Some Open Challenges for Improving the Energy Efficiency of the Internet

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***Abstract*—The main objective of this paper is to summarize recent researches on energy efficiency of the Internet and pose several open challenges toward future energy-efficient network architecture. The rapid deployment of network-ready devices in the last decade has greatly contributed for enabling full-time access to a wide variety of services on the Internet. It is commonly recognized that required bandwidth will be increasing rapidly to support rich services such as IPTV for the next decade. On the other hand, global energy saving is a matter of public concern, and now there is a lot of interest in reducing energy consumption of IT systems. Guaranteeing full-time connectivity in the Internet is also power consuming. For mobile networks and wireless sensor networks, there are many researches on energy efficiency. However, there is not much effort on reducing power consumption of wired networks. Office/home LAN switches, access networks and backbone networks are continuously consuming a lot of electric power. From this point of view, we summarize previous works on energy efficient networks to provide a bird's-eye view of the technology and discuss several open challenges to address the issue.**

I. Introduction

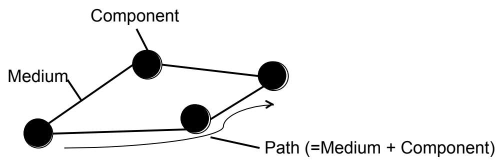
The Internet is a very energy consuming system in which a large number of devices are working for guaranteeing IP reachability and service continuity. Year-by-year traffic of the Internet backbone is exponentially increasing to support rich multimedia services including video streaming. Provisioning high-speed network equipment is a major solution to satisfy this demand. However, semiconductor device technology says that increasing frequency (i.e. bit rate or clock speed) directly relates to power consumption of CMOS devices[**?**]. VLSI technologies are now suffering from leakage current problem, and it is said that near half of the total power consumption of a high-end processor is due to the leakage current problem. Without a breakthrough of semiconductor technologies, reducing energy consumption with low-power and high-speed CMOS technology will not be practical in the future. This implies that power consumption of the future internet will increase exponentially in the worst case scenario. A recent report estimates that required electric power for network devices (not including data centers, terminals and displays) rises about 1,300% by year 2025 in Japan. Saving energy consumption of the future internet is necessary even though this kind of estimation usually contains several uncertainties.

For mobile networks and wireless sensor networks, there are many researches on energy efficiency. However, there is not much effort on reducing power consumption of wired networks while office/home LAN switches, access networks and backbone networks are continuously consuming a lot of electric power. All-optical network technology may solve this problem. However, it still remains an open question how much power can be reduced with compared to the current Internet by using all-optical network technology. Also, we do not know when the technology becomes commonly available. From this point of view, we summarize previous works on energy efficient networks to provide a bird's-eye view of the technology and discuss what kind of challenges we should consider for the future internet.

II. Survey

Gupta et al. introduced power saving problem in their pioneer work[**?**]. The indicated problem implies architectural change may be required for the Internet to enable reduction of power consumption since the major protocols used in the current Internet inherently do not consider intermittent operation (i.e. sleep and wake up) of network equipment. Thus, drastic change in protocol and architecture designs is required for enabling fully energy-efficient internet architecture. They proposed uncoordinated and coordinated sleeping mechanisms to reduce the power consumption of routers and discussed impact of the mechanisms on LAN switch and routing protocols. Following their work, there are several works related to the improvement of the energy efficiency of the Internet. As summarized in Fig. 1, these works are categorized by combinations of target, method and metric.

