GROOMING TELECOMMUNICATIONS NETWORK: OPTIMIZATION MODELS AND METHODS

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ABSTRACT

The rapid expansion of the use of internet in the last decade has been made feasible largely by optical networks with high bandwidth and consistency. This paper explores the meaning of grooming, the methodological context in which it can be applied. An innovative nomenclature incarcerates useful aspects of grooming problems and is used to review publications on traffic-engineering and optimization problem class. The paper proposed an efficient traffic grooming model for all optical networks. The model has low complexity and it can be easily implemented for traffic grooming problems.

1. INTRODUCTION

The challenge of creating cost-effective and efficient designs for telecommunications networks is often complicated by conflicts in the “low-level" activities of circuit routing and channel assignment. Grooming techniques can address such conflicts and substantially enhance the effective capacity of a given transport system. Grooming is useful in order to improve bandwidth utilization and optimize network throughput by a procedure of efficiently multiplexing and de-multiplexing different wavelength channels (Zhu et al., 2003b).

1.1. Definition of the term “grooming”

Grooming has drawn closer a range of different meanings from different scholars within the telecommunications industry and literature. The cited examples replicate this diversity.

Weston-Dawkes and Baroni (2002) converse about grooming architectures, in the context of mesh networks, using optical switches (OSs) and optical cross connects (OCXs) as “a strategy for the placement of intermediate grooming sites, routing of traffic, and rules for how often traffic is groomed as it traverses the network.”

Dutta and Rouskas (2002) delineate grooming in WDM (wavelength-division- multiplexing) networks as “techniques used to combine low-speed traffic streams onto high-speed wavelengths in order to minimize the network-wide cost in terms of line terminating equipment and/or electronic switching.”

Cinkler (2003) describes grooming as combining traffic streams to carry a more data and distinguishes between end-to-end (sub-rate) and intermediate (core) grooming. He further examines traffic grooming, wavelength, grooming and defines hierarchical grooming as the combination of both.

Zhu and Mukherjee (2003) define traffic grooming in WDM optical networks as the bundling of “low-speed traffic streams onto high-capacity optical channels” and concur with Barr and Patterson (2001) that “grooming is a term used to describe the optimization of capacity utilization in transport systems by means of cross-connections of conversions between different transport systems or layers within the same system.”

Zhu et al. (2003) explore “next-generation optical grooming switches” and their impact on network throughput and network resource efficiency.
They define traffic grooming as “a procedure of efficiently multiplexing/de-multiplexing and switching low-speed traffic streams onto / from high capacity bandwidth trunks in order to improve bandwidth utilization, optimize network throughput, and minimize network cost.” They further affirm that “traffic grooming is an extremely important issue for next generation optical WDM networks to cost-effectively perform end-to-end automatic provisioning.”

Consequently, a compromise is reached describing telecommunication grooming as the optimization of network transmissions that span multiple distinct transmission channels or methods. Grooming can occur within multiple layers of the same technology or between technologies. Grooming can be performed when signals are bundled for extended-distance transmission and when cross-connection equipment converts signals between different wavelengths, channels, or time slots.

Hence, Bennett, 2002, stated that grooming is more than assigning time-slots or optimizing traffic routing. Grooming is complex routing, and often implicitly assumes bundling or multiple capacities or multiple layers of transmission.

In a conceptual sense, grooming is a complex multi-commodity network flow problem with multiple transmission layers, each having its own set of constraints related to hops, distance travelled, speed of travel, capacity, etc.

Network grooming is repeatedly described in the framework of a particular technology, such as SONET, WDM rings, and WDM mesh networks (Zhu and Mukherjee, 2002).The vital constituent for a telecom network transport problem to be called "grooming" is that there are multiple layers of transport within the system. The domino effects of grooming uphill struggle comprise:

- Altering circuits' channels and time-slot assignments,
- Eradicating wavelength-continuity and distinct-channel assignment constraints on a few or all circuits,
- Improving capacity utilization,
- Escalating the number of functional routing possibilities and
- Simplifying the problem by staling it into easier component to solve associate problems (Barr and Patterson, 2001).

