Cyber Journals: Multidisciplinary Journals in Science and Technology, Journal of Selected Areas in Telecommunications (JSAT), April Edition, 2013
Volume 3, Issue 4

A New Network Architecture using Cloud Control Plane for Reducing Power Consumption in Future Network

Shan Gao, Hidetoshi Takeshita, and Naoaki Yamanaka

Abstract—**To allow the Internet to provide a wide variety of communication services, high transfer speeds and high control speeds are essential. Developing such technologies for the future network will increase the power consumption of networks; a problem that is now is becoming an important issue. In this paper, we propose a novel network architecture, called the cloud control plane (Cloud C-plane), to reduce the power consumption of networks. Unlike conventional architectures, the forwarding functions and control functions are divided in the Cloud C-plane network architecture, and the control functions are placed in the cloud. Network equipment such as routers or switches are controlled and managed in the Cloud C-plane. In addition, the physical network topology is modified by activating deactivating network equipment so as to improve overall energy efficiency in response to changes in the traffic patterns. Implementing the routing engine on a dynamically reconfigurable processor (DRP) is one key to realizing the Cloud C-plane architecture. We also propose a traffic engineering method for reducing power consumption based on the new network. In, performance evolution, our method can reduce by 20%~50% power-on link. We also implement proposed method on an actual DRP.**

Index Terms—**Cloud Control plane (Cloud C-plane), power consumption, Dynamically Reconfigurable Processor (DRP)**

I. INTRODUCTION

Today, the Internet is becoming the key global infrastructure for telecommunication. The rapid adoption of the Internet is promoting the growth of the world economy and globalization. Internet traffic is rapidly increasing due to the increasing number of users and their use of higher bandwidth services. Internet Service Providers have been rushing to expand the capacity of their routers and switches and increasing network bandwidth to satisfy the users' demands. In addition, more powerful routers and switches are being developed. However, the use of these enhanced transmission equipment is triggering a sharp rise in power consumption [1]. Power consumption is becoming one of the key issues for future network technologies. Existing network such as routers, switches and hubs consumed an estimated 6.4 TWh/yr. in the U.S in 2004 [2]. One TWh/yr. is equivalent to 85 million dollars at 0.085 dollars per kWh [3] and about 0.75 million tons of carbon dioxide [4]. As a result, the power consumption of the network is roughly equal to the output of one nuclear power plant. The new network architecture is essential if we are to drastically reduce the power consumption of networks.

Network equipment designs have been described with the goal of reducing the power consumption of networks [1, 5-7]. In [5] authors describe the use of optics in routers as a means for increasing capacity and reducing power consumption. A method for decreasing the power consumption of the interconnection fabric was researched in [7]. Power consumption has become a key issue in network equipment designs.

Other studies have examined the power consumption of the network transmission system. The power consumption of Ethernet links was measured in [10,11]. It was shown that 100Mbps links consume about 4W less than 1Gbps links. This suggests that it is possible to reduce power consumption by operating links at a lower data rate during low utilization periods. An IEEE 802.3 Energy Efficient Ethernet Study Group was established [8]. They are exploring the standardization of ideas related to Adaptive Link Rate (ALR) [9]. ALR can be used to switch the data rate of Ethernet links automatically. In [12], switching policies suitable for variable link data rates were studied.

SDN [20] attracts attention as new network architecture. However, the power consumption problem is not resolved in this popular architecture.

This paper introduces new network architecture that decouples the forwarding and control functions of a router. Decoupling makes the network more advanced since the speeds at which their technologies evolve are different. It is better to decouple the control function from the router itself. Separating the forwarding and control functions is very suitable for cloud computing [13–15]. Cloud computing is being researched as a massive, distributed data center infrastructure created by network connections. In our proposed network architecture, control functions can be placed in the cloud. We call this architecture the cloud control plane (Cloud C-plane). In a Cloud C-plane based network, control functions can be run on a powerful server. Thus, sophisticated traffic engineering can be realized.

