# Energy-efficiency of Drop-and-Continue Traffic Grooming

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**Abstract:** This paper evaluates the energy-saving achievable by performing traffic grooming in WDM networks with drop-and-continue node architecture. Different grooming strategies are compared in terms of network performance and energy usage.

**OCIS codes:**

## 1. Introduction

An energy-efficient management of WDM networks has the potential to reduce the network operational expenditures (OPEX) as well as the impact on the environment. The energy-efficiency can be achieved by limiting the number of devices that are active [1] and through a careful traffic engineering. A solution to reduce the number of active devices is to aggregate (or groom) the traffic in the intermediate nodes, to fill up the wavelength capacity.

Although potentially effective for energy saving purposes, traffic grooming may require the installation and activation of additional devices for adding and dropping local traffic, which may lead to an increase of the power consumption. Moreover, typically traffic grooming is achieved by exploiting optical-electrical-optical (OEO) conversion of the bypassing signal. This grooming solution is well known to be power thirsty [2].

To overcome the latter issue, this paper considers a WDM network where traffic grooming is achieved by sharing the optical connections, or lightpaths, and optically dropping the local traffic [3]. The rationale is that expensive and power-consuming electronic devices are not required in the intermediate nodes if traffic needs only to be dropped (i.e., not added). In this way, lightpaths can be shared by connections towards different destination nodes and can be dropped locally at the intermediate (destination) nodes, having drop-and-continue (DAC) architecture.

Energy-efficiency of a dynamic WDM network with DAC nodes is explored in this paper. The aim is to estimate the energy-effectiveness of traffic grooming performed using DAC paradigm. To achieve this goal, different traffic grooming strategies and the relation between network performance and power consumption are evaluated.

## 2. Drop-and-Continue Node Architecture

Consider a WDM network whose nodes are optical cross-connects (OXC) with drop-and-continue (DAC) functionalities. In DAC optical cross-connects, the incoming optical signals can be split unequally. Thus, a fraction of the optical power can be dropped (e.g., by using passive devices called tap-and-continue) and processed electronically, while the remaining power can continue to travel all-optically to the next node with negligible degradation. In this paper, we assume that the power loss that a lightpath may experience as it passes through a sequence of nodes can be optimally compensated. DAC architecture allows an available lightpath to be shared by connections whose destinations are intermediate or end nodes of the lightpath. Different strategies can be used for grooming the different connections on the same lightpath.

## 3. Lightpath-based Grooming (LBG)

By exploiting DAC nodes, a lightpath-based grooming (LBG) grooming can be achieved by transmitting connections destined to different destinations on the same lightpath and by dropping such lightpath in the intermediate (destination) nodes. The principle of LBG algorithm is based on the auxiliary graph [3], whose links represent the (existing, potential, potential extended or sub-) lightpaths, referred to as optical links, and the grooming capability of the node, referred to as grooming links. The LBG algorithm consists of two separate routines, namely, *SetupRequest* and *TeardownRequest*. The *SetupRequest* routine establishes a new auxiliary graph for each new connection request. Each graph represents the current status of the network. The *SetupRequest* finds the shortest path between the requested node pair. On the other hand, the *TeardownRequest* routine is performed when a request is completed. The following steps are taken when *TeardownRequest* is executed. *Step 1*: The connection is removed from all lightpaths carrying the request. *Step 2*: All wavelength links which are inactive an do not carry any requests are removed. In case all wavelength links on a lightpath are inactive, the entire lightpath will be removed. *Step 3*: The network state is updated in order to represent the latest available resources.

