Flow-based Routing Schemes for Minimizing Network Energy Consumption using OpenFlow

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***Abstract*—With the growing amount of traffic on the Internet, network devices are consuming increasing energy as their transmission capacity increases. Therefore, the reduction of network power consumption is an important issue. Software-defined networking is receiving significant attention as a means to manage increased network traffic efficiently. We consider energy efficient routing schemes with traffic aggregation for each flow that maintain acceptable performance using OpenFlow. The proposed schemes aggregate traffic to build a network using the minimum active devices necessary. Through simulation evaluation, we show that the proposed schemes can reduce power consumption, in comparison with the conventional routing protocol.**

Keywords-Routing; Energy-Efficiency; Green network; OpenFlow; QoS.

I. Introduction

Power saving technology for network devices has become an important issue due to growing demand for power conservation. In addition, Software-Defined Networking (SDN) is receiving significant attention as a means to manage increasing network traffic efficiently. OpenFlow, which enables flexible and centralized network management, plays a central role in SDN enabled routing for each flow and allows dynamic control of network routing and metrics.

Many researchers have proposed network power saving schemes [1][2][3], such as ElasticTree [4]. Some of these schemes control traffic aggregation with using network devices, effectively building a power saving sub-network. These schemes can reduce unnecessary power consumption by restructuring the network relative to traffic activity and requirements. However, these schemes have some inherent issues. For example, increasing wait time for optimization of all network flows and reduced responsiveness of new flows.

In this study, we consider a dynamic and energy efficient routing scheme that applies traffic aggregation for each flow while maintaining acceptable performance using OpenFlow. The proposed schemes can build a power saving sub-network by changing only the operating mode of nodes and links as required without restructuring the entire network. Simulation results indicate that the proposed schemes can reduce network power consumption, in comparison with Open Shortest Path First (OSPF) [5].

In Section II, we describe related works in this area. Section III shows the proposed scheme. Section IV shows the simulation model, and its results will be discussed in Section V. Finally, we describe our conclusion in Section VI.

TABLE I. POWER CONSUMPTION SUMMARY FOR ENTERPRISE SWITCHES

Configuration	Rack Switch(W)	Tier-2 switch(W)
Chassis	146	54
Linecard	0 (include in chassis)	39
10Mbps/port	0.12	0.42
100Mbps/port	0.18	0.48
1Gbps/port	0.87	0.90

II. Related study

Existing routing protocols, such as OSPF or IS-IS [6] provide shortest path. Also, many researchers have proposed TE (Traffic Engineering) which uses effective network resource for achieving QoS. Many of TE approaches try to spread the load among multiple paths, so they do not consider the power saving. Therefore, we require the new routing scheme for achieving power saving without deteriorating communication quality.

Many researchers have proposed power saving schemes in a network area. In this section, we first show the power saving effect on the network. Then, power saving schemes for node and link are described. Finally, we show the power saving with traffic engineering.

A. Power saving effect

Mahadevan et al. measured the power consumption of network devices in their data center [7]. They measured power usage of each linecard and chassis, and of different transmission rate at a port. The obtained measurement is summarized in Table I. From this table, the power consumption of network devices such as switch or router is about 100 W, and of link is about 1.0 W. Therefore, we can expect power saving if the number of active nodes and links are dynamically adapted to the arriving traffic.

B. Node and Link state control for power saving

Gupta et al. proposed three policies for power saving by putting network components to sleep mode [8]. In the first policy, the device sets a sleep timer, and only wakes up when the timer expires. All packets arriving during the sleep period are lost. This approach can achieve stable power saving

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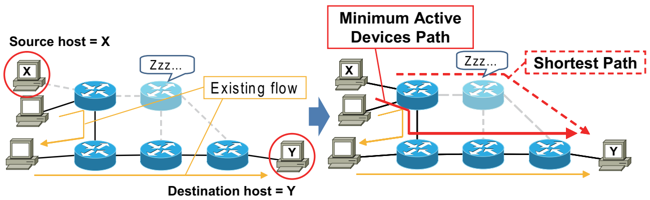

Figure 1. Overview of proposed schemes

performance, but cause performance degradation because of packet loss. The second is Hardware Assisted Sleep (HAS) policy in which the interface wakes up by an incoming packet; however, the packet is lost. The third is the Hardware Assisted Buffered Sleep (HABS) policy, to buffer the incoming packets while the interface is in the sleep mode. HABS consumes the power in the sleep state to buffer the incoming packets, but avoid the packet loss.