Shan Gao, Hidetoshi Takeshita, and Naoaki Yamanaka are with the Yamanaka Laboratory,
Department of Information and Computer Science, Keio University, 3-14-1 Hiyoshi, Kohoku, Yokohama, Kanagawa, JAPAN 223-8522
(e-mail:shan.gao@yamanaka.ics.keio.ac.jp)

The physical topology of the forwarding plane should change to better track changes in the traffic patterns in order to reduce the power consumption of the network. The physical topology change is not advertised to prevent the network from becoming unstable. The advertised network topology is independent from the physical topology, and the physical topology is optimized in terms of energy efficiency. The advertised network is used in the forwarding plane for routing.

Path calculation is a key element of Cloud C-plane, so we realize this function by a traffic engineering method and implementing it on a Dynamically Reconfigurable Processor (DRP)[22]. This approach makes use of an on-chip emulated network. Emulated packets are transmitted throughout the emulated network, and the shortest path is identified because the first emulated packet from the source node to the destination indicates the shortest path.

This paper as organized as follows. Section II describes the proposed architecture of Cloud C-plane. In Section III, we explain the proposed traffic engineering algorithm. The simulation results are is shown in Section IV, and implementation of our method is provided in Section V. Finally, we summarize this paper in Section VI.

II. CLOUD CONTROL PLANE

The current network devices consist of two main functions; forwarding and control function. This paper uses the terms forwarding element and control element to refer to blocks that offer forwarding functions and control functions, respectively. The control element of the current network device corresponds to its operating system that includes IOS [16], JUNOS [17] and so forth. The forwarding element and control element are tightly coupled in the current router as shown in the left side of Fig. 1. Our proposed network architecture, on the other hand, decouples them as shown in the right side of Fig. 1. Since the forwarding element and control element have different rates of evolution, decoupling is advantageous because they can be advanced independently.

Each control element is responsible for controlling and managing the tasks of its corresponding forwarding element such as routing. A control element communicates with its forwarding element by the Forwarding Element Control Protocol (FECP), which is similar to GSMP [18] or OpenFlow Protocol [19]. It is an interface between forwarding elements and control elements. For example, a control element sets the forwarding configuration via FECP. Across the network, the control elements form the control plane and the forwarding elements the forwarding plane.

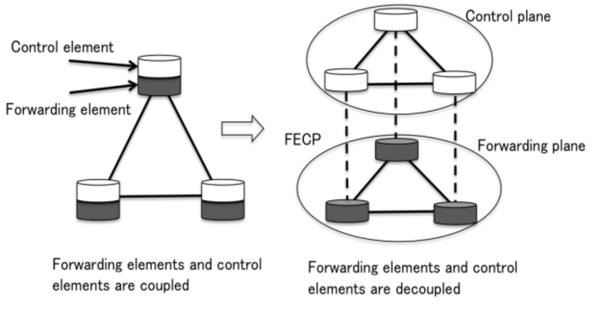


Fig. 1 Forwarding element and control element are decoupled in our proposal

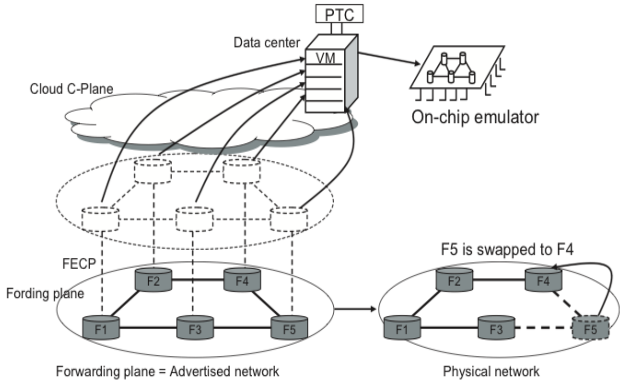


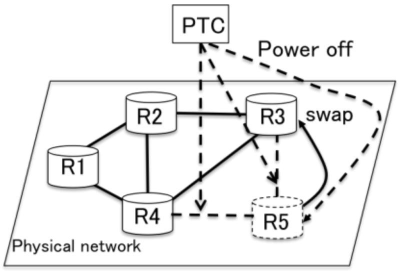
Fig. 2 Network architecture of Cloud control plane

A control element does not have to be co-sited with its forwarding element. Figure 2 shows that the control plane lies in the cloud. Control elements can be virtualized as a software service because they are physically decoupled from their forwarding elements. We call this architecture the cloud control plane (Cloud C-plane). As a result, control elements run on virtual machines, and are likely to be placed in a server in a data center.

