Issues and Architectures For Better Quality of Service (QoS) from the Internet

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ABSTRACT

With the exponential growth of the Internet, the demand for end-to-end Quality of Service (QoS) guarantees has gained significant importance. Internet of the future will be characterized by applications right from voice, video to normal data. To provide a seamless integration of these applications into the Internet, we need to provide the right kind of QoS support at all types of environment. This paper evaluates on all the factors that govern Internet QoS. Highlighting all-important factors will then derive a unified approach when looking into the issue of QoS management in the Internet. The paper also reports on the ongoing work related to QoS in the Internet and discusses future directions.

1. INTRODUCTION

Definition of QoS doesn't restrict to a few parameters but it is essentially distributed to a diverse set of QoS characteristics. In other words, perceivable QoS should not be judged only by parameters like packet loss, bandwidth, delay or delay jitter, rather these have to be looked upon as just a subset of the overall set that characterize QoS [15]. A sound description of the QoS architecture is essential to understand its dependencies at various levels and highlight upon issues that require further investigation. Consideration of all such issues would then derive a relevant approach towards proper QoS management from the Internet.

The guiding principle for such an article is to make the readers aware of QoS concepts, investigate factors that affect Internet QoS and similar issues that relates to QoS. The paper also provides a simplified overview of the ongoing work on QoS in the Internet and discusses future directions.

The article is organized as follows: Initially, we present a simple paradigm on QoS concepts and discuss the factors that affect IP-QoS. We then elaborate on each of these factors. Later, a description on the IP QoS models will be followed by a brief explanation of their inter-working. QoS management in a wireless-IP domain will also be briefly explored in this issue. Other factors affecting QoS like congestion, routing, self-similarity, link sharing will be accounted. Finally, future support for QoS in the Internet will be discussed.

2. QoS: A Wider Perspective

A model to enclose the dependencies related to the QoS in the Internet is presented [Figure 1]. It provides a good insight towards better QoS management issues looking from two very different levels of QoS. We term them here as *Network level QoS* and the *Host level QoS*.

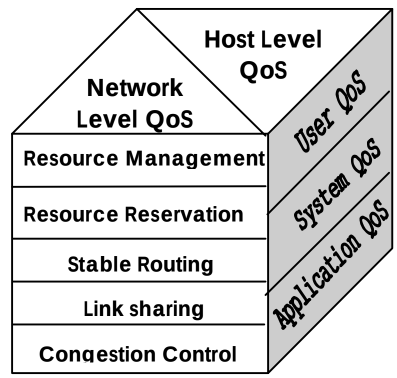

Figure 1: QoS Perspective

The figure shows the QoS-plane along with factors that affect QoS at each of the levels. Such a perspective related to QoS helps to easily construe and evaluate a flexible framework, for the development and deployment of multimedia applications over the Internet. We investigate the issues in detail both from the host level as well as from the network level perspective.

2.1 Host level support for QoS

This can be distinguished further into three levels of abstraction. i.e. user level, application level and system level.

User QoS is mainly concerned with the requirements of a user that varies from a corporate user to that of a normal user. As such, *pricing* is an important entity to the service provider for providing QoS. A user can request resources only if it is available. This makes resource *availability* an important constituent of User QoS. Finally, the preference level of an end user is always relative and it is not easy to figure out what factors build up user preferences.

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Therefore, all parameters that usually govern QoS (or User QoS) may not always be deterministic and it is left to the user to decide if the perceptual quality (e.g. CD quality) is good enough to meet the (user) requirements. Usually, the supporting environment across the user plays an important role in such decisions.

Application QoS makes up an important constituent to the host level QoS. It can be classified more accurately into static level and dynamic level QoS support. At the static level, support is in terms of static compression and decompression techniques applied at the end hosts. While dynamic level support mostly caters to make the application robust in order to adapt it to the prevailing network conditions.

