Energy-Efficient Opaque IP over WDM Networks with Survivability and Security Constraints

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Abstract: Mixed deployment of sleep-enabled and non-sleep-enabled router cards is suggested at each node of an IP over WDM network along with survivability and security constraints. This is used to design a green network which is observed to reduce energy consumption (by up to 28% for an example network) compared to a network where the router cards are not sleep-enabled.
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1. Introduction

The ever-increasing volume of Internet traffic requires more and more network equipments resulting in high energy consumption in the network. As stated in [1], reducing the energy consumption in communication networks is driven both by ecological motivations towards reduction of CO_2 emissions as well as economic ones, in order to keep operational costs (OPEX) down by reducing electricity consumption in the network. This has motivated several research efforts towards the design and implementation of energy-efficient networks. A common approach for achieving higher energy efficiency is to turn off network devices selectively when they are not needed or put some of them into a sleep mode (low power state) when the traffic falls below a certain predetermined threshold [2, 3]. However, this strategy can create problems when network survivability and security are important. Turning off network devices can impact the network's overall connectivity and this in turn would have a negative impact on network survivability [2]. Moreover, enabling software control to turn off network devices or put them into a sleep mode may also lay the network open to hostile attacks, i.e., a hostile attacker can turn off or put to sleep a large part or even all of the network devices in order to paralyze the entire core IP over WDM network. It should also be noted that network devices which can be put into a sleep mode are generally more expensive than devices which do not have this feature and using the former will increase the overall network cost. Therefore, designing an energy-efficient IP over WDM network will imply tradeoffs between the network's energy consumption, cost, and its survivability and security.

IP routers in an IP over WDM network are generally considered to be both the most energy-hungry [4] and the most expensive. Therefore, the network device that we focus on in this paper is the IP router. We also assume that the power consumption of a router's line cards constitute the total power consumption of the IP router [5 6]. Viewing the traffic day-night pattern and considering the additional requirements of network survivability and security, we configure a mix of sleep-enabled router cards and non-sleep-enabled router cards at each network node, where some or all the sleep-enabled router cards may be put to sleep to save energy when the network traffic is low.

2. Network model

We consider traditional point-to-point (P2P) IP over WDM optical network (i.e., *opaque* IP over WDM network [7]). In the opaque IP over WDM network, IP traffic should be groomed and forwarded in the electronic domain by router at every intermediate node. This network configuration is also referred to as a lightpath non-bypass network.

Unlike earlier studies, we measure the energy consumption of both types of routers based on the router line cards instead of router ports. Note that a core router is designed to be modular, and a modular router line card typically contains several router ports (e.g., a Cisco CRS-1 four-port OC-192c POS card contains four router ports) [8]. Thus, it is more practical to put a router card to sleep and measure energy consumption based on the router cards instead of independently putting router ports to sleep and measure energy consumption based on the router ports. The condition applied is that a router card can sleep only if all its router ports are free of traffic; otherwise, the card has to be active. In addition, we neglect the power consumption of a router card when it is sleeping and assume that it always consumes a fixed amount of power, regardless of the number of router ports that are active, when it is not in the sleep mode.

3. Design Strategy for a Green Network

In this section, we discuss how to design a green (i.e., energy-efficient) IP over WDM network which jointly considers network cost, energy consumption, and network survivability and security using a mix of sleep-enabled and non-sleep-enabled router cards at each node.

3.1 *Network Cost and Energy Consumption*

We assume that there are two kinds of router cards, i.e., non-sleep-enabled router cards and software controlled sleep-enabled router cards. Non-sleep-enabled router cards do not have the capacity to sleep for energy saving. Thus, they must be active all the time regardless of the diurnal traffic variations and will consume fixed energy in a period (e.g., one day). In contrast, sleep-enabled cards can be put to sleep under software control when they are free of traffic so that energy can be saved. It is also not surprising that the sleep-enabled router cards are more expensive because of their higher complexity and software cost.

