSPF. EIGRP, on the other hand, outperforms OSPF when dealing with an isolated real-time application network. Majid and Fuada [18] use the GNS3 simulator and enterprise network simulation platform (ENSP) to compare the performance of OSPF and RIP routing protocols. The results show that the OSPF has a faster time and efficiency in connection than RIP. In [19] implement many experiments to study the performance of the IS-IS protocol, the results of the simulation demonstrate that we can used the IS-IS protocol in large networks. In [20] used the OPNET simulator to compare between the EIGRB, OSPF and RIP to conclude the best routing protocol for the internet of things (IoT) network applications. In [21] investigate at network performance through dropping and recovering network connections over a long period of time. In [22] that in the event of failure, BGP as an inter-domain routing protocol suffers delayed convergence, resulting in significant delays in a variety of internet/web applications. The evaluation performance and suitability comparison between the dynamic routing protocols was presented in [23] using the packet tracer simulation. The findings demonstrate that OSPF is more reliable and has faster convergence than RIP and EIGRP.

3. METHODOLOGY

Network simulation has a valuable function to analyze network performance cost-effectively and offers design requirement that reduces time. OPNET modeler 14.5 software is used as a simulation tool to design and analyze our proposed network. OPNET is considered a robust software to simulate networks operate with different protocols [24], [25]. The proposed network topology scenario is shown in Figure 1. The network consists of 16 routers, 2 workstations, an application server. The routes are distributed around the world to cover a large area network, workstations are used to evaluate the network performance by doing a ping test between them.

Web browsing and real-time applications such as voice and video conferencing are configured as network applications by using an application definition and profile definition. To support these applications, application server added to the network. For our proposed network, three services are supported and configured using the application ethernet server. Distance vector and link state routing protocols such as RIP, EIGRP, OSPF, and IS-IS are configured and simulated in different scenarios. The network specifications and configuration utilities are collected in Table 1.

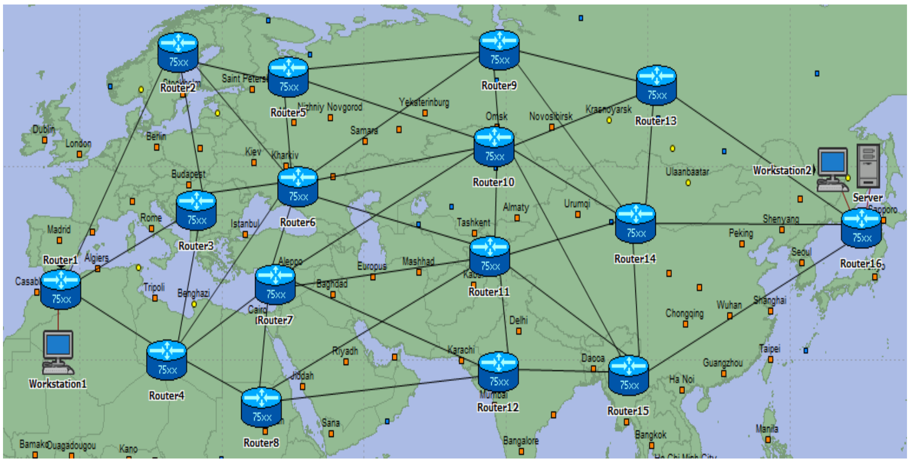


Figure 1. Proposed network topology

Table 1. Selecting attributes for network simulation

Attributes	Type or value
Simulator	OPNET (modeler 14.5)
Simulation time	15 minutes
No. of scenarios	3
Router model	CISCO CS-7000
Workstations and servers	Ethernet
Network coverage area	Around the world
Network addressing	Internet protocol version 4 (IPv4)
Routing protocol	RIP, EIGRP, OSPF, IS-IS
Transport layer protocol	TCP and UDP (depending on the application)
Applications	HTTP web browsing (heavy) Voice over internet protocol (IP) call (pulse code modulation (PCM) quality) Video conferincing (high resolution)
Connection links	PPP_DS3 duplex link (connecting routers) Ethernet 100BaseT (connecting workstations and server)
Link data rate	44.736 Mbps (for PPP) 100 Mbps (for Ethernet)

4. SIMULATION METRICS

Several metrics are configured to investigate the performance of the routing protocols. Configured metrics include HTTP page response time, voice packet delay variation, video packet delay variation, network convergence, and ping request and response time. To test network connectivity behaivier when change occurs in network topology, ping request from workstation 1 to workstation 2 is configured and simulated for the proposed network.

