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Performance Analysis of Traffic Engineering (TE) in IPv6 with IPv4 over Multi Protocol Label Switching (MPLS)

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Abstract: The emergence of next generation protocol (IPv6) and MPLS has been seen as technologies that will drive the next generation networks. Together with Traffic Engineering (TE), Quality of Service (QoS) requirements for high bandwidth consuming flows as well as optimization of network performance can be achieved. Traffic engineering delivers the traffic flows in a network without jamming and provides better network resiliency for failures. In this paper, performance analysis has been done to investigate the traffic engineering outcome in sample scenarios. Investigations were done on IPv4 as well as IPv6 based MPLS networks with and without Traffic Engineering approach involving six scenarios. Parameters such as queuing delay, link delay, Label Switched Path (LSP) delay, packet loss and utilization were evaluated for these scenarios using simulations. The results obtained reveal the applicability as well as usefulness in employing Traffic Engineering in MPLS and also the performance of it with respect to the two addressing protocols of IPv4 and IPv6.

Keywords: MPLS, IPv6, Traffic Engineering, TE, MPLS-TE, OPNET, QoS

1. Introduction

Due to variety of traffic flows in the Internet, there has always been a need for Quality of Service requirements for these flows. These traffic flows which are mostly real-time require certain constraints like high throughput, minimum delay etc. To provide these constraints, it is not always possible to replace the routers or media as it might be costly or time consuming. Internet Protocol (IP) was started as a connectionless network layer protocol with no differentiation between various flows [1-2]. MPLS is one of the technologies that will help in providing better QoS for these traffic flows. MPLS was developed in 2001 by Internet Engineering Task Force (IETF) for enhanced and fast packet-forwarding. MPLS defines a label which is small in size and can work with any underlying protocol. It provides connection-oriented Label Switched Path (LSP) for flow of traffic. With MPLS, explicit paths can be used to route the traffic which helps in load balancing. MPLS provides various features in addition to QoS like VPNs etc. and it has introduced an important technology that is Traffic Engineering (TE) which plays an important part in minimizing the overcrowding of networks.

Traditional IP tries to send the packet to its destination as soon as possible, therefore choosing a best path for the flows that is the shortest path. However, this path need not always be the best path for the flows. Even though there are multiple redundant paths available in a network for traffic flows but due to the limitations of the routing protocol, only specific routes are utilized like the shortest path in OSPF routing protocol. This creates extensive congestion in the network, resulting in packet loss, long delays, and lesser throughput. Traffic engineering with its explicit paths can alleviate this problem of congestion of links as a traffic management scheme. With Traffic Engineering, MPLS provides various solutions to these problems by Source-based routing, efficient traffic routing through the network by avoiding over-utilized/under-utilized links and automatic adaptation to changing bandwidth [3].

Due to the tremendous growth of devices over the Internet, the available IPv4 addresses have depleted. Therefore, a newer version of Internet Protocol known as IPv6 has been introduced as replacement for IPv4. In addition to large number of addresses, IPv6 provides better security, stateless auto configuration, better optimization, scalability etc. Several integration mechanisms have been developed to leverage an existing IPv4 MPLS network into IPv6 based MPLS network. The conducted simulations of both IPv4 as well as IPv6 addressing protocols, compare the two by

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providing their effect on the utilization of links, throughput, packet loss and LSP delays. The presented simulation results proved that Traffic Engineering is an efficient and applicable solution over IPv6 in MPLS networks for traffic management decisions.

This paper is organized as follows: Section 2 describes the basics of MPLS, its working and its application over IPv6. Section 3 introduces Traffic Engineering over MPLS and Section 4 explains the simulation scenario setup using network simulator explaining the network topology, simulation parameters, traffic generation and configurations. Section 5 gives the analysis of results, addressing the findings and gives possible future work in this field. Conclusion of the research is given in Section 6.

