Paper

IP over optical network: strategy of deployment

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Abstract — In this paper, we present main issues of application IP technology directly over optical transport network. The capabilities of WDM transmission systems and techniques which allow the integration of IP with the physical layer are discussed. A detailed description of most solutions is reported. In particular the MPLS/MPλS techniques are discussed in detail. Also problems for further development are outlined.

Keywords — optical networks, WDM, IP, MPLS, MPLambdaS.

1. Introduction

At the rise of the new millennium communication era we witness the convergence of concepts that were quite opposite in the past. Such traditional distinctions as “wired or wireless”, “stationary or mobile”, “voice or data”, or “radio or optical”, have lost much of or even all their relevance. This is reflected in novel concepts as “radio over the fibre”, “voice over IP, “IP over optical”, “free-space optical”, “wireless Internet”, “convergence of mobile and fixed networks”. Further examples are “wireless LANs”, “MPLS towards MPλS”, or “software defined radio”.

There is no doubt that the demand for multi- and hipermedia services foreseen for the near future will require qualitatively new telecommunication technology approaches. Although some of them, e.g. UMTS, 3G, 4G, 5G, or IMT-2000 and beyond, have been already defined, much more should emerge in the near future. Consequently, it is of crucial importance to draw a roadmap for harmonised migration from present communication technologies towards future systems that will be highly efficient at local, regional, and universal scale.

Actually, it is difficult to find a domain of human activity in the world, which would be granted with more global interest and popularity than the Internet and related technologies. Telecommunication technology achievements represented by the exponential growth of the Internet traffic have resulted in the technical availability and the foreseen intense demand for broadband services. Almost all types of traffic are expected to run over Internet. Internet traffic is growing around 10% a month and it is estimated that it would represent over 90 percent of the total public network traffic by the year 2002 [1]. Foreseen immense interest of IP (internet-protocol) technology in the nearest future induces a research for more effective methods of utilising this technology. The most straight and also bringing greatest profit method making possible enlargement of transmission performance seems to be the elimination transmission protocols which lay between physical and IP layers with simultaneous superposition of their functions directly over optical and IP layers.

Development of transmission systems based on dense wavelength division multiplexing (DWDM) technology will make possible building of completely optical networks in the not-distant future where all information will be transmitted and converted as optical signal. Optical crossconects (OXC), optical add-drop multiplexers (OADM) and optical amplifiers will establish optically transparent core of such systems [2]. As it would not be necessary to convert the optical signal to the electrical form for regeneration and switching purposes, the signal degradation resulting from switching procedure as well as the bit-error rate (BER) level will be much lower in those systems [3]. An obvious advantage of DWDM systems is also huge available transmission capacity that significantly exceeds the demand of present applications. At present, transmission systems that can carry up to 40 Gbps on each wavelength are tested commercially [3]. However, the main advantage of DWDM is its compatibility with SONET/SDH, ATM and IP systems.

Two technologies have emerged recently to this purpose. The multi-protocol label switching (MPLS) technology, worked out to assure quality of service (QoS) mechanisms in IP environment, makes possible the integration of IP with other transmission technologies and provides the tools to support different types of services including real-time services [4]. Consequently, the multi-protocol lambda switching (MPλS) technology developed for WDM facilitates wavelength switching mechanism [5].

A huge research is ongoing at global scale to introduce more intelligence in the control plane of the optical transport systems, which should make them more flexible, survivable, controllable and open for traffic engineering. Some of the essential desirable attributes of optical transport networks include real-time provisioning of optical channel trails, providing new capabilities that enhance network survivability, providing functionality and interoperability 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 IP with wavelength division multiplexed (WDM) layer.

In the paper the recently proposed technology solutions for IP and optical network integration, grouped according to main issues, are reviewed and discussed.

2. Architecture

One approach for sending IP traffic on WDM networks would use a multi-layered architecture consisting of IP/MPLS layer over ATM over SONET/SDH over WDM [6]. If an appropriate interface is designed to provide access to the optical network, multiple higher layer protocols can request lightpaths connected across the optical network. An alternative consists of dropping away the ATM layer, and use a packet over SONET/SDH approach, by putting IP/PPP/HDLC into SONET/SDH framing.

The fact that it supports multiple protocols will increase a complexity for IP-WDM integration because of various edge-interworkings required to route, to map, and to protect client signals across WDM subnetworks. The existence of separate optical layer protocols will increase management costs for service providers. Problems could also arise from the high level of multiplexing. The optical fibre transmission systems comprise a large number of higher layer flows such as SONET/SDH, IP flows or ATM VCs. Since these have their own mechanisms, a flooding of alarm messages can take place.

