Light-trails: Distributed Optical Grooming for Emerging Data-Center, Cloud Computing, and Enterprise Applications

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Abstract: Light-trails – generalized lightpaths – are used for provisioning emerging applications leading to the concept of spatial traffic grooming. We investigate the effects of this technology from the perspective of application support and transport.

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1. Introduction

Lightpath communication using point-to-point wavelength circuits dominated much of metro transport over the past two-decades. Meeting the needs of growing new and dynamic services are critical to the future of metropolitan and enterprise networks and include providing sub-wavelength communication, optical layer multicasting, and dynamic bandwidth allocation. SONET/SDH and its imminent replacement ITI-T G.709 OTN have solved many of these service requirements, but have been expensive because of the requirement to convert the signal to the electrical domain at every node, involving prototyping, emerging data-centric solutions such as Gigabit Ethernet with Carrier Ethernet manifestations of PBB-TE and MPLS-TP or the IEE802.17 resilient packet rings, though lower cost than SONET/SDH, are plagued by efficiency and operational expenditure issues. What is needed is an optical layer solution that can meet the demands of emerging services and application. The thrust of keeping the data in the lower layers is critical both from an energy saving and an OPEX reduction perspective. We consider the issue of spatial traffic grooming using the well-investigated light-trail [1] approach. Section 2 highlights the spatial grooming approach. Section 3 focuses on comparison with existing technologies. Section 4 discusses application scenarios and Section 5 presents results of our studies in using light-trails for comparison to other technologies.

Fig. 1. Light-trails and Lightpaths.

2. Spatial Grooming: The Light-trails Approach

Light-trails are a generalization of a lightpath – a lightpath is a point-to-point optical circuit, while a light-trail is a multipoint-to-multipoint unidirectional wavelength bus. What enhances light-trails are their ability to support dynamic bandwidth allocation, optical layer multicasting, sub-wavelength spatial grooming at low price-points using contemporary technology. At one level, a light-trail is a semi-permanent unidirectional optical bus, on which nodes can communicate by forming dynamic connections. Connection provisioning does not require nodal reconfiguration, implying no optical layer switching and thereby is most suitable for dynamic scenarios. Connections cannot overlap in time. Thus light-trails offer a time-shared and spatially groomed connection provisioning mechanism. Due to time-sharing, each node in the light-trail has access to only a fraction of the total wavelength bandwidth, implying sub-wavelength grooming. Further, since the light-trail grooming solution is disjoint – nodes are located at different spatial locations – we refer to such kind of grooming as spatial grooming.

To facilitate a light-trail, every node must be able to support drop-and-continue, passive add, and burst-mode-optics features. The first two features, drop-and-continue and passive add, are essential for the formation of a wavelength bus, while the last feature, burst-mode optics, facilitate efficient time-sharing of the bus. At the node level, the creation of a wavelength bus is done by the use of passive couplers with disproportionate coupling ratios (for example 80:20 or 90:10 power splitters and combiners) [1-3]. Burst-mode optics has been prevalent in the access (FTTH) industry and is deployed to make best use of a connection grant. To effectively time-share the bus bandwidth, we make use of the optical supervisory channel – an out-of-band (OOB) control channel that is optically

Fig. 2. Node architecture for Light-trails (Ring Networks).
dropped at each node, electronically processed and reinserted back into the emanating fiber from a node. The light-trail flow is regulated between the start and end nodes by using an ON/OFF switch, in the OFF position. This switch is maintained in the ON position at intermediate nodes to facilitate bus function. Switching is seldom as the light-trails are semi-permanent – created ahead in time as a response to a statistical traffic model optimization process.

The above architectures are depicted in Fig. 2 for ring networks and Fig. 3 for mesh networks. It is particularly to be noted that all the elements are essentially contemporary. Apart from using burst-mode optics, the nodes in a light-trail also have to store data. Conventional continuous mode transponders are hence modified to support burst-mode transponders that also have fast memories. These burst-mode transponders with built-in memory are called trailponders. For efficient time-sharing, the light-trail deploys an arbitration protocol through the control channel. The light-trail bandwidth itself is time-slotted, and slot sizes are comparable with a (small) integral multiple of the SONET slot (125 microseconds). Nodes send their requests to the end node (through the OOB control channel), and the end node intimates (using a separate control channel) which node should transmit in the next timeslot. The arbitration and slot-allocation process is hence done out-of-band and ahead in time. The separation of control and data planes conserves efficiency at the data-layer [4].

