High energy efficient Internet architecture by Optical Aggregation Network

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***Abstract*—This paper proposes a high energy efficient network architecture having Giant Center Router and Optical Aggregation Network. Giant Center Router is power scalable with an amount of traffic proportionally. Optical Aggregation network is realized by circuit switches, and wavelength multiplexers/demultiplexers. Ethernet-frames of users are aggregated and transferred through Optical Aggregation Network to Giant Center Router transparently by dynamic optical resource allocation. The proposed network realizes the reduction of power consumption to 1/20-1/30 compared to the conventional Internet. In addition, the proposed network and the conventional Internet can be coexisted, and the conventional Internet can migrate to the proposed network smoothly.**

I. Introduction

The Internet users have been increasing 16% every year, and in June 2010, it grew up 1967 million users [1]. Real-time traffic reaches nearly 14Tbps [2]. The Internet is extremely useful network and becomes an infrastructure of life.

Three big problems occur. First problem is that the network structure of the conventional Internet does not fit in traffic centralization to data centers, second problem is the rapid increase in power consumption of the conventional Internet, the last problem is a long RTT, and a delay jitter.

Especially, the power consumption is a big problem. The worldwide power consumption of network equipments has been increasing over 12% every year and would be 97GW in 2020 (about 4 times compared to 2008) [3]. The power consumption of the Internet has been increasing rapidly according to the expansion of the Internet. Internet Engineering Task Force (IETF) had started to discuss power consumption problem from December 2007 [4].

This paper proposes a high energy efficient network architecture to reduce power consumption and realize smooth migration from the conventional Internet. The proposed network consists of Service Cloud and Optical Aggregation Network. Service Cloud consists of Giant Center Router and application servers. Giant Center Router is power scalable with an amount of traffic proportionally. Optical Aggregation Network consists of multiplexers/demultiplexers by optical circuit switches, and wavelength multiplexers/demultiplexers. Routers are integrated in Giant Center Router, and servers are integrated application servers in Service Cloud. Ethernet-frames of users are aggregated and transferred through Optical Aggregation Network to Giant Center Router transparently by dynamic optical resource allocation. And layer-3 switching function is only executed by Giant Center Router. So, a simple one hop network is realized. In addition, the proposed network and the conventional Internet can be coexisted by keeping the "Local access provider interface" in the conventional Internet, and the conventional Internet can migrate to the proposed network smoothly.

Consequently, the proposed network realizes the reduction of power consumption to 1/20-1/30 compare to the conventional Internet, and realizes smooth migration from the conventional Internet.

The rest of the paper is organized as follows. In Section II, we describe the requirements for Green IP network. In Section III, the power consumption trend of routers and switches is summarized. In Section IV, a new network architecture realized Service Cloud and Optical Aggregation Network is proposed. In Section V, we evaluate power consumption and migration. Finally, in Section VI, we summarize this paper.

II. Requirements for Future network

The conventional Internet structure has several shortcoming for today's services and applications. This paper focuses the shortcoming which is high energy consumption, and the requirement which is smooth migration from the conventional Internet.

A. High energy efficient network

The total power consumption of the Information and Communication Technology (ICT) and network equipments has been increasing rapidly. The Internet users have been increasing 16% every year, and in June 2010, it grew up 1967 million users [1]. Real-time traffic reaches nearly 14Tbps [2], the power consumption of network equipments has been extremely increasing. In 2008, the ICT power consumption grew 168GW, and in 2020, it would be 430GW (nearly 2.6 times) [3], that is nearly 8% increasing rata. In 2008, the power consumption of network equipments was 25GW, and in 2020, it would grow up to 97GW (nearly 4 times) [3], that is nearly 12% increasing rate. In Japan,the power consumption of routers would be 3.6GW in 2010 [6]. So, IETF had started to discuss power consumption problem [4].

The Internet had started at flat cluster structure suitable for data communication, and source user's data can reach the destination by rerouting in spite of router trouble. The Internet can be seen as a one large packet switch, where many extra switches and routers exist. And then, the Internet has been realizing various kinds of services and expanding with a large number of Autonomous Systems (ASs). Consequently, not only device level power reduction but also a high energy efficient network architecture are needed to solve the power consumption problem.

