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Evaluation of virtual routing appliances as routers virtual environment

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Evaluation of Virtual Routing Appliances as routers in a virtual environment

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Abstract:

A virtual routing appliance is a system for the rapid, automated management and employment of virtual networks. Virtual routing appliances utilize virtual machines to enable virtual infrastructure, and they have been used commonly in order to implement experimental networks and devoted subnets over a virtual network. Existing research in this area such as cluster-based virtual routers, and Xen routers require the use of physical resources to establish connectivity and to guarantee efficient resource utilization. The virtual routing appliance uses dynamic routing protocols such as RIP, and OSPF to forward traffic between different subnets and manage IP packets at the IP layer. The virtual routing appliance permits rapidly deployable virtual infrastructure, which is helpful for installing isolated infrastructure for restricted purposes, and which is also vital to the deployment of both network and application services. This research is a self-sufficient initiative to evaluate the feasibility of setting up virtual routing appliances in a virtual environment. A virtual routing appliance can convey about substantial cost benefits to organizations, especially educational institutions with limited use of physical resources.

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1. Introduction:

Routing is one of the most significant aspects in modern computer networks that need to connect with other networks. It is also the most complicated function of a network. Routing is utilized for sending a packet from one machine and taking it via the network to another machine on a different network. This routing functionality can be accomplished by using a router. Routing is no longer the function of just standalone routers; however, routing can be achieved by computers. The combination of virtual routing functionally that is running on top of computer operating systems will make it possible to have a virtual router.

Whether using physical or virtual environment, routing protocols must be configured in order to make the connection successfully happen. There are various routing protocols in the area of computer networks. The Routing Information Protocol or RIP is one of the oldest and most important routing protocols. It uses distance-vector algorithms to calculate routes. Another routing protocol which uses more factors for routing decision is called Interior Open Shortest Path First (OSPF). This protocol was proposed particularly as an IP routing protocol for use within autonomous systems. It computes routes based on the destination IP address found in IP datagram headers.

The primary concern for a virtual routing appliance is forwarding network traffic from one interface to another based on routing metrics, a latency induces bottleneck in the virtual network, and the ability to monitor all network devices and generate traffic polls. Analyzing virtual routing appliances entails performance analysis in the following areas:

- *Routing Capabilities (functionalities):* Building a comprehensive virtual routing appliance require some kinds of functions that perform and use routing protocols such as RIP, and OSPF. Free software is available online that has the ability to support routing functionality. One of these applications is called GNU Zebra which can route packets at a faster rate than with traditional software. GNU Zebra is powerful free software that maintains TCP/IP based routing protocols.

- *Latency:* A virtual routing appliance is required to capture all network traffic traversing on the different network segments. This operation is significant to keep track of packets in a virtual environment and can induce latency or delay in the path of the packet. The ability of a virtual routing appliance to determine paths in real time at wire speed and in a virtual environment using VMware is a critical factor in the choice of a routing protocol. My experiments will have to be benchmarked for latency measured either as one way delays (OWD) or round trip time (RTT)
- *Throughput:* Nagios is an open source application that is used to monitor networks. It warns and watches hosts across the network and alerts an administrator in case suspicious events occur and when those events come back to the normal status. This tool will be greatly helpful in this research because Nagios monitors various network services such as SMTP, ICMP, SNMP and others. Throughput is vital factor in a testing environment. SNMP agents are

mainly deployed in the virtual routing appliances' interfaces. This helps Nagios to check the throughput in the virtual environment.   .

2. Literature Review:

Introduction:

Virtual routers are not new subject. For the purpose of this literature review, three themes will be examined. The first theme will identify routing protocols between routers. The second theme will describe the development of methodologies and the last theme is going to be routing in a virtualization environment.

2.1 Cluster-Based Virtual Router:

The idea of the experimental research accomplished by Qian and Ge is to find a way to develop and implement a network in medium to large ISPs [1]. This virtual router will act as a transparent router to other routers in order to avoid complexity in the Internet structure as well as the path of the packets.

2.1.1 Virtualization mechanism:

The authors presented their research as a solution for huge networks that require scalability and survivability. They suggested that in order to successfully maintain the rate of growth of the network, there is a need to have some sort of virtual routers in the middle of the network topology. Those virtual routers are utilized to arrange and schedule the non-virtual routers.

In addition, the authors also used a number of external link selection algorithms for virtual router in response to utilization and survivability enhancement in backbone networks. The following figure gives a simple topology of the work done by Qian and Qe[1]:

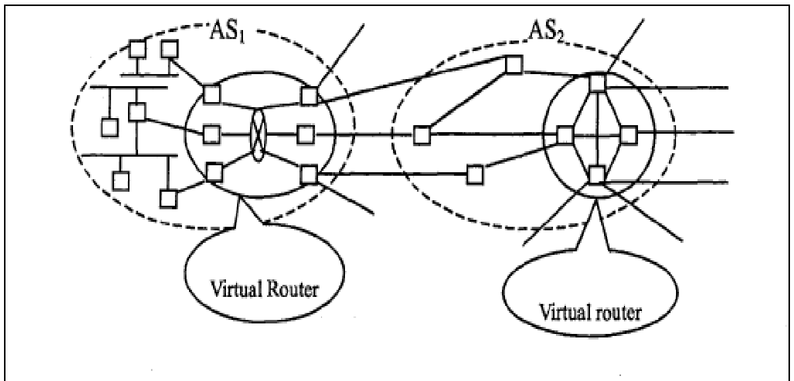


Fig 1 Topology of Virtual Routers

Figure 1: Topology of virtual routers

In order to perform routing and forwarding functions with the external (physical routers), the virtual router needs to do the following: first, the virtual router has to obtain routing information sent by the external routers. Then, this router will execute the flood operation, which means that this router will send the routing information to all internal nodes. Finally, using external links, this virtual router will be able to send routing information to exterior routers.

2.1.2 Routing Protocols:

These virtual routers can support interior and exterior routing protocols. For example, OSPF as well as IS-IS will be run to route traffic within the same AS and BGP with other ASs as a border router. In contrast, my research is intended to only use interior routing protocols such as RIP, RIPv2. This means that one router and one AS will be put in place in order to route traffic across the network. In addition, cluster-based virtual routers are a solution for ISPs. My experiment will be of primary use for educational purpose. For instance, a faculty member may use my virtual routing appliance to help them set up a fully virtualized environment for their research as well as a demonstration to students on how routing protocols work.

2.1.3 Testing Environment:

Authors of this paper tested the reliability, scalability, and load balancing. They utilized a simulation tool which is called "Network Simulator-NS Ver.2". The purpose of this application is to test the ratio of bandwidth of the external link as well as the load.

This paper is different from mine in many ways. The paper done by Qian and Ge is targeting data centers. They proposed a solution to fulfill the requirement of backbone networks' survivability and scalability. This issue led them to embed virtual routers between local networks and the ISP. The reason is to allow these virtual routers to organize and schedule packets in a particular AS (Autonomous system). The key advantage in my architecture from this paper is that mine will be completely virtualized while this paper uses virtual routers mainly in the middle of the network topology.

2.2. Xen Router Virtualization:

Xen is an open source virtualization project hat provides similar virtualization services as VMware except with a more integrated hypervisor. This can only work under Linux operating systems [2].

2.2.1 Virtualization Mechanism:

According to [3], the architecture of Xen simulates that there are multiple domains and a Xen hypervisor in each physical computer. The Xen hypervisor (also known as the Virtual machine monitor) has the responsibility of managing the access to the physical resources at the computer. In addition, each domain controlled by the Xen hypervisor represents a single virtual machine. The authors of this research point out that in case one of those virtual machines needs to utilize privileged command, a module called hypercall must be used. The function of this module is to inform the hypervisor that a virtual machine needs to perform a privileged instruction.

The first virtual machine in Xen is named "domain0". This domain is used by system administrators in order to start a new virtual operating system. Furthermore, when the hypervisor boots, dom0 automatically boots and controls management of the physical hardware. In addition to that, all drivers are stored in dom0 (also known as IDD, Isolated Driver Domain), so all devices kept in dom0 are accessed by all other domains through point-to-point links [3].

The following figure illustrates the Xen's system architecute. The operation of forwarding packets in Xen has been divided into three methods. The first one is called bridging [3]. In this mechanism, in order to permit transparency for applications between the real and the virtual interface, Xen utilizes bridging along with dom0. The purpose of the following figure is to show how the packets have been moved from the Driver Domain (dom0) to the guest domain (dom1) using software bridges in dom0.

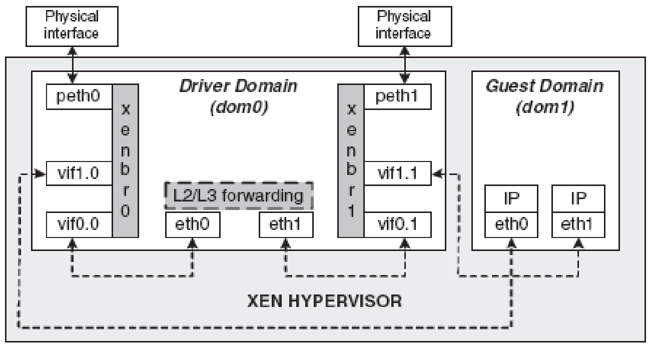


Fig. 1: Xen's classical network internals

Figure 2: Xen's classical network internals

The second mechanism is called routing. Unlike the first mechanism, IP addresses are required to be assigned to interfaces in the guest domains and dom0 to facilitate packet routing. The following figure shows how this operation is accomplished. In this case, packets are first moved from the dom0's physical interface (noted as ethY interface) to the proper back-end interface, vifX.Y. Then, it is the responsibility of the Xen hypervisor to route the packets from both back-end interfaces reside in dom0 and domU.

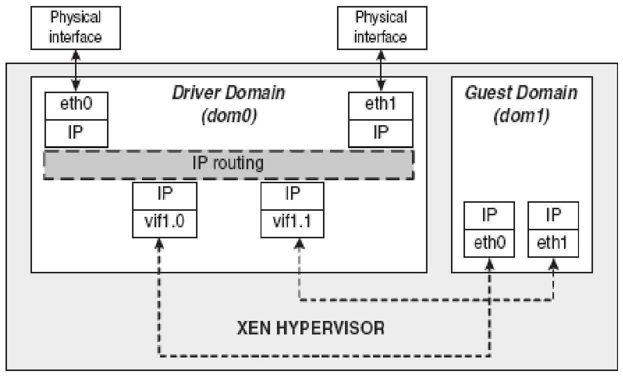


Fig. 2: Xen's routed network internals

Figure 3: Xen's routed network internals

2.2.2 Routing Protocols:

This paper does not indicate any routing protocols used in the Xen architecture. This is reasonable because all network traffic occur internally (in the same subnet). This means that there is no need for routing protocols to be deployed in this scenario.

2.2.3 Testing Environment:

Clark developed an architecture called the Heterogonous Experimental Network (HEN) testbed. This environment basically consists of many network hosts with different capabilities. Every node in HEN has multiple interfaces which makes it easy for an experimenter to change the OS in the node in a timely manner. The testbed consists of three components: traffic generator, traffic sink, and the system under test. They used Dell servers in order to perform both traffic generator and traffic sink and a Sun Fire X4100 with one 2.2 GHz AMD for the system under test.

Even though this paper seems to have some points in common with my research such as using hypervisors to manage all guest domains, it is slightly different from the solution I propose. In my case, I will be using open source tools in order to perform routing functionality to transfer packets between the virtual routing appliance and hosts.

2.3 Network-Based Virtual Personal Overlay Networks Using Programmable Virtual Routers:

Some attempts have been made towards virtualization using network programmability. Programmable networking aims to simplify the use of network services. As a result, the network will be able to provide the process of service creation and deployment [4]. The next paper examines the use of programmable virtual routers in virtual personal overlay networks.

2.3.1 Virtualization mechanism:

Louati and Zeghlache suggested a new method of facilitating communication between Virtual Private networks. A virtual router model must be utilized in both providers' edge (PE) networks in order to simplify the dynamic deployment and management of Virtual Personal Overlay Networks (VPONs). A VPON is defined as a number of network tunnels that specify a virtual overlay of individual clusters on top of the actual network communication topology [5]. Moreover, a new terminology has been introduced in their research which is Personal networks (PNs). A personal network is a set of clusters that involves wireless nodes around the user that is called the Private Personal Area Network (P-PAN) [5].

Louati and Zeghlache outline in their paper two different types of VPON: user-managed VPON and provider-provisioned VPON. The difference between these two categories is that the first one has the VPON application deployed and maintained by the user. However, the second category relies on the service provider for managing and deploying the VPON service [5]. Thus, in order to make this happen, programmable virtual routers are needed to run on both edge nodes. As a consequence, these two virtual routers will provide flexibility and will support dynamic tunneling deployment and management [5].

The following figure depicts the provider provisioned network-based VPON remote access VPON approach. In this example, the VPON involves both secure cluster gateways and secure provider edge. As we can notice from the figure, any wireless nodes in the P-PAN cluster needs to establish a connection with the secure cluster gateway. This will ensure a connection in a secure manner. As a result, all nodes in the network can communicate with each other using the VPON. The provider edge (PE) routers are required to be flexible, adaptive, and self-organized in order to support the dynamic aspect. As a result, programmable virtual router instances need to set within PEs [5].