3. Coexistence with popular technologies

This spatial grooming can coexist with other popular technologies, especially from a transport perspective.

Light-trails with OTN: ITU-T G.709 Optical Transport Network is becoming an important standard in the industry for transport across metropolitan and core networks. The OTN hierarchy is perfectly suited to WDM providing per-channel OAM&P capabilities while enabling good reach and significant intra-channel grooming. OTN technology fits directly in a light-trail network. Connections can be provisioned either as OMS or OCh payloads. This is a slight departure from traditional point-to-point systems, where only the OMS is sent into the fiber. However, in the case of light-trails, we can send either the OMS or the OCh. If we choose to terminate the signal at the OCh itself, then the OMS becomes the spatially groomed bus – implying that multiple connections, each sending their OCh form the light-trail. The multiplicity of connections results in a distributed OMS. We must note that, since connections are time-differentiated, the signal is stored in the light-trail trailponder.

Light-trails with Carrier Ethernet: The dominance of SONET/SDH is being continuously eroded by the advent of Carrier Ethernet. Both flavors of PBB-TE and MPLS-TP are being explored by providers. Light-trails are excellent candidates for provisioning Carrier Ethernet. Ethernet Switched Paths (ESPs) can be set up as connections over a light-trail infrastructure. The critical design modification required for the support of Carrier Ethernet is the support of OAM&P features. Since connections are time-shared, care must be taken to ensure that the time-slotted light-trail is designed such that no two slots for a node are separated beyond the maximum allowable time for that node.

4. Application Scenarios

A few applications described below will find applications of light-trails appealing.

Cloud Computing and Computational Grids: computing requires movement of data-chunks across the network. The light-trail feature of dynamic bandwidth provisioning is intrinsic to the success of cloud computing and grids [5]. Moreover, the light-trail apparatus allows instant connection formation and fast virtual topology changes – both features essential for cloud computing. Dynamic bandwidth provisioning is essential for virtualization, while optical layer multicasting is a feature that is well used for resource consolidation.
Storage Area Networks: The application of Light-trails for SAN applications is natural. Time-sharing through dynamic bandwidth provisioning has been used for SAN applications as a wavelength resource conserver. The optical layer multicasting feature allows concurrent writing of data into both primary and secondary sites. The light-trail architecture as shown through simulations provides significant wavelength reduction – useful for SANs.

100 Gigabit Support: For supporting serial 100Gbps as well as parallel PHY and the work in the P802.3bg group, there is a need for smart data add/drop. The light-trail architecture through the bus-support readily enables smart adding and dropping of data at high line-rates without the need for electronic conversion at intermediate nodes.

Video on Demand (VoD): The dynamic bandwidth allocation feature when coalesced with the sub-wavelength granularity support is an excellent source for VoD applications. No new CAPEX or OPEX is needed for support of VoD support when we use a light-trail based backhaul infrastructure.

5. Performance of light-trails under Applications
In this Section, we report on a simulations study showcasing the benefits of spatial grooming using light-trails. The simulation was performed over a 64 node arbitrarily connected mesh network. Line-rates were assumed to be at 1Gbps and 10Gbps. Trailpanders could store 5 ms of data. Time-slots were assumed at 300 microsecond duration. Load was computed as the average amount of data in the network to the maximum capacity divided by the average hop-count (over all source-destination pairs). Fig. 4 depicts results of the light-trail protocol as compared to SONET, OTN and MPLS-TP. Note that light-trail protocol despite optical time-sharing performs better than all others implying wavelength (CAPEX) savings. Fig. 5 depicts comparison of energy consumption for the 64-node network with 16 channels and 10Gbps line-rates. Light-trails perform about 45% better than the next best (Carrier Ethernet) and 130% better than SONET/SDH. Fig. 6 tests the dynamic bandwidth allocation – how quickly can the protocol react. SONET/SDH outperforms light-trails at low loads, but at medium to heavy loads, the light-trail solution is able to hold its performance to within 3 ms – resulting in about 35% average improvement over SONET/SDH. We define grooming efficiency as how well the channel can be used and showcase the same for light-trails, SONET/SDH and GigE in Fig. 7. While the OEO based SONET/SDH and light-trails perform neck-to-neck at low and medium loads; the light-trail solution performs slightly better at very high loads.

6. Conclusion
We have showcased the benefits of spatial grooming as a transport solution for metropolitan and core networks. The light-trail technology as a spatial grooming solution is justified through simulations from an efficiency, energy consumption, response and spatial grooming perspectives.

References