Performance Evaluation of First Hop Redundancy Protocols in IPv4 and IPv6 Networks

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***Abstract*— To enhance IP network availability, First Hop Redundancy Protocol (FHRP) is a necessary tool that used to achieve this goal. FHRPs are group of protocols that used to manage and maintain network first hop router (i.e. default router) failure. This work compares and evaluates different FHRPs which are Hot Standby Router Protocol (HSRP), Virtual Router Redundancy Protocol (VRRP), and Gateway Load Balancing (GLBP), in both IPv4 and IPv6 networks. The comparison among the three mentioned protocol was accomplished based on convergence time, packet loss and CPU utilization, after implementation, testing and optimization. GNS3 emulation tool was used. The comparison results highlights which protocol performed the best in each scenario and which protocol can be considered as the best among the three FHRPs.**

Keywords— FHRP, VRRP, HSRP, GLBP

I. Introduction

In today's network, availability has a significant importance for enterprises and businesses. Even few minutes of network outage cloud affect the business and cost thousands of dollars. To reduce network outage which means increase uptime, one possible solution is to add redundant links and nodes. Adding additional redundancy is efficient, however, the cost is high. As every business can tolerate downtime differently based on their custom needs, thus no one single solution is able to provide optimal availability for all networks. The availability usually measured as a percent of the ratio between uptime to total time, where total time period could be a year, month, week, day, or hour. If a network is up 165 hours in a week, total time period in hours is 168 hours, weekly availability equals 98.21 percent [1].

In general, availability relates to the network operational time. Availability and reliability both terms are linked to each other, reliability has a more global meaning as it can refer to set of parameters and issues, for instance, accuracy, error rates, stability, and the amount of time between failures, however, availability has a specific meaning which is uptime percent [2].

II. Related work

In 2022, "Performance Evaluation of First Hop Redundancy Protocols IPv6" by M. Mansour [3], focused on the FHRP performance in terms of packet loss and convergence time.

In 2021, "Performance Analysis and Functionality Comparison of First Hop Redundancy Protocols" by M. Mansour [4], studied the effect of different parameters mainly bandwidth consumption, traffic flow, convergence time and CPU utilization.

In a previous study [5], by Imelda et al in 2020, entitled "Performance Analysis of VRRP, HSRP, and GLBP with EIGRP Routing Protocol", a comparison in performance between VRRP, HSRP, and GLBP were introduced, EIGRP routing protocol was applied.

In addition, a previous study [6] in (2019) by A. Zemtsov under the title"Performance Evaluation of First Hop Redundancy Protocols for a Computer Networks of an Industrial Enterprise", were convergence time was the main focus of this study.

Research "Performance Evaluation of First Hop Redundancy Protocols (HSRP, VRRP & GLBP)" [7], by Rahman et al. in 2017, evaluates FHRPs in terms of only one factor, packet loss.

III. First Hop Redundancy Protocols

The group of individual protocols that provide redundancy at the level of first hop, are known as First Hop Redundancy Protocols. The problem is that even if the network has another backup gateway with the capability to take the role of default router gateway, all hosts on this shared network don't know about it, as their configuration includes the IP address of primary router only as default gateway. As a result, network will be down if the primary gateway router fails, as the traffic will not be sent to the backup router. HSRP, VRRP and GLBP are the three main FHRPs, they are used to provide a solution this practically problem [8].

HSRP and VRRP does not support load balancing. However, GLBP can load balance traffic among multiple gateways.

A. Hot Standby Routing Protocol

Hot Standby Routing Protocol (HSRP) was invented by Cisco to provide dynamically failover between routers within HSRP group in case of failure. There are two versions of HSRP, the second version (HSRPv2) was enhanced to support IPv6.

HSRP provides a group of routers known as an HSRP group, work together as a single virtual router from the prospective of the hosts on the local subnet. A single router from the group will be elected as the active router, this election is done based on device priorities. The responsibility of packet forwarding is assigned only to the active router. If the primary router considered down, a standby router within the group will take over packet forwarding duties, this process occurs automatically and independently of users [9].

All routers within hot standby group are considered as one virtual router, with a virtual MAC and IP addresses. Multiple hot standby groups could be configured, each group operates independently [10].

For IPv6 network, HSRPv2 supports also IPv6 network. IPv6 neighbor discovery route advertisement (RA) messages are used so that hosts can learn about available IPv6 routers [11].

In IPv6 network, based on HSRP group number the MAC address of the virtual router is derived, link local address is assigned to virtual router based on virtual MAC [12].

By default, in both IPv4 and IPv6 networks, hello messages are sent every 3 seconds to ensure routers availability. The hold time is 10 seconds, which means that the active router is considered down if the hold time period passed and no hello packets are heard from it. Also the backup router will take over to be in active status. These timers are tunable in order to optimize network performance.

B. *Virtual Router Redundancy Protocol*

Virtual Router Redundancy Protocol (VRRP) is an open standard protocol, designed to provide redundancy dynamically and ensure the default router availability. VRRP and HSRP both follow the same main concept and objective [13].

VRRP provides a group of routers known as a VRRP group, work together as one virtual router from the prospective of the hosts on the local subnet. A single router from VRRP group will be elected as the master router, this election is done based on device priority. Only master router forwards traffic, if the primary router considered down, a backup router will take over packet forwarding duties, this process occurs automatically and independently of users [14].

For IPv6 network, VRRP version 3 (VRRPv3) can provide redundancy for default gateway routers within a LAN. The benefit of implementing VRRPv3 is faster switchover to backup devices that can be achieved using standard IPv6 neighbor discovery mechanisms. With VRRPv3, failover could be achieved in a few seconds with less overhead traffic automatically and no interaction with the hosts is needed. VRRP default timers allow fast convergence, the default value of hello message timer is 1 second, hold timer default value is three times of hello timer.

C. *Gateway Load Balancing Protocol*

Gateway Load Balancing Protocol (GLBP) was invented by Cisco, GLBP can provide load balancing in addition to redundancy functionality to enhance performance. GLBP uses a single virtual IP address but multiple virtual MAC addresses to provide load balancing over multiple gateways [12]. The main difference between GLBP and the previously discussed router redundancy protocols is that all routers within GLBP group contribute to forward packets. GLPB can be applied in both IPv4 and IPv6 networks. Within GLBP group election process based on router priority must be completed in order to elect Active Virtual Gateway (AVG) [15].

By default GLBP timers are similar to HSRP timers, i.e., 3 seconds for hello time and 10 seconds for hold time. Timers are also tunable and could be optimized to obtain minimum convergence time and better performance.

IV. Design and Simulation

In this paper, first hop redundancy protocols are implemented on a network that have three enterprises in different sites, on the first site HSRP is implemented, for the second site VRRP, and for the third site GLBP. The same scenario repeated for IPv4 and IPv6 network. On each site the LAN is connected to two ISPs to ensure high availability and provide redundancy, in incident of a gateway failure the other gateway will take over, to increase network up time and reduce downtime

A. *Simulation Tools*

In this work GNS3 network emulator software was used to implement network scenarios. GNS3 Virtual PC also known as VPC, can generate traffic flow by using ICMP, TCP or UDP data flow. VPCs are used to generate traffic thus we can measure network performance. To simulate network fail over track object is configured. IP SLAs network performance measurement and diagnostics tool is used for active monitoring.

B. *Network Design*

The network designed to have two default gateway routers, each router connected to a different ISP, in LAN side there are two access switches connected to end devices, access switches connected to gateway routers in a partial mesh network topology, the same design is applied to three different enterprises, to provide routing between nodes from different subnets OSPF routing protocol is used, the topology is shown in Fig. 1.

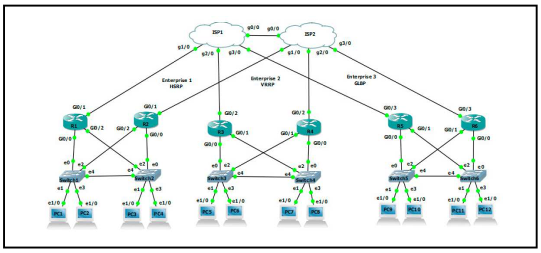

Fig. 1. Network Topology.

