Green Virtual Network Embedding for Collaborative Edge Computing in Environment-Friendly Optical-Wireless Networks

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ABSTRACT

To reduce the cost and delay caused by transferring data to the remote cloud, the trend is to design an intelligent Edge Device (ED) for preliminary data processing, i.e., edge computing. Some EDs usually form a group where they wirelessly communicate with each other. Different ED groups are interconnected by optical fiber cables. Through coordinating the use of ED groups, we can perform a collaborative edge computing in a hybrid network where a cost-efficient optical-wireless convergence is achieved by virtualization. In this paper, we use the virtual network to describe one computing-application's requirement for the substrate resource, and we investigate how embed multiple virtual networks onto the common network infrastructure. In our approach, a graph-cutting algorithm is firstly utilized to embed as many virtual networks as possible onto the specified EDs within the same group. However, a single ED group cannot handle all computing applications competing for limited wireless and computing resources. To solve this challenging problem, we transform the virtual networks—impossibly embedded onto the same ED group—into new ones processed by ED groups. Simulations results demonstrate the green feature of our solution: 1) the total transmitting power assigned for EDs is effectively reduced using the graph cutting algorithm provided that all of computing applications can be solved by a single ED group; 2) our method accepts more virtual networks with the improvement ratio of 77%, through the coordination of ED groups. In addition, there is a good match between the algorithm result and the optimal number of consumed wavelengths per optical fiber cable.

Keywords

edge computing; environment-friendly optical-wireless network; green virtual network embedding

WWW'17 Companion, April 3–7, 2017, Perth, Australia.
ACM 978-1-4503-4914-7/17/04.
http://dx.doi.org/10.1145/3041021.3054768

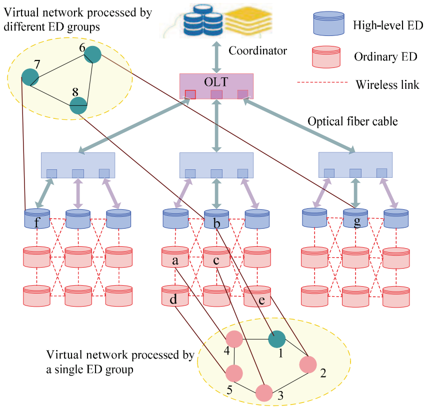


Figure 1: Virtual network embedding for collaborative edge computing in an optical-wireless network.

1. INTRODUCTION

The cost and delay—caused by transferring data to the remote cloud—is unacceptable. Moreover, it is not sustainable to send so much data to the cloud, as it would saturate network bandwidth. To address these issues, the trend is to design an intelligent Edge Device (ED) for preliminary data processing, i.e., edge computing [1]. Note that the ED is the device that normally provides authenticated access to backbone networks. Some EDs usually form a group where they wirelessly communicate with each other [2, 3]. Different ED groups are interconnected by optical fiber cables. Through coordinating the use of ED groups [4], we can perform a collaborative edge computing in an environment-friendly optical-wireless network.

Under the aforementioned optical-wireless environment, the differences of physical infrastructures and protocol stacks restrict the interaction between wireless and optical subnets. Network virtualization is an advisable approach to solve this problem [5, 6]. Virtualization of the optical-wireless environment is also an economical way for subscribers to customize their computing applications through a common network infrastructure. After network virtualization, a computing application is abstracted into the virtual network which deploys its own routing protocol and forwarding mechanism.

To reduce the cost and delay of data sending to the remote cloud, the virtual network is preferentially mapped onto appropriate EDs in the same group. As an example of the virtual network represented by the bottom circle in Fig. 1, the virtual node 1 is mapped onto the high-level ED b, while virtual nodes 2, 3, 4 and 5 are mapped onto ordinary EDs e, c, a, and d, respectively. The computing resources of mapped EDs are consumed for data processing, while the radio bandwidth is used to support the inter-ED communication along mapped wireless links.

However, a single ED group cannot handle all computing applications competing for limited wireless and computing resources. In fact, the virtual networks impossibly embedded onto the same ED group can be transformed into new ones processed by different ED groups. As an example of the virtual network represented by the top circle in Fig. 1, the virtual nodes 6, 7, and 8 are mapped onto high-level EDs f, b, and g. In addition to the computing resources of mapped high-level EDs, the wavelengths are consumed on optical fiber cables.