B. Smooth migration from the conventional Internet

The proposed network should be realized smooth migration from the conventional Internet. This is because, the proposed network should enable to minimize investment in migration and to maintain service continuity. Therefore, we must select the migration interface point in the conventional Internet for minimum investment and smooth migration.

III. Power consumption trend of routers and switches

A. Power consumption of routers

There is the relation between router switch-capacity and power consumption [5], [7]. Dr. Tucker found the relationship between router switch capacity and power consumption utilizing source data [8]. The power consumption of routers is shown as the following equation [5], [7].

$$P = A \cdot C^{2/3}, \quad (1)$$

where P [watt] is power consumption, C is router switch-capacity [Mbps], and A [watt $\cdot$ Mbps $^{-2/3}$] is a proportion constant. The value of A is 1.0 in Eq. (1). This equation indicates that power consumption per bit decreases as the increase of switching capacity. In case of 1Tbps-capacity, we need 1000 systems of 1Gbps-router and power consumption is 100KW, or we need 1 system of 1Tbps-router and power consumption is only 10KW [5], [7]. So, 1Tbps-router can reduce the power consumption 1/10 compare to 1000 systems 1Gbps-routers. Therefore, an large capacity router contributes the reduction of power consumption in the same switching capacity, and large capacity router is very efficient.

B. Power consumption of switches

In the paper [9] and [10], optical switch contributes reduction of power consumption of switching equipment evolutionary. At 100Tbps-switch, the power consumption of SOA (Semiconductor Optical Amplifier)-based packet switch is nearly 55KW, the power consumption of MEMS (Micro Electro-Mechanical Systems)-based circuit switch without wavelength-converters is only 2KW, and the power consumption of electric packet switch is 1000KW. So, SOA-based packet switch can reduce power consumption nearly 1/18, and MEMS-based circuit switch without wavelength-converters can reduce power consumption nearly 1/500 compared to the electric packet switch. Therefore, optical circuit switches contribute the reduction of power consumption of switching equipments drastically.

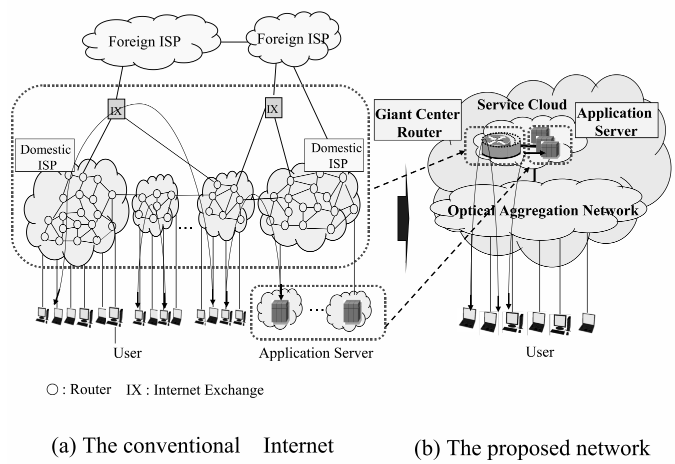

Fig. 1. The conventional Internet and Proposed Network.

IV. Proposed Network

A. Proposed network architecture

Figure 1 shows the conventional Internet and the proposed high energy efficient network architecture for Green IP network. Routers and servers are integrated in Service Cloud, and all IP traffic are transferred through Optical Aggregation Network to Giant Center Router in Service Cloud transparently. The proposed network consists of Service Cloud and Optical Aggregation Network. Service Cloud consists of the power scalable Giant Center Router and application servers. Routers and servers in the conventional internet are integrated to Giant Center Router and application servers respectively. Optical Aggregation Network consists of optical circuit switches, and wavelength multiplexers/demultiplexers. All IP traffic are transferred through Optical Aggregation Network to Service Cloud transparently by dynamic optical resource allocation. So, a simple one hop network is realized.