2. An innovative nomenclature of grooming problems

Grooming of telecommunications networks involves optimizing an interrelated set of functions or problems. These signal-routing and traffic-engineering functions are abridged in the subsequent *CASER* of nomenclature grooming activities:

Confederate lower-speed signal units into higher-speed transport units. Examples: aggregating a set of T-1 demands into ATM cells at an access node and combining a set of ATM cells into a SONET frame.

Assigning of demand units to transmission channels (e.g., time-slots, frequencies, wavelengths) within a given transport layer. Examples: assigning demands to SONET time-slots (TSA) and assigning WDM light paths to specific wavelengths on each span of a given mesh or ring network.

Switching signals between channels in the same transport layer. Examples: employing Time-Slot Interchange (TSI) within a SONET ADM to rationalize time slots of transitioning traffic and using an optical cross connect (OXC) to change light paths' wavelengths at a transitioning node or to toggle both time-slot and wavelength for a given signal.

Establishing/ Introducing lower-speed signal units to form transitioning higher speed units. For example, using an add drop multiplexer (ADM) or BDCS to terminate a lower-rate (sub-wavelength) SONET demand.

Routing demand units between their origins and destinations. Examples: determining the OD path that each OC-3 or DS-0 demand will follow and creating a set of light paths in an optical network for a given demand matrix.

Grooming research concentrate on different CASER subsets, where the acronym is used to categorize the various models and approaches.

3. Multiplexing and Bundling

The motivation for grooming springs from the application of multiplexing and bundling, techniques that combine multiple traffic streams into composite, higher-speed transport units (Doverspike, 1991). Multiplexing is the simultaneous transmission of different messages over the communication network through a partitioning of the available bandwidth or other resources.

Optical networks make use of three types of multiplexing, each of which can be viewed as partitioning a given resource into a set of separate resources (Stern & Bala, 1999):

Space-division multiplexing (SDM) - the partitioning of physical space to increase transport bandwidth. For example, bundling a set of fibers into a single cable or using several cables within a given network link.

Frequency-division multiplexing (FDM) - partitioning the available frequency spectrum into a set of independent channels. The use of FDM within optical networks is termed (dense) wavelength-division multiplexing (DWDM or WDM) which enables a given fiber to carry traffic on many distinct wavelengths (λ- channels). WDM divides the optical spectrum is into coarser units, called wavebands, which are further divided into λ-channels.

Time-division multiplexing (TDM) - dividing the bandwidth's time domain into repeated, fixed-length time-slots. Using TDM, multiple signals can share a given wavelength if they are non-overlapping in time.

Clearly, a given optical network can use all three multiplexing and bundling techniques to transport traffic. From a top-down, de-multiplexing, and partitioning viewpoint, network links consist of cables of bundled fibers, each fiber uses WDM to carry multiple wavelengths, each with several wavebands made up of multiple λ-channels; the λ-channels may carry many separate signals through the application of TDM. From a bottom-up, multiplexing point of view, separate signals can be combined via TDM to create channels that are grouped into wavebands, each of which is transported via one of many WDM wavelengths in a fiber; fibers are bundled into cables, and each network link can represent multiple cables.

The motivation for multiplexing is simple. Most messages take only a fraction of the bandwidth available. By multiplexing the communications network, multiple smaller messages can be sent simultaneously over the same transmission medium, often in opposite directions, thus increasing the capacity utilization and driving down the cost per message transmitted.

4. Routing and Channel Assignment for Light paths

Point-to-point, origin-destination connections (ODs) are routed over optical networks through light paths, logical circuits transported from origin node to destination node via one or more fiber links. In wavelength-routed networks without conversion equipment, light paths are established by assigning a distinct channel (e.g., wavelength) to the circuit and ensuring continuity of the channel from source to destination. These wavelength-continuity and distinct-channel assignment (DCA) constraints require that the connection be carried on the same wavelength on all links in the light path. Similar constraints apply to other bandwidth partitions in FDM networks, time-slots in TDM designs, and λ-channels in waveband-routed networks.

Light path routing and channel-assignment (RCA) for all ODs in a given network can be a computationally challenging problem (Day & Ester, 1997; Mukherjee, 1997) because of the wavelength-continuity and DCA constraints. Moreover, these two rules of operation can lead to channel conflicts and contention, even with optimized designs. These conflicts can result in stranded, Unused, and unusable capacity (both working and spare) and limitations on wavelength reuse. It is the goal of grooming to minimize such inefficiencies.

