Internet Protocol over DWDM

Tonći Kovačević
Ericsson Nikola Tesla d.d.
Poljicka 39, Split, Hrvatska
Telefon: 021-480104 E-mail: tonci.kovacevic@ericsson.com

Ivan Livaja, Marijan Fijolić
Podjedinica za Veleprodaju
T-HTd.d.
Hebrangova 32-34, Zagreb, Hrvatska
Telefon: 01-4912300 Fax: 01-4912333 E-mail: ivan.livaja@t.ht.hr; marijan.fijolic@t.ht.hr

Abstract - In this paper we describes the problematic of the integration IP over optical network.

I. INTRODUCTION

As we present growth rate of the number of Internet users at the same time we need high-speed networks to connect multiple locations between users. Internet Protocol over DWDM is the concept of sending data packets over an optical layer using DWDM for its capacity and other operations. In the modern day world, the optical layer has been supplemented with more functionality, which were once in the higher layers. With the recent developments in dense wavelenght-division multiplexing technology, all optical networks offer an almost unlimited potential for bandwith. Research is ongoing to introduce more intelligence in the control plane of the optical transport system , which will make them more survivable, flexibile, controllable and open for traffic engineering. One approach for sending IP traffic on WMD networks would use a multi-layered architerture comprising of IP/MPLS layer over ATM over SONET/SDH over WDM layer. This architecture has 4 management layers. The objective of this paper is to describe how the IP forwarding layer can be combined with the cross-connect layer in a scalable and bandwidth efficient manner in a global network. This is of particular interest considering the emerging flexible cross-connect network control plane, that allows for frequent changes of trunk paths and resources allocated to these paths. These flexible control planes can be used for high-capacity-cross-connect technologies such as DWDM (Dense Wavelenght Division Multiplexing), as well as for SONET/SDH, ATM and MPLS.

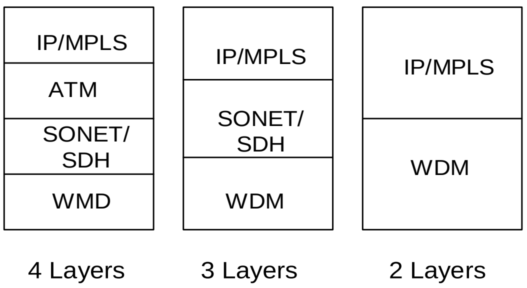

Figure 1

II. ARCHITECTURE

The optical layer has emerged as the main transmission layer for telecommunications backbone networks. The choises today include SONET/SDH, IP and ATM. SONET/SDH layer as the common transmission layer above the optical layer.

Figure 1 shows a logical view of the layers. When using the ATM layer as the common service layer, IP and other services are brought into the ATM layer. The ATM switches are directly connected to optical layer equipment. The ATM switches embed their cells in frames, typically using SONET/SDH framing. When using the IP layer as the common service layer, the routers use a framing protocol to embed the packets before they are transmitted over the optical layer.

It is becoming clear that SONET/SDH will not remain the core transmission layer for much longer. Rather, SONET/SDH will be moved toward the edge of the network and used to multiplex lower-speed circuit-switched lines and bring them into the optical layer. Other network elements such as IP routers and ATM switches will also bring in traffic into the optical layer.

One recent core network trend is the consolidation of multiple Layer 2/3 networks into a single IP/Multiprotocol Label Switching (IP/MPLS) infrastructure. In spite of this Layer 2/3 convergence, however, the underlying transport layer (Layer 1) has continued to use SONET/SDH, an infrastructure that was introduced in the early 1990s to support traditional time-division multiplexing (TDM)-based data and voice services.

In the latter part of the 1990s, DWDM emerged as a way to significantly increase the efficiency of the installed fiber plant by allowing transmission of multiple wavelengths over a single physical fiber. This function introduced another level of multiplexing and demultiplexing at the optical level to support greatly increased bandwidth at the core of the network, which was primarily caused by the dramatic rise of IP-based networks fueled by the explosion of the World Wide Web (WWW). The SONET/SDH layer, which now handled increasing amounts of IP traffic, was mapped into wavelengths at the DWDM transport layer to be carried across.