2. MULTI PROTOCOL LABEL SWITCHING (MPLS)

Multi Protocol Label Switching (MPLS) [4-6] has been set up as the important technology for the packet networks for improving the packet forwarding performance [7]. MPLS provides high speed packet switching, forwarding and great scalability and in addition to this, it provides several services like Traffic Engineering, Virtual Private Networks (VPN) etc. with QoS guarantees [8-13]. For MPLS to work, all routers in the network must be MPLS-enabled [14]. This technology is also called as Layer 2.5 technology due to the fact that its function lies between the Data Link Layer (Layer 2) and Network Layer (Layer 3)[15]. The purpose of MPLS is to use MPLS labels of 32 bit length instead of longer IP addresses (32 bits in Internet Protocol version 4 and 128 bits in Internet Protocol version 6) in switching of packets. Figure 1 illustrates the structure of MPLS Label [16-17].

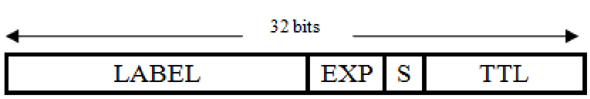

Figure 1. MPLS Label

MPLS has signaling protocols like Constraint Based Routing over Label Distribution Protocol (CR-LDP) or Resource Reservation Protocol (RSVP) which permits routing with QoS restrictions [18-20]. Label Switched Path (LSP) is an explicit path established using these signaling protocols in which a short label, inserted in the packet header, is used for making forwarding decision [21].

MPLS flows are connection-oriented and packets are routed along LSPs. After entering into MPLS domain, the first MPLS enabled router, known as Label Edge Router (LER) or Ingress LER is assigned the task of labeling the packet. For each hop there is a distinct label for the packet and when the packet reaches the last router, known as Egress LER, the label is removed [22-24]. This is depicted in Figure 2.

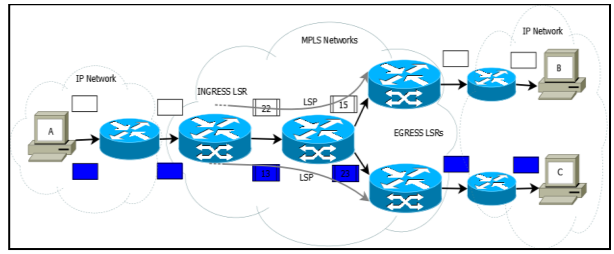

Figure 2. MPLS Network within IP Network

MPLS is independent from both network layer protocols and data link layer media and its infrastructure has minimal core impact to provide IPv6 services [25-26]. There are several models for the IPv6 implementation over MPLS networks; 6PE model: Extend edge LSRs only, keep using IPv4 routing and signaling on core LSRs, Extend routing and signaling protocols to support IPv6, Native IPv6 network and IPv4 CE-to-CE Tunnels [27].

3. TRAFFIC ENGINEERING OVER MPLS

IP based routing protocols like Open Shortest Path First (OSPF) work on the property of shortest path. Whether the route is congested or not, the protocol will still send the packet through the shortest path. The protocol does not consider the available bandwidth of the link nor any problem like packet drop due to excessive traffic. Due to this, some redundant paths always remain under utilized where as some paths are over utilized. Over utilized links can be upgraded by increasing bandwidth, however this is time consuming as well as economy wise may not be feasible. Also, this would not be best optimization of the network. TE is the technology used for diverting traffic across redundant paths which are available between a pair of routers. It is required to optimize network resources utilization at the same time as guaranteeing the quality of service (QoS). MPLS gives a big advantage in facilitating Traffic Engineering. MPLS-TE is a connection oriented mechanism and combines explicit routing capabilities with a Constraint Based Routing (CBR) mechanism with dynamic resources discovery like ISIS-TE, OSPF-TE and RSVP-TE [28-32]. Traffic Engineering-Label Switched Paths (TE-LSPs) can assure a set of traffic engineering constraints such as the bandwidth in addition to network resources optimization, Quality of Service (QoS) and fast recovery upon link or node failures [33].

MPLS makes it possible for services provided by an IP network to apply effective Traffic Engineering (TE) for support of QoS guarantees. With explicit routes, MPLS utilizes a capable way to establish paths for IP traffic known as LSPs with Flows and Traffic Trunks. LSRs involved in creating of LSPs utilize the labels for the explicit routes. Explicit routes also help in constraint based routing [34-35]. MPLS with Traffic Engineering (MPLS-TE) provides efficient spreading of traffic in the network with taking into account static bandwidth, link attributes and does automatic adaptation with respect to any changes in the network. In addition to this, rather than using IP destination based routing, MPLS-TE utilizes source based routing [3]. For building the scenario of MPLS-TE; link constraints, FEC with Traffic trunks, signaling protocol like RSVP, routing protocol like OSPF/OSPFv6, and LSP details were provided for traffic engineering which is discussed in Section 4.

4. SIMULATION SCENARIO

OPNET Modeler has been used for simulation which is a network simulator comprising of a suite of protocols and technologies with a sophisticated development environment. OPNET analyzes networks to compare the impact of different technology designs on end-to-end behavior [36]. Figure 3 illustrates the scenario that has been created for simulation for Traffic Engineering. The topology includes 4 Label Edge Routers (LERs), 6 Label Switching Routers (LSRs), 4 traffic generating clients and 4 servers. 4 clients have been configured for traffic generation of VoIP, web, video and ftp and servers have been configured accordingly to receive the 4 traffic flows. The link used to connect the routers and clients is a Duplex link of DS1 with the maximum bandwidth of 1.544 Mbps.

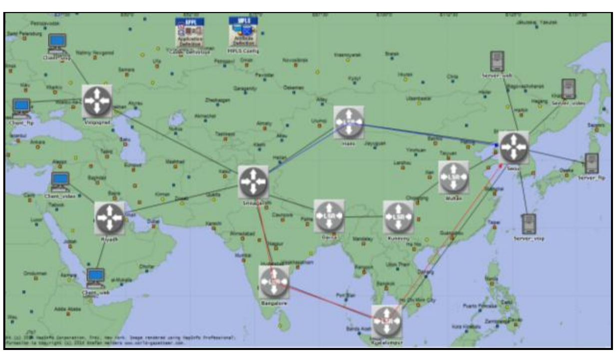

Figure 3. Simulation Senario

A. *Simulation Parameters*

The LER used is an IP-based protocol running MPLS and supporting up to two Ethernet interfaces and up to 8 serial line interfaces at 1.544 data rate. The client used is a point-to-point workstation node model representing a workstation with client-server applications running over IPv4 as well as IPv6 supporting one SLIP connection. The server used is a point-to-point server model representing server node with server applications running over IPv4 and Ipv6 with SLIP connection. The routing protocol used is OSPF for IPv4 and OPSFv6 for IPv6.

Six scenarios were created to simulate different protocols. The scenarios include:

Scenario 1: IPv4 without MPLS

Scenario 2: IPv4 with MPLS

Scenario 3: IPv4 MPLS with Traffic Engineering

Scenario 4: IPv6 without MPLS

Scenario 5: IPv6 with MPLS

Scenario 6: IPv6 MPLS with Traffic Engineering

Scenario 1 was created as a simple IP network with IPv4 as the addressing protocol. There was no implementation of MPLS or Traffic Engineering in it. The Scenario 2 implemented MPLS over IPv4 network and Scenario 3 had both MPLS as well as Traffic Engineering. Scenario 4 had the implementation of IP network with IPv6 as the addressing protocol. Scenario 5 has IPv6 over MPLS and Scenario 6 had both MPLS as well as Traffic Engineering over IPv6. The IP addressing in all the scenarios were auto-assigned. Figure 4 shows the topology into consideration.

