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Power-aware provisioning strategy with shared path protection in optical WDM networks

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ABSTRACT

As the Internet continues to grow, the power consumption of telecommunication networks is rising at a considerable speed, which seriously increases the operational expenditure and greenhouse gas emission. Since optical Wavelength Division Multiplexing (WDM) networks are currently the most promising network infrastructures, power saving issue on these networks has received more attention in recent years. In traditional optical WDM networks, a large amount of power is drained by the redundant idle resources and reserved backup resources although these powered on resources do not carry traffic in most of the time. In order to reduce the network power consumption, turning off the corresponding network components or switching them to a low-power, standby state (or called sleep mode) is a promising greening approach. In this paper, we study the power-aware provisioning strategies and propose a sleep mode based Power-Aware Shared Path Protection (PASPP) heuristic algorithm to achieve the power efficiency of optical WDM networks. By jointly utilizing link-cost and fiber-cost in path routing, resource assignment, and resource release, PASPP makes working paths and backup paths converge on different fibers as much as possible, and switch idle and backup components to sleep mode to realize power saving. Simulation results show that our PASPP can obtain notable power saving and achieve satisfactory tradeoff between power efficiency and blocking probability with respect to Power-Unaware Shared Path Protection (PUSPP).

1. Introduction

As the Internet service requirements continue to increase dramatically, a large amount of network equipments with larger capacities, higher transmission rates, and faster processing speeds are introduced into the telecommunication networks [1], which leads to serious rise in power consumption, operational expenditure, and greenhouse gas emission. In broadband enabled countries, the Internet consumes about 4% of total electricity consumption or even more as the access rate increases [2]. The importance of power efficiency of telecommunication networks has been acknowledged by many international standards organizations, such as ITU (International Telecommunication Union), IEEE (Institute of Electrical and Electronics Engineers) and ETSI (European Telecommunication Standard Institute) and relevant standardization works for power-efficient networks are ongoing in different technology areas [3]. Since optical Wavelength Division Multiplexing (WDM) networks are currently the most promising network infrastructures, power saving issue on these networks has received more attention in recent years [4]. A general greening approach for optical WDM networks is, by considering various network states and different service provisioning demands, selectively turning off the redundant and/or underloaded resources, or switching the idle and/or backup protection resources to low-power, standby state to improve the network power efficiency and reduce the operational expenditure.

1.1. Previous work

In recent years, some power-aware service (or: connection) provisioning approaches have been proposed to achieve power efficiency for optical WDM networks.

In order to minimize the power consumption in optical networks, authors in [5] propose an Integer Linear Program (ILP) formulation of Power-Aware Routing and Wavelength Assignment (PA-RWA), as well as two PA-RWA heuristic algorithms, to make maximum usage of powered on devices and turn off additional idle devices. Another PA-RWA heuristic algorithm is proposed in [6],

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which improves the power efficiency of optical networks by reducing the number of optical amplifiers in active as much as possible, where a load factor is formulated for link cost adjustment. However, both [5,6] do not consider protection requirements.

Authors in [7] consider shared path protection issue and propose a static and offline heuristic algorithm to optimize the power consumption of optical networks, which, under a pre-assumed network traffic load, selectively switches off as more optical fibers as possible and reroute the influenced connections (including both working lightpaths and backup lightpaths) on the residual powered on fibers in the optical networks. In [8], an ILP formulation is proposed for power-efficient dedicated protection problem, where a low-power and inactive state, named sleep mode, is used to reduce power consumption of devices in optical WDM networks. That is the reserved backup resources can be put into sleep mode and woken up upon a failure occurrence. In [9], another ILP formulation is proposed to minimize both wavelength capacity consumption and power consumption, where the traditional backup sharing constraint is formulated and the sleep mode is used to the reserved backup resource. Although the ILP formulations proposed in [8,9] can obtain the optimal solution in their given scenarios, they are of computational complexity and are not viable for large networks.

Authors in [10] proposed a power-aware and sleep mode based heuristic algorithm for dedicated path protection in WDM networks, which starts with an initialization phase to pre-compute a large number of working and backup path candidates for any possible source and destination node pairs. For each connection request, this algorithm assigns various power-cost to each link within several selectable values according to the network state and chooses the least cost paths among the pre-computed path candidates as the power-efficient working or backup paths. However, the solution proposed in [10] is not a complete dynamic solution, since the complex and time consuming initialization phase may make it lack of flexibility and scalability when network topology changes for network components failing down or network expanding.

