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B. Zhang
J. Shi
Univ. of Arizona
J. Dong
M. Zhang
Huawei
M. Boucadair
France Telecom
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Power-Aware Networks (PANET): Problem Statement
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Abstract

Energy consumption of network infrastructures is growing fast due to exponential growth of data traffic and the deployment of increasingly powerful equipment. There are emerging needs for power-aware routing and traffic engineering, which adapt routing paths to traffic load in order to reduce energy consumption network-wide. This document outlines the design space and problem areas for potential IETF work.

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1. Introduction

Driven by exponential growth of Internet traffic, networks worldwide are expanding their infrastructures at a fast pace by deploying more high-capacity, power-hungry routers, which also leads to increasing energy consumption. For example, in the US, the energy bill for powering the wired network reaches up to 2.4 billion dollars per year [[Doverspike10](#)]. Telecom Italia, the largest ISP in Italy, is now the second largest consumer of electricity after the National Railway system [[Pileri07](#)]. As one of the biggest energy consumers in the United Kingdom, British Telecom consumed about 0.7% of the entire nation's electricity in 2007 [[Bolla11](#)]. In Japan, predictions say that routers will consume 9% of the total electricity by 2015 [[Nakamura07](#)]. Besides operational costs and environmental impacts, the ever-increasing energy consumption has become a limiting factor to long-term growth of network infrastructure due to challenges in power delivery and heat removal for both router components and hosting facilities [[Gupta03](#)] [[Epps06](#)].

Traditionally energy efficiency is improved at the device level or the link level. For example, energy management techniques can be applied to adjust router CPU's power status or CPU frequency in response to different CPU workload; Links can be put to sleep mode when it has been idle for a while. More recently, there have been a number of research work that look beyond a single router or linecard for network-wide solutions towards energy proportionality.

The purpose of this document is to discuss the problem scope, outline potential approaches, and problem areas for IETF work on power-aware networks.

2. Motivation and Problem Scope

Today's ISP networks have redundant routers and links, over-provisioned link capacity, and load-balancing traffic engineering. As a result, routers and links operate at full capacity all the time

with low average usage, typically less than 40% of link utilization. This practice makes networks resilient to traffic spikes and component failures, but also makes networks far from energy-efficient.

Power-aware routing and traffic engineering have been proposed to improve network's energy efficiency, for example, by aggregating traffic onto a subset of links and putting other links with no traffic into sleep. Data from various sources (e.g., [[Heddeghem12](#)] [[Chabarek08](#)]) have shown that line cards are a significant source of router's power consumption, accounting for 40% - 70% of total power consumption. Most of the energy is consumed even in standby state,

and forwarding packets at full speed only increases the energy consumption by a small percentage. This implies that being able to put links into sleep mode can potentially save a lot of energy. In face, this has been demonstrated in several research works such as [[GreenTE](#)] [[Nedevschi08](#)] [[Chabarek08](#)].

Designing practical protocols, however, has been challenging, because making routing protocols power-aware brings significant changes to the routing system and the entire network, thus it involves hardware support, protocol design, network monitoring, and operational practices. These issues often depend on the specific network environments under discussion. In order to focus on protocol-related issues, we suggest that as the first step we limit the scope of the discussion to intra-domain routing within one administrative domain, to avoid inter-domain policy issues. This includes transit networks as well as edge networks. We leave data center networks out of this draft since that usually requires concerted efforts beyond network protocols.

[3.](#) Potential Solution Approaches

The high-level idea of power-aware networks is to adjust routing paths based on traffic level. When traffic level is high, use more links to carry the traffic; when traffic level is low, merge traffic onto a subset of all links so that other links can be put to sleep or reduce rate in order to save power. This needs to be done without significantly impacting network QoS, network resiliency, and interoperation with other protocols.

In the last few years a number of power-aware network designs have emerged. Instead of listing them individually, here we categorize the solutions along three different dimensions.

Link Sleep vs. Rate Adaptation

Sleeping and rate adaptation are two major ways to save energy in computer systems. Many hardware, including line cards and chassis, consumes a significant amount of power when they stand by without doing any actual work. When put into sleep mode, they will consume only a little power. Thus putting an idle component to sleep is a common way to save energy. If there is a need to use this component, it can be waken up and become usable after a transition time. The longer a component is in sleep mode, the more power saved. A power-aware protocol adjusts routing paths to increase the sleep time for certain links in the network.

