# Optimized Routing Information Exchange in Hybrid IPv4-IPv6 Network using OSPFv3 & EIGRPv6

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***Abstract*—IPv6 is the next generation internet protocol which is gradually replacing the IPv4. IPv6 offers larger address space, simpler header format, efficient routing, better QoS and built-in security mechanisms. The migration from IPv4 to IPv6 cannot be attained in a short span of time. The main issue is compatibility and interoperability between the two protocols. Therefore, both the protocols are likely to coexist for a long time. Usually, tunneling protocols are deployed over hybrid IPv4-IPv6 networks to offer end-to-end IPv6 connectivity. Many routing protocols are used for IPv4 and IPv6. In this paper, researchers analyzed the optimized routing information exchange of two routing protocols (OSPFv3 & EIGRPv6) in hybrid IPv4-IPv6 network. Experimental results show that OSPFv3 performs better than EIGRPv6 in terms of most of the parameters i.e. convergence time, RTT, response time, tunnel overhead, protocol traffic statistics, CPU and memory utilization.**

***Keywords—EIGRPv6; OSPFv3; Hybrid IPv4-IPv6; Route Redistributio; Route Summarization; Tunneling***

## I. Introduction

The Internet is growing day by day throughout the world. Everyday, different types of devices are becoming part of the Internet. All these devices require IP address for communication with each other over the network. In Internet, “Internet Protocol” (IP) is the most broadly used routed protocol [1]. There are two versions of IP: IPv4 and IPv6. IPv4 protocol uses 32-bit addressing structure. It was introduced in 1981. Due to the anticipated shortage of its addresses, IPv6 protocol was designed by the “Internet Engineering Task Force” (IETF) in 1990 [2]. IPv6 uses 128-bit addressing scheme. The future is of IPv6 [3]. It will gradually replace IPv4 throughout the world. IPv4 is comparatively easy to configure, however, IPv6 is more complicated due to its nature of complex addresses [4]. Furthermore, IPv6 has more advantages than IPv4 in terms of header format simplification, efficient routing, built-in security, QoS and route optimized mobility [5, 6]. There are millions of devices around the world which are being used in IPv4; therefore, it is not easy to transit at once. A study report shows that after twenty-five years, it has replaced approximately 10 – 15 % around the world [7]. The core issue is compatibility and interoperability between the two protocols. Therefore, both the protocols are needed together for a long time. Multiple transition solutions i.e., dual stack, tunneling and translation techniques have been designed to work in the hybrid IPv4-IPv6 network [8].

Routing becomes a challenging task in case when both IPv4-IPv6 protocols are co-existed in a network. The co-existence of IPv4 and IPv6 at “Internet Service Providers” (ISPs) bring the major challenges for the users. Packet traversing is one of the main challenges, in which communication is between two IPv6 hosts over an IPv4 network. Packet traversing is achieved through tunneling. There are multiple tunneling standards [9]. These two IP protocols are not interoperable with one another. Each supports different kinds of routing protocols. For example, (RIP, IGRP, EIGRP, OSPF and BGP) are routing protocols of IPv4 network while (RIPng, EIGRPv6, OSPFv3 and BGPv4) are routing protocols of IPv6 [10]. EIGRP and OSPF are widely used in corporate and enterprise networks. However, their configuration method, metrics, administrative distance, convergence speed and performance are differed to each other.

In a corporate network, there are many routes in a routing table of the router. It can be million in case of IPv4, while it can be billion in case of IPv6. Some routes are directly connected while the remaining are transported by other routers. These transferred routes in a router may stretch by using “Route Redistribution”. After that, the size of the routing table is increased. In dynamic routing, it will increase the convergence time over the network. More convergence time will require more bandwidth and it affects the performance of the router. “Route Summarization” is used in routing protocols to minimize the convergence time and to reduce the size of the routing table. Both routing protocols (EIGRP & OSPF) support route summarization and route redistribution in hybrid IPv4-IPv6 network [10].

This study focuses on the performance analysis and comparison of optimized routing information exchange in hybrid IPv4-IPv6 network by using EIGRPv6 and OSPFv3 based on convergence time, tunnel overhead, protocol traffic statistics, end-to-end delay, response time, packet delivery ratio, CPU and memory utilization. We deploy and configure this mechanism on CISCO routers by using “Graphical Network Simulator” (GNS). To achieve these goals, we test these two routing protocols in hybrid IPv4-IPv6 network with the help of a simulator and conclude the results either, which one is more suitable for the “Next Generation Network” (NGN). The rest of the part of this paper is structured as follows: Section II presents related work and compares this research work to existing studies. Section III highlights a brief description of the routing protocols and their differences. Section IV gives the brief description of transition mechanisms. In section V, we display the experimental results. Finally, section VI concludes the paper.

## II. Related Work

Performance of routing protocols have been analyzed in many papers [11, 12, 18, 22, 23]. The authors have examined and compared the performance of different routing protocols (RIP, EIGRP and OSPF) by using multiple simulators. The researchers tested the different applications based on several parameters and concluded the results that EIGRP performed better in terms of convergence time, CPU utilization, throughput, end-to-end delay and bandwidth control as compared to RIP and OSPF. In [22], researchers observed and compared the performance of two routing protocols (EIGRP and OSPF) in three different networks with same topologies. One network is configured with EIGRP, second is configured with OSPF and third is configured with EIGRP and OSPF. This research study shows that EIGRP consumed fewer system resources as compared to OSPF in real time applications. Although, in these related works, researchers compared routing protocols with IPv4. However, these studies lack the evaluation for the IPv6.

Other closely related works are presented in [4, 13, 14, 15, 24, 26] in which authors compared and analyzed two routing protocols (OSPFv3 & EIGRPv6) based on their performance in a small network. In [4], the researchers focused on configuration analysis and compared IPv6 configuration commands with IPv4 configuration commands and analyzed that IPv6 configuration commands are more complex than IPv4 configuration commands because of IPv6 addresses complexity. Research study [15] showed that IPv6 provided better QoS as compared to IPv4. In [13, 27] studies, the researchers tested routing protocols in IPv6 network and examined that EIGRPv6 has the advantages over OSPFv3 in term of convergence time in a small network with the help of multiple simulators. These studies did not specifically evaluate the performance of the routing protocols in the hybrid IPv4-IPv6 network.