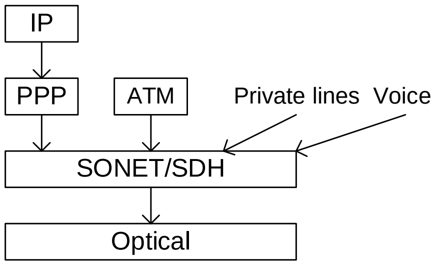

Figure 2

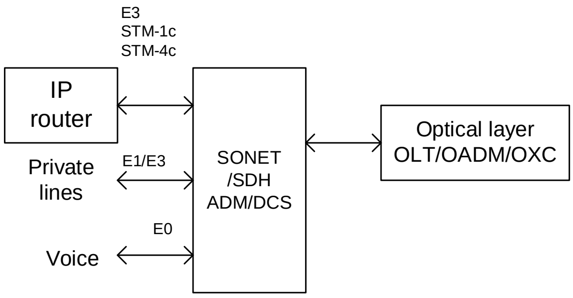

Figure 3

Including ATM and IP, are carried over the SONET/SDH layer. Figure 2 shows a logical view of the layers, while Figure 3 shows hoe the equipment is interconnected in a typical configuration. IP packets are typically carried over a link layer protocol such as PPP (point-to point protocol), which provides link-level integrity of the frames on a link-by-link basis. IP packets are encapsulated into PPP frames for link layer functions and then mapped into SONET/SDH frames for transmisison over the fiber. The bit rates indicated are for illustration purposes only. All these functions are performed by a line card inside the router. The router is connected to a SONET/SDH box, which multiplexes this connection along with others for transmission over the optical layer.

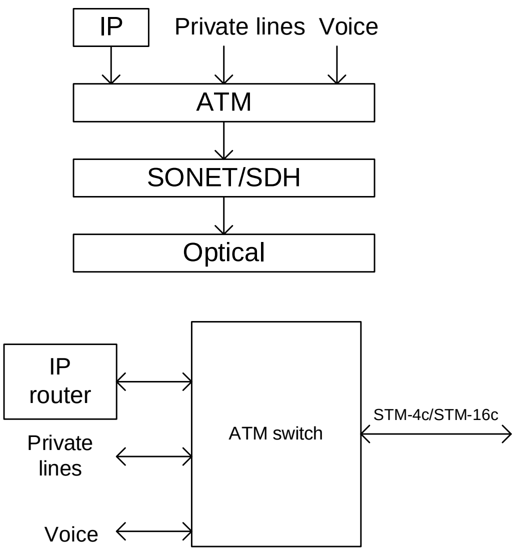

Figure 4

Figure 4 shows a model where ATM is used as the common link layer (Layer 2) with all services riding above the ATM layer. In this case , the ATM switches are directly connnected to optical layer equipment. The ATM switches need to use a framing protocol to embed the cells before transmitting them over a optical layer. The framing protocol allows the date to be formatted for transmission over a physical link and allows various overheads to be added for management purposes. The ATM layer is relatively more mature than the IP layer in terms of providing quality-of –services (QoS) quarantees such as latency and bandwith.

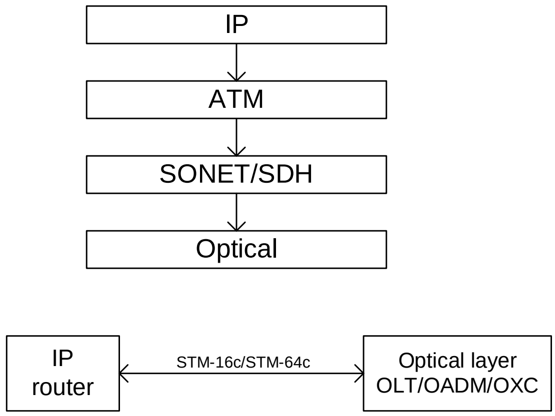

Figure 5

Figure 5 shows a model where the IP layer resides directly on top of the optical layer. The IP layer classically belongs to layer 3 of the OSI hierarchy. With the advent of MPLS, the IP layer also includes layer 2 functionaly. In this case, IP routers are directly connected to optical layer equipmen

III. IP OVER DWDM VARIANTS

We have talked about directly connecting IP routers to the optical layer, in the IP over WDM paradigm. The differences pertain primarily to the manner in which traffic passing through intermediate nodes is handled and the degree of agility provided in the optical layer. In general the trend to date has been that the total capacity that can be switched by a top-of-the-line router is much smaller than the total switching capacity of an optical crossconnect (OXC). The cost per router port is usually much larger than the cost per equivalent OXC port.

The simplest architecture for IP over WDM is to connect the IP routers directly into optical line terminals (OLTs). Passthrough traffic at intermediate nodes is handled by the routers. This, however, has the highest cost for dealing with passthrough traffic, since expensive router ports need to be used to handle all this traffic.