Uncoordinated sleeping informs its neighbor before network devices put into the sleep mode [9]. In this scheme, in order to avoid the packet loss, the neighbor hosts send a wake up packet to the hosts with sleep state. Nedevschi et al. proposed the power management schemes to reduce the energy consumption in the network [10]. Putting network elements to sleep mode during idle times and rate adaptation according to the arrival traffic are used. Their work focuses on edge routers in the Internet.

C. *Traffic control for power saving*

Heller et al. proposed the ElasticTree, which is the network wide power manager [4]. ElasticTree can dynamically adjust the number of active nodes and links. This scheme increases the more computational cost by growing the size of the network. Therefore, throughput is lower because of decreasing the processing speed of devices.

Vasic and Kostic proposed the Energy-Aware Traffic engineering (EATe), which reduces the power consumption while maintaining same traffic rate [11]. This scheme distributes traffic while periodically exchange link utilization between nodes. Therefore, we think that power saving performance is relatively low.

From the above, we propose a scheme that can achieve higher energy efficiency without deteriorating the throughput.

III. PROPOSED SCHEMES

In this section, we propose two schemes that consider not shortest paths but dynamic flow aggregation to increase sleep state in nodes and links. Overview of both proposed schemes is shown in Fig. 1. OpenFlow is used in the proposed schemes to manage network operations, allowing centralized and dynamic control of network routing and metrics.

A. *Routing for Minimization of Active Devices*

We refer to this scheme as Routing for Minimization of Active Devices (RMAD). This scheme selects a path to maximize the number of active state links from several shortest path for minimization of active links in the whole of middle or low load network. In the RMAD scheme, we use not only the shortest hop count but also number of active links as a routing metric. The number of active links is changed dynamically according to flow arrival using OpenFlow routing management. The procedure of RMAD scheme is shown in Fig. 2 and is as follows:

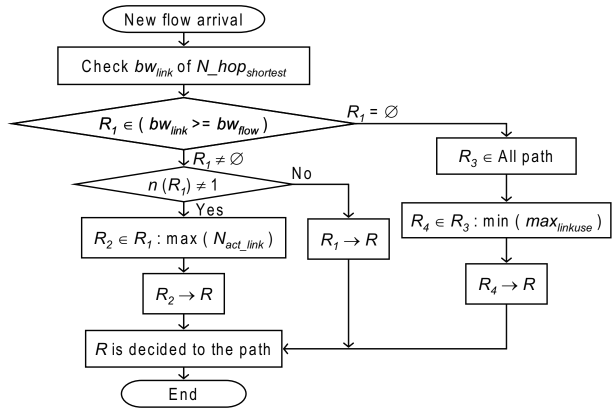

Figure 2. Procedure of RMAD scheme

(1) We obtain the shortest paths to the destination. Then, the paths of which residual bandwidth (bw_{link}) is larger than reguired bandwidth of new flow (bw_{flow}) are denoted as candidates R_1.
(2) If $R_1 \neq \phi$, we select the path that maximizes the number of active links (N_{act_link}) from R_1. If the chosen path includes the sleep state link, the link is set to active state.
(3) If $R_1 = \phi$, we select the path that minimizes the maximum link utilization ($max_{linkuse}$) on the path.

RMAD can aggregate new flows to the links of active state, so that the number of active links in the network is reduced. In addition, communication performance degradation is avoided by using shortest path and the path which minimizes the maximum link utilization on the path even if we cannot find the R_1.

B. *Routing for Minimization of Active Devices plus*

As previously mentioned, RMAD considers only active links to reduce power consumption. However, we can expect greater power savings by decreasing the number of active nodes using dynamic routing controlled by OpenFlow because node power consumption is greater than link power consumption [7]. We refer to this scheme as "RMAD+". The procedure of RMAD+ scheme is shown in Fig. 3 and is as follows:

(1) We obtain paths with hop counts that do not exceed the shortest path ($N\_hop_{shortest}$) plus δ. Next, the paths with residual bandwidth (bw_{link}) larger than the reguired bandwidth of new flow (bw_{flow}) are denoted as candidates R_1.
(2) If $R_1 \neq \phi$, we select the path R_2 that minimizes the number of active nodes in the entire network ($N\_all_{act\_node}$) from R_1.
(3) We select the path R_3 that minimizes the number of active links in the entire network ($N\_all_{act\_link}$) from R_2.