An incoming connection request is routed according to the shortest path from its source to destination node in the auxiliary graph. The weight of the links in the auxiliary graph is determined based on the grooming strategy. The considered LBG strategies are:

- *Minimize the number of logical hops (MinLH)*, i.e., minimize electronic processing of the connection requests. Optical links in the auxiliary graph have same weight.
- *Minimize the number of physical hops (MinPH)*, i.e., maximize the wavelength utilization. Optical links in the auxiliary graph have weight equivalent to the number of physical hops between the source-destination node pair.
- *Minimize the number of new lightpaths (MinNL)*, i.e., minimize the number of transmitters and receivers. Optical links representing the existing and potential extended lightpaths are assigned lower weight than new lightpaths.
- *Minimize the number of physical hops on lightpaths carrying the request (MinTH)*, i.e., maximize the wavelength utilization. Optical link weight is equivalent to the number of physical hops, including the ones beyond the destination node.

In case of multiple shortest paths at equal weigh, the route with the least number of physical hops is selected. When limited resources are available, the above LBG strategies lead to a different utilization of the network resources and, thus, to a different level of network performance, in terms of request blocking probability, and energy consumption.

## 4. Performance Analysis

Network performance in terms of blocking probability and energy consumption have been evaluated in the 14-node NSF network with $L = 21$ bidirectional links. Each link supports $W = 4$ wavelengths in each direction, operating at rate, $C_w$ corresponding to OC-192. Network capacity is, thus, $2 \times L \times W \times C_w$. Connection requests are generated dynamically, following a Poisson process with uniform distribution among the node pairs. Rate of connection requests, $C_d$, is uniformly distributed among OC-3, OC-12, or OC-48 rates. Each node is equipped with 4 transmitters and 4 receivers. The power consumption of the grooming module (transmitter or receiver, including the E/O and O/E) is 160 W/module. This figure is based on the power consumption of the Cisco Catalyst 6500 series published in [5]. We assume that all unused modules (i.e., not processing traffic) are in idle mode and consume negligible amount of power. Results of the different LBG strategies (namely MinLH, MinPH, MinNL, MinTH) are compared against the traditional grooming mechanism, based on OEO conversion in the intermediate nodes, i.e., where no drop-and-continue capabilities (NoDC strategy). NoDC requires that nodes are equipped with hybrid OXC.

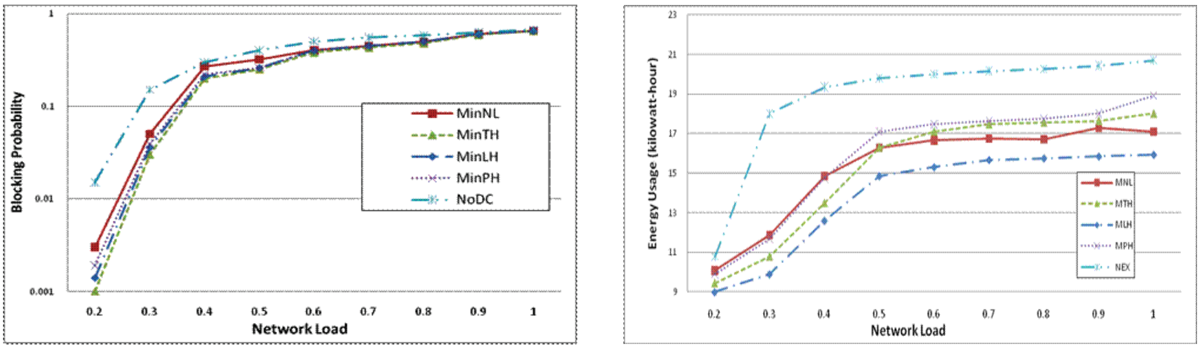

Fig. 1. Blocking probability (right) and energy usage (left) vs. load.

