Approaches to Green Networks

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Communication networks show promise as a means of reducing carbon dioxide emissions. However, as networks carry more traffic, their electric power consumption will increase: network power consumption in 2025 is predicted to be 13 times the 2006 level, so energy-saving technology that reduces power consumption is becoming increasingly important. Besides the energy-saving technologies currently under development for application to individual devices, technology that provides system-wide energy-savings for networks overall will be necessary in order to meet the target of keeping the power consumption in 2025 down to 2006 levels. The power consumption of routers is almost constant irrespective of the volume of transferred packets, and about 40% of it is generally used for the processing necessary for packet transfer routing. In response, we have investigated the end-to-end traffic flow and traffic characteristics of routers. In this paper, we clarify technical problems related to system-wide energy-savings focusing on router power consumption and introduce technology under development to solve these problems.

1. Introduction

Ways of resolving global warming issues that include reducing of carbon dioxide emissions are becoming increasingly important. While the use of networks is considered a prospective[1] means to reduce CO_2 emissions in the fields of telework and supply chain management (SCM), it will increase the volume of traffic flowing into networks accordingly. The total volume of traffic of broadband subscribers in Japan as of 2006 was 637 Gb/s. In 2025, the volume is estimated to increase to 121 Tb/s, approximately 190 times that of 2006, which will cause estimated network power consumption of 103.3 billion kWh/year,[2] 13 times that of 2006. With the total power generation of Japan currently at one trillion kWh/year, that estimate means that about 1/10th of Japan's power output will be consumed by networks alone. The Kyoto Protocol compiled in 1997 states that Japan is obliged to reduce its CO_2 emissions as of 2012 by 6% as compared with that of the 1990 level. For this reason, there has been a growing importance to have networks capable of significantly reducing power consumption in 2025 to a level equivalent to that of 2006.

To address this issue, we have developed a power-saving technology of the traffic forwarding mechanism itself which functions in response to traffic variations. The aim is to improve the power consumption efficiency of an entire network.

In this paper, we present approaches to controlling the power consumption in 2025 at the present level and outline the present technologies based on this perspective. In addition, we show their challenges and describe the developed technologies to solve them.

2. Concept of control of network power consumption

To control the power consumption in 2025 to the present level, the following approaches are considered necessary:

1) Restraint on capital investment on network devices themselves
2) Improvement of power consumption efficiency of an entire network

Regarding 1), one conceivable technique is to reduce the volume of traffic to be forwarded within a network. As a specific method, the volume of traffic can be controlled by providing a cache server at the entrance of a network so as to cache frequently-accessed content on the cache server to allow many users to use the cache. Meanwhile, capital investment on networks is generally made to deal with peaks of traffic. For this reason, leveling the traffic as much as possible can reduce the number of network devices in which to invest, in order to save energy. One method is scheduling, which allows broadcast content to be distributed in advance.

In relation to 2), possible techniques include forwarding large volumes of traffic with less power consumption and energy saving in accordance with the traffic variation that cannot be leveled by 1). Focusing on the improvement of power consumption efficiency of an entire network mentioned in 2), the following sections describe the present technologies to address the issue and their scope of application and also outline technologies that will be required in the future.

3. Energy-saving technologies and their challenges

Techniques to forward large volumes of traffic with less power consumption include use of evolving device technology and employment of optical nodes along with traffic aggregation. Device technology can be applied to any of the LAN/home network, access network, metro network and core network domains shown in **Figure 1** and offers prospects for energy saving

