Quality of Service Mechanisms and Challenges for IP Networks

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ABSTRACT

In the past decade, Quality of Service (QoS) parameters have posed great challenges for Network Operators. This is partly because of the growth in network varied traffic demands. The Internet is a best-effort technology, and therefore, not optimized for the transport of delay sensitive services. Real time voice, video, and some applications, such as multimedia applications, video streaming, etc. have placed increasing demands on networks, straining their ability to provide customers with good quality services. An attempt to address this problem has resulted in numerous mechanisms for providing quality of service networks. The ultimate goal of these mechanisms is to provide improved network service to the applications at the edges of the network. This paper reviews advances in QoS mechanisms and recommends how they can be integrated and implemented in order to take advantage of optimized network resources.

(Keywords: quality of service, internet, real time services, voice communication networks, telecommunications, delay sensitive traffic, MPLS, DiffServe, IntServ)

INTRODUCTION

Over the last decade, Quality of Service (QoS) has increasingly become a topic that keeps telecom operators and researchers awake. Since communication networks have become a very essential part of our life, much effort has been geared towards improving their QoS in order to achieve more customer satisfaction, which leads to strong loyalty [1, 3]. Furthermore, QoS has, by itself, become a profit manipulation tool for service providers to achieve global efficiency in resource utilization [3]. Moreover, recent advances in high speed networking technology have created opportunities for the development of delay sensitive services such as multimedia applications, Internet telephony and voice over IP technologies characterized by multiple QoS requirements [4].

Often times, QoS is used as a misnomer. Frequently, people use it interchangeably with related terms like customer satisfaction, first class, golden class, good or bad services, Total Quality Management (TQM), quality rather than quantity, etc. Primarily, QoS refers to the capability of a network to provide better service to selected network traffic over various technologies, including Frame Relay, Asynchronous Transfer Mode (ATM), Ethernet and 802.X networks, SONET, and IP-routed networks that may use any or all of these underlying technologies [2, 4]. The primary goal of QoS is to provide priority, dedicated bandwidth, controlled jitter, and latency required by some real-time and interactive traffic, and improved loss characteristics.

This paper is concerned with QoS mechanisms for the transport of delay sensitive traffic over a best effort network such as Internet or IP networks. “Best Effort” is a model in which an application sends data whenever it must, in any quantity, without requesting permission or first informing the network [2, 3].

For best-effort service, the network delivers data, if it can, without any assurance of reliability, delay bounds, or throughput. Therefore, beyond the best-effort network services like Differentiated Services (DiffServ) and Integrated Services (IntServ) QoS mechanisms are essential. A third network core packet-forwarding mechanism, Multiprotocol Label Switching (MPLS) has also been suggested [5] as a QoS mechanism. DiffServ and IntServ are very well established QoS mechanisms. MPLS as a QoS mechanism is yet to be fully defined.

The intent of this paper is to propose how MPLS can be combined with either IntServ or DiffServe in order to achieve better quality of service, much better than either IntServ or DiffServe can individually offer. This paper will therefore review the components and mechanisms of QoS in later sections. These will be followed with recommendations on how MPLS could be combined with either DiffServ or IntServ in order to achieve better QoS.

QOS COMPONENTS AND PARAMETERS

Network resources are often limited and hence the efficient management of QoS parameters is essential to network operators and service providers. The need for QoS cannot be over emphasized. In a proprietary study [6], it was discovered that for both Residential and Business Applications, premium services would be the main contributor to Average Revenue per User (ARPU). Figure 1 shows relative contributions of ARPU based on different classes of services for Business Applications and Services. It is observed that one-to-one video and video streaming contributes more value to operators' business and these applications demand unprecedented network resources. So, optimal management of the various network resources with respect to class of services requires the efficient handling and manipulation of QoS parameters.

QOS PARAMETERS

Different applications have different requirements regarding the handling of their traffic in the network. Applications generate traffic at varying rates and generally require that the network be able to carry traffic at the rate at which they generate it. In addition, most premium applications are more or less intolerant of traffic delays in the network and of variations in traffic delay. Certain applications can tolerate some degree of traffic loss while others cannot. Thus, the various QoS requirements are expressed using throughput, bandwidth availability, latency, jitters, packet losses, and service availability.

