Energy Efficient Grooming of Scheduled Sub-wavelength Traffic Demands

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Abstract: We investigate how awareness of demand holding times can be exploited for energy efficient traffic grooming in optical networks. We present an optimal formulation for minimizing the energy consumption of a set of scheduled demands.
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1. Introduction

The tremendous growth in high-bandwidth applications and devices used in backbone networks has led to a corresponding increase in power consumption. In this context, it is extremely important to utilize the available power efficiently [1,2]. The goal is to reduce both the static and dynamic (load dependent) portions of power consumption as much as possible, although static power consumption typically dominates for most network components [3]. Therefore, the typical approach has been to switch off some components such as line cards and router ports during low demand periods. Traffic grooming techniques that minimize the number of active router ports and/or line cards have been proposed minimize energy consumption of the network.

In this paper, we investigate how awareness of demand holding times can be exploited for energy efficient grooming in optical networks. We present an integer linear program (ILP) formulation that minimizes both the static and dynamic components of power consumption. Static power consumption is reduced by routing sub-wavelength traffic demands in a way that minimizes number of active router ports (corresponding to active lightpaths carrying some non-zero traffic). Dynamic power consumption is reduced by minimizing the amount of electronic switching required for each demand.

2. Energy efficient grooming of scheduled demands

We adopt the power model given in [4], which can be expressed as

$$P_{total} = \sum_{l \in L} (P_0 + p_t \cdot t_l) \quad (1)$$

where L is the set of active lightpaths, P_0 corresponds to the static power consumption for a lightpath $l \in L$, p_t is the additional power needed for each traffic unit carried on l, and t_l is the traffic on lightpath l.

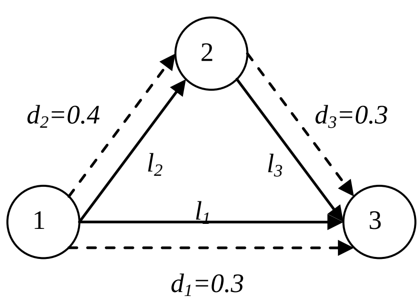

Figure 1(a). Logical topology and traffic routing.

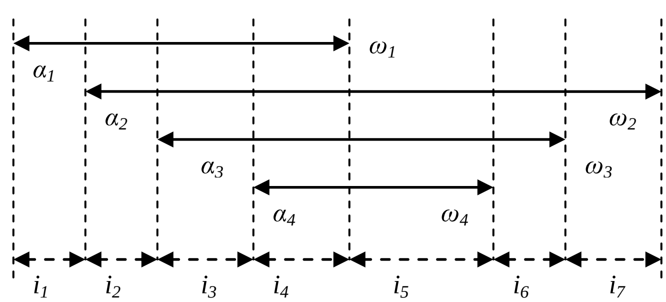

Figure 2(b). Overlapping demands.

In order to see how knowledge of demand holding times can be exploited to obtain more power efficient grooming, we consider the network of Fig. 1(a), which shows three logical edges (corresponding to active lightpaths l_1, l_2 and l_3) and three demands d_1, d_2 and d_3, which are routed over these lightpaths. In the figure, the lightpaths are shown as solid lines and the routes for each demand are shown as dashed lines. The bandwidth requirement for each demand is expressed as a fraction of the lightpath capacity. Fig. 1(b) shows the start time (α_i) and end time (ω_i) corresponding to each demand d_i, including a new demand d_4. Based on the start and end times of the demands, the entire time period of interest can be divided into a number of consecutive time intervals i_1, i_2, i_3, ... i_{max}, as shown in

Fig. 1(b). For our example there are *7* such intervals. Now, suppose the new demand d_4, with bandwidth requirement of 0.4 is to be routed from node *1* to node *3*. It is possible to route d_4 in two ways: 1) using only lightpath l_1, or 2) using lightpaths l_2 and l_3. In either case, there is no change in static power consumption (no new lightpaths are needed), but option 1 requires somewhat less energy, since it avoids additional electronic switching at node 2. However, when we consider the demand holding times, we see that if d_4 is routed over l_2 and l_3, then l_1 can be switched off from time ω_1. On the other hand, if d_4 is routed over l_1, then l_1 must remains active until ω_4. Since switching off a lightpath, reduces the *static* power consumption, routing d_4 over lightpaths l_2 and l_3, results in significant energy savings. In general, by appropriately choosing the routes of the scheduled demands, we can ensure that the number of *active* lightpaths at any given time is minimized, leading to considerably reduced energy requirements. We note that our approach does not require reconfiguring the optical switches etc, since the lightpaths are not rerouted. The ports for an existing lightpath are simply turned off, when there is no traffic on the lightpath.

