Redundancy In Networks

An Analysis of Various FHRP Protocols

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***Abstract*—This paper presents a comparative study of three gateway redundancy protocols, namely HSRP, VRRP, and GLBP, using GNS3 simulations. The objective is to analyze how each protocol provides fault tolerance, load sharing, and failover performance in an enterprise LAN environment. Three separate topologies were designed to test each protocol individually, followed by an integrated topology that combines all three. Key parameters such as convergence time, load-balancing behavior, and protocol priority were observed. Results indicate that HSRP and VRRP offer simple and stable failover, while GLBP additionally provides active load sharing. The combined topology demonstrates how mixed redundancy solutions can coexist in multi-router networks. The paper concludes with recommendations for protocol selection based on network requirements.**

I. Introduction

Modern computer networks require high availability to ensure uninterrupted communication between devices. A common single point of failure in LANs is the default gateway. To prevent this, networks use First Hop Redundancy Protocols (FHRPs), which include Hot Standby Router Protocol (HSRP), Virtual Router Redundancy Protocol (VRRP), and Gateway Load Balancing Protocol (GLBP).

This project evaluates these three protocols through GNS3 simulations. We configure and test each protocol independently and then design a combined topology to observe coexistence behavior. The goal is to compare performance, understand protocol differences, and identify the best use cases for each.

II. Background

In largely popular statically routed enterprise networks with dynamic host configuration protocols, the dependence on a single router creates a single point of failure. Loss of the default router isolates all end devices within the network that are unable to reach alternate paths [1]. The general solution being approached is First Hop Redundancy Protocols, which serve to remove dependency on a single pathway for the connection of end devices with a network [2]. The primary purpose of this protocol was to facilitate Ethernet as well as Token Ring networks [3]. Of these protocols, the most widely adopted is the Virtual Router Redundancy Protocol (VRRP) because of its ease of configuration [4]. Other FHRP protocols include Hot Standby Router Protcol (HSRP) [5] and Gateway Load Balancing Protocol (GLBP) [6].

Scholarly research has worked on the evaluation of FHRP protocols in isolation. [6] evaluated GLBP failover behavior and concluded that its introduced redundancy sufficiently reduces single-point bottlenecks. [7] explores the simulation of GLBP and HSRP protocols in OMNeT++ discrete-event simulator to validate behavior under controlled conditions. Evaluation of VRRP in [8] highlights the increased network stability and efficient load balancing provided with this protocol. All explored research evaluates performance based on key parameters such as convergence time, failover reliability, protocol overhead, and load balancing efficiency, which is also an approach used in this paper.

III. Methodology

This study compares the performance of HSRP, VRRP, and GLBP in small network topologies, focusing on failover time, packet loss, and load balancing under simulated link failures. All experiments were conducted in GNS3 Simulator where separate network topologies were built for HSRP, VRRP, and GLBP, each with routers, switches, and host PCs. Traffic between hosts was tested using continuous ping commands. Failures were simulated by disconnecting router links in GNS3, and protocol behavior was monitored through 'Wireshark' and failed ping commands helped in measuring packet loss.

For HSRP, four PCs belonging to two different VLANs were connected to 2 routers via a single switch; the routers were configured with HSRP to provide redundancy for the host, and although both routers supported both VLANs, one router had a higher priority for one VLAN while the other router had a higher priority for the other VLAN.

For VRRP, two routers were each connected to separate switches, which were then interconnected, with two host PCs connected to the switches; VRRP provided a virtual gateway for the hosts.

For GLBP, three routers were used, where two routers connected to a switch and the third connected to one of the routers, while two host PCs were connected to the switch; GLBP provided load-balanced redundancy across the routers.