COMPONENTS OF QOS

QoS parameters have to be properly managed and controlled in order to achieve varying QoS performance levels for the various Classes of Services (CoS). QoS management and control are achieved with the aid of these QoS components:

1) Traffic Classification, which is responsible for sorting data flows of different traffic into separate classes of services;

2) Service Level Agreement (SLA), the contract between the Service Provider and the customer for a specific class-of-services;

3) Admission Control and Policing, which is used by Service Providers to manage CoS defined in the SLA and controls the ability of the network to refuse customers resources requirements when demand exceeds capacity; and

4) Active Queue Management (AQM), which is responsible for managing network queues based on a Service Level Agreement

QOS MECHANISMS

In this section we review briefly the various types of QoS mechanism, namely:

1) Integrated Services (IntServ)
2) Differentiated services (DiffServ), and
3) Multiprotocol Label Switching (MPLS).

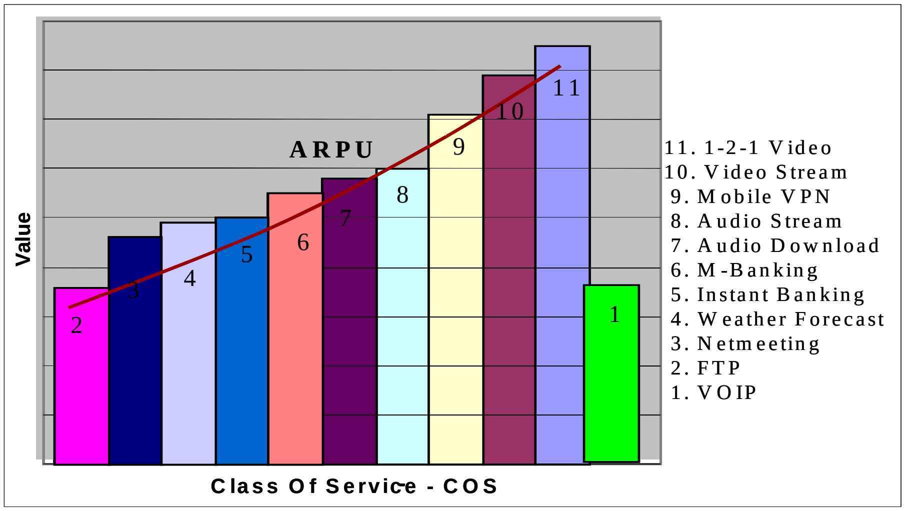


Figure 1: ARPU Contributions by Business Applications and Services.

INTEGRATED SERVICE OVERVIEW

Integrated service is a multiple service model that can accommodate multiple QoS requirements. In this model, the application requests a specific kind of service from the network before sending data. The request is accomplished by explicit signaling; the application informs the network of its traffic profile and requests a particular kind of service that would meet its bandwidth and delay requirements. The request is carried out for the application by sending RSVP packets across the network, if it is capable of doing so, or it is done on its behalf by the edge (ingress) router or switch through the network to the egress router. The application is expected to send data only after it gets a confirmation from the egress router. The network performs admission control, based on information from the application and available network resources. It also commits to meeting the QoS requirements of the application as long as the traffic remains within the profile specifications. The network fulfills its commitment by maintaining per-flow state and then performing packet classification, policing, and intelligent queuing based on that state. There are two types of IntServ mechanism: the guaranteed Service (GS) and Controlled Load Service (CS).

GUARANTEED SERVICE (GS)

GS is an IETF RFC 2212, which allows applications to reserve bandwidth to meet their requirements. For example, a Voice over IP (VoIP) application can reserve 64 Kbps end-to-end using GS. The Weighted Fair Queuing (WFQ) with RSVP is used to ensure that data throughput and delay will be guaranteed. GS attempts to offer strict qualitative end-to-end guarantees, which are essentially used by delay jitter and rigid delay intolerant applications to emulate circuit-oriented kind of services. Every element along the path must be GS aware, otherwise the reservation could not be accomplished.

CONTROLLED LOAD SERVICE (CS)

CS is another IETF RFC 2211, which allows applications to have low delay and high throughput, even during times of congestion. For example, adaptive real-time applications such as playback of a recorded conference can use this kind of service. RSVP with Weighted Random Early Detection (WRED), provides CS. [7]

IntServ RSVP is layer-3 protocol. Traditionally, it uses IntServ semantic to convey per-conversation QoS requests across the network [8]. There are two main RSVP messages: PATH and RESV. The PATH message, which is sent by the application towards an RSVP receiver, describes the data to be sent, and in return, the receiving end sends back an RESV messages to the sender. The message indicates the traffic profile. In the case of multicast traffic flow, RESV messages are aggregated making RSVP QoS suitable for multicast traffic [9].