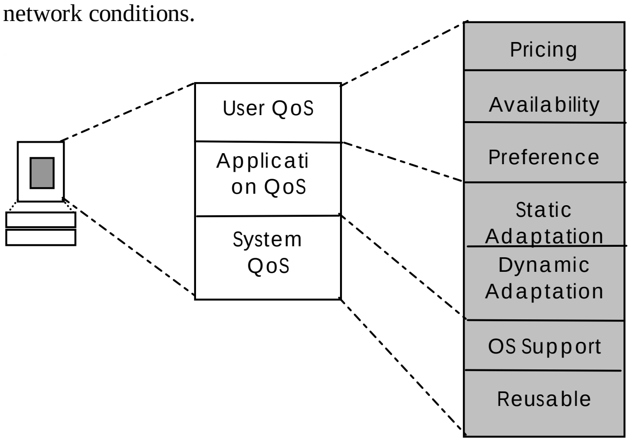

Figure 2: Host Level QoS

However, adaptive nature of these applications can be based either on delay adaptation or bandwidth adaptation. Mbone tool called *vat*[1] used a delay adaptive algorithm to adjust the stability of the playback points to make the applications adaptive.

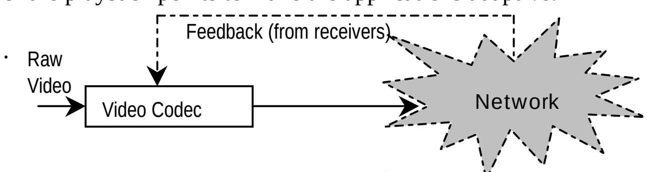

Figure 3: Dynamic Adaptation

In the other case, algorithms like hierarchical encoding to variable compression schemes can provide dynamic adaptation based on bandwidth adaptation. Most of the techniques are largely based on feedback available from the network so as to make the applications adapt to the network conditions[13]. Here (Figure 3), the receivers were polled and packet loss rate was taken as the feedback parameter to the video codec at the sender end.

However, such an architecture that involves multicasting is still not scalable to a large numbers of receivers since it causes *feedback implosion*[2] problem at the sender end. The use of weights for each individual session was suggested, but its use still remains questionable in case of low bandwidth session employing large number of receivers.

[1] audio conferencing tool

[2] large amount of feedback is available to the video codec from the receivers

System QoS defines the QoS that includes all sorts of components located in between the applications and the underlying network. These include the operating system (kernel), filters, device drivers, libraries (static and dynamic) and other middleware components. Therefore, these are also termed as *reusable components*. Experiences here suggest that all parameters relating to CPU (computation time, cycle time, utilization etc.) and memory (e.g. memory requests) affect the system level QoS. Design optimization contributes significantly towards the improvement of QoS at this level.

2.2 Network Level QoS

The ***Network Level support*** can be visualized in terms of two parameters i.e. *Device level QoS* and *physical network QoS*. The *device level QoS* relates to peripheral devices or system components. These components build up the *Physical network QoS*. Examples include cells/second in ATM, frames/sec in a video capture etc.

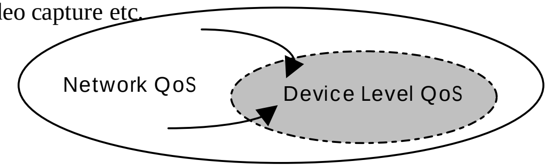

Figure 4: Network QoS

As shown in Figure 4, device QoS builds up network QoS. But not all QoS attributes can be dedicated only to physical network QoS. Much of it also depends upon how the software component supports the network QoS. These include tasks like scheduling, filtering, classification etc. for achieving the desired QoS. The decision significantly contributes to efficient handling of QoS in a given network domain. We investigate most of them here in brief.

2.2.1 Resource Management

Resource management allows for successfully sharing resources across several applications. This is important for general purpose distributed environments where resources (bandwidth) need to be shared across multiple contending applications. There are several ways to achieve proper resource management. Presently, we brief up two techniques that will be used more often in the future.