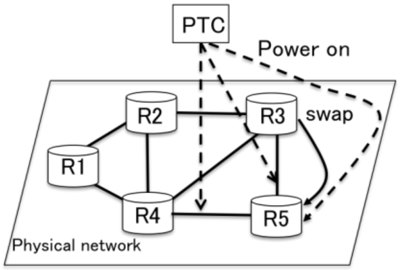
The Cloud C-plane architecture allows the physical network topology to change so as to minimize the network's overall power consumption. However, the advertised network topology does not change in order to maintain the network's stability. The advertised network remains unchanged even when the physical topology changes. Physical Topology Controller (PTC) is responsible for decisions about activating/deactivating forwarding elements. Each control element monitors the amount of traffic through its corresponding forwarding element, and periodically reports the traffic information to PTC. Consequently, PTC knows the load of all links in the network, and all information about the physical topology. PTC determines which forwarding elements should be active according to the current network state. In Fig. 2, forwarding element F2 is going to be powered off so its functions are virtually switched to F3 to maintain the advertised topology. PTC configures the control elements to complete the above procedures without modifying the topology of the advertised network.

The number of active routers and links is large (small) when the network load is high (low). Figure 3 shows physical topology modification when the amount of traffic changes. In this case, network forwarding element R3 is turned off and virtually moved to R1 at low network loads, so the power consumption of two links and one network equipment can be saved. However, these two links and R3 will be reactivated *when network load is high.*

PTC and control elements placed in the cloud are important components of our proposal. As shown in Fig. 2, each control element is running on a virtual machine, and several virtual machines are sited in a server. To speed up path computation in



(a) When network load is low



(b) When network load is high

Fig. 3 Power management of network by changing the physical topology

these control elements and optimization in PTC, we propose that the elements and optimization in PTC, we proposed that the server be equipped with a routing engine. The engine can be shared among the control elements on the virtual machines.

We propose the routing engine to be based on a Dynamically Reconfigurable Processor (DRP). The proposed routing engine architecture is described in detail in the next section.

III. TRAFFIC ENGINEERING METHOD

A. Mechanism

We propose a traffic engineering method to reduce the power consumption in the low-load period of network. The approach is that we aggregate the traffic load to certain\ links and raise the utilization rate of these links. To other idle links, which no traffic pass through, we can set them power-off. In this way, we raise the utilization of links and power off the idle links so that we can save the power consumption of idle links. In addition, we set a threshold of the load of each link in order to avoid congestion. While the load of link is below the threshold, it is considered that no traffic congestion happens.

OSPF is general routing protocol that used in the network. According to the OSPF protocol, traffic adopts the shortest path algorithm to choose paths. And the shortest path algorithm is executed based on the weight of paths. In a word, the weight of link decides whether the link carry traffic or not. Therefore, we modify the weights of links, in other words dynamically increase or decrease weights, to change the paths of traffic and achieve the aggregation of traffic.

B. Detailed Flow

The main process of the proposed approach is shown in Fig. 4. The details steps are as follows.

Step 1 : Firstly, each node looks up any links that link to another node.

Step 2 : Meanwhile, the traffic load of these links cannot exceed the threshold. If the links that meet the conditions exist, go to next step.

Step 3 : Compare the load of links and choose one link which has larger load to decrease the weight. Notice the node which the modified link connects to that the weight of this link has been modified and do not need to modify it again; Notice new link status to other nodes.

Step 4 : After getting new information of weights of links, each node re-calculates the paths to reach other nodes. According to the new path vectors, the traffic re-chooses the transmission paths.

Step 5 : Each node checks the traffic load of links. If any link has no traffic load, determine the connectivity of the whole network without this link. If the network remains connected, set the link power-off. If not, end the process. Check the load of links again. If the load is still below the threshold, go to step 2. Or when the number of all power-on links in the network becomes the minimum of number of links guaranteeing the network connectivity, the whole process stop.

Step 6 : If the load of link is beyond the threshold, the process should stop decreasing the weight and recover links to the previous status. That is, set the weight of link to the previous weight and if set certain link power-off in the previous step, reset the link power-on. After that, the whole process ends.

