Next Generation Green Metro/Access Network Architecture using Time-slot-based Optical Aggregation Network for Multi-service Access

Naoaki Yamanaka, Hidetoshi Takeshita, Kazumasa Tokuhashi, and Takehiro Sato.

***Abstract*—An extremely energy efficient layer-3 network architecture based on optical slot-type aggregation is proposed for the future Internet. Huge numbers of user traffic streams are multiplexed by optical wavelength/time-slots at the central data center router. Each time-slot is transparent, so all types of service can be integrated on any slot. In other words, user IP packets are aggregated and transferred through the Optical Aggregation Network to the centralized router, transparently. The proposed network architecture realizes a network structure well suited to traffic centralization, and reduces the power consumption to 1/10-1/20 compared to the existing Internet.**

***Index Terms*—Energy efficient, Internet, Metro network, Access network, Optical Aggregation,**

I. Introduction

The Internet is an extremely convenient network and infrastructure for network service. Statistical traffic data indicates that real-time traffic and routing flows now total almost 15 Tbps [1]. Internet traffic consists of Peer-to-Peer (P2P) traffic for mutual communication (file exchange, Voice over IP (VoIP), etc) and Client-to-Datacenter (C2D) traffic for server-client communication (Web access, data download, content download, etc). The current traffic champion, P2P traffic, is being dethroned by C2D traffic [1].

Even though optical access technology is being used to support the huge traffic demands, the Internet is suffering from two big problems. The first problem is that today's Internet network structure does not well support traffic centralization onto data centers. Because the Internet is basically a clustered structure on an autonomous system (AS) interconnection network, it is scalable and thus easy to expand. Second is the rapid increase in the power consumption of the Internet.

The traffic of the Internet is becoming more centralized onto data centers. There are two reasons. One is that P2P traffic is being overwhelmed by C2D traffic, and download traffic has been increasing rapidly due to the adoption of cloud computing. The dominant Internet service providers (ISPs) and content delivery network (CDN) providers are called the hyper-giants. The top 30 hyper-giants (Google, Yahoo, Akamai, etc.) occupy 30% of all Internet traffic [1]. The worldwide power consumption of network equipment has been increasing over 12% every year and will reach 97 GW in 2020 (about 4 times that of 2008) [2]. The power consumption of the Internet has been increasing rapidly in lock-step with its expanded usage.

Fiber-to-the-home (FTTH) is a key access network technology, and it is just an alternative to x-Digital Subscriber Line (x-DSL) or other metal access to the Internet. Passive Optical Network (PON) [3] is used around the world as a FTTH, and its bandwidth enhancement has been continued for increasing of broadband traffic [4], [5]. Optical technology has been greatly improved by advanced technology such as wavelength division multiplexing (WDM), high-speed optical switch and digital technologies. Optical technology is very attractive not only its huge bandwidth but also low power consumption. To accommodate a large number of users and to enable long reach, Long-Reach Passive Optical Network (LR-PON) is researched for decreasing capital and operational expenditure for the network operator in the access/metro area [6], [7].

Given the above background, this paper proposes a new Metro/Access optical network architecture. The architecture uses a large optical time slot/WDM aggregation network to provide access to the large layer-3 routers in the data centers. In other words, the traffic is gathered to a large centralized layer-3 router via an optical aggregation network. The optical aggregation network is realized by the combination of WDM and (time) slot switching to achieve large-scale subscriber aggregation. Slot switching is realized as periodic optically-transparent switching. So multi-services, such as residential service, business user, Small Office Home Office (SOHO), distributed data center interconnection and mobile backhaul are integrated on each time slot. Note that each time-slot is transparent from client to center. The proposed network architecture makes the optical Metro/Access aggregation network the center of the network and dramatically