RIP, EIGRP, OSPF, and IS-IS are investigated using the above metrics in different scenarios. The first scenario investigates the performance when all network routers are working normally without any fail, the second scenario examines the performance in the event of three routers are failing to work, and the third scenario investigates the performance in case of seven routers are failing to work. Failure node is configured to simulate this failing in network routers.

5. SIMULATION RESULTS AND DISCUSSION

In this section, different scenarios are simulated and analyzed to evaluate the performance of distance vector routing protocols and link state routing protocols that included RIP, EIGRP, OSPF, and IS-IS. The evaluation was done by using mentioned metrics, response time of HTTP page (sec), voice and video packet delay variation (sec), network convergence (sec), and ping request and response time (sec). The duration of the simulation is set to be 900 seconds (15 minutes). The obtained results are discussed in the following subsections.

5.1. The first scenario (all routers are working without failing)

This scenario aims to investigate the performance of the all routing protocols (RIP, EIGRP, OSPF, and IS-IS) in case of all network routers are working normally with no failing or shutdown. The network simulation metrics evaluated in this scenario include HTTP page response time, voice and video delay variation, and network convergence activity. Obtained simulation results after running this scenario are displayed and discussed as follows.

5.1.1. HTTP page response time

The response time of the HTTP page gives the time needed to return the requested page with all the contained on-line. To test the performance of web browsing for each routing protocol, the response time of the HTTP page metric is considered during the simulation. Figure 2(a) shows the simulation results of the HTTP page response time. Simulation results demonstrate that the EIGRP routing protocol gives better performance than other routing protocols, it has the fastest response time elapsed between the web browser and web server (228.4 msec).

5.1.2. Voice packet delay variation

This metric measures the variation in voice packet end-to-end delays. A voice packet's end-to-end delay is measured from the time it is created to the time it is received. The variation in voice packet delay is taken into account in our simulation. Figure 2(b) shows the obtained results for the voice packet delay and demonstrates that the EIGRP routing protocol is the best compared with the other routing protocols, it gives the minimum voice packet delay variation concerning other protocols. The voice packet delay for EIGRP is about (1 μsec).

5.1.3. Video packet delay variation

Video packet delay variation measure the variance among end-to-end delays for video packets. So this metric is considered in our simulation to evaluate the performance of real-time video applications for link state and distance vector routing protocols. Figure 2(c) shows the comparison of the performance response for video conferencing packet delay. The results show that EIGRP has the best video packet delay variation which gives the minimum video packet delay variation (0.17 μsec) concerning other protocols.

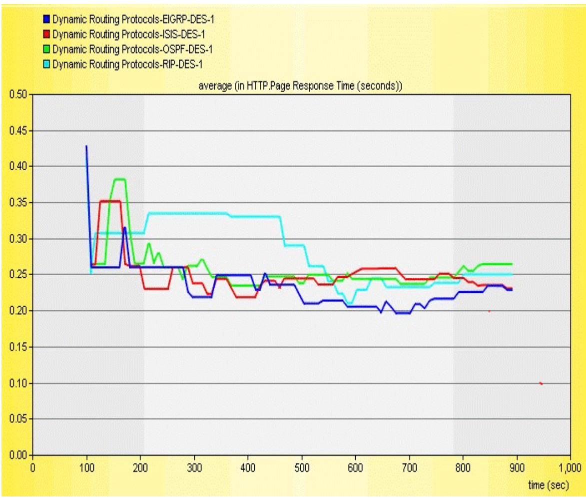
5.1.4. Network convergence

Network convergence is considered one of the most important metrics to investigate the performance of routing protocols. Network convergence implies the length of the time stretches during which converged was on the network's IP forwarding tables has been accomplished. To test the network convergence, network convergence activity was used, network convergence activity records square wave alternating between zero and one. When there is no indication of convergence activity in forwarding tables, network convergence activity records zero and through the time in which there are convergence indication in forwarding tables it records one. Network convergence results are shown in Figure 2(d). The network convergence time for each routing protocol is collected and displayed in Table 2. Obtained results show that EIGRP gives the best network convergence (5.05 sec). Simulation results for the first scenario are collected in Table 3.