2.2.1.1 Agent Technology

The main objective here is to assess the practical implications and concepts of mobile agent technology for use in resource management. This includes tasks right from dynamic management of VPN's (virtual private networks) to all solutions related to network management software[10]. The only target in all such cases is to use what is available and not always to provide an enhanced agent platform.

2.2.1.2 Active network support

The concept emerged because the lead user applications could perform user-driven computations at the nodes within the network. This has been possible due to the emergence of the mobile code technology that makes dynamic network service invocation attainable[11][12]. Networks are active in the sense that routers and switches can perform customized operations on a per-user or per-application basis. This idea of carrying procedures and data is seen as a step beyond the conventional switching or routing, which can in turn rapidly adapt the network to the changing requirements.

2.3 Resource Reservation

Reservation is one of the efforts to characterize QoS at the network level. Once resources are reserved, the application is assured a minimum amount of acceptable QoS. A protocol that enables reservation in the Internet is RSVP (more description in section [3.1]).

2.4 Effect of Routing on QoS

Many types of instabilities related to routing exist in the Internet. Route fluttering, routing asymmetry, routing loops are some of the common problems in the Internet that results into the degradation of QoS parameters. All related QoS parameters are affected, consequently degrading the Quality of Service (QoS) available to the end user.

Constraint based routing is a panacea to the problem discussed above. In addition to selecting routes that meet QoS requirements, it also provides increased network resource utilization. However, it may also lead to increased communication and computation overhead, larger routing table size and may sometimes result into potential instability [1]. Effective and stable routing is therefore essential in providing QoS in the Internet.

2.5 Congestion Avoidance

It amounts to network support by employing effective techniques to avoid congestion within a given network. The best way to control congestion is to avoid it. One such technique to avoid congestion in gateways is *RED* (Random Early Detection)[20]. It avoids congestion by controlling the average queue size of the gateway buffers. Additionally, it also eliminates global synchronization problem and maintains its steady bias against burst traffic. The gateway calculates an average queue size that is compared to two thresholds, one denoting the minimum queue size while another denoting the maximum size. Below the minimum limit, no packet is marked while every packet is marked above the maximum threshold. In between the two, the packets are marked with a probability that remains a function of the average queue size. The packets are then treated according to their marked probability. Such type of control effectively avoids congestion and thereby results into improved QoS in the network.

3. QoS Models for the Internet

Two different architectures along with its applicability to two different groups in IETF (Internet Engineering Task Force) viz. IntServ (Integrated Services) and DiffServ (Differentiated Services) are discussed. Quite conventional to our belief, DiffServ was realized because the former had certain shortcomings in its architecture.

3.1 IntServ IP QoS Model

IntServ architecture [3][5] uses Resource Reservation Protocol (RSVP) as its working protocol to achieve its end-to-end signaling. Resources are reserved at each of the router along the path between sender and receiver through explicit signaling for any flow that demands QoS. The benefit of end-to-end signaling is its ability to convert the connection-less Internet into a connection-oriented network. The IntServ formulated three types of service class:

1. *Guaranteed Quality Service*: Applications with rigid end-end delay bounds use this type of service.
2. *Controlled Load Service*: For applications with looser performance criterion than Guaranteed Quality Services but requiring higher attributes than normal best effort services.
3. *Best Effort Service*: Services provided by the Internet as of today.

RSVP is a soft–state adaptive protocol. It also has other advantages like receiver initiated reservation, merging of reservation requests and support from various underlying transmission technologies. Indeed, all these benefits are available at the expense of certain shortcomings inherent in this model. One of the most important drawbacks in IntServ model is heterogeneity. Majority of the end-user networks in the Internet constitutes of Ethernet. Ethernet cannot inherently provide any temporal performance guarantees. It cannot support deterministic network access delay because of its contention-based medium access protocol. This makes it contrary to the preferential resource requirement of real time traffic.