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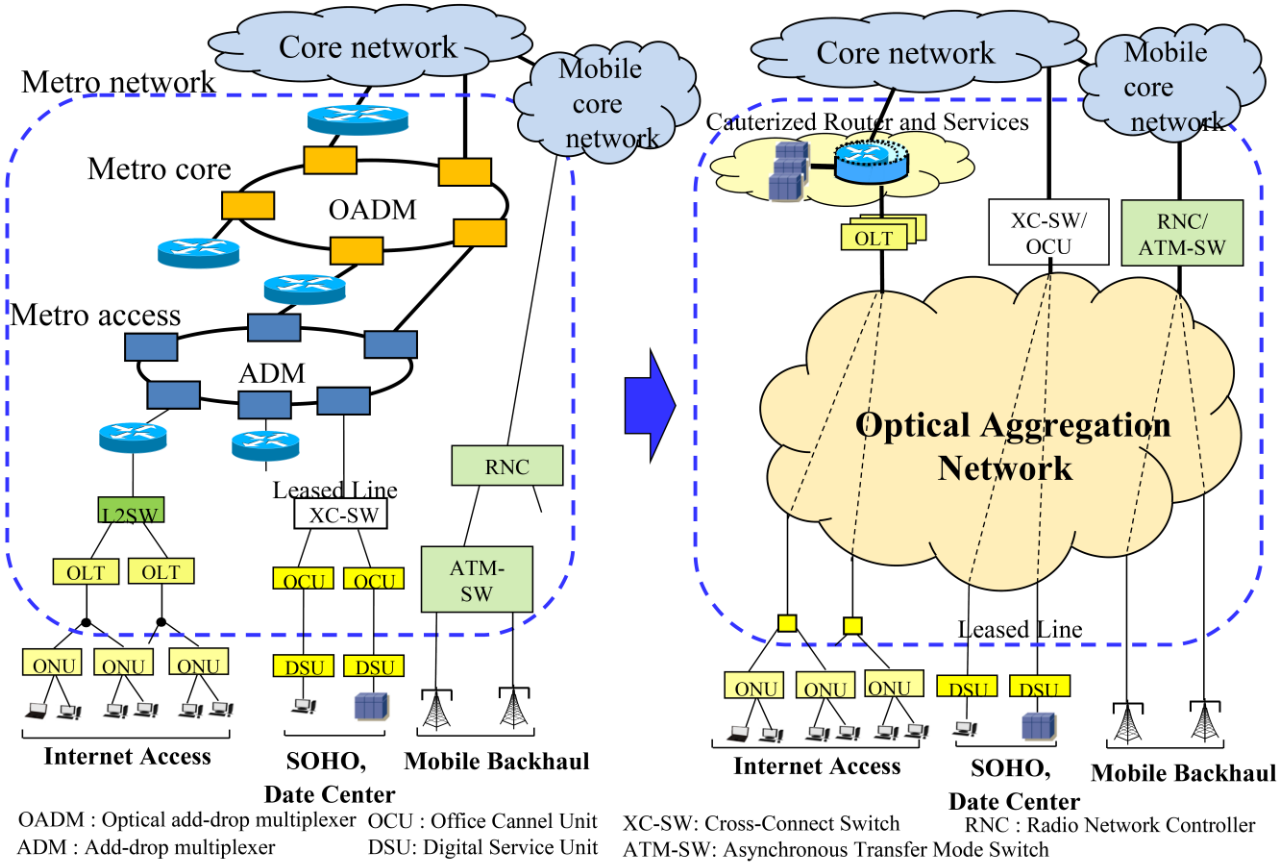

(a) Conventional Internet architecture

(b) High energy-efficient Layer-3 network architecture (proposed)

Fig. 1. Conventional Internet architecture (a) and proposed High energy-efficient Layer-3 network architecture (b).

decreases the network power consumption to 1/10-1/20 and Quality of Service (QoS) guarantees for multiple services can be provided easily.

Requirements of the future Internet are as follows; it should suit traffic centralization onto data centers and realize a highly energy efficient layer-3 network. This paper proposes a high energy-efficient next generation network architecture. It combines the large layer-3 router located at the data centers with the Optical Aggregation Network.

II. Future Network Architecture

A. Architecture

Next generation services are moving toward the C2D service. In addition, the optical access service will encompass not only residential services such as video or voice which likely have QoS requirements, but also business or mobile backhaul service. This suggests that the whole network architecture needs to be discussed, not just the access network. Figure 1 (a) shows the conventional metro core and metro access network.

The optical access network is mainly used to access the Internet. The proposed Metro/Access aggregation network, shown in Fig. 1 (b), is a more optical access centric network. Proposed network realizes to accommodate a large number of users and to enable long reach, supports various kinds of services through Optical Aggregation Network. Optical Aggregation Network also can reduce power consumption of network by reducing the number of equipment and using optical technology instead of electrical technology. Traffic, including P2P, is transferred to the large centralized layer-3 router at the data center. This router is scalable to traffic demands and realizes statistical multiplexing gain.