To the best of our knowledge, our new study is the first to focus on finding green mapping solutions for collaborative edge computing in environment-friendly optical-wireless networks. The main contributions of this paper are summarized in the following.

1) Owing to the existence of the wireless communication between EDs in the same group, the transmitting power should be assigned to the ED. We try to embed as many virtual networks as possible onto the substrate same ED group. Though it shares similarity with the Virtual Network Embedding (VNE) in Wireless Mesh Networks (WMNs), a novel graph-cutting-based mapping approach performs a new objective of saving the transmitting power assigned for EDs. Moreover, different from the VNE in WMNs, a collaborative edge computing among ED groups is also achieved via optical fiber cables.

2) Some virtual network may not be successfully embedded due to the limited wireless and computing resources in a single ED group. We transform these virtual networks into new ones processed by high-level EDs from different groups. Because the wavelengths of optical fiber cables are consumed to support this type of VNE operation, we derive an optimal bound for the number of used wavelengths.

3) Simulation results demonstrate the green feature of our solution: 1) the total transmitting power can be effectively reduced using the graph cutting algorithm provided that all of computing applications can be solved by a single ED group; 2) our method embeds more virtual networks with the improvement ratio of 77%, through the coordination of ED groups. In addition, there is a good match between the algorithm result and the optimal bound analyzed by us. In summary, our solution well complies with the principles of social, economic and ecological sustainability.

2. PROBLEM STATEMENTS

We first introduce the network model and key notations. We then define the problem and discuss problem bounds.

2.1 Network model

The proposed environment-friendly optical-wireless network has n ED groups, each of which owns M high-level EDs and P ordinary EDs. A high-level ED has both wireless and wireline interfaces. An ordinary ED only has wireless interfaces. In every group, EDs communicate by mesh radio. Owing to the existence of the wireless communication in each ED group, the transmitting power $r(u)$ should be assigned to the ED u. The pre-determined wireless-link weight $P_u(v)$ denotes the transmitting power required for directly sending data from the ED u to the ED v. Obviously, a longer physical distance—between two linked EDs u and v—corresponds to a larger $P_u(v)$. Thus, the internal structure of each ED group can be represented by a weighted directed graph Γ. In Γ, there are $(M+P)$ vertexes, and the wireless-link weight is $P_u(v)$. The wireless link (u, v) exists in Γ if the actually assigned transmitting power $r(u) \geq P_u(v)$. One optical fiber cable is reserved between a high-level ED and the unique optical path switch. If we regard the proposed optical-wireless network as a WOBAN, the unique optical path switch is an Optical Linear Terminal (OLT) shown in Fig. 1. The optical fiber cable has several wavelengths, each of which has an initial bandwidth provisioning ba. Note that this substrate network model can be well extended to the case where each group has different numbers of EDs.

The virtual network—which is processed by a single ED group—can be represented as a 4-tuple model $vn(s, \phi, wb, c)$. s is the virtual node mapped onto the high-level ED, such as the virtual node 1 in Fig. 1. ϕ denotes the set of virtual nodes mapped onto ordinary EDs, such as virtual nodes 2, 3, 4 and 5 in Fig. 1. We assume that virtual nodes have the same requirements of computing resources c to process data, and the virtual link between a pair of virtual nodes consumes the same radio bandwidth wb.

As previously mentioned, we first try to embed as many virtual networks as possible into the substrate same ED group. However, a single ED group cannot handle all computing applications competing for limited wireless and computing resources. The virtual networks—impossibly embedded onto the same ED group—need to be changed into new ones processed by ED groups. Then, if necessary, the virtual network $vn(s, \phi, wb, c)$ can be transformed into a 3-tuple model $vn(S, wb, C)$. S is the set of virtual nodes mapped onto high-level EDs from different groups. Since there are n groups, each transformed virtual network also has n virtual nodes (such as virtual nodes 6, 7 and 8 in Fig. 1), i.e., $|S| = n$. Because the total requirement of computing resources is $c \cdot (1 + |\phi|)$ in the virtual network $vn(s, \phi, wb, c)$, each virtual node—owned by the corresponding transformed virtual network $vn(S, wb, C)$—will consume $C{=}[c \cdot (1 + |\phi|)]/n$ computing resources.

