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Study of IP over WDM networks using MPLS System

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Abstract— Though enormous improvement has occurred in the field of transmission media layer for which gigantic amount of data can be transferred but there is bottleneck problem at the upper layer protocol stack so that eventually the data transmission process becomes slower. Data may be transferred by optical fiber as a physical media which have large bandwidth but at the intermediary system the O-E-O process is accomplished for routing purpose which makes the system slower. At the intermediate nodes there are also buffering problem for this conversion. So beneath the IP layer a process called MPLS is proposed for removing the extra processing at the intermediary system. At the optical layer the point-to-point WDM technology is enhanced with light path known as wavelength routing resolves O-E-O processing and buffering problem. It also enhanced the node processing capability and protocol transparency. There is also a challenge of wavelength assignment for the limitation of wavelength. So, a wavelength routing algorithm is used for the purpose of wavelength assignment and route selection various important concerns still need to be addressed regarding IP/WDM integration. This include light path routing coupled with tighter inter networking with IP routing and resource management protocols, survivability provisioning, framing / monitoring solutions and others.

Index Terms— Multi Protocol Label System, Wavelength Routing, Wave Division Multiplexing, Overlay and Integrated model

1 INTRODUCTION

IT has become clear that the common traffic convergence sub-layer in communication network is going to be IP, the reason being that practically all forms of end-user communication today make use of the ubiquitous TCP/IP protocol [2]. In parallel with the developments in the IP protocol arena, developments n WDM technologies have yielded a windfall of available capacity on fiber optic links. 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.

IP over WDM networks where IP packets are directly carried over the WDM network is expected to offer an infrastructure for the next generation Internet [6]. The transport network architecture consists of 3 layers: circuit, path, and physical media layers [7]. Existing networks utilize WDM technology as a physical media layer for point-to-point transmission. In point-to-point WDM network O-E-O is done at the intermediate node. While these networks enhance transmission capacity, they do not posses sufficient node processing capability. Due to E-O conversion at intermediate nodes, the messages delay increases and also, large buffers for more optical receivers and transmitters are required at the nodes [1].

A viable alternative to overcome the short comings of point to point WDM network is to apply WDM technology to the path layer. In this case, a message is transmitted from the source to destination by using a light path without requiring any O-E conversion and buffering at the intermediate nodes. This is known as wave length routing [1]. At the optical path layer, light paths are established between a subset of node pairs, forming a virtual topology. WDM networks with optical path layers have several advantages, such as enhanced node processing capability and protocol transparency.

In such a network, the lightpath should be prepared among every end node pairs within the MPLS domain, which requires too many wavelengths [3]. To alleviate the problem, we split the lightpath within the network. In this approach, it may take two or more lightpaths within the IP over WDM network for the packets to be forwarded. Then, the IP routing capability becomes necessary within the network

The optical path layer is formed between the transmission media layer and the electrical path layer in the transport network architecture. This layer is protocol transparent and can support various kinds of services and protocols at the higher layer, such as SONET / SDH, ATM and IP.

The architecture of a WDM network consists of WXC interconnected by fiber links. A WSXC routes a message arriving at an incoming fiber on some wave length to an outgoing fiber on the same wavelength. It is realized by wave length demultiplexers, wave length multiplexers, and optical switches. The architecture may not achieve the best network performance due to the wave length continuity constraint, which requires that the same wave length must be used on all the fiber links throughout the route of data transmission. An alternative is to use a wave length inter-

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changing cross connect (WIXC) which employs wave length conversion. Wave length-interchange (convertible) networks yield better performance than wave length selective networks. However, wave length converters are very expensive. So, the use of WC is limited.

2 Proposed Architecture

1. IP routers interconnected with WDM links with built-in WDM transceivers
2. An optical cloud (core) accessed by IP routers at the edge
3. pros: provide fat and easy-to-provision pipes either transparent (i.e., OOO) or opaque (i.e., O-E-O) cross-connects (circuit-switches)
4. proprietary control and IP based routing
5. IP and *MPLS* on top of every optical circuit or *packet* switch :
   - IP-based addressing / routing (electronics), but data is optically switched (Burst)
   - MPLS-based provisioning, traffic engineering and protection / restoration
   - Internetworking of optical WDM subnets with interior and exterior (border) gateway routing

