Simulation of All Optical Networks

Raul Valls Aranda
Communication Department
Polytechnic University of Valencia (UPV)
C/ Camino de Vera s/n
Valencia, Spain

Pablo A. Beneit Mayordomo
Communication Department
Polytechnic University of Valencia (UPV)
C/ Camino de Vera s/n
Valencia, Spain

TR-GCO-2003-01
April 2003

Abstract

Over the last decade changes in telecommunication networks have been led by WDM technique and its related technologies. The great number of possibilities and expectations that have been created in optical networking makes that these subjects have an important interest in the research community.

This paper describes simulation models of optical devices that make a set of simulation libraries. The objective is to allow the study, understanding and research of all optical networks from the point of view of simulation approaches.

Key words

DWDM, AWG, OADM, OXC, Mesh Networks, Ring Networks, MP2S, Packet Switching, Label Swapping, Burst Switching, Opnet, Simulation
1. Introduction

The growing and operation of Internet demands efficiency, strength, scalability and enough waveband to the next IP networks.

The set of protocols being part of the MPLS control plane have been designed to solve some of these demands, keeping packet routing apart from packet forwarding, making faster routing processes and providing valid tools for traffic engineering.

On the other hand, the advances in optical communications (DWDM technologies) have succeeded in providing huge transmission capacity in each wavelength while allowing the use of a substantial number of wavelengths in a single fiber.

Other advances in optical devices have improved the concept of optical networking, making feasible that classical “electronic” network functions, as protection, restoration and routing, can be developed in the “optical” domain (i.e. without optical-electronic-optical conversions), with the resulting increase of efficiency.

All this advances make that IP, MPLS and optical networking walk together towards next IP networks. In this sense, an important evolution is succeeding in all the subjects related with optical networking.

Thanks to the AWG’s, OADM’s, wavelength converters, OXC’s \[1\] and other devices it is possible to design any kind of physical topologies, and added to the wavelength assignment algorithms, it can be also possible to design all kind of routing topologies.

MP$\lambda$S (the control plane MPLS \[4\] applied to optical networks) allows to route IP traffic with QoS through a WDM network, making easy network adaptations and providing resources on real time by means of protocols adapted to the optical environment:

- Common IP routing protocols: OSPF/IS-IS to distribute link state information between routers.
- MPLS signalling protocols: CR-LDP/ RSVP-TE, to define paths over the network and to allocate resources beside the paths.
- MP$\lambda$S specifically created: LMP, to verify control and data channels.

Other evolution can be observed in the area of network operation modes: from circuit provisioning and switching to optical packet switching, passing through optical label swapping \[3\] and optical burst switching.

Specially in the last two modes, WDM-SCM \[3\] combined technique has an important role, allowing routing and forwarding processes to act without disturbing data signal, opening a new way of application of these technologies to core LAN’s and MAN’s \[2\].

Sections below describe simulation models of optical devices forming a set of simulation libraries.

2. Overview & Design

Our work has focused on the development of a mesh architecture network supporting the set of communication protocols that forms MP$\lambda$S and another ring-shaped one that supports a token ring protocol (simple and specifically designed for device testing), both of them implemented with some devices that turns them into all optical network architectures.

2.1. DWDM and Optical Networks

DWDM technology greatly increases optical fiber capacity, basically, it allows using multiple wavelengths over the same medium.\[5\] At its core, DWDM involves a small number of physical-layer function. These are showed in the Figure 1, which shows a DWDM schematic for four channels, where each optical channel occupies its own wavelength.
The system performs the following main functions: generating the signals, combining them, transmitting them, separate the received ones and receive them properly.

Modeler’s node domain transmitter and receiver modules capabilities make feasible modelling DWDM working scheme, for these modules also play the role of multiplexers and demultiplexers, as Figure 2 depicts.

Thus, each channel (that we can actually consider as a wavelength, simply by assigning to it the proper bandwidth parameter value) can be obtained separately; and in the same way, many channels can be introduced into a transmitter module as if they were different wavelengths, getting separately at its exit the set of wavelengths travelling over the same link (that we can consider a fiber). Optical devices’ in charge of generating and detecting the signal accurate implementation is out of our work.

