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Virtual Routing Function Allocation Method for Minimizing Total Network Power Consumption

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***Abstract*—**In a conventional network, most network devices, such as routers, are dedicated devices that do not have much variation in capacity. In recent years, a new concept of network functions virtualisation (NFV) has come into use. The intention is to implement a variety of network functions with software on general-purpose servers and this allows the network operator to select their capacities and locations without any constraints. This paper focuses on the allocation of NFV-based routing functions which are one of critical network functions, and presents the virtual routing function allocation algorithm that minimizes the total power consumption. In addition, this study presents the useful allocation policy of virtual routing functions, based on an evaluation with a ladder-shaped network model. This policy takes the ratio of the power consumption of a routing function to that of a circuit and traffic distribution between areas into consideration. Furthermore, the present paper shows that there are cases where the use of NFV-based routing functions makes it possible to reduce the total power consumption dramatically, in comparison to a conventional network, in which it is not economically viable to distribute small-capacity routing functions.

***Keywords*—**Virtual routing function, NFV, resource allocation, minimum power consumption.

I. Introduction

In recent years, a new concept of network functions virtualization (NFV) [1]-[3] has been introduced. The main idea of NFV is the decoupling of physical network equipment from the functions that run on them. By virtualizing and consolidating network functions traditionally implemented in dedicated hardware and using cloud technologies, network operators expect to achieve greater agility and accelerate new service deployments while driving down both operational and capital costs.

The NFV implements a variety of network functions with software on general-purpose servers, enabling the network operator to select their capacities and locations without any constraints. In addition, since NFV makes it easy to change functions and their locations and capacities dynamically to suit the usage condition, an economical network can be constructed flexibly. Therefore, the efficient algorithm to determine the place where network functions are located and how much capacities of network functions are required is essential for economical network design.

The rest of this paper is organized as follows. Section II explains related works. Section III presents points of NFV-based routing function. Section IV proposes a virtual routing function allocation algorithm with least total power consumption. Section V evaluates the proposed algorithm using a ladder-shaped network model, which simulates the shape of Japan, and identifies the useful function allocation policy. Section VI presents the conclusions. This paper is an extension of the study presented in [15].

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II. Related Work

Reference [2] summarizes the main differences between the conventional networks and NFV-based networks as follows:

- Decoupling software from hardware
- Flexible network function deployment
- Dynamic operation

The above features of NFV enable the network operator to select any capacities and locations of network functions without any constraints. Therefore, the efficient algorithm to determine the place where network functions are located and how much capacities of network functions are required is essential for economical network design.

The issue of placing network functions would be related to virtual network embedding (VNE) [4], [5], which is used to allocate physical resources for virtual nodes/links to construct virtual network. Through dynamic mapping of virtual resources onto physical hardware, the benefit gained from existing hardware can be maximized. Reference [6] proposes a VNF chaining placement that combines location-routing and VNE problems, solving first the placement and then the chaining. Reference [7] focuses on a hybrid scenario where services are provided by dedicated physical hardware and virtualized service instances, and formulates the placement problem as an Integer Linear Program (ILP) with an objective of allocating a service chain onto the physical network minimizing the number of servers used. Reference [8] investigates the influence of virtualizing the S-GW and P-GW functions on the network load and network delay. It showed differences in performance when the functions were either fully virtualized and when their data and control planes were separated. The authors showed that four data centers are required to support a full virtualized gateways deployment for an exemplary gateway deployment in a US network. Reference [9] formulates the vDPI (virtual Deep Packet Inspection) placement as a cost minimizing problem, capturing the different constraints the operator is facing, and solves it as an integer linear program (ILP).

References [10]-[12] propose the joint multiple resource allocation method in a cloud computing environment that consists of multiple data centers with processing ability and bandwidth to access them, and demonstrate by simulation evaluations that the proposed methods can reduce the total resource much, compared with the conventional allocation method. The proposed resource allocation model is related to the online bin packing problem with composite bins, in which two bins (processing ability bin and a bandwidth bin) are consolidated.

As for dynamic allocation, [13] evaluates the online virtual function mapping and scheduling problem and proposes a set of greedy algorithms. Reference [14] proposes the automatic placement of the virtual nodes and the allocation of network services on them, supported by a monitoring system that collects and reports on the behavior of the resources.

Most of these studies mainly try to embed the virtual network functions to physical resources economically. On the other hand, this paper tries to determine the optimal capacity and location of virtual network functions without any physical constrains. This should be necessary for the network operators to design their network. This paper also tries to show that the use of NFV-based routing functions makes it possible to reduce the total power consumption dramatically.

III. Points of NFV-Based Routing Function Allocation

In an NFV-based network, routing functions are implemented with software on general-purpose servers. Therefore, routing functions of any capacities can be allocated economically at any locations. In general, routing functions can be allocated either in a centralized manner or in a distributed manner, as illustrated in Fig. 1. In a conventional network, the centralized allocation would be an economically viable option because capacity variations of routers are limited. Particularly, small capacity routers are not available.

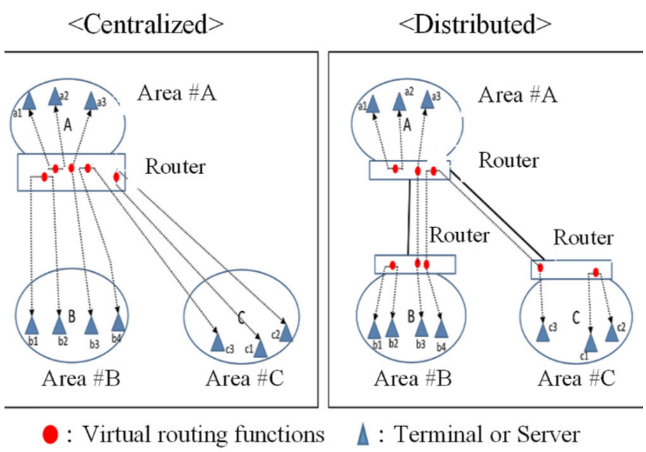

Fig. 1 Allocation examples of virtual routing functions

If distributed allocation is adopted, intra-area traffic does not need to go through routing functions outside the area concerned, resulting in less power consumption than in a centralized distribution. In addition, packet transfer delay is shorter, thereby enhancing the quality of service. It is necessary to take these factors into consideration in considering the routing function allocation in an NFV-based network.

IV. Virtual Routing Function Allocation Algorithm with Least Total Power Consumption

A. Proposed Allocation Algorithms

<Algorithm 1> Initially, allocate a routing function to every area. Then, select the area with the minimum number of packets sent or received per unit time (referred to as "integration-origin area"). If integrating the routing function of the selected area with that of another area (referred to as "integration-destination area") reduces the total power consumption, integrate them. Repeat this until the total power consumption can no longer be reduced or there is no integration-origin area left.

<Algorithm 2> Initially, allocate a routing function only to the area where the number of packets sent or received per unit time is the largest. Then, select the area where the number of packets sent or received per unit time is the second largest. If making the routing function of the first area handle the routing of the second area reduces the total power consumption, do so. Repeat this until the total power consumption can no longer be reduced or there is no area which can be handled by the routing function of another area.

In the next section, we explain the detailed allocation algorithm assuming Algorithm 1.

B. Detailed Algorithm of Routing Function Allocation

1. Overview of Processing Flow

The processing flow for determining whether to integrate two areas is described below by referring to Fig. 2.

Step 1. Selection of integration-origin area

Select an area with the least volume of packets sent or received per unit time, so as to minimize the amount of detour traffic (Area #3 in Fig. 2).

Step 2. Selection of integration-destination area

Select all area as integration-destination candidates except integration origin area.

Step 3. Integration

If the total power consumption after integration is smaller than the total power consumption before integration (P_A), the routing function of the integration-origin area is integrated into that of the integration-destination area in which the integration results in the smallest total power consumption. For example, if P_{B1} <P_{B2} <P_A, the routing function is integrated into the one in Area #1. If the total power consumption after integration is not smaller than that before integration, no integration is made.

2. Policy for Selecting Integration Source Areas Taking Their Locations into Consideration

Unless the volumes of traffic flows in the two directions between two areas are greatly unbalanced, integration source area candidates are selected in descending order of the distance from the center of the network. For example, in the ladder-shaped model shown in Fig. 3 (which simulates the shape of Japan and consists of 10 areas), it is desirable to reduce the total circuit length by integrating areas into G_3 (which contains Areas #5 and #6), which is close to the center of the network so that the total power consumption can be reduced. Areas #1, #2, #9, and #10 included in group G_1, which is the farthest from the center of the network, are first selected one by one as integration-origin area candidates. Whether to integrate them is determined using the algorithm described in Section 4.2.1. When all the areas in G_1 have been examined, Areas #3, #4, #7, and #8 in G2 are selected as integration-origin area candidates.

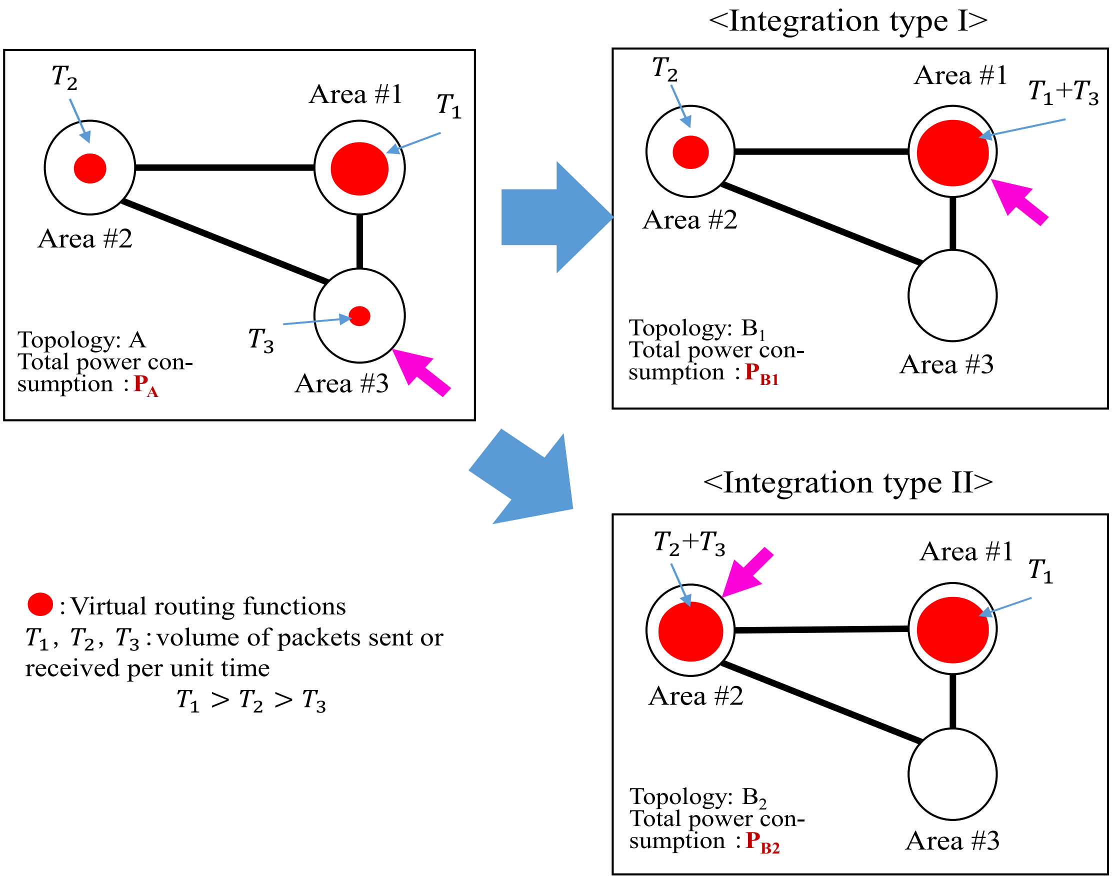

Fig. 2 Proposed algorithm of virtual routing function

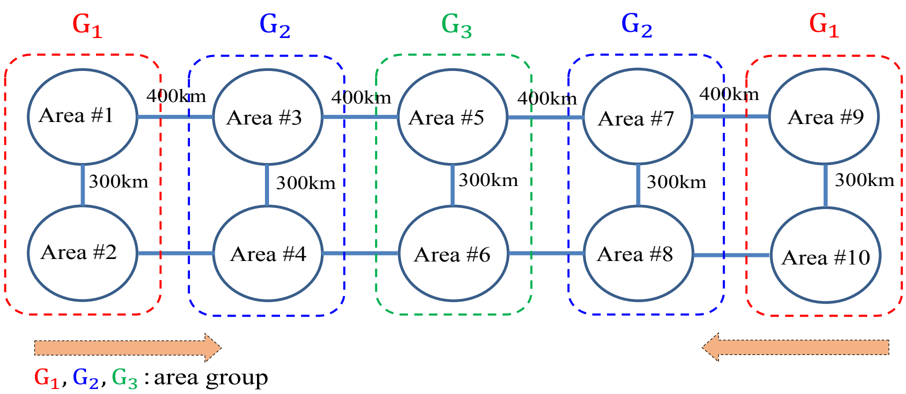

Fig. 3 Ladder-shaped network topology which simulates the shape of Japan

V. Evaluation of the Proposed Routing Function Allocation Algorithm

A. Evaluation Conditions

(1) Network structure: The ladder-shaped network illustrated in Fig. 3 is used for evaluation. There are 10 areas and the distance between two adjacent areas in the horizontal direction is 400 km while that in the vertical direction is 300 km.

(2) Traffic Model: It is supposed that there are 110 simultaneously communicating terminals in each area. If it is assumed that 20% of all terminals are communicating simultaneously, the total number of terminals in all areas will be about 5000 and this number is representative of

that of small-to-medium enterprises. The terminals are broken down into 11 sets of 10 terminals, and each set is communicating with a different area. Since it is desirable to consider applications that require the largest bandwidths and the largest number of packets, video traffic is assumed. The bandwidth (one way) required for communication by each terminal is set to 1.8 Mbps, and the packet length is set to 7200 bits. The capacity of each routing function (one way) is 250 pps.

(3) In addition, to evaluate unbalanced traffic distribution, it is assumed that traffic concentrated on the central area (Area #5 in Fig. 3). To evaluate the effect of traffic concentration on Area #5, it is assumed that the volume of traffic between Area 5 and any of the other areas is **M** times (referred to as "peak coefficient") larger than that between non-Area #5 areas. If M is one, the traffic distribution is uniform.

(4) **Z** is defined as the ratio of the power consumption of a routing function to that of a circuit is critical, as in (1):

$$Z=\alpha/\beta \tag{1}$$

where α [W] is the power consumption of a routing function per pps, and β [W] is the power consumption of a circuit per Mbps per 10 km. Since NFV is assumed, the fixed power consumption of a routing function or a circuit bandwidth when there is no traffic is disregarded.

(5) Evaluation tool: We built an evaluation tool in the C language to evaluate the above power consumption. We also verified the evaluation result with computation using Microsoft Excel.

B. Evaluation Results and Discussion

Evaluation results of the final routing function allocation that minimizes the total power consumption are shown in Figs. 4 and 5. The size of a circle, ○, in an area indicates the capacity of the routing function. Fig. 4 shows how the final function allocation changes as Z is varied and M is fixed at 2. Fig. 5 shows how the final function allocation changes as M is varied and Z is fixed at 2.

The following points are clear from these Figs:

(1) The greater Z (i.e., power consumption ratio) is, the greater the power consumption of the routing function relative to that of the circuit and the more advantageous to integrate the two areas concerned.

In the example of Fig. 4, routing functions are allocated in all areas when Z≦0.8, in half of all areas when Z≒1.8, and only in Area 5 when Z≦3.5.

(2) The greater M (i.e., peak coefficient) is, the greater the effect of integrating one area into another tends to become.

This is explained in detail with Fig. 6. When one area is integrated into another area, the circuit capacity that is newly required for intra-area communication in the first area consumes additional power (x_1) while power (x_2) previously consumed by the routing function capacity that had been required to relay traffic to another area becomes zero. The greater M is, the greater x_2 becomes (even when x_1 remains the same), resulting in an increase in the number of cases where integration is advantageous (the right part in Fig. 6). As a result, it becomes advantageous to integrate as many areas as possible. Fig. 5 reflects this effect.

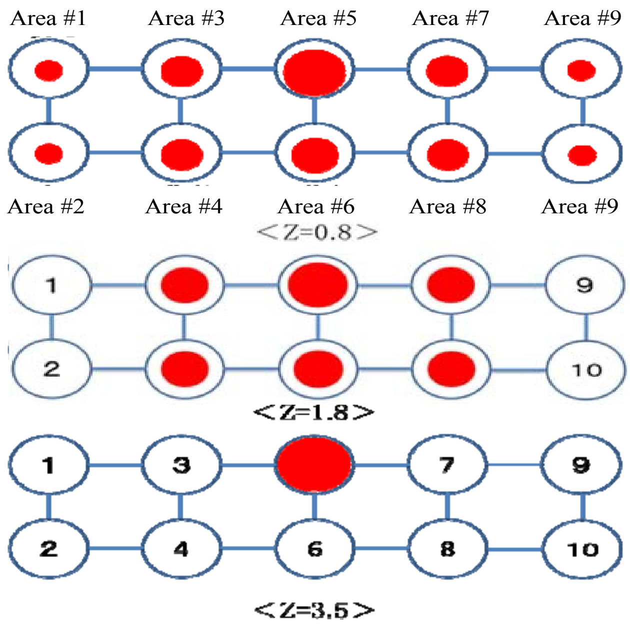

Fig. 4 Allocation topology of virtual routing functions with least total power consumption (M=2)

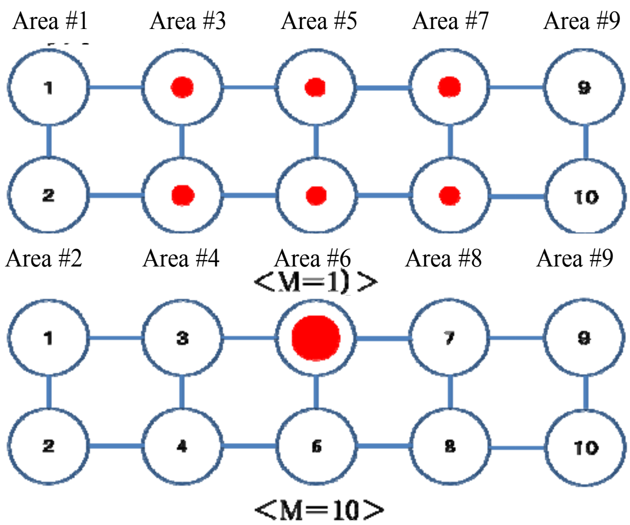

Fig. 5 Allocation topology of virtual routing functions with least total power consumption (Z=2)

To ascertain the above-mentioned trend, we examined how the ratio of the number of areas that have routing functions to the total number of areas, **δ**, changes when Z and M are varied. The result is shown in Fig. 7. The horizontal axis represents Z while the vertical axis represents δ. The minimum value of δ is 0.1 while its maximum value is 1.0. As in Figs. 4 and 5, the greater Z is and the greater M is, the more advantageous integration tends to become.

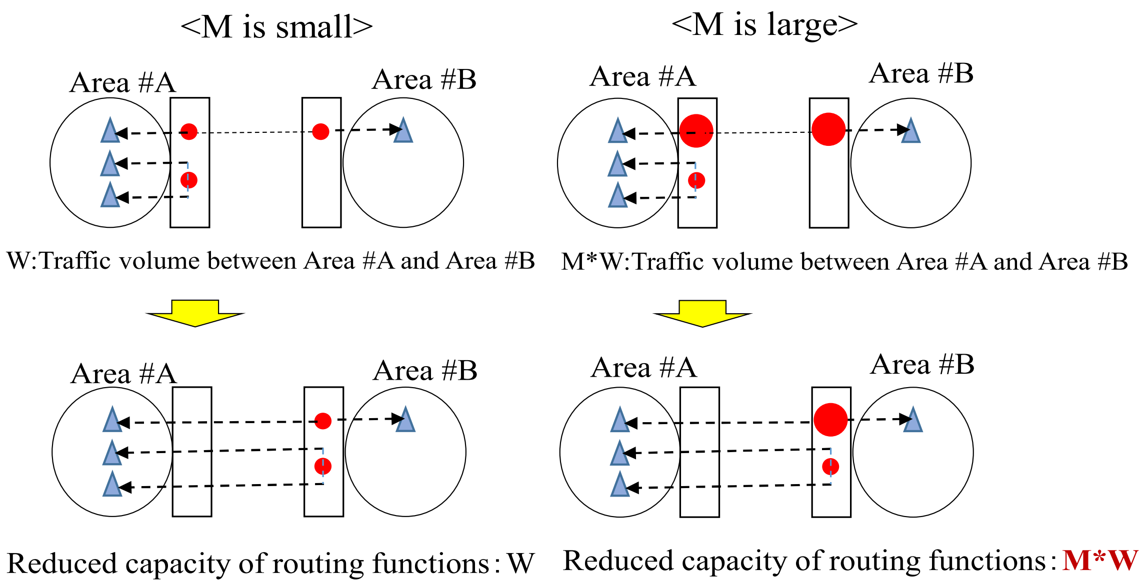

Fig. 6 Comparison of area integration effect

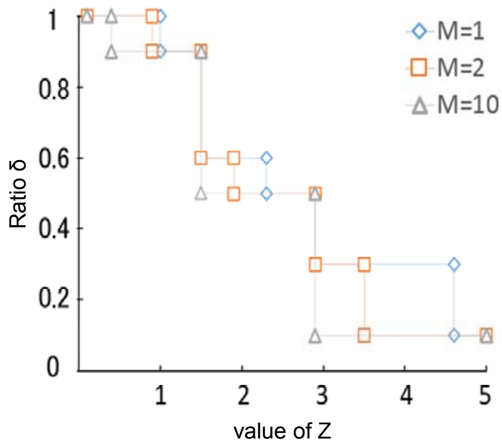

Fig. 7 Ratio δ vs. value of Z and M

(3) Fig. 4 shows that, when Z=0.8, the final function allocation is to distribute a routing function to every area. However, this allocation is not viable in the conventional non-NFV network because a routing function needs to have a capacity that is higher than a certain level, Q. For example, if Q is twice the capacity of the routing function allocated in the case of Fig. 4 (Z=0.8), the total power consumption of the conventional network increases by 20%. This takes only the power consumption of the routing function capacity and the circuit bandwidth into consideration, and does not include the fixed power consumption of servers and circuits, which must be taken into consideration in the conventional network. Therefore, NFV-based routing function allocation could make it possible to distribute small-capacity routing functions in a network, resulting in a large reduction in power consumption in comparison to the conventional network.

VI. Conclusions

This paper has proposed the virtual routing function allocation algorithm in the NFV network for minimizing the total network consumption. The proposed allocation algorithm has been evaluated with a ladder-shaped network model, which simulates the shape of Japan. It has been found that, the greater the power consumption of a routing function relative to that of a circuit is and the greater the peak coefficient of traffic between areas is, the smaller the total power consumption can be made by integrating the routing functions of some areas into those of a small number of areas. Furthermore, the present paper has indicated that there are cases where the use of NFV-based routing functions makes it possible to reduce the total power consumption much, compared with a conventional network.

It is required to study the routing function allocation that minimizes the total network cost and considers the maximum number of transit routing functions.

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