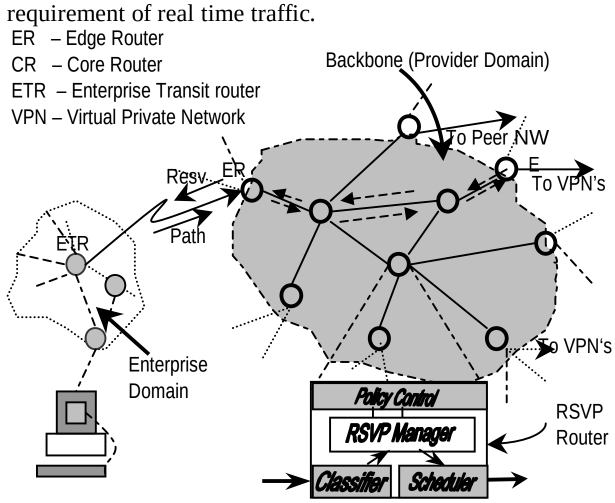

Figure 5: Integrated Services (IntServ) IP-QoS Model

Some of the work in this direction lead to a protocol called RETHER [2] (real-time Ethernet protocol) used to reserve bandwidth on an existing Ethernet without any additional hardware for real-time applications demanding bandwidth. Secondly, as gradual replacement is time consuming it will take considerable amount of time to replace the existing Internet routers with RSVP capable routers. Third, the IntServ model involves costly and complex signaling. Finally, IntServ paradigm is not scalable. It cannot scale with large number of sessions states and requires extensive signaling that means even aggregation and merging of sessions does not help.

3.2 DiffServ IP QoS Model

The main problem that makes IntServ infeasible was scalability. Maintaining thousands or millions of connections in an IntServ router is impractical. With the enormous number of sessions existing in the backbone, the amount of computation complexity involved overburdens the router [4].
Towards a solution, a new working group called DiffServ was formed to look into this issue. This group proposed a model that completely eliminated the storage of session states in the router[7][8]. The model is computationally inexpensive for a router even in the backbone. DiffServ implements the concepts of aggregation of flows and per-hop behavior applied to a network-wide set of traffic classes. Flows are classified according to pre-determined rules, so that many application flows are aggregated to a limited set of class flows.

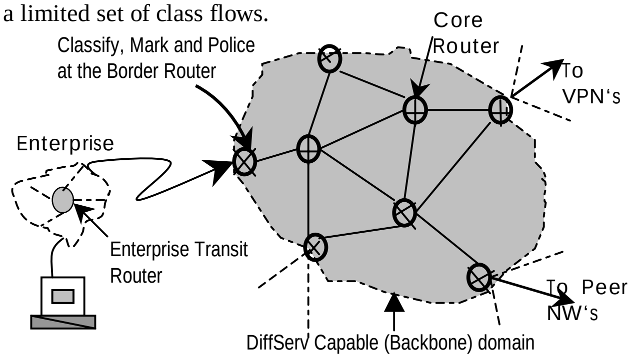

Figure 6: Differentiated Services (DiffServ) IP-QoS Model

Traffic entering the network domain at the border router (BR) is first classified for consistent treatment at each transit or core router (CR) [see Figure 6] inside the network. The classification is based on IPv4 (or IPv6) Type of Service (TOS) Header field also called as DS (differentiated services) field. Currently two bits are engaged in for standardization while rest six reserved for use in the future. The representation of the code points for DS field defines the standard code point. Each of the core routers within the DiffServ domain will read the DS field of the packets and treatment will usually be applied by separating the traffic into queues according to the class of traffic. This type of framework is more scalable than IntServ mainly for flow aggregation and minimization of signaling requirements. In all cases, it is also suitable for Enterprise domains (Intranets) provided all hosts and legacy routers mark the DS field according to the policies of the domain.