From the obtained results, we can conclude that when no changes occurred in network topology, EIGRP performs better in terms of routing HTTP traffic, voice and video packet delay, and network convergence compared to RIP, OSPF, and IS-IS protocol. The reason for that is, EIGRP uses differnet metrics included delay, bandwidth, load, and reliability in making its routing decisions. The EIGRP routing algorithm was created to provide routers with a much better awareness of neighboring routers.

Table 2. Network convergence time

Routing protocol	Network convergence time (sec)
RIP	14.45
EIGRP	5.05
OSPF	13.60
IS-IS	10.50



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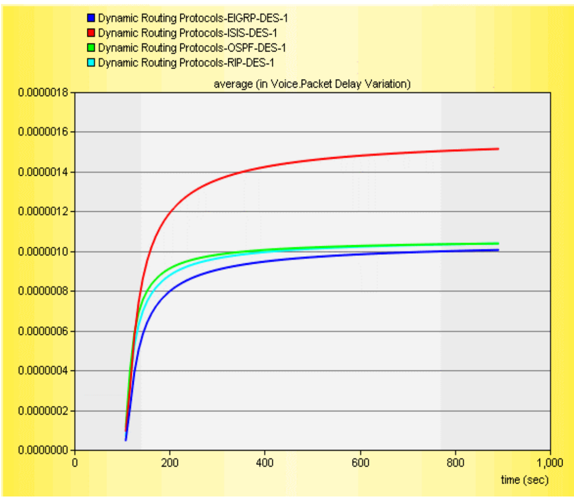

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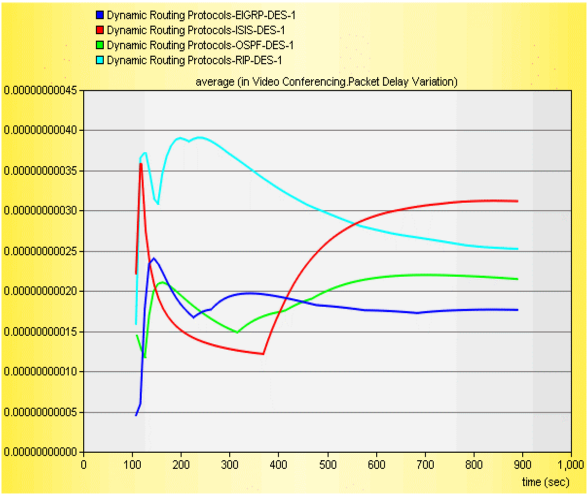

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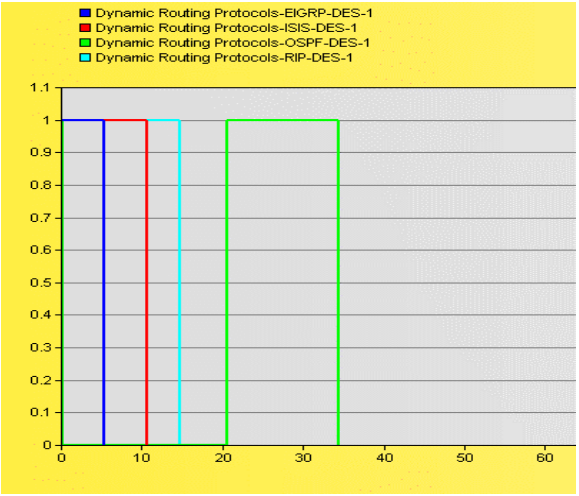


(d)

Figure 2. Simulation results for the first scenario of (a) HTTP page response time, (b) voice delay variation, (c) video delay variation, and (d) network convergence activity

Table 3. Summary of the results obtained for the first scenario

Protocol type	HTTP page response time (m sec)	Voice delay variation (µ sec)	Video delay variation (µ sec)	Network convergence (sec)
RIP	249.9	1.038	0.252	14.45
EIGRP	228.4	1.005	0.176	5.05
OSPF	264.1	1.038	0.214	13.60
IS-IS	232.2	1.514	0.311	10.50

5.2. The second scenario (three routers are failing)

In this scenario, the performance of routing protocols in case of three routers are failed to work suddenly is investigated. We configured this scenario to fail three routers at 200 seconds simulation time to show the performance of routing protocols with this failing. Simulation results are displayed and discussed as follows.