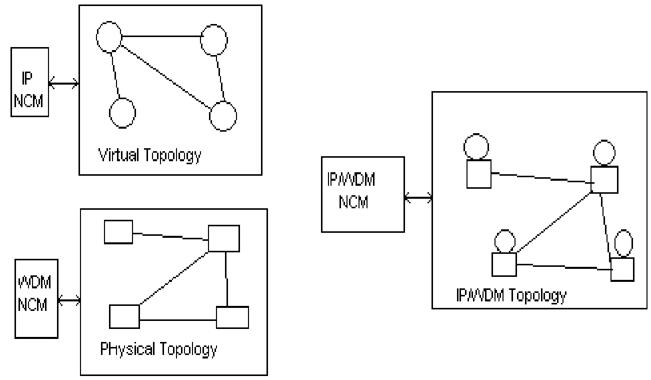
3 Overlay And Integrated Models For IP/WDM Networks

The IP routers are the network elements in the IP layer, whereas the wavelength cross-connects (WXCs) and wavelength add-drop multiplexers (WADMs) are the network elements in the WDM optical layer. The optical layer can be reconfigured by adding new lightpaths and deleting some existing lightpaths. The management and control function include configuration and connection management, fault management and performance management. The configuration and connection management deals with the optical connection (lightpaths). It maintains virtual topology and aid reconfiguration. The fault management performs functions such as fault detection, localization, failure recovery, signal regeneration, and protection and restoration mechanisms. Traffic engineering can be used to monitor the traffic and improve the performance of IP / WDM networks.

The IP / WDM networks may adopt an overlay model or an integrated model. The above two models are shown in the following figure.

3.1 Overlay Model

In this model, the IP layer and the optical layer managed and controlled independently. There exist two distinct control planes, each corresponding to a different layer. Here, the optical layer acts a server and the IP layer acts a client. The lightpath services are provided by the optical layer to the IP layer. The IP layer treats a lightpath as a link between two IP routers. The topology perceived by the IP layer is the virtual topology wherein the IP routers are interconnected by lightpaths,



(a)Overlay Model (b)Integrated Model

Fig: Network control and management in IP/WDM networks

On the other hand, the topology perceived by the optical layer is a physical topology wherein the WDM network elements are interconnected by physical fiber links. The IP layer uses its own routing method, such as “open shortest path first” (OPSF) to route the traffic. The optical layer manages wavelength resources and chooses the route and wavelength for each of the lightpaths in an optimum way. If WXCs have conversion capability, then a lightpath can use more then one wavelength. The IP network control and management (IP-NCM) attempts to optimize performance in the IP layer, and the WDM network control and management (WDM-NCM) attempts to optimize performance in the optical layer. The IP-NCM and WDM-NCM modules may interact and exchange information through a user-network interface (UNI) to attempt performance optimization globally.

3.2 Integrated Model

In this model, an IP router and a WXC are together treated as a single network element. The functionality of both IP and WDM are integrated at each network element so that the resources at both the IP and optical layers can be utilized in an efficient way. The topology perceived by the layers is a single IP / WDM topology, with the lightpaths viewed as tunnels. These two layers provide a single unified control plane.

4 Traffic Engineering In Ipaffic Engineering In IP/WDM Networks

In IP / WDM networks, both the overlay and integrated approaches can be used for traffic engineering. Traditional IP networks employ routing algorithm such as OSPF, which are less sensitive to dynamically changing flows. The IP routing algorithms select shortest paths for transferring data. They are topology depended, ignoring bandwidth availability and traffic load information [5]. IP networks can be provided with traffic engineering capabilities by using

MPLS protocols. The IP layer usually performs congestion control to ensure speedy transfer of data between routers. The IP layer usually performs resource allocation control in order to assign wavelength resources to the lightpath in an efficient way. In IP/WDM networks, congestion control can be performed at both the flow level and topology level. The flow-level control methods reroute traffic on a congested LSP over alternative LSPs in order to reduce congestion. The topology-level control method reconfigures the virtual topology to adapt to the traffic changes so that network congestion is reduced.

The IP layer and the optical layer keep the network state information to facilitate traffic engineering. Information about the virtual topology and the offered load on each of the links in the virtual topology is maintained by the IP layer. Information about the physical topology, wavelength usage/availability on the physical links, capability of the WXCs, and the physical route and wavelength used by each of the lightpaths is maintained by the optical layer. In the overlay model the two layers keep the information independently, whereas in the integrated model the information is maintained collectively by the IP/WDM NEs.

