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Towards fast rerouting-based energy efficient routing

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The inefficiency of energy usage on the Internet has become a critical problem with its rapid growth, as all network devices operate at full capacity in spite of the real traffic load. Existing studies try to develop energy efficient routings by aggregating traffic and switching underutilized devices into sleep mode. However, most existing approaches do not address the problem of routing convergence well. Since traffic changes frequently in a network, routing convergence may be triggered frequently for an energy efficient routing, which may induce routing loops and black holes, resulting in severe packet loss. In this paper, we present a fast rerouting-based (FRR-based) energy efficient routing scheme, namely GreenFRR, which leverages the technique of fast rerouting to reduce the convergence time. We first study typical fast rerouting techniques and address the challenge of guaranteeing loop-free routing. Then, we formalize the FRR-based energy efficient routing problem and prove that the problem is NP-hard. In order to solve this problem, we design heuristic algorithms to maximize the number of sleeping links. In particular, we consider link utilization ratio and path stretch in our algorithms. We evaluate our scheme by simulations on real and synthetic topologies with real and synthetic traffic traces. The results show that the power consumed by line cards achieves a saving of 40% and the convergence time can be reduced by 95%.

1. Introduction

Building a greener world has become a global concern and energy conservation has become an important issue in many different areas such as building design and transportation. Saving energy in computer systems, e.g., data centers and the Internet, is also recognized as an inevitable trend [1–3].

Specially, the Internet has been growing rapidly since the inception and has become a big consumer for electrical energy. In the Internet, network equipments such as routers and switches consume the majority of electrical energy. For example, a Cisco CRS-1 router consumes as much as 1 MegaWatts in full configuration, about 10,000 times of a PC. By 2010, there were 5,000 CRS-1 routers deployed in the Internet [4]. The high energy consumption has motivated many studies on greening the Internet [5–9].

Some studies try to develop energy efficient routers for energy conservation in the Internet. They reduce the energy consumption of key components such as processors [10] and TCAMs [11]. However, deploying new equipments requires a long-term process. On the other hand, researchers find that the Internet is usually underutilized, so there is an opportunity to save energy without any modification in equipments. They aggregate the traffic to a few components and switch the idle routers (or part of the routers such as line cards) into sleep mode. Such a scheme is called an energy efficient routing.

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To address the issue of the energy efficient routing design, centralized and distributed approaches have been proposed. Centralized approaches [6,12] compute a green routing for each end-to-end path, and does not scale well. Also, centralized approaches have the problem of single point of failure. In distributed approaches [7–9], the sleeping nodes or links can be computed either centralizedly or distributedly, while the routing is computed on the remaining topology in each router distributedly, using a method similar to current routing protocols such as OSPF. Nevertheless, the sleeping or waking up of a link can trigger recomputing of the routing in distributed approaches. This process is well-known as the routing convergence, during which routing micro-loops and black holes [13] may be incurred. Routing micro-loops and black holes can cause severe packet loss and thus degrade the availability of the network. Existing energy saving approaches cannot address such an issue well.

In this paper, we aim at designing an energy efficient routing approach that scales well and can provide available rerouting paths quickly when a routing convergence is triggered. The key technique to achieve our goal is Fast ReRouting (FRR). FRR is originally developed to enhance network survivability. In FRR, backup rerouting paths are computed in advance. Once a failure is detected, packet are switched to the rerouting paths using tunnels or directed forwarding, and thus the disruption during a routing convergence is reduced. Some FRR techniques have become IETF standards [14–16] and been implemented by commercial routers. FRR has a great potential in energy efficient routing, since the sleeping of a node or link can be considered as a planned failure.

There are several challenges for designing fast rerouting-based energy efficient routing (GreenFRR). First, loop-free routing must be guaranteed. FRR is designed to guarantee a loop-free routing for single link or node failures, as most failures in the Internet are single failures [17]. In an energy efficient routing, however, multiple nodes or links may sleep simultaneously to minimize the energy consumption. Second, energy conservation should be maximized. This problem is difficult even with centralized computing [6], and is more complex when using FRR. Third, network performance parameters such as link utilization ratio and end-to-end delay should be co-considered.

We have done a comprehensive study in this paper to overcome the challenges. First, we study the FRR approaches, and develop the candidate rerouting paths that can provide a loop-free routing for energy conservation. Second, we model the FRR-based energy efficient routing problem formally, analyze some intrinsic properties, and prove the NP-hardness of the problem. Then, we present our distributed approach to compute GreenFRR routings. We develop an algorithm to compute all the candidate rerouting paths, and design a heuristic to select actual rerouting paths. Sleeping links are then selected distributedly while they guarantee link utilization constraints. In addition, we study the packet forwarding, and design an advanced approach to avoid rerouting path overlappings and reducing path stretches.

The proposed GreenFRR can achieve a high power save ratio by maximizing the number of sleeping links. Furthermore, the decision of switching a link into sleep mode is made locally, and only affect a few link loads. The routing converges much more quickly than existing approaches when a traffic change occurs. We evaluate our approach by simulations on synthetic and real topologies and traffic traces. The results show that we can save 30% to 40% of the power consumed by line cards and reduce the routing convergence time by 50% to 95%.

The rest of this paper is organized as follows. Section 2 summarizes the related work. A background of FRR is briefly reviewed in Section 3 and an overview of GreenFRR is presented in Section 4. Then, we formulate and analyze the problem in Section 5. Section 6 is dedicated to algorithm development, followed by discussions in Section 7. The evaluation is shown in Section 8. At last, Section 9 concludes the paper.

2. Related work

There are studies on saving energy in the Internet from different layers. Some studies reduce the energy consumption in layer-1 or layer-2. For example, there are studies on building energy efficient ethernet [18] or ADSL [19]. Some studies develop energy efficient TCP [20]. Beside them, many studies do energy conservations in the network layer. Some studies save energy from the equipment point of view. They carefully design and manage the key components in the network equipment, such as processors [10] and TCAMs [11], to produce energy efficient routers. Other studies save energy from the angle of the network, i.e., develop energy efficient Internet routing. Our work falls into the latter category.

Energy efficient routing can be achieved in either centralized or distributed ways. For centralized approaches, Zhang et al. proposed GreenTE [6], which uses a heuristic algorithm to solve a multi-commodity flow problem with the objective to effectively aggregate traffic and switch more network components into sleep mode. Kist et al. [21] proposed dynamic topologies and Cuomo et al. [22] proposed network pruning to save energy by topology control. They identifies underutilized router line cards by leveraging topological properties of the graph. Then, routing paths are computed after pruning these line cards. Kim et al. [12] proposed an ant colony based self-adaptive energy saving routing. Lee et al. [23] formulated an integer linear programming for an multi-topology and link weight assignment problem to save energy with loop-free routing table update. Amaldia et al. [24] proposed a mixed integer linear programming based algorithm to minimize the energy consumption by adjusting OPSF link weights. The centralized approaches have the problems of poor scalability and single point of failure. To address these issues, our approach computes in a distributed manner.

For distributed approaches, Vasic et al. [25] proposed REsPoNse, which identifies energy-critical and on-demand paths offline. Packets are delivered online to aggregate traffic and use sleep mode. Cianfrani et al. [7] proposed to enhance OSPF, enabling each router to select adjacent links for sleeping. Bianzino et al. proposed fully distributed algorithms in [8,9], where the routers select sleeping links