B. Energy efficiency

Figure 2 shows the relationship between router throughput and power consumption [8], [9]. The power consumption of routers is given by the following equation [8], [9].

$$P=A \cdot C2/3, \qquad (1)$$

where P [watt] is power consumption, C is router switch-capacity [Mbps], and A [watt・Mbps$^{-2/3}$] is a constant. The value of A is 1.0 in Eq. (1).

This equation indicates that power consumption per bit

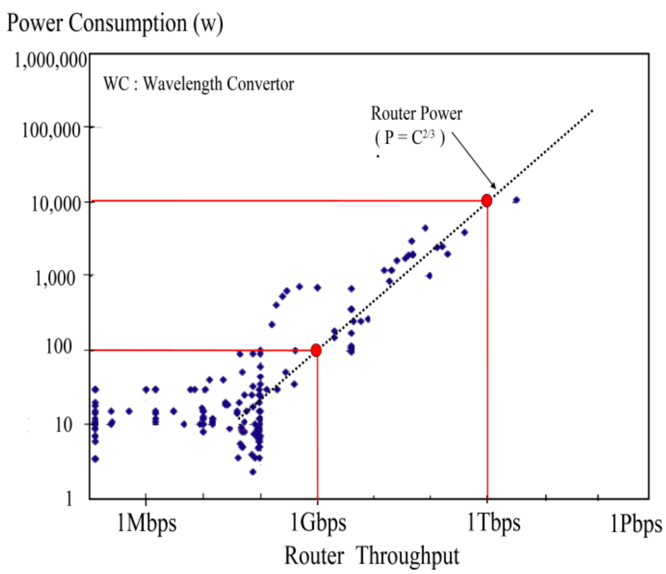

Fig. 2. Router and optical switch power consumption.

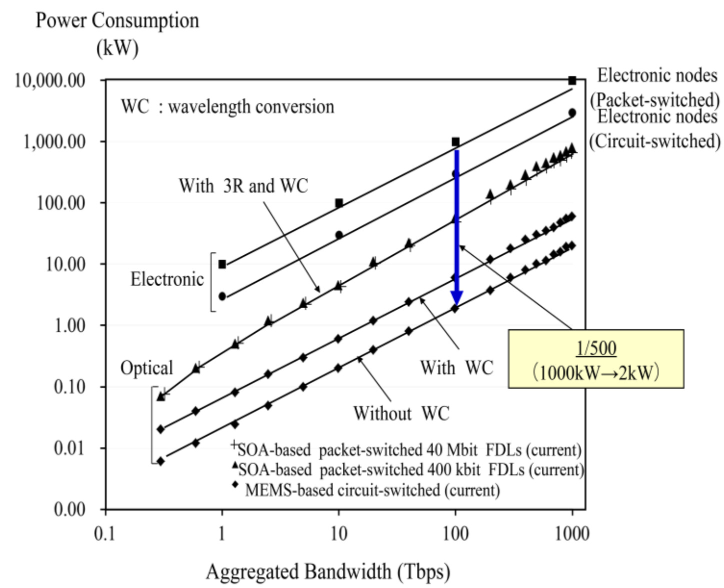

Fig. 3. Power consumption of switches.

decreases as switching capacity is increased. For the capacity of 1Tbps, we need 1000 systems using 1Gbps-routers and the total power consumption is 100KW as shown by Eq. (2). When we use one system with a 1Tbps-router, power consumption is 10KW as shown by Eq. (3). Thus the 1Tbps-router can reduce the power consumption to 1/10 compared to the 1Gbpsrouter.

With 1 Gbps-router:

$$\text{Power consumption} = 100\text{W} \times 1000\text{sys} = 100\text{KW} \qquad (2)$$

With 1 Tbps-router:

$$\text{Power consumption} = 10\text{KW} \times 1\text{sys} = 10\text{KW} \qquad (3)$$

Therefore, large capacity electrical routers are very effective for achieving power savings. I propose a new network architecture that utilizes large capacity electrical routers.

