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Performance study of MPLS and DS techniques to improve QoS routing for critical applications on IP networks

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ABSTRACT

This paper aims to analyze the QoS performance of two main technology mechanisms, Multi-Protocol Label Switching (MPLS) and Differentiated Services (DS). The introduction of both mechanisms to support throughput and delay sensitive real-time media traffic will have an impact on critical applications with respect to QoS and traffic engineering. MPLS is a traffic forwarding mechanism that allows traffic to use multiple paths and DS is a mechanism that provides for aggregate traffic to be classified and conditioned at the edge of the network routers.

The two modeled techniques and their performance will be evaluated with respect to their end-to-end delay. The QoS will be incorporated in both the MPLS and DS mechanisms while preserving the efficiencies of the backbone structure of the Internet, and also the performance is compared with the existing IP routing algorithms.

Keywords: Multiprotocol Label Switching, QoS, DSCP, Traffic Engineering, Simulation, Routing, Label Switch Paths, Service Level Agreement, Per-Hob Behavior.

1. INTRODUCTION

Different service classes provide different forwarding treatment or per-hop-behavior (PHB). A service defines the packet characteristics for transmission through the network in one direction. Packets are classified and possibly conditioned at the boundary of the network. Core routers forward aggregate traffic according to a relative queuing priority scheme assigned. MPLS is another forwarding scheme that assigns labels to packets at the boundary of an MPLS domain. Labels specify the service, classification, and forwarding. Traffic engineering provides for a way to arrange traffic through the network [1, 2]. QoS must assure that interactive multimedia traffic has priority and delay is kept to a minimum. The scalable DS technique gives the ability to distinguish among the needs of different interactive multimedia applications. Different applications have different QoS needs depending on the composition of the multimedia; provisioning resources for some applications may be easier than others, some applications have known and predictable behavior, like packet size, traffic volume, and traffic behavior, where others have many variables that makes it extremely difficult to configure traffic conditioning thresholds, maximum queue size, and bandwidth limits for high priority queues [2].

MPLS is based on a label-swapping forwarding algorithm [3, 4], where a label is a short, fixed-length value, carried in the packet's header to identify a forwarding equivalence class (FEC). The label effect is link-local, and does not encode information from the network layer header, and maps traffic to a specific FEC. An FEC is a set of packets that are forwarded over the same path through a network, even if their ultimate destinations are different. QoS must assure that interactive multimedia traffic has priority and delay is kept to a minimum. The scalable DS and MPLS techniques give the ability to distinguish among the needs of different interactive multimedia applications. Different applications have different QoS needs depending on the composition of the multimedia; provisioning resources for some applications may be easier than others, some applications have known and predictable behavior, like packet size, traffic volume, and traffic behavior, where others have many variables that makes it extremely difficult to configure traffic

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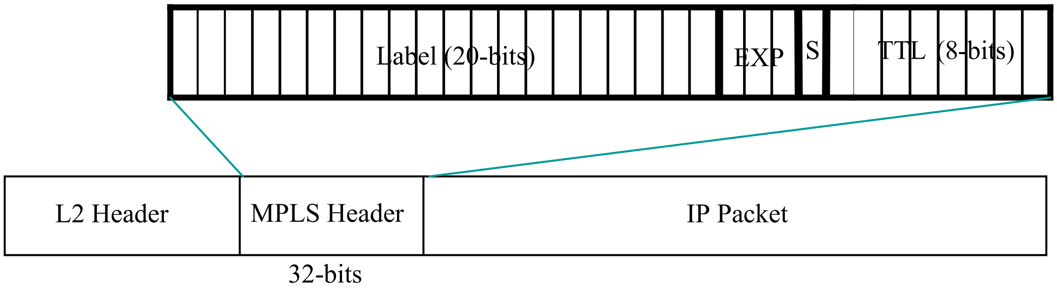
conditioning thresholds, maximum queue size, and bandwidth limits for high priority queues [3]. Hence, Traffic Engineering (TE) is needed to manage and arrange traffic flows through the network, efficiently maximizing bandwidth and queue utilization, and increasing the Internet capacity to handle different traffic with different requirements.

