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Energy-aware traffic engineering with reliability constraint

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ABSTRACT

Current network infrastructures are over-provisioned to increase their resilience against resource failures. Such strategies exhibit poor energy efficiency during off-peak periods. In this respect, energy aware Traffic Engineering (TE) solutions aim to maximally switch off redundant network resources when traffic load is low. However, these green TE solutions do not consider their effects on network fault-tolerance. In this paper, we first aim to quantify the effects of five recently proposed green routing approaches, namely FGH, GreenTE, MSPF, SSPF, and TLDP, on the following two reliability measures: (i) terminal reliability (TR), and (ii) route reliability (RR). Experiments using three topologies with real and synthetic traffic demands show that green approaches that switch off redundant links affect TR and RR significantly. Specifically, routing traffic through multiple paths impacts reliability less while reducing energy, especially when the paths are link disjoint. Interestingly, TLDP and MSPF have better route reliability than using shortest path (SP) routing. We then formulate a problem, called reliable energy-aware-routing (R-EAR), which aims to maximally switch-off network cables subject to link utilization as well as TR/RR requirement. We also propose an effective algorithm, called reliable Green-Routing (R-GR), to solve R-EAR. Evaluation on three real topologies shows that R-GR can save energy while satisfying both reliability and link utilization requirements. Specifically, for the GEANT network, R-GR saves up to 25.65% in energy usage without reducing RR, and saves up to 48.65% whilst reducing its average RR only by 9.1%. For the same network, our solution achieved an energy saving of 28.38% while reducing its average TR by only 8.5%.

1. Introduction

In the past two decades, new and popular Internet applications, such as electronic commerce, voice over IP, social networking, have emerged on the Internet [1]. Some emerging applications, such as online banking and health care services, are business critical and time sensitive and therefore require a high degree of network reliability [2]. In this context, network resiliency, i.e., the ability to recover quickly and smoothly from resource failures or disruptions is a key concern in modern IP networks. Consequently, commercial carriers, e.g., AT&T, BT and NTT, routinely set network reliability as a critical performance objective when deploying communication services. This is in addition to network usability and fault processing capabilities [3]. While over-provisioning resources to provide backup paths and conducting route restoration using traffic engineering (TE) help improve reliability, these solutions exhibit poor energy efficiency, especially when the traffic load is low.

Recently, reducing energy consumption has become an important part of networking research, especially when recent reports [4,5] show that the energy consumption of Internet Service Providers (ISPs) has increased tremendously. As mentioned in [4], the projected 95 GW energy consumption rate by the ICT sector in 2020 will generate around 1.4Gt of CO_2. The authors of [5] projected that even small systems such as Akamai will consume $10 M worth of electricity annually.

To this extent, many green solutions [6–11] have been proposed to reduce the energy consumption of networks. Of particular interest are approaches such as [6] that consider line cards that have active/idle toggling capability, and are connected by multiple physical cables. In fact, as standardized by the IEEE 802.1 AX [12] these cables form one logical bundled link [13]; that is, the Medium Access Control (MAC) layer treats them as a single link. Evaluation on recently proposed energy-saving routing protocols, i.e., FGH [6], GreenTE [7], MSPF [8], SSPF [9], and TLDP [10], shows these protocols to be effective in saving energy. For example, when evaluated on the Abilene, GÉANT and Sprint topologies using both real and synthetic traffic, FGH [6], can save energy by up to 53.3%, 58.5%, 43.02% respectively. The aforementioned green approaches use TE to re-route traffic in order to maximally switch off network cables or links to minimize energy consumption. In addition to minimizing energy, they also aim to maintain network perfor-

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mance subject to constraints such as path length and/or maximum link utilization. Notably, none of them consider network reliability.

Our main contributions are twofold. First, we study the impact of switching off cables using five recent energy-aware routing mechanisms, namely FGH [6], GreenTE [7], MSPF [8], SSPF [9], and TLDP [10], on two important network reliability measures: (i) terminal reliability (TR), and (ii) route reliability (RR). The first reliability measure gives the probability of obtaining at least one operational path from a source (s_d) to terminal (t_d) for each demand d in the event of link failures. The RR measure on the other hand is the reliability of each selected path to route traffic in the event of link failures. As discussed in Section 5.2, the aforementioned five algorithms significantly reduce a network's TR, and thus significantly reduce the possibility of any path restoration in the event of link failures. The results in Section 5.2 also show the significant effects these algorithms have on a network's RR. We believe the results also hold for other energy-aware routing algorithms, and thus it is imperative that we incorporate reliability measures in green routing protocols. We remark that some of our preliminary results have appeared in [14]. In this paper, we extend [14] by proposing a new problem and its solution. We formulate the problem, called reliable energy-aware-routing (R-EAR), which aims to switch-off as many cables as possible to maximally save energy while maintaining the required level of TR or RR and maximum link utilization (MLU). To the best of our knowledge, we are the first to consider TR or RR measure while switching off unnecessary cables. Further, we propose an algorithm, called reliable Green-Routing (R-GR), to solve R-EAR. Our experiments in Section 5 show that R-GR can effectively guarantee TR or RR and MLU requirements while gaining significant energy savings.