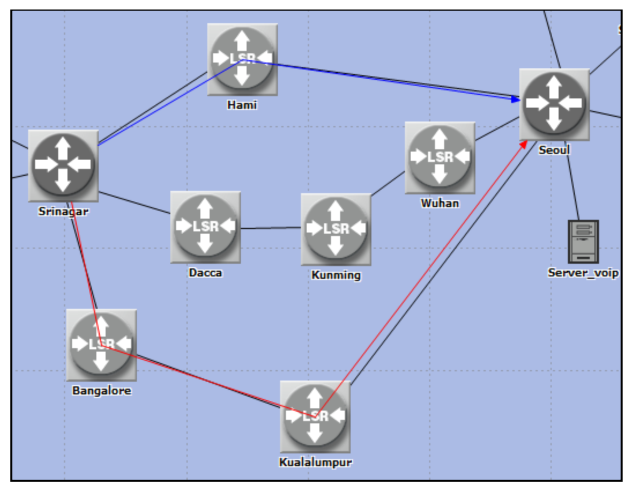

Figure 4. Network Topology

The traffic generated across all the networks was similar. Since OSPF was used as the routing protocol, the topology was designed such that there are multiple paths between SR and DR, both of which are Label Edge Routers (LERs) as shown in Figure 4. Three possible paths between Source Router (SR) and Destination Router (DR) include; Srinagar – Hami – Seoul (2 hops), Srinagar – Bangalore – Kualalumpur – Seoul (3 hops) and Srinagar – Dacca –Kunming – Wuhan – Seoul (4 hops). During each scenario, over-utilized links were checked and accordingly a new scenario was developed to improve the performance of the network.

B. *Network Traffic Generation*

IP unicast traffic was created for each scenario with same traffic flows. The unicast traffic flows were created from the clients to the servers with traffic intensity of 200 packets per second with 200,000 bits per second for duration of 6 hours. A total of 7 traffic demands were created between source and destination with the traffic of web, voice, video and ftp using Best Effort type of service. Generated traffic was mixture of 25% Explicit (packet-by-packet) traffic and 75% Background (analytical) traffic. Explicit traffic generates individual packets that represent the total demand volume resulting in a very detailed representation of the flow whereas Background traffic represents the traffic demand in an aggregated way, not as a collection of individual packets, but rather as an analytical flow with certain volume and characteristics [37]. The total traffic volume on all 7 flows is 2.917 GB with average traffic volume per flow 426.701 MB.

C. MPLS and Traffic Engineering Configuration

MPLS was enabled in all the routers which were used for MPLS based scenarios and in addition to this loopback interfaces were enabled for SR and DR that is LERs which are the source and destination for LSPs. Two Dynamic LSPs with explicit routes were created between the SR and DR Label Edge Routers through two different links of different hop counts. This is depicted by Red and Blue colored LSPs in Figure 4. One LSP was through the shortest path routers Srinagar-Hami-Seoul and another through the next shortest path, Srinagar-Bangalore-Dacca-Seoul.

With Dynamic LSP, CR-LDP establishes an LSP from the source node of LSP to the destination node. The two LSPs will act as backup LSP for each other as well as for TE, both will be equally utilized. In configuration for MPLS, 2 Forwarding Equivalence Classes (FECs) were created, which consists of one or more traffic flows that can be treated as traffic aggregate. 2 Traffic Trunks were created, which aims to characterize the FECs that are mapped onto it, one for each FEC already created. To send the traffic through LSPs, Traffic mapping was configured as Static Mapping with FECs and Traffic Trunks created. Resource Reservation Protocol (RSVP) was used for Traffic Engineering.

5. Analysis of Results

This section explains the results and the corresponding analysis performed. All the scenarios were simulated for 6 hours and accordingly the statistics were collected. In case of pure IP networks without Traffic Engineering, the shortest path links were over utilized and therefore the delays were also high. It was done so in order to obtain baseline results to study the effect of MPLS and Traffic Engineering on the network.

A. Link Utilization

Link utilization is the percentage of a link's bandwidth that is currently being consumed by network traffic and consistently high utilization which is greater than 40% indicates points of network slowdown or failure and a need for changes or upgrades in your network infrastructure [38]. The redundant LSP was not utilized as the second LSP was not having shortest path.

With traffic engineering the redundant LSP was utilized equally and this is shown in Table I, which gives the list of link utilizations of each link which is into consideration to see the effect of traffic engineering, MPLS as well as IPv4/IPv6.

