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Multi-layer MPLS network design: The impact of statistical multiplexing ☆

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Abstract

The possibility of adding multi protocol label switching (MPLS) support to transport networks is considered an important opportunity by telecom carriers that want to add packet services and applications to their networks. However, the question arises whether it is suitable to have MPLS nodes just at the edge of the network to collect packet traffic from users, or to introduce also MPLS facilities on a subset of the core nodes in order to exploit packet switching flexibility and multiplexing, thus inducing a better bandwidth allocation. In this paper, we propose a mathematical programming model for the design of two-layer networks where MPLS is considered on top of transport networks (SDH or WDM depending on required link speed). Our models take into account the tradeoff between the cost of adding MPLS support in the core nodes and the savings in the link bandwidth allocation due to the *statistical multiplexing* and the *traffic grooming* effects induced by MPLS nodes. The traffic matrix specifies for each point-to-point request a pair of values: a *mean* traffic value and an *additional* one. Using this traffic model, the effect of statistical multiplexing on a link allows to allocate a capacity equal to the sum of all the mean values of the traffic demands routed on the link and only the highest additional one. We propose a path-based Mixed Integer Programming (MIP) model for the problem of optimizing the number and location of MPLS nodes in the network and the link capacities. We apply Lagrangian relaxation to this model and use the subgradient method to obtain a lower bound of the network cost. As the number of path variables used to model the routing grows exponentially with the graph size, we use an initially limited number of variables and a column generation approach. We also introduce a heuristic approach to get a good feasible solution. Computational results are reported for small size and real-world instances.

Keywords: Multi-layer network design; MPLS; Statistical multiplexing; Traffic grooming; Optimization models; Heuristics; Lagrangian relaxation

1. Introduction

With classical IP routing, packet forwarding is performed independently at each router in the network and is based only on the destination address

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carried in the packet. Classical IP routing policy selects the shortest path to the destination exploiting distributed routing protocols. Hence, when the resources available on the shortest path are not sufficient the quality degrades.

Recently, substantial effort has been spent to improve conventional IP routing architecture and protocols by providing them with additional functionalities using the multi protocol label switching (MPLS) [1]. One of the key aspects of MPLS is a new connectivity abstraction. In particular, explicitly routed point-to-point paths, named label switched paths (LSP), can be established using label based forwarding mechanisms. This allows a per flow path selection and Quality of Service (QoS) parameters to be taken into account by the routing algorithm [2]. The notion of QoS has been introduced to capture the quantitatively defined performance contract between the service provider and the user. The QoS requirement of a connection can be given as a set of link constraints, e.g. by requiring that there is enough bandwidth on the path selected for the connection of the requesting user [3].

The capacity needed at MPLS layer is provided by the underlying transport network which may be based on Synchronous Digital Hierarchy (SDH) or Wavelength Division Multiplexing (WDM), depending on the link speed. The transport network can be devoted to MPLS services only, or, more often, shared with circuit switched services such as the phone service. In this network architecture some or all nodes must support both transport network technology and MPLS. Hence, a telecom carrier that wants to offer MPLS based packet switched services must add label switching capabilities to some nodes of the transport network. A node supporting MPLS is named Label Switched Router (LSR). Edge nodes must necessarily support MPLS in order to collect packet switched traffic from users. Core nodes may or may not support MPLS. LSRs and virtual links connecting them define a logical network topology on top of the physical topology of the transport network (Fig. 1). Virtual links in the logical topology are mapped into paths of physical links in the physical topology. These paths between LSRs are circuits (or light-paths) and may cross several nodes of the transport network not supporting MPLS. Circuits must be dimensioned according to bandwidth requirements and then the capacity of each physical link must be selected based on the circuits crossing it and the discrete set of possible values defined by the transport technology.

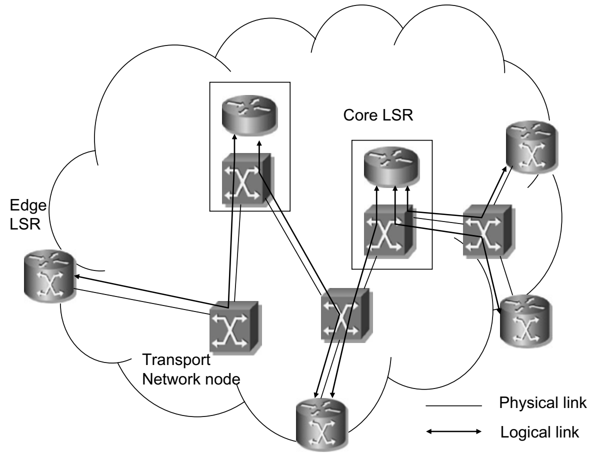

Fig. 1. MPLS over transport network: physical and logical topologies.

In this context, we have to take into account jointly the transport network layer and the MPLS layer when designing the network. This means that we have to decide which core nodes must support MPLS, how to connect LSRs within the transport network, and the bandwidth reserved on each link. A simple solution could be that of adding MPLS support to edge nodes only. In this case, we have to setup a circuit between each pair of edge LSRs and to dimension it according to the bandwidth required by the LSPs connecting them. The advantage of this solution is that we save the costs of adding MPLS support to core nodes. However, we cannot exploit the multiplexing gain for traffic demands routed on the physical link since LSPs traversing different LSR pairs must use different circuits. On the other side, we could add MPLS support to all the core nodes. In this case, we can exploit at best the multiplexing gain saving bandwidth on the physical links. Which of these opposite solutions is the more profitable depends on the relative costs of the nodes and the bandwidth and on how the multiplexing gain is modelled and exploited in the network. More in general, due to the tradeoff between multiplexing gain and cost of MPLS nodes, the best solution will be an intermediate one where only a subset of nodes are equipped with MPLS capabilities.

The effect of multiplexing on the bandwidth required to support a set of LSPs is twofold. Since the capacity provided by the transport layer is available with discrete values, multiplexing allows to reduce the quantization effect. In some cases where the minimum available capacity is quite high, as in