5.2.1. HTTP page response time

To test the performance of web browsing for each routing protocol, the response time of the HTTP page metric is considered in this scenario. After running the simulation for 15 minutes, HTTP page response time results are displayed as shown in Figure 3(a). The results show that the IS-IS is the best routing protocol, which gives the minimum HTTP page response time (307.7 msec).

5.2.2. Voice packet delay variation

To evaluate the performance of the dynamic routing protocols, the variation in voice packet delay is considard in this scenario. Figure 3(b) represents the results of the voice packet delay variation. The results demonstrate that the IS-IS gives the best performance, which satisfies the minimum voice packet delay variation (2.7 µsec) with respect to other routing protocols.

5.2.3. Video packet delay variation

Video packet delay variation metric evaluates the performance of real-time video application for each simulated dynamic routing protocol (RIP, EIGRP, OSPF, and IS-IS). After fifteen minutes of executing the scenario, the obtained results for the video packet delay variation are shown in Figure 3(c). The results show that IS-IS gives the best video packet delay variation (about 3 µsec) concerning other routing protocols.

5.2.4. Network convergence

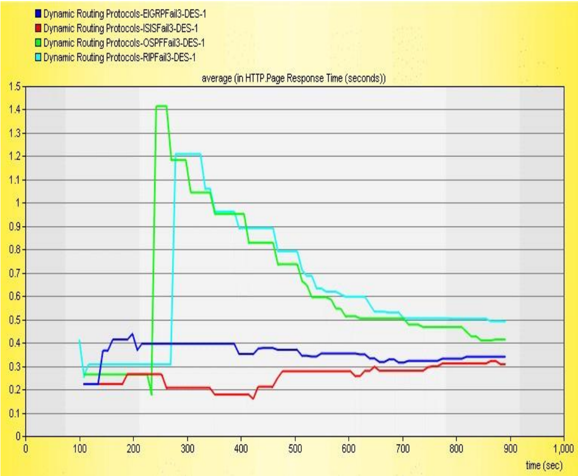
For the dynamic routing protocols that were simulated. The network convergence is evaluated in this scenario by using network convergence activity metric. Simulation result for this metric is presented in Figure 3(d). The results show the network convergence activity after failing three network routers. The results display that the IS-IS gives the best network convergence with the narrowest network activity width after running the simulation and failing three routers at 200 sec simulation time. The summary of the simulation results for the second scenario in case of three routers are failed to work suddenly is collected in Table 4.

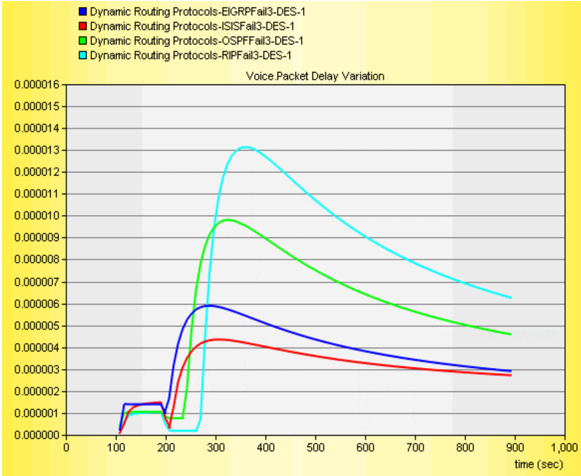
Table 4. Summary of the results obtained for the second scenario (three routers fails)