Generally, PATH messages traverse the network elements from the sender to the receiver. Each RSVP aware elements in the path records the path info and establishes state-flow in accordance with the path message [11]. As the RESV message returns to the sending end, each element examines the resources requirement; if the element is unable to meet the requirement it rejects the RESV message and sends it back to the receiver [10].

The sending of the PATH and RESV messages are shown in Figure 2.

DIFFERENTIATED SERVICES

DiffServ is a CoS model defined in RFC 2474 and it differentiates traffic by user, service requirements, and other criteria. It marks packets so that network nodes can provide different levels of service via priority queuing or bandwidth allocation, or by choosing dedicated routes for specific traffic flows. A policy management system controls service allocation [9,10]. Unlike IntServ, DiffServ takes a stateless approach that minimizes the need for nodes in the network to remember anything about flows.

DiffServ is implemented by using a 6-bit field in the Type of Service field of IPV4 and that of Traffic Class field of IPV6 as shown in Figure 3. The 6-bits, which is often referred to as DiffServ Code Point (DSCP) are capable of 64 DSCP or traffic markings. Network elements simply respond to these markings, on a per-hop basis, without the need to negotiate paths or remember extensive state information for every flow. In addition, applications don't need to request a particular service level.

A Per-Hop Behavior (PHB) is a description of the externally observable forwarding behavior of a DiffServ capable node applied to a particular DS behavior aggregate.

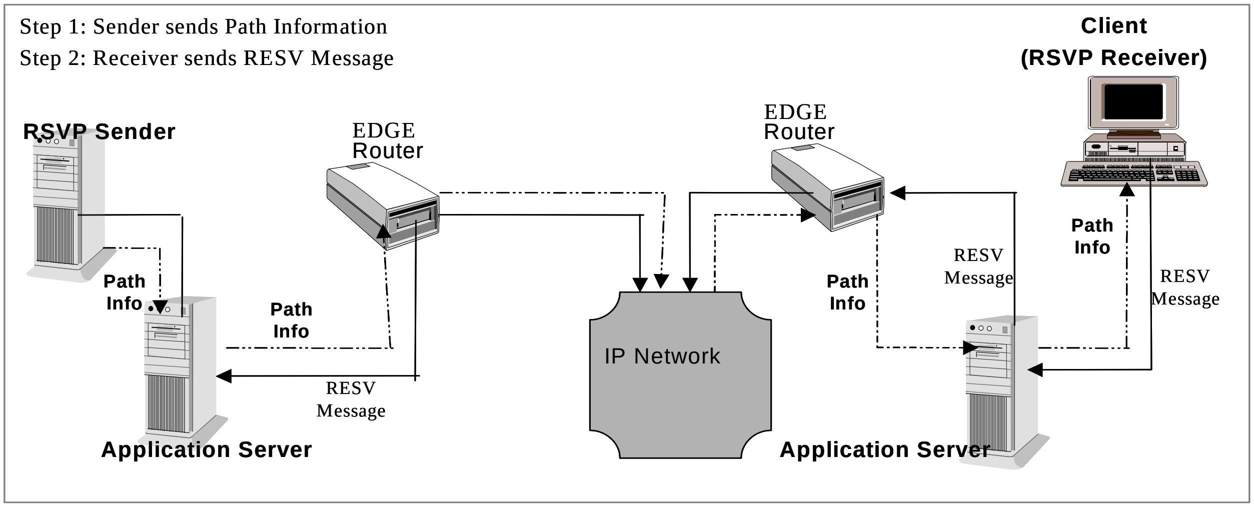
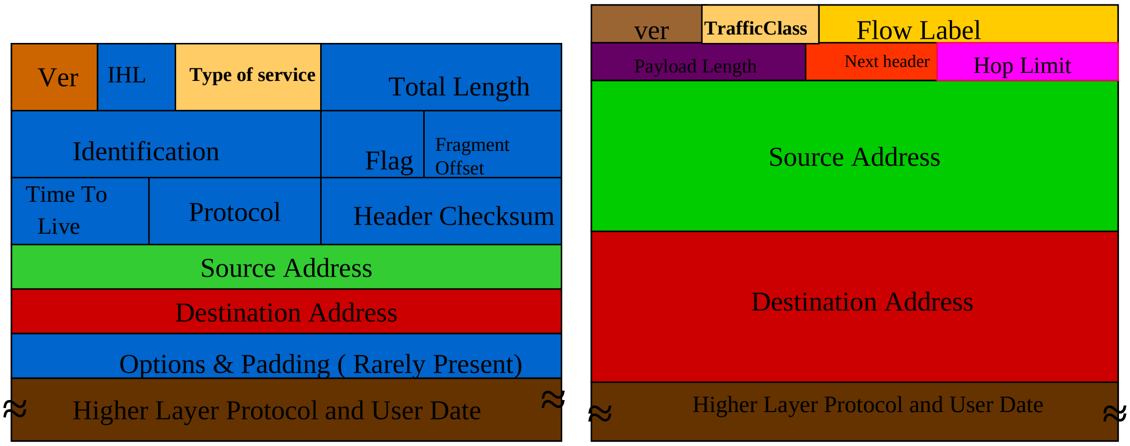