A. Hot Standby Routing Protocol

HSRP, or the Hot Standby Router Protocol, is a Cisco-proprietary First Hop Redundancy Protocol (FHRP) designed to provide network devices with a resilient and highly available default gateway. In any network, if the primary router fails, all traffic destined outside the local subnet is halted. HSRP solves this by allowing two or more routers to function as a single logical entity, sharing one Virtual IP Address (VIP) and one Virtual MAC Address [5]. One router is designated the Active router, which handles all traffic for the VIP, while the other is the Standby router, which constantly monitors the Active router via multicast Hello packets. If the Active router fails, the Standby router takes over the VIP and Virtual MAC address, ensuring client devices experience minimal disruption and continue communicating without any configuration changes. Advanced deployments, known as Multi-Group HSRP (MHSRP), allow routers to be Active for different VLANs simultaneously, providing both redundancy and efficient load sharing across the infrastructure. The network topology used is:

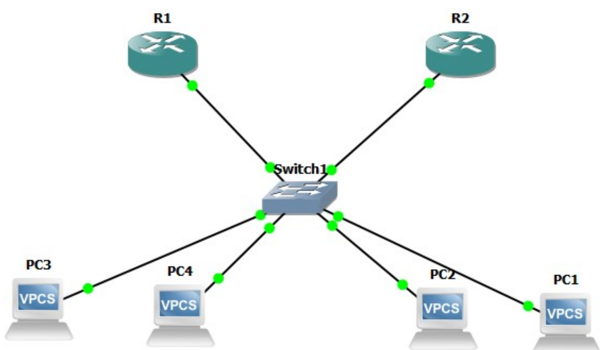
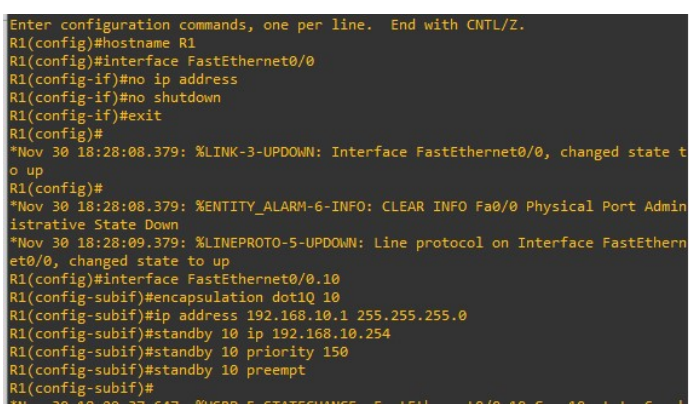


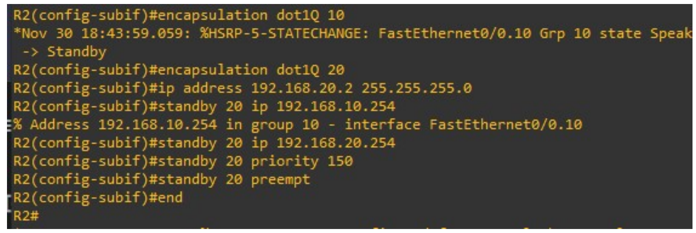
Fig. 1. HSRP GNS3 Network Topology

In this topology, the single switch carries both VLAN 10 and VLAN 20 traffic via trunk ports to the routers. R1 is configured as the Active gateway for VLAN 10, while R2 is Active for VLAN 20, efficiently balancing the traffic load . All client PCs use a Virtual IP (VIP) as their default gateway. If the primary router for a VLAN fails, the standby router immediately takes over the VIP and Virtual MAC address, ensuring traffic routing continues with minimal disruption, proving the network is resilient. The configuration for the Active VLANs on each router can be seen below:



```
Enter configuration commands, one per line.  End with CNTL/Z.
R1(config)#hostname R1
R1(config)#interface FastEthernet0/0
R1(config-if)#no ip address
R1(config-if)#no shutdown
R1(config-if)#exit
R1(config)#
*Nov 30 18:28:08.379: %LINK-3-UPDOWN: Interface FastEthernet0/0, changed state t
o up
R1(config)#
*Nov 30 18:28:08.379: %ENTITY_ALARM-6-INFO: CLEAR INFO Fa0/0 Physical Port Admin
istrative State Down
*Nov 30 18:28:09.379: %LINEPROTO-5-UPDOWN: Line protocol on Interface FastEthern
et0/0, changed state to up
R1(config)#interface FastEthernet0/0.10
R1(config-subif)#encapsulation dot1Q 10
R1(config-subif)#ip address 192.168.10.1 255.255.255.0
R1(config-subif)#standby 10 ip 192.168.10.254
R1(config-subif)#standby 10 priority 150
R1(config-subif)#standby 10 preempt
R1(config-subif)#
```