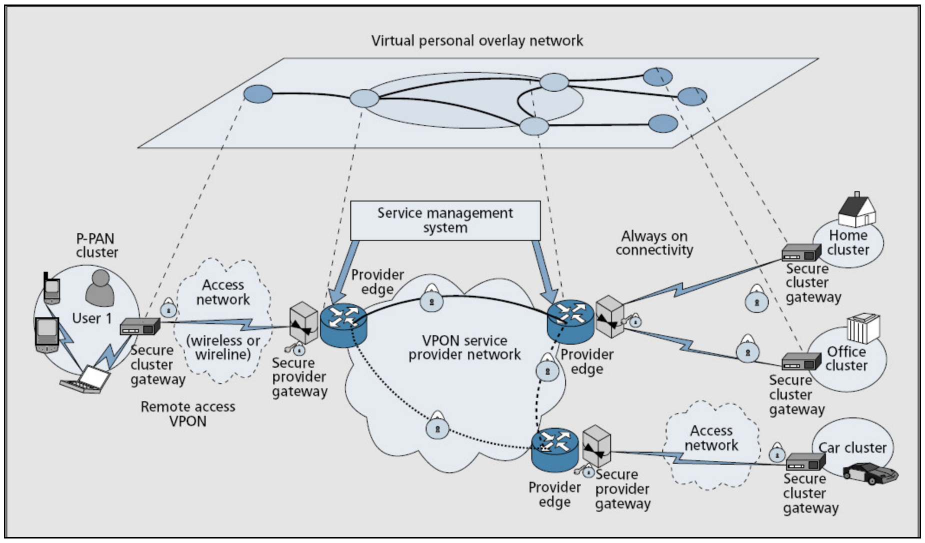


Figure 4: virtual personal overlay network

In order to provide the routing decision between different programmable virtual router instances, a Click router in being used. The Click router is a software architecture and is used to facilitate the design of the router forwarding mechanism [5]. The following figure demonstrates the design of a virtual router. An IP classifier is responsible for isolating the incoming traffic coming and going from all virtual router instances. In addition, each one of those intake has its own logical address. So, the IP classifier parameter contains the logical IP address of the instance and the

VPON-ID. Louati and Zeghlache stated that "The VR instance and IP classifier parameters are added at runtime when a new VPON-ID is provisioned by the management plane into the PE ".

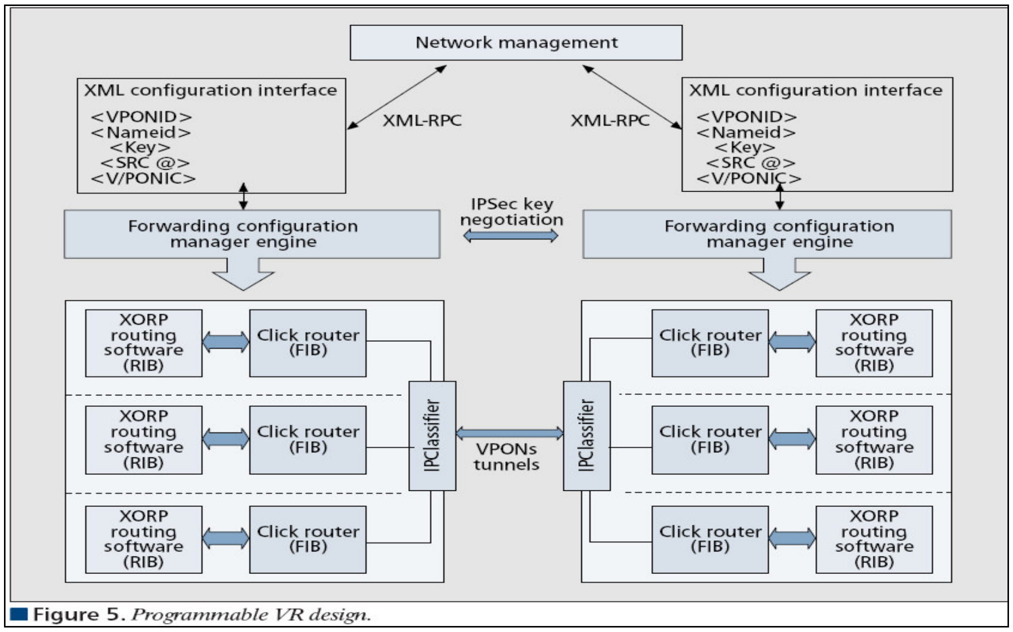

Network management
XML configuration interface
<VPONID>
<Nameid>
<Key>
<SRC @>
<V/PONIC>
XML-RPC
XML-RPC
XML configuration interface
<VPONID>
<Nameid>
<Key>
<SRC @>
<V/PONIC>
IPSec key negotiation
Forwarding configuration manager engine
Forwarding configuration manager engine
XORP routing software (RIB)
Click router (FIB)
IPClassifier
VPONs tunnels
IPClassifier
Click router (FIB)
XORP routing software (RIB)
Figure 5. Programmable VR design.

Figure 5: Programmable VR design

2.3.2 Routing Protocols:

Even though this paper does not mention what routing protocols they used for the experiment, it seems that a combination of interior and exterior routing protocols is deployed. We can clearly see from figure 4 that three gateways have been used to perform the routing decision. Some of those protocols that I would imagine may include OSPF, IS-IS, and RIP.

2.3.3 Testing Environment:

In this research, the authors implemented their virtualized environment using Click Router. It is innovative application architecture for creating configurable routers. Elements are packet processing modules that are the input in order to assemble a Click Router. According to Morris, Kolher, Jannotti, and Kaashoek, Individual elements implement simple router functions like packet classification, queuing, scheduling, and interfacing with network devices [6].

This research is different from mine because it is intended for ISPs. It helps edge providers and maintains a network infrastructure to connect their users including wireless hosts with each other. In terms of programming, as was observed in the above figure, the authors employ XML (Extended Markup Language) in order to forward network traffic. On the other hand, the virtual routing appliance will be quite simple in terms of implementation. It will only provide access to wired users that will be administrated within the same AS. Additionally, if needed, the interfaces attached to the virtual routing appliance will be programmed using Perl or Shell programming languages.

2.4. IP Infusion Virtual Routing for Provider Edge Application:

The idea of using virtual routing has been introduced and published by ISPs and other firms that are interested in this topic. According to [7], the authors of the article suggest that Internet Service providers may need to use Virtual Private Network (VPN) to solve the issue of scalability. Deploying VPN services instead of utilizing real network hardware will help companies to decrease the cost to the end user. They define "Virtual routing" as a router which can be configured to act as multiple routers in the same time [7].

2.4.1 Virtualization mechanism:

Then, the authors demonstrated some general requirements that must be taken care of before deploying virtual routers. First, each virtual router needs to be completely separated from other router and must have its own information about the routing decisions and protocol. Also, in terms of manageability, the virtual router should be controlled by authorized administrators of that specific virtual router, and these administrators are required to apply standard management protocol and services [7].

There are also some VPN specific virtual router requirements associated in this technology. They stated that all routers should share the same VPN id if they are members in that specific VPN domain. Additionally, they said that any routing protocols can be used in the backbone network as long as they do not affect the traffic flow of the VPN services. From security point of view, it is recommended that designers need to provide some level of security such as authentication and encryption in the network where needed.

In this solution, the authors point out that all virtual routing occur in the software layer. This layer is basically an emulation of the physical router in the application layer. The virtual router consists of all components that might be expected on a physical router. Furthermore, there is a new component that is called "VR Management Authority". This element is responsible for maintaining the router configuration and managing the configuration of the router.

2.4.2 Routing Protocols:

The virtual router has a set of routing protocols for performing routing decision. This may include learning the routes about other networks, building relationship with neighbor routers, and discovering neighbors. There is also a component called "Forwarding Plane Base". This is used by the TCP/IP stack to send packets to a particular virtual interface, and when we want to forward packets, it is the role of the TCP/IP stack to decide the appropriate FIB to use based on the received interface. IP Infusion virtualized environment initially focuses on BGP, static routing, or RIP.

2.4.3 Testing Environment:

Throughout the IP Infusion's discussion, the authors focus mostly on the concept of virtual routing. They do not explain which testing applications they use to test their experiment. However, this is going to be different from my research. One of the tasks that will be included in my research is to implement a testing environment in order to measure the quality of the routing decision.

In general, this solution is good for Internet service providers to deliverer packets from one machine to another over the Internet/Intranet. IP Infusion suggests using virtual routing along with VPN to reduce the cost of using many network resources and make it easy for network designers to scale their networks based on this technology. Unlike this research however, the virtual routing appliance that I propose will be focusing not only on the routing protocols, but it will provide a testing environment for the topology that will be created. Furthermore, this research is intended to be a solution for ISPs and mine will be used towards educational environment.

2.5 VROOM: Virtual Routers On the Move:

Network management is not new in the area of networking. Much research has been published looking as ways to address issues such as scalability, availability, or redundancy. Other researches have dealt with problems allowing virtual routers to move from one physical router to another without the need to change the IP address. The next paper with discuss this technology in details.

2.5.1 Virtualization mechanism:

Wang, Merwe, and Rexford propose a new solution for allowing a virtual router to easily move from one physical router to another. They came up with a new technology which is called VROOM (Virtual ROuter On the Move).The authors argued that in order in reduce the complexity of network management, there is a need to split the physical and the logical configuration of a network. As was discussed in their research, VROOM is a new architecture that has the ability to give the virtual routers the absolute freedom to move from one physical node to another.

Furthermore, VROOM does not disrupt the flow of traffic or modify the logical topology when VROOM migrates with a virtual router to a different physical router. This sometimes occurs when a physical router must go for planned maintenance. The virtual router can move to another physical router in the same Point-of-Presence (POP). The following figure depicts a router in the VROOM architecture. The figure yields that there are two layers, a substrate layer and a logical layer. According to [8], "The primary purpose of the substrate layer is to provide a dynamic binding between the interfaces of the logical routers and interfaces and links in the substrate level". On the other hand, the logical layer includes virtual router and is the same as the today's physical IP level routers.

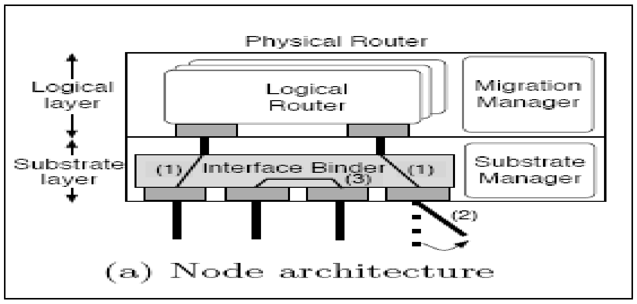


Figure 6: VROOM node architecture

In the next figure, Router A is re-binding from router B to router C using the programmable transport. The research that is done in this paper suggested that in order to make this happen, two extensions need to be made. The first extension is to dynamically adjust the binding between the physical host and its logical router. Secondly, the virtual router needs to migrate from one physical router to another.

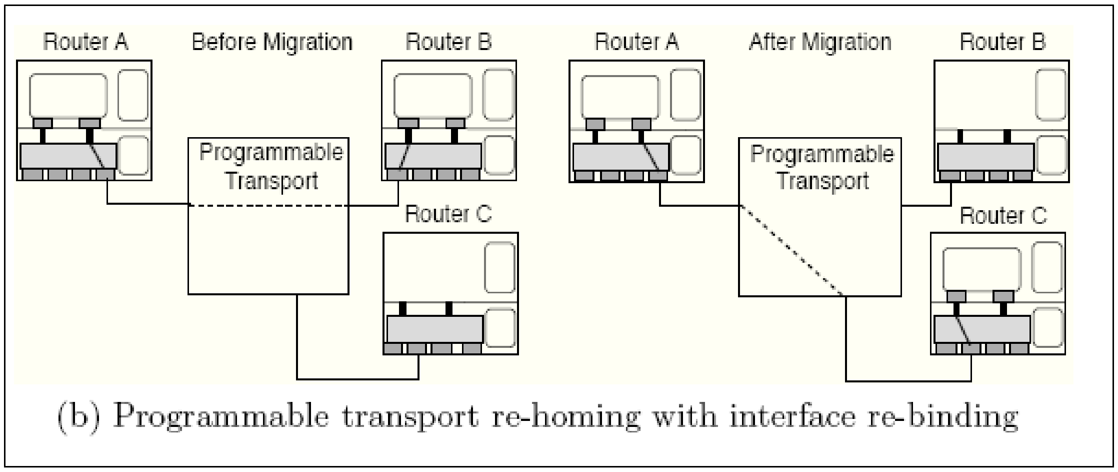


Figure 7: Programmable transport re-homing with interface re-binding

2.5.2 Routing Protocols:

The authors of this research deploy the Border Gateway Protocol (BGP) which is the core routing protocol of the Internet. BGP does not utilize traditional interior gateway protocols metrics. It makes routing decisions based on network policies and path.

2.5.3 Testing Environment:

The network topology consists of two subnets. Each subnet has four physical servers. The goal of this topology is to study the round-trip delay time for the migration. The authors did not spend much time testing and verifying the technologies they discussed in their research.

In conclusion, this research is different from mine in many ways. First of all, the authors run their virtualized experiment under Linux OS using Xen virtual machines. In my experiment, I will intend to use VMWare in order to create a virtual environment. Also, this research was a primary target at ISP network so it will facilitate traffic moving among backbone routers. On the other hand, my paper will aim to be used in education. Lastly, it is clearly seen that VROOM research lacks a clear testing methodology and uses powerful testing tools in order to accurately measure different aspects of monitoring their testing environment. However, in my experiment, I am using tools such as Nagios and I-ITG to generate and test packets coming from virtual machines.

3. Routing Protocols in a Virtual Environment:

The purpose of routing is to decide where to send network packets intended for addresses that are located outside the local network. Routers, specifically virtual routers, collect and maintain gathered routing information in order to permit the sending and receiving of such packets.

