A Perspective on MPLS in WDM Networks

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Abstract - This paper provides a study about history of MPLS in order to later introduce concept of MPLS, its architecture, operation, header and applications of MPLS. MPLS in WDM networks is being envisioned as one of most attractive architectures for the new internet.

Keywords - *MPLS (Multi Protocol Label Switching), WDM (Wavelength Division Multiplexing), QOS (Quality of Service), ATM (Asynchronous Transfer Mode).*

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1. Introduction

In parallel with the developments in the IP protocol arena, developments in WDM technologies have yielded a windfall of available capacity on fiber optic links [1]. WDM can readily support many hundreds of gigabits per second on a single fiber. Furthermore, since WDM is a FDM technique, it partitions the fiber bandwidth into smaller segments can also carry multiple independent signals on a single fiber. In WDM networks where IP packets are directly carried over them is expected to offer infrastructure for the next generation internet. Mainly WDM technology is applied to the optical path layer. In this case, a message is transmitted from the source to destination by using a light path without requiring any Optical-Electrical conversion and buffering at the intermediate nodes. This is known as wave length routing. WDM networks with optical path layers have several advantages, such as enhanced node processing capability and protocol transparency. In such a network, the light path should be prepared among every end node pairs within the MPLS domain, which requires too many wavelengths [1]. MPLS provides promising way to alleviate the capacity limits of the routers. By MPLS, switching and forwarding capabilities are separated to fully utilize a high speed switching capability of the underlying network such as ATM. Packet forwarding to determine the destination is only performed at the edge of the MPLS domain. While MPLS needs to establish a closed domain for utilizing a new lower-layer technology, it is useful to incorporate the WDM technology for building the very high-speed Internet.

2. Concept of MPLS

In this section detailed concept of MPLS is introduced with its history, MPLS header, MPLS architecture.

2.1 History of MPLS

The earliest motivation for MPLS was to simplify wide-area IP backbone networks by overlaying IP and the new emerging high-speed technology. During the mid-90's, the only solution was ATM in which fixed-size packets (called *cells*) are switched in hardware at nodes. It is a main reason that ATM
can provide the high-speed switching capability. In IP over ATM networks, ATM is used only for providing the link-level connectivity although ATM itself had been developed in order to offer its native networking capabilities. Then the industry needed to deliver a solution that provided the price and performance of an ATM switch and the control of an IP router, while eliminating the complex mapping required by the IP-over-ATM model. One alternative was multilayer switching solutions which maintained the IP control component and used ATM label swapping as the forwarding component. The challenge facing the ISP community was that each solution was proprietary and therefore not interoperable. Also, the majority of multilayer switching solutions required an ATM transport because they could not operate over mixed media infrastructures (Frame Relay, PPP, SONET, and LANs). If multilayer switching was to be widely deployed by ISPs, there had to be a multivendor standard that could run over any link layer technology. So the solution was MPLS i.e Multi Protocol Label Switching. In early 1997, the IETF established the MPLS working group to produce a unified and interoperable multilayer switching standard. They left in the IP functionality, but removed all of the ATM protocols, replacing them with MPLS label swapping.

2.2 MPLS Meaning

MPLS stands for Multi Protocol Label Switching. MPLS is a highly scalable, protocol agnostic, data-carrying mechanism. In an MPLS network, data packets are assigned labels. Packet-forwarding decisions are made solely on the

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contents of this label, without the need to examine the packet itself. This allows one to create end-to-end circuits across any type of transport medium, using any protocol. The primary benefit is to eliminate dependence on a particular data link layer technology, such as Asynchronous Transfer Mode (ATM), Frame Relay, Synchronous Optical Networking (SONET) or Ethernet, and eliminate the need for multiple layer-2 networks to satisfy different types of traffic. MPLS belongs to the family of packet-switched networks.