We give an example to explain the virtual network transformation. In the left part of Fig. 2, for the virtual network $vn(s, \phi, wb, c)$: the virtual node 1 should be mapped onto the high-level ED, i.e., $s = 1$; there are 4 virtual nodes (2, 3, 4 and 5) which should be mapped onto ordinary EDs, i.e., $|\phi| = 4$; the required computing resource is the number inside each virtual node, i.e., $c = 3$. Therefore, the total requirement of computing resources is $c \cdot (1 + |\phi|) = 15$ for the virtual network $vn(s, \phi, wb, c)$ in the left part of Fig. 2. The corresponding transformed virtual network $vn(S, wb, C)$ is shown in the right part of Fig. 2, where $n = 3$ virtual nodes should be mapped onto high-level EDs from different groups. Then, we have $C = \frac{15}{3} = 5$ and this value is located inside the virtual node in the right part of Fig. 2.

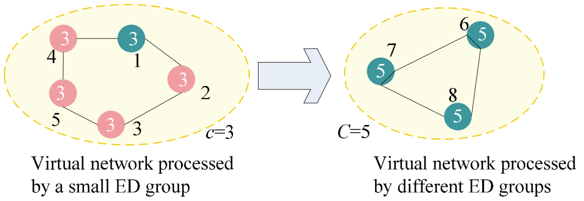


Figure 2: Virtual network transformation.

2.2 Problem definition

We first try to embed as many virtual networks as possible into the substrate same ED group. During this VNE phrase, we should select the most qualified ED group Γ^* for the virtual network $vn(s,\phi,wb,c)$. Then, the virtual network $vn(s,\phi,wb,c)$ will be successfully embedded onto Γ^* if the following cases are satisfied: 1) in Γ^*, we can find an appropriate high-level ED $m \in [1,2,..,M^*]$ to hold the virtual node s, i.e., the node-mapping solution $s \to m \in [1,2,..,M^*]$ is found; 2) in Γ^*, we can find a set of appropriate ordinary EDs $p \subseteq [1,2,..,P^*]$ to hold the virtual nodes located in ϕ, i.e., the node-mapping solution $\phi \to p \subseteq [1,2,..,P^*]$ is found; 3) all mapped EDs have available computing resource not smaller than c; 4) as to the link mapping, all the wireless links—traversed by the path between any pair of mapped EDs—have available radio bandwidth not smaller than wb; 5) in Γ^*, the total assigned transmitting power $TP_{\Gamma^*} = \sum_{u\in\Gamma^*} r(u)$. Let the variable N_1 record the number of successfully embedded virtual networks processed by a single ED group, then the total transmitting power assigned for EDs is given in the following.

$$TP = \sum_{i=1}^{N_1} \sum_{\Gamma^*=1}^{n} (\alpha^i_{\Gamma^*} \times TP_{\Gamma^*}). \tag{1}$$

Here, $\alpha^i_{\Gamma^*}$ is the boolean variable that is 1 if the $i^{th} (i \in [1,N_1])$ virtual network has been successfully embedded onto the most qualified ED group Γ^*, otherwise it is 0.

For the virtual network impossibly embedded due to the limited resource provisioning of a single ED group, we transform it into the new one $vn(S,wb,C)$ according to the method mentioned in subsection 2.1. Since the transformed virtual network will be processed by n ED groups, the following cases should be satisfied: 1) we can find n appropriate high-level EDs—which come from different groups—to hold the virtual nodes located in S, i.e., the node-mapping solution $s_j \to m_k$ is found. Here, the virtual node $s_j \in S$, $j \in [1,n]$, and m_k is the mapped high-level ED in the group k, $k \in [1,n]$; 2) all mapped high-level EDs have available computing resources not smaller than C.

The link mapping is unnecessary for the transformed virtual network $vn(S,wb,C)$. We have the following three reasons: 1) there is a constant wavelength path between any pair of mapped high-level EDs from different groups. As an example in Fig. 3, once the mapped high-level EDs have been determined as {f, b, g}, three wavelength paths (red arrow lines) have also been determined and remain unchanged; 2) a hybrid path—combined with wavelength and wireless subpaths—is not considered in our work. In Fig. 3, for example, a hybrid path can be established from g to o, then to Z and finally to OLT, which unfortunately requires additional expensive conversion components; 3) one wavelength capacity ba is always larger than wb.