Conceptually, there are two basic methods for routing. Routers can utilize planned static routes, or they can dynamically compute routes using any routing protocols, such as RIP, or OSPF. The second type of routing has the ability to discover routes when those routers broadcast their routing tables through Ethernet or serial interfaces.

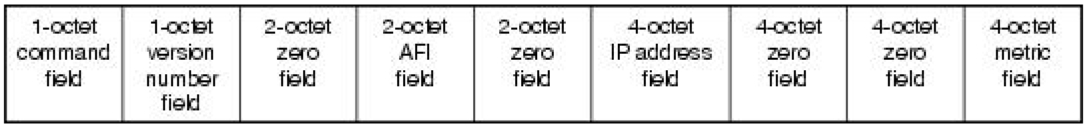
For the purpose of my thesis, no static routes are used within the virtual routing appliance. Instead, the above dynamic routing protocols are the core protocols that are used for the scenario. The next few paragraphs discuss these routing protocols in detail for better understanding of how they are actually designed and how they work.

Routing Information Protocol (RIP):

RIP is considered to be one of the oldest routing protocols. This protocol calculates routes by using distance-vector algorithms. RIP is most functional as an interior gateway protocol [9]. Thus, it is not common that to see this protocol used in Internet. Routing protocols that are controlled and administrated within the same autonomous systems are referred to as an interior gateway protocol. Some of capabilities and features that RIP supports will be discussed next. This includes routing timers, routing update process, routing stability, and RIP routing metrics.

RIP broadcasts its routing information at regular basis and when the network topology alters. In case any changes occur in the topology, the virtual router updates its routing table to adopt the new route. When the virtual router uses RIP, it only maintains the best route to a destination network. RIP then informs other virtual routers of the change, but only after it updates its own routing table. In terms of routing metrics, RIP only uses one metric, which is the hop count, for routing calculation between a source and destination network. Each path from the source to the destination is given a value. Therefore, when a packet leaves the source machine and reaches the first virtual routing appliance, the hop count is incremented by 1 and that is added to the metric value.

RIP maintains routing stability by avoiding routing loops from occur. It limits the number of the hop count that is allowed in a path between the source and the destination. The virtual routing appliance will drop packets that have hop counts exceeding 15 and the network destination is considered unreachable [10]. RIP route timers are used to maintain the validity of each route that is saved in the routing table. Figure 1 depicts the RIP packet format that consists of nine fields.



1-octet command field	1-octet version number field	2-octet zero field	2-octet AFI field	2-octet zero field	4-octet IP address field	4-octet zero field	4-octet zero field	4-octet metric field

Figure 8: RIP packet format

As we saw in the previous figure, a RIP packet format consists of nine fields. This paragraph will expand each component listed in the format. The command field which requires one octet shows whether the packet is generated as a request or as a response to a request. In the first case, the request asks the virtual router to send all or part of its routing table. A response packet can be generated in either response to a request or as an unsolicited update [10]. The version number field is used to determine a RIP version that was used to generate the RIP packet. Yet, only two version numbers have been assigned, number 1 and 2. Although I am primary concerned with RIP version 1, it is important to explain the difference between those two versions. The key features that RIP 2 provides but not RIP1 are authentication and subnet masking. RIP 2 has the ability to use a simple authentication mechanism to secure table updates. More importantly, RIP 2 supports subnet masks. If the network address does not have a subnet mask, this field is set to zero.

The Address-Family Identifier (AFI) indicates the address family used. RIP is implemented to provide routing information for different protocols. Consequently, the open standard RIP needed a mechanism for determining which type of address is being carried in its packets. The AFI for IP is 2. The address field contains an internetwork address. This can be a gateway, a network or even a host. Finally, the metric field specifies the number of virtual routers have been traversed to the destination. This value is incremented as it passes through a virtual router. The following paragraph explains the commands that are used in my experiments for RIP.

Traditional routing applications present all of the routing protocol functionalities as one process software. However, Quagga approaches this differently. Quagga is implemented from a number of many daemons that work collectively in order to construct the routing table. In Unix and other multitasking operating systems, a daemon is a computer program that runs in the background, rather than under the direct control of a user [11]. For example, the Ripd daemon deals with the RIP protocol; the last letter “d” represents the term “daemon”. In addition, there is a kernel routing table manager zebra daemon which is running under the virtual routing appliance machine. This is used to update the kernel routing table and for redistribution of routes between several routing protocols. If there is a need to add new routing protocols daemons to the whole routing system, this can be accomplished by running only the protocol daemon associated with routing protocol in use.

The first command that needs to be issued is **router rip**. This command is necessary in order to enable RIP protocol. This command must be entered before issuing any other RIP command. Then, RIP protocol needs to be set by a network. The command for this is **network a.b.c.d**. For example, if network 10.0.0.0/24 was RIP enabled, this would result in all pool addresses from 10.0.0.0 to 10.0.0.255 being enabled for RIP protocol. Another command that can be optionally used is **neighbor a.b.c.d**. It is to establish a direct link between virtual routers when a neighbor does not understand multicast.

Although RIP protocol has been marvelously suited during the early days of networking, technology has radically adjusted the way internetworking used and built. Some of the greatest limitations of RIP protocols are failure to support paths longer than 15 hops, relatively slow convergence, reliance on fixed metrics to calculate routes, and inability to provide dynamic load balancing.

Open Shortest Path First (OSPF):

OSPF is the second virtual routing protocol that is supported in my experiment. This paragraph sheds some light on this protocol. One endeavor to enhance the scalability of networks was to base routing decisions on link states rather than hop counts or other distance vectors. OSPF has two major features. The first characteristic is that the protocol is open, which indicates that its specification is in the public domain [12]. The second feature is that OSPF is based on the

Shortest Path First (SPF) algorithm, which is also referred to Dijkstra's algorithm [12]. This algorithm permits the selection of routes based on link states, as opposed to only distance vectors. This protocol was originally implemented as an IP routing protocol for exercise within autonomous systems. Therefore, OSPF is not capable of carrying out datagrams of other routable networks such as Apple-Talk or even IPX.

One of the key advantages that an OSPF supports is the ability to rapidly detect topological changes in the autonomous system. Other advantages include calculating a separate set of routes for each IP type of service, utilizing multicasting to minimize the load on systems not participating OSPF and carrying out data equally between equal-cost routes [13]. Unlike RIP protocol, the core concept of OSPF routing protocol is that it works within a hierarchy. The biggest part of the hierarchy is the autonomous system. Each AS can be divided into several areas which can possibly contain a group of contiguous networks as well as hosts. Virtual routing appliance can be assigned to different areas based on interfaces that re associated with a network. The following drawing gives an example how OSPF looks like in a virtual environment.

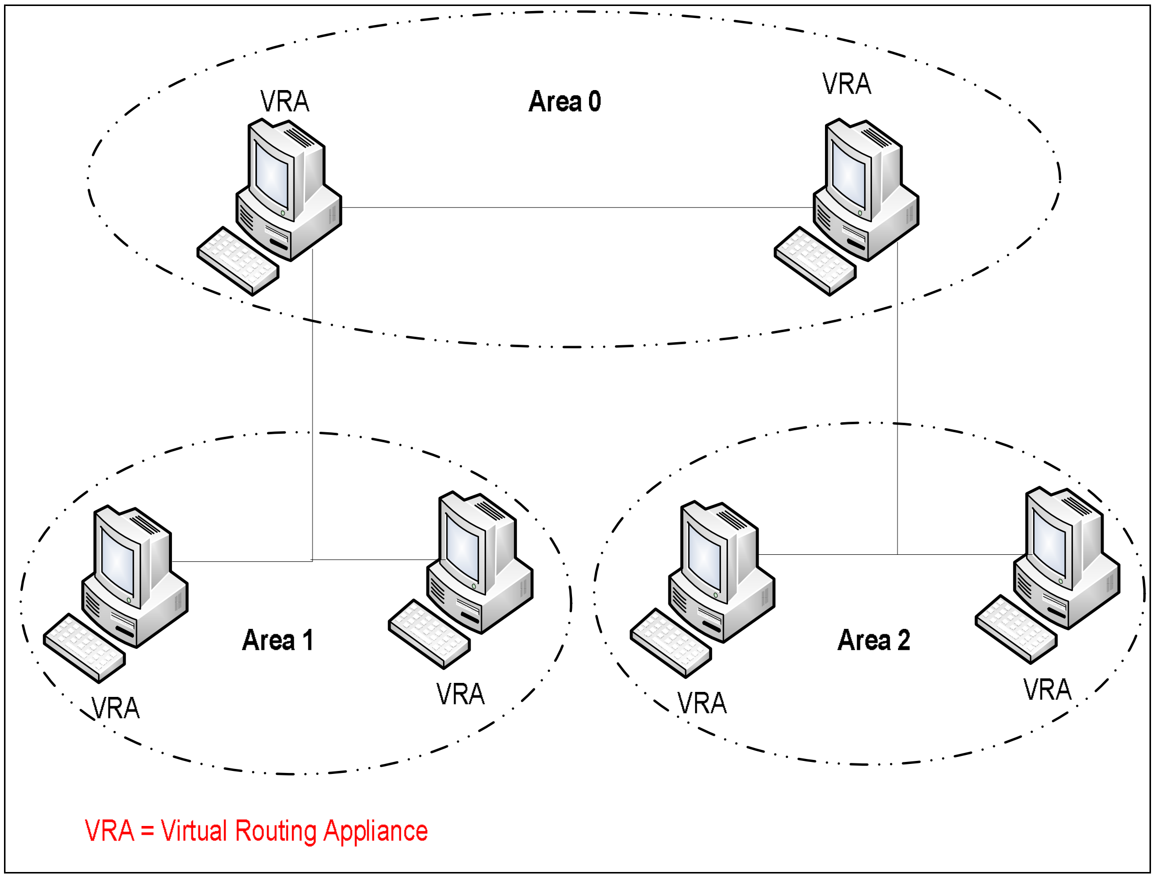


Figure 9: OSPF in a virtual environment

This paragraph discusses an OSPF packet format. OSPF is considered to be a fairly complex routing protocol. Thus, it utilizes an extensive amount of data structure and each structure executes a particular task. This is identified as the OSPF header. The following figure shows the OSPF packet format which contains of nine fields and has a header size of 24 bytes.

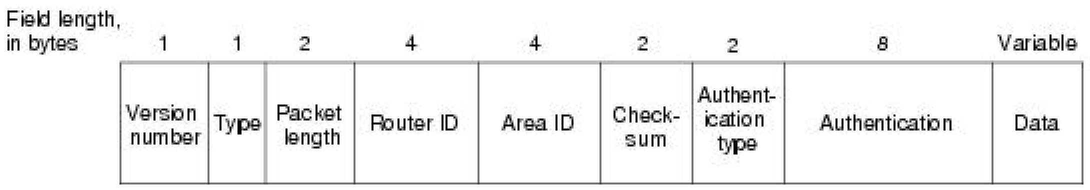


Figure 10: OSPF packet format

- Version Number: The first field seen in an OSPF header is intended to identify the version number. The current virtual routing appliance that I am proposing supports OSPF version 2 and version 3.
- Type: This field explains which of the five different OSPF packet types is associated to this specific header. The header type can be one of the following:
    - Hello packets (type 1): Is utilized to initiate and maintain relationships among neighboring virtual routing appliance.
    - Database description packets (type 2): This packet is used between two OSPF virtual routing appliances in order to build an adjacency.
    - Link-state request packets (type 3): This packet describes a virtual routing appliance requests particular piece from a neighboring virtual routing appliance. This happens when the neighboring virtual routing appliance has more current information.
    - Link-state update packets (type4): This packet is response to link-state request packets and is responsible to carry out Link-state Advertisements (LSAs) to neighboring virtual routing appliances.
    - Link-state acknowledgment packets (type 5): This packet ensured reliability of LSA packets distribution. Therefore, the receiver virtual routing appliance must acknowledge a receipt of the packet.

- Packet length: This packet is used to notify the receiver the total length of both the payload and the OSPF header.
- Router ID: Each virtual routing appliance is given a unique ID number. It is populated by the OSPF protocol before sending any other information to other virtual routing appliances.
- Area ID: As discussed in figure 3, this field is responsible to specify the area ID number.
- Checksum: This field stores a result of a mathematic algorithm calculation to make sure that a packet received is identically the same as the on sent.
- Authentication type: Involves the authentication type. Each virtual routing appliance must be authenticated during OSPF protocol exchanging.
- Authentication: This filed is used for actual carrying of authentication information.
- Data: Contains encapsulated upper-layer information.

In order to start the OSPF configuration process in Quagga, it is necessary to first identify the OSPF virtual routing appliance. The command **router ospf** enables the OSPF process. The second step is to set up the virtual routing appliance ID of the OSPF process. This can be accomplished by issued **ospf router-id a.b.c.d** command. The ID number can be either an IP address of the virtual routing appliance or any arbitrary 32 bit number and must be unique. The next step is to associate a network as well as an area to a specific interface by typing **network a.b.c.d/m area a.b.c.d** command. These are the essential commands that are required to get virtual routing appliance route traffic properly.

OSPF is considered to be one of the most great and provides several features in terms of open source routing protocols. Its complexity is probably the biggest limitation because building, maintaining, and designing OSPF networks require a degree of expertise. One way to decrease this complexity to use the default setting which greatly helps to simplify the design of this kind of networks. When setting properly, users will notice quick convergence and solid performance.