One of the most important capabilities brought by an all optical network is transparency, this consisting of incoming data going out of it without having been examined or modified. This goal requires some protocols and devices to make it possible, as for example optical switches (OXC) that in addition, reduce data switching time. Undoubtedly, this is the most significant optical device in an optical core network, for it is the one in charge of making the incoming information’s (packets, bursts or whole wavelengths) switching decisions between the right source and destination nodes, that locally translates into switching the signal between certain input and output optical interfaces.

Optical Crossconnects (OXC) provide optical connection through the network, with no timing constraint or buffering involved. At the edge of the optical domain, high speed routers allow network to adapt to the growing volume of IP traffic flows, the added diversity of data service requirements, and the increasing amount of available bandwidth provided by DWDM. High speed routers have the ability to support fast switching and forwarding techniques, route lookup and differentiated services (packet classification, buffer management and packet scheduling) in order to eliminate bottlenecks and improve performance in the management of the new traffic patterns.

In the control plane, the network require on demand lightpath service, route establishment for individual connections, network topology discovery, and information distribution (available resources, network status, network reachability). Optical networks also need restoration and management capabilities in order to address end-to-end bandwidth provisioning and distribution at the optical layer.
2.2. MP\&S Overview

MP\&S [8] is a tailored version of MPLS for the optical domain where optical channels (lambdas) concepts are like LSPs and OXCs similar to LSRs. The objective of MP\&S is to provide a control plane to the OXCs with the capability of establishing optical channels, supporting traffic engineering functions and supporting protection and restoration schemes.

At present, IP is the prevailing network layer protocol, edge-routers classify incoming traffic flows (mainly IP) to be able to forward them together over lightpaths that are calculated by executing a signalling process between an ingress router and an egress router. Protocols in charge of finding the most appropriate path are CR-LDP (Contraint Rate –LDP) or RSVP-TE (RSVP –Traffic Engineering), based in some parameters or constraints that the network administrator can set and that, in the end, determine QoS given to the information that gets into the network. Once constraints being set, the resources’ establishment, maintenance and release involved in the lightpath management are totally automatic, though it is also possible to create explicit paths if it is required by the data priority or if the network congestion recommends it.

Information that allows to take switching decisions on the OXCs is brought by another protocol, OSPF or IS-IS, that verifies periodically the state of the links between switches and conveys the results of this query to the OXCs, so when it is required to calculate a lightpath for incoming data, it can access a reliable database of the state of the whole network in order to take the proper switching decision.

For scalability purposes, multiple data links can be combined to form a single traffic engineering (TE) link [6]. Furthermore, the management of TE links is not restricted to in-band messaging, but instead can be done using out-of-band techniques what makes feasible to completely separate the control plane (OSPF, CR-LDP,RSVP-TE) from the data plane (TE links mainly with IP data). This can be made in different ways as we can see in Figures 3-4, i.e. with a control network fully separated from the data network (with an own infrastructure that connects OXC between them); or dedicating only for control information transport one of the wavelengths inside the fibers connecting the switching devices.

LMP protocol runs between neighbouring nodes and is used to manage TE links among some other things. Specifically, LMP is used to maintain control channel connectivity, verify the physical connectivity of the data links, correlate the link property information (that is checking that the grouping of links into TE links as well as the properties of those links are the same at both end points of the links), suppress downstream alarms, and localize link failures for protection/restoration purposes in multiple kinds of networks.

Figure 3. (a) Mesh network with a dedicated control wavelength. (b) OXC Node model
2.3. Ring Network and OADM Design
Developed ring architecture uses a token ring protocol. For the moment, it works on a single wavelength, where OADMs connecting the ring with the user stations are used to decide if the fiber incoming information must be sent to the connected station or must be left in the ring until it finds its destination.