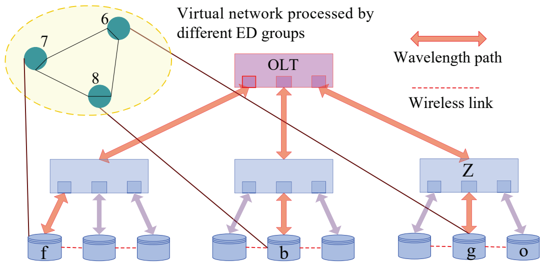


Figure 3: Link mapping for the transformed virtual network processed by different ED groups.

Let the variable $N_2^{'}$ record the number of successfully embedded transformed virtual networks processed by ED groups, then the total number of consumed wavelengths per optical fiber cable is given as follows.

$$TW = \lceil \frac{wb \cdot N_2^{'}}{ba} \rceil. \tag{2}$$

In summary, our objective is to minimize the transmitting power and the number of consumed wavelengths, while successfully embedding the largest number of virtual networks. The following comprehensive objective function is given below.

$$max_{(N_1+N_2^{'})} min\{\sum_{i=1}^{N_1} \sum_{\Gamma^*=1}^{n} (\alpha^i_{\Gamma^*} \times TP_{\Gamma^*}) + \lceil \frac{wb \cdot N_2^{'}}{ba} \rceil\}. \tag{3}$$

Intuitively, we can get the green feature and network sustainability if the above-mentioned can be well satisfied.

2.3 Problem and bound analysis

SC_l is the initial computing capacity of each ordinary ED. We assume that $(n \cdot P)$ ordinary EDs are replaced by one single ED with aggregated computing resources, then the following maximum number of successfully embedded virtual networks—processed by a single ED group—is obtained.

$$N_1^{\max} = (n \cdot P \cdot SC_l)/(c \cdot |\phi|). \tag{4}$$

Here, the term $(n \cdot P \cdot SC_l)$ denotes the aggregated computing resources of all $(n \cdot P)$ ordinary EDs; the term $(c \cdot |\phi|)$ is the total amount of computing resources required by all $|\phi|$ virtual nodes in the virtual network processed by a single ED group.

If all computing applications can be handled by a single ED group, then we have $N_1 = N_1^{\max}$ and $N_2^{'} = 0$. Thus, our objective function Eq. (3) is simplified as follows.

$$min\{\sum_{i=1}^{N_1^{\max}} \sum_{\Gamma^*=1}^{n} (\alpha^i_{\Gamma^*} \times TP_{\Gamma^*})\}. \tag{5}$$

Therefore, given the assumption that all computing applications can be handled by a single ED group, we can use Eq. (5) to check whether our solution can effectively save the total transmitting power or not.

If not all computing applications can be handled by a single ED group, we have the following minimum number of transformed virtual networks to be processed by ED groups.

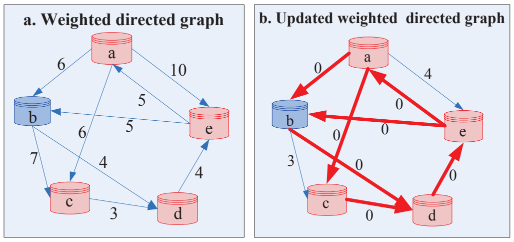


Figure 4: An illustration of embedding the virtual network processed by a single ED group.

$$N_2^{\min}{=}(L - N_1^{\max}). \tag{6}$$

Here, L is the total number of virtual networks.

Because $N_2^{'} \leq N_2^{\min}$, i.e., $max_{N_2^{'}} = N_2^{\min}$, our objective function Eq. (3) can be transformed as follows.

$$min\{\sum_{i=1}^{N_1^{\max}} \sum_{\Gamma^*=1}^{n} (\alpha_{\Gamma^*}^i \times TP_{\Gamma^*})\} + min\{\lceil \frac{wb \cdot N_2^{\min}}{ba} \rceil\}. \tag{7}$$

Since the first term $min\{\sum_{i=1}^{N_1^{\max}} \sum_{\Gamma^*=1}^{n} (\alpha_{\Gamma^*}^i \times TP_{\Gamma^*})\}$ in Eq. (7) can be seen as a constant, the objective is given in the following, if there are impossibly embedded virtual networks in our system.

$$min\{\lceil \frac{wb \cdot N_2^{\min}}{ba} \rceil\}. \tag{8}$$

Intuitively, the optimal bound for the number of consumed wavelengths is $W_{bound} = \lceil \frac{wb \cdot N_2^{\min}}{ba} \rceil$.