Fig. 2. Configuration Commands for Setup



```
R2(config-subif)#encapsulation dot1Q 10
*Nov 30 18:43:59.059: %HSRP-5-STATECHANGE: FastEthernet0/0.10 Grp 10 state Speak
 -> Standby
R2(config-subif)#encapsulation dot1Q 20
R2(config-subif)#ip address 192.168.20.2 255.255.255.0
R2(config-subif)#standby 20 ip 192.168.10.254
% Address 192.168.10.254 in group 10 - interface FastEthernet0/0.10
R2(config-subif)#standby 20 ip 192.168.20.254
R2(config-subif)#standby 20 priority 150
R2(config-subif)#standby 20 preempt
R2(config-subif)#end
R2#
```

Fig. 3. Configuration Commands for Setup

HSRP is a critical routing protocol because it provides transparent and rapid network resilience at the access layer, directly addressing the single most common point of failure: the default gateway.

- Continuous Connectivity: Uses a Virtual IP (VIP) so clients never lose their gateway, ensuring business operations continue during a failure .
- Efficient Load Sharing: Protocols like MHSRP allow multiple routers to forward traffic simultaneously, maximizing the use of expensive hardware.
- Rapid Failover: The Standby router quickly takes over the VIP and traffic handling, minimizing service disruption time.
- Simple Management: Easy to implement with minimal configuration changes required on the end-user devices.

Hence, through this we can see that HSRP transforms a fragile single-gateway setup into a robust, redundant, and highly efficient network edge.

B. Virtual Router Redundancy Protocol

VRRP involves the grouping of redundant routers under a virtual router with a unique personal IP address. This virtual router replaces the original single router as the default gateway of all end devices within the network. Instead of sending traffic to an individual router, host devices send it to the virtual router address, and it is the protocol that determines the pathway that may be used depending on the availability of routers and their priority. It is the master router that is the preferred traffic pathway and only if it goes down does the backup router begin work. If the master router were to come back up at any point, it regains control of traffic in the network [7].

To minimize network traffic, only the master for each virtual router sends periodic VRRP Advertisement messages. A backup router will not attempt to preempt the master unless it has higher priority. This eliminates service disruption unless a more preferred path becomes available. VRRP failure detection operates by monitoring periodic advertisement packets sent by the master router to the multicast group 224.0.0.18.

The network topology used is as follows:

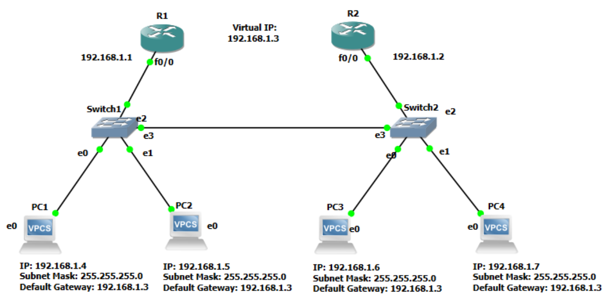


Fig. 4. VRRP GNS3 Network Topology

In this topology R1 and R2 are configured with VRRP to share the virtual IP 192.168.1.3, which serves as the default gateway for all PCs (PC1–PC4). The configuration is done on their console:

```
Router1(config)#int fa0/0
Router1(config-if)#vrrp 1 ip 192.168.1.3
Router1(config-if)#
*Nov 30 15:50:49.923: %VRRP-6-STATECHANGE: Fa0/0 Grp 1 state Init -> Backup
*Nov 30 15:50:49.943: %VRRP-6-STATECHANGE: Fa0/0 Grp 1 state Backup -> Init
*Nov 30 15:50:49.943: %VRRP-6-STATECHANGE: Fa0/0 Grp 1 state Init -> Backup
Router1(config-if)#
*Nov 30 15:50:53.555: %VRRP-6-STATECHANGE: Fa0/0 Grp 1 state Backup -> Master
Router1(config-if)#do show vrrp
FastEthernet0/0 - Group 1
  State is Master
  Virtual IP address is 192.168.1.3
  Virtual MAC address is 0000.5e00.0101
  Advertisement interval is 1.000 sec
  Preemption enabled
  Priority is 100
  Master Router is 192.168.1.1 (local), priority is 100
  Master Advertisement interval is 1.000 sec
  Master Down interval is 3.609 sec
```

Fig. 5. Configuration Commands for Setup

R1, having the higher priority, initially assumes the Master role and handles all traffic to the virtual IP. R2 operates as the Backup router, monitoring the Master's status through periodic VRRP advertisement messages. Key VRRP parameters observed in this setup include:

- Priority values: Determines which router becomes Master.
- Advertisement interval: Time between VRRP announcements, impacting failover speed.
- Convergence time: Time taken for Backup to assume Master role after failure.

