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Cost-effective single-hub WDM ring networks: A proposal and analysis

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Abstract

In this paper, we study a new concept of traffic grooming in wavelength-division multiplexing (WDM) ring networks that aims at eliminating both the bandwidth underutilization and the scalability concerns that are typical of all-optical wavelength routed ring networks. Our objective is to reduce the network cost while preserving the benefits of all-optical WDM ring networks. In order to assess the efficiency of our proposal, all underlying network costs are compared. These costs include that of the transceivers required at node level, as well as the number of wavelengths. Our results show that the proposed aggregation technique can significantly improve the resource utilization while reducing the network cost.

Keywords: Traffic grooming; Optical networking; All-optical and opaque ring networks; Network dimensioning; Cost evaluation

1. Introduction

During the last decade, we have witnessed a continuous growth in data traffic. This growth, driven primarily by the proliferation of the Internet, has created a rising demand for robust networks, with increasingly high-link capacity and node throughput. Due to the new incumbent challenges, operators are progressively migrating towards optical core networks thus taking advantage of the tremendous transmission capacity offered by the optical technology. Thanks to the wavelength-division multiplexing (WDM) in core networks, the need for more capacity may be satisfied. However, there is a need for an efficient solution for transporting and switching huge amounts of data at the boundaries of backbone networks, especially at metropolitan and local area networks.

In metropolitan area networks, infrastructures are generally organized over a ring topology (Fig. 1). Typically, a metro network consists of a feeder ring network and multiple access nodes. Each node serves one or more access networks. Most of the traffic from the access networks is destined to

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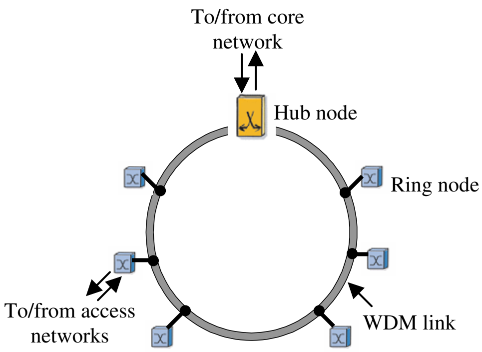

Fig. 1. Single-hub WDM ring.

nodes outside of the ring network. Such traffic, carried to the core via the hub node, is called hubbed traffic. In this paper, we consider hubbed traffic since it is an important class of traffic and is often observed in access ring networks.

One of the main issues when designing metro networks is cost-effectiveness. Minimizing cost becomes the main concern in network design, since such a network handles much smaller group of end users compared to long-haul networks. For metro networks, we can save cost in two ways: by sharing bandwidth efficiently and by reducing usage of expensive network equipment.

In optical networks, a significant portion of the network cost is due to the equipment used to convert signals from the electrical to the optical domain. In view of this, the optical layer is migrating from an opaque network, consisting of WDM links with electrical processing at the ends of the link, to an all-optical network, where traffic is switched at intermediate nodes in the optical domain. The optical layer here provides circuit switched lightpaths to the higher layer equipment such as SONET and IP boxes.

Using optical pass-through instead of electrical processing, can lead to an order of magnitude savings in the cost. Nonetheless, the rigid routing granularity entailed by such an approach can lead to bandwidth waste. In order to use the link bandwidth efficiently, we have to allow different access nodes to share a single wavelength. In addition, routing at the wavelength level puts a serious strain on the number of wavelengths required in the network. For full connectivity, an N node all-optical ring suffers from the N-squared problem, since each node requires $N-1$ lightpaths. Even for moderate values of N, the total ring capacity is quickly exhausted.

In contrast, an opaque ring has the advantage of being able to use efficiently the link bandwidth. Nonetheless, this results in a maximum transceiver cost since nodes do not have an optical bypass. In the long term, optical packet switching (OPS) appears as a promising solution. In fact, a major advantage of electronic packet switching is its bandwidth efficiency achieved through statistical multiplexing. However, OPS is not ready yet and it is hampered by major technology limitations due to the issues related to the fine switching granularity adopted at high bit rate [1].

To alleviate the aforementioned problems, we propose a new solution, which combines the advantage of the optical bypass in transparent wavelength routed networks with statistical multiplexing gain. In this technique, a lightpath, which remains entirely in the optical domain, is shared by the source node and all the intermediate nodes up to the destination. So, in essence, a single lightpath is used to establish a multipoint-to-point (MptoP) connection. We refer to this technique as the distributed aggregation scheme.

To a certain degree, the approach proposed in this paper can be seen as an extension of an earlier proposal called the Dual Bus Optical Ring Network (DBORN). The DBORN architecture is described in this paper. For more details please see Ref. [2].

In this study, we provide a typical design of ring networks that function according to the distributed aggregation scheme. This new architecture is called the MptoP all-optical ring network. Moreover, we assess the cost savings introduced by the MptoP architecture with respect to DBORN, all-optical and opaque ring networks. To achieve this, all underlying network costs are evaluated. These costs include that of the transceivers required at the node level and the number of wavelengths. Note that in practice, the transceiver cost dominates the cost of the number of wavelengths in a network.

The rest of the paper is organized as follows. In Section 2 we give a literature review and point out our position relative to previously published papers. A detailed description of this new approach is given in Section 3. The DBORN architecture and its main features are given in Section 4. The general problem statement is presented in Section 5, and in Section 6, all underlying network costs are evaluated. In Section 7, a cost comparison between our proposal and existing solutions is drawn based on a mathematical model. Finally, the conclusions are given in Section 8.