Even with all these advantages, DiffServ model is still devoid of qualitative guarantees. Unlike IntServ, once a packet enters into a DiffServ domain, its behavior is unpredictable because of the absence of explicit connection oriented end-end signaling. All the routers are expected to trustfully mark the packets and provide them the required level of treatment. In such cases it is completely up to the provider to provide the best possible services.

Service level agreements (SLA) is always considered a serious challenge to the providers implementing such services. SLA requirements between two different domains implementing DiffServ would necessarily involve thousands of rules that govern their inter-working. Such issues become more complicated if each of them provide different number of service classes. Proper QoS *Mapping* in all such cases will require lots of considerations beforehand. As of now, many issues regarding DiffServ are still under investigation within the IETF. However to reiterate, the focus of DiffServ has been entirely on how to support QoS in IP.

3.3 Inter-working IP QoS Models

In clear technical viewpoints, IntServ and DiffServ are complementary tools in the pursuit of end-end QoS. Each has an important role in a QoS enabled network. A manner in which both the models can be simultaneously used has been identified[9].

Here, the IntServ model is limited to the enterprise domain that is usually a small network compared to the backbone, which is a DiffServ domain [see]. The direct implication of it results into considerable reduction of maintaining session states within an IntServ router. The mapping of the IntServ service type to a PHB (per-hop behavior) of DiffServ should be necessarily justified by considering the service specific type requirements of IntServ to the appropriate PHB of DiffServ to invoke a similar service. All SLA's essentially needs to be taken into account for such a mapping.

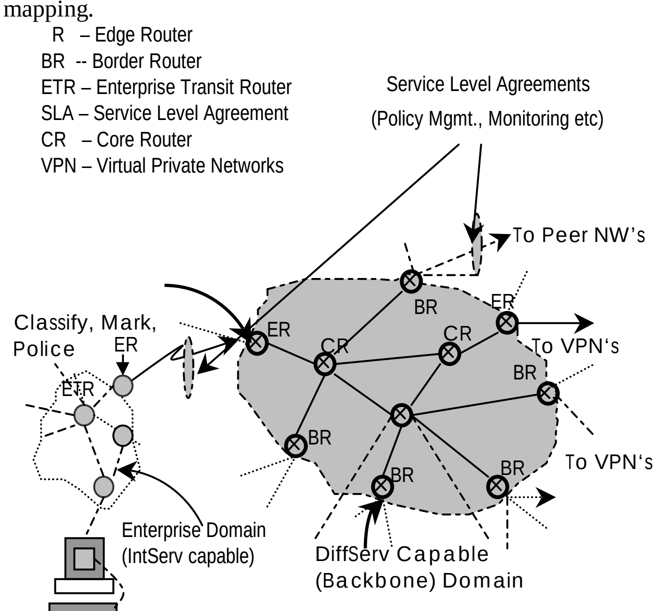

Figure 7: Inter-working IntServ and DiffServ

One of the main aspects of establishing end-end QoS is to ensure need-based availability of both quantitative as well as qualitative guarantees. While IntServ can provide both, DiffServ can provide only qualitative guarantees. In addition, one of the main differences between both models is admission control. In DiffServ, admission is provided implicitly while in IntServ the admission control is explicit (through control messages).

The former therefore breaks down the end-to-end support for QoS since neither the application traffic nor the intermediate nodes take any corrective action in case of admission failure occurring within the DiffServ domain. In case that happens, information about the failure should be explicitly communicated to the RSVP capable IntServ nodes accessible from this domain. SLAs if statically provisioned, admission control functionality is provided by static configuration. Otherwise dynamically variable SLAs can be propagated to inform the current DiffServ domain resource availability as an explicit admission control information to the IntServ networks.