The IP traffic variations follow a day-night pattern as shown in Fig. 1. This allows sleep-enabled router cards to be put to sleep when the traffic demand is low. It may be noted that the traffic load is not zero even during time slots when the traffic demand is the lowest, i.e., some nominal traffic will still be present even during such times. This implies that it is not feasible to put all the router cards at a node to sleep at those times, i.e., some router cards will still have to be kept active. Thus, we can configure these cards as non-sleep-enabled cards for cheaper cost. We can use this property to have a mix of sleep-enabled and non-sleep-enabled router cards at a node where only the sleep-enabled cards are put to sleep when the traffic demand is low. Such a mix strategy will keep network costs low but still allow energy efficient operation of a network node.

In our earlier work [6], we found that in a P2P IP over WDM network where several router ports are typically grouped (located) on a common router card (four router ports are assumed per card in this paper), router ports allocated to carry traffic between a given node pair can affect the sleeping opportunity of router cards and will affect the overall energy consumption in the network. Thus, we need to properly consider the actual allocation of router ports for the energy efficient design of an IP over WDM network.

3.2 *Network Survivability and Security*

Using software controlled sleep-enabled router cards in the IP over WDM network will save energy consumption. However, this may have negative effects on network survivability and security. Specifically, because of software-controlled sleeping, any bug in the software on the control plane may provide access to hackers to attack the core IP over WDM network (e.g., by putting router cards to sleep even when that should not be done). This can be tackled by using a mixed configuration of sleep-enabled and non-sleep-enabled router cards at each node in the network because the non-sleep-enabled router cards cannot be put to sleep even under the software attacks. This approach will also be useful from the viewpoint of network survivability and security.

In this paper, we enforce the rule that, in any time slot, *r* percent of the traffic demand between each node pair must be carried on non-sleep-enabled router cards in order to ensure network survivability and security. This ensures that even if all the sleep-enabled router cards are forced to sleep because of a hacking attack, the green IP over WDM network will still be able to function properly.

We employ the mixed integer linear programming (MILP) technique to solve the above problem. However, the details of the mathematical MILP model are not presented here because of space limitations.

4. Numerical results

We assume that the traffic demand varies according to the day-night pattern [9] shown in Fig. 1. This pattern is approximated to be a simple sinusoidal function as $\lambda^{sd,t} = \lambda^{sd}[\frac{1-\rho}{2}(1 + sin\,(f_0(t-8))) \; + \rho]$, where $f_0 = \frac{\pi}{12}$. We set $\rho = 0.2$, which means that the lowest traffic demand is equal to 20% of the peak-hour traffic demand. In addition, for different node pairs (*s, d*), we control the maximum traffic demand between them (i.e., λ^{sd}) to be a random variable uniformly distributed within a given range. Based on the shortest path routing algorithm, a traffic grooming process is applied on each link. The capacity of each wavelength and router port is assumed to be 40 Gb/s. To evaluate energy consumption, we assume that each active sleep-enabled router card and non-sleep-enabled card consumes one unit of energy per hour and subtract from this the power consumption of router cards which are sleeping. The six-node eight-link n6s8 network and 14-node 21-link NSFNET network are considered as our test networks as shown in Fig. 2.

Fig. 3 shows the energy consumption in a day for the n6s8 network when *r*=60%; here, 60% of the traffic between each node pair must be carried on non-sleep-enabled router cards to ensure that at least 60% of the traffic can be transmitted properly even under hacking attack scenarios where all the sleep-enabled router cards have been put to sleep. We compare the results of (i) non-sleep case (i.e., all router cards are non-sleep-enabled cards) with (ii) sleep with the mixed configuration. Comparing with the results of the non-sleep case, we can see that the mixed configuration, which employs the cards based on the sleep strategy, can save as much as 28% energy in a day even if we force 60% of the traffic to be carried on non-sleep-enabled cards so as to ensure network survivability and security. The MILP model can also be solved for large networks such as the 14-node 21-link NSFNET. Fig. 4 shows the energy consumption in a day for the NSFNET network. Similar observations can be concluded for the network and up to 27% energy can be saved in a day compared with the non-sleep case.