2. MULTIPROTOCOL LABEL SWITCHING (MPLS)

MPLS is used to traffic engineer IP networks, and to allow traffic to use multiple paths, rather than the single optimal path used by conventional routing-based networks. This approach is based on the capability of MPLS to create explicit label-switched paths from one edge node of an MPLS network domain to another. Label Switched Paths (LSPs) could be determined and modeled with a collection of traffic engineering tools that reside on a workstation, and then downloaded to network devices. One approach is to maintain a path state with each path, along with a record of available capacity within the state information. Each ingress node can use this information to place traffic across multiple paths, attempting to balance the available capacity on each path. This is an important aspect for traffic engineering, giving network administrators the ability to define explicit paths through an MPLS cloud based on any arbitrary criteria [3].

The basic components needed for traffic engineering in a packet-switching network include the distribution of topology information, whereby, the node can build the topology map of the network and store it in the Traffic Engineering Link State Database (TE-LSDB) when information about link or node failure must be propagated through the network; other components needed are the path selection to compute connectivity information between nodes; bandwidth; delay; shortest path; and directing traffic along the computed paths by building a forwarding table. Each node builds its connectionless forwarding independently; however, nodes in connection-oriented forwarding use signaling protocol that assists intermediate nodes along the path in building their forwarding tables [3].

QoS has several possibilities with MPLS in which the most straightforward one is a direct mapping of the 3 bits carried in the IP precedence of the incoming IP packet headers to a Label CoS field, also called the EXP bits. As IP packets enter an MPLS domain, the edge MPLS router is responsible for mapping the bit settings in the IP packet header into the CoS field in the MPLS header, as shown in Figure 1 [4, 5].



Label: MPLS Shim Header Label.
L2 Header: Layer 2 Header
TTL: Time-to-Live
EXP: Experimental Bits.
S: End of label stack bit (used for hierarchal LSP)

Figure 1: EXP or CoS bits carried in the MPLS Header

The label-swapping forwarding algorithm requires packet classification at the ingress edge of the network to assign an initial label to each packet. In Figure 2, the ingress label switch receives an unlabeled packet with a destination address of 192.2.2.1. The label switch performs a longest-match routing table lookup and maps the packet to an FEC—192.2/16. The ingress label switch then assigns a label (value of 4) to the packet and forwards it to the next hop in the label-switched path (LSP) [3].

An LSP functions like a virtual circuit, because it defines an ingress-to-egress path through a network that is followed by all packets assigned to a specific FEC. The first label switch in an LSP is called the ingress, or head-end, label switch. The last label switch in an LSP is called the egress, or tail-end, label switch [5].

In the core of the network, label switches ignore the packet's network layer header and simply forward the packet using the label-swapping algorithm. When a labeled packet enters at a switch, the forwarding component uses the input port number and label to perform an exact match search of its forwarding table. When a match is found, the forwarding component retrieves the outgoing label and outgoing interface, and the next-hop address, from the forwarding table. The forwarding component then swaps (or replaces) the incoming label with the outgoing label and directs the packet to the outbound interface for transmission to the next hop in the LSP [3, 6].

When the labeled packet arrives at the egress label switch, the forwarding component searches its forwarding table. If the next hop is not a label switch, the egress switch discards the label and forwards the packet using conventional longest-match IP forwarding [6].

Label swapping provides a significant number of operational benefits when compared to conventional hop-by-hop network layer routing, first, label swapping gives a service provider tremendous flexibility in the way that it assigns packets to FECs. i.e., to simulate conventional IP forwarding, the ingress label switch can be configured to assign a packet to an FEC based on its destination address. However, packets can also be assigned to an FEC based on an unlimited number of policy-based considerations—the source address alone, the application type, the point of entry into the label-swapping network, the point of exit from the label-swapping network, the CoS conveyed in the packet header, or any combination of the above.

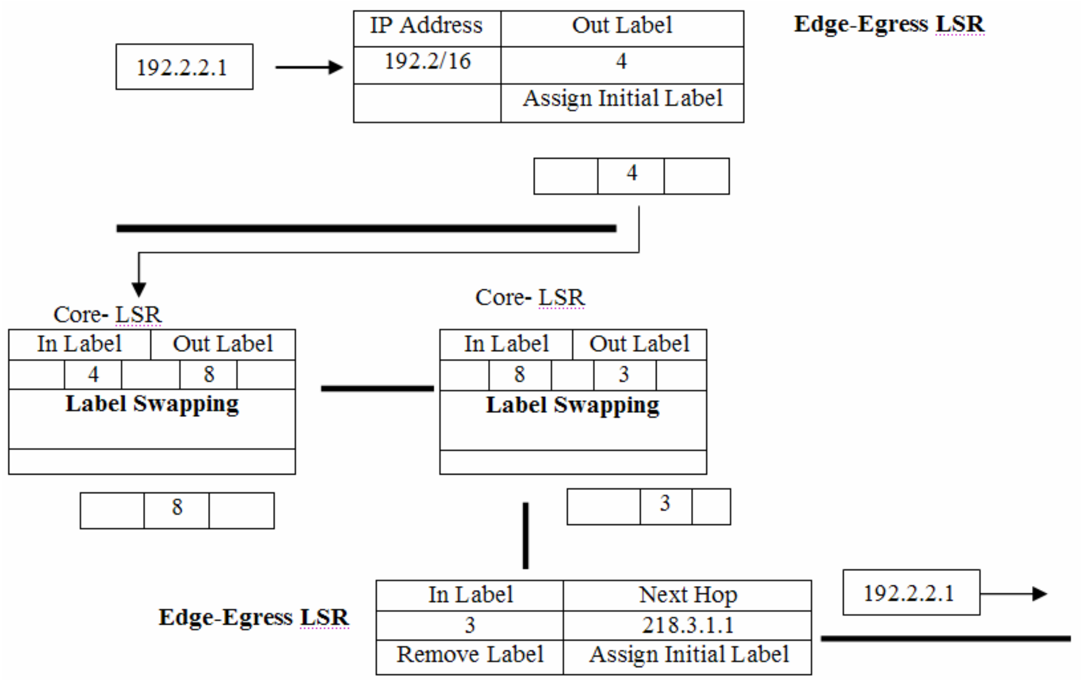


Figure 2: Packet traversing a Label Switched Path

Second, service providers can build customized LSPs that support specific application requirements. LSPs can be designed to minimize the number of hops, meet certain bandwidth requirements, and support exact performance requirements, go around potential points of congestion, direct traffic away from the default path selected by the IGP, or simply force traffic across certain links or nodes in the network.

Third, label-swapping forwarding algorithm benefit come from its ability to take any type of user traffic, associate it with an FEC, and map the FEC to an LSP that has been specifically designed to satisfy the FEC's requirements. The deployment of technologies based on label-swapping forwarding techniques offer ISPs accurate control over the flow of traffic in their networks. This exceptional level of control results in a network that operates more efficiently and provides more predictable service [6].

Several parallel paths may exist from one end of an MPLS network domain to another, for example, each of varying bandwidth and utilization. It is certainly possible to choose explicit ingress-to-egress paths for each specific CoS type, where each path offers a distinct differentiated traffic with characteristics labeled with higher CoS values that could be forwarded along a higher-speed, shorter-delay path; whereas traffic labeled with a lower CoS value could be forwarded on a lower-speed, longer-delay path.

QoS is characterized by parameters such as delay, delay jitter, bandwidth, and packet loss, while the mechanisms to implement a QoS solution include admission control, flow identification and traffic policing and scheduling [1].

MPLS affects how traffic transits the Internet and the services that the Internet delivers. The advantages of using MPLS technology on ISPs are [4]:

1. Provide flexible support for several services and service models at the edge, and deliver high-quality IP-based services.
2. Predict performance with SLAs.
3. Simplify the network architecture by developing an adaptable core.
4. Overcome existing infrastructure limitations by not letting a single service determine the core strategy.
5. Build a reliable and scalable Internet service that supports multimedia applications and provides flawless access to private and public services.