3.4 QoS Management in a Wireless -IP Domain

Wireless access to the Internet is becoming more and more popular because of increasing use of wireless access technologies in various capacities and ranges (IEEE 802.11, Wireless ATM, IMT-2000 etc.). A flexible mapping technique is therefore needed between IP level QoS and corresponding radio access QoS. The Wireless-IP system must be capable of distinguishing flows both on the network side as well as on the air interface side. Figure 8 shows one such scenario that involves Wireless-IP integration [21][22].

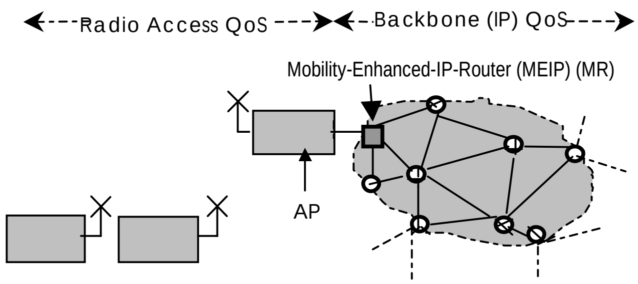

Figure 8: Integrating Wireless-IP

For proper QoS management in this plane, the mobility- enhanced IP Router (MEIP) and the Radio Sub System (RSS) must assign appropriate QoS parameters to various IP flows. Depending upon the MEIP – RSS interface, the IP QoS service classes should be correspondingly *mapped* into the service categories supported by a given transmission technology. For example, if ATM is chosen a translation from Internet Service class parameters to ATM service classes should be made [Figure 9].

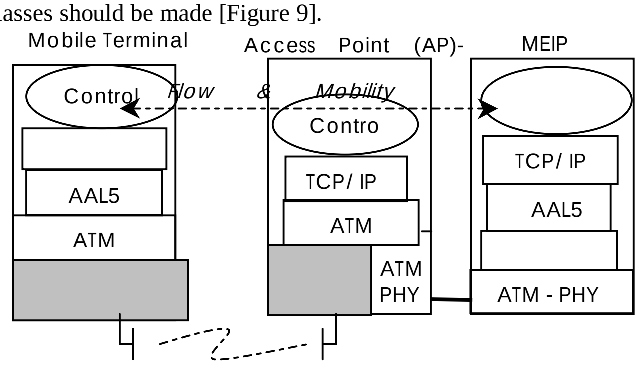

Figure 9: Data Plane in ATM

If the backbone implements IntServ or DiffServ QoS model, it should be possible to translate the service classes of any of the IP QoS model into ATM service class parameters. One such mapping between IntServ classes (Guaranteed, Controlled Load, Best Effort) into ATM (CBR, rt-VBR, nrt-VBR, ABR, UBR) has been proposed[23].

Similar mapping can also be extended for transmission techniques that employ an Ethernet option. While the former i.e. an ATM is intended for public telecommunication networks owned by a public operator, Ethernet is meant for private business LAN's such as customer – premises networks.

4. Self Similar Internet Traffic

An event that displays long term co-relations for packet arrivals across a wide range of time scales in an aggregated Internet traffic is a self-similar process. Usually burst traffic can be described using the notion of self-similarity. Such long-range dependence can also lead to drastic reductions in the effectiveness of deploying *buffers* in the Internet routers to absorb transient increase in the traffic load.

4.1 Effect on QoS

Studies have revealed that queue length distribution decayed more slowly for long-range dependent sources than for short-range dependent source[17]. The implication of such self-similar behavior of Internet traffic results in increased sizes of buffers at switches and multiplexes than those predicted by analysis and simulations. Once the buffer size is increased, it leads to higher Queuing delays than originally anticipated. This in turn has obvious effects on the quality of multimedia applications requiring higher bandwidth and lower latency, such as video conferencing and other distributed real-time applications. Self-similar behavior of the Internet has therefore added further complexities to the problem of optimizing performance in the Internet.