During testing, both routers were assigned a priority value of 100, making the IP address the basis for selection of master and backup. VRRP advertisements were observed to be sent at a regular interval of approximately one advertisement per second, consistent with the default VRRP timer. It was observed that the backup router assumed the master role after 0.67 seconds of advertisement loss, matching the standard VRRP timing behavior described in [4]. This topology demonstrates VRRP's ability to provide high availability, maintain network stability, and ensure minimal disruption for hosts during router failures.

C. Gateway Load Balancing Protocol

GLBP provides both redundancy and load balancing for default gateway services. Unlike HSRP and VRRP that rely on a single active router, GLBP allows multiple routers to forward traffic simultaneously and assigns a virtual IP to the virtual gateway that is shared among all the routers. GLBP selects one router as the Active Virtual Gateway (AVG) - responsible for assigning virtual MAC addresses to each router; while others become Active Virtual Forwarders (AVF) - participate in forwarding traffic. This allows GLBP to distribute traffic across multiple routers eventually improving throughput. In case a router goes down, there is already a backup router that takes over. The network topology used is as follows:

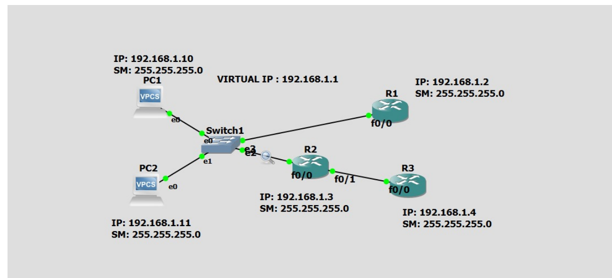


Fig. 6. GLBP GNS3 Network Topology

This topology uses R1 as the AVG whereas R2 is the AVF as well as the standby router. This hierarchy is determined through assigning priorities to the routers which allows them to step in as the main router. The *show glbp* command shows how GLBP behaves:

```
R1
FastEthernet0/0 - Group 1
  State is Active
    6 state changes, last state change 03:35:08
  Virtual IP address is 192.168.1.1
  Hello time 3 sec, hold time 10 sec
    Next hello sent in 2.556 secs
  Redirect time 600 sec, forwarder time-out 14400 sec
  Preemption enabled, min delay 0 sec
  Active is local
  Standby is 192.168.1.3, priority 100 (expires in 9.080 sec)
  Priority 120 (configured)
  Weighting 100 (default 100), thresholds: lower 1, upper 100
  Load balancing: round-robin
  Group members:
    ca01.2bfc.0000 (192.168.1.2) local
    ca03.281c.0008 (192.168.1.3)
  There are 3 forwarders (1 active)
  Forwarder 1
    State is Active
      5 state changes, last state change 03:34:40
    MAC address is 0007.b400.0101 (default)
    Owner ID is ca01.2bfc.0000
    Redirection enabled
```

Fig. 7. Configuration Commands for R1

```
R2
FastEthernet0/0 - Group 1
  State is Standby
    140 state changes, last state change 00:27:01
  Virtual IP address is 192.168.1.1
  Hello time 3 sec, hold time 10 sec
    Next hello sent in 1.124 secs
  Redirect time 600 sec, forwarder time-out 14400 sec
  Preemption enabled, min delay 0 sec
  Active is 192.168.1.2, priority 120 (expires in 8.644 sec)
  Standby is local
  Priority 100 (default)
  Weighting 100 (default 100), thresholds: lower 1, upper 100
  Load balancing: round-robin
  Group members:
    ca01.2bfc.0000 (192.168.1.2)
    ca03.281c.0008 (192.168.1.3) local
  There are 3 forwarders (2 active)
  Forwarder 1
    State is Listen
      112 state changes, last state change 00:27:11
    MAC address is 0007.b400.0101 (learnt)
    Owner ID is ca01.2bfc.0000
    Time to live: 14398.644 sec (maximum 14400 sec)
```

Fig. 8. Configuration Commands for R2

On R1, the router is in the *Active State* indicating that it acts as AVG with the highest priority of 120, allowing it to assign MAC addresses and balance loads. On R2, the router is in the *Standby State* with a lower priority of 100. This indicates that R2 acts as a Standy Virtual Gateway in case R1 fails. Despite being standby it still participates in forwarding traffic as an AVF.