4. Creation of Virtual Networks:

Three virtual routing appliances are utilized in this research in order to test the traffic behavior. Those virtual routers are the core aspects and act as packet forwarders between heterogeneous LANs. Routing decision is made based on the routing table resides in each configuration of the virtual routing appliances. Additionally, six VLANs are created using VMware features in order to ensure that all VLANs are isolated from each other and there is no way for packets to be forwarded among VLANS unless there is a layer three device. The network topology shown below is used to perform two different experiments. Each one of those experiment employs specific dynamic routing protocol, RIP and OSPF respectively. I am using 192.168.X.X IP address poll for all nodes in this research.

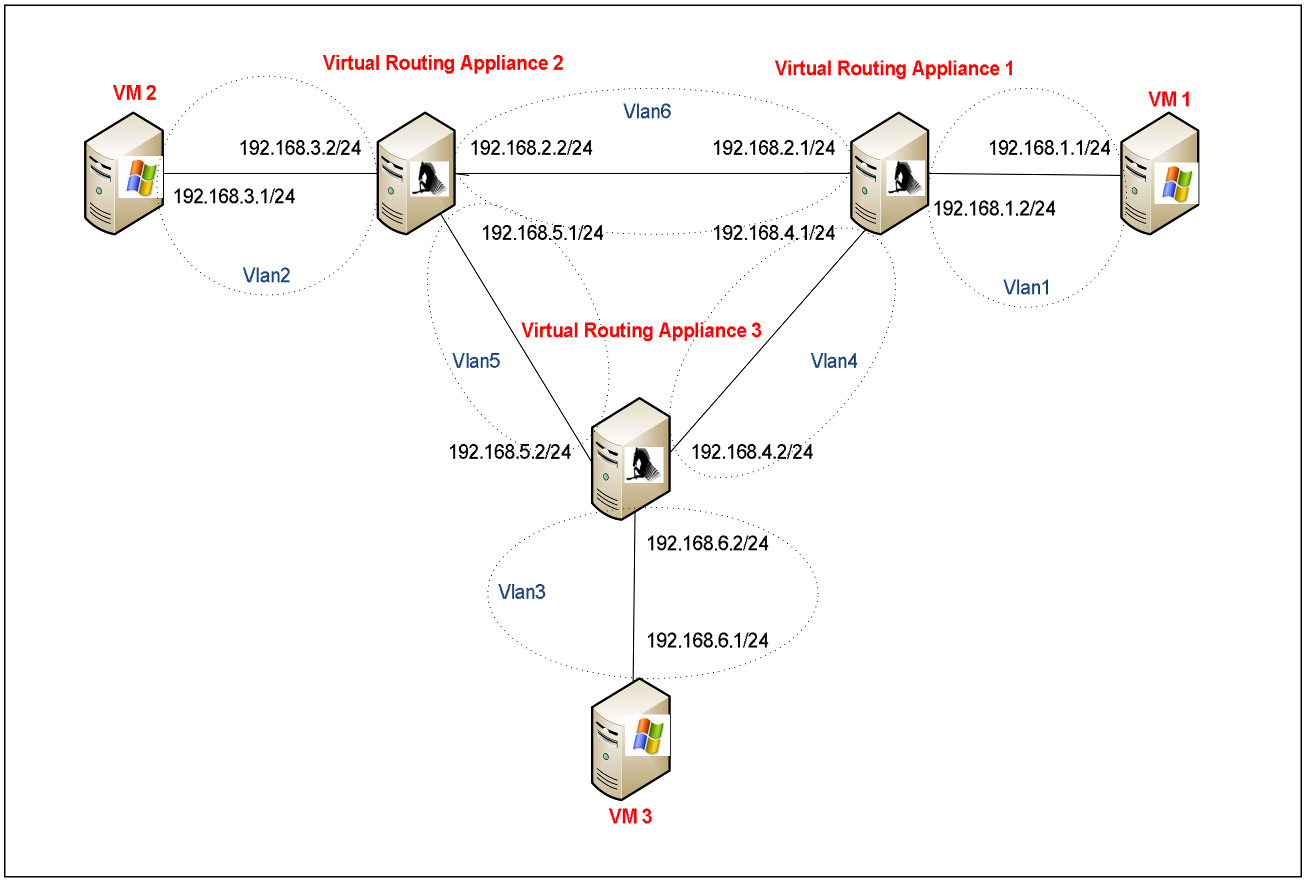


Figure 11: General VRA topology

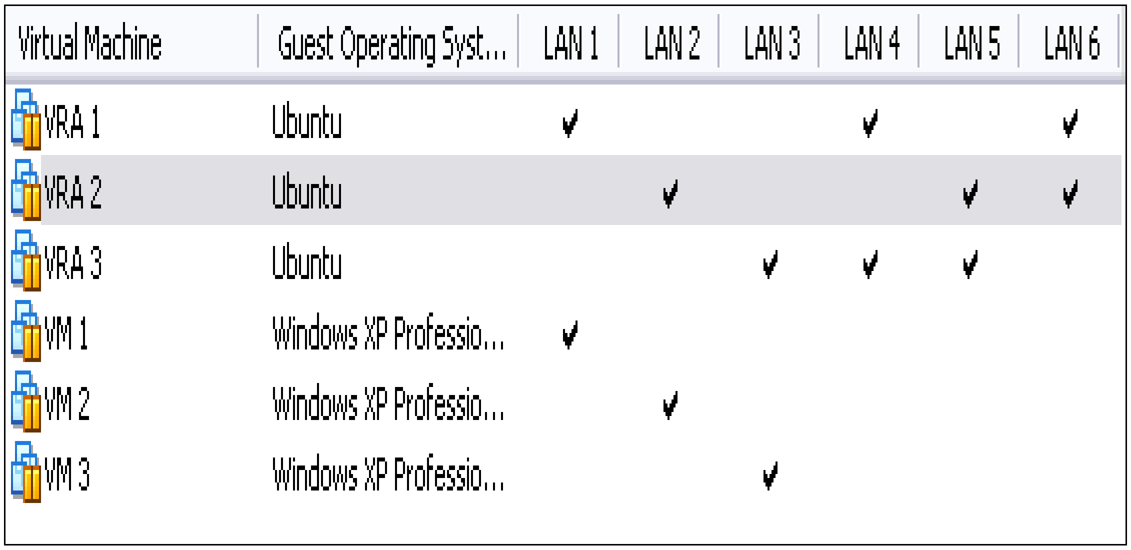
The above figure shows that some nodes have three interfaces. This can be possibly added using the VMware feature called "Add Adaptor". It is important to know which interface corresponds to which IP address. The following table illustrates all interfaces in the previous network topology and the IP address associated with each adaptor.

Device Name	VLAN Name	Interface/Adaptor	IP Address
VRA 1	VLAN 6	Eth1	192.168.2.1/24
VRA 1	VLAN 1	Eth2	192.168.1.2/24
VRA 1	VLAN 4	Eth3	192.168.4.1/24
VRA 2	VLAN 5	Eth1	192.168.5.1/24

VRA 2	VLAN 2	Eth2	192.168.3.2/24
VRA 2	VLAN 6	Eth3	192.168.2.2/24
VRA 3	VLAN 5	Eth1	192.168.5.2/24
VRA 3	VLAN 3	Eth2	192.168.6.2/24
VRA 3	VLAN 4	Eth3	192.168.4.2/24
VM 1	VLAN 1	Eth1	192.168.1.1/24
VM 2	VLAN 2	Eth1	192.168.3.1/24
VM 3	VLAN 3	Eth1	192.168.6.1/24

Table 1: Virtual routing appliances' interfaces and configuration

The previous table shows that all virtual routing appliances have three interfaces. Each interface is assigned into different VLAN. As a result, for example, if VM1 needs to send packets to virtual routing appliance 1, packets should be forwarded to Eth2 in the virtual router. This ensures that all VLAN are totally isolated from each other. The following screenshot is taken from my VMware Workstation's main page:



Virtual Machine	Guest Operating Syst...	LAN 1	LAN 2	LAN 3	LAN 4	LAN 5	LAN 6
VRA 1	Ubuntu	✓			✓		✓
VRA 2	Ubuntu		✓			✓	✓
VRA 3	Ubuntu			✓	✓	✓	
VM 1	Windows XP Professio...	✓					
VM 2	Windows XP Professio...		✓				
VM 3	Windows XP Professio...			✓			

5. Installations and Configurations:

Three major applications are needed to be set up and configured in order to establish the test environment for my experimental research. One physical machine is used to emulate this testing environment. Quagga, which is a newer version of GNU Zebra project, is installed in two virtual routing appliances that are running under Linux Ubuntu OS. These virtual routing appliances represent the core function for routing between virtual hosts that are running under Windows XP SP2. In this sense, most of the configuration and tuning are applied to the virtual routing appliances. This component utilizes the same Cisco ISO commands for routing. Although Quagga is intended to work under a physical machine, it can be tuned to work in a virtual environment. In addition, Nagios, which is a tool that performs monitoring tasks, is installed in both virtual routing appliances. Even though all these nodes are residing in the same physical machine, they are totally isolated into three subnets. This involves virtual Network Interface Cards (NICs) on both virtual hosts and virtual routing appliances.

Hardware and Software Specifications:

1. Laptop
    - Processor: Intel Pentium® M 2.00 GHZ
    - RAM: 1 GB
    - Hard Disk: 80 GBs.
    - Microsoft Windows XP Version 2002 (Service Pack 2).

Step 1: Installation and Configuration of Quagga:

Ubuntu 7.10 the Gutsy Gibbon release, which is a Linux based OS, has been selected as the foundation for Quagga. The only prerequisite to get Quagga to work is to update all packages from Synaptic Package Manger and choose to install Quagga. This experiment uses Quagga 0.99.9 release which supports BGP4, BGP4+, OSPFv3, IS-IS, RIPv1 as well as RIPv2. An operating system with Quagga installed operates as a dedicated router. Using Quagga, a virtual machine can exchange routing information with other virtual routers utilizing routing protocols. Quagga takes advantage of this information to update the kernel routing table so that the right packet is forwarded to the right destination. The latest version of GNU Quagga can be downloaded from http://www.quagga.net. The simplest way to install this package after downloading is to type the three following commands:

```
% configure
% make
% make install
```

The next step is to configure and make some adjustments to this utility. It is necessary to specify what routing protocols Quagga is going to support. By default, the only routing protocol that Quagga supports is RIP. In order to change the default configuration, a user needs to activate the Quagga daemons matching the routing protocols that are required on a virtual routing appliance. The following command allows the user to choose the proper routing protocol:

```
#vim /etc/quagga/daemons
```

Each routing protocol has three options:

Entry Number	Priority
0 or “No”	Disabled
1 or “Yes”	Highest priority
2 → 10	Lower priority

Table 2: Quagga configuration’s options

The “daemons:” configuration file looks like the following:

Notice that in the following example zebra, ospf and rip routing protocols are included and the OSPF has a higher priority when routing information than rip.

```
zebra=yes

bgpd=no

ospfd=yes

ospf6d=no

ripd=2

ripngd=no

isisd=no
```

After successfully choosing the routing protocols for your needs, it is required to create a configuration file every time a Quagga daemon is activated. There can be six configuration files based on the implementation of a virtual network. For instance, files such as bgpd.conf and ripd.conf are used in order to store configuration commands within these two specific files. Upon starting Quagga, these files are loaded into the running configuration in the virtual appliances’ memory. This will facilitate a user ability to enter a set of commands in the Quagga command line. These files must be saved in the **/etc/quagga/** directory. The following is a sample config files for zebra and ripd daemons:

```
!
! Zebra Configuration Saved from vty
! 2008/06/11 04:11:31
!
hostname Router
enable password zebra
!
interface eth0
ipv6 nd suppress-ra
!
 interface lo
!
linevty
```

Sample of Zebra config file

```
!
! Zebra Configuration Saved from vty
! 2008/06/11 04:11:31
!
hostname ripd
password zebra
log stdout
!
Router rip
!
line vty
!
```

Sample of ripd config file

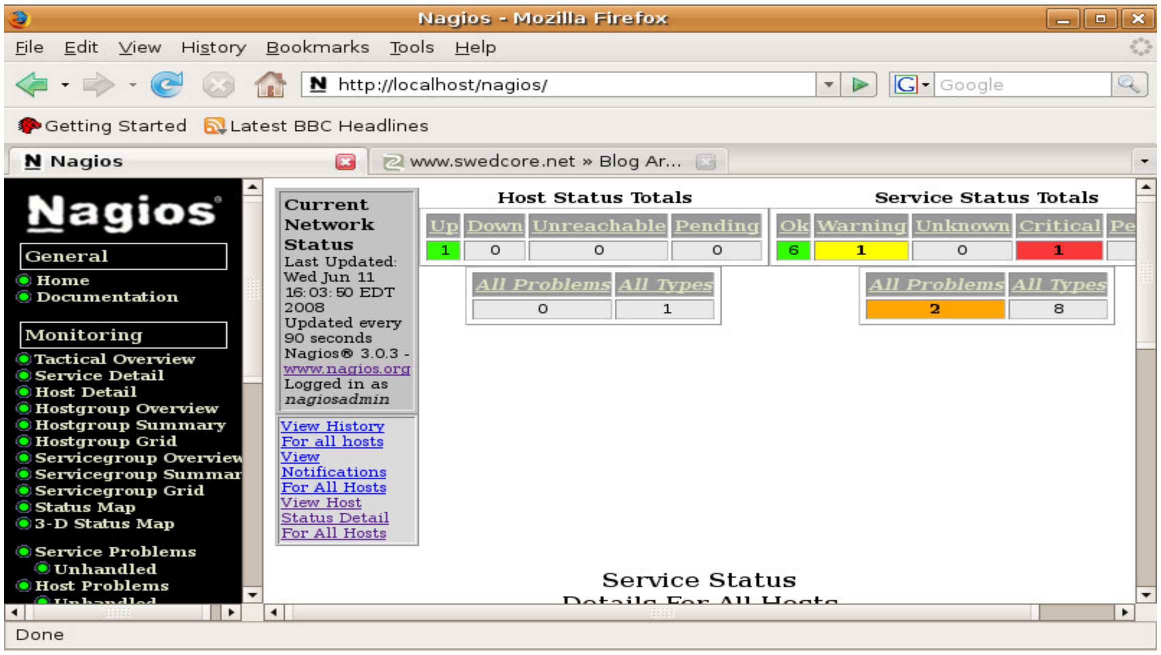
The first config file basically assigns a hostname to the virtual router as well as the password. It also states that these commands have been entered via a local administrator. The other config file has almost the same characteristics except that the virtual router utilizes rip as a routing protocol. Finally, it is necessary to provide a user or group ownership to Quagga and Quaggavty respectively to the files inside the /etc/quagga directory:

```
#chown quagga.quaggavty/etc/quagga/*.conf

#chmod 640 /etc/quagga/*.conf

#vtysh
```

Step 2: Installation and configuration of Nagios:

Nagios is installed on the target virtual routing appliances. For monitoring purposes, it is important to install and configure this software in order to study the results. Before installing Nagios, a user must install the following packages:

- *Apache2*: Apache provides several features, many implemented as complied modules that expand the major functionality. These range from a server-side programming language scheme to authentication support. Apache is essentially utilized to support both static content such as text and pictures and dynamic Web pages such as Flash technologies. The combination between Nagios and Apache enables me to use the web interface to poll the status of different hosts that are assigned in the configuration file for Nagios. The following snapshot explains the different services that monitor the localhost that resides in the virtual routing appliances.