Figure 2: RSVP Path and RESV.



IPV4 **IPV6**

Figure 3: DiffServe Field in IPV4 and IPV6 Header.

Useful behavior distinctions are mainly observed when multiple behaviour aggregates compete for buffer and bandwidth resources on a node. PHBs may be specified in terms of their resource (e.g. buffer, bandwidth) priority relative to other PHBs, or in terms of their relative observable traffic characteristics (e.g. delay, loss). PHBs are implemented in nodes by means of some buffer management and packet scheduling mechanisms. Typical buffer management schemes used are RED, ARED, FRED, SRED, WRED etc.

Typical scheduling schemes used are weighted round-robin, CBQ, WFQ, and variants of WFQs. PHB's are indicated by specific values in the DSCP. Although, each PHB's definition also provides a "recommended" DSCP value. DiffServ allows multiple DSCP values to map to the same PHB whether in the same or different DiffServ Domains. The two standardized PHBs are: Expedited Forwarding (EF) and Assured Forwarding (AF)

EF is represented by a single DSCP. The behavior is intended to emulate a virtual leased line, which is similar to ATM CBR service. To minimize any delay that may occur when congestion exists, this behavior suggests using a marking or code point in the DSCP field to identify traffic that should receive preferential link access. Furthermore, because packets using the EF behavior get treatment superior to that of all other packets, the delay variation, or jitter is minimized as well. When the packets get through routers quickly even during times of congestion, the end-to-end delay they experience is minimized.

The second PHB is Assured Forwarding (AF). AF uses four sets of DSCP values. Each set corresponds to a delay class. Within each set, there are three DSCP code points corresponding to different drop precedence levels. Table 1 shows the DSCP values for each AF PHB group.

Each AF service class is distinguished by the level of forwarding resources (bandwidth and queue space) it receives at each hop, independent of the other three service classes (implying the use of WFQ, WRR, or similar schedulers). To prevent possible re-ordering of packets belonging to application flows within a service class, an AF-compliant router must not map different service classes into the same queue and is not allowed to distribute packets belonging to a single service class across multiple queues.

Specific drop probabilities for each precedence level are assigned to meet the desired packet-loss characteristics for each class. Although there are three drop-precedence levels, a minimal AF implementation may get by with only two distinct drop probability functions. In this case, both precedence 2 and 3 are mapped to the function returning the higher drop probability. As with EF, actual edge-to-edge service based on an AF PHB group requires coordination between edge routers (to limit the type of traffic mapped to each AF class and drop precedence) and the core routers (to ensure that appropriate resources and behaviors are provided to each class and drop precedence).

Table 1: IETF DiffServe Code Points.

AF	Class 1	Class 2	Class 3	Class 4
Low Drop Precedence (1)	001010	010010	011010	100010
Medium Drop Precedence (2)	001100	010100	011100	100100
High Drop Precedence (3)	001110	010110	011110	100110

MPLS OVERVIEW

MPLS stands for Multi-Protocol Label Switching. MPLS assigns labels to IP flows, placing them in the IP frames. The frames can then be transported across packet or cell-based networks and switched based on the labels rather than being routed using IP address look-up. In IP networks, IP packet is forwarded through a network on a hop-by-hop basis using Interior Gateway Protocol (IGP) such as Routing Information Protocol (RIP) or Open Shortest Path First (OSPF). The forwarding decision is made by looking up the packet destination layer-3 address (IP address) against the routing table to determine the next hop. In contrast, MPLS uses labels to forward IP packets. The router at the edge of the MPLS network attaches labels to packets based on a Forwarding Equivalence Class (FEC). Packets would then be forwarded through the MPLS network based on their associated FEC by swapping the labels through the routers or switched at the core of the network to their destination.

