An Architecture for MPLS Implementation in Wireless Networks

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Abstract : With the explosion of the IP based mobile network in the offing, the two most important challenges will be traffic engineering and quality of service in addition to the integration of services. IP packets are switched at layer three and is connectionless in nature. This poses a severe challenge to the IP networking in general and adds to the complexity of mobile IP networking. Multiprotocol Label Switching (MPLS) is a relatively new technique that speeds up routing, performs Quality of Service and provides a great solution for traffic engineering by controlling traffic flows in the network. It can provide efficient bearers for multimedia and real time traffic. The purpose of this paper is to evaluate MPLS as a technique to be integrated in the high-speed mobile packet switching node.

1 Introduction

Packet based networks are maturing to become the default mode for carrying information in the fixed networking world. Trial networks are working on the possibility of Voice and video traffic also being carried by packet based networks. While the advantages and business potential of packet based mobile networks are immense, the complexity of implementation are also enormous. IP networks are expected to provide more than a mere routing functionality, but to ensure deterministic quality of service.

Mobile wireless network operators face increasingly stringent market requirements for service reliability, quality and cost besides the increasing bandwidth requirement. Increasing competitive pressures due to global deregulation have created the need to deploy new service offerings and create differentiation in increasingly competitive markets. Multiservice access technology provides the wireless operator with an upgrade path that eliminates the high cost and lengthy planning cycles associated with replacing existing access equipment.

3G Wireless standard and standard-influencing forums are currently looking at how they can incorporate IP technology in the Wireless Network. The reasons for doing so revolve around cheaper networking equipment reuse of existing IETF protocols to accomplish parallel/same functions (as 2G cellular systems), reduced cost of ownership by reducing the cost of operating the network, etc. All these in addition to the advantages provided by the IP protocols, for automatic routing, re-configuration etc.

The packet data part of UMTS is based on the TCP/IP protocols. The packet data node of UMTS is to a large extent an IP router. The node also includes functionality that provide wireless users with seamless mobility. As a third generation network, UMTS supports multimedia applications and real time traffic.

Over the last few years, the Internet has evolved into a ubiquitous network and inspired the development of a variety of new applications in business and consumer markets. These new applications have driven the demand for increased and guaranteed bandwidth requirements in the backbone of the network. In addition to the traditional data services currently provided over the Internet, new voice and multimedia services are being developed and deployed. The Internet has emerged as the network of choice for providing these converged services. However, the demands placed on the network by these new applications and services, in terms of speed and bandwidth, have strained the resources of the existing Internet infrastructure. This transformation of the network toward a packet- and cell-based infrastructure has introduced uncertainty into what has traditionally been a fairly deterministic network.

IP is by nature connectionless and is routed in layer 3. At present there are no QoS guarantees available in IP network. Providing QoS guarantees is complicated by the connectionless nature of IP, unless an assumption is made of unlimited bandwidth availability in every segment of the network!! This necessitates ways to control traffic flows. Class of service (CoS) and QoS issues must be addressed in order to support the diverse requirements of the wide range of mobile network users.

This paper aims to show how MPLS can be used to accomplish these goals. A MPLS-based wireless architecture is presented, which takes advantage of MPLS's flexibility to address wireless-specific requirements such as micro mobility as well as non-wireless specific requirements, such as Quality of Service. This architecture encompasses mostly IETF protocols to address all required functions of tomorrow's converged/unified networks, from initial IP-level authentication and configuration, security, session control, resource reservation, admission control, to quality of service and policy management, enhanced only where necessary to address the idiosyncrasies of the mobile wireless environment.

2 Routing in Mobile IP Networks

Mobile IP is an internet protocol designed to support host mobility, unlike the current IP which needs to fix the IP address point of attachment to the network. Its goal is to provide the ability of a host to stay connected to the internet regardless of their location. Mobile IP is able to track a mobile host without needing to change the mobile host's long-term IP address.

2.1 Entities of Mobile IP

Mobile IP consists of the following entities:

Mobile Node (MN): A host or router that may change its point of attachment from one network or subnetwork to another through the internet. This entity is pre-assigned a fixed home address on a home network, which other correspondent hosts will use to address their packets to, regardless of its current location.

Home Agent (HA): A router that maintains a list of registered mobile nodes in a home network. It is used to forward mobile node-addressed packets to the appropriate local network when the mobile nodes are away from home. After checking with the current mobility bindings for a particular mobile node, it encapsulates datagrams and sends it to the mobile host's current temporary address where the mobile node is.