3. DIFFERENTIATED SERVICES TECHNIQUE

DS maps the type of service (TOS) byte field in IP packet header to DS code point (DSCP) is shown in Figure 3. Based on the DSCP value, a router allocates resources (buffer, bandwidth) to a behavior aggregate (BA). BA is a pool of packets crossing a link in a specific direction with the same DSCP value [2]. A per-hop-behavior (PHB) describes the external measurable forwarding treatment (i.e. packet loss, jitter, or delay) employed at a DS-compliant router to a DS BA. PHBs may be specified in terms of their resource priority (i.e. buffer, bandwidth) relative to other PHBs, or in terms of their relative measurable traffic characteristics (i.e. loss, jitter, delay). PHBs are implemented in nodes by means of packet scheduling mechanisms (queue based) and buffer management (rate based).

The DS is realized by the mapping of a DSCP to a particular forwarding behavior (PHB) in each node along DS domain(s) path. A code point may have more than one PHB (different profiles with the same DSCP). If a code point is not mapped to a certain PHB, it will be assigned to the default PHB (Best-effort) [2]. The services are realized using packet classification and traffic conditioning combined with forwarding treatments (PHBs) along the transit path of the traffic.

A customer must have service level agreement (SLA) with an Internet Service Provider (ISP) to receive differentiated services. The SLA specifies the classes, amount of traffic allowed in each class, may specify packet classification and remarking rules, and specify traffic profiles of traffic as in-profile or out-of-profile. Customers can mark the DS field of packets or have a boundary router mark them for the desired service class. Traffic profile specifies the properties of a traffic stream such as average rate, peak rate, and burst size, selected by a classifier. Traffic profile provides rules for determining whether a packet conforms to the SLA service class (in-profile) or exceeds the SLA service class (out-of-profile).

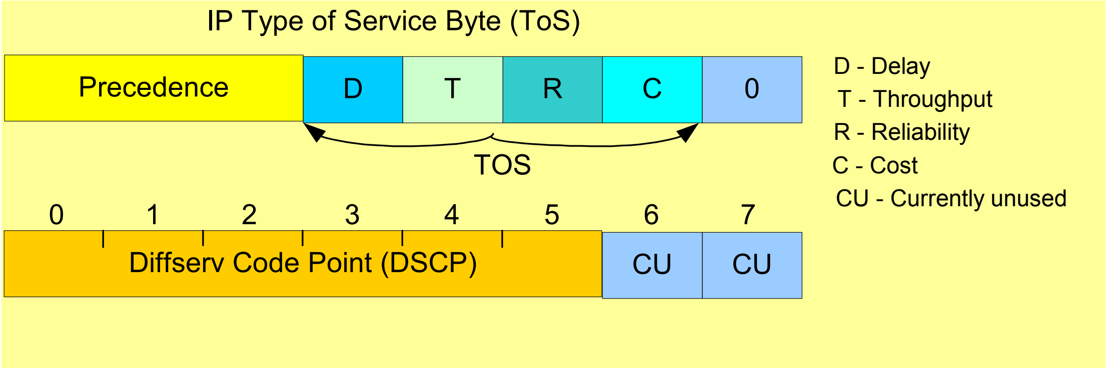


Figure 3: Mapping of DS field to ToS field in the IPv4 header.

If traffic flow conforms, it will be transmitted according to the service class priority, otherwise, it will either be assigned to a lower priority class (re-shaped, or delayed) or be dropped.

4. PERFORMANCE OF MPLS VERSUS DS: IMPLEMENTATION OF REAL-TIME MULTIMEDIA OVER THE INTERNET

The challenge for the Internet is to be able to support non-real-time and real-time applications in one common platform. An application profile will be created to do just that [9, 10].