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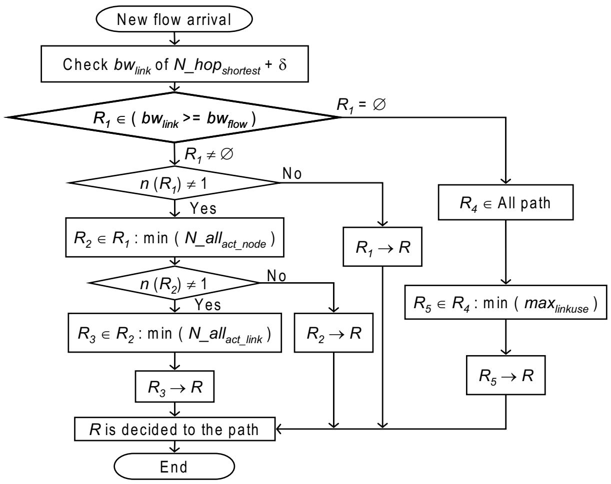

Figure 3. Procedure of RMAD+ scheme

(4) If $R_1 = \phi$, we select the path that minimizes the maximum link utilization ($max_{linkuse}$) on the path.

RMAD can aggregate new flows to active links, thus reducing the number of active links in the network. Moreover, RMAD+ considers the number of active nodes and concentrates flows on active paths. Therefore, we can expect greater power saving compared to RMAD. In addition, communication performance degradation is avoided by using the path that minimizes the maximum link utilization on the path even if we cannot find a satisfactory R_1. Furthermore, RMAD+ avoids paths with high link utilization, thus communication performance does not degrade significantly.

IV. Simulation Model

We evaluate the proposed schemes in terms of both data transfer and power saving performance. Simulation experiments were performed by using the network simulator, *ns-2*.

In our simulation, we used a multi rooted fat-tree topology, which is commonly used in many data centers. The multi rooted fat-tree topology consists of three-layer (i.e., Edge, Aggregation, and Core layers) on top of the end hosts. A pod of the fat-tree topology is a set of Edge and Aggregation routers. In our simulation, we use a 4-pod fat-tree topology with 16 end hosts. The average communication period follows the *exponential distribution*, and its average was set to α. In the data transmission, end hosts transmit data only during the *ON* time, and the *OFF* time is determined at the end of each data transmission according to the exponential distribution. Thus, the hosts are silent in the *OFF* time and start data transmission again after this interval. We defined the each *ON* time as a flow, and end hosts send Constant Bit Rate (CBR) packets at transmission rates of 500 Kb/s as a flow in each *ON* time. The network load ρ is defined by the following equation:

$$\rho = \frac{\text{Sum of } \alpha}{\text{Simulation Time}}$$

In this simulation, we vary the load factor ρ from 0.1 to 0.9.

In the simulation, each end host selected the destination randomly or specifically. In the first case, the destination was selected uniformly from the end hosts. In contrast, 70% of the flows in the second case were distributed among four end hosts in a single pod. Figure 4 shows an overview of case of concentrating flows. We conduct our simulation experiments for 20 seconds. The parameters used in our simulation are summarized in Table II.

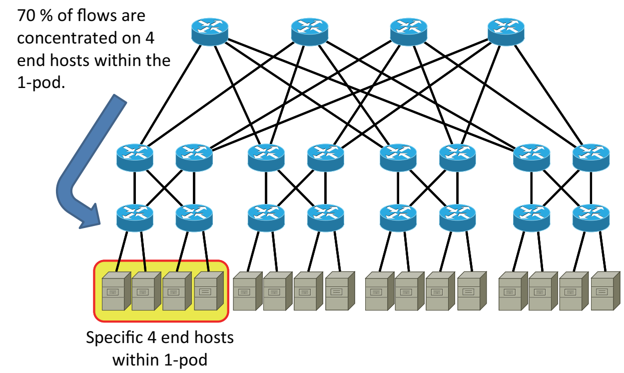

Figure 4. Simulation model of concentrating flows

TABLE II. SIMULATION PARAMETER

Simulation Time	20 s
Link Bandwidth	5.0 Mb/s
Link Delay	1.0 ms
Packet Size	1500 Byte
Transmission Rate	500 Kb/s
Average Time of Flow, α	1.0 s
Number of Flow Concurrent	1 / end hosts
Network load, ρ	0.1 $\sim$ 0.9

V. Simulation Results

We compared the performance of RMAD and RMAD+ against OSPF in terms of both power efficiency and communication performance. To quantify the performance of the proposed schemes, we used Node Sleep Ratio, Average Transmission Time, and Packet Loss Ratio as performance measures. Node sleep ratio defined as the percentage of device sleep time indicates power saving efficiency, and the average transmission time and packet loss ratio indicate communication performance.