The second approach is similar to the first, except that the passthrough traffic is handled by connecting patch cables between back-to-back WDM terminals within the optical layer. This approach is the lowest-cost option, as all passthrough traffic is handled without additional equipment or using up router ports. However, it is relatively inflexible in the sense that lightpaths cannot be configured dynamically in the network. Also it may be important to perform some demultiplexing and multiplexing of the lightpaths, that is, grooming, at intermediate nodes, if partial signals have to be dropped and added locally.

A variety of architectures have been implemented by carriers. One carrier has deployed an ATM over SONET/SDH over WDM network and transports lower-speed IP traffic over it. Higher-speed IP interfaces out of router are in most cases carried directly over the optical layer. Voice and private lines are carried over the SONET network. Another carrier that provides just IP services has deployed the IP over WDM architecture. Yet other carriers have deployed an ATM network operating directly over the optical layer and are using it to deliver both virtual circuit and packet-oriented services.

For these reasons, the network is migrating gradually to the mesh network made up of optical crossconnects, optical add/drop multiplexers (OADMs), and optical line terminals. The network supports a variety of traffic types, including SONET, ATM, and IP. High-speed traffic streams are directly connected into the optical layer, whereas lower-speed streams may be multiplexed and brought into the network using one of the common service layers described above. Capacity is provisioned and allocated dynamically in the network by the OXCs and the OADMs.

SONET/SDH will remain to support voice and private line traffic, as it is the best architecture for this purpose. In fact some of this multiplexing, particularly at the higher speeds, may be done by optical layer equipment, rather than separate SONET/SDH boxes. IP over the optical layer will become more ubiquitous as QoS guarantees arc better implemented in the IP layer, MPLS matures to provide direct connections between routers, and protection functions are implemented well in the optical layer and/or the IP layer.

IV. IP OVER DWDM ISSUES

Optical routing

Routing in the optical domain involves switching data to the appropriate optical ports at the crossconnect level. It involves computing the path subject to various network constraints (both physical & service level).

There are two approaches when it comes to optical routing: Integrated Routing and Domain Specific Routing.

Integrated routing is used for the peer optical interaction model where optical routers and optical switches act as peers and there is only one instance of a routing protocol running in the optical domain and in the IP domain. An IGP like Open Shortest Path First (OSPF) or Intermediate System – Intermediate System (ISIS) with suitable optical extensions is used to exchange topology information. These optical extensions will capture the unique optical link parameters. The OXCs and the routers maintain the same link state database. The routers can then compute end to end paths to other routers across the OXCs. This lightpath is always a tunnel across the optical network between edge routers. The routing protocol defines forwarding adjacencies which represent and replace the link state advertisements.

Domain Specific Routing - This routing model supports the augmented routing model. In this model the routing between the optical and the IP domains is separated with a specific routing protocol running between the domains. The focus is on the routing information to be exchanged at the IP optical interface. IGP concept-based protocols as OSPF or BGP can help in route discovery and collecting reachability information. Determination of paths and setting up of the Lambda Switched Paths (LSP) is a traffic engineering decision. Interdomain routing protocols like Border Gateway Protocol (BGP) may be used to exchange information between the IP and optical domain. OSPF areas may also be used to exchange routing information across the UNI. BGP will allow IP networks to advertise IP addresses within its network to external optical networks while receiving external IP prefixes from the optical network. Specific mechanisms to propagate the BGP egress addresses are yet to be determined. OSPF supports the concept of hierarchical routing using OSPF areas. Information across a UNI can be exchanged using this concept of a hierarchy. Routing within each area is flat. Routers attached to more than one area are called Area Border Routers (ABR). An ABR propagates IP addressing information from one area to another using a summary LSA. Domain specific routing can be done within each area. IP client networks can be running OSPF with TE extensions.