Traffic engineering in IP/WDM networks uses various functional units such as traffic monitoring, traffic demand prediction, reconfiguration trigger, reconfigurable virtual topology design, and topology migration. The traffic between the pairs of NEs and on the links over the virtual topology is monitored and the traffic statistics are collected by the traffic monitoring functional unit. Based on the traffic statistics collection in the recent past, the traffic demand between the NEs in the immediate future is estimated. The reconfiguration trigger unit defines a set of policies to decide when to reconfigure. The reconfigurable virtual topology unit designs a new virtual topology, taking the current virtual topology and the estimated traffic statistics as input and considering constraints such as wavelength availability on the physical links and the transmitter/receiver/port availability at the NEs. The new topology should have minimal impact on the existing traffic while reducing metrics such as congestion. Since, the lightpath operates at the rate of gigabits per second and the WXC switch configuration takes tens of milliseconds, the number of changes made in the current topology should be kept minimum in order too reduce service disruption. The topology migration unit determines the sequence of additions and deletions of lightpaths in the process of transferring the current topology to the new topology. The integrated model carries out the above functions in a unified way. The overlay model decouples the functions between the layers. For example, the IP layer determines the virtual topology as set of source-destination pairs. The optical layer determines the physical routes and wavelengths for the lightpaths and configures the NEs.

5 MPLS

MPLS is an Internet Engineering Task Force (IETF) specified framework that provides for the efficient designation, forwarding, routing and switching of traffic flows through the network.

MPLS performs the following function:

1. Specifies mechanism to manage traffic flows of various granularities, such as flows between different hardware, machines, or even flows between different applications.
2. Remains independent of the layer-2 and layer-3 protocols.
3. Provides a means to map IP addresses to simple, fixed length labels used by different packets-forwarding and packets-switching technologies.
4. Interfaces to existing routing protocols such as resource reservation protocol (RSVP) and open shortest path (OSPF).
5. Supports the IP, ATM and frame relay layer-2 protocols.

In MPLS, the data transmission occurs in label-switched paths (LSPs). LSPs are a sequence of labels at each and every node along the path from the source to the destination. LSPs are established either prior to data transmission (control-driven) or upon detection of certain flow of data (data-driven). The labels, which are underlying protocol-specific identifiers, are distributed using label distribution protocol or RSVP or piggybacked on routing protocols like border gateway protocol (BGP) or OSPF [4]. Each data packet encapsulates and carries the labels during their journey from source to destination. High-speed switching of data is possible because the fixed-length labels are inserted at the very beginning of the packet or cell and can be used by hardware to switch packets quickly between links.

The devices that participates in the MPLS protocol mechanism s can be classified into label edge router (LERs) and label switch routers (LSRs)

5.1 LSR

An LSR is a high-speed router device in the core of an MPLS network that participates in the establishments of LSPs using the appropriate label signaling protocol and high-speed switching of the data traffic based on the established paths.

5.2 LER

The LER is the device that operates at the edge of the access network and MPLS network. LER supports multiple ports connected to dissimilar networks (such as frame relay, ATM and Ethernet) and forwards this traffic on 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 an important role in the assignment and removal of labels, as traffic enters or exits an MPLS network.

5.3 FEC

The forward equivalent class (FEC) is a representation of group of packets that share the same requirements for their transport. All packets in such a group are provided the same treatment en route to the destination. As opposed to conventional IP forwarding, in MPLS, the assignment to a particular packet to a particular FEC is done just once, as the packets 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 buildings.

6 MPLS OPERATION

The following steps must be taken for a data packet to travel through an MPLS domain: 1)label creation and distribution, 2) table creation at each router, 3) label-switched path creation, 4) label insertion / table look up, and 5) packet forwarding

The source sends data to the destination. In an MPLS domain, not all of the source traffic is necessarily transported through the same path. Depending on the traffic characteristics, different LSPs could be created for packets with different CoS requirements.

The steps of MPLS operations that occur on the data packets in an MPLS domain are given below:

6.1 Label creation and distribution:

Before any traffic begins the routers make the decision to bind a label to a specific FEC and build their tables. 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 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

Existing routing protocols such as BGP, RSVP have been extended to support piggybacked exchanged to label. IETF has also defined a new protocol named LDP for explicit signaling and management of the label space.

6.2 Table creation at each router:

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.

6.3 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.

6.4 Label insertion / table look up:

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.

6.5 Packet forwarding:

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 para-

digms (ATM, frame relay, PPP)

7 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 (WR) algorithm is used to choose a lightpath to satisfy the request. A good WR algorithm is critically important in order to improve network performance in terms of blocking probability of connections. A WR algorithm has two components, *route selection* and *wavelength selection.*

7.1 Route Selection Algorithms:

Route selection algorithm can be broadly classified into three types: fixed routing (FR), alternate routing (AR), and Exhaust routing(ER).