Reference [10] addresses power consumption issues in future high-capacity switching and routing elements and examines different architectures based on both packet-switched and circuit-switched designs by assuming either all-electronic or all-optical implementation. Those are large electronic packet switch, large electric cross-point switch, large Semiconductor Optical Amplifier (SOA)-based optical packet switch, and large Micro-Electro-Mechanical System (MEMS)-based optical cross connect as shown in Fig. 3.

Figure 3 shows the relation between switch-capacity and power consumption [10], [9]. Upper lines plot electric switching performance (electric router and electric circuit switch), lower lines plot optical switching performance (Semiconductor Optical Amplifier (SOA) switch and Micro-Electric-Mechanical System (MEMS) switch). This graph shows that optical switching can significantly reduce the power consumption of switching equipment. For a 100Tbps-switch, the MEMS based circuit switch without wavelength-converters has a power consumption of 2 kW while the power consumption of the equivalent electric packet switch is 1000 kW. Thus a MEMS-based circuit switch without wavelength-converters can reduce power consumption to 1/500 compared to the electric packet switch. Since optical random access memories are not feasible yet, optical buffering is mostly realized by using Fiber Delay Lines (FDLs). Very large buffers, often required in high-performance packet-switched Internet routers, are impractical when implemented by using FDLs because of their large physical size. Therefore, we utilize the optical circuit switch to realize Optical Aggregation network which suits traffic centralization and reduces power consumption.

III. Service Integration Network

A. *Multi-service access network*

Detailed structure of the proposed Metro/Access Optical Network is shown in Fig. 4. Proposed network supports various kinds of services by Optical Aggregation Network. Optical Aggregation Network transparently transports various kinds of data, those are Internet access service, Small Office/Home Office (SOHO) service, and Mobile Backhaul service, etc. Optical Aggregation Network consists of multiplexers /demultiplexers with optical circuit switches by optical time slots switching. Optical time slot means a fixed period within which transparent data transfer is realized. Figure 4 also shows the relation between service and wavelength/slot. Optical slot Containers can accommodate and transparently transport Ethernet frame which is Gigabit Ethernet-Passive Optical Network (GE-PON), Time Division Multiplexing (TDM) digital data which is leased line service or mobile backhaul service, Asynchronous Transfer Mode (ATM) digital data which is leased line service or mobile backhaul service, and so on.

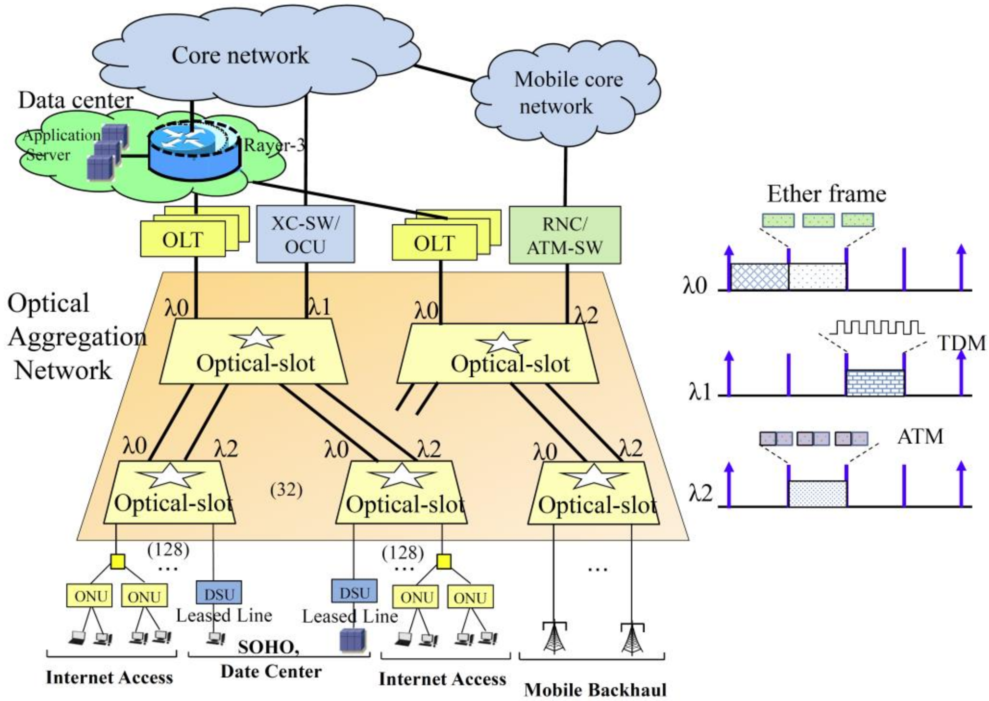

Fig. 4. Multi-service optical slot access network structure.