In our formulation, we are given a set (Q) of scheduled sub-wavelength demands to be routed over a logical topology $G(N,L)$, where N is the set of nodes and L is the set of logical edges (lightpaths). At any given time a lightpath $l \in L$ is *active*, if it is carrying some non-zero traffic. The router ports of an *inactive* lightpath may be switched off to reduce energy consumption. We use the following notation in our ILP:

- P_o: traffic independent portion of power used for a lightpath
- p_t: additional power consumed by a lightpath for each traffic unit carried
- T_i: duration of interval i
- i_{max}: total number of intervals
- $r_{q,i}$: a parameter given as input to the ILP and set to 1 if demand q is active during interval i
- α_q (ω_q): start (end) time of demand q
- $s_q(d_q)$: source (destination) node of demand q
- t_q: traffic corresponding to demand q
- $o(l)$ ($e(l)$): originating (terminating) node for lightpath l
- g: the capacity of a single lightpath
- $\gamma_{l,i}$: a binary variable which is set to 1 if lightpath l is active during interval i
- $x_{q,l}$: a binary variable which is set to if demand q is routed over lightpath l

The ILP formulation given below calculates the optimal routing for each scheduled demand that is needed to achieve the minimum overall energy consumption.

$$\text{Minimize } \sum_{i=1}^{i_{max}} P_i \cdot T_i \tag{2}$$

Subject to:

$$\sum_{l:o(l)=j} x_{q,l} - \sum_{l:e(l)=j} x_{q,l} = \begin{cases} 1, if\ j = s_q \\ -1, if\ j = d_q \\ 0, otherwise \end{cases} \quad \forall j \in N, \forall q \in Q \tag{3}$$

$$\sum_{q \in Q} t_q \cdot x_{q,l} \cdot r_{q,i} \le g \cdot \gamma_{l,i} \qquad \forall l \in L, i = 1,2...i_{\max} \tag{4}$$

$$x_{q,l} \le \gamma_{l,i} \qquad \forall i, \alpha_q \le i \le \omega_q \tag{5}$$

$$P_i = \sum_{l \in L} \gamma_{l,i} \cdot P_o^l + \sum_{l \in L} \sum_{q \in Q} t_q \cdot r_{q,i} \cdot p_t^l \cdot x_{q,l} \qquad \forall i, i = 1,2...i_{\max} \tag{6}$$

The objective function (2) minimizes the weighted sum of the total energy consumption during each interval. Since each interval i is weighted by its corresponding duration (T_i), the ILP tries to ensure that a lightpath remains inactive as long as possible. Constraint (3) is the standard flow equation used to find a route for each demand. Constraint (4) ensures that the total traffic on a lightpath, during any interval, does not exceed its capacity g, and no traffic is routed over an *inactive* lightpath. Constraint (5) states that if demand q is routed over lightpath l, then l must remain active for the entire duration of the demand. Finally, (6) calculates the total power consumption corresponding to all active lightpaths during interval i. The first term represents the static power consumption and the second term calculates the load dependent component, based on the traffic on each lightpath.

3. Results and conclusions

We conducted our initial experiments on a 6-node network. The logical topologies were constructed based on the approach outlined in [5]. We calculated the average number of active lightpaths in each interval and the total energy consumption (both static and load dependent components), for different sets of scheduled demands with varying amounts of overlap among the demands. We classified the demand sets as having low, medium and high demand overlap (referred to as LDO, MDO and HDO respectively), as defined by the demand overlap factor (δ) [6], for each demand set. The demand overlap factor characterizes the amount overlap among a set of demands and varies between 0 (no two demands overlap with each other in time) and 1 (all demands overlap in all intervals). The average values of δ for the LDO, MDO and HDO sets were $\delta = 0.05$, $\delta = 0.28$, and $\delta = 0.5$ respectively, and for each case the results were compared the *holding time unaware* (HTU) case, which corresponds to $\delta = 1$. As shown in Fig. 2, it is possible to get significant energy savings (7% - over 40%), by utilizing knowledge of the demand holding times. The improvements over the HTU model increases steadily as the demand overlap factor decreases. We note that the overall improvement in energy consumption closely follows the reduction in the number of active lightpaths. However, some additional savings are obtained by proper routing of the scheduled demands as well. We are currently conducting experiments with 10-node and 14-node topologies and the preliminary results follow the same pattern as for the 6-node network.

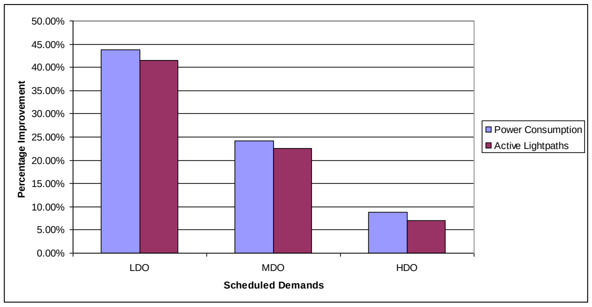

Figure 2. Percentage improvement in total power consumption and the average number of active lightpaths compared with HTU case for 6-node network.

In this paper, we propose a new formulation for energy efficient traffic grooming of scheduled sub-wavelength demands. We note that our approach differs significantly from most existing energy-aware traffic grooming approaches, which consider holding-time-unaware demands and attempt to design a logical topology that minimizes energy consumption. Typically, this reduces to a formulation that minimizes the number of lightpaths (assuming static power consumption dominates the load dependent component). The formulation presented in this paper, on the other hand, assumes that the base logical topology is already given. It exploits knowledge of connection holding times to route the demands in a way that allows the maximum number of lightpaths (from the specified base topology) to be switched off at any given time.

4. References

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