Further very close related works of this paper are [1, 16, 17, 19, 28, 29] in which the researchers compared and analyzed the performance of dissimilar routing protocols in hybrid IPv4-IPv6 network based on user traffic. Research studies [19, 28, 29, 31] focused on transition methods. Researchers discussed in detail the pros and cons of different transition methods in terms of QoS and security perspective. In [16], the researchers investigated the video protocols traffic in dual-stack and tunneling (IPv6to4 and IPv6in4). Results showed that EIGRPv6 gave better performance in terms of packet loss and CPU utilization in dual stack transition method. Dual-stack is a transition mechanism in which a network or a host runs both IPv4 and IPv6 addresses. Both versions of IP protocol are configured and operated simultaneously on the device. In [17], the researchers experimented EIGRP and OSPF in different topologies of dual-stack network. Their study showed that EIGRP is much better than OSPF in packet loss performance.

Although, the researchers evaluated the performance of routing protocols (EIGRP & OSPF) in IPv4 networks, in pure IPv6 networks and in dual-stack networks based on numerous parameters like (RTT, packet loss, throughput, end-to-end delay, convergence time, jitter, CPU and memory utilization) for user traffic. To the best of our knowledge, these two protocols and their behavioral are not tested in tunneling. It is strongly needed to investigate the interoperability of these two routing protocols (EIGRP & OSPF) in tunneling regarding routing information exchange in terms of others parameters like (response time, tunnel overhead, end-to-end delay, hello messages exchange and memory utilization). Our focus in this research paper is to relate the performance of routing protocols (EIGRPv6 & OSPFv3) based on optimized routing information exchange in hybrid IPv4-IPv6 network by using a tunneling technique.

## III. Routing Protocols

Routing protocols are classified into two categories: distance vector routing protocols and link state routing protocols. Distance vector routing protocols use “Bellman-Ford” algorithm to calculate the best path, while link state routing protocols use “Dijsktra” algorithm to calculate the best route. RIP, IGRP and BGP are distance vector routing protocols, while IS-IS and OSPF are link state routing protocols. Moreover, EIGRP is considered a hybrid. EIGRP uses “Diffusion Update Algorithm” (DUAL) to calculate the best routes. Routing table consists of calculating best paths in the form of network ID called routes. If the destination route is not in the routing table, then router discards the packet. ISPs use routing protocols per their need to keep the routing tables updated [18]. When IPv6 has been successfully launched as a next generation network, routing protocols have also been upgraded for next generation network.

### A. EIGRPv6

Enhance Interior Gateway Routing Protocol (EIGRP) is a CISCO proprietary protocol. It is said to be a hybrid routing protocol, which means it is a crossover between link state and distance vector routing proctors. EIGRP was introduced in 1993 and it is IPv4 supported [19]. EIGRPv6 is the advance version and it is IPv6 supported. It works in the “Autonomous System” (AS). AS is a group of similar routers exchanging routes under the same administrative control [20]. It is said to be a classless routing protocol and supports “Variable Length Subnet Mask” (VLSM). VLSMs enable you to allocate required host bits on a granular basis. The main feature of this routing protocol is its unequal load balancing.

There are three tables in the EIGRPv6 routing protocol, which help to routing decisions. Neighbor table, topology/database table and routing table. By default, “bandwidth and delay” are the metrics of EIGRPv6 to determine the best path, however, reliability, load and MTU may also be used as metrics. It sends “hello messages” to its neighbors after every 5 seconds on the links (Ethernet and FDDI) and after 60 seconds on the links (Frame Relay and SMDS) [21]. Its administrative distance is 90. It uses as multicast updates instead of broadcast. FF02::A is multicast address [3].

### B. OSPFv3

Open Shortest Path First (OSPF) is a link state routing protocol. It is an open standard and the most popular routing protocol proposed by IETF in 1988. IETF published a revised version of OSPFv3 for IPv6 in 1999. It is characterized by stability and scalability. Due to open standard, its specification is freely available [21]. It divides the network into areas to group similar routers together for better management. If there are multiple areas, then one area is said to be a "backbone area". Backbone area is referred to as "area 0". Multiple areas are connected to the backbone through virtual links. It is also a classless routing protocol and supports VLSM [22]. It also supports load balancing up to 16 equal paths. Cost is the metric to determine the best path. Its administrative distance is 110.

In OSPFv3, there are also three tables. Neighbor table, topology table and routing table. The topology information is carried in "Link State Advertisement" (LSAs). There are several types of LSAs. Some are normally used. "Router link LSA" (LSA type 1) describes the state of the router's interfaces, "network link LSA" (LSA type2) represents a broadcast in LAN and describes the routers connected to the LAN, "network summary LSA" (LSA type3) is for Area Border Router (ABRs), "Autonomous System Border Router (ASBR) summary LSA" (LSA type4), "external LSA" (LSA type5) and "Not So Stubby Area (NSSA) external LSA" (LSA type7) [23]. Five types of packets: Hello, Database Description (DBD), Link State Request (LSR), Link State Update (LSU) and Link State Acknowledgment (LSACK), which are used in the normal operation of OSPFv3 [24]. It sends "hello messages" after every 10 seconds to its neighbor for establishing and maintaining the relationship.

In OSPFv3, the method of Hello packets has changed. The ID of interface must be copied into the Hello packet before the Hello packet is sent [25]. If a neighbor does not reply within 40 seconds (dead interval time) then the neighbor is considered as dead. Neighbor can be in a different state. There are seven states in OSPFv3 and they are (Down, Init, 2Way, ExStart, Exchange, Loading and Full) [26]. In multi-access network, it works as "Designated Router" (DR) or "Backup Designated Router" (BDR). In OSPFv3, DR/BDR routers are identified by their routers ID's instead of their IP addresses. DR is the responsible for making adjacencies with all neighbors on a multi-access network (such as Ethernet or FDDI). BDR is used to provide redundancy in the network. If DR fails, then the BDR immediately becomes the new DR. Multicast LSAs are used to communicate with each other. LSAs are sent to the DR/BDR at FF02::6 and other routers at FF02::5 [3].