The hypothetical optical network model shown in Figure 1 illustrates the potential impact of the wavelength continuity and DCA constraints (Betts, 1998). Each span has an identical capacity of 3λand there is a demand of 1λ between the following origin- destination node pairs: 1-4, 2-4, 4-6, 3-5, 6-5, and 2-6.

Within the tree topology, the routing for each demand is unique and there is sufficient aggregate capacity on the spans to accommodate all O-D circuits. However, not all of the demands can be assigned to one of the three λ-channels available on each link. O-D 1-4 cannot be accommodated; hence the routing and channel-assignment problem and the overall design are infeasible. One solution is to add one additional λ of capacity on links (1, 2), (2, 3), and (3, 4) to accommodate this circuit, giving an overall capacity utilization of 13/18 = 72.2%.

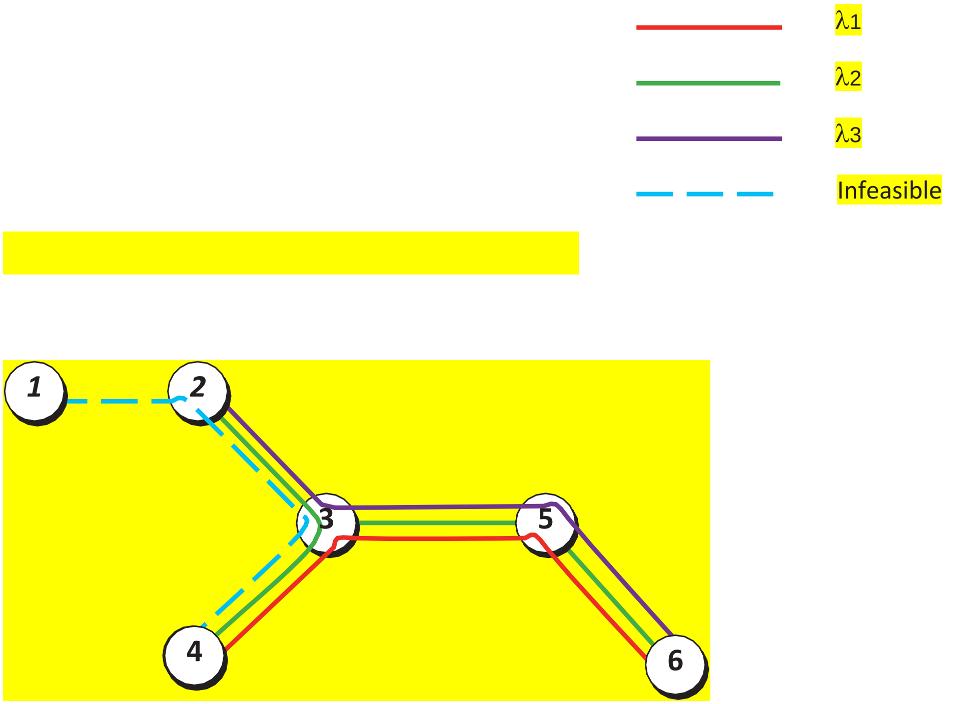


Figure 1: Unroutable 1-4 traffic due to wavelength-continuity constraints (barr and Pettersons 2001, Betts, 1998).

5. Synchronous optical networking

Synchronous optical networking (SONET) and Synchronous Digital Hierarchy (SDH) are standardized protocols that transfer multiple digital bit streams synchronously over optical fiber using lasers or highly coherent light form light emitting diodes (LEDs). At low transmission rates data can also be transferred via an electrical interface. The method was developed to replace the Plesiochronous digital hierarchy (PDH) system for transporting large amounts of telephone calls and data traffic over the same fiber without synchronization problems.

An advantage of SONET is that it is synchronous, or precisely timed. This allows individual channels to be accessed and manipulated without breaking down the SONET frame. An initial problem with SONET, though, was that it used fixed-sized VTs were often a mismatch to formats other than T-1, resulting insufficient or unused capacity in the SONET frame when lower-speed signals were mapped.