TABLE I. Link Utilization

Link	Scenarios					
	IPv4	*IPv4 MPLS*	*IPv4 MPLS TE*	*IPv6*	*IPv6 MPLS*	*IPv6 MPLS TE*
Srinagar - Hami	76.03	76.17	38.50	76.29	75.80	38.59
Srinagar -Baglore	0	0	38.25	0	0	38.32
Hami - Seoul	76.32	76.26	38.35	76.36	75.97	38.44
Banglre-Klumpur	0	0	38.25	0	0	38.32
Klumpur – Seoul	0	0	38.37	0	0	38.18

It can be observed from the table that the links in scenarios of pure IPv4/IPv6 as well as IPv4/IPv6 MPLS, the utilization of alternate paths available is 0%. This is due to the fact that OSPF will take the shortest path regardless of the link utilization and delays and the utilization of the shortest path is greater than 70%. However, it can be seen that with Traffic Engineering, the over utilization of links of Srinagar-Hami and Hami-Seoul have been considerably reduced and therefore the alternate routes have been equally utilized. Thus, the scenarios of IPv4 with MPLS Traffic Engineering and IPv6 with MPLS Traffic Engineering are best suited for the topology.

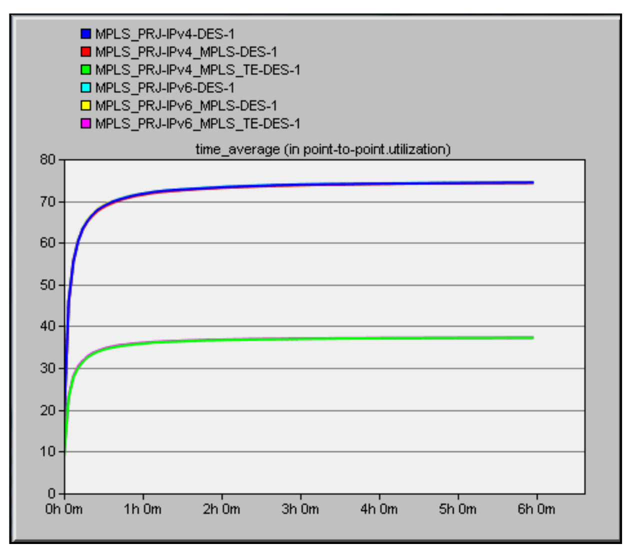

Figure 5. Point-to-Point Utilization of Srinagar-Hami Link

As an example, the link between Srinagar and Hami has been taken into account in the graph of Figure 5. It can be observed that link utilization of IPv4/IPv6 and IPv4/IPv6 with MPLS is more than 70%. This means that the link is over utilized and the redundant LSP has been completely ignored as the utilization of 2nd LSP is 0% in these scenarios. This will eventually lead to higher delays, packets drops due to traffic congestion and lesser throughput. However, the scenarios in which traffic engineering has been used, the utilization of the same link have been reduced to an optimal level of less than 40%. This is both for IPv4 as well as IPv6 MPLS with Traffic Engineering.

B. Queuing Delay

Queuing delay is an important design and performance characteristic of a network and is defined as the time a job waits in a queue until it can be executed. With regards to the queuing delay in the various scenarios of the network, it was observed that for the same link under observation, i.e. Srinagar – Hami, the queuing delay was minimum for both the IPv4 and IPv6 MPLS scenarios involving Traffic Engineering. This is due to the fact that Traffic Engineering divided the incoming traffic equally between the two LSPs. The first LSP (Srinagar-Hami-Seoul) as well as a redundant LSP (Srinagar-Bangalore-Kualalumpur-Seoul) that is next shortest path was utilized.

Figure 6 shows the comparison of average queuing delays of all the scenarios. While comparing the average queuing delay of traffic engineered scenarios, it was observed that for IPv6 MPLS with traffic engineering, the delay was lower as compared to the IPv4 MPLS with Traffic engineering scenario. With respect to the scenarios without traffic engineering, the average queuing delay of IPv6 scenarios was lesser as compared to IPv4.