### C. *Route Redistribution*

Route redistribution is the process of advertising routes from one routing protocol to another routing protocol [9]. When a router relates to two dissimilar routing protocols, then the routes cannot be advertised from one routing protocol to another routing protocol without redistribution. Static and directly connected routes may also be advertised into routing protocols through redistribution [10]. During the redistribution process, metric is used by the routing protocol in which the routes would be advertised [26]. Redistributed routes become external routes into the routing table. In our scenario, there are 15 static routes and 15 loopback interfaces on "Router-1" as it has shown in figure 1 and these routes can be advertised into routing protocol through redistribution. EIGRPv6 and OSPFv3 both support redistribution for IPv4-IPv6.

### D. *Route Summarization*

Route summarization, also termed as route aggregation is the optimization process in which different advertised routes can be consolidated during convergence between routers. There can be millions of routes in a routing table. Route summarization decreases the number of routes in the routing table. It advertises a single route that is called summary [24]. It will increase the speed of convergence, decrease the size of the routing table in memory and reduce the routing update traffic. In our scenario, there are 15 static routes and 15 loopback interfaces on a "Router-1" as it is shown in figure 1 and these routes can be advertised into routing protocol as a summary address through summarization. EIGRPv6 and OSPFv3 both support summarization for IPv4 and IPv6. During experiments, we will perceive the impact of summarization in these protocols.

### E. *Protocol Comparison*

OSPFv3 and EIGRPv6 have many similar features: both support VLSM and "Classless Inter-Domain Routing" (CIDR). CIDR is also known as "prefix routing". It just identifies the number of bits of the network ID and host ID. Both use 32-bit router ID's. Both maintain three tables. Both send partial routing updates when any change occurs instead of periodic [12]. Both support route summarization and redistribution.

EIGRPv6 is only supported on CISCO routers because of CISCO proprietary while OSPFv3 is an open standard and easily configured on all brands that's why it is also known as the industry standard [27]. EIGRPv6 usually uses a combination of metrics to calculate the best path while OSPFv3 uses only one metric and that is cost. An administrative distance of EIGRPv6 is 90 while OSPFv3 is 110. Lower administrative distance means high priority if both routing protocols are running on the same device. EIGRPv6 is designed for flat network while OSPFv3 is designed for large flat network, its hierarchical nature gives an advantage over EIGRPv6. EIGRPv6 is simple to be configured while the configuration in OSPFv3 is difficult because it works in areas and there are numerous types of areas, each of them can be stubby, transit or not so stubby. Differences in these areas and their purposes may increase the level of understanding and difficulty of configuration [4].

*1) Configuration Point of View:* Some comparisons are given below per their configuration. Both protocols (EIGRPv6 & OSPFv3) are same configured in interface mode. Both protocols require 32-bit router IDs and it is configured in global configuration mode. OSPFv3 demands enter its router ID before its configuration while EIGRPv6 does not require its router ID before its configuration. Route redistribution is configured in global configuration mode in both protocols. In OSPFv3, route summarization is configured in global configuration mode while in EIGRPv6, it is configured in interface mode. When we advertise external routes in EIGRPv6 as a summary address, it displays in routing table with code "D" as an EIGRP route as shown in figure 3 while when we advertise external routes in OSPFv3 as a summary address, it displays in routing table with code "OE2" as an OSPF external route as shown in figure 5.

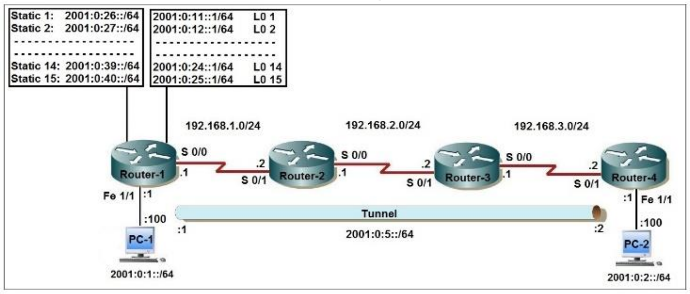


Fig. 1. IPv6 tunnel over IPv4

## IV. HYBRID IPV4-IPV6 NETWORK

IPv4 and IPv6 are not compatible with each other. ISPs must provide services in both IPv4/IPv6 network because users can be mixed. Some users are only in IPv4 network, some are in dual-stack and in future, there would be only IPv6 network users [28]. The primary reason for the transition is that the user may need to access data that will only be available in IPv6. There are multiple modes of transition:

- Dual-Stack
- Tunnelling
- Translation

### A. Dual-Stack

In dual-stack mechanism, IPv4 and IPv6 are established and operated simultaneously on the device. It is a transition technique. It allows to IPv4 supported device to communicate with only IPv4 supported while IPv6 based nodes can communicate explicitly with IPv6 based nodes [16]. However, IPv6 based nodes can't communicate with IPv4 nodes. It is the easiest technique but it also has some complex network management and troubleshooting issues.

### B. Tunneling

Tunnel is a logical connection which is created over the existing network. In tunneling mechanism, IPv6 traffic is sent over existing IPv4 network by encapsulating in IPv4 header at one end [29]. At the second end of the tunnel, node extracts the IPv6 datagram from the IPv4 header and forwards it to its actual IPv6 network. Interesting part of the tunneling is that the start and end nodes of the tunnel are dual-stack enabled. There are multiple tunneling approaches and some of them are:

- Configured Tunnelling
- 6to4 Tunnelling
- GRE Tunnelling

*1) Configured Tunneling:* It is a static and point-to-point tunnel. In this tunnel, both ends are manually configured. A permanent virtual link is built between two IPv6 networks over the IPv4 network. Both end nodes of the tunnel have IPv4 route able addresses and an IPv6 address is required to configure a tunnel. This tunnel is not scalable because it must be configured manually. It is easy to deploy and available on most platforms.