1.2. Motivation

According to the literature aforementioned, all of these connection provisioning approaches can achieve visible power efficiency in their given scenarios respectively, in which two basic instruments are used to save power. That is: (1) turning off idle network components – off mode, (2) switching idle and/or backup resources into low-power and standby state – sleep mode.

For off mode used in [5–7], redundant or idle network components are selectively turned off for power saving. However, repowering on and/or reload these network components is time consuming, which may sometimes decrease the network connectivity and cause longer connection routes and higher blocking probability especially under a sudden increasing network load. It means that the off mode is just profitable for static connection provisioning and stable network environment.

As currently the most important network infrastructure, optical WDM networks provide enormous bandwidth capacities. Any outage of network components (fibers or OXC/Optical-Cross-Connects) may lead to tremendous data loss and severe traffic blocking. Therefore, for survivability purpose, a large amount of resources are reserved as backup resources to guarantee the protection of the networks against failures. When a working path is interrupted by a failure, the corresponding backup path should be timely switched to working state. For the sleep mode used in [8–10], the idle and/or reserved backup resources in sleep state can be woken up promptly if needed. This mode can also effectively achieve power efficiency and can accommodate dynamic connection provisioning and variable network environment.

In this paper, we consider a dynamic and online connection provisioning strategy and propose a sleep mode based Power-Aware Shared Path Protection (PASPP) heuristic algorithm to achieve the power efficiency of optical WDM networks. By jointly utilizing link-cost and fiber-cost in path routing, resource assignment, and resource release, PASPP makes the working paths and the backup paths converge on different fibers as much as possible, and switch idle and backup components to sleep mode to realize power saving. Simulation results show that our PASPP can gain notable power saving and achieve satisfactory tradeoff between power efficiency and blocking probability with respect to Power-Unaware Shared Path Protection (PUSPP, i.e. sleep mode based SPP).

The rest of this paper is organized as follows. Section 2 illustrates PASPP and PUSPP by a simple example, and presents the network model and the power consumption model. Section 3 gives fiber-cost and link-cost adjustment, resource assignment and release, and algorithm procedure and complexity analysis. Section 4 provides the simulation results and analysis. The main results are concluded in Section 5.

2. Problem statement

2.1. A simple example for PASPP and PUSPP

In survivable optical WDM networks, by using sleep mode, power-aware connection provisioning with shared path protection can achieve visible power efficiency. Here, we use an example to compare PASPP with PUSPP in terms of resource utilization and power consumption.

As shown in Fig. 1, there is an optical WDM network topology. We assume that each link contains just one fiber with three bidirectional wavelength channels and the link cost is equal to one (hop). Each node has full wavelength conversion capability. Four connection requests are to be provisioned in this network. In this example, we only consider the power consumed by fibers. The power consumption of a single fiber in active state is assumed as 1 power unit, and the power consumption of a single fiber in sleep state is considered negligible. Before the first Connection Request (CR) arrives, all network components are in sleep mode.

In Fig. 1a, four Connection Requests ($CR_{3\text{-}2}$, $CR_{12\text{-}3}$, $CR_{3\text{-}8}$, $CR_{10\text{-}7}$,) are provisioned by PUSPP, where a shortest path algorithm, such as Dijkstra's algorithm, is used to compute the link-disjoint Working Path (WP) and Backup Path (BP) pairs for each CR respectively. We can see in this figure that the WP is always the shortest path and the BP is always the shortest path link-disjoint to its corresponding WP for each CR. According to conventional shared path protection rule, (BP_2 and BP_3) and (BP_2 and BP_4) can share common wavelengths on link 3-6 and link 5-12 respectively, since their corresponding WPs are link-disjoint. For these four CRs, the number of wavelength links assigned for WPs is 10, the number of wavelength links assigned for BPs is 12, and the power consumed by active fibers is 10 units in total.

As a comparison in Fig. 1b, the same four CRs are provisioned by PASPP. However, for routing WPs the primary objective is not the shortest distance but the least increment on power consumption and the second objective is to make the distance as shorter as possible. In this figure we can see that PASPP encourages WPs to traverse the active fiber links as much as possible according to the primary objective which leads WP_1, WP_2, and WP_3 to converge on the links of 2-5, 3-6, and 5-6. For CR_4, although path 10-2-5-12-7 can reuse two active fiber links 2-5 and 5-12, the increment of power consumption is same to path 10-1-7 and the latter one is much shorter. So, according to the second objective mentioned