Network Topology:
Using OPNET, a one-tier 24 nodes (core routers) based on Waxman algorithm is created. The network topology model was created (see Figures 4, 5 and 6) to compare and predict the response time and queuing delay of traditional best-effort IP routing to differentiated services approach. The nodes have been placed

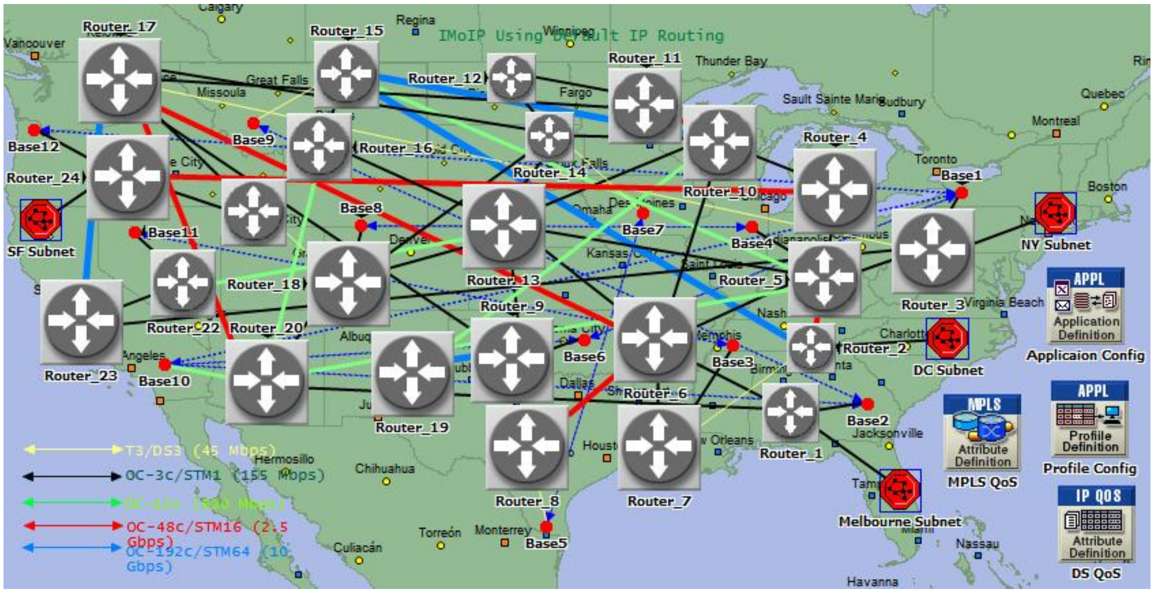


Figure 4: Network Topology (Backbone View)

randomly over parent subnet. The links distributions ranged from a capacity of T3 (45 Mbps) to OC192c (10 Gbps). The core router location is based on heavy-tailed distribution. A baseline model was first created to measure the response time between two city offices. OSPF is used as the routing mechanism to route conventional IP traffic. We established a baseline, increased traffic and filled the links with real-time and other non-real-time traffic to mimic the Internet. Links with higher bandwidth became heavily congested and in some parts over-utilized, lower bandwidth links were less utilized, since OSPF takes the shortest path and higher bandwidth links as the preferred way of routing.

Background, Raw Packet Generator (RPG), and explicit are the three traffic types used in our simulation. Background traffic is analytically modeled to impact the performance of explicit traffic. It introduces delays in queues based on their length, and causes queues build-up between devices. It does not model particular events. Background traffic in our simulation is represented as flows between source and destination, also called conversation pair traffic. The DiffServ capabilities were added using the same model. The response time will show a significant improvement using the DiffServ scheme.