The function of decreasing the weight we choose when the load is less than or equal to the threshold is

$$weight' = k \times weight(load < threshold)$$

(Weight' is the modified weight of link. k is coefficient)

When the traffic load increases and the load of certain link exceed the threshold, we need to recover to the previous status. Hence, the weight of link is changed as follows:

$$weight' = weight / k(load < threshold)$$

In a word, the weight of link is modified as follows:

$$weight' = \begin{cases} k \times weight(load \leq threshold) \\ weight / k(load > threshold) \end{cases} \quad (1)$$

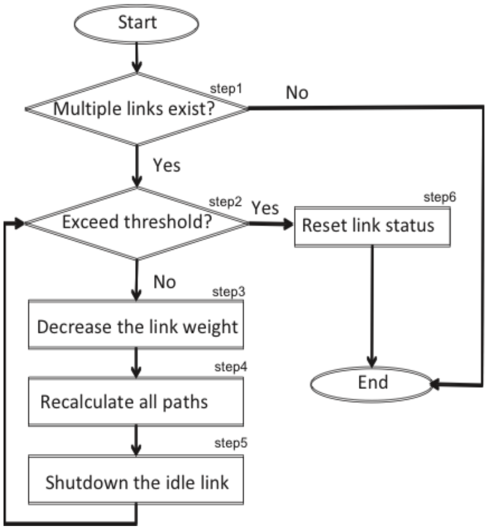


Fig. 4 The main flow of traffic engineering method

C. An Example

For a detailed description of our approach, take the following simple network with three nodes as an example. The initial weights of links are shown in Fig. 5.

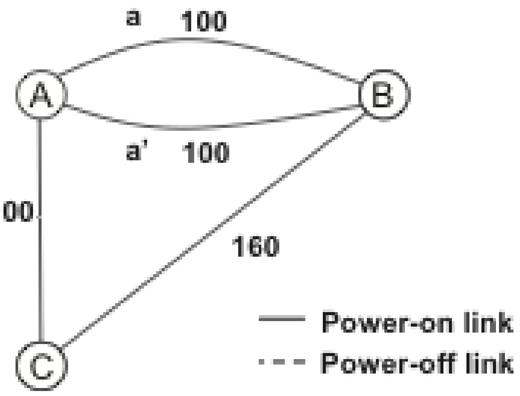


Fig. 5 Three nodes Network (Initial state)

We assume that the capacity of load of each link is 1.0. Each node has the same traffic to other nodes and the traffic load is 0.1. That is, Node A has traffic to Node B and Node C, and the traffic load is 0.1; Node B also send traffic which load is equal to 0.1 to Node A and Node C; So is the same as Node C. Based on the shortest path algorithm and the load balancing strategies, we can get the original load of each link and show in the Table I.

TABLE I
THE LINK LOAD TALBE

Link	load
Link a	0.1
Link a'	0.1
Link AC	0.2
Link BC	0.2

Take Node A as an example. Node A is found to have two links (link a and link a') leading to Node B, and the sum of the load of two links does not exceed the threshold (the threshold is selected as 0.8 in this example). Therefore, Node A chooses one link to modify the weight, that is, Link a is chosen and the weight of Link a is revised to 70 (here we have chosen k = 0:7). Next step is to notice the new link state to Node B and Node C. To Node B, it does not need to modify the weights of Link a or Link a' because Node A modifies the weights of link. According to the new link states, each node re-calculates the paths to other nodes, and traffic re-selected paths to destinations. A new links' load table is shown Table II.

From Table II, it is found that no traffic pass through Link a'. Node A and Node C checked the network connection again without Link a0. The result showed the entire network is still connective. Hence, we set Link a' power-off. At the same time, the load of Link a dose not meet the threshold, so Node A modified the weight of Link a to 49. After exchanging the link states among nodes, each node got new path vectors. In particular, the traffic from Node C to Node B changes the paths and passed though Link a and Link AC. At this time, the load links table is as Table III.

TABLE Ⅱ
THE LINK LOAD TALBE

Link	load
Link a	0.2
Link a'	0
Link AC	0.2
Link BC	0.2

TABLE Ⅲ
THE LINK LOAD TALBE

Link	load
Link a	0.4
Link a'	0
Link AC	0.4
Link BC	0

As a result, Link BC is an idle link now and Node B and Node C can still reach the other nodes without Link BC. Therefore, set Link BC power-off. Right now the entire network only has the minimum number of links power-on, so end the algorithm. Finally, the network connection diagram is as figure 6.