1) Internet access and communication: The proposed network realizes Internet access as a GE-PON compatible service and 10GE-PON compatible service. However, the WDM/Time Division Multiplexing (TDM) technique of the proposed access network as shown in Fig. 4 allow it to handle extremely large numbers of users. All Internet traffic streams are transferred to the large layer-3 router switches in the data center through Optical Aggregation Network. Data from user device can be transferred to the data center entrance transparently. Therefore, IP functions such as Network Address Translation (NAT), Firewall and Domain Name System (DNS) server are realized by application servers in the data center. Such functions can be realized by Software as a Service (SaaS) of the data center [11]. This makes more flexible services possible [12].

2) *Leased line service:* Leased line service is realized by TDM or ATM technologies. Some optical slots are assigned for leased line services such as distributed data center interconnection or SOHO. ATM or TDM leased lines services are also integrated into the Optical Aggregation Network as shown in Fig. 4 without special leased line equipment in current leased line network as shown in Fig. 1 (a). Therefore, we can reduce the number of equipment, then we can reduce the power consumption which reduces operating expenditure and capital expenditure.

3) *Mobile Backhaul service:* In mobile networks, the evolution towards Long Term Evolution (LTE) and 4th Generation (4G) supporting higher bandwidth for mobile data and video applications is forcing mobile backhaul for access/metro networks. Micro-cell or Picocell mobile network base stations are being widely installed, and Micro-cell and Picocell base stations need many installation sites. Customer premises are very suitable for installation sites to utilize Optical fiber subscriber line. For this service, clock distribution is needed. Because an optical time slot is a transparent time slot, this service is also integrated on the access network as shown in Fig. 4.

Note that, Internet Access, leased line service and mobile backhaul service can be realized by high quality optical transparent aggregation network.

IV. PROOF OF CONCEPT

We have already demonstrated a proof-of-concept prototype system by using very high-speed (10 ns) (Pb,La)(Zr,Ti)O3 (PLZT) optical switches [14], [15]. The experimental set up is shown in Fig. 5. The prototype system includes a newly proposed automatic ranging function [16] that is packet based.

In addition, the system supports up to 128 users with span of more than 40km [17]. PLZT switch offers nanosecond order high-speed switching, and can greatly reduce optical power loss than an optical splitter which is used in current PON system. Therefore, the system supports up to 128 users which is four times larger than the current PON system, and can achieve optical signal transmission over 40km which is two times longer than the current PON system.. Then, the system can greatly contribute to energy saving.

All 1x2 switch elements which compose a 1x128 optical switch must be controlled synchronously to shorten guard time. We designed the skew of triggers at switch driver circuits to be