Current Network Status
Last Updated: Wed Jun 11 16:03:50 EDT 2008
Updated every 90 seconds
Nagios® 3.0.3 - www.nagios.org
Logged in as *nagiosadmin*

Host Status Totals

Up	Down	Unreachable	Pending
1	0	0	0

All Problems	All Types
0	1

Service Status Totals

Ok	Warning	Unknown	Critical	Pe
6	1	0	1	

All Problems	All Types
2	8

Service Status Details For All Hosts

Figure 12: Snapshot of Nagios Running on a Virtual Routing Appliance

- *GCC compiler and development libraries:* GNU Compiler Collection contains a number of compliers implemented for various programming languages by the GNU Project. The GNU compiler was originally produced to only handle C programming language. By the time, this project was extended to compile Java, C++, Pascal, and FORTRAN. This package is mandatory in order to compile the Nagios that is written in C.
- *GD development libraries:* GD library stands for Gif Draw and is used to manipulate images. Additionally, it can create other image formats such as PNG, JPEG and WBMP images. This package is required in Nagios since there is an option to visualize the host machines from the web interface.

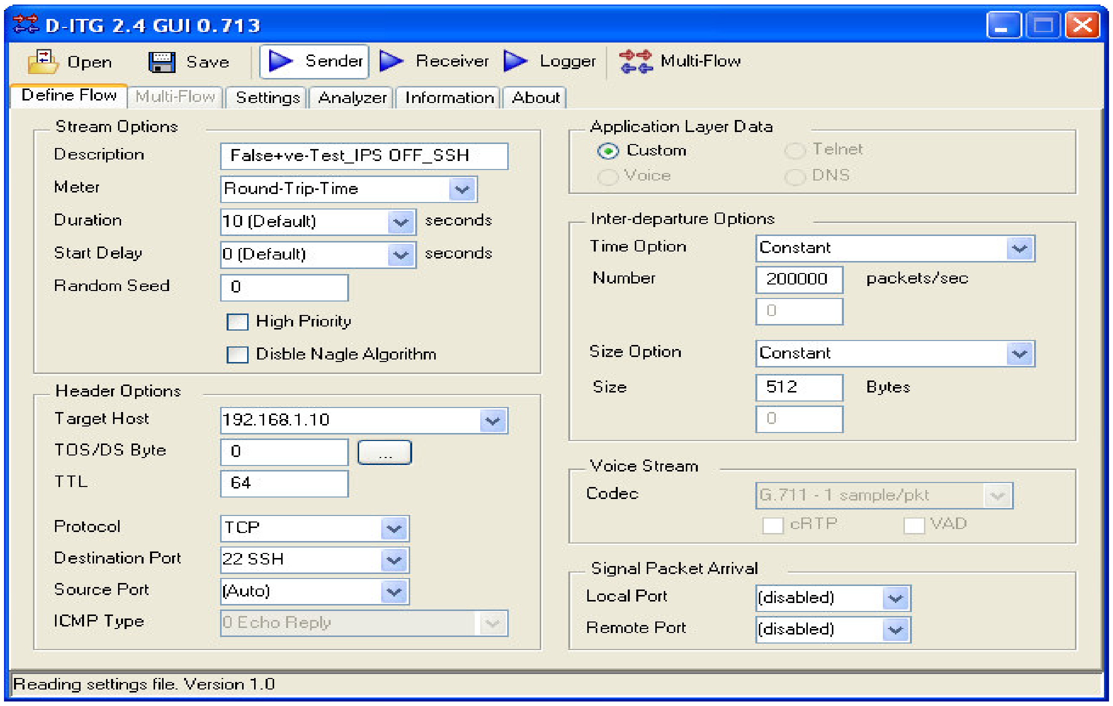
The configuration of Nagios begins by creating a new Nagios user account and giving it a password. This step is important for authentication purposes when a user needs to connect to the web interface. The following sets of commands should be utilized to create a new user:

```
#/usr/bin/useradd nagios

#passwd nagios
```

Step 3: Installation and configuration of Distributed Internet Traffic Generator

D-ITG Configuration:

D-ITG offers two options for packet delivery. The first one, which works under Windows OS, uses GUI to manage traffic flows as shown below. The second alternative runs under Linux OS and requires a user to type commands manually. Several parameters cab be assigned in a D-ITG command such as delay meter, protocol, source and destination ports, traffic speed and volume.



Stream Options
Description: False+ve-Test_IPS OFF_SSH
Meter: Round-Trip-Time
Duration: 10 (Default) seconds
Start Delay: 0 (Default) seconds
Random Seed: 0
☐ High Priority
☐ Disble Nagle Algorithm

Header Options
Target Host: 192.168.1.10
TOS/DS Byte: 0
TTL: 64
Protocol: TCP
Destination Port: 22 SSH
Source Port: (Auto)
ICMP Type: 0 Echo Reply

Application Layer Data
[● Custom] Telnet
Voice DNS

Inter-departure Options
Time Option: Constant
Number: 200000 packets/sec
0
Size Option: Constant
Size: 512 Bytes
0

Voice Stream
Codec: G.711 - 1 sample/pkt
☐ cRTP ☐ VAD

Signal Packet Arrival
Local Port: (disabled)
Remote Port: (disabled)

Reading settings file. Version 1.0

Snapshot Sample of D-ITG GUI Interface

Component of D-ITG:

ITGSend: this is the sender component of the D-ITG component. ITGSend creates several simultaneous flows of protocol traffic. It is a multithreaded platform accountable for producing and sending network packets according to particular input parameters [14]. This component exists on the sender virtual host and has the capability of generating a number of several flows concurrently. Each flow is managed by a single thread. The traffic flow behavior can be controlled by various command line options. As listed above, those options may include but are not limited to meter (one way delay or round trip delay), source and destination ports, packet size, protocol type, and flow duration.

ITGRecv: This component has the role of receiving traffic sent by ITGSend. It should apparently run on the receiver virtual host to achieve a connection [14]. It is mandatory to synchronize the clocks in the sender and the receiver virtual hosts for accurate results when calculating one way delay. Clocks can be not synchronized if a round trip delay is utilized for measurement of the delay. The logs may be sent to a third virtual host but I chose to capture it locally on the receiving virtual host for the purpose of this testing.

ITGDec: This is the decoder component and is responsible for analyzing the results of the testing generated by utilizing the D-ITG platform. It parses the log files generated by ITGSend and ITGRecv components and computes jitter, delay, and bit rate at specific intervals on the test as a whole. Delay is the time variation between sending and receiving packets. On the other hand, the testing time is between the reception of the first and last packet received by the ITGRecv component.

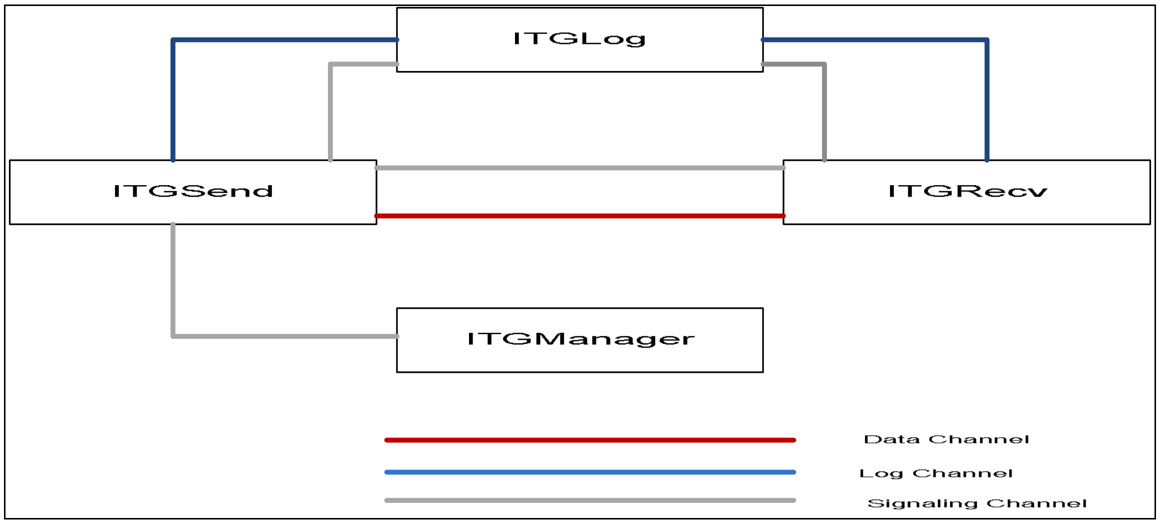


Figure 13: D-ITG Component Architecture

6. Observations and Findings:

RIP Scenario:

The first routing protocol installation in my proposed virtual environment is RIP. As discussed earlier in this report, RIP relies only on hop count to measure a cost to a given route. It is important to notice that all links in this topology have the same link speed although it is not affecting the routing decision for any of the virtual routing appliances. The following drawing gives a better understanding of the whole environment including the three virtual routing appliances as well as the virtual machines.

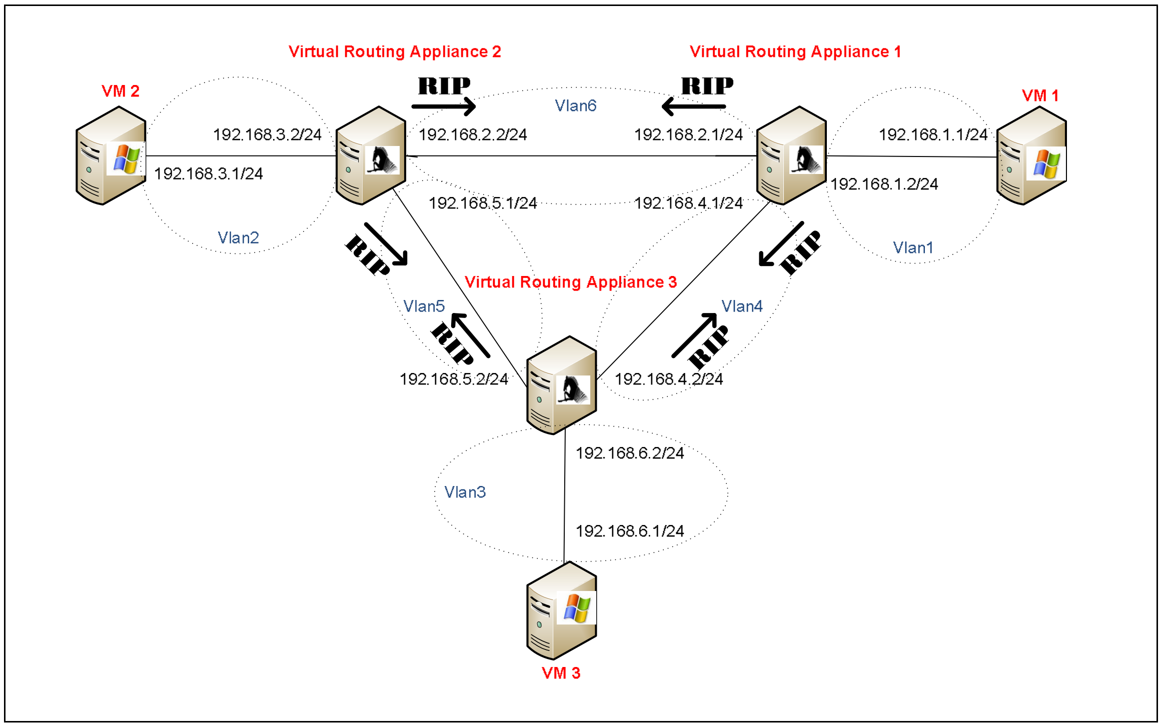
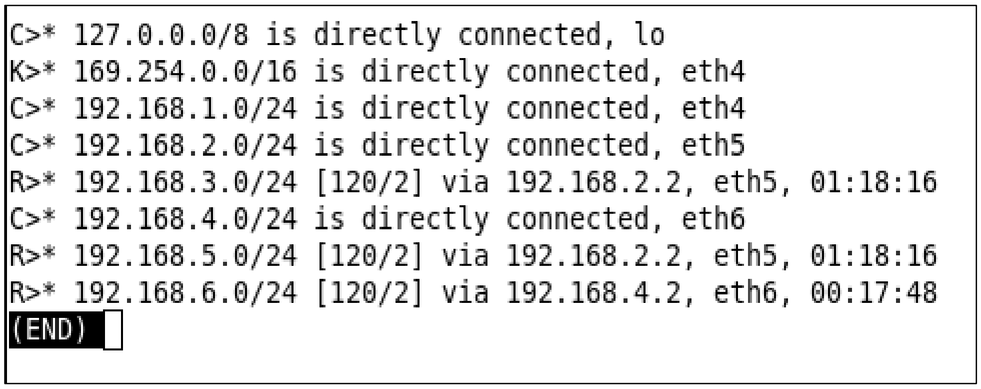