Foreign Agent (FA): A router that assists a locally reachable mobile node that is away from its home network. It delivers information between the mobile node and home agent.

Care-of-address (COA): An address which identifies the mobile node's current location. It can be viewed as the end of a tunnel directed towards a mobile node. It can be either assigned dynamically or associated with its foreign agent.

Correspondent Node (CN): This node sends the packets which are addressed to the mobile node.

Home Address: A permanent IP address that is assigned to a mobile node. It remains unchanged regardless of where the mobile node is attached to the internet.

Mobility Agent: An agent which supports mobility. It could be either a home agent or a foreign agent.

Tunnel: The path which is taken by encapsulated (IP datagram gets enclosed with another IP header) packets. It is the path which leads packets from the home agent to the foreign agent.

When the mobile node is away from home, it registers its care-of-address with its home agent, through the foreign agent so that the home agent knows where to forward its packets. Depending on the network configuration, the mobile node could either register directly with its home agent, or indirectly via the help of its foreign agent.

A CDMA voice call can be backhauled from up to three BTSs simultaneously. Soft handoff requires that both voice and signaling traffic from each of the three cells arrive at the MSC at roughly the same time. ATM technology proves especially effective for soft handoff in two primary ways. First, the virtual connections established between all BTSs and MSCs allow an individual CDMA call to use a single vocoder for the duration of the transmission. Even when the call hands off to an adjacent MSC, the original vocoder can still be used to encode/decode the voice traffic. Second, output buffering in the ATM switch allows the signaling traffic to be rerouted if delays in the output buffer are likely. This feature enables handoff of voice traffic seamlessly and without delay.

2.2 Basic Mobile IP Protocol

Basic Mobile IP protocol enables IP mobility for wireless data, without losing the transport and higher-layer connections while moving across networks. It allows any mobile node to move about within Internet, while continuing to be identified by its home IP address.

As shown in Figure 2-1, correspondent nodes send datagrams to a mobile node using a mobile's home IP address. When a mobile node is within the home network, a local agent called 'home agent' serves it. Once it's away from the home network, an agent in the currently visited network called 'foreign agent' handles the routed datagrams. Normal IP routing algorithm is used to send datagrams to the mobile node when it is in its home network. Mobile IP protocol uses tunneling mechanism to deliver packets to mobile nodes that are away from their home network. Home agent tunnels each packet to the current foreign agent, which in turn delivers the packets to the mobile node. Foreign agent also serves as a router for the mobile node to send packets.