OADM is an optical device which has two positions: pass and cross. The output port is swapped between both positions, that is if in the pass position the connection is: input1-output1 and input2-output2, when it changes to the cross position, the connection is: input1-output2 and input2-output1. What makes an OADM to be in one position or another is the information it receives from the inputs. This information is analysed at the input and based on some criteria over its content, it is switched from one position to the other. This device is tuned in a concrete wavelength and can be designed to work on a packet or a wavelength oriented manner. The design made in our case (Figure 6) is packet oriented, and the information taken from the incoming packet, thanks to SCM (which is explained below), is its header, and depending on its content and some internal routing tables it is decided if the position must be pass or cross.
SCM (Sub-Carrier Multiplexing), is basically a radio-frequency multiplexing technique that implies a second level of multiplexing: the spectrum is divided into bands/channels with a central carrier or frequency (wavelength in DWDM), that are also divided in sub-bands/sub-channels with its corresponding sub-carriers. At present, it is possible to extract and insert a sub-carrier tied to a wavelength without any E-O-E conversion and, what is more significant, without modifying the signal carried over the main frequency. This ability can be used to carry and process the routing labels attached to packets: the packet or the useful load is transmitted over the main channel (central wavelength) while the label travels over the secondary channel (sub-carrier). When it gets to the node, it can be extracted and processed in order to make routing decisions over the packet and in addition reinsert the new label that will go along with the routed packet. Using SCM as described above will have possible applications in a core Campus LAN or MAN.

2.3. Other Optical Devices

We have designed with Modeler some optical devices for the deployment of an all optical network. The simplest devices are AWG, star coupler and wavelength converter, and the ones that required a more complex development are OADM and OXC, which are in charge of the packet switching thanks to information provided to them through dynamic routing protocols or that is statically introduced by the network administrator. Next, we briefly describe some of these devices.

The AWG (Arrayed Waveguide Grating) is an optical device where several copies of the same input signal, but shifted in phase by different amount, are added together in its output. It can be used as a \( N \times 1 \) wavelength multiplexer, where the \( N \) inputs are signals at different wavelengths that are combined onto the single output. The inverse of this function, namely, \( 1 \times N \) wavelength demultiplexing, can also be performed using an AWG. It also can be used as a static router, However, this router is not capable of achieving an arbitrary routing pattern. Although several interconnection patterns can be achieved by a suitable choice of the wavelengths and the free spectral range of the device, the most useful one is illustrated in the following picture. This figure shows an \( 4 \times 4 \) router using four wavelengths with one wavelength routed from each of the inputs to each of the outputs. Such a device may be useful to interconnect broadcast-star networks.
The star coupler is a passive optical device that when receiving a signal on one of its inputs, corresponding to optical fiber interfaces, it immediately introduces it into every output (even in the one the signal arrived from) exactly with the same incoming wavelength, without any wavelength conversion. Its broadcast ability puts this device into the LAN domain, since it is equivalent to a bus logical topology.

Finally, the wavelength converter is an optical device which function is simply to change at the output the wavelength the input signal came with.

3. Conclusions and Future Work

Several (D)WDM devices used in optical networks like multiple wavelength fiber links, passive star couplers, wavelength multiplexers, wavelength converters, fiber delays, optical crossconnects (OXC), etc. have been designed and validated with the OPNET simulation environment. They have been tested in mesh, star and ring networks.

All of them, along with a specific simulation models and interfaces form an initial OPNET library that allows WDM networks simulations and related subjects: from survivability to QoS provisioning, from LAN to WAN, applications and performance.

At the moment there are three lines of work opened with OPNET Modeler:

- WDM token ring networks, for MAN’s and core LAN’s. The objective is to define the suitable WDM-SCM interface and the most efficient access protocol together with the most efficient protection mechanism. Other important scheme is the integration with the newest IEEE 802.3 standard version.

- MPLS networks, for core transport optical networks. The objective is developing a MPLS control plane that manage optical network, providing the goals that MPLS is supposed to do, combining QoS and different virtual topologies.

- Packet switching modes. The objective is to model and compare different structures of packet switches, both for label and burst switching.

References