As we have two routers at each site, high availably could be achieved by applying one of FHRPs. To eliminate and reduce down time failures need to be detect and verify in a fast way, thus object tracking is used, each router is configured to track an object to ensure connectivity and detect failures, if a failure occurs the track object decrements active/master priority such that standby/backup can take over.

In our design, for enterprises1, 2 and 3, R1, R3, and R5 are configured with higher priority to be elected as active or master, if the priority is equal in two routers, then the tie-breaker is the IP address, where the higher IP address wins.

C. *Configuration*

IP SLA with track object are configured on all routers to monitor ISP connectivity and report results to FHRP router, to allow backup routers to take place in case of primary router is down.

In order to optimize the results and enhance network performance, default timers could be tuned, Hello and Hold time timers will be optimized for HSRP and GLBP in both IPv4 and IPv6 networks, and the results before and after the optimization will be compared, however for VRRP the same timer values are applied, i.e., default timers are used also as optimized values, as VRRP has the best default timer allowing it to converge fast. VRRPv3 can use millisecond timers, as timer value can be between 100 milliseconds and 40000 milliseconds, however using millisecond timers should be applied carefully and only with testing in some specific use cases.

Table. 1 shows FHRP timer values before and after optimization.

TABLE I. SIMULATION PARAMETER

Simulation Parameter	**Value (Seconds)**	
	Default	*Optimized*
HSRP Hello Time	3	1
HSRP Hold Time	10	3
VRRP Hello Time	1	1
VRRP Hold Time	3	3
GLBP Hello Time	3	1
GLBP Hold Time	10	3

Following configuration details for IPv4 and IPv6 use cases:

1) *IPv4 Network:* For enterprise 1, HSRP is configured on R1 and R2 gateway routers.

For enterprise 2, VRRP is configured on R3 and R4 gateway routers.

For enterprise 3 GLBP is configured on R5 and R6.

2) *IPv6 Network:* For enterprise 1, HSRPv2 is configured on R1 and R2 gateway routers.

For enterprise 2, VRRPv3 is configured on R3 and R4 gateway routers.

For enterprise 3 GLBP is configured on R5 and R6.

V. RESULTS

This section presents FHRP performance measurement results of HSRP, VRRP and GLBP in both IPv4 and IPv6 networks, before comparing them in next section.

The measurements are taken in terms of Convergence Time, CPU Utilization and Hello Packet Consumption. As mentioned before in configuration sub-section, FHRP results will be presented before and after optimize timers.

A. *IPv4 network results*

This sub-section presents and discusses the FHRP measurements for IPv4 use case.

1) *HSRP Results*

a) *Convergence Time*

- HSRP convergence time without hello and hold timers' optimization is equal to 7.25 seconds, from failure detection to hand over and change R2 from standby to hot active router (from 01:10:04.243 until 01:10:11.493), meanwhile 4 ICMP packets were lost, as shown in Fig. 2.

- HSRP convergence time with hello and hold timers' optimization is equal to 3.271 seconds, from failure detection to hand over and change R2 from standby to hot active router (from 01:31:12.151 until 01:31:15.422), meanwhile only 1 ICMP packets was lost, as shown in Figure. 3.

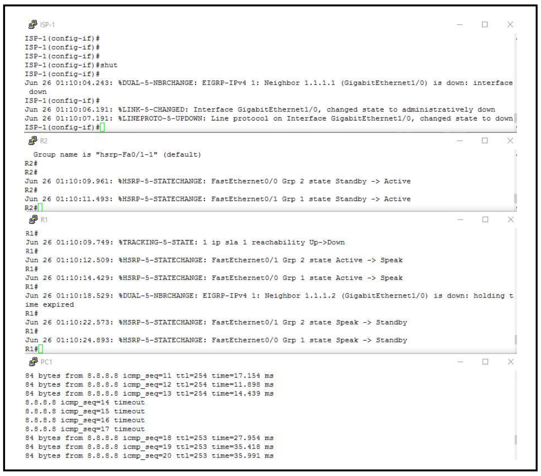

Fig. 2. IPv4 network- HSRP Convergence Time without timers' optimization.