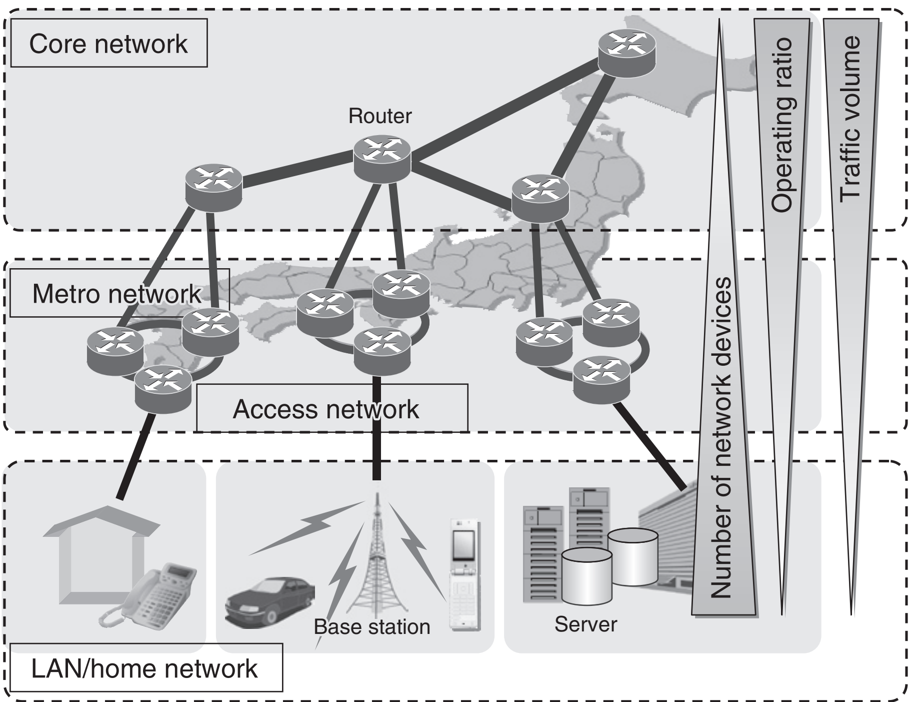

Figure 1
Features of each network domain.

by LSI microfabrication and reduction of driving voltage. Use of optical nodes requires traffic aggregation as a prerequisite and its scope of application is core networks.

Techniques to achieve energy saving in accordance with traffic variations include sleep control[3] and dynamic voltage scaling (DVS) control.[4] Sleep control saves energy by putting a device to "sleep" when it is not in use, and DVS control works by reducing the traffic forwarding capacity of devices such as the CPUs, line cards and network interface cards (NICs) when the traffic volume is low. For this reason, sleep control and DVS control are effective when they are applied to LAN/home networks, which characteristically have a large number of devices, low volume of traffic handled by individual networks and low device operating ratios, as shown in Figure 1.

By contrast, access and metro networks do not have device operating ratios low enough to make sleep control and DVS control effective or a degree of traffic aggregation high enough to use optical nodes, which is shown in Figure 1, and there is no effective technology available for power reduction in the present circumstances.

Optical packet switching, which is an energy-saving technique for the traffic forwarding mechanism of individual devices, has a potential to offer an energy-saving effect of three digits as compared with the conventional electric routers by applying the technique to core networks including some metro networks as well. However, the implementation of inexpensive and high-capacity optical buffers, or the possibility of their mass production, is not yet on the horizon. Accordingly, technology that can be applied mainly to access and metro networks up to core networks while being capable of systematically saving energy in entire networks by identifying the flows and characteristics of end-to-end traffic is required. The following sections show the technological challenges involved.

3.1 Technological challenge for energy saving of the traffic forwarding mechanism itself by systematization

The Internet uses packet forwarding, which achieves efficient accommodation of applications by the statistical multiplexing effect. The other side of the coin is that further increases in the speed and capacity of transmission lines in the future will require special types of memory that are high-speed, high-capacity and high-power-consumption (such as static random access memory [SRAM] and content addressable memory [CAM]) for buffering and routing. Even now, a case has been reported in which packet routing accounts for 37% of all power consumption of routers.[5] However, video traffic, which is expected to increase in the future, is characterized by continuous generation in one direction while a session is maintained and routing is required only on a session-by-session basis. This eliminates the need to use CAM, which is intended for packet-by-packet routing and requires high power consumption, and packet buffers. Accordingly, one technological challenge is to build a new forwarding mechanism that does not require these types of memory to be used.

3.2 Technological challenge for systematic energy saving in accordance with traffic variations

Cloud computing is expected to proliferate and the dissemination of ubiquitous services that use sensors is also anticipated, which indicates a possibility of increased machine-to-machine burst traffic. This type of traffic is characterized by dynamic variations in terms of time and place. Power consumption of routers, on the other hand, is almost independent of the volume of traffic forwarded and just driving routers consumes a certain amount of electric energy.[6] Accordingly, putting routers to sleep when traffic does not flow into them provides a possible energy-saving technique. In the present situation, however, traffic is distributed for forwarding on a network according to the paths predefined by routing protocols or other methods, which means that traffic, if low volume, flows into each router even when the overall volume of traffic is low, resulting in the need to keep each router running all the time. This points to the technological challenge of how to control traffic paths in an entire network in such a way that allows routers to be brought into a sleep state.

The sections below first describe the packet forwarding mechanism that we have developed (Energy Cost saving Overlay switching [ECO switching]) as one technique to achieve energy saving of traffic forwarding mechanism itself by systematization. The description goes on to outline the path aggregation control mechanism (Energy Cost saving Overlay routing [ECO routing]) developed as an approach to systematic energy saving in accordance with traffic variations.

4. ECO switching

ECO switching is a new switching method for energy saving and achieves the purpose by eliminating packet buffering and routing tables at routers. A conceptual diagram of the ECO switching operation is shown in **Figure 2**.