1) Service Cloud: Service Cloud consists of Giant Center Router and application servers. Thousands of routers in the conventional Interne are integrated to Giant Center Router, and we can reduce the total capacity of routers by integration. Besides, Giant Center Router is power scalable with an amount of traffic proportionally. In other words, Giant Center Router changes the switching capacity dependent on traffic amount, and the power consumption of Giant Center Router is controlled by switching capacity. Giant Center Router is composed of several function units; line interface units, switch fabric units which consist of sub-switch fabric units, and controller units. Power consumption of each unit is controlled with a amount of traffic proportionally. According to the traffic amount, each unit is controlled in power-on-mode, power-off-mode, or sleep-mode respectively. Therefore, Giant Center Router can reduce the power consumption by reduction of the total router capacity and power scalable structure corresponding to a amount of traffic.

2) Optical Aggregation Network: Optical Aggregation Network consists of multiplexers/demultiplexers by optical circuit switches, and wavelength multiplexers/demultiplexers. Optical

Aggregation Network transfers Ethernet-frame of users transparently by dynamic optical resource allocation. It means that, conventional User Network Interface (UNI) is moved to the entrance of Giant Center Router. Ethernet-frames of a source user are transferred to Giant Center Router through Optical Aggregation Network (upstream) and layer-3 switching is always only executed by Giant Center Router, and transferred to a destination user through Optical Aggregation Network (downstream). So, the proposed network is very simple one hop network using optical techniques.

B. Smooth migration from The Internet

The proposed network architecture enables smooth migration from the Internet. The author showed that the proposed network can reduce the power consumption to nearly 1/1000 drastically compared to the conventional Internet [11]. However, it is difficult to migrate from the conventional Internet to the proposed network, because Optical Aggregation Network is realized with full optical techniques, and it is necessary to replace the conventional Internet by the proposed network. So, we select the interface point in the conventional Internet for migration with considering of access networks occupy majority of the Internet, and minimizing the investment in migration. According to our real network investigation, we define the network structure model as stage structure in spite of remaining flat cluster structure, and select "Local access provider interface" as the interface point for migration.

C. Realization of propose network architecture

Figure 2 shows the proposed network architecture considering smooth migration from the conventional Internet in case of broadband users in Japan. Optical Aggregation Network is serial combination with optical time slot multiplexers/demultiplexers (Mux/Dmux) and wavelength multiplexers/demultiplexers. To realize the easy migration from the conventional Internet, the interface "Local access provider interface" is kept. Ne in Fig. 2 is the number of Ethernet-interfaces, and Ns is the number of electric aggregation equipments which is connected to one Optical-slot Mux/Dmux.

Figure 3 shows Optical Aggregation Network structure for Fig. 2. We have many experiences utilizing PLZT optical switch [12], and control protocol for optical slot-based access network [13], [14], so PLZT optical switch is assumed to be used in Optical Aggregation Network. Optical time slot Mux/Dmux is realized by PLZT optical switch module (16x1, 8x1) [15] and wavelength Mux/Dmux is realized by Array Waveguide Gratings (AWG). Optical line speed is 40Gbps, the number of wavelength multiplexer/demultiplexer is forty.

Figure 4 shows the block diagram of electric aggregation equipment, which is a converter among 10-Gbit/s Ethernet(10GE)-interface and optical time slots interface. Electric aggregation equipment converts Ne 10GE-interfaces to one or several optical time slots in 40Gbps-optical-highway which consists of frames with Ns optical time slots.

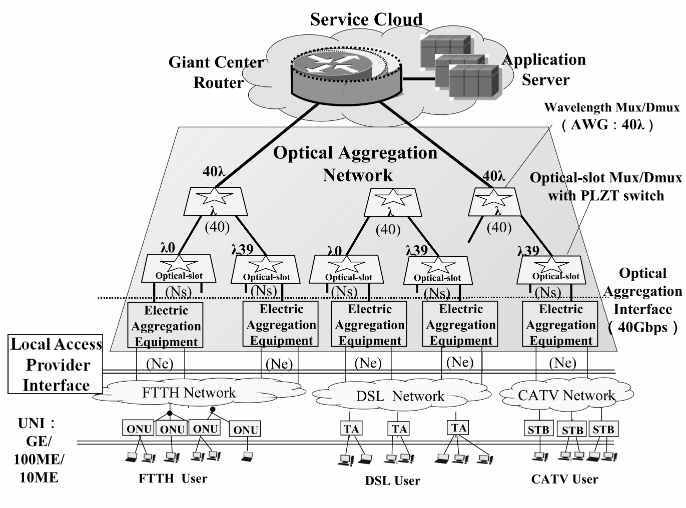

Fig. 2. Realization of proposed network (Model B)

