Computer Networks 52 (2008) 1916–1926

Contents lists available at ScienceDirect

Computer Networks

journal homepage: www.elsevier.com/locate/comnet

A Bayesian decision theory approach for the techno-economic analysis of an all-optical router (extended version)

Víctor López [a,*], José Alberto Hernández [a], Javier Aracil [a], Juan P. Fernández Palacios [b], Óscar González de Dios [b]

[a] Universidad Autónoma de Madrid, 28049 Madrid, Spain
[b] Telefónica I + D, 28043 Madrid, Spain

ARTICLE INFO

Article history:
Received 10 July 2007
Received in revised form 12 February 2008
Accepted 18 February 2008
Available online 16 March 2008

Keywords:
Multilayer router
Bayesian decision theory
Techno-economic trade-off
IP over WDM

ABSTRACT

Typically, core networks are provided with both optical and electronic physical layers. However, the interaction between the two layers is at present limited, since most of the traditional transport functionalities, such as traffic engineering, switching and restoration, are carried in the IP/MPLS layer. In the light of this, the research community has paid little attention to the potential benefits of the interaction between layers, multilayer capabilities, on attempts to improve quality of service control.

This paper shows when to move incoming label switched paths (LSPs) between layers based on a multilayer mechanism that trades off a QoS metric, such as end-to-end delay, and techno-economic aspects. Such a mechanism follows the Bayesian decision theory, and is tested with a set of representative case scenarios.

1. Introduction

Core networks are typically equipped with both electronic and optical resources. This means that incoming traffic can be routed in either the optical or electrical domain. Essentially, electronic routing has the well-known advantages of statistical multiplexing and granularity, but is a hard-computational process for high-speed networks and it further introduces queuing delay to packets. On the other hand, data packets switched in the optical domain only experience propagation delay. However, optical resources provide a granularity which is too coarse for typical Internet streams, even if they come from the multiplex of many users.

In this IP over WDM scenario new challenges appear, since it is necessary to manage two layers, which can provide some functionalities to both of them. This is the case of routing, traffic engineering, quality of service, resilience techniques, resources optimization, etc. which could be carried out in either the IP or the WDM layer. Over the few years, a considerable effort has been dedicated to the development of automatic switched optical network (ASON) and generalized multiprotocol label switching (GMPLS). Thanks to this development, a standardized control plane has been defined, which allows a framework to propose solutions to the previous problems: traffic engineering [1], routing [2,3] or grooming [3,4].

In conclusion from previous papers in this area [4–7], it is highly desirable to efficiently combine the benefits of both optical and electronic domains to solve previously cited problems. With this aim, architectures to build multilayer-capable routers have been defined [5,8]. In this situation, incoming label switched paths (LSPs) traverse the multilayer-capable router, which has to decide whether to perform optical or electronic switching (Fig. 1). If an incoming LSP is routed in the electronic domain, it suffers hop-by-hop opto-electronic conversion (with subsequent delay), otherwise the router provides an optical bypass. The choice of electronic or optical switching is based upon a set of previously-defined rules in the multilayer-capable router. However, these rules

* Corresponding author. Tel.: +34 914972268.
E-mail address: Victor.Lopez@uam.es (V. López).

1389-1286/$ - see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.comnet.2008.02.018

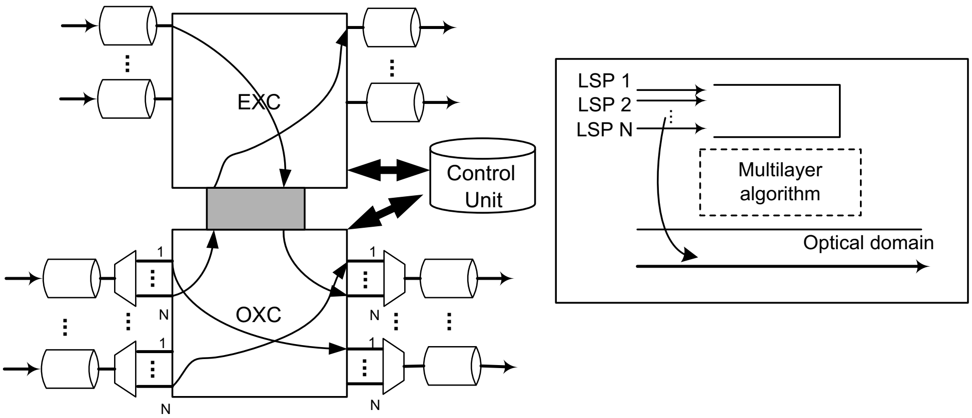

Fig. 1. Multilayer-capable router scenario.