Figure 14: RIP topology

After configuring those virtual routing appliances to be RIP capable, all router are staring to learn new networks. Upon configuring RIP protocol in the virtual routing appliances, each virtual routing appliance learns and advertises RIP routes with all neighbors by default. My observation is that all virtual routers are successfully able to learn all routes in my topology and hence can ping any virtual appliance/machine. The following is a screenshot taken from the first virtual appliance when typing **show ip route**.



```
C>* 127.0.0.0/8 is directly connected, lo
K>* 169.254.0.0/16 is directly connected, eth4
C>* 192.168.1.0/24 is directly connected, eth4
C>* 192.168.2.0/24 is directly connected, eth5
R>* 192.168.3.0/24 [120/2] via 192.168.2.2, eth5, 01:18:16
C>* 192.168.4.0/24 is directly connected, eth6
R>* 192.168.5.0/24 [120/2] via 192.168.2.2, eth5, 01:18:16
R>* 192.168.6.0/24 [120/2] via 192.168.4.2, eth6, 00:17:48
(END)
```

The above screenshot shows many routes that need to be explained in this paragraph. First, the "C" sign indicates that loopback address for that specific machine. This is generally used for testing purpose to ensure that that machine can ping itself. The "K" sign is only found if one used GNU Zebra which refers to a kernel route. The idea behind it is that Gnu Zebra supports multi-thread by combining all routing protocols into single configuration file.

I also found that three routes are directly connected to the first virtual appliance. The reason is that this virtual machine is assigned with three NIC different interfaces and referred to the symbol "C" which means that this route is directly connected to the virtual machine. Finally and most importantly, I observed that three new routes have been learned from neighbors. Going back to the topology, we can obviously see that 192.168.3.0/24 network has been learned via the second virtual routing appliance which the IP address of 192.168.2.2.

The value of 120 indicates the administrative distance of the information source which is RIP in this topology and the hop count value in this case is 2 because packets are forwarded through two virtual routers to reach to that specific network. Eth5 means that RIP has been advertized by this interface. The last value specifies the last time the route was updated, in hours: minutes: seconds.

The last observation in this section discussing the path are taking when leaving the first virtual machine and targeting the second virtual machine. After studying the behavior of RIP protocol and applying its configuration in my virtual environment, the result was that the sender virtual machine is taking the shortest path to the destination which goes through VLAN6. The next drawing clearly demonstrates the behavior of packets sent from the first virtual machine to the second virtual machine.

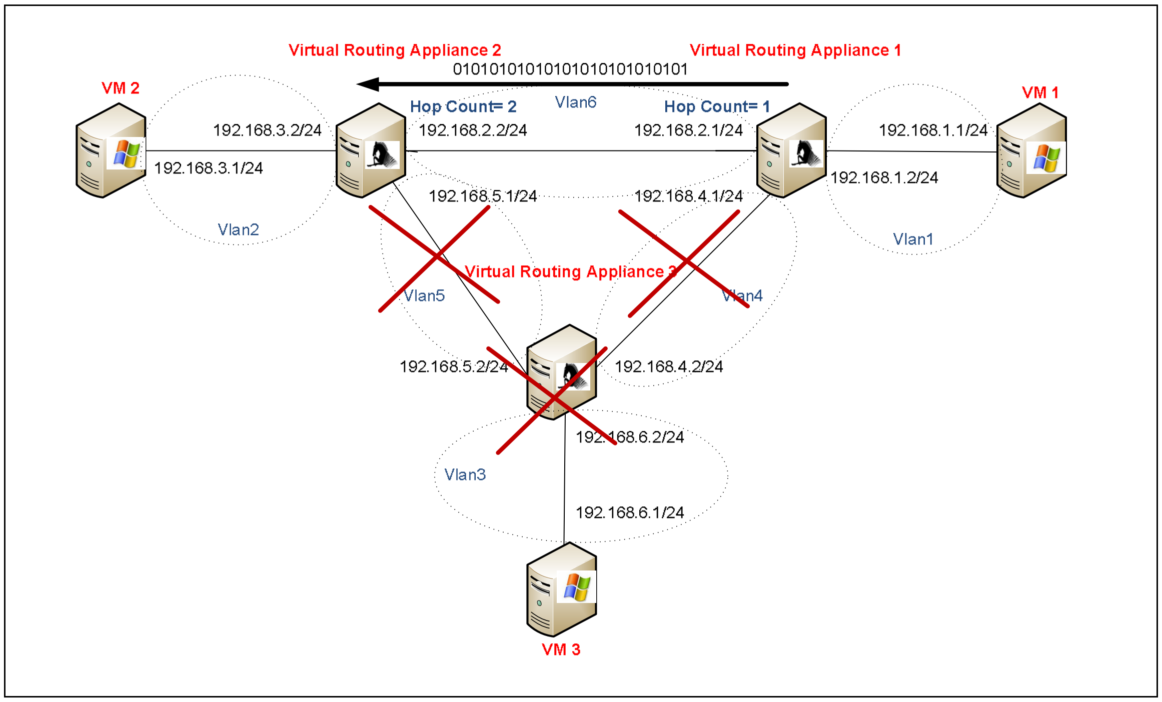
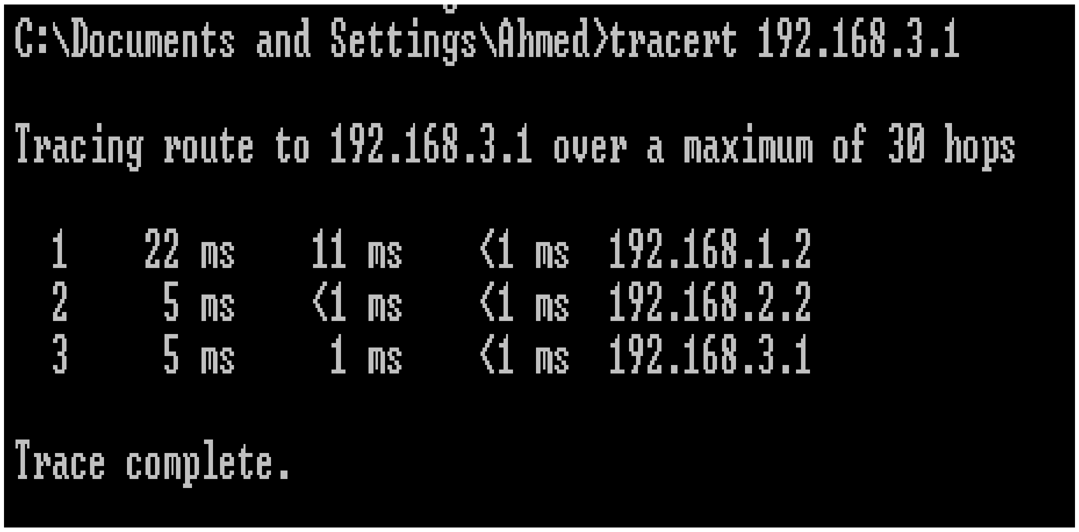


Figure 15: RIP routing decision topology

The following is a **tracert** command issued from the first virtual machine and targeting the second virtual machine. The result is that all packets are traversing from VRA1 to VRA2 which proves the concept of the RIP routing protocol.



```
C:\Documents and Settings\Ahmed>tracert 192.168.3.1

Tracing route to 192.168.3.1 over a maximum of 30 hops

  1    22 ms    11 ms    <1 ms  192.168.1.2
  2     5 ms    <1 ms    <1 ms  192.168.2.2
  3     5 ms     1 ms    <1 ms  192.168.3.1

Trace complete.
```

OSPF Scenario:

The second experiment that is conducted in this research uses an OSPF protocol in all virtual routing appliances. Unlike the RIP protocol, OSPF depends on different measurements and criteria when calculating routing paths. As described in RFC, the OSPF protocol employs path cost at its basic routing metric. In practice, it is known by the link speed (bandwidth) of the interface addressing the given route. In my virtual network environment, I tend to use mixed speed that can be set up from the VMware options and from a virtual routing appliance command line. The following drawing shows all VLANS associated with their link speed. This enables me to study the behavior of the OSPF protocol.

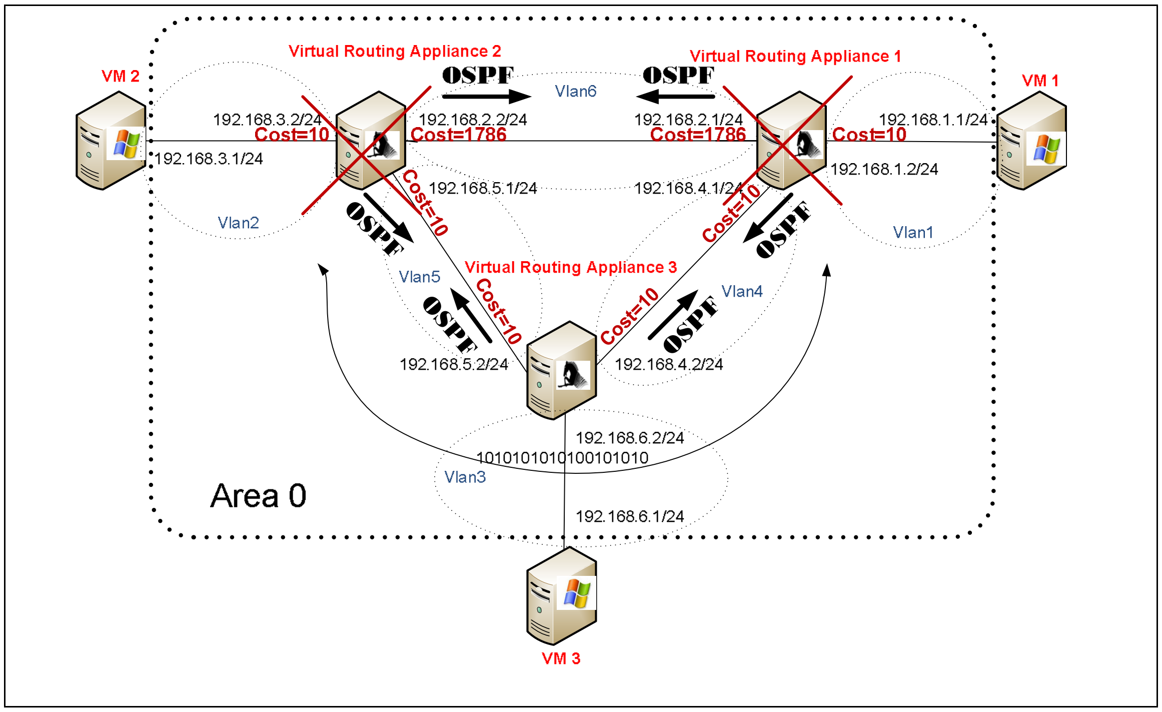
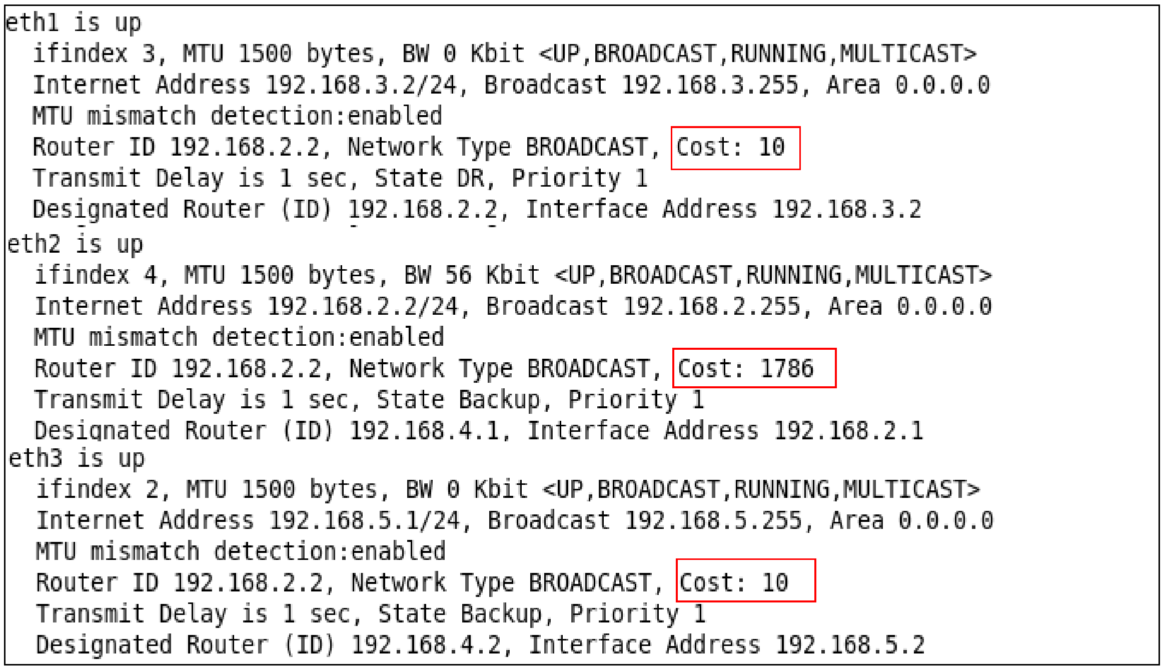


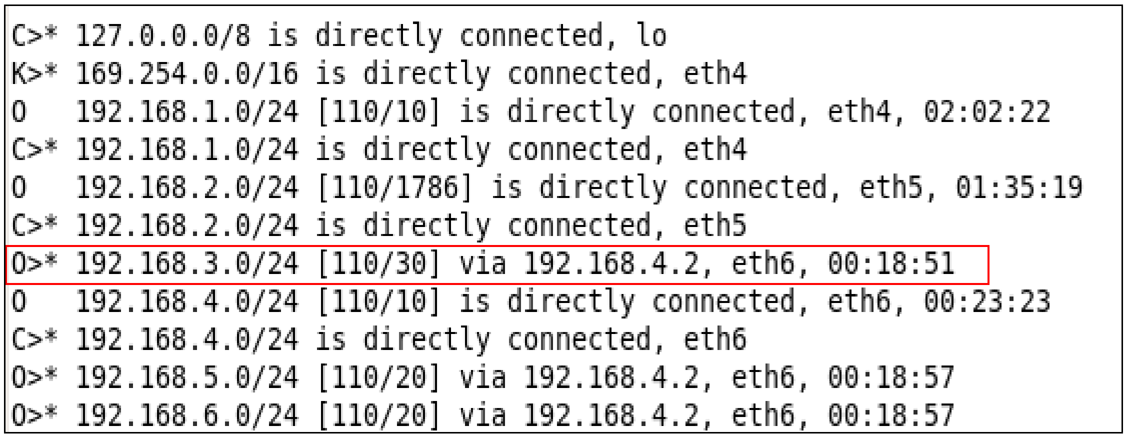
Figure 16: OSPF topology

The purpose of this experiment is to see what path packets are taking when sending traffic from the second virtual machine to the second virtual machine. It is important to notice in the above topology that not all links have the same speed of bandwidth. The screenshot taken from the first virtual appliances explains the path cost for all three interfaces connected to that virtual node. It shows that the Ethernet1 and Ethernet3 have the path cost of 10, meaning that their speed links are 10 Mbps. On the other hand, I tuned the speed link for Ethernet2 to be 56 Kbps using the **bandwidth 56** command. As a result, Ethernet 1 and Ethernet 3 have a total path cost of 10 and Ethernet 2 has a cost of 1786. This means that Eth1 and Eth3 have a higher priority when sending traffic.



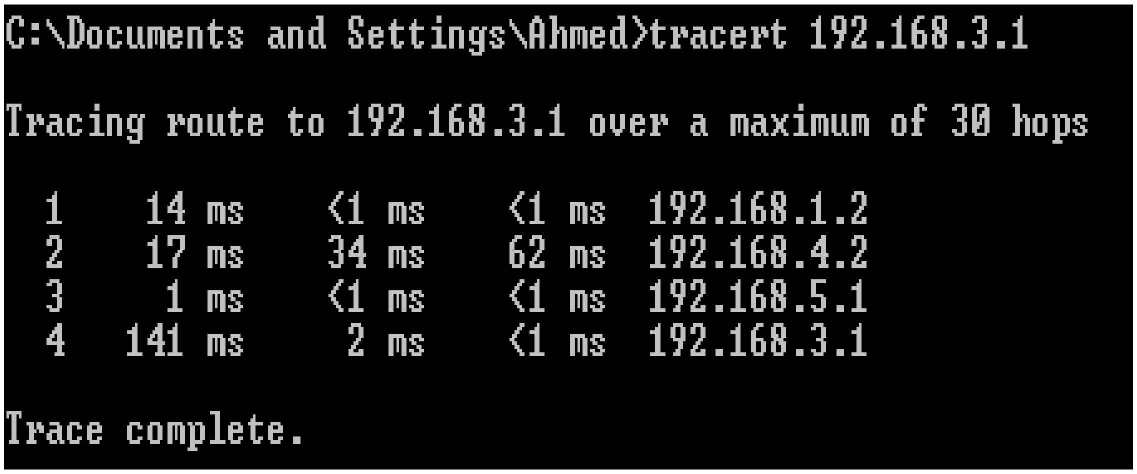
```
eth1 is up
  ifindex 3, MTU 1500 bytes, BW 0 Kbit <UP,BROADCAST,RUNNING,MULTICAST>
  Internet Address 192.168.3.2/24, Broadcast 192.168.3.255, Area 0.0.0.0
  MTU mismatch detection:enabled
  Router ID 192.168.2.2, Network Type BROADCAST, Cost: 10
  Transmit Delay is 1 sec, State DR, Priority 1
  Designated Router (ID) 192.168.2.2, Interface Address 192.168.3.2
eth2 is up
  ifindex 4, MTU 1500 bytes, BW 56 Kbit <UP,BROADCAST,RUNNING,MULTICAST>
  Internet Address 192.168.2.2/24, Broadcast 192.168.2.255, Area 0.0.0.0
  MTU mismatch detection:enabled
  Router ID 192.168.2.2, Network Type BROADCAST, Cost: 1786
  Transmit Delay is 1 sec, State Backup, Priority 1
  Designated Router (ID) 192.168.4.1, Interface Address 192.168.2.1
eth3 is up
  ifindex 2, MTU 1500 bytes, BW 0 Kbit <UP,BROADCAST,RUNNING,MULTICAST>
  Internet Address 192.168.5.1/24, Broadcast 192.168.5.255, Area 0.0.0.0
  MTU mismatch detection:enabled
  Router ID 192.168.2.2, Network Type BROADCAST, Cost: 10
  Transmit Delay is 1 sec, State Backup, Priority 1
  Designated Router (ID) 192.168.4.2, Interface Address 192.168.5.2
```

One of the key observation when looking at the routing table of the first and the second virtual routing appliances is that they have two paths to the same destination in case all their interfaces have the same link speed. However, the following routing table taken from the first virtual routing appliance shows that there is only one entry stored in that table. This is because OSPF selects the best route to the destination and stores it in its routing table. Note that the first routing appliance in this scenario is forwarding packets to 192.168.4.2/24 when the first virtual machine pings the second virtual machine.



```
C>* 127.0.0.0/8 is directly connected, lo
K>* 169.254.0.0/16 is directly connected, eth4
O   192.168.1.0/24 [110/10] is directly connected, eth4, 02:02:22
C>* 192.168.1.0/24 is directly connected, eth4
O   192.168.2.0/24 [110/1786] is directly connected, eth5, 01:35:19
C>* 192.168.2.0/24 is directly connected, eth5
O>* 192.168.3.0/24 [110/30] via 192.168.4.2, eth6, 00:18:51
O   192.168.4.0/24 [110/10] is directly connected, eth6, 00:23:23
C>* 192.168.4.0/24 is directly connected, eth6
O>* 192.168.5.0/24 [110/20] via 192.168.4.2, eth6, 00:18:57
O>* 192.168.6.0/24 [110/20] via 192.168.4.2, eth6, 00:18:57
```

The next screenshot obtained from the first virtual machine shows the complete route from the first virtual machine to the second virtual machine. It explains an obvious observation that the traffic is traversing through the third virtual routing appliance even though it is longer.



```
C:\Documents and Settings\Ahmed>tracert 192.168.3.1

Tracing route to 192.168.3.1 over a maximum of 30 hops

  1    14 ms    <1 ms    <1 ms  192.168.1.2
  2    17 ms    34 ms    62 ms  192.168.4.2
  3     1 ms    <1 ms    <1 ms  192.168.5.1
  4   141 ms     2 ms    <1 ms  192.168.3.1

Trace complete.
```

Determination of Latency:

Part 1: TCP

Delay measurement with RIP protocol

This section presents the commands utilized for measuring latency induced by RIP protocol for each of the two protocols of TCP and UDP. The precise commands and their output are shown. The results points out the average delay for each packet. A delay measurement is applied for both RIP and OSPF scenarios and the results are summarized in the table at the end of this section. All the following commands are generating from the first virtual machine and targeting the second virtual machine.

Command: ITGSend.exe –m rttm –a 192.168.3.1 –rp 10001 –T TCP –t 30000 –l send_tcp_rip –C 100000 –c 1000

```
----------------------------------------------------------
Flow number: 1
From 192.168.1.1:1036
To   192.168.3.1:10001
__________________________________________________________
****************  TOTAL RESULTS   ******************
__________________________________________________________
Number of flows         =           1
Total time              =     29.970407 s
Total packets           =     31717
Minimum delay           =     0.010905 s
Maximum delay           =     0.681792 s
Average delay           =     0.131910 s
Average jitter          =     0.001435 s
```

```
Delay standard deviation =     0.069519 s

Bytes received           =     31717000

Average bitrate          =     8466.218026 Kbit/s

Average packet rate      =     1058.277253 pkt/s

Packets dropped          =             0 (0.00 %)
```

Delay measurement with OSPF protocol

Command: ITGSend.exe –m rttm –a 192.168.3.1 –rp 10001 –T TCP –t 30000 –l send_tcp_ospf –C 100000 –c 1000

```
----------------------------------------------------------

Flow number: 1

From 192.168.1.1:1064

To   192.168.3.1:10001

__________________________________________________________

****************  TOTAL RESULTS   ******************

__________________________________________________________

Number of flows          =             1

Total time               =     29.947127 s

Total packets            =     7450

Minimum delay            =     0.035168 s

Maximum delay            =     1.786886 s

Average delay            =     0.401525 s

Average jitter           =     0.006812 s

Delay standard deviation =     0.309101 s

Bytes received           =     7450000

Average bitrate          =     1990.174216 Kbit/s

Average packet rate      =     248.771777 pkt/s
```

```
Packets dropped          =            0 (0.00 %)
```

Part 2: UDP

Delay measurement with RIP protocol

Command: ITGSend.exe –m rttm –a 192.168.3.1 –rp 10002 –T UDP –t 50000 –l send_udp_rip –C 100000 –c 1000

```
----------------------------------------------------------

Flow number: 1

From 192.168.1.1:1055

To   192.168.1.10:10001

__________________________________________________________

****************  TOTAL RESULTS   ******************

__________________________________________________________

Number of flows          =            1

Total time               =     49.974237 s

Total packets            =     33367

Minimum delay            =     0.000772 s

Maximum delay            =     1.453843 s

Average delay            =     0.015954 s

Average jitter           =     0.001533 s

Delay standard deviation =     0.055672 s

Bytes received           =     33367000

Average bitrate          =     5341.4722247 Kbit/s

Average packet rate      =     667.684031 pkt/s

Packets dropped          =     191773 (85.18 %)

Error lines              =            0
```

Delay measurement with OSPF protocol

Command: ITGSend.exe –m rttm –a 192.168.3.1 –rp 10002 –T UDP –t 30000 –l send_udp_ospf –C 100000 –c 1000

```
-----------------------------------------------------------

Flow number: 1

From 192.168.1.1:1070

To   192.168.3.1:10002

___________________________________________________________

****************  TOTAL RESULTS   ******************

___________________________________________________________

Number of flows          =            1

Total time               =      30.004165 s

Total packets            =      923

Minimum delay            =      0.079857 s

Maximum delay            =      7.485252 s

Average delay            =      0.777670 s

Average jitter           =      0.0383684 s

Delay standard deviation =      0.838684 s

Bytes received           =      923000

Average bitrate          =      246.099167 Kbit/s

Average packet rate      =      30.762396 pkt/s

Packets dropped          =      230525 (99.60 %)
```

Final results for latency:

For each of the two protocols of TCP and UDP, the results for delay are summarized in the following table. The latency induced by RIP protocol is unlike the delay with the OSPF protocol. Finally, the mathematical mean for all two protocols is calculated to show the average latency induced by RIP and OSPF routing protocols in a virtual environment.

Sr. No.	IP Protocol	RIP Protocol (in milliseconds)	OSPF Protocol (in milliseconds)
1	TCP	131.910	401.525
2	UDP	15.954	777.670
	Average Latency	73.932	589.5975

Table 3: Latency results

The average latency of all two protocols at **10 Mbps** is **73.932 milliseconds** for the RIP scenario and **589.5975 milliseconds** for the OSPF scenario.

Determination of Throughput:

This section targets the performance of the virtual environment, particularly the throughput. The throughput is always measured as a packet per second. Throughput would be to take two measurements of the total number of packets that have come in or out of a particular interface and take the packets at the second time and subtract it from the packets at the first time. This calculates the number of packets that have gone in and out in that time period. Finally, the time at point one and the time at point two needs to be collected and then subtract them and perhaps multiply them by a scale. The following formula illustrates the way the throughput is measured:

$$\boxed{pktsPerSecond = \frac{(inPackets_2 - inPackets_1)}{\sec onds_2 - \sec onds_1 * Scale}}$$

The idea here is simple. The first virtual routing appliance is responsible to monitor the other two virtual routing appliances and the virtual router itself. The first appliance generates SNMP requests throughout the network and list the result in a nicely format in Nagios. The following drawing shows the interfaces that send or receives SNMP requests.