Protocol type	HTTP page response time (m sec)	Voice delay variation (µ sec)	Video delay variation (µ sec)	Network convergence (sec)
RIP	490.73	6.256	20.149	116
EIGRP	339.71	2.910	9.233	109
OSPF	413.36	4.587	14.300	111
IS-IS	307.74	2.719	3.059	108

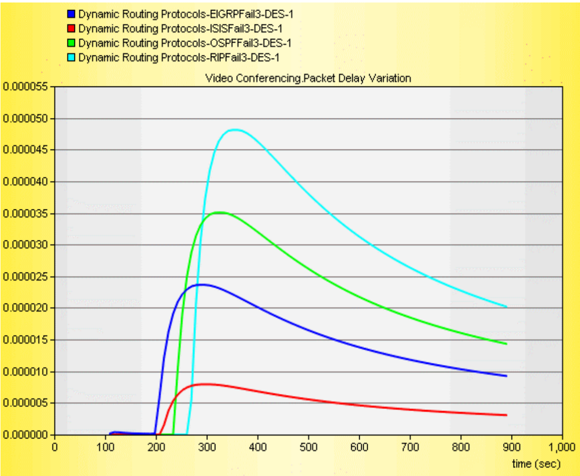
5.2.5. Ping test

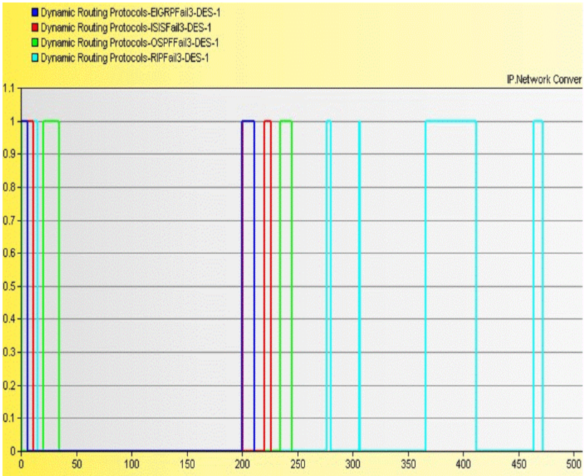
The time taken to send the message from the source to the destination is called ping request time and the time taken to return the message through the network to the source represents the ping response time. Ping packets traveled through the network from workstation 1 to workstation 2. Ping response time results for each routing protocol are displayed in Figure 3(e). The results show that the IS-IS routing protocol satisfies the minimum ping response time, which is (108 msec). The summary of the simulation results for the second scenario in case of three routers are failed to work suddenly. Based on the results, we can conclude that the IS-IS routing protocol operates with the best performance over the large coverage area network in the case of three network routers are failing to work.



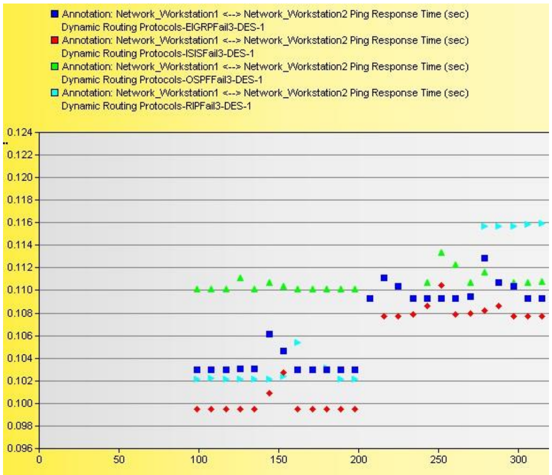


(a) (b)





(c) (d)



(e)

Figure 3. Simulation results for the second scenario of (a) HTTP page response time, (b) voice delay variation, (c) video delay variation, (d) network convergence activity, and (e) ping response time

5.3. The third scenario (seven routers are failing)

In this scenario, we evaluate the performance of routing protocols using different metrics when seven routers are fault to work unexpectedly. This scenario is configured to fail seven network routers at 200 seconds simulation time to show the performance of routing protocols with this failing. Simulation results are displayed and discussed as follows.