Fortunately SONET evolved to include enhanced mappings of other formats (such as ATM) by cleverly working around the fixed boundaries. The first was virtual concatenation whereby VTs could be connected to carry higher-speed inputs. The Generic Framing Procedure defines how to more efficiently map and groom a wide variety of lower-speed signals, including ATM and Ethernet, into a SONET frame. The Link Capacity Adjustment Scheme defines how to dynamically adjust the capacity on SONET links dynamically. SONET also uses DCSs that allowed for regional grooming but also introduced a new type of equipment called the add-drop multiplexer (ADM). The ADM allowed adding or dropping lower-speed signals at intermediate locations along a route with less equipment than previously required and by function also became a grooming point.

6. WDM NETWORK

WDM network design can be divided into two sub-problems: Network design and Routing and Wavelength Assignment (RWA) problem.

Network design involves physical topology and configuration design. The physical topology of a WDM network consists of Network Access Station, Optical Cross Connects (OXC), and fiber links. Each access station is equipped with transmitters and receivers to transmit data from or receive data to multiple data sources such as terminal equipment, or local sub-networks. OXC can route the optical signal coming in on a wavelength of an input fiber link to the same or different wavelength in an output fiber link. Since transmitters, receivers, and OXCs are expensive, each network access station may be equipped with only limited amount of these devices. Physical topology design is to determine the number of Optical Cross Connects (OXC), transmitters and receivers and their interconnectivity in order to provide low-cost and efficient networks.

Logical topology of WDM network is the topology viewed by higher layers such as SONET, ATM, IP. Logical topology consists of network nodes and light paths. A light path is a logical all-optical connection associated with wavelengths established to satisfy data communication requests between source node and destination node. In WDM networks without wavelength converter, a light path must be assigned same wavelength along all the fiber links it traverses. In an N-node network, if each node is equipped with N-1 transmitters and receivers and if there are enough wavelengths on all fiber links, then every node pair can be connected by an all-optical light path. The logical topology design is to determine how to set up light paths to accommodate all traffic demand while make optimal use of network resources.

Once the physical topology and logical topology are decided, we need to map the light paths to physical topology and assign wavelengths to them. Routing and Wavelength Assignment (RWA) problem is to set the routes of light paths need to be established on a given network and allocate wavelengths to these light paths so that maximum number of light paths may be established. Depending on static traffic or dynamic traffic request, there are two kinds of RWA problems, static RWA problem and dynamic RWA problem. Static RWA problem is used to solve static light path allocation problem, in which the number of light path and traffic pattern is known a priori. Static traffic is usually for long haul backbone networks. However, with the development of technology, optical networks become more popular. Besides the static setup light paths in long haul optical networks, individual or companies may need to lease light paths for temporary use of crucial traffic. These light paths will need to be allocated dynamically upon requests.

7. Asynchronous transfer mode

Asynchronous Transfer Mode (ATM) is a technology and related protocols that accepts multiple streams of data in many different formats, converts them to packets and statistically multiplexing them together into cells. Placing the different streams of information within an ATM cell is accomplished using virtual circuits whereby permanent or semi-permanent logical connections are set up in the network which are used as long as they are needed and then automatically torn down. In other words, it is a “soft” connection (rather than hard-wired) through the network for transferring multiple formats simultaneously.

To avoid individual packet inspection for routing, ATM is based on label switching, where cells with a common destination are assigned a label that the ATM switch uses to reference a routing table to determine the outgoing port and associated link on which the cells will be transferred. ATM uses encapsulation of input data streams (such as IP) and provides the overhead with labels to communicate the information that it provides.

ATM uses two labels: the Virtual Circuit Connection (VCC), which identifies the connection endpoints and the Virtual Path Connection (VPC), which identifies a bundle of VCCs with the same endpoints. It is at the VPC level where grooming is accomplished (Grover, 2004). When an ATM switch receives cells, it looks at the cells’ VPC/VCCs as well as incoming streams from other ATM switches, combines those with common endpoints (labels) and assigns new labels to new cells that are going to other switches, a technique referred to as label swapping. ATM is “virtual” in that streams going to many locations are aggregated using labels and share common links while being switched to other locations when the commonality diverges.