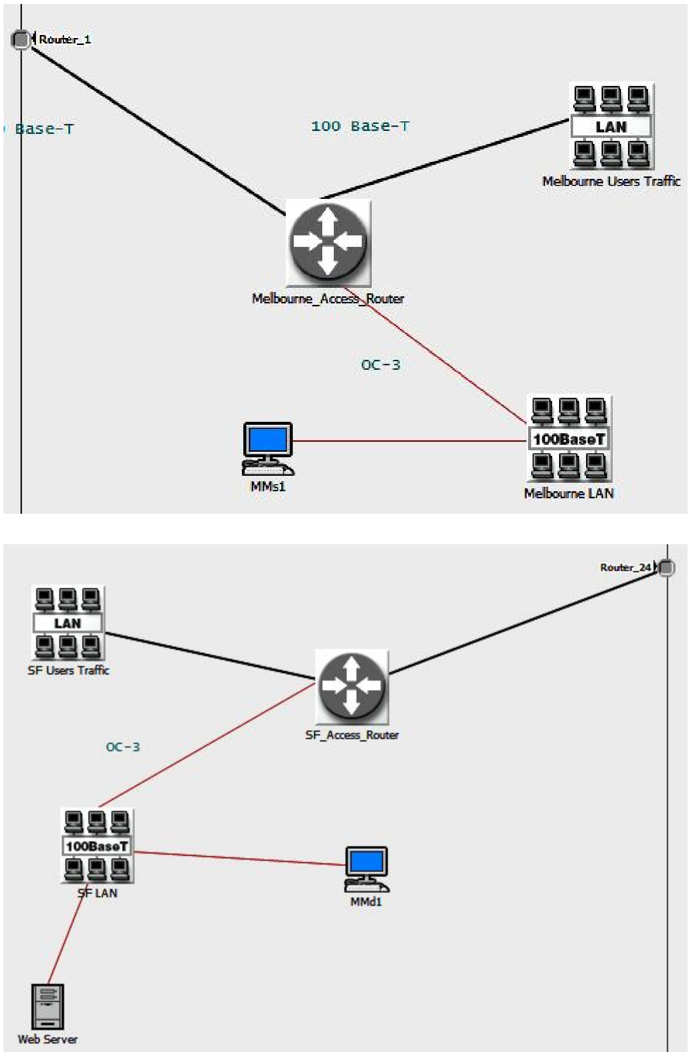


Figure 5: City_1 and City_5 subnets

In MPLS, prioritized aggregated traffic flows will be assigned to different LSPs depending on ToS. Protected LSPs (via MPLS Secondary LSP) will be used to meet Voice/Video reliability issues. Based on this service model, a network topology is assumed to be given. User constraints will be passed to Constrained Shortest Path First (CSPF) algorithm with explicit routing information and CoS priorities. With the help of the TE-LSDB, CSPF algorithm will be run to calculate the Constraint Shortest LSPs. Five subnets were constructed to represent traffic between five offices (City_1 (i.e. Melbourne), City_2, City_3, City_4 and City_5 (i.e. San Francisco)). Four transit IP_Nets were created to demonstrate a backbone (core) domain to apply Traffic Engineering (TE) to the traffic passing through the network.

Assumptions:

Voice and video conversations between two offices (City_1 and City_4) will be conducted in real-time simulation. City_1 will initiate conversations. The main concern is the delay and jitter. Packet loss is not a factor since enough buffer space is allocated.

Traffic will be classified at the edge of each subnet according to its service class or per-hop behavior. The backbone (core) routers are enabled as both MPLS and DiffServ domains. Voice will be given higher priority over video within the same service class. Web traffic will be marked and queued to be output on the output bandwidth port at the edge router. Within each City office, there will be traffic from and to the subnet, to mimic the subnet's users. Traffic generators (see Figure 4 Bases) have been distributed randomly throughout the backbone to demonstrate other users in the Internet. These traffic generators are represented by sites (Backbone level) and by single nodes (Subnet level). Each site will load the backbone with traffic at an average rate of 150 Mbps. Single node's Raw Packet Generator (RPG) is used to generate self-similar prioritized traffic in an adjustable rate of 10-100 Mbps. The essential part of the simulation is to set measures of QoS provisioning and guarantees and demonstrate how they might be achieved through weight assignment of LSPs. The weight assignment of LSPs will be determined based on the application requirements or the application's ToS. The 3-experimental bits can be used to identify ToS that a specific application needs. QoS requirements of each application type may be specified in terms of delay, delay variation and packet loss.

Delay requirements:

Real-time voice and video should have a maximum end-to-end one-way delay of 150 ms. An upper bound on delay variation should not exceed 50 ms. G 723.1 codec was used to encode the voice traffic, using one voice frame per packet. The video is transported at a rate of 15 frames per sec, using a frame size of 128 x 240 pixels. The generated real-time traffic will be simulated as discrete event traffic, since it provides accurate results, high degree of detail, and queuing effects [7, 8]. Web traffic, simulating the Internet, was generated as background traffic. The traffic was classified at the edge router and marked as in Table 1.

