A Novel Node Architecture for Light-trail Provisioning in Mesh WDM Metro Networks

Ashwin Gumaste¹, Admela Jukan¹, Akhil Lodha¹, Xiaomin Chen² and Nasir Ghani³

¹Dept. of CSE, Indian Institute of Technology (IIT), Bombay, India 400076.
²Dept. of ECE, Technische Universität Carolo-Wilhelmina zu Braunschweig, Germany 38106.
³Dept of ECE, University of New Mexico at Albuquerque, USA 87131.

Email: ashwing@ieee.org, jukan@ida.ing.tu-bs.de, alodha@cse.iitb.ac.in, xiaomin@ida.ing.tu-bs.de, nghani@ece.unm.edu

Abstract: We propose an efficient node architecture to support light-trails (intelligent-shared-wavelength bus) in mesh WDM metro networks. Simulation results and performance benefits as compared to legacy technologies are shown.

OCIS codes: 060.4250 Networks; 060.4250 Networks

1. Introduction

Metropolitan networks are undergoing two major changes, different from any previous evolution. First they are becoming true “networking” environments, driven by the advancement in broadband communication and enterprise services. Specifically, the growth of data traffic and dynamic services such as VoIP, triple-play, pseudo-wires, video-on-demand (VoD) and data-centers are imposing key network requirements such as flexibility and bandwidth connectivity. Circuit-based SONET/SDH technologies are proving increasingly static for these services, often resulting in their over-provisioning, and a new wave of packet oriented technologies are being deployed – in particular Ethernet based flexible approaches. Second, metropolitan networks are extending into regional overlays and becoming “mesh-like”, driven by several reasons, such as the enterprise need to have back-up sites at significant distances from the primary sites, supply-chain business application requiring multiple office sites to be connected across a single regional network, and adaptation of data-centric technologies that do not require ring protection [3].

From a bandwidth connectivity perspective, the new emerging services require one or more of the following characteristics: sub-wavelength granularity, optical multicasting, dynamic-bandwidth provisioning and lower operating costs. To overcome the limitation of traditional lightpath technologies, light-trails were initially proposed in [1, 2] and their advantages described for metro ring networks. While their properties make light-trail an attractive solution for emerging metro services, adapting light-trails to mesh networks adds a number of key technological challenges, in particular from an architectural point of view. In this paper, we introduce a novel node architecture applied to mesh WDM metro networks and analyze the performance in comparison to the legacy network counterparts. To this end, we presents the node architecture for light-trails in a mesh environment, its accompanying control plane concepts and show illustrative results on an example mesh metro network in Dallas.

3. Mesh Node Architecture to Support Light-trails

Light-trails are the time-shared realization of the lightpaths, in the sense that they allow multiple source-nodes to communicate with multiple destination-nodes over the same wavelength without any switch-reconfiguration [1, 2]. As such, light-trails generalize the lightpath concept and thereby realize what can be seen as a time-shared wavelength bus; nodes communicate to each other by forming time-shared connections (over the bus). There are three main challenges in designing a node architecture that supports light-trails in a mesh network: (i) ability to passively drop-and-continue the incoming optical signal (wavelength); (ii) ability to store data locally in the electronic domain, and schedule the data into the light-trail triggered by a control-channel protocol; and (iii) ability to passively-add data into the light-trail bus. Fig. 1 shows the proposed node architecture that meets these requirements. For illustration, it supports 4 input and 4 output fibers. The architecture is based on 1xX Wavelength Selectable Switch (WSS) devices, which support switching of a pre-selected combination of wavelengths from a single input port to any of the X output ports and result in low attenuation as compared to AWG or wavelength blocker devices. This approach allows efficient wavelength routing on a per-wavelength basis.

(a) Local processing for add-drop and storage. If a particular incoming wavelength (carrying a light-trail) is to be locally processed (implying that the node is actively involved in the communication of that light-trail), then this wavelength is switched to port 1 of the WSS. Since multiple wavelengths can be locally processed, port 1 would possibly have any subset of wavelengths from the incoming composite WDM signal. Port 1 is hence connected to an AWG (DEMUX) that de-multiplexes the incoming signal into ITU-wavelengths. Each de-multiplexed wavelength is then sent through two optical couplers separated by an ON/OFF shutter. If the node is a start/end-node for a particular light-trail, the shutter is in the OFF position, whereas if the node is an intermediate node, then the shutter is in the ON position. The first coupler supports drop-and-continue functionality, while the second coupler supports
passive addition of local signal into the light-trail. The two couplers are connected to a client switch with configuration shown in Fig. 2. This switch not only can store data locally in the electronic domain, and schedule the data into the light-trail, but it is also a key element of the control plane [1, 5], as described later. From the add-coupler, the light-trail wavelength is then sent to a second AWG that acts as a MUX. The MUX generates the WDM signal created from all the locally processed light-trails and sends it to a 1xD local WSS. The local WSS switches the incoming wavelengths to output ports which are connected to the corresponding output fibers (global output WSS). In this way, we provide strict non-blocking switching as well as local access to the data on the light-trail.