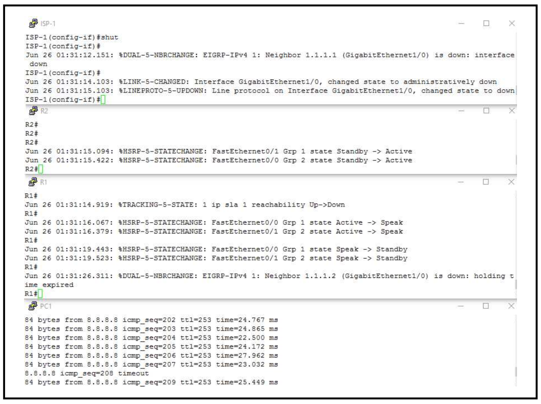

Fig. 3. IPv4 network- HSRP Convergence Time with timers' optimization.

b) *CPU Utilization*

- Without timers' optimization, HSRP average CPU consumption is equal to 15%.
- With timers' optimization, HSRP average CPU consumption is equal to 32%.

2) *VRRP Results*

a) *Convergence Time*

Convergence time is equal to 4.861 seconds, from failure detection to hand over and change R4 from backup to hot master router (from 00:19:28.103 until 00:19:32.964), meanwhile 3 ICMP packets were lost, as shown in Fig . 4.

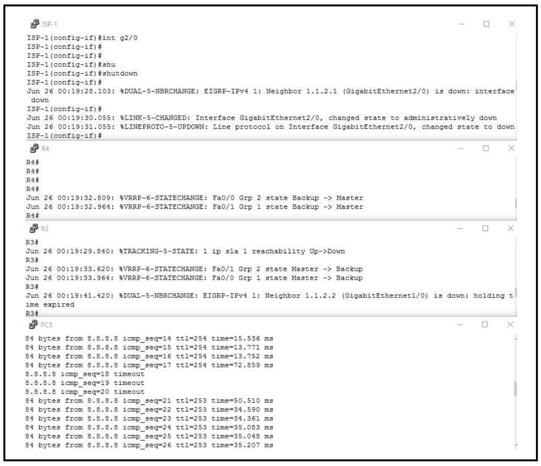

Fig. 4. IPv4 network- VRRP Conversion Time.

b) CPU Utilization

average CPU consumption is equal to 11%.

3) GLBP Results

a) Convergence Time

- GLBP convergence time without hello and hold timers' optimization is equal to 30 seconds, (from 02:37:26.655 until 02:38:05.607), 10 ICMP packets were lost, as shown in Fig. 5.
- GLBP convergence time with hello and hold timers' optimization is equal to 2.372 seconds, (from 00:25:54.411 until 0:25:56.783), no ICMP packets were lost, as shown in Fig. 6.

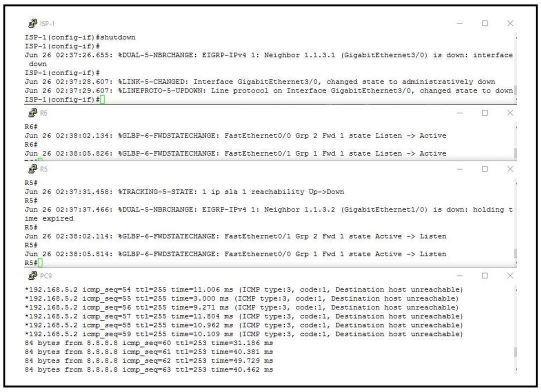

Fig.5. IPv4 network- GLBP Convergence Time without timers' optimization.