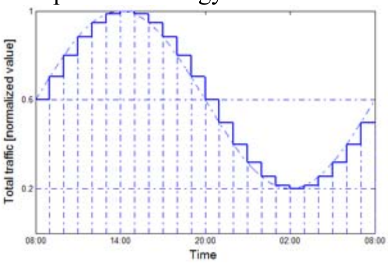

Fig. 1. Daily traffic pattern.

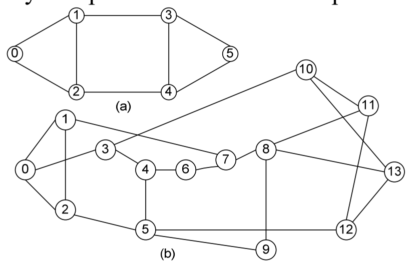

Fig. 2. Test networks: (a) n6s8 network; (b) NSFNET network.

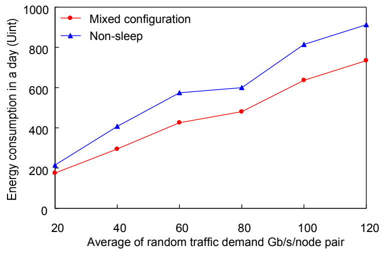

Fig. 3. Total energy consumption in a day for the n6s8 network.

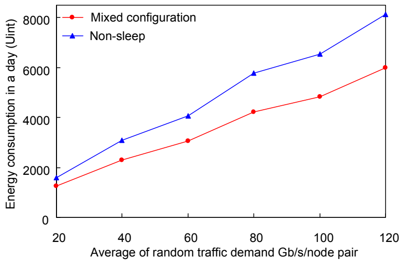

Fig. 4. Total energy consumption in a day for the NSFNET network.

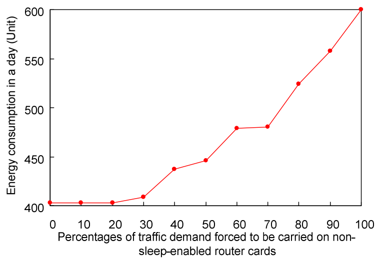

Fig. 5. Energy consumption in a day with different percentages of secured node pair capacity (n6s8).

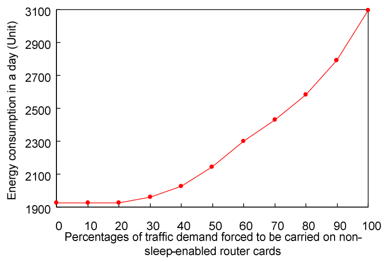

Fig. 6. Energy consumption in a day with different percentages of secured node pair capacity (NSFNET).

As discussed earlier, there is a tradeoff between network cost, energy consumption and network survivability and security when designing a green IP over WDM network. Fig. 5 shows the energy consumption in a day where different percentages of traffic demand are forced to be carried on non-sleep-enabled router cards for the n6s8 network. We can see that the network consumes less energy in a day when smaller percentages of traffic demand are forced to be carried on the non-sleep-enabled cards. This would, however, increase network costs (CAPEX) and decrease the network survivability and security as more sleep-enabled cards would be deployed in the network. In addition, the network consumes the same energy in a day when the percentages of traffic demand forced to be carried on non-sleep-enabled cards are below 20%. This is due to the traffic model used in the MILP model, where we set the lowest traffic demand to 20% of the peak-hour traffic demand. This leads to the fact that 20% of traffic demand between each node pair is always active all the time and this traffic should be carried on the non-sleep-enabled router cards no matter how many percentages of traffic demand which is below 20% required carried on non-sleep-enabled cards. Thus, any percentages of traffic demand below 20% forced to be carried on non-sleep-enabled cards will consume the same energy. The NSFNET network performs similarly as shown in Fig. 6.

5. Conclusion

We configure a mix of sleep-enabled and non-sleep-enabled router cards at each node to design a green IP over WDM network which can still ensure network survivability and security. Simulation results based on some test networks indicate that the proposed method can save up to 28% energy consumption even when 60% of traffic demand between each node pair is forced to be carried on non-sleep-enabled router cards to ensure network survivability and security compared to the situation where only non-sleep-enabled router cards are used.

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