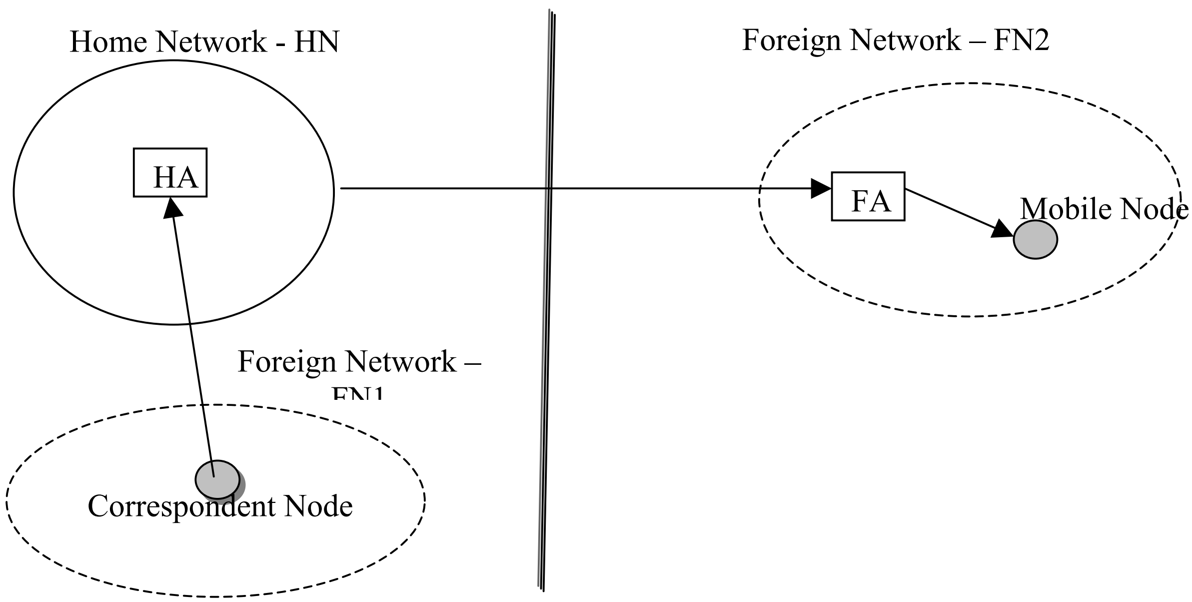

Figure 2-2 : Mobile IP network basic functionality

2.3 QoS control in Mobile IP networks

IP Traffic in the mobile Network is expected to be increasing rapidly with various customer requirements, as in the fixed IP networks of today. Today's IP service provides unpredictable and undifferentiated packet loss and jitter characteristics. If an output port becomes the focal point for two or more aggregate traffic streams, the outbound packets are simply first in first out queued. Queuing introduces latency, and potential for packet loss if a queue overflows when traffic is more. Latency introduced by queuing varies unpredictably from packet to packet, manifesting itself as jitter.

In IP networks the goal of per hop QoS is to enable congestion-point routers and switches to provide predictable loss, latency and jitter characteristics to traffic classes of interest to the service provider or customers. A single FIFO Queue cannot support QoS-sensitive and insensitive traffic together. While a long queue has less chances of overflow during traffic burst. Thus reducing packet loss probability, it in turn increases the queuing latency for non dropped packets. A short queue reduces this latency but increases the packet loss. To overcome this, traffic is split across multiple queues at each congestion point, thus different classes of traffic are assigned to different queues for each class of desired loss, latency and jitter characteristics. Therefore QoS enabled routers and switches must classify packets, differentially queue packets per class. And thus provide controllable and predictable scheduling of packet transmissions from each queue to outbound link. This called as classify, queue and schedule architecture (CQS).

In IP routing the shortest path between a packet's current location and its destination is determined and the packets follows that direction. This may cause heavy traffic in the network as they can be the hot spots in the network. Thus packet loss, rates, latency and jitter increase as the average load rises. It can be overcome by two mechanisms. One is distributing the packet forwarding across alternate routes as we will see in MPLS and faster routers and links.

2.4 Issues with IP Forwarding

In IP forwarding each packet's next hop and output port is determined by a longest prefix match forwarding table lookup with the packet's IP destination address as the key. Additional packet classification is done in order to derive output port queuing and scheduling rules. If it is not done then a single FIFO queue is assumed. With this information the packet is queued at appropriate output port. Rule for IP signalling protocol is placed on Resource Reservation Protocol. As we have seen above this mehod of forwarding causes Queuing latency, which in turn causes packet loss and increases jitter. We will see in the next section how MPLS architectural aspects can overcome this.

3 Multi Protocol Label Switching for Mobile Networks

Multiprotocol label switching (MPLS) is a versatile solution to address the problems to be addressed by next generation mobile networks — bandwidth, scalability, quality-of-service (QoS) management, and traffic engineering. MPLS can emerge as an elegant solution to meet the bandwidth-management and service requirements for next-generation Internet protocol (IP)–based mobile networks. MPLS addresses issues relating to scalability and routing (based on QoS and service quality metrics) and can exist over existing asynchronous transfer mode (ATM) and frame-relay networks.

3.1 Basic Functionalities of MPLS

MPLS performs the following functions :

- Specifies mechanisms to manage traffic flows of various granularities, such as flows between different hardware, machines, or even flows between different applications

- Remains independent of the Layer-2 and Layer-3 protocols. Supports IP, ATM, and frame-relay Layer-2 protocols.
- Provides a means to map IP addresses to simple, fixed-length labels used by different packet-forwarding and packet-switching technologies.
- Interfaces to existing routing protocols such as resource reservation protocol (RSVP) and open shortest path first (OSPF).

Label (20 Bits)	Exp (3 Bits)	Stack (1 Bit)	TTL (8 Bits)

Figure 3-1 : MPLS Label Stack Entry Format

Link Layer Header	“Shim” Label Header	Network Layer Header	Packet Information

Figure 3-2 : MPLS Labelling with SHIM header

In MPLS, data transmission occurs on label-switched paths (LSPs). LSPs are a sequence of labels at each and every mobile node along the path from the source to the destination. In a end-to-end MPLS based mobile network, the mobile user equipment also participates in the path establishment. LSPs are established either prior to data transmission (control-driven) or upon detection of a certain flow of data (data-driven). In a mobile environment where label is not carried as a part of the link layer header, an additional “shim” label is carried (as shown in Figure 3.2). This is inserted between the link layer and network layer headers.