*2) 6to4 Tunneling:* It is an automatic and point-to-multipoint tunnel. In this tunnel, both ends are automatically configured with IPv6 global address prefix "2002:wwwxx:yyzz::/16". The "wwwxx:yyzz" is the colon-hexadecimal representation of a public IPv4 address and is obtained dynamically from the IPv4 address embedded in the IPv6 destination address. It is not only a tunneling technique but an address assignment as well. It is used to assign global IPv6 address in the network [30]. It is introduced to provide the configuration simplicity. It is less secure than static tunnel.

*3) Generic Route Encapsulation (GRE Tunneling):* It is also a static and point-to-point encapsulation tunnel. In this tunnel, both ends are manually configured. Like a configured tunnel, it is also configured between two points with a separate IPv6 address over the IPv4 network. In GRE tunnel, end-points are authenticated by a simple key. This simple key is transmitted in clear text during the setup of the tunnel. In GRE, IP protocol type 47 traffic would must be opened for inbound/outbound.

### C. Translation

It is a simple method. It translates the IPv6 traffic to IPv4 traffic without encapsulation. In this method, the traffic is simply converted into destination form. There are two translation methods:

- NAT-PT
- NAT64

*1) NAT-PT:* "Network Address Translation-Protocol Translation" (NAT-PT) method converts IPv6 traffic to IPv4 and vice versa. It is configured as statically or dynamically. This method is like NAT function but protocol translation function is additional in it. NAT-PT is attached with an "Application Layer Gateway" (ALG) functionality that can convert "Domain Name System" (DNS) mappings between protocols. ALG consists of a security components that enhances a firewall or NAT. It allows customized NAT traversal filters to be plugged into the gateway.

*2) NAT64:* One drawback in NAT-PT was its attachment with ALG. It is said to be a burden to deployment. NAT64 also originated DNS64. Both are configured independently. NAT64 can be deployed as stateless or state-full.

## V. EXPERIMENTS AND RESULTS

In this study, GNS3 simulator is used for all experiments. GNS3 is a network emulator software and it is used to simulate complex network. It uses dynamips emulation software to simulate CISCO IOS. Dynamips is an emulator computer program and can emulate the hardware of the CISCO series routing platforms by directly booting an actual CISCO IOS image into the emulator. That's why its results are very close to the results obtain by real routers and it can valid for decisions. Figure 1 shows the topology of our network design. Topology consists of four CISCO 7200 series routers connected to each other with serial link with an IPv4 addresses. By default, serial link provides 1.5 mbps bandwidth. Two virtual hosts (PC-1 & PC-2) are also connected through fastEthernet link with edge routers with IPv6 addresses. By default, the fastEthernet link supports 100 mbps bandwidth. Table-1 shows the description of devices.

Router-1 and Router-4 are dual-stack routers. An IPv6 tunnel is established between two edge routers (Router-1 & Router-4) over IPv4 network. We used static tunnel because studies show that it is more secure and its working is better than others. We advertised all static routes and loopback interface routes as a summary address through this tunnel and then gather results. Data will be collected by using router's commands. Whireshark tool is also used for packets capture and analysis. In this study, all experiments are repeated 5 times during different times of the day and the reported results are averaged over these runs. Performance evaluation of OSPFv3 and EIGRPv6 is measured for this topology based upon convergence time, round trip time (RTT), response time, protocol traffic, tunneling overhead, CPU and memory utilization.

TABLE I. DEVICES & DESCRIPTION

| S# | Device | Description |
|---|---|---|
| 01 | Router | GNS3 based CISCO 7200 series, IOS v. 12.4(11)T1, c7200-adventerprisek9-mz.124-11.T1.bin Total = 4 |
| 02 | PC | GNS3 based IPv6 Client Machines Total = 2 |

## A. EIGRP Configuration

Our testbed is a hybrid IPv4-IPv6 network. So, we need to configure both versions of routing protocols as well as routed protocols in our scenario. Router-1 and Router-4 are dual stack routers. First, make sure IPv6 routing is enabled on these two routers then assign IP addresses on all interfaces per topology. EIGRP works in AS. We configured AS 10 for EIGRP and AS 100 for EIGRPv6.

Now create a tunnel interfaces on edge routers and assign IP addresses per figure 1. Configure source and destination IP addresses in tunnel interface. Finally, select tunnel mode and configure EIGRPv6 with AS 100.

*1) EIGRPv6 Route Redistribution:* In our scenario, there are total 15 static routes and 15 loopback interface routes. Create all static routes in global configuration mode. Create all loopback interfaces and then assign IPv6 addresses. Now redistribute all these routes into EIGRPv6. Both versions of EIGRP are redistributed routes in global configuration mode. We can see the advertised routes as external routes in routing table as shown in figure 2 given below.

```
Router-4#sh ipv6 route
IPv6 Routing Table - 36 entries
Codes: C - Connected, L - Local, S - Static, R - RIP, B - BGP
       U - Per-user Static route, M - MIPv6
       I1 - ISIS L1, I2 - ISIS L2, IA - ISIS interarea, IS - ISIS summary
       O - OSPF intra, OI - OSPF inter, OE1 - OSPF ext 1, OE2 - OSPF ext 2
       ON1 - OSPF NSSA ext 1, ON2 - OSPF NSSA ext 2
       D - EIGRP, EX - EIGRP external
D   2001:0:1::/64 [90/297246976]
     via FE80::C0A8:101, Tunnel0
C   2001:0:2::/64 [0/0]
     via ::, FastEthernet0/0
L   2001:0:2::1/128 [0/0]
     via ::, FastEthernet0/0
C   2001:0:5::/64 [0/0]
     via ::, Tunnel0
L   2001:0:5::2/128 [0/0]
     via ::, Tunnel0
EX  2001:0:11::/64 [170/297372416]
     via FE80::C0A8:101, Tunnel0
EX  2001:0:12::/64 [170/297372416]
     via FE80::C0A8:101, Tunnel0
EX  2001:0:13::/64 [170/297372416]
     via FE80::C0A8:101, Tunnel0
EX  2001:0:14::/64 [170/297372416]
     via FE80::C0A8:101, Tunnel0
EX  2001:0:15::/64 [170/297372416]
     via FE80::C0A8:101, Tunnel0

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EX  2001:0:36::/64 [170/297244416]
     via FE80::C0A8:101, Tunnel0
EX  2001:0:37::/64 [170/297244416]
     via FE80::C0A8:101, Tunnel0
EX  2001:0:38::/64 [170/297244416]
     via FE80::C0A8:101, Tunnel0
EX  2001:0:39::/64 [170/297244416]
     via FE80::C0A8:101, Tunnel0
EX  2001:0:40::/64 [170/297244416]
     via FE80::C0A8:101, Tunnel0
L   FF00::/8 [0/0]
     via ::, Null0
```