One of the main goals of the integration architecture is to make the optical channel provisioning driven by IP data paths and traffic engineering mechanisms. This will require a tight co-operation of routing and resource management protocols at the two layers. The multi-layered protocol architecture can complicate the timely flow of the possibly large amount of topological and resource information. The two-layer model, which aims at a tighter integration between IP and optical layers, offers a variety of important advantages over the current multi-layer architecture. The benefits include more flexibility in handling higher capacity networks, higher network scalability, more efficient operations and better traffic engineering.

Multi-protocol label switching for IP packets is believed to be the best integrating structure between IP and WDM [7]. MPLS brings two main advantages. First, it can be used as a powerful instrument for traffic engineering. Second, it fits naturally to WDM when wavelengths are used as labels. This extension of the MPLS is called the multi-protocol lambda switching.

Multi-protocol label switching is a switching method in which a label field in the incoming packets is used to determine the next hop. At each hop, the incoming label is replaced by another label that is used at the next hop. It works similarly like switching of the virtual channels (VC) and the virtual paths (VP) in ATM.

The path that is realised this way is called a label switched path (LSP). Each LSP has a set of criteria associated with it, that describe the traffic that the LSP traverses. LSPs can be established using MPLS signalling, e.g., RSVP-TE or CR-LDP [8]. A device that can classify incoming traffic is called a label edge router (LER), while the devices which base their forwarding decision only on the basis of the incoming labels (and ports) are called label switched routers (LSRs).

The model of the network proposed by Internet Engineering Task Force (IETF) consists of both types of IP routers attached to an optical core network (Fig. 1). The optical network consists of multiple optical crossconnects interconnected by optical links. An OXC is a hybrid node consisting of switching element referred to as the optical layer crossconnect (OLXC) and a control plane. Each OXC is capable to switch the data stream from an input port to an output port using a switching function, controlled by appropriately configuring the crossconnect table. OXCs are programmable and should support wavelength conversion and translation.

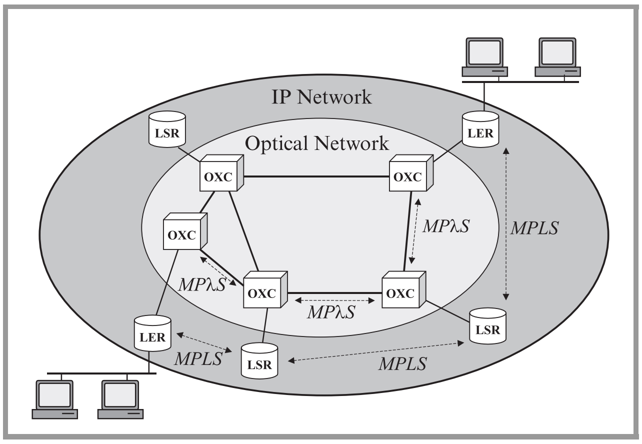

Fig. 1. IP optical network model.

3. Switching in optical network

The exponential growth in Internet traffic leads to a need to scale networks far beyond present speed, capacity and performance. Wavelength division multiplexed transmission and switching are considered the potential solutions to the performance and scaling bottlenecks and offer a limited transparency to packet data-rate and format. However internet-protocol (IP) packet routing and forwarding present a bottleneck in the individual fibre links approach since terabit/s packets must be processed at nearly real-time. Optical WDM switching technology is becoming essential for realisation of the evolving transmission method which is IP over WDM networks.

Evolution of switching in IP/WDM network assumes two phases. First version bases on connection-oriented circuit-switched WDM optical layer, which is supported by MPLS technology. Second phase will make possible fast optical switching in connectionless packet-switched WDM optical layer environment [9]. The two phases are discussed in detail below.

3.1. Phase I

The optical network model consists of multiple optical crossconnects interconnected by optical links in a general topology (referred to as an "optical mesh network"). Each OXC is assumed to be capable of switching a data stream from a given input port to a given output port. This switching function is controlled by appropriately configuring a crossconnect table. Conceptually, the crossconnect table consists of entries of the form <input port i, output port j>, indicating that data stream entering input port i will be switched to output port j. An "lightpath" from an ingress port in an OXC to an egress port in a remote OXC is established by setting up suitable crossconnects in the ingress, the egress and a set of intermediate OXCs such that a continuous physical path exists from the ingress to the egress port. Lightpaths are assumed to be bi-directional, i.e., the return path from the egress port to the ingress port follows the same path as the forward path.

Multi-protocol label switching has been proposed as the integrating structure between IP and optical layers in the Phase I.