This demonstrates GLBPs ability to provide both redundancy and dynamic load distribution across multiple gateways.

D. All Three FHRP in One

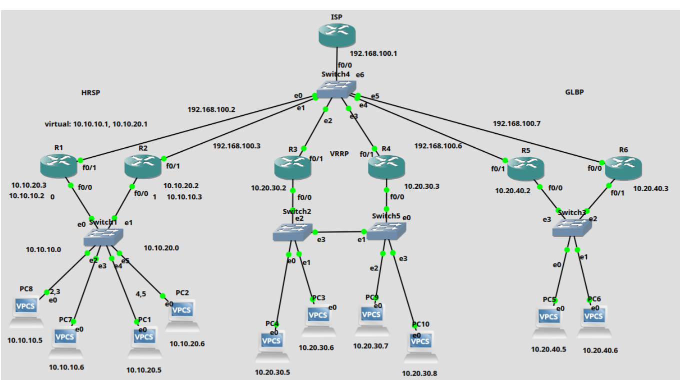


Fig. 9. Network Topology

After testing all three First Hop Redundancy Protocols on three different network topologies, we then integrated all of them together in one big network. This network topology simulates a real world enterprise network where different branches use different protocols based on its requirements. Each FHRP is implemented in a separate zone.

In the above network topology, HSRP is configured on routers 1 and 2 along with two VLANS. VRRP is configured on routers 3 and 4, and GLBP on routers 5 and 6. All of these routers are then connected to one switch, which connects everything to an above ISP router. All of the devices use IPv4 addressing protocol.

```
R1#show standby
FastEthernet0/0.10 - Group 10
  State is Active
    2 state changes, last state change 02:02:26
  Virtual IP address is 10.10.10.1
  Active virtual MAC address is 0000.0c07.ac0a
    Local virtual MAC address is 0000.0c07.ac0a (v1 default)
  Hello time 3 sec, hold time 10 sec
    Next hello sent in 0.132 secs
  Preemption enabled
  Active router is local
  Standby router is unknown
  Priority 100 (default 100)
  IP redundancy name is "hsrp-Fa0/0.10-10" (default)
FastEthernet0/0.20 - Group 20
  State is Standby
    4 state changes, last state change 01:52:38
  Virtual IP address is 10.10.20.1
  Active virtual MAC address is 0000.0c07.ac14
    Local virtual MAC address is 0000.0c07.ac14 (v1 default)
  Hello time 3 sec, hold time 10 sec
    Next hello sent in 0.888 secs
  Preemption enabled
  Active router is 10.10.20.2, priority 110 (expires in 9.892 sec)
  Standby router is local
  Priority 100 (default 100)
  IP redundancy name is "hsrp-Fa0/0.20-20" (default)
```

Fig. 10. HSRP on R1

```
R3#show vrrp
FastEthernet0/0 - Group 10
  State is Master
  Virtual IP address is 10.20.30.1
  Virtual MAC address is 0000.5e00.010a
  Advertisement interval is 1.000 sec
  Preemption enabled
  Priority is 110
  Master Router is 10.20.30.2 (local), priority is 110
  Master Advertisement interval is 1.000 sec
  Master Down interval is 3.570 sec
```