Table 1: Traffic Classification

Applications		Type of Service	Bandwidth share of queue	Weight
Real-time multimedia	Voice	DSCP 252	25 %	25
	Video	DSCP 244	25 %	25
Web Traffic		DSCP 0 (Default)	50 %	50

The strategy was to use a combination of queuing schemes that will yield the best performance measured by the response time. Priority Queuing (PQ), Weighted Fair Queuing (WFQ), Committed Access Rate (CAR), Modified Weighted Round Robin (MWRR), Modified Deficit Round Robin (MDRR), Deficit Weighted Round Robin (DWRR) and Weighted Random Early Detection (WRED) were used in different scenarios.

Simulation Results: The edge router's links were overloaded (congested) with traffic to represent a bottleneck, reaching 90-100 % utilization, and in some instants, the links were over utilized. The model network was simulated for 600 seconds. During the first 200 seconds, the backbone was in a normal traffic-load with links underutilized. Through examination, it was found that OSPF was sending traffic through the shortest route with the highest bandwidth. These routes were used repeatedly throughout the scheduled traffic growth. Lower priority traffic was competing with higher priority traffic. Therefore, traffic engineering is not supported by the current IP routing used in the Internet. Video-packet end-to-end delay reached 43.5 ms for the DS mechanism using MWRR at the edge of the network, and DWRR at the core of the network; and 32.8 ms for MPLS, and Voice-packet end-to-end delay reached 39.5 ms of voice-packet end-to-end delay for the DS, and 29.8 ms for the MPLS (see figure 6 below).

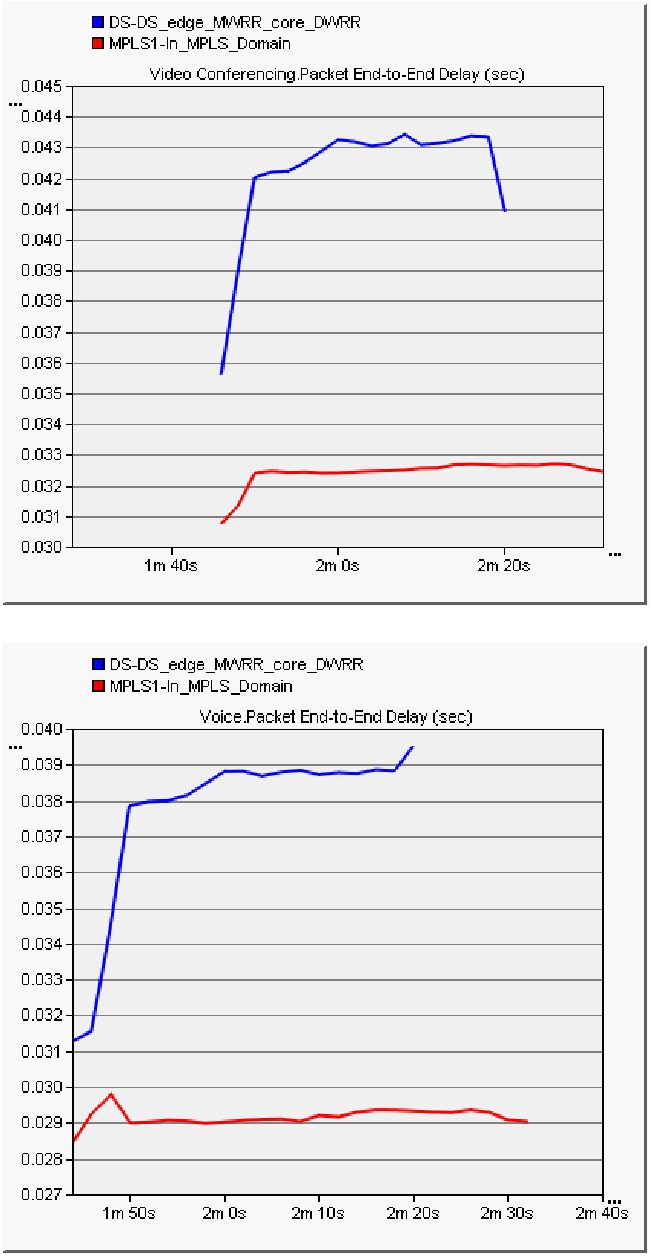


Figure 6: Video and Voice End-to- End delay using DS and MPLS forwarding mechanisms.