8. Generalized Multiprotocol Label Switching (GMPLS)

GMPLS is a family of IP-based control plane protocols devised within the Internet Engineering Task Force (IETF), and intended to offer an advanced and uniform control plane for a variety of network technologies from packet switching networks, through layer 2 and time-division multiplexing (TDM) networks, to lambda and fiber switching. Significant drivers for the development of GMPLS were advances in wavelength-division multiplexing (WDM) technology and the promise of a unified control plane for the new optical networks.

Because the protocols of GMPLS are extensions of IP/MPLS, and unlike traditional TDM transport protocols, can interact directly with IP and MPLS, allowing the transport network to be optimized for data-centric communication and even eliminating the use of ATM and TDM layers for the transport of IP over dense WDM (DWDM) networks. The promise was that with the new all-optical transparent lambda switches, the design of GMPLS carrier networks would be revolutionized.

The savings from simplifying operations, and the additional revenue from new on-demand optical services such as lambda on demand and optical virtual private networks (VPNs) would be reason enough to cut over from traditional transport networks to this brave new world.

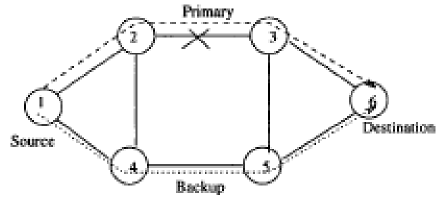
However, GMPLS is in direct competition with legacy proprietary protocols. This has created obstacles to deployment in several different ways; for example, the inability to upgrade legacy equipment, different technology requirements, and established operational procedures. One solution that has been proposed to overcome these obstacles is to utilize GMPLS within a network model where protocol interfaces are placed between network elements that use different protocols.

GMPLS defines five layers whereby labels and paths could be assigned: (1) the Packet Switching Capable layer, for IP, ATM, MPLS and similar streams; (2) the TDM-Capable layer, for older and SONET TDM systems components; (3) the Lambda (wavelength) Switching Capable layer, for wavelengths in WDM equipment and MPLambda S-type systems; (4) the Waveband Switching Capable layer, for grouping and assignment of multiple wavelengths; and (5) the Fiber Switching Capable layer, for assigning wavelengths to groups of fibers.

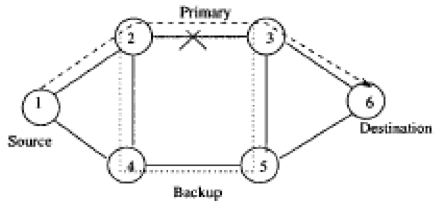
9. Grooming with Protection

Connection may also require protection from network failure, typically fiber cuts or duct cuts, which may cause large data and revenue loss. How to efficiently groom low-speed connections while satisfying their protection requirements becomes practically interesting and theoretically challenging. A path that carries traffic during normal operation is known as a *working* path. When a working path fails, the connection is rerouted over a *backup* path.

Fault-recovery capability is critical for optical networks, as a single failure may affect a large volume of traffic. There are generally two types of fault-recovery mechanisms, namely protection and restoration.



(a) Path protection



(b) Link protection

Fig 2 : Protection schemes

9.1 Protection: Protection aims at extremely fast recovery. The backup connection is established before the failure. Protection is classified into link protection and path protection.

9.2 Path Protection: In path protection, the source and destination nodes of each connection statically reserve backup paths on an end-to-end basis during call setup. The backup path must not share a common resource with its primary path. This requirement prevents a single failure from affecting both the backup path and the primary path.

9.3 Link Protection: In link protection, all the connections that traverse the failed link are rerouted around that link. In link protection, during call setup, backup paths and wavelength are reserved around each link of the primary path.

9.4 Restoration: Restoration dynamically establishes a connection to recover from a failure after the failure occurs. In path restoration, the source and destination nodes of each connection that traverses a failed link dynamically discover a backup route on an end-to-end basis, and in link restoration, the end-nodes of the failed link dynamically discover a route around the link, for each wavelength that traverses the link.

CONCLUSION

Although grooming has been issues in telecommunications network design since the invention of multiplexing, many are unfamiliar with the term.
It is the goal of this article to shed more light on network grooming, and demonstrate its importance and how the performance of all-optical network can be improved using an innovative acronym called CASER. CASER is introduced to incarcerate five key aspects of telecommunication network grooming problems: Confederate, Assigning, Switching, Establishing, and Routing.

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