5.3.1. HTTP page response time

The HTTP page response time metric is one of the most significant metrics that evaluates web browsing for the simulated routing protocols, therefore this metric is taken into account in this scenario when some network routers fail. After running the simulation, the response time of the HTTP page results are shown in Figure 4(a). From the results, we notice that the IS-IS routing protocol is the best compared with other routing protocols, which gives the minimum HTTP page response time (247.8 msec).

5.3.2. Voice packet delay variation

Using the voice packet delay variation metric, the variation in voice packet delay is taken into account in our simulation. Figure 4(b) represents the results of the voice packet delay variation. From the results, we observe that the IS-IS protocol is the best which gives the minimum voice packet delay variation (4.1 µsec) with respect to other protocols.

5.3.3. Video packet delay variation

Using the video packet delay variation metric, the variance of the end-to-end delays for video packets is taken into account in this scenario. Figure 4(c) shows obtained results for the video packet delay variation for the four tested routing protocols. The results demonstration that the IS-IS protocol offers the best video packet delay variation (8.8 µsec) with respect to other routing protocols.

5.3.4. Network convergence

In this scenario, network convergence activity metric is used to evaluate the performance of routing protocols in the situation that network routers fail. After failing seven of network routers for our proposed network topology, network convergence activity performance for the four tested routing protocols is displayed in Figure 4(d). Obtained results show that the IS-IS provides the best network convergence with the narrowest network activity width after running the simulation and failing seven routers at 200 sec simulation time.

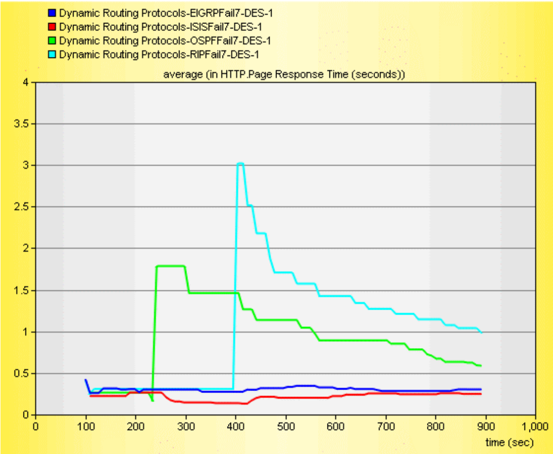
5.3.5. Ping test

Figure 4(e) shows the results of ping response time for each RIP, EIGRP, OSPF, and IS-IS. The results show that the IS-IS routing protocol satisfies the minimum ping response time, which is (115 msec) compared with the other routing protocols. Table 5 summarizes the simulation results obtained for the third scenario in terms of different metrics.

Table 5. Summary of the results achieved for different metrics for the third scenario (seven routers fails)

Protocol type	HTTP page response time (m sec)	Voice delay variation (µ sec)	Video delay variation (µ sec)	Network convergence (sec)
RIP	983.425	9.043	25.811	122
EIGRP	302.170	6.313	19.549	120
OSPF	587.184	5.807	19.493	120
IS-IS	247.801	4.190	8.831	115

After running the simulation with changes in network topology (router failing in the second, and third scenarios), we notice that the IS-IS protocol has the lowest HTTP page response time, the lowest voice and video packet delay and the network convergence is fast with respect to other protocols. The reason for this is that the IS-IS routing protocol distributes topology and IP network information to the closest neighboring routers. When delivering the updates, information is shared using a special protocol known as OSI protocols, which included connection less network protocol (CLNP) and connection less network service (CLNS).



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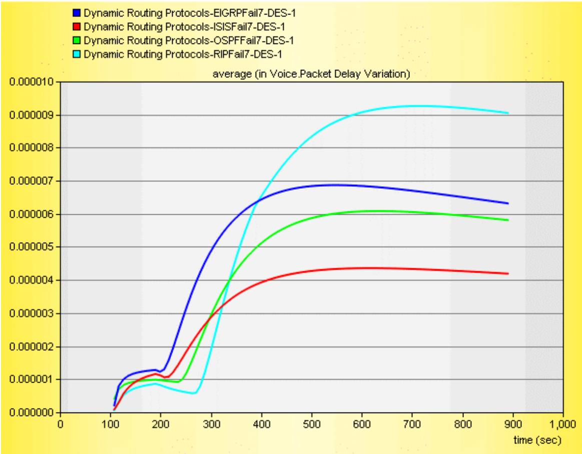