Figure 6 shows that the number of power-on links is the minimum required number of links. So, at the time the power consumption of this network reduces to the least value and save the max of power consumption.

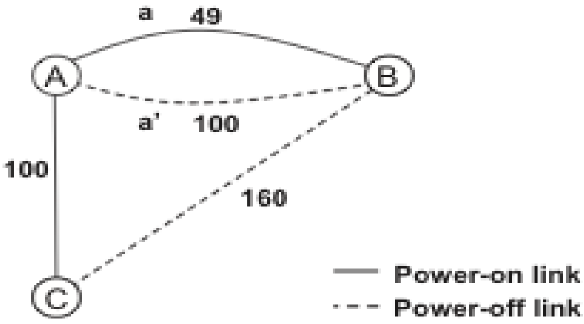


Fig. 6 3-nodes network

IV. PERFORMANCE EVALUATIONS

We evaluated the performance of the link power-off approach in computer simulation. The topology of network in simulation is shown as figure. 7.

In this network, there are six nodes and eleven links. Especially three pairs of links link to the same nodes and have the same weight originally.

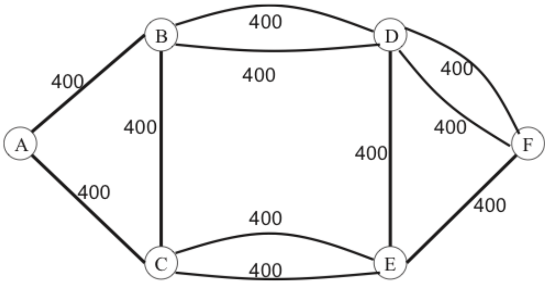


Fig.7 The topology of network

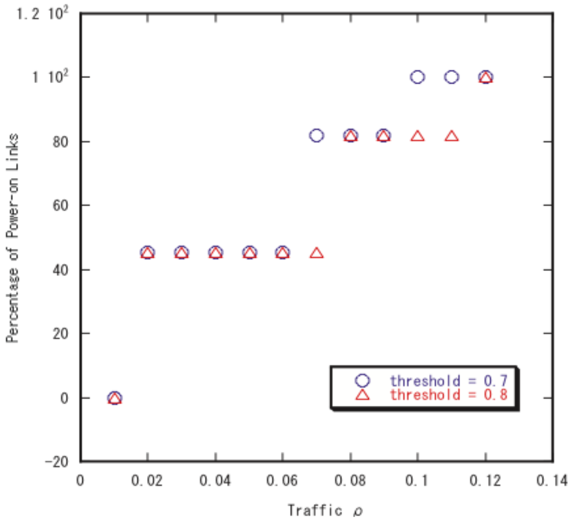


Fig. 8 The percentage of power-on links

We defined the traffic capacity of each link as 1.0. In the simulation, traffic load is assumed in static state. Each node sends the same traffic ρ to other nodes. The traffic load ρ varies from 0.01, gradually increases by 0.01 until the load of links is beyond the threshold. We did the simulation respectively when the threshold was selected as 0.7 and 0.8.

Figure 8 shows the relation of the percentage of power-on links and the traffic load when the threshold of load of links is different. In this network, the minimum number of links that should be power-on is 5 to ensure that each node is connective. In other words, the minimum percentage of power-on links is about 45.5%. From figure 8, we can see that the number of power on links remain the least even though the traffic load increase 7 times from 0.01 to 0.07 when threshold is selected as 0.8. And while the traffic load varies from 0.08 to 0.11, there is 80% links set power-on. Similarly, when the threshold is 0.7, the power-on links are still the minimum link set until the traffic load is beyond 0.06. While the traffic load is medium, we also can set 20% links power-off.

Figure 9 shows the probable reduced power consumption in the case of Cisco GSR 12008 as router. In [21], the power consumption of 1 port Oc-48/POS in a router line card is 70 watts. And one link setting power off means two ports of router line can be shut down. In other words, one link set power-off can reduce 140 watts power. In the simulation, the maximum of the number of power-off links is 6. So the reduced power consumption can reach 840 watts in the period of low traffic and 280 watts in the period of medium traffic.