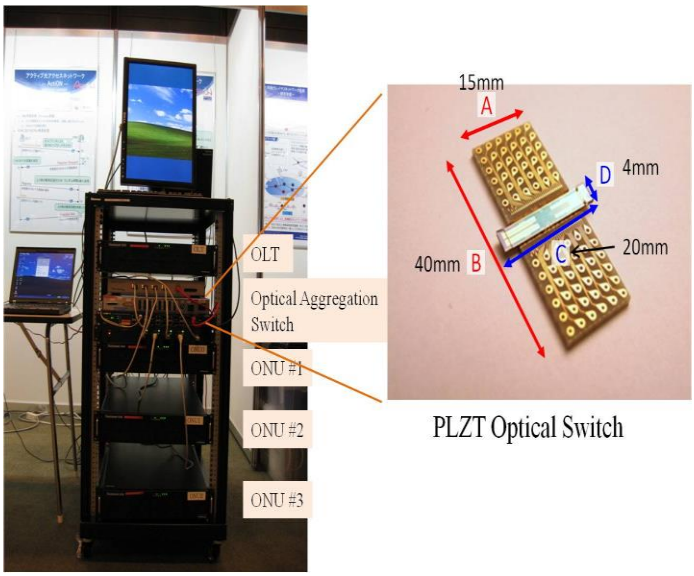

Fig. 5. Prototype of optical slot aggregation switch network

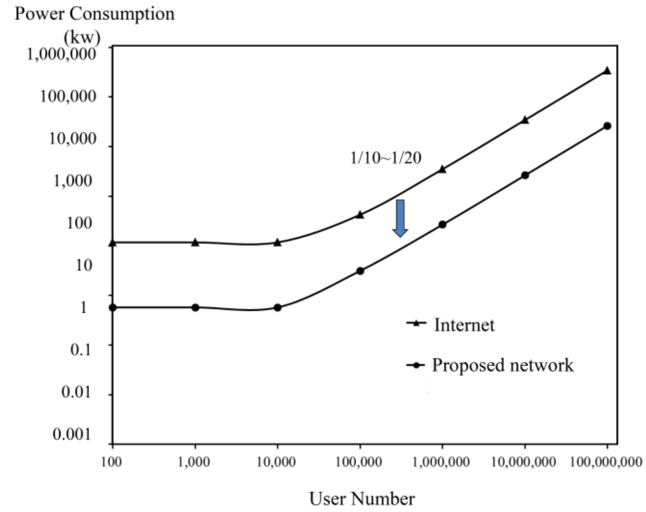

Fig. 6. Power consumption reduction by proposed architecture.

zero, and also electric wirings between switch driver circuit and 1x2 switch element to be equivalent. Triggers for two 1x2 switch elements reached simultaneously, so we confirmed that 1x2 switch elements could be controlled synchronously [17].

The measured power consumption of the PLZT switch modules is shown in Table I. In a demonstration, high-quality video signaling and Internet access were realized via optical slots.

A. *Energy reduction by proposed network*

The proposed Metro/Access network is used as the optical WDM/slot aggregation network to feed the data center. The traffic flows are aggregated in the optical lower layer and layer-2/3 or high layers are realized within the center node. Figure 6 shows the power consumption of an IP network realized by the conventional Internet and that of the proposed optical metro/access network. The proposed network architecture reduces the power consumption to 1/10-1/20 compared to the existing Internet.

This evaluation compares the power consumption of the Optical Aggregation Network with the equivalent components of the current Internet. We use the power consumption of each component shown in Table I.

TABLE I
TYPICAL POWER CONSUMPTION OF COMPONENTS

Comparison Network	Component	Capacity	Power consumption
Internet	SONET ADM	95Gbps	1,200W [18]
	OADM	N/A	450W [18]
	EDFA(Erbium-Doped optical Fiber Amplifier)	N/A	8W [18]
	Metro first stage router	51.2Gbps	1,380W [13]
	Metro second stage router	256Gbps	4,030W [13]
	Metro third stage router	320Gbps	4,680W [13]
Proposed network	PLZT switch (including driver)	1x16switch, 1x8switch	2.4W, 2.4W
	EDFA	N/A	8W [18]
	3R(Re-amplifying, Reshaping, Re-timing)	N/A	2.79W [10]
	WC (Wavelength Converter)	N/A	1.65W [10]
	Controller	N/A	150W [10]

V. Conclusion

This paper proposed a new Metro/Access optical aggregation network architecture for the next generation network. The architecture is consists of a large layer-3 router and optical metro/access aggregation network. Internet traffic flows are transferred to data centers, within which large layer-3 routers switch the traffic. The conventional Internet employs many hops but this architecture needs only one. Optical metro/access aggregation network can realize simple metro/ access network without ADM and OADM as shown in Fig. 1 (b). Therefore, we can reduce capital expense and power consumption. The resulting optical aggregation network has much lower electrical power consumptions than the current electrical router configuration; power reductions of the order to 1/10-1/20 are possible. Tests on an experimental system using 10ns PLZT optical switches confirmed the capability of the proposed architecture. The proposed architecture and system can be applied future Metro/Access networks.

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REFERENCES

[1] D. McPherson, ”ATLAS Internet Observatory,” ISOC Researchers, IETF76, Hiroshima, Japan,12 Nov. 2009.

[2] M. Pickavet, W. Vereecken, S. Demeyer, P. Audenaert, B. Vermeulen, C. Develder, D. Colle, B. Dhoedt, and P. Demeester,” Worldwide Energy Needs for ICT: the RISE of Power-Aware Networking, ” IEEE ANTS 2008, Bombay, India, 15-17 Dec. 2008.