(b) Optical bypass. If a particular input wavelength is to be passed through the node without any local processing, then the input global WSS (as shown in Fig. 1) switches this wavelength to an output port that is further connected to the corresponding output global WSS. Each output global WSS (in 2Dx1 configuration) is connected to an outgoing fiber link. The 2Dx1 configuration implies that it can receive signals (wavelengths) from any of the D input global WSSs in addition to receiving signals from any of the D local WSS (see Fig. 1). The DxD switch fabric that is created by the D input global and D output global WSSs is hence strictly non-blocking.

4. The Accompanying Control Plane Concepts

The control plane concept we use and the abstraction of control and data are illustrated in Fig. 2. Data received from higher layers in Ethernet frames is tagged with VLANs that allow service/latency differentiation. Mapping of the Ethernet port to VLAN tag is done through the control plane. Addition of VLAN tags allows to maintain service differentiation within the same bandwidth pipe – a feature that is necessary to meet multiple SLAs. While adding VLAN tags to the incoming services, the switch is able to provide certain administrative information such as creating virtual tunnels that have specific bandwidth and delay profiles. When the number of service requests exceeds the number of VLAN IDs (VIDs) available, we stack VIDs in Q-in-Q fashion (802.1Q). The controller of a light-trail allocates time-slots to nodes by considering the size of the queue and the latency of the service, which are precisely the parameters sent by the node as a bid. In this scheme for every light-trail there is a controller that accepts bids from all the nodes in the light-trail and then assigns connections (data-time-slots) to member nodes taking service requests into consideration. If the SLA of a service is not met through a light-trail, then a new light-trail is created for this service (routing). This control plane mechanism is an extension of the dynamic two-stage auctioning scheme proposed in [4], here applied to mesh light-trails.

The route selection, i.e. new light-trail formation, is performed whenever a packet flow-request cannot find an existing light-trail. The problem in mesh is non-trivial as several possible solutions exist and we desire to choose the optimal light-trail to satisfy the request. As a preliminary concept and basis for our future work, we propose a simple heuristic which involves creation of two data-bases: EXIST and POSS. EXIST data-base contains all the existing light-trails and corresponding ports at every node through which an existing light-trail passes. POSS data-
base on the other hand contains the set of light-trails which are possible, such that each element of POSS leads to what we call a hitless routing, i.e., the routing which does not affect the performance of any existing light-trail. A light-trail that yields the best optical signal-to-noise ratio (OSNR) at the end-node is chosen from POSS to satisfy a new request. Finally, it is important to consider the case where a light-trail is requested to accommodate multiple packet-flow requests so as to maximally utilize light-trail bandwidth. Each such request may require the light-trail to change the state of a node from optical bypass to local-access resulting in extra per-node loss. Note that if a request has to be routed through an existing light-trail, the OSNR of all already existing connections are taken into consideration.

5. Performance study and numerical results
We simulated a 16-node network corresponding to Dallas metro topology (see Fig. 3), with light-trail provision in response to 30% voice, 20% video and 50% data-traffic. Every node deploys the architecture shown in Fig. 1. The simulation assumed light-trails supporting line-rates at either 1 Gbps or 10 Gbps. Arrival requests assume a Poisson distribution and exponential holding times, unless otherwise stated. The results related to light-trails were compared to SONET/SDH, OBS (burst-switching), OBT (burst-transport). The abstraction of control and data is done through 12-bit VLAN ID (VID) field as earlier shown in Fig. 2. For the results, we use a simple routing heuristic described earlier, where from the list of all possible light-trails, a light-trail that yields the best OSNR (in terms of number of spans) at the end-node is chosen. As previously mentioned, if a request has to be routed through an existing light-trail, the OSNR of all already existing connections are taken into consideration.

![Fig. 3. Dallas Metro mesh](image)

![Fig. 4. Efficiency comparison](image)

![Fig. 5. Number of LTs and lightpaths](image)

Fig. 4 shows the results from an efficiency perspective as a function of load. The efficiency is computed as average time the system is busy in carrying useful data, while the load is computed as the ratio of total transmitted bits to line-rate. As can be seen in Fig. 4, there is almost 50% efficiency improvement over OBS, which is due to large switch configuration time in burst-switching with state-of-the-art switches, i.e., 5 ms per burst. The efficiency improvement is 30% over OBT, due to the time lost in system being idle while bursts are being aggregated, and 15% over SONET/SDH, due to TDM nature of SONET/SDH unable to facilitate dynamic services resulting in gross over-provisioning. Our simple routing scheme, where circuit requests are created every time over an existing light-trail, also shows a reduction in number of light-trails created as compared to the number of lightpaths created in WDM. Finally, Fig. 6 shows a comparison of our hitless routing algorithm as compared to an OSPF algorithm from an OSNR perspective for creation of light-trails. Since OSPF does not take physical-layer impairment into consideration, the OSNR (at the end-node) falls below the requisite (28dB) threshold that is necessary to maintain a BER of 10E-13, which is pre-requisite for communication at 10Gb speeds.

6. Conclusion
We have proposed a novel node architecture for light-trails in mesh metro networks based on Wavelength Selectable Switching (WSS) elements. Performance benefits achieved in comparison with SONET/SDH, OBS and OBT show a significant potential of our architecture and provides basis for future work.

7. References
3. Heavy Reading, ROADM and the Future of Metro Optical Networks [website]