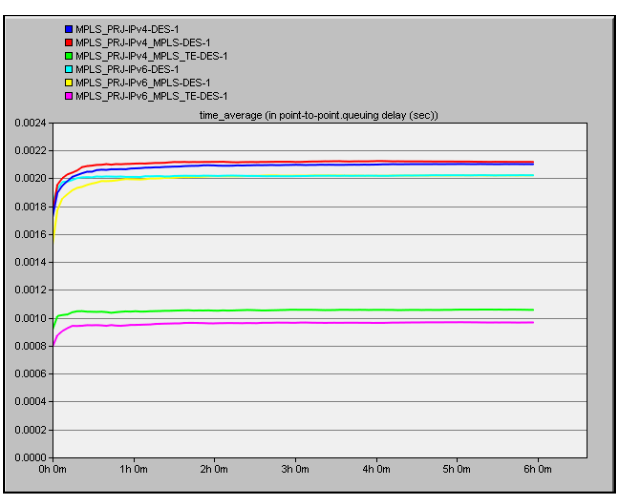

Figure 6. Average Queuing delay over Srinagar-Hami link

C. Packet Drop

Packet loss takes place when one or more packets travelling in a network fail to reach the destination and this loss happens when a network device is overwhelmed and cannot allow extra packets at that time. Due to packet drop, the destination has to inform the sender to re-send the dropped packet and this adds to the traffic and thereby adding towards network congestion. Packet loss over 2% is considered as an issue in the network. With respect to the packet drop in traffic engineering scenarios, it was seen that average packet drop is higher in IPv6 MPLS based traffic engineered networks as compared to the IPv4 MPLS based traffic engineered networks by almost double. This is due to the fact that the size of IPv6 packet is double than the IPv4 packet. The average packet drop in IPv4 based scenario is around 0.75 and for IPv6 based scenario is 1.5. This is shown in Figure 7. However, both the scenarios have packet drop less than 2%.

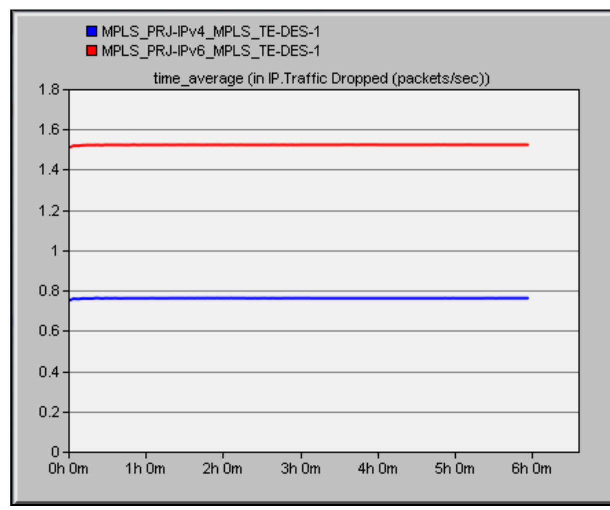

Figure 7. Average Packet Drop in Traffic Engineered Scenarios

D. LSP Delays

All the routers in the network are MPLS enabled and LSP has been configured between the Srinagar and Seoul LERs as shown in Figure 4. The traffic between these two LERs will traverse through the two dynamically created LSPs. This delay is based on the LSP rate, average packet size, propagation speed, length of the LSP and the queuing delays.