A network interface often supports multiple data rates. Operating at a lower data rate usually consumes less energy, though the actual

rate-power curve varies from device to device. Rate-adaptation-based approaches operate interfaces at lower data rates when the traffic demand is low and increase the data rate when traffic demand is high. Thus the routers can save power during low utilization period.

These two approaches are also related in the case of "bundled links" [[Fisher10](#)]. A bundled link is a virtual link comprised of multiple physical links. A sleep-based approach can put some physical links into sleep to save power, which is same as conducting rate adaptation on the virtual link with adjustment unit of a physical link.

Configured vs. Adaptive

The key in power-aware routing and traffic engineering is to adjust routing paths in response to traffic changes, so that the power state of routers (or router components) will also change accordingly to achieve energy saving. Different approaches differ at the granularity of the adjustment.

Some approaches take the long-term traffic average as input, and output a routing configuration that is applied to the network regardless of short-term traffic variation. This is mostly useful

when network traffic exhibits a stable, clear pattern, e.g., diurnal pattern where traffic is high during work hours and low during off hours. It can only exploit the target traffic pattern; it cannot react dynamically to short-term traffic changes to either save energy (by putting links to sleep) or avoid congestion (by waking links up), but the design and implementation should be simple.

Another type of approach is to adapt to traffic changes dynamically on much smaller time granularity. This approach may be able to save more energy and have better performance because it is more responsive, but the design and implementation usually are more complicated. This approach needs to continuously collect traffic data in order to adjust routing dynamically. The adjustment may be done periodically or whenever significant traffic changes are observed.

Distributed vs. Centralized

In distributed solutions, routers make power-aware adjustment decisions, such as link sleep/wake-up and rate increase/decrease, locally without a central controller. These routers need to exchange information in order to achieve consistent network states. Distributed approach fits the Internet operation model well but its design is the most challenging. Traditional routing does not respond to traffic variation while power-aware routing does, and it needs to do so without causing loops or congestions.

In centralized solutions, a controller computes the routing paths considering the network topology and traffic demand, and informs routers how to adjust their routing paths. A centralized server usually has more complete information, more computation power, and more memory and storage than routers, thus it may make better decisions than distributed approach. The server locates in the network NOC and can be backed up by server replicas. Nevertheless, this approach requires high reliability of the server.

Both distributed and centralized solutions may find their places in ISP networks. For example, centralized solution can be integrated into the Path Computation Element (PCE) framework [PCE-WG]. There can also be hybrid designs, e.g., using a centralized solution based on long-term traffic pattern, and distributed mechanisms to handle short-term traffic variations.

[4.](#) Problem Areas for IETF

Power-aware networks have great potentials to improve network energy efficiency while maintaining network services at desired levels. Its effectiveness, however, depends on various supports from hardware and software, especially protocol designs that address operational issues. In this section we list a few problem areas that will benefit from additional input from the IETF community, or have the potential to become work items in related IETF working groups.

Motivation and Problem Scope

- o What are the motivations for Power-Aware Networking (PANET)?
- o To what extent power consumption is a key factor for Internet scaling?
- o To what extent power-aware system at router level and link level are not sufficient to reduce the overall energy consumption of networks?

Technical Development

- o What are the technical requirements for an efficient PANET solution?
- o What are the technical tracks to reduce the overall power consumption at the level of an IP network?
- o How protocols can be designed to be power-aware and still maintain enough network resiliency?

- o What are the technical challenges for deploying efficient PANET solutions?
- o How routing protocols (e.g., OSPF) can be extended to disseminate power-related information?
- o How PCE architecture can be used to compute power-aware paths?

- o How PANET can be deployed in centralized or in distributed model?

Operation Practice

- o What will be the impacts of PANET to network operations?
- o What will be the guidelines for deploying PANET systems?

5. Security Considerations

This draft is a discussion on the Internet's necessity to follow an evolutionary path towards the future. There is no direct impact on the Internet security.

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Authors' Addresses

Beichuan Zhang
Univ. of Arizona

Email: bzhang@cs.arizona.edu

Junxiao Shi
Univ. of Arizona

Email: shijunxiao@cs.arizona.edu

Jie Dong
Huawei

Email: jie.dong@huawei.com

Mingui Zhang
Huawei

Email: zhangmingui@huawei.com

Mohamed Boucadair
France Telecom

Email: mohamed.boucadair@orange.com