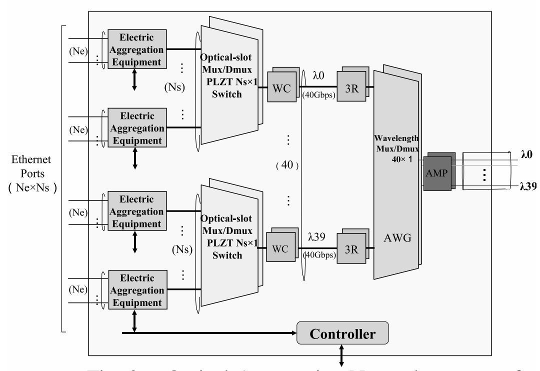

Fig. 3. Optical Aggregation Network structure for Fig. 2

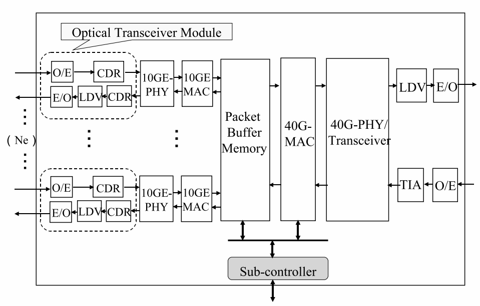

Fig. 4. Block diagram of electric aggregation equipment.

V. Evaluation and Discussion

A. Power consumption model

1) Traffic condition: Table I shows broadband traffic per user at the end of 2009 in Japan [16]. Over one-third of upstream traffic is transferred to foreign ISP and twice traffic of upstream traffic return as downstream traffic from foreign ISP [16], [17]. The peak average traffic of upstream is 42kbps and the peak average traffic of downstream is 64kbps as shown in Table I.

2) Network model: Model A, Nationwide ISP: Figure 5 shows the conventional Internet network model as model A.

TABLE I
BROADBAND TRAFFIC/USER IN JAPAN (2009)

	Average	Peak Average
Upstream	29.9 kbps	41.6 kbps
Downstream	43.2 kbps	63.9 kbps
Total	73.1 kbps	105.5 kbps

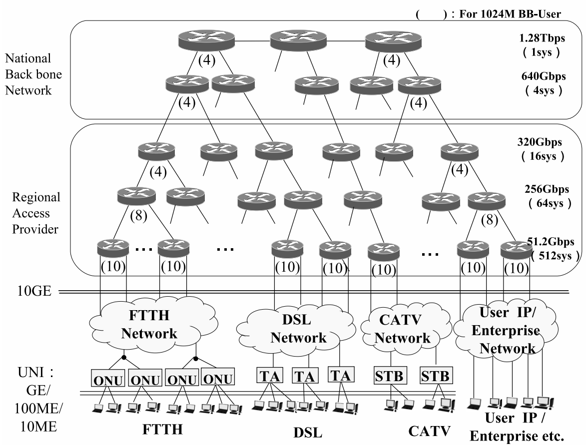

Fig. 5. The conventional Internet (Model A).

We define the peak average traffic of upstream is 42kbps and the peak average traffic of downstream is 64kbps per user as shown in Table I. Router switching capacity is defined with reference to vender catalogues on the market.

Model B, proposed network: Figure 2 shows the proposed network model as model B. We define the traffic in evaluation is the peak average traffic in Table I, and define that Ne is six and Ns is one hundred in Fig. 2. An electric aggregation equipment converts six 10GE-interfaces to optical time slots in 40Gbps optical highway. The bandwidth of one optical time slot is nearly 384Mbps; 40Gbps optical highway is divided into one hundred optical time slots. We control the bandwidth of communication by the optical time slots allocation dynamically. In other words, the bandwidth is controlled by the number of optical time slots in 40Gbps-optical-highway. The controller in Optical Aggregation Network as shown in Fig. 3 manages and controls the optical time slots allocation in close cooperation with sub-controller in electric aggregation equipments in Fig. 4. The power consumption of Giant Center Router is calculated by Eq.(1). Table II shows the details of the power consumption of electric aggregation equipments. We calculate power consumption of each function block with reference to packet router's line card with 40Gbps ports [9], the power consumption of 10GE-optical-transceiver-module refers to the evaluation report [18], and LSI vendor catalogues.