4.2 Re-engineering the Internet

Self-similar traffic has highlighted the importance of efficient Tele-traffic modeling for the Internet. Detailed investigation in this direction will provide a reasonable approach to redesigning and re-engineering of the network devices that can be used even in the presence of self-similar nature of the Internet.

5. Link Sharing

Link sharing refer to sharing of bandwidth into portions that are then used by different *entities*. Entities here can be referred to aspects of sharing bandwidth. Bandwidth can be shared among agencies, different protocol suites (SNA, IP, IPX etc.), different classes of traffic or for that matter types of protocol (Ftp, Telnet etc.) within a given protocol suite[24]. This can also be looked into hierarchically. For this reason it is also called as *hierarchical link sharing.* Several rules and considerations are followed to provide this sharing. Studies are ongoing in the direction to involve link-sharing issues within the framework of reservation. However, this can cause problem only in one aspect of reservation i.e. Admission Control. If it is assumed that most of the future traffic will be variable bit rate (VBR) traffic, use of a statistical admission control can provide a high degree of bandwidth utilization. However the use of such link sharing techniques clearly violates the use of a statistical admission control based algorithms, as it lowers the degree of statistical gains obtained (see[25], pg. 95-96). This can be however be overcome by letting the scheduler or traffic shaper to ignore the changes in the link bandwidth provided by link sharing. A study on these issues will be definitely a matter of interest in the future.

6. Future Support for Improved QoS

There are several steps taken by the Internet community in support of QoS. We elaborate on some of the areas where the ongoing work will have an implication on the developmental work relevant to QoS in the future.

6.1 IPv6

IPv6 is an enhanced version of IPv4 protocol specification. Incorporating QoS is not the only reason for transiting from IPv4 to IPv6, there are other reasons as well. Security considerations, mobility issues and increased address usage in the network domain, were some of issues considered while formulating IPv6 [6].

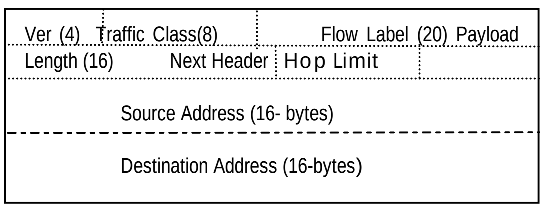

Figure 10: Internet Protocol (version 6) header [RFC-2460]

Essentially it consists of two QoS related fields [RFC 2460] in its header [Figure 10]. First component is 8-bit *Traffic Class field* while the second one is a 20-bit *Flow Label*. The purpose of Traffic Class field is to identify and distinguish between different types of classes or priorities of IPv6 packets. The Class field is intended to allow some sort of differentiated services similar to that of type of service (TOS) field of IPv4. Much of it will depend upon the way TOS field undergoes eventual standardization. The flow label is a 20-bit field that is used to characterize flows accordingly. More specifically it is meant for special handling of the flows (for e.g. in case of RSVP to differentiate between default service and other real-time services). *Flow Label* is assigned to a flow by the flow's source node or the node originator. Hosts or routers that do not support the functions should set the field to zero.

6.2 Advance Reservations: QoS availability in a resource limited Network

Reservations are needed because of the scarcity of network resources. If resources are plentiful, one need not even make an immediate reservation at all. In advance reservations, duration of the reservations along with the starting time and the finishing time are included. Renegotiations are possible if sessions require shorter or longer time. Admission control works on the basis of currently active flows as well as future requests [Figure 11]. States are maintained for all the current and future requests. The number of states established is proportional to the total number of current and future requests.

There are minimum two ways by which advance reservations can be achieved: using RSVP control messages [19]and using agents [18]. In the first case, advance reservations can be set up by continually sending PATH and RESV messages down the tree. This ensures that reservation has been done for the future, although the actual resources are still not allocated. Advantages include little changes into the existing protocol (RSVP) while its disadvantages involve both sender and receiver presence before the session starts and a large number of per-connection states in the router.