Fig. 2. EIGRPv6 Route Redistribution

*2) EIGRPv6 Route Summarization:* Multiple external routes are advertised in routing protocols. Routing table size will increase if they are not summarized. Configure summary address in tunnel interface. Route summarization decreases the size of routing table as shown in figure 3 given below.

```
Router-4#sh ipv6 route
IPv6 Routing Table - 6 entries
Codes: C - Connected, L - Local, S - Static, R - RIP, B - BGP
       U - Per-user Static route, M - MIPv6
       I1 - ISIS L1, I2 - ISIS L2, IA - ISIS interarea, IS - ISIS summary
       O - OSPF intra, OI - OSPF inter, OE1 - OSPF ext 1, OE2 - OSPF ext 2
       ON1 - OSPF NSSA ext 1, ON2 - OSPF NSSA ext 2
       D - EIGRP, EX - EIGRP external
D   2001::/32 [90/297244416]
     via FE80::C0A8:101, Tunnel0
C   2001:0:2::/64 [0/0]
     via ::, FastEthernet0/0
L   2001:0:2::1/128 [0/0]
     via ::, FastEthernet0/0
C   2001:0:5::/64 [0/0]
     via ::, Tunnel0
L   2001:0:5::2/128 [0/0]
     via ::, Tunnel0
L   FF00::/8 [0/0]
     via ::, Null0
```

Fig. 3. EIGRPv6 Route Summarization

## B. OSPF Configuration

OSPF works in different areas. We configured area 0 for OSPFv2 and area 0 for OSPFv3. OSPFv2 is configured in global configuration mode while OSPFv3 is configured per interface.

Now create a tunnel interfaces on edge routers and assign IP addresses per figure 1. Configure source and destination IP addresses in tunnel interface. Finally, select tunnel mode and configure OSPFv3 with area 0.

*1) OSPFv3 Route Redistribution:* Create all static routes. Create all loopback interfaces and then assign IPv6 addresses. Now redistribute all these routes into OSPFv3. Both versions of OSPF are redistributed routes in global configuration mode.

We can observe that all these routes are present in routing table as external routes as shown in figure 4 given below.

```
Router-4#sh ipv6 route
IPv6 Routing Table - 36 entries
Codes: C - Connected, L - Local, S - Static, R - RIP, B - BGP
       U - Per-user Static route, M - MIPv6
       I1 - ISIS L1, I2 - ISIS L2, IA - ISIS interarea, IS - ISIS summary
       O - OSPF intra, OI - OSPF inter, OE1 - OSPF ext 1, OE2 - OSPF ext 2
       ON1 - OSPF NSSA ext 1, ON2 - OSPF NSSA ext 2
       D - EIGRP, EX - EIGRP external
O   2001:0:1::/64 [110/11112]
     via FE80::C0A8:101, Tunnel0
C   2001:0:2::/64 [0/0]
     via ::, FastEthernet0/0
L   2001:0:2::1/128 [0/0]
     via ::, FastEthernet0/0
C   2001:0:5::/64 [0/0]
     via ::, Tunnel0
L   2001:0:5::2/128 [0/0]
     via ::, Tunnel0
OE2  2001:0:11::/64 [110/20]
     via FE80::C0A8:101, Tunnel0
OE2  2001:0:12::/64 [110/20]
     via FE80::C0A8:101, Tunnel0
OE2  2001:0:13::/64 [110/20]
     via FE80::C0A8:101, Tunnel0
OE2  2001:0:14::/64 [110/20]
     via FE80::C0A8:101, Tunnel0
OE2  2001:0:15::/64 [110/20]
     via FE80::C0A8:101, Tunnel0
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OE2  2001:0:36::/64 [110/20]
     via FE80::C0A8:101, Tunnel0
OE2  2001:0:37::/64 [110/20]
     via FE80::C0A8:101, Tunnel0
OE2  2001:0:38::/64 [110/20]
     via FE80::C0A8:101, Tunnel0
OE2  2001:0:39::/64 [110/20]
     via FE80::C0A8:101, Tunnel0
OE2  2001:0:40::/64 [110/20]
     via FE80::C0A8:101, Tunnel0
L   FF00::/8 [0/0]
     via ::, Null0
```

Fig. 4. OSPFv3 Route Redistribution

*2) OSPFv3 Route Summarization:* Configure summary address in global configuration mode. Routing table after summarization is given below in figure 5.

```
Router-4#sh ipv6 route
IPv6 Routing Table - 7 entries
Codes: C - Connected, L - Local, S - Static, R - RIP, B - BGP
       U - Per-user Static route, M - MIPv6
       I1 - ISIS L1, I2 - ISIS L2, IA - ISIS interarea, IS - ISIS summary
       O - OSPF intra, OI - OSPF inter, OE1 - OSPF ext 1, OE2 - OSPF ext 2
       ON1 - OSPF NSSA ext 1, ON2 - OSPF NSSA ext 2
       D - EIGRP, EX - EIGRP external
OE2  2001::/32 [110/20]
     via FE80::C0A8:101, Tunnel0
O   2001:0:1::/64 [110/11112]
     via FE80::C0A8:101, Tunnel0
C   2001:0:2::/64 [0/0]
     via ::, FastEthernet0/0
L   2001:0:2::1/128 [0/0]
     via ::, FastEthernet0/0
C   2001:0:5::/64 [0/0]
     via ::, Tunnel0
L   2001:0:5::2/128 [0/0]
     via ::, Tunnel0
L   FF00::/8 [0/0]
     via ::, Null0
```

Fig. 5. OSPFv3 Route Summarization

### C. Convergence Time

When a router is exchanging its topological information with other routers within the network and try to complete its routing table, it is said to be a convergence state. In convergence state, only routing information is exchanged. Convergence time is the measure of how fast a set of routers reach the state of convergence. It is an important performance indicator for routing protocols. The size of the network also plays an important role. A large network will converge slower than small network. In our experiments, we calculated convergence and re-convergence time of both routing protocols (EIGRPv6 & OSPFv3) over the IPv6 tunnel before and after summarization as shown in figures 6 & 7.

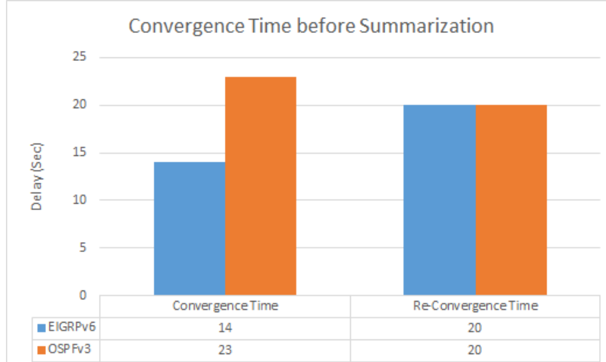



Fig. 6. Convergence Time before Summarization

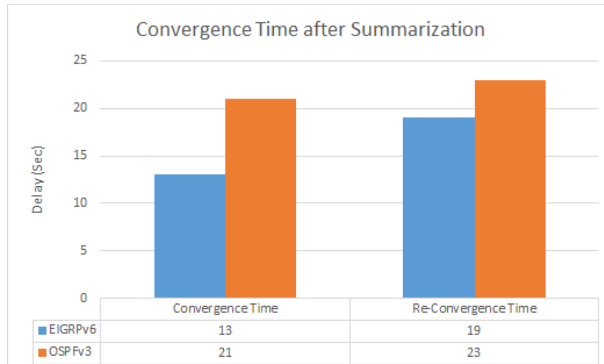



Fig. 7. Convergence Time after Summarization

In the figures 6 & 7, average convergence time for multiple rounds (5 times) is noted for both routing protocols from “up state of serial interface” to “adjacent state of tunnel interface” on Router-4. We observed that EIGRPv6 provides fast convergence as compared to OSPFv3 in before and after summarization. We also observed that summarization plays an important role in fast convergence for both protocols.

### D. Round Trip Time (RTT)

It is the total time taken by a packet to travel from source to destination and time taken by an acknowledgement back. RTT is a key parameter in the network layer. “Transmission Control Protocol” (TCP) protocol is used on top of the “Internet Control Message Protocol” (ICMP) to ping messages to get the RTT results between sender and receiver. Figure 8 shows the average RTT statistics for multiple rounds by using two routing protocols (OSPFv3 & EIGRPv6) without summarization over the IPv6 tunnel. Results are calculated from PC-2 to Loopback-1.

For validating the results, we calculated “coefficient of variation” (CV). General formula of CV is given below (1). Where S is the standard deviation and $\overline{X}$ is the mean. In this experiment, calculated CV of EIGRPv6 is 63 ms while CV of OSPFv3 is 37 ms. Results show that the RTT of OSPFv3 is much better than EIGRPv6 without summarization.

$$CV = \frac{S}{\overline{X}} * 100 \qquad (1)$$

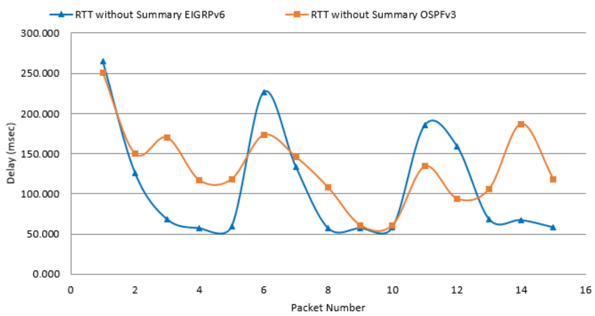



Fig. 8. Round Trip Time before Summarization

Figure 9 shows the average RTT statistics with summary address over the IPv6 tunnel. Results are calculated from PC-2 to Loopback-1. CV of EIGRPv6 is 45 ms while CV of OSPFv3 is 51 ms in this experiment. Results show that EIGRPv6 provides better performance than OSPFv3 with route optimization.

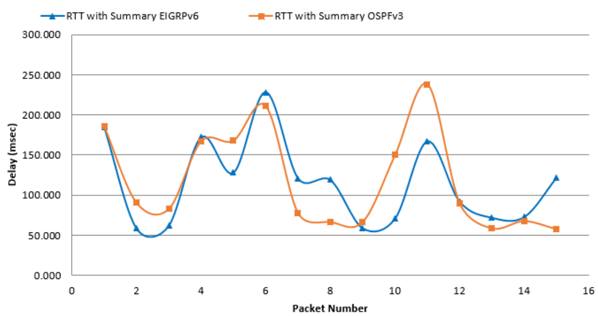



Fig. 9. Round Trip Time after Summarization

### *E. Response Time*

It is the total time that it takes to respond to a request for the service. In our experiments, response time is measured for both OSPFv3 and EIGRPv6 over the hybrid IPv4-IPv6 network before and after summarization. Figure 10 shows the average response time for different rounds without summarization. Results are calculated from PC-2 to Loopback-1. CV of EIGRPv6 is 81 ms while the CV of OSPFv3 is 79 ms. Results show that OSPFv3 has an advantage over EIGRPv6 in this experiment.