Fig. 1 (left) displays the blocking probability experienced by the different strategies as a function of the load, when the overall network load varies from 20% to 95% of the network capacity. This figure shows that in the presence of a

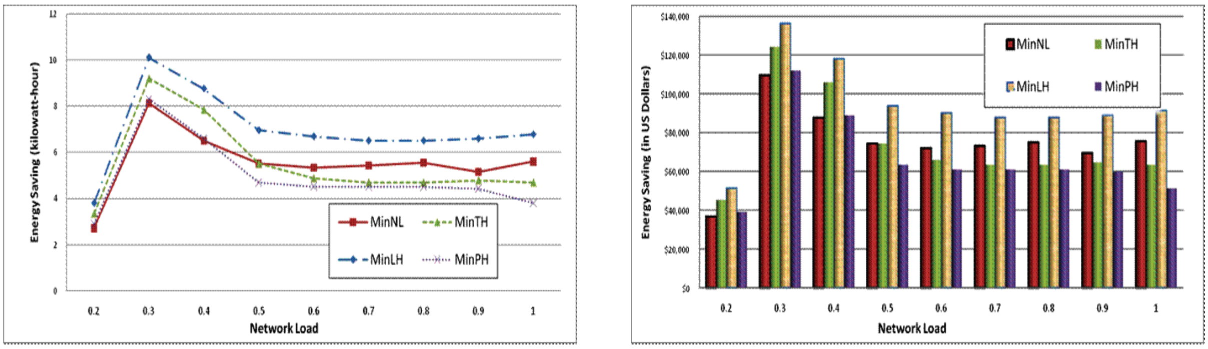

Fig. 2. Energy saving of the different strategies in kW/h (left) and in dollars (right).

limited number of receivers and transmitters, applying drop-and-continue can improve the overall blocking probability when compared to NoDC, regardless of the grooming strategy. Moreover, the results indicate that the best performance is achieved using MinTH. Among the proposed LBG strategies, the poorest performance is achieved by MinNL. This happens because MinNL attempts to use available resources before establishing new lightpaths.

Fig. 1 (right) evaluates total energy usage in kilowatt-hour and compares the considered LBG strategies with NoDC strategies. It is interesting to compare the blocking probability against the energy efficiency. Higher blocking probability leads to a lower effective load, so intuitively it would be expected that the best performing strategies in terms of blocking may drain higher energy for the same (requested) load. Instead, NoDC experiences both a high blocking and a high energy consumption as the traffic grooming is performed by exploiting the traditional, power-hungry OEO conversion. Among LBG strategies, MinNL strategy experiences a high blocking and high energy consumption, making this strategy unable to efficiently groom the traffic on the lightpaths. On the other hand, MinLH appears as the best performing strategies, from the point of view of both network performance and energy consumption.

Fig. 2 shows the annual energy saving of networks with DAC nodes (i.e., LBG strategies) with respect to the networks with traffic grooming based on OEO (i.e., NoDC strategy). Energy saving in kW/h and in dollars are displayed on the left and right side of Fig. 2, respectively. It must be mentioned that in calculating the energy savings, the power consumption for cooling (e.g., air conditioning the building) is not accounted. Furthermore, it is assumed that the electronic switch fabric is always fully active, independently from the traffic load. We believe these two assumptions make the energy saving results very conservative. Significant energy saving of up to 10 kW/h (i.e., 80%) can be achieved by exploiting DAC architectures. Assuming a rate of 11 cents/kWh, the energy saving can result in considerable cost saving per year. For example, the annual OPEX saving using MinLH, with relatively competitive blocking probability, at medium to high loads (0.5 to 0.9) is about $90,000 on average.

## 5. Conclusion

The main motivation for this study was to understand energy-saving benefits using drop-and-continue technologies and the impact of the different strategies. Network performance and power consumption of different grooming strategies for WDM network with DAC nodes were compared.

The results indicate that, in general, when the number of tributary transmitters and receivers is limited, lightpath-based grooming using drop-and-continue technologies can perform better in terms of blocking probability. Furthermore, the proposed lightpath grooming policies can also offer a significant energy saving and OPEX reduction. Among the strategies, the minimization of the logical hops is the best performing strategy that can achieve both low blocking probability as well as minimal energy consumption.

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