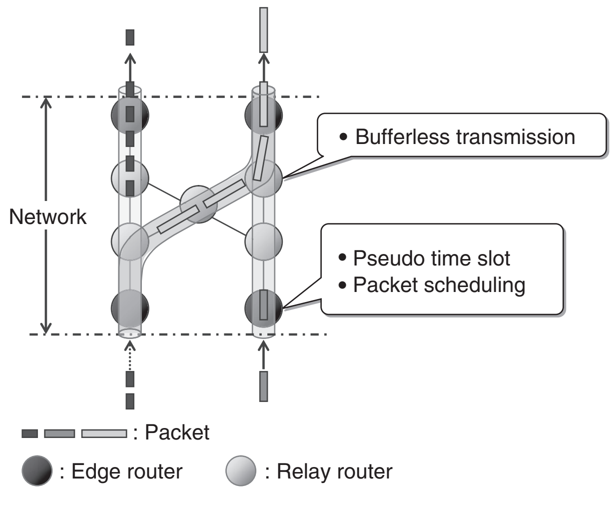

Figure 2
Diagram of ECO switching.

ECO switching, which has slimmed down the forwarding process, is composed of the following two basic techniques.

1) Bufferless transmission

Bufferless transmission achieves bufferless communication by eliminating buffering intended for avoiding collision of packets directed to the same destination at routers. Specifically, the edge router at the entrance of a network is used to synchronously generate pseudo time slots at regular intervals, according to which packet sending is appropriately scheduled, thereby avoiding packet output wait and conflict at relay routers in a network. This can reduce the buffer memory requirements of relay routers, which leads to a reduction of power consumption required in this process.

2) Switching based on pseudo time slots

This is a technique for switching packets output based on appropriate scheduling made by the bufferless transmission described above. Specifically, pseudo time slots are identified for switching on temporal axes, rather than referencing routing tables on a packet-by-packet basis at relay routers. This eliminates the need for routing table memory at relay routers and routing table search engine, which allows a reduction of power consumption required in this process.

5. ECO routing

While a number of technologies for dynamically controlling paths according to the traffic are being researched, they are basically dispersion control for avoiding deterioration of quality and do not achieve energy saving. On the other hand, ECO routing aggregates paths when the traffic volume is low and brings as many routers as possible to a sleep state, thereby saving energy. A conceptual diagram of the ECO routing operation is shown in **Figure 3**. ECO routing comprises two techniques: path computation to find the most appropriate path in terms of energy saving, and routing control for

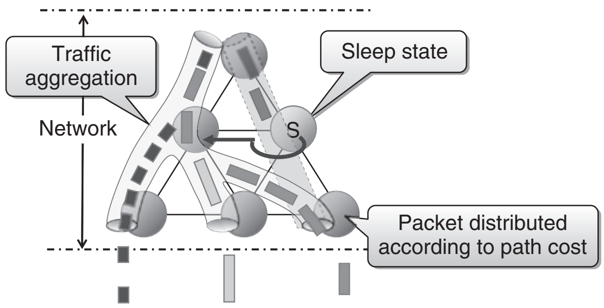

Figure 3
Diagram of ECO routing.

redirecting the traffic to the path determined by the technique above.

1) Most appropriate path computation

Because of the varying power consumption of devices and processing capacity of the individual routers, the energy-saving effect may significantly differ depending on which router is put to sleep. For this reason, a path computation technique in view of power efficiency with reference to the forwarding processing of the individual routers is necessary. ECO routing characteristically uses path cost determined by traffic distribution and power consumption efficiency of the individual routers to derive the most appropriate path that maximizes the energy-saving effect.

2) Path control

Along with computing the most appropriate path mentioned above, ECO routing requires the following to be performed:

- Traffic aggregation for forwarding in a range that does not cause congestion
- Traffic dispersion to more than one path for forwarding when congestion is likely to occur

In addition, smooth transition between the aggregation and dispersion states is required. ECO routing is characterized by convergence of traffic to the most appropriate routing state by adequately performing a traffic control measure.

6. Conclusion

As approaches to keeping the power consumption in 2025 down to the present level, reducing the amount of network equipment and improving the efficiency of power consumption of the devices are mentioned. The focus has been placed on the latter to outline ECO switching and ECO routing technologies as systematic energy-saving technologies of an entire network, which will become necessary in the future.

From now on, we intend to develop new elemental technologies as well as the existing ECO switching and ECO routing technologies to organically combine technologies and initiatives to reduce the amount of network equipment through cooperation with domestic and overseas organizations. The aim is to help achieve the ultimate purpose of keeping the power consumption in 2025 down to the 2006 level.

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