The key components of MPLS are: Labels, Label Edge Router (LER), Label Switching Path (LSP), Label Switching Router (LSR) and Forward Equivalent Class (FEC).

RECOMMENDED COMBINATION OF MPLS WITH OTHER QOS MECHANISM

In this section we recommend how DiffServ or IntServ could be mapped to MPLS in order to achieve an optimum quality of service results.

DIFFSERV TO MPLS MAPPING

The DSCP is an IP header field that is set based on the class of service to be met. While DiffServ is a good QoS mechanism, it slows down packet forwarding because of per-hop examination of the IP header. MPLS on the other hand uses different priority performance levels. The Label Edge Router (LER) sets the LSP. Once these LSPs are created the Label Switching Routers (LSR) would forward the packets without examining the IP header for IP addresses and do not need to make routing decisions. At the egress, the LER removes the Label and forward the service based on IP address to receiving application (Figure 4).

INTSERV MAPPING WITH MPLS

Similarly like the DiffServe mapping to MPLS, the RSVP sender at the LER sends the Path Information and on receipt of RESV Messages from the egress LER, the flow information is converted into MPLS LSP or MPLS tunnel for the different class of flow information. Recent versions of MPLS include an RSVP, which serves as a Label Distribution Protocol (LDP) that establishes LSPs through the MPLS network. It also performs explicit routing, which allows a node in the MPLS network to establish LSPs that are independent of any layer 3 routing protocols and therefore not limited by route selection process. This mapping is illustrated in Figure 5.

CONCLUSION

Network operators and service providers are embracing premium services as a means of improving average revenue per user. These premium services often pose great resource requirements. The efficient management of limited resources is therefore inevitable in order to create service differentiation and maximization of the income of service providers. This has obviously raised the awareness of QoS challenges among the providers in the last decade.

There are essentially two ways to resolve the QoS challenges. The first is simply to provide unlimited resources. This is simple, but obviously impracticable and cost prohibitive. The second approach would be to use DiffServ, IntServ, or MPLS to improve the QoS. In this paper we have reviewed the various QoS mechanisms open for exploitation.

It is recommended that a combination of MPLS in the core of the network with either DiffServ or IntServ at the edge of the network would provide optimum end-to-end quality of service parameters.

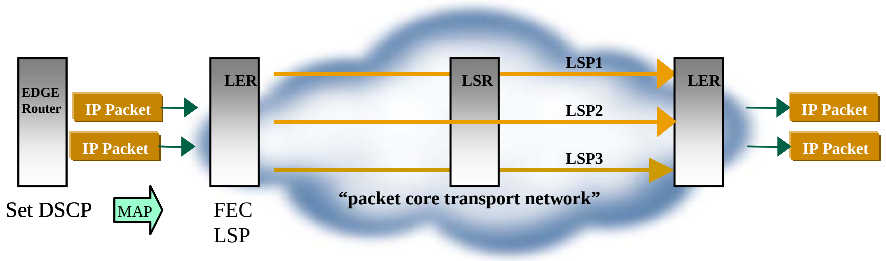


Figure 4: DiffServe to MPLS.

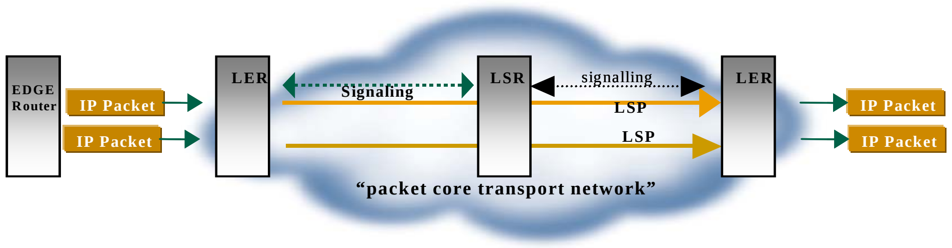


Figure 5: IntServ to MPLS.

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