MPLS operates at an OSI model layer that is generally considered to lie between traditional definitions of layer 2 (data link layer) and layer 3 (network layer), and thus is often referred to as a "layer 2.5" protocol. It was designed to provide a unified data-carrying service for both circuit-based clients and packet-switching clients which provide a datagram service model. It can be used to carry many different kinds of traffic, including IP packets, as well as native ATM, SONET, and Ethernet frames.

2.3 Header in MPLS

The 32 bits MPLS header contains the following fields:

TTL	S	EXP	LABEL
8	1	3	20

Figure 1: MPLS Header

The label field (20 bits) carries the actual value of the MPLS header. The EXPerimental field (3 bits) for QOS provisioning. The Stack field (1 bit) supports a hierarchical label stack. The Time To Live field (8 bits) provides conventional IP TTL functionality.

2.4 Architecture of MPLS

Multiprotocol Label Switching is thought of as a heterogeneous protocol where different network components are able to be be founded. For example in an MPLS backbone could coexist with IP routers without MPLS capabilities or NIF (native forwarding) routers, with ATM-MPLS switches and MPLS routers called LSR (Label-Based Switch Routers). These last routers are given a different name if they are located in the MPLS backbone (where they are called core routers) or at the edge of the backbone (where they are called Label Edge Routers LERs). LER routers are ingress routers and egress routers, depending on whether or not they are a source node or the end node. (Figure 2 shows an MPLS backbone, formed with an ingress node, an egress node and all intermediate LSR nodes)[2].

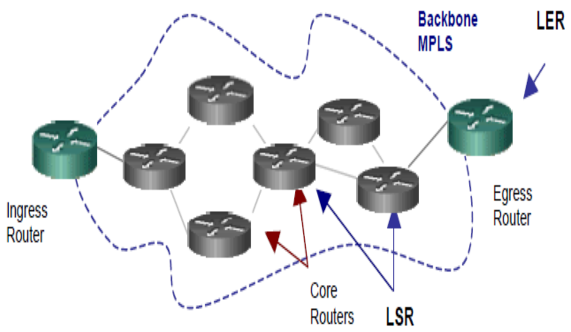

Figure 2: MPLS Architecture

MPLS uses generally label switching for packet forwarding.

2.4 Operation of MPLS

Using a conventional routing protocol and a signalling protocol usually a Label Distribution Protocol (LDP) or a Reservation Protocol (RSVP), Label Switch Routers build forwarding tables and distribute their labels into them, creating a MPLS path called LSP (Label Switch Path). An Ingress node computes “edge LSR function”, which means that it applies an initial label to an IP ingress packet, after examining the IP header. Once a time label is assigned the next LSR can only execute the forwarding function by using this label. LSRs compute forwarding functions using label swapping paradigms (exchange labels at each LSR). At the end of the LSP the egress node computes the reverse function (changing the MPLS label for an IP direction). MPLS allows hierarchical labels to be supported as a LIFO label stack. A packet is always processed based on the top label and regardless of the other labels that may be below it. In a label stack, the label at the bottom of the stack is called the level 1 label, and labels above it are numbered consecutively up to the level n level. After the top label is processed, a router may pop or push the label stack.

So there are different steps that are given below that must be taken for travelling of data packet through MPLS domain: 1) label creation and distribution. 2) table creation at each router. 3) label switched path creation. 4) label insertion/table look up. 5) Packet forwarding.

2.4.1 Label creation and distribution

The routers make the decision to bind a label to a specific FEC and build their tables before any traffic begins. In LDP, downstream routers initiate the distribution of labels and the label/FEC binding. In addition, traffic related characteristics and

MPLS capabilities are negotiated using LDP. A reliable and ordered transport protocol should be used for the signaling

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protocol. LDP uses TCP. A label is carried and encapsulated in a layer-2 header along with the packet. The receiving router examines the packets for its label content to determine the next hop. Once a packet has been labeled, the rest of the journey of the packet through the backbone is based on label switching. The label values are of local significance only, meaning that they pertain only to hops between LSRs. Label assignment decisions may be based on forwarding criteria such as following:
1. destination unicast routing
2. traffic engineering
3. multicast
4. private virtual network (VPN)
5. QoS

There are several methods for label creation:
1. Topology based method
2. Request based method
3. Traffic based method

2.4.2 Table creation at each router

Table creation in MPLS at each router is done by following manner: 1) On receipt of label bindings each LSR creates entries in the label information base (LIB). 2) The contents of the table will specify the mapping between a label and an FEC. 3) Mapping between the input port and input label table to the output port and output label table. 4) The entries are updated whenever renegotiation of the label binding occurs.