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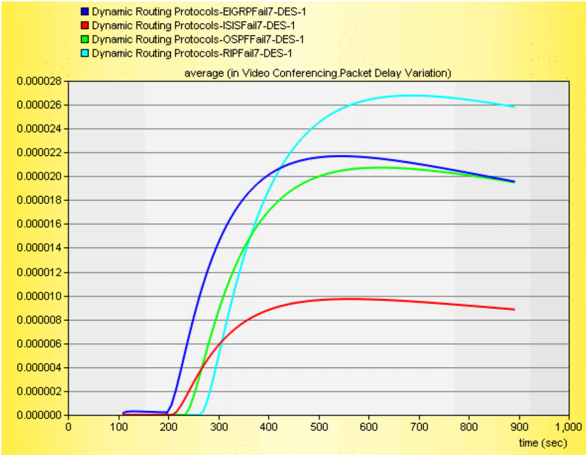

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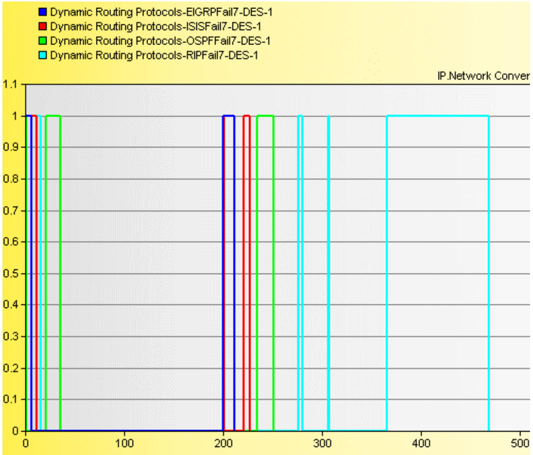

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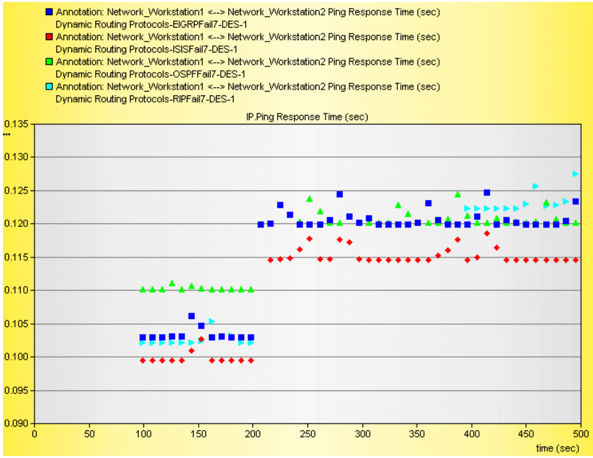

(e)

Figure 4. Simulation results for the third scenario of (a) HTTP page response time, (b) voice delay variation, (c) video delay variation, (d) network convergence activity, and (e) ping response time

6. CONCLUSION

There are many different dynamics and static routing protocols that may be configured on a network, but deciding which one to use is still a challenge. Therefore, it is important and necessary to choose an appropriate routing protocol to work in the network under the worst conditions that may occur to the network. In this paper, distance vector and link-state routing protocols included RIP, EIGRP, OSPF, and IS-IS have been evaluated and investigated over a large coverage network using OPNET 14.5 simulator. The metrics involved this work are response time of the HTTP page, voice and video packet delay variation, speed of network convergence, and ping request and response times. The results show that the EIGRP routing protocol provides the best network performance when all network routers worked without failure. In the other hand, in case any router or link is failure in network topology, we notice that the IS-IS routing protocol was the most effective routing protocols. Therefore, we can conclude that compared with the other routing protocols the link-state IS-IS routing protocol has the best performance over the large coverage area network size, in case there are some routers are failing to work in terms of HTTP page response time (247.8 msec), voice delay variation (4.190 µsec), video delay variation (8.831 µsec) and ping request and response times (115 msec).

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