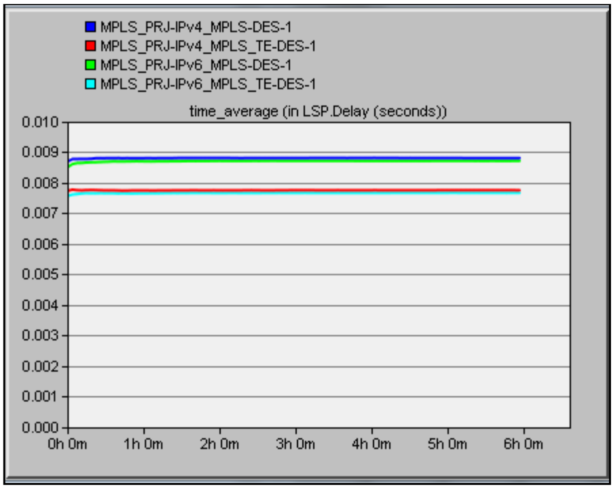

Figure 8. Average LSP Delay in MPLS based Scenarios

With regards to the average delay in first LSP i.e. Srinagar-Hami-Seoul, the 4 scenarios of MPLS were taken into consideration. It was observed that delays in the traffic engineered scenarios of both IPv4 as well as IPv6 were lower as compared to the scenarios in which traffic engineering was not utilized. This is due to the fact that with traffic engineering the traffic on this LSP was lower and therefore the delays were also low. With respect to IPv4 and IPv6 based MPLS Traffic Engineering, it can be observed from Figure 8 that IPv6 shows lesser delay than IPv4, the reason being that the throughput of IPv6 is greater than IPv4 as the packet size of IPv6 is bigger.

Figure 9 depicts the graph for Average LSP flow delays. It can be seen from the graph that traffic engineered flows have lesser delays as compared to other scenarios. This is because the flows in non-traffic engineered networks face more traffic congestion due to which the delay increases. Again, for IPv4 and IPv6 MPLS Traffic engineering scenarios, IPv6 based scenario has slightly lesser delay as compared to IPv4. This is due to the throughput of IPv6 being higher than the IPv4.

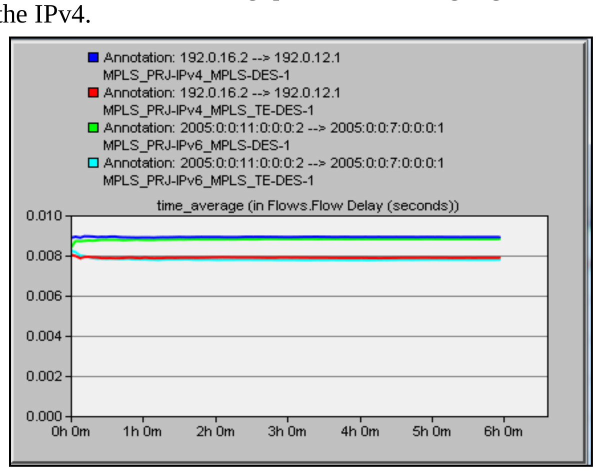

Figure 9. Average LSP Flow Delay in MPLS based Scenarios

6. Conclusion and Future Work

Due to the tremendous traffic over the Internet, which has been caused due to increase in the demand of heavy audio/video traffic and other real time services, it has become need of the day to introduce the bandwidth optimizing technologies like MPLS with Traffic Engineering. In this paper, evaluation of the performance of traffic engineering with MPLS has been done in various scenarios involving IPv4 and IPv6 addressing protocols. By making the most of the under-utilized links for various traffic flows, it was observed that network resources could be managed well. The Traffic Engineering provided better link utilization by reducing the utilization of the over-utilized links to half, i.e. from 80% to 40%. This reduction was almost same for both scenarios of IPv4 and well as IPv6. With respect to Queuing delay, it was less for both the IPv4 and IPv6 MPLS scenarios involving Traffic Engineering. Due to reduced traffic over LSPs because of the traffic engineering, it was seen that packet drop was also reduced in MPLS-TE scenarios. However, it was observed that average packet drop is higher in IPv6 MPLS based traffic engineered networks as compared to the IPv4 MPLS based traffic engineered networks by almost double. Lastly, it was observed that average LSP delays in the traffic engineered scenarios of both IPv4 as well as IPv6 were lower as compared to the scenarios in which traffic engineering was not utilized. Thus, the conducted simulations have verified the applicability of the IPv6 based Traffic Engineering over MPLS.

Further evaluations are needed to compare the performance of MPLS with multicasting like P2MPLS involving traffic engineering. Different QoS profiles can also be evaluated like DiffServ, IntServ with respect to both IPv4 as well as IPv6 in MPLS-TE environments.

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