The labels, which are underlying protocol-specific identifiers, are distributed using label distribution protocol (LDP) or RSVP or piggybacked on routing protocols like border gateway protocol (BGP) and OSPF. Each data packet encapsulates and carries the labels during their journey from source to destination. High-speed switching of data is possible in the mobile network elements because the fixed-length labels are inserted at the very beginning of the packet or cell by the mobile and can be used by hardware to switch packets quickly between nodes in the mobile networks.

3.2 LSRs and LERs

The devices that participate in the MPLS protocol mechanisms can be classified into label edge routers (LERs) and label switching routers (LSRs). An LSR is a high-speed router device in the core of an MPLS network that participates in the establishment of LSPs using the appropriate label signaling protocol and high-speed switching of the data traffic based on the established paths.

An LER is a device that operates at the edge of the access network and MPLS network. LERs support multiple ports connected to dissimilar networks (such as frame relay, ATM, and Ethernet) and forwards this traffic on to the MPLS network after establishing LSPs, using the label signaling protocol at the ingress and distributing the traffic back to the access networks at the egress. The LER plays a very important role in the assignment and removal of labels, as traffic enters or exits an MPLS network.

From the Mobile network MPLS implementation perspective, each mobile performs the LER functions, initializing routing labels, and the mobile network nodes perform the LSR functionality.

3.3 FEC

The forward equivalence class (FEC) is a representation of a group of packets that share the same requirements for their transport. This might be thought of as partitioning the set of all possible packets that a router can forward into a finite number of disjoint subsets. Packets within the subsets are treated the same way, though the information in the network layer header can be different. All packets in such a subset are provided the same treatment en route to the destination.

As opposed to conventional IP forwarding, in MPLS, the assignment of a particular packet to a particular FEC is done just once, as the packet enters the network. FECs are based on service requirements for a given set of packets or simply for an address prefix. Each LSR builds a table to specify how a packet must be forwarded. This table, called a label information base (LIB), is comprised of FEC–to-label bindings.

3.4 Consistentcy Maintenance in MPLS Routing

Control mechanisms need to consistently distribute labels end-to-end across the MPLS domain. This is necessary to construct forwarding tables (and thus FECs and associated next hops) out of the routing information. Forwarding component in each mobile node needs to consistently parse the packets for labels, associate with forwarding bindings across multiple nodes.

4 MPLS Architecture for Mobile Networks

MPLS architecture needs to be specified for label maintenance and distribution that supports unicast, multicast, a hierarchy of routing knowledge and explicit paths. The basic architectural issues lie in defining procedures and protocols for label distribution, encapsulation, reservation and QoS mechanisms, and definition of mobile host behaviors.

Figure 4.1. shows a simplified model of a mobile network with labels distributed between a correspondent node and the destination mobile node in a foreign network. This shows an instance where the mobile hosts are directly participating in the label switched network. Host participation in label switching is a little easier in data driven approach, where the mobile initiates label request based on traffic flows, rather than on a control driven approach, where routing protocols are involved.