One of the main services that should be provided by a transport network is restoration. Restoration introduces the constraint of physically diverse routing. Restoration can be provided by pre-computed paths or computing the backup path in real time. The backup path has to be diverse from the primary path at least in the failed link or completely physically diverse. A logical attribute like the Shared Risk

Link Group (SRLG) attribute is abstracted by the operators from various physical attributes like trench ID and destructive areas. Such an attribute may be needed to be considered when selecting the path a network. Two links which share a SRLG cannot be the backup for one another because they both may go down at the same time. Another restoration mechanism is restoration in a shared mesh architecture wherein backup bandwidth may be shared among circuits. The case where two link disjoint paths share a backup path in the network. This may be possible because a single failure scenario is assumed. Another constraint of interest is the concept of node, link, LSP inclusion or exclusion, propagation delay, wavelength convertibility and connection bandwidth among other things. Wavelength convertibility is a problem encountered in waveband networks. It refers to ability to crossconnect two different wavelengths. The wavelengths may be completely different or slightly different. Since wavelength convertibility involves cost & latency, conversion vendors may selectively deploy these converters inside the network. Therein lays the problem of routing a circuit over a network using the same wavelength. This requires that the path selection algorithm know the availability of each wavelength on each link along the route. There are optimizations that obviate the global knowledge. Bandwidth availability is another consideration in routing. This is simplified in a wavelength optical network since requests are end to end.

However in a TDM transport network such as a SONET/SDH network requests can be variable bandwidth. Routing needs to ensure that sufficient capacity is available end to end. Detailed resource information on local resource availability is only used for routing decisions. The route computation, after receiving all network parameters in the form of link state packets, reduces to a mathematical problem. It involves solving a problem of Routing and Wavelength Assignment (RWA) for the new connection. The problem is simplified if there exists a wavelength converter at every hop in the optical network. But, current technology invalidates such an assumption. Suitable solutions already exist to the RWA problem which makes optical routing a practical possibility.

Signaling and Control

Signaling refers to messages used to communicate characteristics of services requested or provided. This section discusses a few of the signaling procedures. It is assumed that there exists some default communication mechanism between routers prior to using any of the routing and signaling mechanisms.

A. Control Plane

In IP-centric distributed optical interworking systems, each entity should have a control plane for a coordinated operation. One alternative is to have centralized control plane. That is within an optical sub-network the control functions are centralized to one OXC. In this case there is no intradomain NNI signaling between OXCs belonging to the same optical sub-domain. For a more scalable solution, a control plane is incorporated at each node. In this case within an optical sub-network intra-domain NNI is established between OXCs. A single control plane would be able to span both routers and OXCs. In such an environment, a lambda switched path could traverse an intermix of routers and OXCs, or could span just routers, or just OXCs. This offers the potential for real bandwidth-on-demand networking, in which an IP router may dynamically request bandwidth services from the optical transport network. To bootstrap the system, OXCs must be able to exchange control information. One way to support this is to pre-configure a dedicated control wavelength (out-of-band) between each pair of adjacent OXCs, or between an OXC and a router, and to use this wavelength as a supervisory channel for exchange of control traffic. Another possibility would be to use in-band or out-of-network channels, in the later case by constructing a dedicated IP network for the distribution of control traffic.A candidate system architecture for an OXC equipped with an MPLS control plane model is shown in Fig 2. The salient feature of the network architecture is that every node in the network consists of an IP routing module and a reconfigurable OLXC. The IP router is responsible for all non-local management functions, including the management of optical resources, configuration and capacity management, addressing, routing, traffic engineering, topology discovery, exception handling and restoration. In general, the router may be traffic bearing, or it may function purely as a controller for the optical network and carry no IP data traffic.

The IP router implements the necessary IP protocols and uses IP for signaling to establish lightpaths. Between each pair of neighbors in the network, one pre-routed communication channel exists that allows router to router connectivity over the channel. These signaling channels reflect the physical topology. As long as the link between two neighbors is functional, there is a signaling channel between those neighbors.

The IP router communicates with the OLXC device through a logical interface. The interface defines a set of basic primitives to configure the OLXC, and to enable the OLXC to convey information to the router. Fig 2 illustrates this implementation. For all of the interfaces, the end of the connection can also be a drop port.

B. Node Addressing

As per the requirements of the IP control plane, every network addressable element must have an IP address.

Typically these elements include each node and every optical link and IP router port. When it is desirable to have the ability to address individual optical channels those are assigned IP addresses as well. The IP addresses must be globally unique if the element is globally addressable.

Otherwise domain unique addresses suffice. A client must also have an IP address by which it is identified. However, optical lightpaths could potentially be established between devices that do not support IP (i.e., are not IP aware), and consequently do not have IP addresses. Whether or not a client is IP aware can be discovered by the network using traditional IP mechanisms.