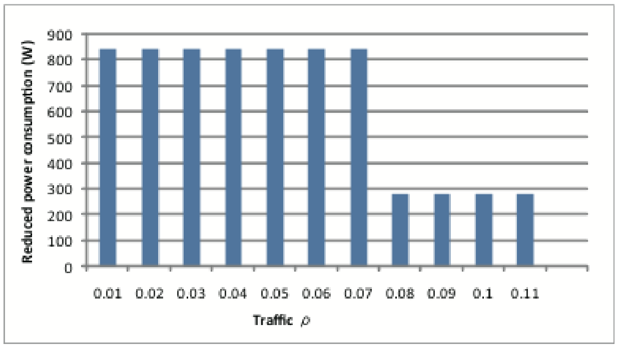


Fig.9. The reduced power consumption

V. IMPLEMENTATION ON DRP

We implement proposed energy efficient method in dynamically reconfigurable processor DAPDNA-2 [23, 24] for calculate energy efficient route in cloud C-plane network. Cloud C-plane network is a centralize control architecture, and a high-speed routing engine is needed. Therefore, we implement our algorithm in a parallel and reconfigurable processor.

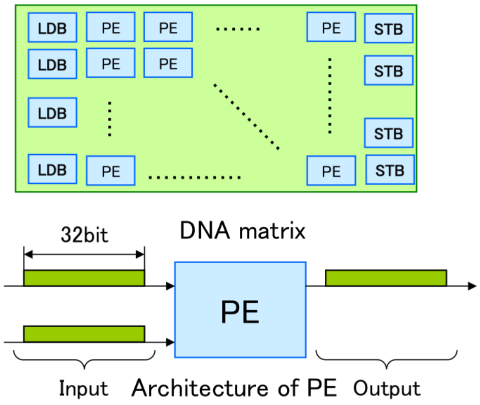


Fig.10 PE composition in DAPDNA-2

DAPDNA-2 consists of DAP (Digital Application Processor), a high-performance RISC core DNA (Digital Network Architecture). The DNA is embedded in an array of 376 PE (Processing Elements), which are comprised of computation units, memory, synchronizers and counters. The DNA has several memory banks to store configurations. There are 3 banks memory in background memory and a bank in foreground. These 4 banks store 4 configurations, but just the foreground memory is active. DNA can change configuration by loading another configuration among 3 background memories.

We construct a diorama network by configuring several PEs in DNA. We set parameters of each PE to emulate various functions which real nodes and real links have. For searching the route from source node to destination node, we send a virtual packet that transmits in the processor. Figure11 shows an example of our diorama network construction. There are 5 nodes and 8 links in real network, so we construct 5 virtual nodes and 8 virtual links by using several PEs in parallel processor, and connect them. Then we read a 32-bit data as a virtual packet from the main memory, and transmit this virtual packet in the processor. The virtual packets are broadcasted from the source node. Finally, we collect virtual packet at destination node and write it into the memory. When we want to use this VPSP, we can read it from the memory.

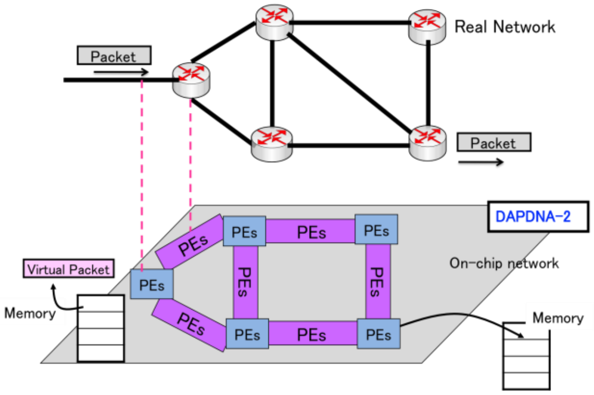


Fig. 11 Construct an On-chip network based on a real network.