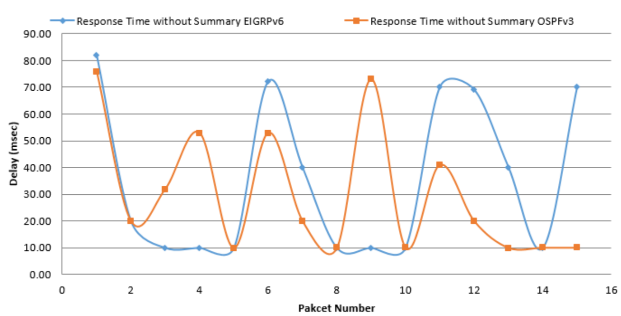



Fig. 10. Response Time before Summarization

Figure 11 shows the average response time with summary address over the IPv6 tunnel. CV of EIGRPv6 is 57 ms while CV of OSPFv3 is 72 ms. Results show that the response time of EIGRPv6 is much better than OSPFv3 with summarization.

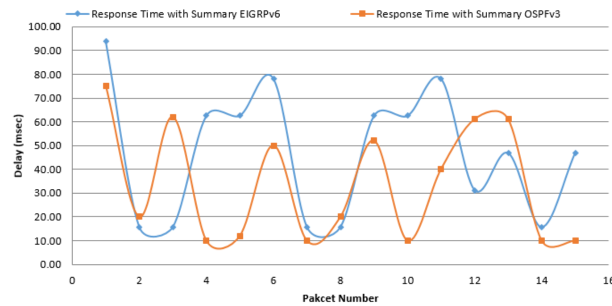



Fig. 11. Response Time after Summarization

### *F. Tunnel Overhead*

Figure 12 displays the status of tunnel in OSPFv3 and EIGRPv6 with same time slot (9 mints) on Router-1 before summarization. Statistics show that Router-1 sent 131 packets to its neighbor and received 118 packets through tunnel by using EIGRPv6 while with OSPFv3, it sent only 75 packets and received 65 packets.

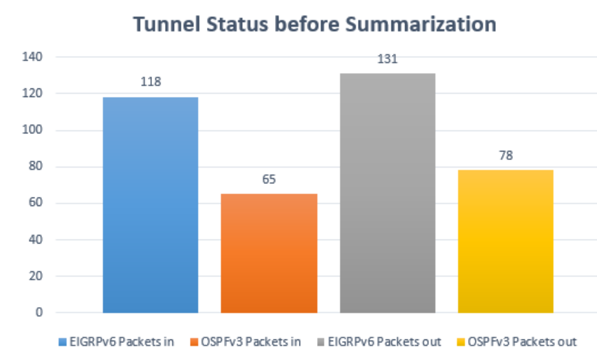



Fig. 12. Tunnel Overhead before Summarization

Figure 13 displays the tunnel overhead after summarization. It can be observed that after summarization, OSPFv3 packets are reduced while EIGRPv6 packets are increased. Results show that in EIGRPv6, total 126 packets are received by tunnel and 134 packets are sent through the tunnel while in OSPFv3, total 61 packets are received and 75 packets are sent. It means EIGRPv6 has approximately 50% higher tunneling overhead than OSPFv3.

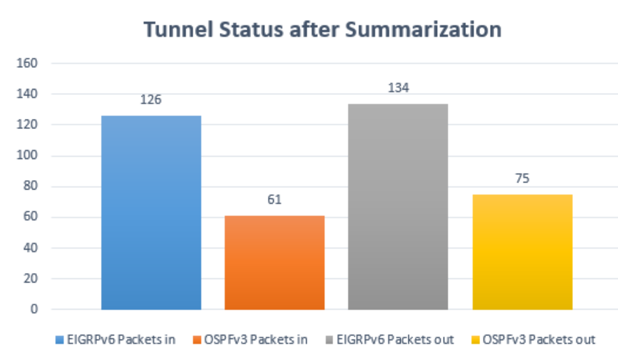



Fig. 13. Tunnel Overhead after Summarization

### *G. Protocol Traffic Statistics*

Figure 14 highlights the traffic statistics of EIGRPv6 and OSPFv3 with same time quantum (6 mints) on Router-1 without route summarization. Statistics show that during this time interval EIGRPv6 has sent 144 "Hello" packets and received only 71 Hello packets while OSPFv3 has sent and receive only 33 Hello packets. It means EIGRPv6 has a higher ratio of Hello packets than OSPFv3 in hybrid IPv4-IPv6 network.

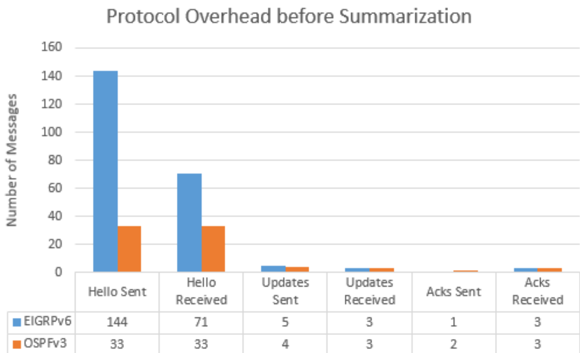



Fig. 14. Protocol Traffic Statistics before Summarization

Figure 15 shows the traffic statistics of EIGRPv6 and OSPFv3 with same time quantum (6 mints) on Router-1 with route summarization. Results show that EIGRPv6 has sent 169 Hello packets and received only 83 Hello packets while OSPFv3 has sent and receive only 33 Hello packets. It means, after summarization, EIGRPv6 has a higher ratio of Hello packets while Hello of OSPFv3 remains same. It can be observed that performance of OSPFv3 is much better than EIGRPv6 in summarization.

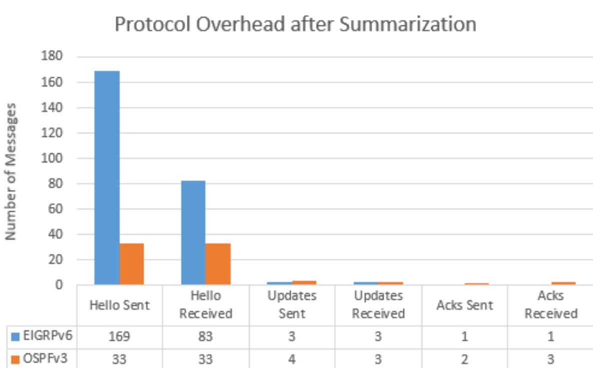



Fig. 15. Protocol Traffic Statistics after Summarization

### *H. CPU & Memory Utilization*

CPU utilization means the percentage of CPU time taken by a running process. CPU utilization is measured using the command "show process cpu" in routers. High CPU utilization may cause the packet loss, delay and slow processing of packets. Memory utilization means the sum of the memory used by all processes listed. Memory utilization is measured using the command "show process memory" in routers. High memory utilization may cause to increase the CPU utilization. Figure 16 shows the comparison of CPU utilization of EIGRPv6 and OSPFv3 without route summarization with same time quantum (2 mints) in hybrid IPv4-IPv6 network. Statistics show that OSPFv3 has better performance of CPU utilization as compared to EIGRPv6.

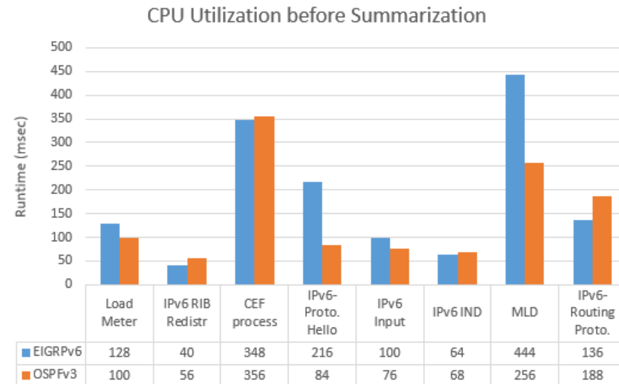



Fig. 16. CPU Utilization before Summarization

Figure 17 shows the comparison of CPU utilization of EIGRPv6 and OSPFv3 after route summarization with same time quantum (2 mints) in hybrid IPv4-IPv6 network. Statistics show that OSPFv3 has better performance of CPU utilization as compared to EIGRPv6. It can be observed that running processes of OSPFv3 consumed CPU in less time than EIGRPv6.

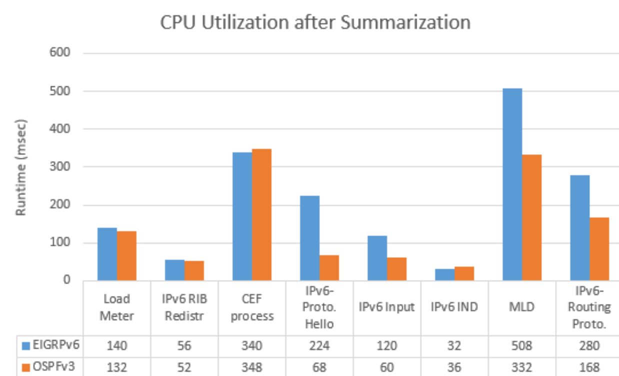



Fig. 17. CPU Utilization after Summarization

Figure 18 shows the comparison of memory utilization of EIGRPv6 and OSPFv3 without route summarization with same time quantum (2 mints) in hybrid IPv4-IPv6 network. Statistics show that OSPFv3 has better performance of memory utilization as compared to EIGRPv6.

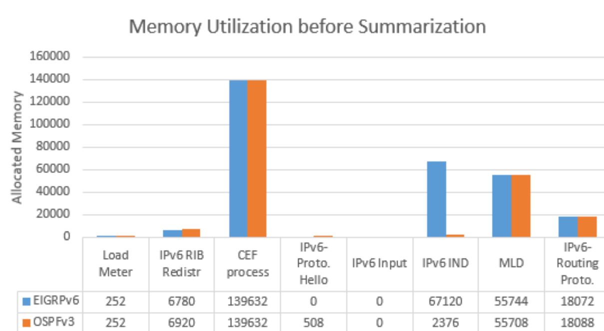
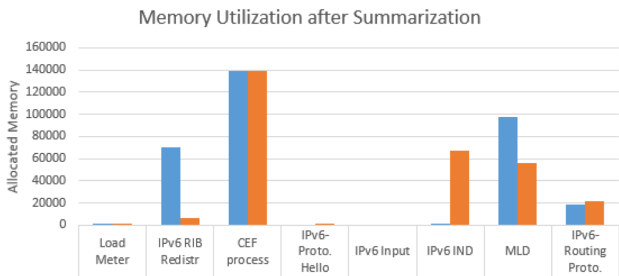



Fig. 18. Memory Utilization before Summarization

Finally, figure 19 displays the comparison of memory utilization of EIGRPv6 and OSPFv3 after route summarization. Statistics show that OSPFv3 has better performance of memory utilization as compared to EIGRPv6.




| | Load Meter | IPv6 RIB Redistr | CEF process | IPv6-Proto. Hello | IPv6 Input | IPv6 IND | MLD | IPv6-Routing Proto. |
|---|---|---|---|---|---|---|---|---|
| EIGRPv6 | 252 | 70208 | 139632 | 0 | 0 | 1620 | 97740 | 18544 |
| OSPFv3 | 252 | 6780 | 139632 | 508 | 0 | 67188 | 55752 | 21140 |

Fig. 19. Memory Utilization after Summarization

## VI. CONCLUSION

This study focused on optimized routing information exchange in IPv6 tunnel over IPv4 network by using routing protocols (OSPFv3 & EIGRPv6). Performance of these routing protocols is measured for the parameters like convergence time, RTT, response time, tunnel overhead, protocol traffic statistics, CPU and memory utilization. Experimental results indicated that the performance of OSPFv3 is better than EIGRPv6 with route summarization for most of the parameters like response time, tunnel overhead, protocol traffic statistics, CPU and memory utilization, while EIGRPv6 has shown better performance for convergence time and RTT with summarization. It means, route summarization has an impact to increase the performance of routing protocols. Our future work is to perform the behavioral analysis of OSPFv3 in terms of interoperability between other tunneling protocols like 6to4, GRE and GRE over IPSec.

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