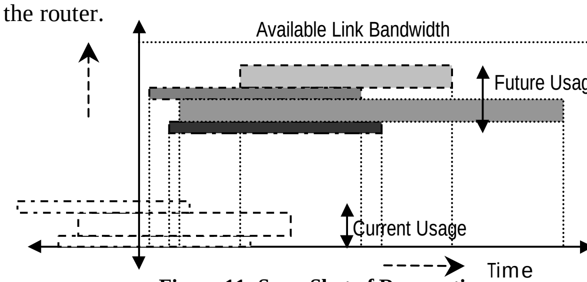

Figure 11: Snap-Shot of Reservations

On the other hand, advantage of using agent is little requirements for support from the routers and no need to maintain states in the router till the start of the session. Reservations can also be made for remote locations into heterogeneous network environments with the advantage of platform independence from such agents. This architecture relieves the router from costly admission control function; sets-up resources along the shortest route and performs QoS routing based on the parameters contained in the admission requests.

6.3 Multi-Protocol Label Switching (MPLS)

MPLS is a non-destination based forwarding strategy used to forward IP packets[8]. Forwarding is done by a Label Switching Router (LSR) that performs a match on a label associated with a packet in an MPLS domain [Figure 12]. This switching stands in between layer-2 and layer-3 of the OSI layer. For this it needs a protocol to distribute label switched paths (LSP's) which in turn can be used as tunnels. Usually Label distribution Protocol (LDP) is used for the purpose. A LSP once set-up, path of a packet can be known by label assigned by the ingress LSR.

Packets are classified at the ingress with an MPLS header attached. The header has 20 bit label along with 3 bit Class of Service (COS) field, 1 bit stack indicator and 8-bit time-to-live (TTL) field. The label acts as an index to search through the forwarding table. After processing of the packet, the incoming label is changed to an outgoing label and the packet is then switched to the next LSR. In this way, a number of flows can be aggregated into a traffic trunk (corresponding to a LSP) of a given service class.

Advantages of MPLS include:

- Faster packet classification and forwarding.
- Efficient tunneling mechanism into number of service classes.

QoS in such a scheme depends upon the labels and Class of Service (COS) fields in an MPLS header. As such it provides a simple mechanism by which number of flows can be aggregated into a single service class. It is this property that enables MPLS to work coherently with differentiated services (DiffServ) IP QoS model. In future, we can expect DiffServ to play a dominant role for providing QoS in WAN's, often in conjunction with Multi-protocol label Switching Protocol.

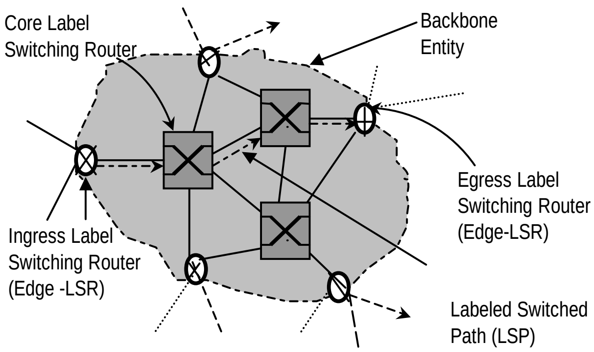

Figure 12: MPLS Domain

7. Summary

We looked into the issue of QoS management in the Internet and selectively addressed factors that affects QoS at each of the levels i.e. Host Level and the Network Level. We discussed IP QoS models and more importantly the existence of both the model i.e. IntServ and DiffServ for their desired inter-working. QoS issues related to the wireless-IP domain were also presented. Other issues at the network level (like congestion avoidance, routing stability) were briefed up that are vital for assuring QoS support from the Internet. Our view about self similar nature of traffic were largely based on reviewing the design constraints that should be kept in mind while designing or redesigning networks for the future. Finally, the importance of QoS in the future was highlighted in with a discussion on IPv6, advance reservations and MPLS.

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