Target: Target indicates physical components of that power consumption should be reduced. It can be decomposed into communication medium (copper wire, optical fiber, etc.), component (hubs, routers, chips, etc.) and path. Path is consists of medium and component.
Technique: We can apply three major techniques for energy saving. The first one is applying new technology including new material and new fabrication technique. Discovering new material for low-power FET is examples of this technique. Replacing exiting networks with all-optical network[**?**] is also in this category. The second method is switching. This is the most fundamental method to reduce the power consumption at system level. Controlling ON/OFF timing, duty cycle and clock frequency(or bit rate) is categorized into this technique. We believe that ultra low-power wake up device[**?**] will



Target	Technique	Metric
Medium	New Technology (Material, Fabrication, etc.)	Traffic Pattern (time, space)
Component	Switching (ON/OFF, Duty, Frequency, etc.)	Energy Loss
Path	Aggregation (Time and Space)	Semantic (time, space, address, packet, application, human behaviors)

Fig. 1. Energy Saving Techniques

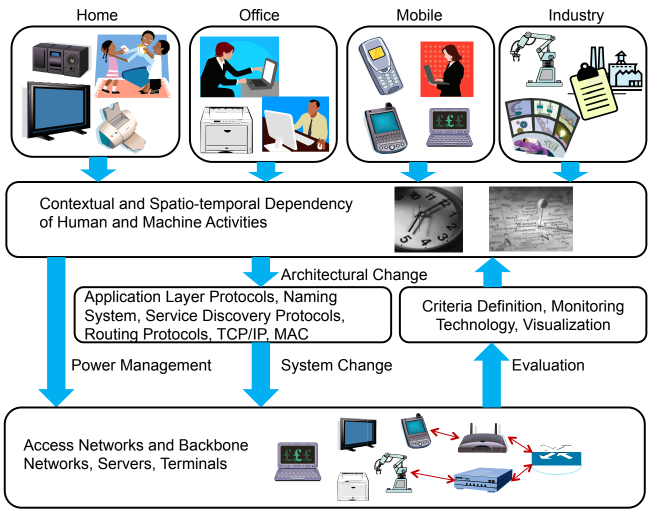


Fig. 2. Challenges

be useful to support switching technique. The last one is aggregation that means integration of physical components. In-network data compression[**?**], Line cards-chasis allocation[**?**], virtualization[**?**] , proxy-based approach[**?**], and DTN (Delay Tolerant Network) are good examples of this category. Usually, almost all power-saving technologies utilize combination of aggregation and switching.

Metric: The key point in power saving is finding adequate metrics for applying switching and aggregation methods. Traffic pattern or access pattern is a popular metric used for improving energy efficiency of the Internet. Integrating physical components into a chassis and using DC power supply are based on the metric of the efficiency of power supply unit (i.e. energy loss). Proxy-based approach utilizes semantic of arrival packets in the network[**?**]. Since power consumption of electric equipments is depending on time, space, and human/machine activities, high-level context information is greatly helpful for finding good metrics[**?**].

III. Challenges

Based on the above survey, we summarize several challenges to address the energy saving issue of the Internet. First of all, we have to make power consumption models of the Internet. For example, we do not know how much energy is required when we send a packet from Japan to Brazil. This kind of criteria is quite important to evaluate the energy efficiency of the Internet. Next, we need to consider consistency between network architecture and power-saving techniques. Current internet architecture is clearly inconsistent with power saving. Protocols for the future Internet must consider this inconsistency. Such protocols must improve both performance and energy efficiency because no one would like to use low-power and low-speed networks.

As discussed in the previous section, power consumption of electric equipments depend on spatio-temporal dependency of machine and human activities. This opens a new research area of context-aware energy saving. Sensor networks will provide various real world oriented information in the future. Extracting rich context information from raw sensor data will be important to find good relations among application usage patterns and energy efficiency. Also, service discovery and naming should be reconsidered since these technologies are bootstraps for various services on the Internet. Visualization is another important technique for power saving since it enables us to find critical energy loss in the whole IT systems.

Finally, it is important to make a practical consideration in deploying energy-efficient techniques. We need to show how to replace energy consuming network with energy-efficient network. Integrating energy-efficient technology to the emission trading market may become a possible solution.

IV. Summary

This paper summarized current research status of the energy efficiency of the Internet and discussed several challenges. Minimizing energy consumption of IT systems is now a critical problem. We believe that a far-sighted vision and a step-by-step approach will be important to face the problem.

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