VI. CONCLUSION

Network power consumption is becoming a serious issue in future network technologies because it is expected that network power consumption will skyrocket in the next decade. Therefore, the new network architecture suitable for improving power efficiency is required. The SDN architecture is currently most popular network architecture. However, they do not discuss SDN architecture about power efficiency issues yet. In this paper, we proposed the new network architecture, Cloud C-plane, to aggressively optimize the power efficiency of the network. In our proposed network architecture, the forwarding plane and control plane is divided, and the controllers are placed in the cloud. Network equipment such as routers or switches are controlled and managed by the Cloud C-plane. Furthermore, the physical network topology is controlled to maintain power optimal topology corresponding to traffic patterns by power on/off control of links or switches fabrics in network equipment or network equipment. We also proposed a traffic engineering method, which dynamically changes link cost to aggregate traffic load in active links and power-off the vacant links or network equipment. This method is implemented on a DRP and network simulations result shows that the method can reduce the network power consumption by 20%~50%.

ACKNOWLEDGMENT

This work is partly supported by the National Institute of Information and Commucations Technology (NICT).

REFERENCES

[1] Luc Ceuppens, Alan Sardella, Daniel Kharitonov, "Power saving strategies and technologies in network equipment opportunities and challenges, risk and rewards," IEEE International Symposium on Applications and the Internet 2008, pp381-384.
[2] K.Roth, G.Larocque, and J.Kleinman, Energy Consumption by office and Telecommunications Equipment in Commercial Buildings, Volume II; Energy Savings Potential, TIAX Reference No.D0065-11.08, December.2004.
[3] United States Energy Information Administration, Electric Power Monthly, Table 5.3, http://www.eia.doe.gov/cneaf/electricity/epm/epm¥_sum.html, June 2007.
[4] "Carbon Dioxide Emissions from the Generation of Electric Power in the United States," US Dept. of Energy and the Environmental Protection Agency, http://www.eia.doe.gov/cne
[5] I. Keslassy, S. Chuang, K. Yu, D. Miller, M. Horowitz, O. Solgaard, and N. McKeown, “Scaling internet routers using optics,” in Proceedings of ACM SIGCOMM ’03, Karlsruhe, Germany, August 2003.
[6] C. Minkenberg, R. Luijten, F. Abel, W. Denzel, and M. Gusat, “Current Issues in Packet Switch Design,” in Proceedings of ACM/USENIX HotNets ’02, Princeton, NJ, October 2002.
[7] A. Wassal and M. Hasan, “Low-power System-level Design of VLSI Packet Switching Fabrics,” IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems, vol. 20, no. 6, June 2001.
[8] IEEE 802.3 Energy Efficient Ethernet Study Group, http://grouper.ieee.org/groups/802/3/eee_study/ May 2007.
[9] C.Gunaratne, K. Christensen, and S.Suen, ”Ethernet Adaptive Link Rate(alr): Analysis of A Buffer Threshold Policy,” IEEE Globecom, 2006.
[10] C.Gunaratne, K. Christensen, and B.Nordman, “Managing Energy Consumptin Costs in Desktop PCs and LAN Switches with proxying, Split TCP connections, and scaling of link speed,” Int.J.Network Management, Vol.15, no.5, pp.297-310, Sept./Oct.2005.”
[11] C.Gunaratne, K.Christensen, S.Suen, “Ethernet Adaptive Link Rate (ALR): Analysis of a Buffer Threshold,” Proc. IEEE Global telecomm. Conf., Nov.2006.
[12] Chamara Gunaratne, Student Member, IEEE, Ken Christensen, Senior Member, IEEE, Bruce Nordman, and Stephen Suen, “Reducing the Energy Consumption of Ethernet with Adaptive Link Rate (ALR),” IEEE TRANSACTIONS ON COMPUTERS, VOL.57, NO4, pp448-461, APRIL 2008.
[13] Gorder, Pam Frost, “Coming Soon: Research in a Cloud,” Computing in Science Engineering, Vol. 10, Issue 6, pp6-10, Nov.-Dec. 2008.
[14] Leavitt, N, "Is Cloud Computing Really Ready for Prime Time," Computer, Vol. 42, Issue 2, pp15-20, Jan. 2009.
[15] Geng Lin; Fu, D.; Jinzy Zhu; Dasmalchi, G, "Cloud Computing: IT as a Service," IT Professional, Volume 11, Issue 2, pp.10-13, March-April 2009.
[16] Cisco IOS, http://www.cisco.com/en/US/products/ps6537/products_ios_sub_ category_home.html.
[17] Juniper Neworks, http://www.juniper.net/jp/jp/products-services/nos/junos/.
[18] A.Doria, F.Hellstrand, K.Sundell, and T.Worster, "General switch management protocol (GSMP) v3," Request For Comments (RFC), no.3292, Jun. 2002.
[19] B.Heller, "OpenFlow switch specification version 0.8.9," http://www.openflowswitch.org/documents/openflow-spec-v.
[20] Goth, G. "Software-Defined Networking Could Shake Up More than Packets" Internet Computing, IEEE Volume:15, Issue: 4, 2011 , pp6-9
[21] Joseph Chabarek, Joel Sommers, Paul Barford, Cristian Estan, David Tsiang, Steve Wright, ”Power Awareness in Network Design and Routing”, Infocom, April 2008.
[22] H.Amano,"A survey on dynamically reconfigurable processors," IEICE Transactions on Communications, vol. E89-B, no.12, pp.13179-3187, Dec.2006
[23] T.Sugawara, K.Ide, and T.Sato, "Dynamically reconfigurable processor implemented with IPFlex's DAPDNA technology," IEICE Transactions on Information and Systems, vol. E87-D, no.8, pp. 1997-2003, Aug.2004.
[24] T. Sato, H. Watanabe, and K. Shiba, “Implementation of dynamically reconfigurable processor DAPDNA-2,” in Proceedings of the IEEE VLSI-TSA International Symposium on VLSI Design, Auto