B. Evaluation and discussion

We evaluate the reduction of power consumption of the proposed network, and smooth migration to the proposed network from the conventional Internet.

1) Power consumption: Figure 6 shows the evaluation of power consumption; total power consumptions are shown by logarithm, and the details of power consumption in proposed

TABLE II

Sub block	Function Implemented	Power consumption (W)
Transceiver	Laser(modulator) driver, TIA, postamp ,equalization, clock and data recovery, mux/demux	5.9
40G-PHY	Encoding/decoding, scrambling/de scrambling for 40G	3.4
40G-MAC	Mapping, framing, slot processing, MAC for 40G	5.0
Packet Buffer Memory	Buffer memory for packet-transfer and receiver	13.6
10GE-PHY	Encoding/decoding, scrambling/de scrambling for 10GE	4.2
10GE-MAC	Mapping, framing, MAC for 10GE	4.2
10G-Optical Transceiver Module	O/E and E/O conversion, LDV (Laser driver), CDR (clock and data recovery) with EDC (electronic dispersion compensation) , mux/demux	6.0
Sub-controller	Aggregation equipment controller	60
Total power consumption		102.3

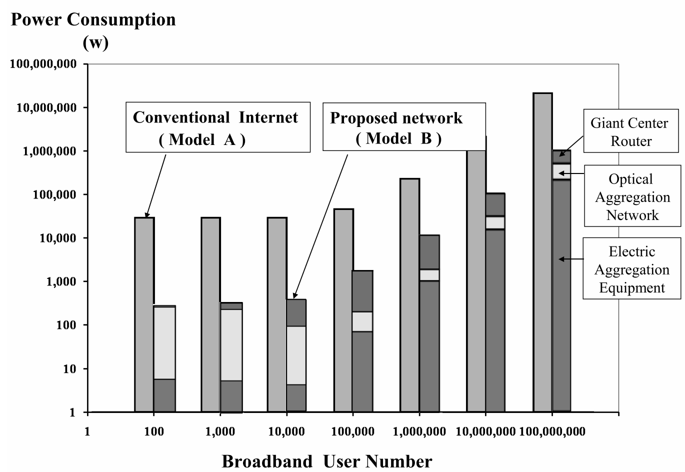

Fig. 6. Evaluation of power consumption.

network are shown by linear. The conventional Internet needs power consumption is 46KW at 100K users and 22MW at 100M users. The proposed network needs power consumption is only 2KW at 100K users and 960KW at 100M users. So, power consumption of the proposed network can be reduced to nearly 1/20 - 1/30 compared to the conventional Internet. The electric aggregation equipments occupy majority of power-consumption-ratio of proposed network, and the occupation-ratio of Optical Aggregation Network is extremely small. So, according the expansion of Optical Aggregation Network toward UNI, we can drastically reduce the power consumption.

2) Smooth migration: We keep the "Local access provider interface" in the conventional internet interface as shown in Fig. 2. So, the proposed network and the conventional Internet can coexist, the proposed network can be introduced overlay on the conventional Internet. Therefore, the conventional Internet can migrate to the proposed network smoothly.

VI. CONCLUSION

This paper has been proposed the high energy efficient network architecture for Green IP network, which consists of Optical Aggregation Network and Service Cloud with power scalable Giant Center Router and application servers. All traffic are aggregated to Giant Center Router in Service Cloud through Optical Aggregation Network transparently by dynamic optical resource allocation. The proposed scheme satisfies two big requirements; high energy efficiency, and easy migration from the conventional Internet. The evaluation result shows that the proposed scheme can drastically reduce power consumption to nearly 1/20 - 1/30 of the power consumption of the conventional Internet. In addition, the proposed network and the conventional Internet can be coexisted, and the conventional Internet can migrate to the proposed network smoothly. The proposed network is expected to be Green IP network with high capacity and high energy efficiency, and to migrate from the conventional Internet smoothly.

ACKNOWLEDGMENT

This work is supported by PREDICT program of the Ministry of Internal Affairs and Communications (MIC) of Japan. This work is supported by Global COE Program "High-Level Global Cooperation for Leading-Edge Platform on Access Space (C12)".

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