[3] ITU-T Recommendation G983.1, “Broadband optical access system based on Passive Optical Access.”

[4] ITU-T Recommendation G.984, “Gigabit-Cable Passive Optical Networks (G-PON): General Characteristics,” Mar. 2003.

[5] IEEE802.3av, “10Gb/s Ethernet Passive Optical Netwrok,” 2009. http://grouper.ieee.org/groups/802/3/av/index.html.

[6] “European 7th Framework Programme project SARDANA,” http://www.ict-sardana.eu.

[7] H. Song, B. Kim, and B. Mukherjee, IEEE communications surveys & tutorials, “Long-Reach Optical Access Networks: A Survey of Research Challenges, Demonstrations, and Bandwidth Assignment Mechanisms,” VOL.12 No.1, pp.112-123, First quarter 2010.

[8] R. S. Tucker, ”Optical Packet-Switched WDN Networks: a Cost and Energy Perspective,” http://people.eng.unimelb.edu.au/rtucker/talks/files/Tucker_ OMG1(2).pdf..

[9] W. V. Heddengen, M. D. Groote, W. Vereecken, D. Colle, M. Pickavet, and P. Deemester, ”Energy-Efficiency in telecommunications networks; Link-by-Link versus End-to-End Grooming,” ONDM2010, Kyoto, Japan, Feb. 2010, and presentation documents by D. Colle. http://www-mura.ist.osakau. ac.jp/ondm2010/ pdf/invited3.pdf

[10] S. Aleksic, ”Analysis of Power Consumption in Future High capacity Network Nodes,” IEEE/OSA Journal of Optical Communications and Networking, Vol.1 No.3 PD245-258D 2009.

[11] N. Yamanaka, K. Tokuhashi, and H. takeshita, ”A state-ofthe-Art LOw-Power Optical Network Research,” The Review of Laser of Engneering, Vol.40, No.5, pp.351-155, May 2012.

[12] H. Takeshita, D. Ishii, and N. Yamanaka, “High-energy EfficentbLayer-3 Network Architecture based on Solitary Universal the Cloud Router and the Optical Aggregation Network,” COIN2010, No.TuC1-2, Jeju, Korea, Jul. 2010.

[13] H. Takeshita, D. Ishii, S. Okamoto, E. Oki, N. Yamanaka, ” High Energy Efficient Layer-3 Network Architecture based on Service Cloud and Optical Aggregation Network,” IEICE transactions on communications, Vol.E94-B, No.04, pp.894-903, Apr. 2011.

[14] K. Nashimoto, “PLZT Waveguide Devices for High Speed Switching and Filtering,” OFC/NFOEC 2008, OThE4, San Diego, USA, April 2008.

[15] K. Tokuhashi, K. Ashizawa, D. Ishii, Y. Arakawa, N. Yamanaka, and K. Wakayama, ”Secure and Scalable Optical Access Network using PLZT high-speed optical switches,” HSPR2009, No. 6-2, Jun. 2009.

[16] K. Tokuhashi, T. Sato, K. Ashizawa, D. Ishii, S. Okamoto, and N. Yamanaka, ”Extended MPCP Slot Data Transmission Experimental System for Active Optical Access Network,” OECC2010, No.8A1-5,Sapporo, Japan. Jul. 2010

[17] K. Wakayama, C. Hasegawa, D. IShii, N. Yamanaka, ”Evaluation of Prototype for 10Gbps Active Optical Access System”, OECC2010, No.8A4-3, Sapporo. Japan, Jul. 2010.

[18] Y. Zhang, P. Chowdhury, M. Tornatore, B. Mukherjee, ”Energy Efficiency in Telecom Optical Networks,” IEEE Communications Surveys & Tutorials, Vol.12,No.4, Fourth Quarter 2010.

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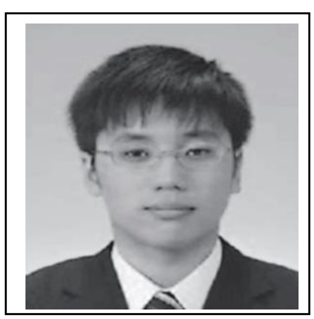

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