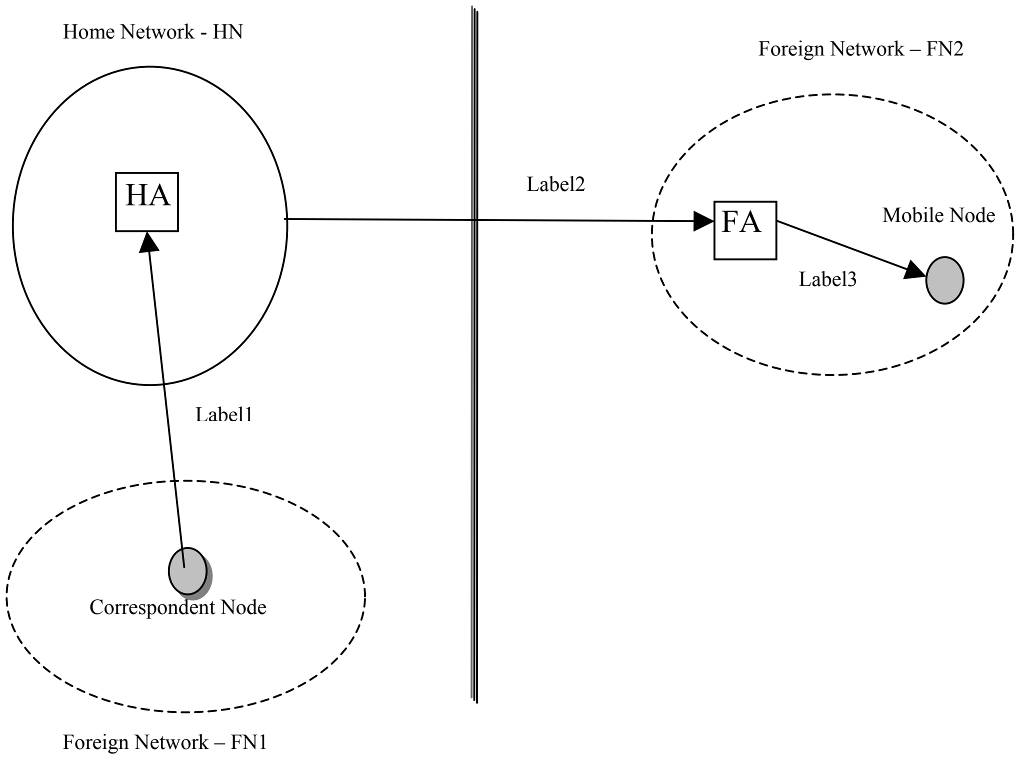

Figure 4-1 : MPLS Labelled Mobile Network

Also when the mobile initiates a path establishment process, in a control driven approach, each mobile will need to have the complete topology of the network and need to run a OSPF like routing protocol. This will not be an optimum solution, since this will require humongus resources for each mobile and each mobile need not learn the topology information of the network where ever they are currently operating. However, it is necessary to utilize all the advantages provided by the routing protocols. Hence routing protocols are run across the mobile switching centers and across the interworking interfaces (between mobile and non mobile networks).

Considering IP forwarding operation, label switched paths can be setup between two edge switches/ nodes of a mobile network and use this path to tunnel the IP packets across. IP packets can be assigned to different label switched paths based on their destination IP address and other criteria, like the QoS attributes.

Whenever a mobile node wants to establish a label switched path a participating mobile switching node in the home area can provide the explicit routing information to the mobile, so that the mobile can initiate signaling with an explicit route specification.

IP forwarding in a mobile node typically involves two distinct operations, namely, aggregate IP packets to a Forwarding Equivalence Class (FEC) and map the FEC to the next hop in the path. This will be done by every mobile node. End-to-end MPLS will let the mobile map packets to the FEC and encode this FEC as a label. Once the path is established, the intermediate mobile nodes (that includes the base transceiver nodes, and mobile switching centers) need to just perform only the second operation, mapping the label to the next hop and performing appropriate label translations.

4.1 MPLS call setup

This section shows how different MPLS components interact during setup, modification and teardown of an LSP. Mobility issue handling is done in the next section. We consider the case of a mobile establishing an MPLS path to another mobile in the network. The signaling protocol used can be RSVP or LDP. Considering the prominence of RSVP in today's environment, we use RSVP as the signaling protocol for path setups.