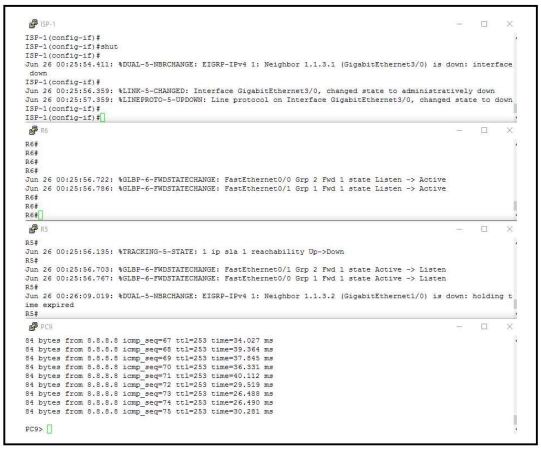

Fig.6 IPv4 network- GLBP Convergence Time with timers' optimization.

b) CPU Utilization

- Without timers' optimization, GLBP average CPU consumption is equal to 13%.
- With timers' optimization, GLBP average CPU consumption is equal to 13%.

B. IPv6 network

This sub-section presents and discusses the FHRP measurements for IPv6 use case.

1) HSRPv2 Results

a) Convergance Time

- HSRPv2 convergence time without hello and hold timers' optimization is equal to 6.177 seconds, from failure detection to hand over and change R2 from standby to hot active router, meanwhile 4 ICMP packets were lost, as shown in Fig. 7.
- HSRPv2 convergence time with hello and hold timers' optimization is equal to 2.94 seconds, from failure detection to hand over and change R2 from standby to hot active router, meanwhile 2 ICMP packets were lost, as shown in Fig. 8.

b) CPU Utilization

- Without timers' optimization, HSRPv2 average CPU consumption is equal to 24.5%.
- With timers' optimization, average CPU consumption is equal to 29%.

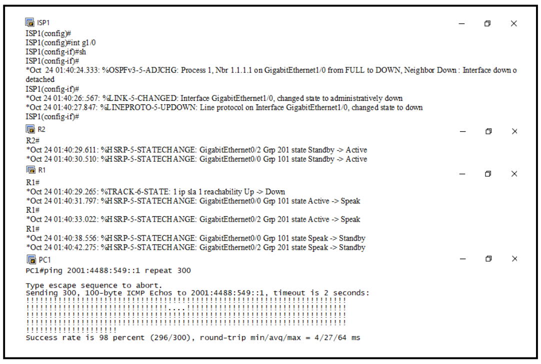

Fig. 7. IPv6 network- HSRP Convergence Time without timers' optimization.

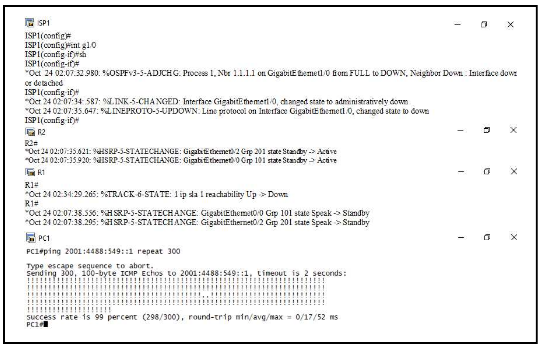

Fig. 8. IPv6 network- HSRP Convergence Time with timers' optimization.

2) *VRRPv3 Results*

a) *Convergance Time*

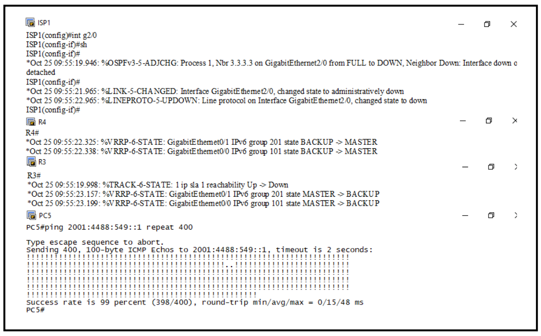

Fig. 9. IPv6 network- VRRP Convergence Time.

Convergence time is equal to 2.392 seconds, from failure detection to hand over and change R4 from backup to master router, meanwhile 2 ICMP packets were lost, as shown in Fig. 9.

b) *CPU Utilization*

VRRPv3 average CPU consumption is equal to 37%.