3.2. Phase II

The routing method supports autonomous transmission method: once the packet enters the network, it propagates uninterruptedly to the final destination, excluding the small delay at each routing junction (order of several tens of nanoseconds). In high-performance optical-networks, optical data packets require rapid routing at all-optical switches. In order to achieve an efficient and high-throughput switching, the individual routing bits in the address header must be recovered sufficiently fast.

One of the methods which facilitates a fast conversion of the address header leading the data packet from source to destination was developed by BATM Advanced Communications and Lynx-Photonic-Networks [10]. The method is based on an all-optical-header recognition, whereby the address header, leading the optical data packet, is stripped off the packet, and side tracked to a recognition module (Fig. 2). The method is suitable for address bit rates of 2.5 GHz, 10 GHz and beyond. Since the data block remains in the optical domain, it can be encoded in a possibly high (and practical) bit rate.

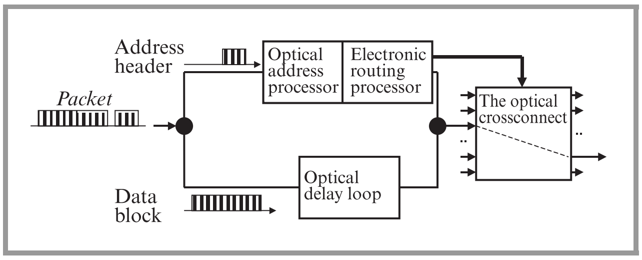

Fig. 2. The routing system based on all-optical address recognition method.

The generated instructions control an OXC, control the entire routing procedure including the regeneration of the new optical address header, restoring it in the proper position. Once the regenerated address has been transmitted into the configured OXC, the data block emerges from the delay loop, following the same path. Each of the OXC's inputs has a dedicated routing module. If collision events (different inputs requiring same OXC output) should become an issue, an optical buffer could be added at the OXC input side, controlled by the electronic module.

4. Signalling & control

Internet Engineering Task Force proposes that control in the IP over optical networks is supported by MPLS control plane. In this solution each node consists of an integrated IP router and reconfigurable optical layer crossconnect equipped with an MPLS control plane.

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.

The IP router implements the necessary IP protocols and uses IP for signalling to establish lightpaths. Specifically, optical resource management requires resource availability per link to be propagated, implying link state protocols such as OSPF [7]. On each link within the network, one channel is assigned as the default routed (one hop) lightpath. The routed lightpath provides router to router connectivity over this link. These routed lightpaths reflect (and are thus identical to) the physical topology. The assignment of this default lightpath is by convention, e.g. the "first" channel. All traffic using this lightpath is IP traffic and is forwarded by the router. All control messages are sent in-band on a routed lightpath as regular IP datagrams, potentially mixed with other data but with the highest forwarding priority. Multiple channels on each link are assumed, a fraction of which is reserved at any given time for restoration. The default-routed lightpath is restored on one of these channels. Therefore, we can assume that as long as the link is functional, there is default routed lightpath on that link.

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.

The mediation device translates the logical primitives to and from the proprietary controls of the OLXC. Ideally, this interface is both explicit and open. One recognises that a particular realisation may integrate the router and the OLXC into a single box and use a proprietary interface implementation. Signalling among various nodes is achieved using CR-LDP and RSVP protocols [7].

Any 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 the individual optical channels those are assigned to 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 he 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. This could be handled either by assigning an IP address to the device, or by assigning an address to the OLXC port to which the device is attached. The network using traditional IP mechanisms can discover whether or not a client is IP aware.

5. Optical network management

Management in a system refers to a set of functions like performance monitoring, link initialisation, and other network diagnostics that allow verifying safe and continued operation of the network. The management functionality in optical networks is still far from being fully developed. The wavelengths in the optical domain will require routing, add/drop, and protection functions that can only be achieved through the implementation of network-wide management and monitoring capabilities.

The links between OXCs will carry a number of user bearer channels and possibly one or more associated control channels. Link management protocol (LMP) that can be run between neighbouring OXCs can be used for both link provisioning and fault isolation [7]. A unique feature of LMP is that it is able to isolate faults independent of the encoding scheme used for the bearer channels. LMP will be used to maintain control channel connectivity, verify bearer channel connectivity, and isolate link, fibre, or channel failures within the optical network.