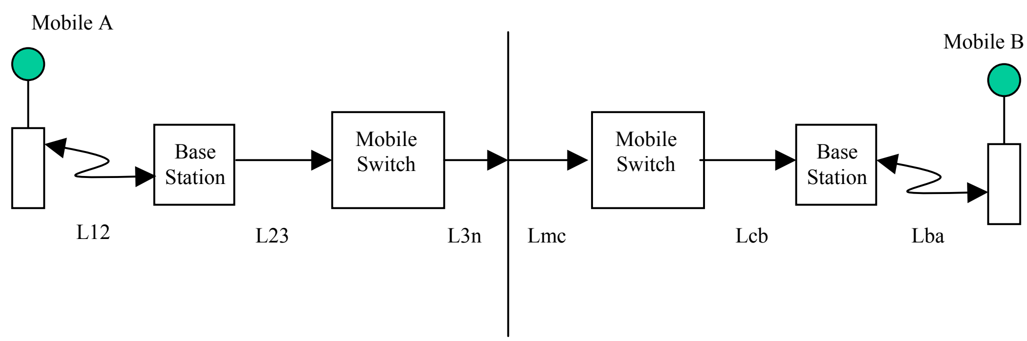

Figure 4-2 : Label Switched Path setup in a mobile network

Figure 4.3 shows a mobile network with LSPs setup end-to-end. As a part of the call setup, mobile A sends a UNI signaling request to its local base station. Local base station registers this request and forwards it to the Mobile switch. Mobile switch which is running the routing protocol maintains the topology of the network and has enough intelligence to determine the path to the destination node, based on the destination nodes, current foreign home location, Quality of Service requested, total bandwidth needed, load balancing to be handled in the network etc. This information is used by the mobile switch to signal the upstream nodes in the path for label setup, upto the destination node B.

Once the destination node responds with the RSVP RESV message every down stream node in the path register this label and create a label forwarding entry. When the origination mobile switch receives this RESV message it signals the orgination base station and mobile A.

Origination base station might ideally combine multiple streams from different mobile station and send them towards a mobile switch. This will then form a label stack hierarchy, with 2 layer of labels, one between the mobiles and base station and the other between the base station and mobile switch.

Once the end to end path is setup the mobiles can then start transmitting packets with the assigned labels which are then routed deterministically to the destination node. Path tear down might once again be initiated by source mobile, the destination or the network itself. In the first two cases, a path TEAR message is sent to every node in the path, which then clears the forwarding entries for the labels. In the third case, the routing protocol takes the responsibility of distributing the stale labels and thus providing information to start the path tear down, upstream or downstream.

4.2 Mobility handling using MPLS

As can be expected in a mobile network both the source and destination nodes can be on the move, moving from (1) one transceiver station to the other, (2) one base station to the other, (3) from one mobile switch to the other, or (4) from one network to the other.

In case 1, the base station can still retain the labels already established between the mobile and base station, and hence there can be very little loss of packets. In case 2, while the path established beyond the originating (destination) mobile switch remains the same, paths need to re-establised between the mobile switch and the mobile through the new base station. In the third case, the old mobile switch can provide the information about the current state of the LSP, but these need to modified and reestablished between the next for router and the new mobile switch, in addition to establishing the path to the mobile. In the last case, it will be a similar case of the old base station providing LSP info, enabling the establishment of the new path to the mobile.

In case the destination mobile moves, all the above transactions need to happen only at the destination side. When the mobile moves from one foreign agent to another foreign agent, the mobile should be able to provide information about the old foreign agent. Based on this information the new foreign agent, can try and establish the downstream broken path and restore the end to end path, between the mobiles.

Thus unlike the classical mobile IP, the source node, need not know the current foreign IP address of the destination mobile, or send all IP packets to the home agent of the mobile for rerouting. This has tremendous advantages to both maintaining a deterministic quality of service and also burdening the network with almost no rerouted traffic flow.

4.3 Traffic Engineering in Mobile Networks using MPLS

Classical IP routing produces a shortest path tree rooted at the current destination mobile switch for a forwarding equivalence class. Shortest path criterion avoids loops and provides a common forwarding criteria. A tree topology results from the optimality of shortest paths.

However as mobile paths get setup using the shortest path, more paths get merged near the far end into common branches of the tree and can cause congestion. Equal Cost multipath (ECMP) technique has been attempted in the past to divide IP flow among equal cost path, though not the shortest. Though this helps in distributing the traffic, it is hard to find ECMPs. Attempts have also been made to relax the shortest path criterion. This can increase the cost dramatically.

MPLS explicit routed paths can be setup to bypass congested areas and take advantage of under utilized network resources without having to modify IGP link metrics.This makes MPLS role very significant in traffic engineering. Hence, as long as the mobile switching nodes can run the routing protocols and run efficient algorithms to find the most optimal path for connection setup, based on the current location information of the destination mobile, MPLS in mobile networks can perform traffic engineering. This helps avoiding congestion on LSP tunnels, allowing traffic rerouting.There can also multiple LSP tunnels between two mobile nodes, corresponding to a local QoS or cost policy.

5 Conclusion

This paper describes the application of Multi Protocol Label Switching to mobile networks. The concepts and challenges to the evolving next generation mobile packet networks and Mobile IP networks specifically, in providing QoS based services is analysed. Finally the functional capabilities of making MPLS useful for traffic engineering in the evolving Mobile IP network is highlighted.

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