3) *GLBP Results*

a) *Convergance Time*

- GLBP convergence time without hello and hold timers' optimization is equal to 41 seconds, meanwhile 7 ICMP packets were lost, as shown in Fig. 10.

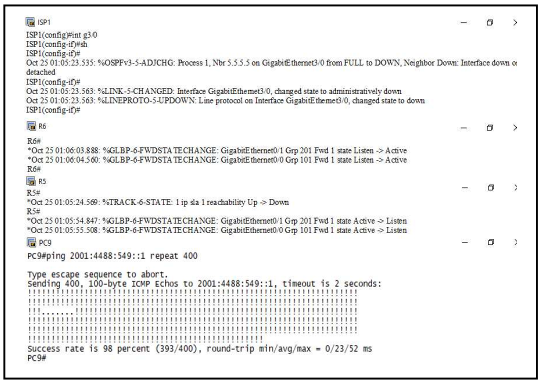

Fig. 10. IPv6 network- GLBP Convergence Time without timers' optimization

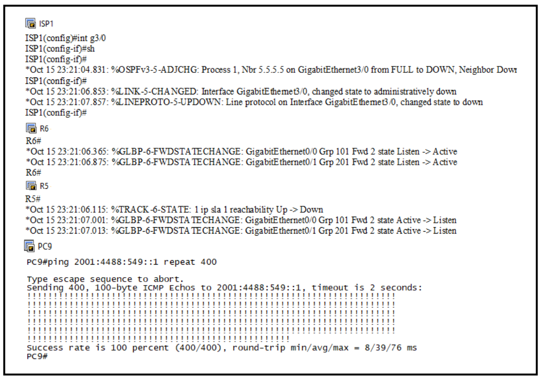

Fig. 11 GLBP IPv6 network- GLBP Convergence Time with timers' optimization

- GLBP Convergence time with hello and hold timers' optimization is equal to 2.044 seconds, meanwhile no ICMP packets were lost, as shown in Fig. 11.

b) *CPU Utilization*

- Without timers' optimization, GLBP average CPU consumption is equal to 25.5% of CPU usage.
- With timers' optimization, HSRPv2 average CPU consumption is equal to 25% of CPU usage.

VI. COMPARISION AND EVALUATION

This section evaluates FHRP results for both IPv4 and IPv6, to highlight which protocol is the best in each scenario and which could be considered as the best in general, comparison parameters are convergence time, packet loss and CPU utilization.

A) Convergence Time Comparison

1) *IPv4 network*

Although without optimization GLBP had the worst convergence time, after optimization GLBP has the best convergence time at 2.372 seconds compared to HSRP and VRRP at 3.271 at 4.861 seconds.

2) *IPv6 network*

We can see from Fig. 12 that GLBP has the best convergence time results at 2.044 seconds when optimized. Also VRRP with default timers has the second better convergence time at 2.392 seconds.

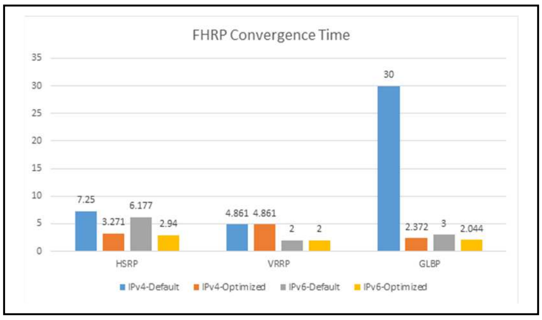

Fig. 12. FHRP Convergence Time Comparison.

B) Packets Loss Comparison

1) *IPv4 network*

During convergence, for HSRP 4 packets were lost before optimization and only 1 packet was lost with optimization, in case of VRRP 3 packets were lost, and for GLBP with default timers 30 packets were lost however, zero packet loss was achieved after optimization .

GLBP after optimization has the best performance in terms of packet loss.