1. In the FR algorithm, for every node pair *p* only one candidate route R_p is provided. The candidate routes for the node pairs are computed offline. A candidate route for a node pair is fixed and does not change with changing network traffic conditions.
2. In the AR algorithm, for every pair *p*, a set of *k* candidate routes (more than 1) is provided. The candidate routes are denoted by R_0^p, R_1^p ,……..R_{k-1}^p. These routes are computed offline. The set of candidate routes provided for a pair is a subset of all possible routes for the node pair. When a connection request arrives for a pair *p*, one of the candidate routes in R^p will be selected.
3. In the ER algorithm, there is no restriction on selecting a route. For a given node pair *p*, a route among all possible routes for *p* is chosen.

7.2 Wavelength Selection Algorithm:

The wavelength selection algorithm can be broadly classified into Most-Used (MU), Least-Used (LU), Fixed-Order (FX), and Random-Order (RN), depending upon the order in which the wavelength are selected.

1. MOST-USED ALGORITHM: The MU algorithm gives preferences to the wavelength, which is used on the greater number of links in the network. The wavelength is searched in the descending order of use. The MU algorithms attempt to pack the lightpaths tightly into wavelengths so that many wavelength-continuous routes will be available for the connection requests, which will arrive later.

2. LEAST-USED ALGORITHM: The LU algorithm prefers the wavelength, which is used in the least number of links in the network. It attempts to distribute the load over the wavelengths uniformly. The wavelengths are searched in the ascending order of use. The intuitive idea behind this algorithm a shorter route can be found on a least-used wavelength when compared to most –used wavelength.

3. FIXED ORDER ALGORITHM: The FX algorithm searches the wavelength in a fixed order. All the wavelengths are indexed, and they are searched in order of their index numbers. The first free wavelength found while searching in this order is preferred.

4. RANDOM-USED ALGORITHM: The RN algorithm searches the wavelength in a random order. All the wavelengths are indexed. Every permutation of these indices is equally probable while generating the order randomly.

5. JOINT WAVELENGTH ROUTE SELECTION ALGORITHM:All the algorithms discussed so far select the route and wavelength independently, one after the other. The Joint Wavelength-Route (JWR) selection algorithm considers the cost of selecting every wavelength-route pair and chooses the least-cost pair. The cost function used for a pair of route and wavelength takes into account factors such as the usage status of the wavelength in the network, the hop length of the route, and the congestion on the route. The JWR algorithm uses an alternate routing approach. For every node pair *p*, a set of *k* candidate routes is provided. The candidate routes are denoted by $R^p{}_0$, $R^p{}_1$,…, $R^p{}_{k-1}$. These routes are computed offline. The set of candidate routes provided for a node pair is a subset of all the possible routes for the node pair. Let $A(w_i)$ denote the number of links on which the wavelength w_i is currently available. Let $L(R^p{}_j)$ and $F(R^p{}_j)$ denote the hop length and free wavelengths on $R^p{}_j$, respectively. Then, the cost of wavelength-route pair is given by

$$C(w_i, R^p{}_j) = \alpha_1 A(w_i) + (1 - \alpha_1)\{\alpha_2 [w - F(R^p{}_j)] + (1 - \alpha_2) L(R^p{}_j)\},$$

$$0 <= \alpha_1 \text{ and } \alpha_2 <= 1$$

Suitable values for the α_1 and α_2 can be chosen to achieve any desired cost function. For example, choosing a large value for α_1 (say $\alpha_1 = 1$) will prefer the most-used wavelength first. On the other hand, a smaller value for α_1 (say $\alpha_1 = 0$) will prefer the least-cost route, ignoring the current level of usage wavelengths. In short, this algorithm tries to combine the advantage of the MU, and FAR algorithms.

8 CONCLUSION

In this paper, we proposed architecture for designing the IP over WDM networks. Moreover, we discuss some prerequisites in designing IP/WDM networks. We discuss all use and views of MPLS protocol which will be sandwiched between the IP and WDM layer. We also discuss the wavelength routing which will be the applicable feature in the IP/WDM design. In addition we highlighted about virtual topology design which will be main problem in designing IP/WDM networks. We will discuss and give some applicable views and algorithm for solving the virtual topology problem in our future research and also will give an applicable design model of IP over WDM networks.

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