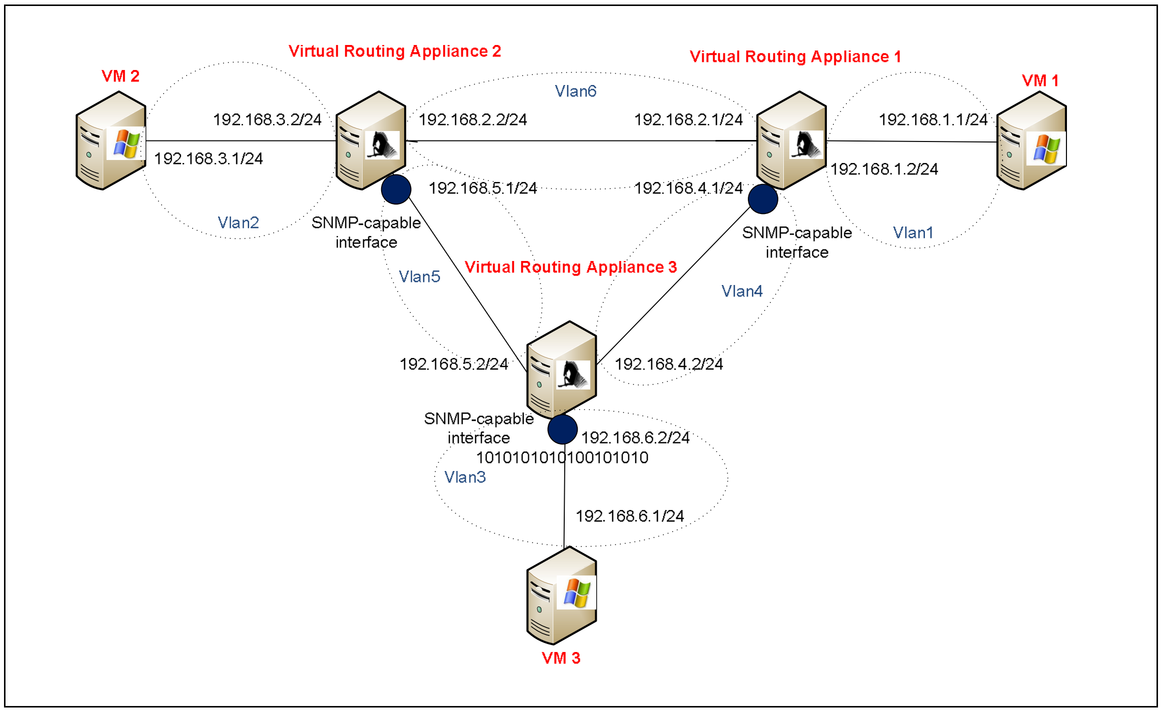
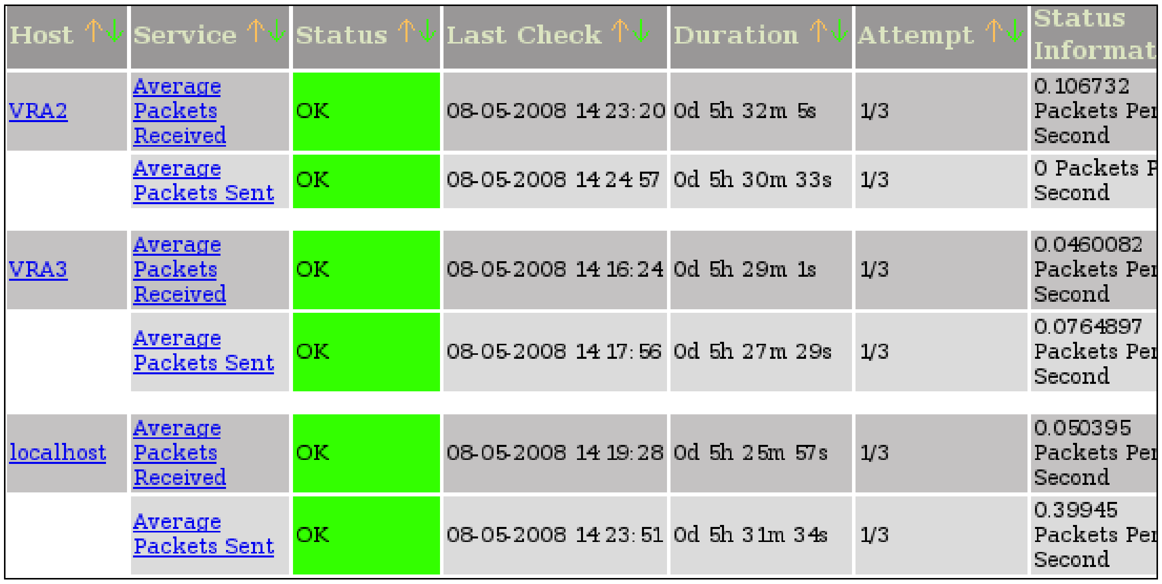


Figure 17: SNMP agents' distribution

The next step is to create services inside Nagios that will appear on the web-based browser. This browser shows the result of the services that have been generated for each piece of a virtual router. The two following files need to be created in order to achieve this task. "localhosts.cfg" is the file where all the IP addresses of the three virtual routing appliances as well as host names are defined. It also specifies the service's name that will appear in Nagios and the command name. The "commands.cfg "shows the actual SNMP command that is used to send a request to a specific router's interface. The appendix section lists all the hosts' and services' configurations.

An awk script is also created to calculate the throughput for the three virtual routing appliances. The script stores the initial reading in a separate file. It then computes the second reading and subtracts it from the first reading. The result of the calculation is shown in Nagios web-browser. In this example, the RIP protocol is used to route traffic between the three different subnets. Since the primary concert is to study the throughput in only the three virtual routing appliances, the other three virtual machines ate omitted from this scenario. The following screenshot taken from Nagios shows the statistic polls from the web-browser. It is important to note that there are two types of services I have created; the average packets sent and the average packets received. The following screenshot and table show the throughput calculated from the awk script and being embedded into the Nagios web-browser.



Host ↑↓	Service ↑↓	Status ↑↓	Last Check ↑↓	Duration ↑↓	Attempt ↑↓	Status Informat
VRA2	Average Packets Received	OK	08-05-2008 14:23:20	0d 5h 32m 5s	1/3	0.106732 Packets Pe Second
	Average Packets Sent	OK	08-05-2008 14:24:57	0d 5h 30m 33s	1/3	0 Packets F Second
VRA3	Average Packets Received	OK	08-05-2008 14:16:24	0d 5h 29m 1s	1/3	0.0460082 Packets Pe Second
	Average Packets Sent	OK	08-05-2008 14:17:56	0d 5h 27m 29s	1/3	0.0764897 Packets Pe Second
localhost	Average Packets Received	OK	08-05-2008 14:19:28	0d 5h 25m 57s	1/3	0.050395 Packets Pe Second
	Average Packets Sent	OK	08-05-2008 14:23:51	0d 5h 31m 34s	1/3	0.39945 Packets Pe Second

Machine Name	Mode	Throughput Rate (packets per seconds)
VRA1	Sent	0.39945
	Received	0.050395
VRA2	Sent	0.00
	Received	0.106732
VRA3	Sent	0.0764897
	Received	0.0460082

Table 4: Throughput results

The average throughput of all three virtual routing appliances is **0.23796985 packets per second** in the sent mode and **0.06771173 packets per second** in the received mode.

7. Final Results and Conclusion:

The last cumulative findings for the quantitative tests accomplished for the virtual routing appliances are the average of results for the all scenarios for latency and throughput parameters.

Parameter		**Average Rate**
Latency	**RIP**	**73.932 milliseconds**
Latency	**OSPF**	**589.5975 milliseconds**

Throughput	**Sent**	**0.23796985 packets per milliseconds**
Throughput	**Received**	**0.06771173 packets per milliseconds**

Table 5: Final results

Details of results for each parameter

- **Latency (RIP):** the latency observed in the RIP scenario is less than from the one found in the OSPF scenario. The reason is that traffic traverses through two hop counts resulting in less network latency although the OSPF build relationship with neighbor virtual routers faster. The value of 73.932 milliseconds came from both TCP and UDP packets generated from D-ITG and calculated the average of those IP packets.
- **Latency (OSPF):** the latency of on the other hand found in the OSPF scenario is obviously much higher than the one seen in the RIP scenario. I had to tune the first scenario by adjusting the bandwidth between the first virtual routing appliances and the second virtual routing appliance to be 56 Kbps. As a result, packets are traversing via the third virtual routing appliance that causes the latency to be higher. In order to get a better performance, the bandwidth between the three virtual routers should return to their previous status which is 10 Mbps.
- **Throughput (Sent/Received):** The throughput values in the above table indicate that the three virtual routing appliances send and receive traffic at low rates. The reason behind it is that I intended to isolate my virtual environment from the Internet. However, in order to increase the throughput rate, it is recommended to add three NIC interfaces and

associate them with each virtual routing appliance. Downloading and uploading files from the Internet would help enhance the throughput rate for all virtual machines.

The virtual routing appliance lessons the degree of building a virtual environment. It can be deployed as a virtual router with the assurance of forwarding packets to the right destination. According to the findings and observations of the tests conducted for this evaluation, a virtual routing appliance is best suited for educational and experimental purposes. It could usually be deployed to route traffic between subnets without the need to add physical resources.

8. Future Work:

The evaluation of the virtual routing appliance was conducted with limited routing protocols and was not using advanced features. The scale of this evaluation can be enlarged by testing the proposed virtual routing appliance with more routing protocols' configurations and conditions. These may include deploying other routing protocols such as EIGRP, BGP, and ISIS. The research can be also expanded by generating traffic for additional protocols, utilizing multiple routing protocols in a single scenario. Future research can also involve using Nagios to calculate additional services such as utilization, bandwidth, and response time.

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10. Appendix A: Nagios Configuration:

Localhost.cfg

```
# There are the virtual hosts' information that are used as an input for Nagios
define host{
        use                     linux-server
        host_name               localhost
        alias                   localhost
        address                 127.0..0.1
        }
define host{
        use                     linux-server
        host_name               VRA2
        alias                   VRA2
        address                 192.168.5.1
                }
define host{
        use                     linux-server
        host_name               VRA3
        alias                   VRA3
        address                 192.168.6.2
}



# These are the services that need to be define

define service{
        use                     generic-service
        host_name               localhost, VRA2, VRA3
        service_description     Average Packets Sent
        check_command           check_OutIpRate
                }
define service{
        use                     generic-service
        host_name               localhost, VRA2, VRA3
        service_description     Average Packets Received
        check_command           check_InIpRate
                }
```

<u>*Commands.cfg*</u>

```
# This command checks the ip packets received in a particular interface

define command{
        command_name            check_InIpRate
        command_line            $USER1$/check_InIpRate $USER1$ $HOSTADDRESS$
                }

# This command checks the ip packets sent to a particular interface
define command{
        command_name            check_OutIpRate
        command_line            $USER1$/check_OutIpRate $USER1$
$HOSTADDRESS$
                }
```

<u>Check_InIpRate:</u>

```
#!/bin/sh
# NOTE: the next three lines should be ONE LONG line in the script
 (echo "$2"; snmpget -v 2c -c public "$2" system.sysUpTime.0 ;snmpget -v 2c -c accessRO "$2"
ip.ipInReceives.0) | awk -f "$1"/check_InIpRate.awk
```

<u>Check_OutIpRate:</u>

```
#!/bin/sh
# NOTE: the next three lines should be ONE LONG line in the script
echo $* >/debug
(echo "$2"; snmpget -v 2c -c public "$2" system.sysUpTime.0; snmpget -v 2c -c accessRO "$2"
ip.ipOutRequests.0) | awk -f "$1"/check_OutIpRate.awk
```

<u>Check_InIpRate.awk:</u>

```
BEGIN                   {
seconds1 = seconds2 = 0;
inPackets1 = inPackets2 = 0;
}
```

```
NR == 1                 {
fname= "/usr/local/nagios/libexec/check_InIpRate_"$1".dat"
rc = system("test -f " fname);
if (rc == 0) {
          getline seconds1 <fname;
          getline inPackets1 <fname;
          }
}
NR == 2                 {
seconds2 = $4;
seconds2 = substr (seconds2, 2);
seconds2 = substr (seconds2, 1, length(seconds2)-1);
seconds2 = int (seconds2 / 100);
}
NR == 3                 {
inPackets2 = $4;
}
END             {
if(seconds1 != 0 || inPackets1 != 0)  {
   ## There IS a file, do the calculation
   pktsPerSecond = (inPackets2 - inPackets1) / (seconds2 - seconds1);
   print pktsPerSecond " Packets per second";
          }
else      {
print "RESULTS NOT AVAILABLE";
          }
print seconds2 >fname;
print inPackets2 >>fname;
}
```

Check_OutIpRate.awk:

```
BEGIN                   {
seconds1 = seconds2 = 0;
outPackets1 = outPackets2 = 0;
}
NR == 1                 {
fname= "/usr/local/nagios/libexec/check_OutIpRate_"$1".dat"
rc = system("test -f " fname);
if (rc == 0) {
          getline seconds1 <fname;
          getline outPackets1 <fname;
          }
}
NR == 2                 {
seconds2 = $4;
seconds2 = substr (seconds2, 2);
seconds2 = substr (seconds2, 1, length(seconds2)-1);
seconds2 = int (seconds2 / 100);
}
NR == 3                    {
outPackets2 = $4;
}
END              {
if(seconds1 != 0 || outPackets1 != 0)  {
   ## There IS a file, do the calculation
   pktsPerSecond = (outPackets2 - outPackets1) / (seconds2 - seconds1);
   print pktsPerSecond " Packets per second";
         }
else     {
print "RESULTS NOT AVAILABLE";
         }
print seconds2 >fname;
print outPackets2 >>fname;
}
```