2.4.3 Label switched path creation

A collection of MPLS-enabled devices represents an MPLS domain. Within an MPLS domain, a path is set up for a given packet to travel based on an FEC. The label switched paths (LSPs) are created in the reverse direction to the creation of entries in the LIBs. MPLS provides following two options to set up an LSP:
1. Hop by hop routing – Each LSR independently selects the next hop for a given FEC.
2. Explicit routing – Explicit routing is similar to source routing. The ingress LSR (i.e., the LSR where the data flow to the network first starts) specifies the lists of nodes through which the ER-LSP traverses.

2.4.4 Label switched path creation

Label switched path is created in MPLS by the following manner:
1. The router uses the LIB table to find the next hop and request a label for the specific FEC.
2. Subsequent routers just use the label to find the next hop.
3. Once the packet reaches the egress LSR, the label is removed and the packed is supplied to the destination.

2.4.5 Packet Forwarding in MPLS

The LER by which the IP packets enter the MPLS domain may not have any labels for these packets as it is the first occurrence of the request. In an IP network, it will find the longest address match to find the next hop. Then the LER will initiate a label request toward LSR (the next hop). The request will propagate through the MPLS network. Each intermediary router will receive a label from its down stream router and going up stream till egress LER. The LSP setup is done by LDP or any other signaling protocol. If traffic engineering is required, CR-LDP will be used in determining the actual path set up to ensure the QoS/CoS requirements are complied with. Ingress LER will insert the label and forward the packet to next LSR. Each subsequent LSR will examine the label in the received packet, replace it with the outgoing label and forward it. When the packets reach, it will remove the label because the packet is departing from an MPLS domain and deliver it to the destination.
The core MPLS components can be broken down into the following parts:
1. Network layer (IP) routing protocols
2. Edge of network layer forwarding
3. Core network label-based switching
4. Label schematics and granularity
5. Signaling protocol for label distribution
6. Traffic engineering
7. Compatibility with various layer-2 forwarding paradigms (ATM, frame relay, PPP)

2.5 Applications of MPLS

MPLS addresses today's network backbone requirements effectively by providing standards based solution that accomplishes the following:

1) It improves packet forwarding performance in the network by enhancing and simplifying packet forwarding through routers using layer-2 switching paradigms. It increases network performance because it enables routing by switching at wireline speeds.

2) MPLS supports QOS and COS for service differentiation.

3) It supports network scalability.

4) It integrates IP and ATM in the network as it provides bridge between access IP and core ATM.

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5) MPLS builds interoperable networks. It facilitates IP over SONET integration in optical switching. MPLS also helps in building scalable Virtual Private networks with traffic engineering capabilities.

3. Wavelength Routing

Wavelength routed WDM networks, which are circuit switch in nature, are primarily targeted to wide area network. A connection request or demand requires that a connection be established from a node, called the source node, to another node, called the destination node. The connection is used for data transmission from the source to destination. A connection is released when it is no longer required. In the wavelength-routed WDM networks, a connection is realized by a light path. When a connection request arrives, a wavelength routing algorithm is used to choose a light path to satisfy the request. A good wavelength routing algorithm is critically important in order to improve network performance in terms of blocking probability of connections. A wavelength routing algorithm has two components, route selection and wavelength selection.

4. Conclusion

In this paper MPLS data carrying technology is discussed in detail with its history, concept, header, architecture and operation. Applications of MPLS are also provided and overview of the MPLS in Wideband division networks is given. Finally wavelength routing in WDM networks is discussed in brief.

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