C. Path provisioning

This section describes a protocol proposed for setting up an end-to-end lightpath for a channel. A complete path might contain the two endpoints and an array of intermediate OXCs for transport across the optical network. Provisioning an end to-end optical path across multiple sub-networks involves the establishment of path segments in each sub-network sequentially. Inside the optical domain, a path segment is established from the source OXC to a border OXC in the source sub-network. From this border OXC, signaling across the NNI is performed to establish a path segment to a border OXC in the next sub-network. Provisioning continues this way until the destination OXC is reached. The link state information is used to compute the routes for the needed lightpaths. It is assumed that a request to establish a lightpath may originate from an IP router (over the UNI), a border node (over the NNI), or a management system. This request carries all required parameters. After computing the route, the actual path establishment commences.

However, once path setup is complete the data transfer happens passively and is straightforward without much intervention from the control plane. The connection needs to be maintained as per the service level agreements. The handshake has been divided into UNI setup and NNI setup. To automate all these processes, there are certain initiation procedures like resource discovery and route computation which help determine the route for each segment (viz. IP host – IP border router, IP border router – border OXC, between border OXCs). These procedures are enveloped inside a routing protocol. Routing within the optical network relies on knowledge of network topology and resource availability. Topology information is distributed and maintained using standard routing algorithms, e.g., OSPF and IS-IS. On boot, each network node goes through neighbor discovery. By combining neighbor discovery with local configuration, each node creates an inventory of local resources and resource hierarchies, namely: channels, channel capacity, wavelengths, and links. This information is used to compute a route between various nodes in accord with the RWA problem.

UNI Path Provisioning - The real handshake between the client network and the optical backbone happens after performing the initial service & neighbor discovery. The continued operation of the system requires that client systems constantly register with the optical network. The registration procedure aids in verifying local port connectivity between the optical and client devices, and allows each device to learn the IP address of the other to establish a UNI control channel.

The following procedures may be made available over the UNI a) Client Registration and b) Client De-Registration The optical network primarily offers discrete capacity, high bandwidth connectivity in the form of lightpaths. The properties of the lightpaths are defined by the attributes specified during lightpath establishment or via acceptable modification requests. To ensure operation of the domain services model, the following actions need to be supported at the UNI so as to offer all essential lightpath services. The

UNI signaling messages are structured as *requests* and *responses* for [7]: 1) Lightpath creation, 2) Lightpath deletion, 3) Lightpath modification, 4) Lightpath status enquiry, and 5) Client Notification. Thus, the above actions provision both edges of the overall connection, while NNI provisioning builds the backbone of the setup

NNI Path Provisioning - The model for provisioning an optical path across optical sub-networks is as follows. A provisioning request may be received by a source OXC from the client border IP router (or from a management system), specifying the source and destination end-points. The source end-point is implicit and the destination endpoint is identified by the IP address. In both cases, the routing of an optical path inside the optical backbone is done as follows:

The source OXC looks up its routing information corresponding to the specified destination IP address. If the destination is an OXC in the source sub-network, a path maybe directly computed to it. If the destination is an external address, the routing information will indicate a border OXC that would terminate the path in the source subnetwork. A path is computed to the border OXC. The computed path is signaled from the source to the destination OXC within the source sub-network. The destination OXC in the source sub-network determines if it is the ultimate destination of the path. If it is, then it completes the path set-up process. Otherwise, it determines the address of a border OXC in an adjacent sub-network that leads to the final destination. The path set-up is signaled to this OXC using NNI signaling. The next OXC then acts as the source for the path and the same steps are repeated.

Thus, NNI provisioning involves looking up in the routing table computed by various schemes mentioned previously and performing path setup within an optical sub-network. Techniques for link provisioning within the optical subnetwork depend upon whether the OXCs do or do not have wavelength conversion. In the case of a network with

Wavelength Converters, the route computation gets simpler. The upstream node just has to intimate the downstream node about a connection underway. It does not need to make decisions about wavelength at each hop. In the case where

Wavelength converters are absent, the source node has to decide the wavelength to use by sending out a vector and getting feedback on channel availability. Note that the lightpath is established over the links traversed by the lightpath setup packet. After a channel has been allocated at a node, the router communicates with the OLXC to reconfigure the OLXC to provide the desired connectivity.

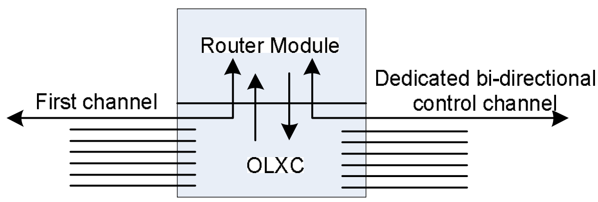

Fig 6 OXC Architecture

D. Signaling Protocols

The OXCs in the optical network are responsible for switching streams based on the labels present. The MPLS architecture for IP networks defines protocols for associating labels to individual paths. The signaling protocols are used to provision such paths in the optical networks. There are two options for MPLS-based signaling protocols – *Resource reSerVation Protocol (RSVP)* or *Constraint Routed Label Distribution Protocol*

(CR-LDP), with appropriate extensions to handle the optical parameters.