The rest of the paper is organized as follows. Section 2 presents an overview of related publications, and Section 3 describes the network model and notations. It also includes an analysis of the manifestations arising from green routing. This analysis thus motivates the R-EAR problem. Section 4 describes our proposed R-GR algorithm. Section 5 evaluates the performance of R-GR using both real and synthetic topologies and data. Finally, Section 6 concludes the paper.

2. Related work

Lisnianski et al. [15] categorize network reliability optimization problems into two types: (i) achieving optimal network reliability subject to various constraints, and (ii) minimizing the resources needed to provide a specific network reliability level. Many studies, e.g., [16,17], work on problem of type (i) but they treat failure recovery and TE independently. Recently, some researchers, see [2,18,19], combine network reliability and TE. For example, Zhang et al. [18] integrate failure recovery with load balancing by rerouting a fraction of the traffic after a single edge failure. Ref. [19] proposes an architecture that uses local rerouting to handle up to F link failures subject to link capacity constraints, while the routing approach in [2] does not require link state flooding and dynamic router reconfigurations. However, all these publications do not consider energy consumption.

There have been a handful of publications on Energy-Aware Traffic Engineering (EA-TE). That is, given a set of traffic demand D, a number of green routing mechanisms [6–11] can be used to generate an energy-aware network G', whereby links/nodes from the original network G are switched off such that all demands in D are satisfied. The authors in [11] formulate the problem of energy consumption as multi-commodity minimum cost flow problems, and provide methods to switch off routers according to policies such as random, least link, least-flow and most-power. Fisher et al. [6] consider each core router in G is connected by a bundled link, and propose to turn-off redundant cables. Their solution, called FGH, re-routes traffic demands using only switched-on cables in G'. This, however, may affect network reliability as compared to using SP routing on the original network G. Zhang et al. [7] observed that network operators usually provide redundant network links and set a link utilization bound, e.g., 40%, to ensure fault-tolerance against network failures and congestion. They propose a power-aware traffic engineering algorithm, called GreenTE, to maximally switch off links while satisfying two performance constraints: maximum link utilization (MLU) and path hop count. The MSPF solution [8] generalizes FGH and GreenTE; it considers bundled links similar to FGH as well as the two constraints used in GreenTE. Lin et al. [9] propose another TE solution, called SSPF, which re-routes each demand using only a single path. They show that single path routing is attractive for its simplicity as well as significant energy savings. In [10], when a demand cannot be rerouted using a single path, the authors propose to reroute it using two-link disjoint paths to improve its throughput and fault tolerance. Note that the multiple paths used in FGH [6], GreenTE [7] and MSPF [8] may not be link-disjoint. While all solutions [6–10] are able to switch off a significant number of redundant links/cables to reduce energy consumption, none of them consider network reliability. In contrast, in this paper, we aim to switch-off as many cables as possible, to maximally save energy, while maintaining one of the following reliability measures: terminal or route. In addition, we consider MLU.

There are also recent studies [33–37] that aim to design energy-efficiency optical Wavelength Division Multiplexing (WDM) networks. In this regard, the work in [33] proposes an intelligent load control mechanism and an auxiliary graph model to overcome the blocking probability drawback while maintaining provisioning connections for optical networks. In [34] it is shown that when designing networks based on power consumption, careful attention should be paid to the trade-off between energy consumption and network performance in order to avoid an unacceptable level of network reliability. In [35], optimum solution to the energy-efficient network planning problem is proposed with the objective of minimizing the power consumption on WDM networks in which optical devices can be configured in sleep mode. The authors of [36] describe an energy efficient survivable connection-provisioning problem. The authors assess the potential power savings in a dynamic provisioning scenario, and explore the potential power savings achieved by deactivating protection resources. In [37], the authors compare four protection strategies, i.e., Dedicated-Link, Dedicated-Path, Shared-Link and Shared-Path, on IP-flow level. They [37] propose ILP formulations for a power-aware design of IP-Over-WDM networks for the four protection strategies. The proposed solution in the paper entails using devices capable of low-power sleep-mode as backup light paths. The authors in [41] propose an evaluation model on survivable power ratio and protection switching time, to show the effect of power saving on hybrid grooming. Two heuristics in the paper [41], called Single-hop Survivable Grooming with considering Power Efficiency (SSGPE) and Multi-hop Survivable Grooming with considering Power Efficiency (MSGPE) focus on traffic switching between different light paths for power saving. The authors in [42] propose shared backup paths protection in WDM network to reduce its power consumption while maintaining its survivability. In their model, either a backup link or path can be shared among different link-disjoint primary paths. However, these publications do not explicitly consider constraint on routing path reliability or terminal reliability that guarantees a given level of network reliability. Specifically, our work aims to generate routes that satisfy given reliability constraints for networks with known link failure rates. Further, in our case, the generated routes are not necessarily disjoint paths.