Shan Gao received B.E. and M.E degrees from Keio University, Japan, in 2008 and 2010, respectively. He is currently working toward the Ph.D. degree in Graduate School of Science and Technology, Keio University, Japan. Since 2010, he has been researching about the network architecture and traffic engineering on the next generation optical network. In 2010, he will became a research assistant of Keio University Global COE Program, ``High-level Global Cooperation for Leading-edge Platform on Access Spaces" by Ministry of Education, Culture, Sports, Science and Technology, Japan. He is a student member of the IEEE of Japan.

Hidetoshi Takeshita graduated from Shizuoka University, Japan where he received the B.E in 1974. In 1974 he joined NEC Corporation, Tokyo, Japan, where he engaged in the development of electronic switching systems, digital switching systems, and system engineering for fixed and mobile carriers. He graduated from Keio University where he received the Ph.D. degree in Sept. 2012. From 2010 to 2012, he was a Research Assistant of Keio University Global COE Program, and from June to September in 2012, he was a researcher in Graduate School of Science and Technology of Keio University. Since Oct. 2012, he has been a project assistant professor. He is a member of the IEEE, and the IEICE.

Naoaki Yamanaka graduated from Keio University, Japan where he received the B.E., M.E., and Ph.D. degrees in engineering in 1981, 1983 and 1991, respectively. In 1983 he joined Nippon Telegraph and Telephone Corporation's (NTT's) Communication Switching Laboratories, Tokyo, Japan, where he was engaged in the research and development of a high-speed switching system and high-speed switching technologies for Broadband ISDN services. Since 1994, he has been active in the development of ATM-based backbone network and system including Tb/s electrical/Optical backbone switching as NTT's Distinguished Technical Member. He is now researching future optical IP networks, and optical MPLS router systems. He is currently a professor of Keio Univ. and a chair of Photonic Internet Lab. (PIL). He has published over 126 peer-reviewed journal and transaction articles, written 107 international conference papers, and been awarded 182 patents including 21 international patents. Dr. Yamanaka received Best of Conference Awards from the 40th, 44th, and 48th IEEE Electronic Components and Technology Conference in 1990, 1994 and 1998, TELECOM System Technology Prize from the Telecommunications Advancement Foundation in 1994, IEEE CPMT Transactions Part B: Best Transactions Paper Award in 1996 and IEICE Transaction Paper Award in 1999. Dr. Yamanaka was Technical Editor of IEEE Communication Magazine, Broadband Network Area Editor of IEEE Communication Surveys, and was Editor of IEICE Transaction as well as director of Asia Pacific Board at IEEE Communications Society. Dr. Yamanaka is an IEEE Fellow and an IEICE Fellow.