2) *IPv6 network*

During convergence, for HSRP 4 packets were lost before optimization and 2 packets were lost with optimization, in case of VRRP 2 packets were lost, and for GLBP with default timers 7 packets were lost however, zero packet loss was achieved after optimization.

GLBP after optimization performed the best, and achieved the lowest packet loss. As the protocol uses load balancing which gives higher availability.

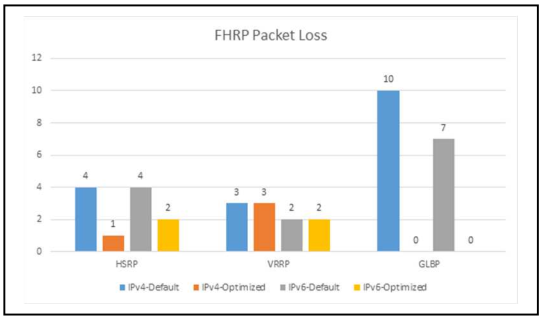

Fig. 13. FHRP Packet Loss Comparison.

C) CPU Utilization Comparison

1) IPv4 network

Fig. 14 shows the percentage of CPU Utilization results in all scenarios. It could be seen that VRRP has the best CPU utilization, next comes GLBP.

2) IPv6 network

Fig. 14 shows that VRRP CPU consumption is the higher among the three protocols, because its timers by default advertise packets every 1000msec, so it could be concluded that VRRP has the worst CPU utilization. On the other hand after optimization GLBP performed the best in terms of CPU utilization, as it supports load sharing among gateways.

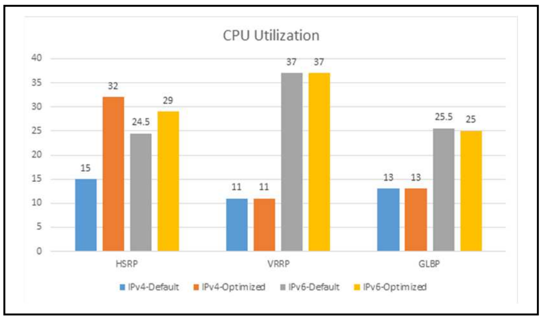

Fig. 14. FHRP CPU Utilization.

D) Overall performance comparison

Following table summarize FHRP performance comparison:

TABLE II. FHRP PERFORMANCE COMPARISON

FHRP	Measurement	Network			
		IPv4		*IPv6*	
		Default	*Optimized*	*Default*	*Optimized*
HSRP	Convergence Time	7.25	3.271	6.177	2.94
	Packet Loss	4	1	4	2
	CPU Usage	15	32	24.5	29
VRRP*	*Convergence Time*	4.861	4.861	2.392	2.392
	Packet Loss	3	3	2	2
	CPU Usage	11	11	37	37
GLBP	*Convergence Time*	30	2.372	41	2.044
	Packet Loss	10	0	7	0
	CPU Usage	13	13	25.5	25

*In VRRP default and optimized results are equal, due to using the same timer values

Note that for the table above Convergence Time measured by seconds, Packet Loss by ICMP packet and CPU Usage as a percentage of usage.

It could be seen that GLBP after timers optimization has the best convergence time and the lower number of packet loss among all protocols in both IPv4 and IPv6 networks.

VII. Conclusion

HSRP, VRRP and GLBP all three protocols has the same main objective which is provide high availably and reduce downtime in a dynamically way, however network performance vary based on the applied protocol. Three important factors which are convergence time, packets loss and CPU utilization were measured in both IPv4 and IPv6 network to evaluate the protocols. As a result it could be seen that GLBP has performed the best for IPv4 and also IPv6. In IPv4, HSRP with optimized timers archived few number of packet loss but the cost was higher CPU consumption, i.e., tradeoff between reducing packet loss and CPU utilization. In IPv6 VRRPv3 has the ability to switch fast during failures, thus convergence time and packet lost can be reduced, however GLBP presents better results with zero packet loss, due to load balancing feature. The main disadvantage in GLBP that it is a Cisco proprietary, but in terms of performance GLBP results with optimized timers could be considered as the best among the three mentioned protocols.

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