And average video packet end-to-end delay leveled about 42.2 ms for DS and about 32.5 ms for the MPLS as seen in figure 7 below. Also, average voice packet end-to-end delay leveled about 37.7 ms for DS and about 29.2 ms for the MPLS.

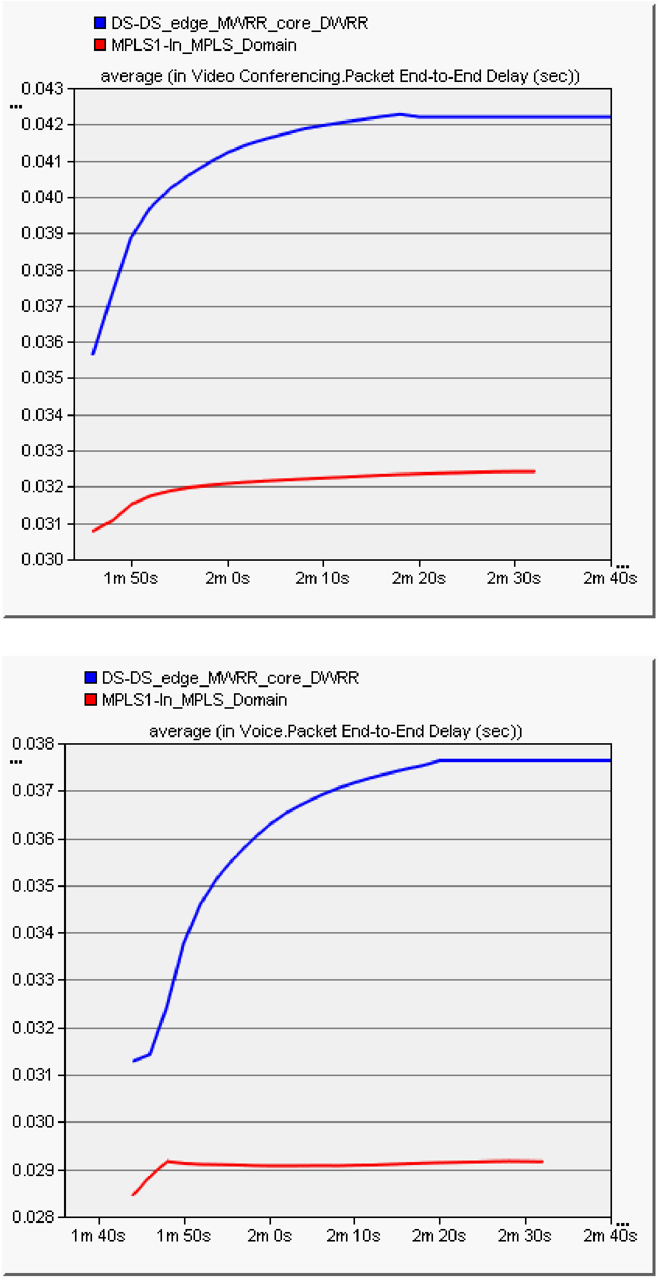


Figure 7: Average Video and Voice End-to- End delay using DS and MPLS forwarding mechanisms.

5. CONCLUSION

Real-time traffic requires QoS guarantees. Comparison of the performance of MPLS versus DS was performed. In the MPLS domain, LSPs weight adjustments between different application-based service types can provide performance tuning solutions affecting critical applications transmitted in the network. Different traffic classes were created and assigned different values called DSCP according to their forwarding treatment or service class. Real-time and non-real-time multimedia traffic were identified and marked according to its priority. The response time was improved based on created service classes that are based on differentiated service (DS) model. Queuing schemes were used at both the boundary and the core of the network respectively. Since queues are not computation intensive, it is possible to implement in high speed routers with multiple ports. In this model, MPLS showed an improvement of 20% over DS. Future work will involve additional simulations based on different profiles, to define a better QoS approach based on the needs and the requirements of different traffic to see if improvement will hold.

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