Fig. 11. VRRP on R3

```
R5#show glbp
FastEthernet0/0 - Group 10
  State is Active
    2 state changes, last state change 01:28:10
  Virtual IP address is 10.20.40.1
  Hello time 3 sec, hold time 10 sec
    Next hello sent in 1.184 secs
  Redirect time 600 sec, forwarder time-out 14400 sec
  Preemption enabled, min delay 0 sec
  Active is local
  Standby is 10.20.40.3, priority 100 (expires in 8.212 sec)
  Priority 120 (configured)
  Weighting 100 (default 100), thresholds: lower 1, upper 100
  Load balancing: round-robin
  Group members:
    ca05.34de.0008 (10.20.40.2) local
    ca06.34fc.0006 (10.20.40.3)
  There are 2 forwarders (1 active)
  Forwarder 1
    State is Active
      1 state change, last state change 01:28:00
    MAC address is 0007.b400.0a01 (default)
    Owner ID is ca05.34de.0008
    Redirection enabled
    Preemption enabled, min delay 30 sec
    Active is local, weighting 100
  Forwarder 2
    State is Listen
    MAC address is 0007.b400.0a02 (learnt)
    Owner ID is ca06.34fc.0006
    Redirection enabled, 597.524 sec remaining (maximum 600 sec)
    Time to live: 14397.360 sec (maximum 14400 sec)
    Preemption enabled, min delay 30 sec
    Active is 10.20.40.3 (primary), weighting 100 (expires in 9.704 sec)
```

Fig. 12. GLBP on R5

Figures 11, 12, and 13 show the different protocols configured on their respective routers.

IV. Discussion of Results

After testing HRSP, VRRP, and GLDP, it was observed that VRRP had faster convergence than the other two due to its shorter advertisement timers, enabling backup routers to take over the master role quickly. GLBP came out to be slightly slower to converge but offers the benefit of load-balancing and allowing traffic to be distributed across routers, efficiently utilizing the network. HRSP on the other hand is simple and reliable, providing consistent gateway redundancy but does not provide traffic load balancing like GLDP, as it operates in an active-standby mode. The comparision is provided in the table below.

Protocol	Convergence Time	Failover Reliability	Protocol Overhead
HRSP	1s	High	Low
VRRP	0.67s	High	Low
GLDP	1.07s	Very High	Moderate

V. Conclusion

This paper successfully tested the three First Hop Redundancy Protocols: HSRP, VRRP, and GLDP. It began by discussing the testing and simulation of all three on separate network topologies. These three topologies were then integrated into one large network, simulating a real world enterprise. Lastly, it compared each protocol, and how each presents distinct trade-offs between failover speed, redundancy, and traffic distribution.

References

[1] J. Pavlik, A. Komarek, V. Sobeslav and J. Horalek, "Gateway redundancy protocols," 2014 IEEE 15th International Symposium on Computational Intelligence and Informatics (CINTI), Budapest, Hungary, 2014, pp. 459-464, doi: 10.1109/CINTI.2014.7028719.

[2] P. S. Mane and S. P. Dandale, "Simulation and Analysis of Gateway Redundancy Protocols using GNS3,"IJARCSSE, vol. 6, no. 4, pp. 245–249, 2016.

[3] R. F. Alshehri, First Hop Redundancy Protocols (FHRP), M.S. thesis, Dept. of Computer Engineering and Sciences, Florida Institute of Technology, Melbourne, FL, USA, 2019. [Online]. Available: https://repository.fit.edu/etd/700.

[4] R. Hinden, "Virtual Router Redundancy Protocol (VRRP)," Request for Comments 3768, Internet Engineering Task Force (IETF), Apr. 2004. [Online]. Available: https://www.rfc-editor.org/rfc/rfc3768.

[5] T. Li, B. Cole, P. Morton, and D. Li, "Cisco Hot Standby Router Protocol (HSRP)," Request for Comments 2281, Internet Engineering Task Force (IETF), Mar. 1998. [Online]. Available: https://www.rfceditor.org/rfc/rfc2281.

[6] T. S. D. N. B. Mira and F. Hariadi, "Failover Performance Analysis on Redundancy Link using Gateway Load Balancing Protocol," Universitas Kristen Wira Wacana Sumba, Indonesia.

[7] V. Veselý, J. Holuša, and O. Ryšavý, "First-hop redundancy protocols in OMNeT++: A new FHRP available in ANSAINET," Faculty of Information Technology, Brno University of Technology, Brno, Czech Republic.

[8] P.Rajamohan, "An Overview of Virtual Router Redundancy Protocol Techniques and Implementation for Enterprise Networks," International Journal of Innovative Science, Engineering and Technology (IJISET), vol. 1, no. 9, pp. 62–65, Nov. 2014.