are still open. The authors in [9] address the multilayer traffic engineering problem, proposing a cost model based on the link occupation. Depending on the link occupation, the router is able to decide the number of LSPs switched through each lightpath. Nevertheless, no QoS evaluation, in terms of end-to-end delay, is performed, while the paper is more focused on load balancing issues. In [1], the authors propose an ILP optimization algorithm to minimize the load in the electronic domain using cut-through lightpaths, subject to the network equipment restrictions.

In this paper, we propose a techno-economic model to help routers take the decision of optical or electronic switching of their LSPs. Such an approach makes use of Bayesian decision theory, and takes into account several aspects concerning the quality of service perceived by packets, by means of queuing delay, and also techno-economic aspects such as the relative cost associated to switching LSPs in either the optical or the electronic domain. The algorithm's computational cost is low and only have to be computed when a new LSP arrives at the router or any of the input parameters of the algorithm vary. This multilayer algorithm could be easily implemented in the control unit of the multilayer-capable router (Fig. 1).

In the light of this, the remainder of this work is organized as follows: Section 2 covers the mathematical foundations for such techno-economic analysis with a Bayesian decisor. In this section, a set of experiments and numerical examples is also provided to show how to reach an optimal decision. Section 3 studies the behavior of the bayesian decisor in a dynamic environment, with its analytical definition and experiments. Finally, Section 4 outlines a summary of the results obtained and further lines of investigation.

2. Analysis

2.1. Problem statement

As previously stated, the aim is to define a mathematically rigorous set of rules that helps such multilayer-capable core routers decide whether to switch a given LSP in the optical domain or in the electronic domain.

At a given time, a multilayer router handles a number of LSPs. Typically, due to QoS constraints, optical switching is preferred due to the lack of queuing delay. In principle, many LSPs can be multiplexed in the electronic domain, whereas the lightpath bandwidth may be underutilized if LSPs are switched in the optical domain. This can be seen as a capacity planning problem. Given a set of input LSPs, the question is to derive the number of LSPs that should be switched in the electronic domain and the amount of LSPs to be switched in the optical domain, in an attempt to maximize utility. It is preferred to switch in the electronic domain because the availability of buffering in core nodes allows for a higher utilization, and the remaining optical bandwidth can be used for newly arriving LSPs.

Thus, the router must trade-off these two parameters: queuing delay versus the cost associated to optical switching (a techno-economic trade-off). Moreover, it needs to have a set of predefined rules to make a decision on how many LSPs should be switched in the optical domain and how many in the electronic domain.

To do so, let N refer to the number of LSPs handled at a given random time by the multilayer router, and let $L(d_i,x)$ refer to the loss function. The loss function $L(d_i,x)$ denotes the cost or loss of switching i LSPs in the electronic domain (thus, $N-i$ LSPs in the optical domain) with subsequent queuing delay experienced by the packets of the electronically switched LSPs, which is denoted by x (for simplicity, the optically switched LSPs have been assumed to experience zero delay). The term d_i denotes the "decision" of routing i LSPs out of a total of N in the electronic domain, and is defined for some decision space $\Omega = \{d_1, \ldots, d_N\}$. In the light of this, $L(d_i,x)$ is given by:

$$L(d_i,x) = (C_e(i) + C_o(N-i)) - U(x), \quad i = 1,\ldots,N, \quad x > 0 \tag{1}$$

where $C_e(i)$ and $C_o(N-i)$ refer to the cost associated to routing i LSPs in the electronic domain and $N-i$ in the optical domain, respectively; and $U(x)$ refers to the utility associated to a queuing delay of x units of time, experienced by the electronically switched LSPs.

Following [10], the Bayes risk, which is essentially the expectation of the loss function with respect to x, equals: