Proceedings of the International MultiConference of Engineers and Computer Scientists 2015 Vol II,
IMECS 2015, March 18 - 20, 2015, Hong Kong

Star-Topology Virtual Network Construction with Optimization Problems for Video Streaming System of Sightseeing Information

Yasuhiro Urayama and Takuji Tachibana

***Abstract*—In Japan, regional activation is one of the most important problems for regional areas such as Fukui prefecture. Therefore, several kinds of activities are performed for local residents. Moreover, some approaches with ICT are performed for sightseeing because the rank of sightseeing in Fukui prefecture is somewhat lower than other prefecture in Japan. It is expected that the sightseeing advances and the region is activated with these approaches. In this paper, we propose a video streaming system for the sightseeing in order to advance the regional activation. In this system, a virtual network for each tourist spot is constructed over a physical network by using the network virtualization technology, and the real-time video of the tourist spot is delivered to other spots over the virtual network. The local residents and the tourists become interested in the tourist spot by watching the video. Here, virtual networks are designed with two optimization problems so that resources are used in each link evenly and the total amount of resources that are used in the virtual networks is minimized. Note that each virtual network is designed as a star topology with the optimization problems. We evaluate the performance of our proposed method with simulation, and numerical examples show the effectiveness of the proposed method.**

***Index Terms*—Virtual networks, Topology design, Optimization problem, Video streaming, Regional activation**

I. Introduction

In Japan, regional activation is one of the most important problems for regional areas such as Fukui prefecture. Several kinds of activities are performed for the regional activation. Table I shows the data in terms of the sightseeing for each prefecture in Japan. From these data, the rank of Fukui prefecture is somewhat lower than other prefectures. Therefore, in Fukui prefecture, several efforts such as the infrastructure construction are performed. In addition, some approaches with ICT have been performed [1], [2]. For example, [2] utilizes virtual networking technologies [3], [4], [5] and delay tolerant network technologies [6], [7], [8] to increase the number of tourists in Fukui prefecture for the regional activation. Such activities are expected to be effective for many regional areas around the world not only for Fukui prefecture.

To increase the number of tourists in regional areas, it is indispensable to provide the sightseeing information in real time with users. On the other hand, the real-time video streaming requires a high bandwidth in the Internet. This degrades the quality of other services, and hence it is not expected that such a video streaming system is utilized worldwide.

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TABLE I
Data of 47 prefectures in Japan [9].

Number of visitors	Travel cost	Degree of satisfaction	Future visit intension
1. Tokyo 14,990,000	1. Okinawa 93,400 yen	1. Okinawa 91.0%	1. Hokkaido 33.8%
2. Hokkaido 9,780,000	2. Hokkaido 66,800 yen	2. Kyoto 90.9%	2. Okinawa 31.7%
3. Kanagawa 8,370,000	3. Tokyo 62,900 yen	3. Miyagi 88.1%	3. Kyoto 17.3%
⋮			
⋮		18. Fukui 84.4%	⋮
⋮			
42. Fukui 1,370,000	⋮	⋮	42. Fukui 1.5%
⋮	43. Fukui 33,600 yen	⋮	
⋮			

In this paper, we propose a video streaming system that utilizes virtual network technologies. In this system, to provide the real-time promotional video of each tourist spot with users, a virtual network where all spots are included is constructed for each tourist spot. Here, the bandwidth of a link between two tourist spots is higher than that of other links. This keeps the quality of the streaming video at other tourist spots. Moreover, a topology of each virtual network is designed by solving two optimization problems. The derived topology can avoid the intensive utilization of network resources at each link and can reduce the total amount of resources that are used to construct virtual networks. We evaluate the performance of our proposed system with simulation.

The rest of this paper is organized as follows. Section II explains related work and Sect. III describes the overview of our proposed system. Section IV describes a virtual network construction method for our proposed system. Section V shows some numerical examples, and Sect. VI denotes conclusions.

II. Related work

As one of the virtual network construction methods, [10] has proposed a construction method with optimization problems. In this method, multiple virtual networks are constructed so as to keep the robustness of a physical network.

In order for a user to utilize a virtual network over a physical network with n nodes, the user sends a request for

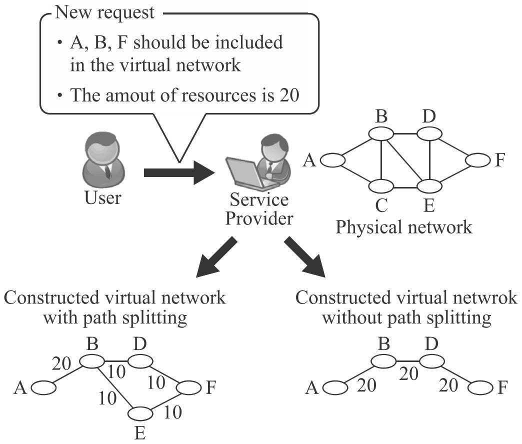

Fig. 1. Path splitting.

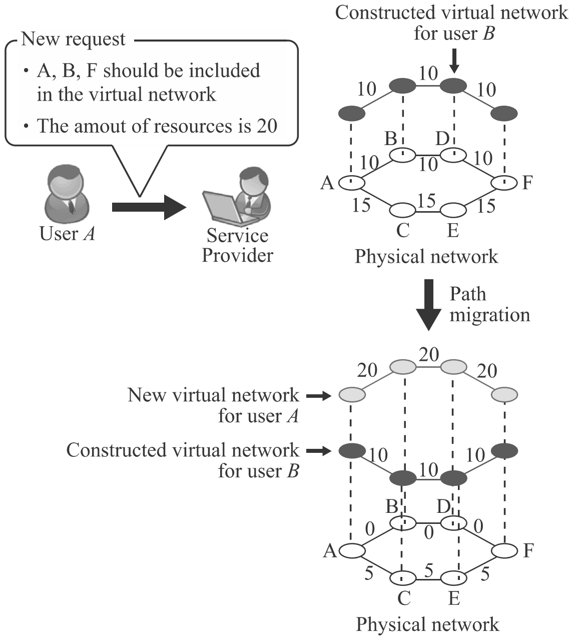

Fig. 2. Path migration.

constructing the virtual network to a service provider. The request has the information about nodes $\{v_1^*, \cdots, v_H^*\}$ that should be included in the virtual network and the amount l of network resources that are used in the virtual network. The service provider designs a topology of the virtual network according to the user's request by performing the path splitting and the path migration. Here, these processes are formulated as optimization problems for the network resource allocation.

In the path splitting, the service provider can design a new virtual network where there are one or more links between any two requested nodes (see Fig. 1). On the other hand, the path splitting may trigger a packet reordering in each virtual network because multiple routes can be used at the same time between a source node and a destination node [11]. Therefore, users select whether the path splitting is used or not by setting the value of m as follows:

$$m = \begin{cases} 1, & \text{path splitting is performed,} \\ 0, & \text{path splitting is not performed.} \end{cases}$$

Now, L virtual networks have been constructed over the physical network. Let the total amount of resources for link e_{ij} between node v_i and node v_j be denoted as U_{ij}^e and the total amount of resources of node v_i be denoted as U_i^v. Moreover, X_{ij}^k and Y_i^k are the amount of resources that have been used for e_{ij} and v_i in the kth $(1 \leq k \leq L)$ virtual network, respectively. In the new virtual network, X_{ij}^{New} denotes the amount of resources that are used in e_{ij}, and Y_i^{New} denotes the amount of resources that are used in v_i.

When a user sends a request for constructing a new virtual network to a service provider, a new topology of the virtual network is designed by solving the following optimization problem.

$$\min \quad \tau' = 2n\mathrm{Tr}(L'^{+}), \qquad (1)$$

$$\text{subject to} \quad \sum_{k=1}^{L} X_{ij}^k + X_{ij}^{New} \geq 0, \qquad (2)$$

$$\sum_{k=1}^{L} X_{ij}^k + X_{ij}^{New} \leq U_{ij}^e, \qquad (3)$$

$$\sum_{k=1}^{L} Y_i^k + Y_i^{New} \geq 0, \qquad (4)$$

$$\sum_{k=1}^{L} Y_i^k + Y_i^{New} \leq U_i^v, \qquad (5)$$

$$X_{ij}^{New} - X_{ji}^{New} = 0, \ \forall i, j = 1, \cdots, n, \qquad (6)$$

$$\sum_{j=1, j \neq S}^{n} X_{Sj}^{New} = l, \qquad (7)$$

$$\sum_{j=1, j \neq D}^{n} X_{jD}^{New} = l, \qquad (8)$$

$$\sum_{j=1, j \neq r}^{n} X_{rj}^{New} = l, \qquad (9)$$

$$\sum_{j=1, j \neq r}^{n} X_{jr}^{New} = l, \qquad (10)$$

$$Y_S^{New} = l, \qquad (11)$$

$$Y_D^{New} = l, \qquad (12)$$

$$Y_r^{New} = l, \qquad (13)$$

$$X_{ij}^{New} \geq 0, \ \forall i, j = 1, \cdots, n, \qquad (14)$$

$$Y_i^{New} \geq 0, \ \forall i = 1, \cdots, n. \qquad (15)$$

In this optimization problem, the topology of the new virtual network is designed by deriving X_{ij}^{New} and Y_i^{New}. In (1), the topology of the new virtual network can be designed so that the robustness of the physical network is maximized, that is, network criticality τ' can be minimized [12]. Here, in this optimization problem, S and D are selected among the requested nodes $\{v_1^*, \cdots, v_H^*\}$ before solving the optimization problem. Note that S and D are selected among the requested nodes and the above optimization problem is performed until the topology design is completed.

On the other hand, in the path migration, topologies of virtual networks that have already been constructed are changed (see Fig. 2). The path migration may decrease Quality of Service (QoS) [13] for the constructed virtual networks when it takes a long time to change those topologies. In this method, each user can select in advance whether the path migration is used for one's own virtual network or not. Therefore, each user can select the utilization of the migration with d as follows:

$$d = \begin{cases} 1, & \text{path migration is performed,} \\ 0, & \text{path migration is not performed.} \end{cases}$$

ISBN: 978-988-19253-9-8
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

Now, L virtual networks have already been constructed over a physical network with n nodes. Here, we assume that the number of virtual networks whose d is equal to 1 is L_1 and the number of virtual networks whose d is equal to 0 is L_0. For the L_1 virtual networks, let l_1^k denotes the amount of resources that have been used in the kth virtual network $(k = 1, \cdots, L_1)$. Moreover, for L_1 virtual networks, we assume that the number of virtual networks whose m is equal to 1 is L_{11} and the number of virtual networks whose m is equal to 0 is L_{10}.

When m is equal to one in a new request, the optimization problem for the path migration is formulated as follows:

$$\text{min} \quad \tau' = 2n\mathrm{Tr}(L'^{+}), \tag{16}$$

$$\text{subject to} \quad \sum_{k=1}^{L} X_{ij}^k + X_{ij}^{New} \geq 0, \tag{17}$$

$$\sum_{k=1}^{L} X_{ij}^k + X_{ij}^{New} \leq U_{ij}^e, \tag{18}$$

$$\sum_{k=1}^{L} Y_i^k + Y_i^{New} \geq 0, \tag{19}$$

$$\sum_{k=1}^{L} Y_i^k + Y_i^{New} \leq U_i^v, \tag{20}$$

$$X_{ij}^{New} - X_{ji}^{New} = 0, \ \forall i, j = 1, \cdots, n, \tag{21}$$

$$\sum_{j=1, j \neq S}^{n} X_{Sj}^{New} = l, \tag{22}$$

$$\sum_{j=1, j \neq D}^{n} X_{jD}^{New} = l, \tag{23}$$

$$\sum_{j=1, j \neq r}^{n} X_{rj}^{New} = l, \tag{24}$$

$$\sum_{j=1, j \neq r}^{n} X_{jr}^{New} = l, \tag{25}$$

$$Y_S^{New} = l, \tag{26}$$

$$Y_D^{New} = l, \tag{27}$$

$$Y_r^{New} = l, \tag{28}$$

$$X_{ij}^{New} \geq 0, \ \forall i, j = 1, \cdots, n, \tag{29}$$

$$Y_i^{New} \geq 0, \ \forall i = 1, \cdots, n, \tag{30}$$

$$\sum_{j=1, j \neq S}^{n} X_{Sj}^k = l_1^k, \ \forall k = 1, \cdots, L_{11}, \tag{31}$$

$$\sum_{j=1, j \neq D}^{n} X_{jD}^k = l_1^k, \ \forall k = 1, \cdots, L_{11}, \tag{32}$$

$$\sum_{j=1, j \neq r}^{n} X_{rj}^k = l_1^k, \ \forall k = 1, \cdots, L_{11}, \tag{33}$$

$$\sum_{j=1, j \neq r}^{n} X_{jr}^k = l_1^k, \ \forall k = 1, \cdots, L_{11}, \tag{34}$$

$$Y_S^k = l_1^k, \ \forall k = 1, \cdots, L_{11}, \tag{35}$$

$$Y_D^k = l_1^k, \ \forall k = 1, \cdots, L_{11}, \tag{36}$$

$$Y_r^k = l_1^k, \ \forall k = 1, \cdots, L_{11}, \tag{37}$$

$$X_{Si}^k = l_1^k, \ \forall k = 1, \cdots, L_{10}, \tag{38}$$

$$X_{Sj}^k = 0, \ i \neq j, \ \forall k = 1, \cdots, L_{10}, \tag{39}$$

$$X_{iD}^k = l_1^k, \ \forall k = 1, \cdots, L_{10}, \tag{40}$$

$$X_{jD}^k = 0, \ i \neq j, \ \forall k = 1, \cdots, L_{10}, \tag{41}$$

$$X_{ri}^k = l_1^k, \ \forall k = 1, \cdots, L_{10}, \tag{42}$$

$$X_{rj}^k = 0, \ i \neq j, \ \forall k = 1, \cdots, L_{10}, \tag{43}$$

TABLE II
NOTATION.

n	Number of nodes in a physical network.
e_{ij}	Link between node i and node j in a physical network.
v_i	The ith node that is requested from a user.
H	Number of nodes should be included in a virtual network.
l	Amount of resources used in a virtual network.
m	Value determined by user when path splitting is performed.
d	Value determined by user when path migration is performed.
L	Number of virtual networks that has been constructed.
τ'	Network criticality.
U_{ij}^e	Total amount of resources for link e_{ij}.
U_i^v	Total amount of resources for node v_i.
X_{ij}^{New}	Amount of resources of link that have been used for e_{ij} in new virtual network.
Y_i^{New}	Amount of resources of node that have been used for v_i in new virtual network.
X_{ij}^k	Amount of resources of link that have been used for e_{ij} in virtual network k.
Y_i^k	Amount of resources of node that have been used for v_i in virtual network k.
M	Number of tourist spots.
V	Set of tourist spots.
N	Set of other general spots.
a_{ij}^k	Amount of resources of virtual link that have been used between spot i and spot j in virtual network k.
e_{ij}^{kh}	Amount of resources of link that have been used for e_{ij} in virtual network k.
b_{ij}^k	Total amount of resources of link that have been used between spot i and spot j in virtual network k.
R	Amount of resources of link that are connected to tourist spot in a virtual network.
$\widehat{R}$	Amount of resources of link that are connected to other general spot in a virtual network.
X	Solution of first optimization problem.

$$X_{ir}^k = l_1^k, \ \forall k = 1, \cdots, L_{10}, \tag{44}$$

$$X_{jr}^k = 0, \ i \neq j, \ \forall k = 1, \cdots, L_{10}. \tag{45}$$

As is the case with the path splitting, S and D are determined in advance. In this optimization problem, for the constructed virtual networks, L_{11} topologies of virtual networks are redesigned so as to satisfy construction conditions from (31) to (37). Moreover, L_{10} topologies of virtual networks are redesigned so as to satisfy construction conditions from (38) to (45).

When m is equal to zero in the new request, the path splitting can not be performed for the new virtual network. Therefore, the above optimization problem (16) to (45) has to be modified. First, construction conditions (22) to (25) is omitted from the above optimization problem, and the following construction conditions are added.

$$X_{Si}^{New} = l, \tag{46}$$

$$X_{Sj}^{New} = 0, \ i \neq j, \tag{47}$$

$$X_{iD}^{New} = l, \tag{48}$$

$$X_{jD}^{New} = 0, \ i \neq j, \tag{49}$$

$$X_{ri}^{New} = l, \tag{50}$$

$$X_{rj}^{New} = 0, \ i \neq j, \tag{51}$$

$$X_{ir}^{New} = l, \tag{52}$$

$$X_{jr}^{New} = 0, \ i \neq j. \tag{53}$$

III. PROPOSED VIDEO STREAMING SYSTEM

In this section, for the regional activation, we propose a video streaming system that utilizes the network virtualization. Table II shows symbols that are used to explain our proposed system.

ISBN: 978-988-19253-9-8
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

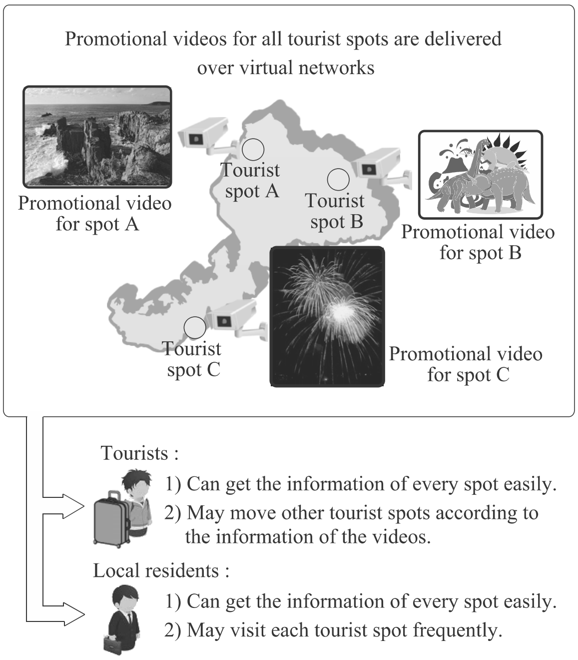

Fig. 3. Overview of our proposed system.

Figure 3 shows an overview and the effective of our proposed system. As shown in Fig. 3, in our proposed system, the real-time promotional video of each tourist spot is delivered to other spots. Local residents and tourists can get the information about each tourist spot in real time, and it is expected that the local residents and the tourists take an interest in the tourist spots by watching the videos. In order to realize our proposed system, a virtual network for each tourist spot is constructed over a physical network. In each virtual network, a promotional video for a tourist spot is delivered to other spots.

Figure 4 shows an example where promotional videos for two tourist spots are delivered to tourists and local residents by using our proposed system. In this figure, a virtual network for the tourist spot A and a virtual network for the tourist spot B are constructed over a physical network. The promotional video of spot A and that of spot B are delivered over the corresponding virtual network, respectively. Because these virtual networks are constructed independently, each promotional video is delivered independently of other promotional videos.

If a tourist watches a promotional video for a tourist spot at another spot and the tourist becomes interested with the tourist spot, he might move to the spot for the sightseeing. Moreover, if local residents watch promotional videos, they may visit the spots frequently. Therefore, it is expected that the number of tourists for each spot increases and the region is activated by utilizing our proposed system.

IV. Topology design of virtual networks

In our proposed system, multiple virtual networks for tourist spots are constructed over a physical network where some existing services have been provided. Therefore, when our proposed system is utilized, it is important to consider the impact of the construction of virtual networks on the quality of the existing services. In particular, it is expected that this system is operated with less network resources because this

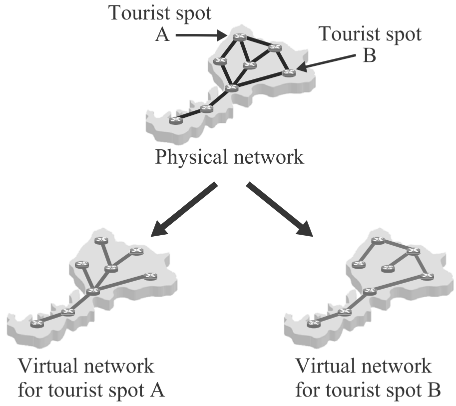

Fig. 4. Virtual networks for two tourist spots.

system is only used for the sightseeing whose priority is not high. In this paper, the topology of virtual networks is limited to the star topology. Moreover, we design these topologies by solving two optimization problems about network resources.

A. Avoidance of intensive utilization of network resources

Now, let denote the number of all spots in a physical network as n and the number of tourist spots as M. In the physical network, M virtual networks are constructed for the tourist spots. Here, the set of the tourist spots is denoted as V, and the set of other general spots that are not included in V is denoted as N. When we denote an adjacency matrix for a tourist spot k $(k \in V)$ as A^k, an element a_{ij}^k for the ith row and the jth column of A^k is given by

$$a_{ij}^k = a_{ji}^k = \begin{cases} R, & \text{if} \quad i = k \neq j, \quad j \in V, \\ \widehat{R}, & \text{if} \quad i = k \neq j, \quad j \in N, \\ 0, & \text{otherwise.} \end{cases} \tag{54}$$

In (54), R and $\widehat{R}$ denote the amount of resources that are allocated to each link in each virtual network, and these are set so as to satisfy $R \geq \widehat{R}$. This means that more network resources (bandwidth) are allocated to a link between two tourist spots nodes in order to deliver the promotional video with high quality (see Fig. 5).

In terms of the virtual network for the tourist spot k, we denote an adjacency matrix for the physical network as B^k. Moreover, the amount of resources that is used in link a_{kh}^k between nodes i and j in the physical network is denoted as e_{ij}^{kh}. Because each virtual network satisfies (54), e_{ij}^{kh} is given by

$$e_{ij}^{kh} = e_{ji}^{kh} = \begin{cases} R, & \text{if} \quad e_{ij}^{kh} \in a_{kh}^k, \quad h \in V, \\ \widehat{R}, & \text{if} \quad e_{ij}^{kh} \in a_{kh}^k, \quad h \in N, \\ 0, & \text{otherwise.} \end{cases} \tag{55}$$

From (55), the element b_{ij}^k for the ith row and the jth column of B^k is given by

$$b_{ij}^k = b_{ji}^k = \sum_{h=1}^{H} e_{ij}^{kh}. \tag{56}$$

When the amount of link resources between node i and node j in the physical network is denoted as U_{ij}^e, M topologies of the virtual networks are designed by solving

ISBN: 978-988-19253-9-8
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

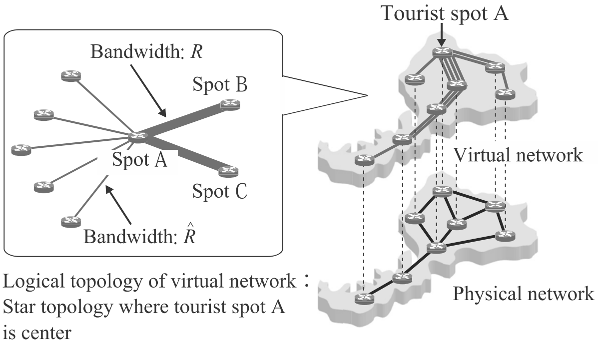

Fig. 5. Topology design of virtual networks for the sightseeing.

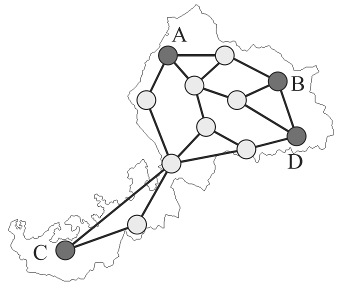

Fig. 6. Physical network for simulation.

the following optimization problem.

$$\min \max_{i,j} \quad \textstyle\sum_{k=1}^{M} b_{ij}^{k}, \quad (57)$$

$$\text{subject to} \quad \textstyle\sum_{k=1}^{M} b_{ij}^{k} \le U_{ij}^{e}, \quad (58)$$

$$e_{ij}^{kh} = e_{ji}^{kh} = R, \quad \text{if} \quad e_{ij}^{kh} \in a_{kh}^{k}, \ h \in V, \quad (59)$$

$$e_{ij}^{kh} = e_{ji}^{kh} = \widehat{R}, \quad \text{if} \quad e_{ij}^{kh} \in a_{kh}^{k}, \ h \in N. \quad (60)$$

In (57), the maximum amount of resources that are used at links in the physical network is minimized in order to avoid the intensive utilization of network resources. Moreover, (58) shows the total amount of resources that can be used at each link in the virtual networks. (59) and (60) show the amount of resources that are used at each link in the virtual networks. By solving the above optimization problem, we can construct the virtual networks while avoiding the intensive utilization of network resources in the physical network.

B. Reduction of total amount of resources for virtual networks

After the optimization problem in the subsection IV-A is solved, another optimization problem is solved and the optimal topologies of the virtual networks can be obtained. By solving the second optimization problem, the total amount of network resources that are needed to construct the virtual networks can be reduced. When the solution of the first optimization problem is X, the second optimization problem is formulated as follows:

$$\min \quad \textstyle\sum_{k=1}^{M} \sum_{i=1}^{H} \sum_{j=1}^{H} b_{ij}^{k}, \quad (61)$$

$$\text{subject to} \quad \min \max_{i,j} \textstyle\sum_{k=1}^{M} b_{ij}^{k} = X, \quad (62)$$

$$\textstyle\sum_{k=1}^{M} b_{ij}^{k} \le U_{ij}^{e}, \quad (63)$$

$$e_{ij}^{kh} = e_{ji}^{kh} = R, \quad \text{if} \quad e_{ij}^{kh} \in a_{kh}^{k}, \ h \in V, \quad (64)$$

$$e_{ij}^{kh} = e_{ji}^{kh} = \widehat{R}, \quad \text{if} \quad e_{ij}^{kh} \in a_{kh}^{k}, \ h \in N. \quad (65)$$

In (61), the total amount of resources that is used in M virtual networks can be minimized. Moreover, in (62), the intensive utilization of network resources can be avoided because the solution of the first optimization problem is kept. In (63), the maximum amount of resources that are used at links in the physical network is minimized as is the case with (58). (64) and (65) show the amount of resources that are used at each link in the virtual networks as is the case with (59) and (60). By solving this optimization problem, we can obtain the topologies so that the total amount of resources for virtual networks are reduced.

V. Numerical Examples

In this section, we evaluate with simulation the effectiveness of our proposed system for a physical network shown in Fig. 6. In this physical network, the number of nodes is 12 and the number of links is 18. Moreover, for M tourist spots, M virtual networks are constructed over the physical network by using our proposed topology design explained in Sect. IV. In each virtual network, the amount R of resources that is allocated to a link between two tourist spots is set to 15, and the amount $\widehat{R}$ of resources that is allocated to other links is set to 2. For the performance comparison, we evaluate the performance of another virtual network construction method that is called *Minimized hops* in the following. In the minimized hops method, star topologies are designed so as to minimize the total number of hops from a tourist spot whose promotional video is delivered to other spots.

Figure 7 shows the maximum amount of resources that are used in links when M is equal to 2. Here, the set V of tourist spots includes two nodes that are selected from A, B, C, and D in Fig. 6. From Fig. 7, we can find that our proposed system can reduce the maximum amount of resources used in links more significantly than the minimized hops method regardless of a pair of tourist spots. Therefore, the intensive utilization of network resources can be avoided by using our proposed system.

Figure 8 shows the total amount of resources that are needed to construct virtual networks when M is equal to 2. From this figure, we can find that our proposed system uses more network resources than the minimized hops method. In the minimized hops method, each spot is connected along the shortest path. As a result, the total amount of resources that are needed to construct the virtual networks is small. However, in the proposed system, the total amount of resources can be reduced by solving the second optimization problem that described in subsection IV-B. As a result, the effectiveness of our proposed method is not lower than the minimized hops method so much.

Figure 9 and 10 show simulation results when M is equal to 3. Here, the set V of tourist spots is selected from A, B, C, and D in Fig. 6. From these results, we can find that simulation results of Fig. 9 and Fig. 10 show the same tendency of those of Fig. 7 and Fig. 8, respectively. Therefore, our proposed system is effective for the promotional video streaming for the sightseeing regardless of the number of tourist spots.