Figure 5 shows the node sleep ratio for the case in which flow destination was selected from the end hosts with uniform probability. Figure 6 shows the node sleep ratio for the case in which the flow destinations were concentrated on specific end hosts. In both figures, RMAD+ (+δ) shows the number of hops to allow.

For both simulated traffic patterns, we observed that the node sleep ratio of the RMAD and RMAD+ schemes was higher than OSPF under any load. In addition, the node sleep ratio of RMAD+ was higher than that of RMAD under low load when the flow destination was selected from the end hosts with uniform probability. Moreover, the node sleep ratio of RMAD+ was always higher than that of RMAD when the flow destinations ware concentrated on specific end hosts.

We also researched the average transmission time and the ratio of packet loss of each schemes in order to show the effect on communication performance. Figure 7 shows the average

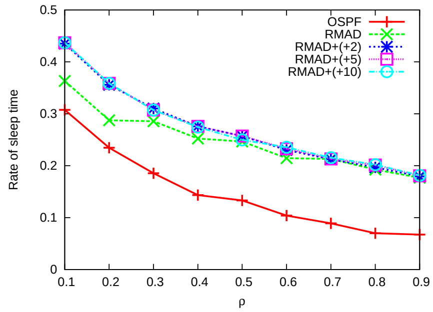

Figure 5. Node sleep ratio of uniform probability model

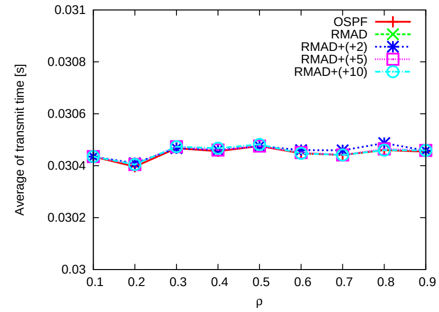

Figure 7. Average transmission time of uniform probability model

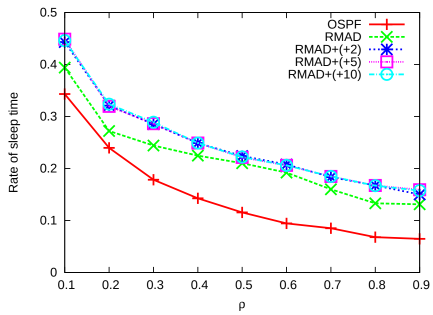

Figure 6. Node sleep ratio of concentrated flow model

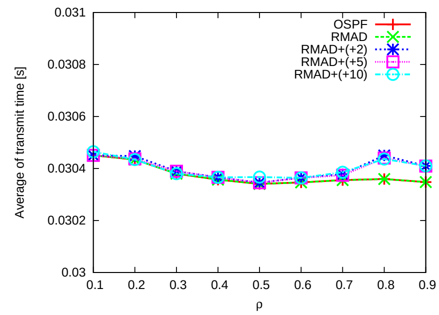

Figure 8. Average transmission time of concentrated flow model

transmission time for the case in which flow destination was selected from the end hosts with uniform probability. Figure 8 shows the average transmission time for the case in which the flow destinations were concentrated on specific end hosts. We observed that RMAD+'s average transmission time was longer than that of OSPF and RMAD. Furthermore, we did not observe any packet loss in the proposed schemes. If flow destinations are selected from specific end hosts, RMAD+ uses a concentrated path by considering power consumption rather than the shortest path. As a result, the node sleep ratio of RMAD+ was higher than that of OSPF and RMAD even under high load. However, the difference in average transmission time between the proposed schemes and OSPF is negligible. From these results, we conclude that the proposed schemes can achieve high energy efficiency without deteriorating communication quality.

VI. Conclusion and Future Work

We have proposed two energy efficient routing schemes that aggregate traffic on active network paths to decrease the number of active network devices while maintaining acceptable performance. By placing network devices without traffic into a sleep mode, power consumption in the network is reduced assuming that information management and path selection is performed by OpenFlow. The performance of the proposed schemes, RMAD and RMAD+ was compared against OSPF in terms of energy efficiency and communication quality. The simulation results indicate that the proposed schemes, on comparison with OSPF, can reduce power consumption without deteriorating communication quality. As a future work, we will compare proposed schemes with the existing energy efficient routing schemes. Also, we will evaluate the performance of the proposed schemes in various network environment.

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