Current-generation DWDM networks are monitored, managed and protected within the digital domain, using SONET/SDH and its associated support systems. However, to leverage the full potential of wavelength-based networking, the provisioning, switching, management and monitoring functions have to move from the digital to the optical domain. The information generated by the performance monitoring operation can be used to ensure safe operation of the optical network. In addition to verify the service level provided by the network to the user, performance monitoring is also necessary to ensure that the users of the network comply with the requirements that were negotiated between them and the network operator. For example, one function may be to monitor the wavelength and power levels of signals being input to the network to ensure that they meet the requirements imposed by the network. Current performance monitoring in optical networks requires termination of a channel at an optical-electrical-optical conversion point to detect bits related to BER of the payload or frame. However, while those bits indicate if errors have occurred, they do not supply channel-performance data. This makes it very difficult to assess the actual cause of the degraded performance.

Fast and accurate determination of the various performance measures of a wavelength channel implies that measurements have to be done while leaving it in optical format. One possible way of achieving this is by tapping a portion of the optical power from the main channel using a low loss tap of about 1%. In this scenario, the most basic form of monitoring will utilise a power-averaging receiver to detect loss of signal at the optical power tap point. The existing DWDM systems use optical time-domain reflectometres to measure the parameters of the optical links.

The procedure of determining the threshold values for the various parameters at which alarms must be declared causes another problem. Very often those values depend on the bit rate on the channel and should ideally be set up depending on the bit rate. In addition, since a signal is not terminated at an intermediate node, if a particular wavelength fails, all nodes along the downstream path of the failed wavelength could trigger an alarm. This can lead to a large number of alarms for a single failure, and provokes the determination of the cause of the alarm and alarm correlation excessively complicated.

Care should be taken in exchanging those performance parameters. The vast majority of commercial telecommunication networks use framing and data formatting overhead as the means to communicate between network elements and management system. It is worth to mention that while the signalling is used to communicate all monitoring results, the monitoring itself is done on the actual data channel, or some range of bandwidth around the channel. Therefore, all network elements must be able to transmit this bandwidth in order to monitor the events that happen at any point in the network.

6. Fault restoration in optical networks

With the introduction of IP in telecommunications networks there is tremendous focus on reliability and availability of the new IP-optical hybrid infrastructures. Automated establishment and restoration of end to end paths in such networks require standardised signalling and routing mechanisms. Layering models that facilitate fault restoration are discussed. A better integration between IP and optical will provide opportunities to implement a better fault restoration.

Telecom networks have traditionally been designed with rapid fault detection, rapid fault isolation and recovery. With the introduction of IP and WDM in these networks, these features need to be provided in the IP and WDM layers also. Automated establishment and restoration of end-to-end paths in such networks requires standardised signalling, routing, and restoration mechanisms.

The concept of SONET/SDH ring architectures can be extended to WDM self-healing optical rings (SHRs). As in SONET/SDH, WDM SHRs can be either path switched or line switched. Multiwavelength systems add extra complexity to the restoration problem. Under these circumstances, simple ring architecture may be not sufficient.

Although the current routing algorithms are very robust and survivable, the amount of time they take to recover from a failure can be significant, on the order of several seconds or minutes, causing serious disruption of service in the interim. This is unacceptable to many operators that aim to provide a highly reliable service, and thus require recovery times on the order of tens of milliseconds. This problem can be solved by MPLS standards enabled for IP layer restoration. The MPLS label-switched paths disrupted by a link failure are restored in the IP layer itself, and no restoration occurs in the OLXC layer. MPLS enables a hierarchy of LSPs to be defined by pre-pending a stack of labels or tags to packet headers. When a failure occurs, packets along a given LSP can be routed to a predefined restoration LSP by modifying the labels maps of the routers at the ends of the original LSP [11]. In fact, a protection priority could be used as a differentiating mechanism for premium services that require high reliability.

There are same particular goals for MPLS based protection. First, MPLS-based recovery mechanisms should facilitate fast (within 10 ms) recovery times. MPLS-based recovery techniques should be applicable for protection of traffic at various granularities and for an entire end-to-end path or for segments of an end-to-end path. As an example, it should be possible to specify MPLS-based recovery for a portion of the traffic on an individual path, for all traffic on an individual path, or for all traffic on a group of paths. MPLS-based recovery mechanisms should be able to take into consideration the recovery actions of other layers. MPLS-based recovery mechanisms should also minimise the loss of data and packet reordering during recovery operations.

7. Conclusion

Development of IP, MPLS and WDM technologies makes possible close integration of the Internet applications based on IP technology and optical network infrastructure. Customers will have access to new high-bandwidth services made possible by the increased capacity affordable by the optical layer. Services that today are considered prohibitively expensive, such videoconferencing to the desktop, electronic commerce, and high-speed video imaging, will become commonplace because they will be technologically and economically feasible. It is a giant step forward towards fulfilment idea of information society, which means wide utilisation of information techniques and universal access to communication applications and resources of information.

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