There are some basic differences between the two protocols, but both essentially allow hop-by-hop signaling from a source to a destination node and in the reverse direction. Each of these protocols is capable of providing quality of service (QoS) and traffic engineering. Certain new features must be introduced in these protocols for lightpath provisioning, including support for bi-directional paths, support for switches without wavelength conversion, support for establishing shared backup paths, and fault tolerance.

Automated establishment of lightpaths involves setting up the crossconnect table entries in the appropriate OLXCs in a coordinated manner such that the desired physical path is realized. The request to establish a lightpath should identify the ingress and the egress OXC as endpoints of the lightpath. The connection request may include bandwidth parameters and channel type, reliability parameters, restoration options, setup and holding priorities for the path etc. On receipt of the request, the ingress node computes a suitable route for the requested path, following applicable policies and constraints. Once the route has been computed, the ingress node invokes RSVP/CR-LDP to set up the path.

Label Distribution Protocol (LDP) is defined for distribution of labels inside one MPLS domain. CR-LDP is the constraint-based extension of LDP. One of the most important services that may be offered using MPLS in general and CR-LDP in particular is support for constraint based routing of lightpaths across the routed network.

V. SUMMARY

Challenges presented by the exponential growth of the Internet have resulted in the intense demand for broadband services. In satisfying the increasing demand for bandwidth, optical network technologies represent a unique opportunity because of their almost unlimited potential bandwidth. Developments in DWDM technology have dramatically increased the traffic capacities of optical networks. Many researches was done in order to introduce more intelligence in the control plane of the optical transport system, which will make them more survivable, flexible, controllable and open for traffic engineering. Some of the essential desirable attributes of optical transport networks include real-time provisioning of lightpaths, providing capabilities that enhance network survivability, providing interoperability functionality between vendor-specific optical sub-networks, and enabling protection and restoration capabilities in operational contexts. The research efforts now are focusing on the efficient internetworking of higher layers, primarily IP with WDM layer. Multi-Protocol Label Switching (MPLS), i.e its extension called Multi-Protocol lamba switching (MPλS) for IP packets is believed to be the best integrating structure between IP and WDM. MPLS brings two main advantages. First, it can be used as a powerful instrument for traffic engineering. Second, it fits naturally to WDM whenwavelengths are used as labels. The IP over DWDM systems shall support the Open architecture and provide complete service transpareny. It shall host a MPLS control plane in the OXC for providing much of the services. Generalised MPλS is gradually being accepted as a unifying protocol for deplaying IP over DWDM networks. Managament of the networks remains rudimentary while protocols are being enhanced for better services. Restoration in the MPλS layer, using rapid signaling of faults, will be a key feature of the future optical networks. The future holds many chalanges to all-optical networks. But, implementations of IP over DWDM solution opens the pathway to Terabit networking and unleashes the enormous bandwidth of the silica fiber.

REFERENCES

[1] J. Luciani, B. Rajagopalan, D. Awuduche, B. Cain, Bilel Jamoussi, Debanjan Saha, "IP Over Optical Networks - A Framework", Internet Draft draft-many-ipoptical-framework-01.txt, November 2000.

[2] D. Awduche, Y. Rekhter, J. Drake, R. Coltun, "Multi-Protocol Lambda Switching: Combining MPLS Traffic Engineering Control With Optical Crossconnects", Internet Draft draft-awduche-mpls-te-optical-02.txt, July 2000.

[3] R. Ramaswami, K.N. Sivarajan, Optical Networks,a Practical Perspective, Morgan Kaufnann Publishers Inc,San Francisco California, 1998.

[4] S. Chaudhuri, G. Hjalmtysson, J. Yates, “Control of Lightpaths in an Optical Network,” Internet Draft draftchaudhuri-ip-olxc-control-00.txt, February 2000

[5] D. Pendarakis, B. Rajagopalan, D. Saha, R. Ramamoorthy, “IP over Optical Networks: Architectural Aspects,” IEEE Communications Magazine, pp.94 – 102, September 2000.

[6] J.P. Laude, DWDM Fundamentals, Components, and Applications, Artech House, Norwood, 2002