ISBN: 978-988-19253-9-8
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

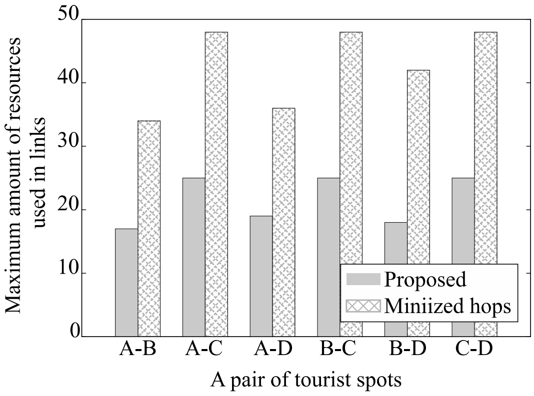

Fig. 7. Maximum amount of resources used in links (M=2) .

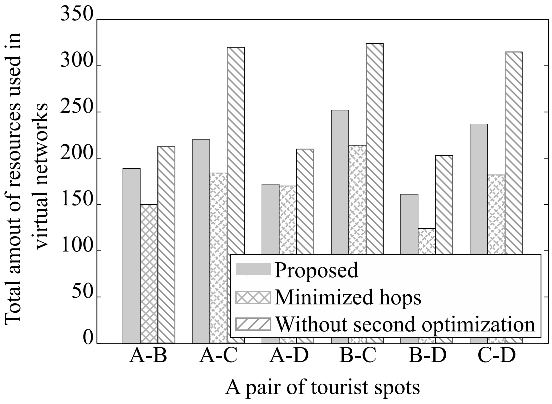

Fig. 8. Total amount of resources that are needed to construct virtual networks (M=2) .

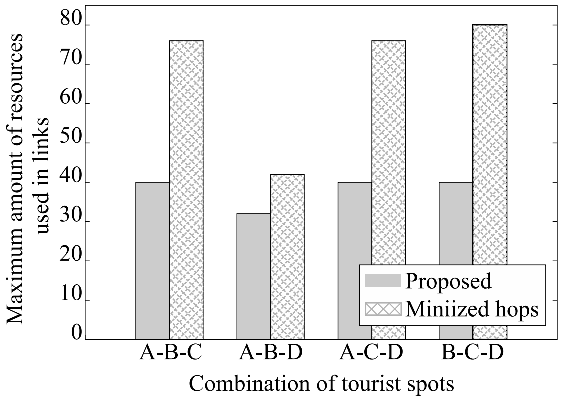

Fig. 9. Maximum amount of resources used in links (M=3) .

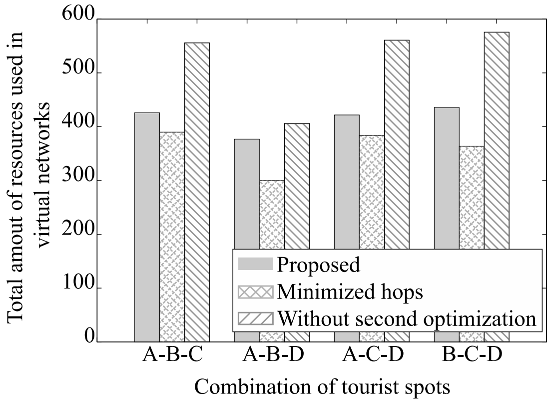

Fig. 10. Total amount of resources that are needed to construct virtual networks (M=3) .

VI. Conclusions

In this paper, for the regional activation, we proposed a video streaming system of the sightseeing information by using network virtualization technologies. In this system, a virtual network is constructed for each tourist spot, and the promotional video for each tourist spot is delivered to other spots over each virtual network. Topologies of these virtual networks are designed by solving two optimization problems. We evaluated the effectiveness of our proposed system with computer simulation. From numerical examples, we found that the intensive utilization of network resources for the physical network can be avoided by using our proposed system. Moreover, we found that the total amount of resources that are needed to construct virtual networks is reduced by performing the optimization problems.

Acknowledgement

This work was partly supported by the Strategic Information and Communications R&D Promotion Programme of the Ministry of Internal Affairs and Communications, JAPAN.

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