Proposition 1: The performance becomes worse if the actual number of consumed wavelengths is lower than W_{bound}.

Proof. If some transformed virtual networks still cannot be embedded by ED groups, we have $N_2^{'} < N_2^{\min}$. Here, $N_2^{'}$ is the actual number of successfully embedded transformed virtual networks. Then, the actual number of consumed wavelengths $W = \lceil (wb \cdot N_2^{'})/ba \rceil < \lceil (wb \cdot N_2^{\min})/ba \rceil = W_{bound}$. Therefore, the algorithm performance gets worse if the actual number of consumed wavelengths is lower than W_{bound}. ☐

3. ALGORITHM DESCRIPTION

In the previous section, we have formulated the problem. In this section, we develop an efficient algorithm to solve it.

First of all, a novel graph-cutting algorithm is proposed to embed the virtual network onto the substrate same ED group. The corresponding procedure is detailed as follows.

Step 1: In the weighted undirected graph Γ of one ED group, we delete the vertexes with available computing capacity lower than c, and delete the wireless links with available radio bandwidth lower than wb. Thus, the updated graph $\Gamma^{'}$ is obtained, as illustrated by Fig. 4(a), where each ED vertex is able to directly transmit data to the others.

Step 2: Update the link weight of $\Gamma^{'}$ as follows.

$$P_u(v) \rightarrow P_u(v) - argmin\{P_u(x), (u,x) \in \Gamma^{'}\}, \tag{9}$$

where $argmin\{P_u(x), (u,x) \in \Gamma^{'}\}$ is the minimal weight among all outgoing links of the ED vertex u. As shown in Fig. 4(a), the weights of outgoing links (b,c) and (b,d)—owned by the ED vertex b—are 7 and 4, respectively. Thus, we have $min\{P_b(x), (b,x) \in \Gamma^{'}\} = 4$. Correspondingly, we update the weights of (b,c) and (b,d) to 3 and 0, respectively, in Fig. 4(b). After updating all link weights, we only reserve the wireless links with none weight (such as the red arrows of Fig. 4(b)).

Step 3: We utilize the following method to decide the most qualified ED group. For the simplified $\Gamma_i^{'}$ of the i^{th} ED group, the sets of high-level and ordinary EDs are $M_i^{'}$ and $P_i^{'}$, respectively. We let Ω_j^i record the available computing resources of the $j^{th}(j \in M_i^{'})$ high-level ED in $\Gamma_i^{'}$, and Ω_k^i record the available computing resources of the $k^{th}(k \in P_i^{'})$ ordinary ED in $\Gamma_i^{'}$. Thus, the most qualified ED group has the following properties.

$$\forall i: \ |P_i^{'}| \geq |\phi|, |M_i^{'}| \geq 1. \tag{10}$$

$$argmin\{[\tau/(\sum\nolimits_j \Omega_{j \in M_i^{'}}^i + \sum\nolimits_{k \in P_i^{'}} \Omega_k^i) \,]\} \ \leq \Upsilon. \tag{11}$$

Here, Eq. (10) ensures that we can find node-mapping solutions on the selected ED group. In Eq. (11), Υ is the maximal delay of processing data, and $\tau(\tau > \Upsilon)$ is the time duration of processing data per unit of computing resources. A short time duration of processing data results in a high data computing efficiency. Thus, Eq. (11) means that we try to obtain a shorter time duration of processing data through selecting the ED group which has a larger amount of computing resources. Above all, we first determine several ED groups satisfying Eq. (10), and then the most qualified ED group Γ^*—which has the smallest term $\Big[\tau/\Big(\sum_{j \in M_*^{'}} \Omega_j^* + \sum_{k \in P_*^{'}} \Omega_k^*\Big) \Big]$—is selected by us.

If not all L virtual networks can be successfully embedded onto a single ED group due to limited resource provisioning, we then transform impossibly embedded virtual networks into new ones processed by ED groups, as mentioned in subsection 2.1. If each group has one available high-level ED holding the virtual node, the corresponding transformed virtual network will be successfully embedded; otherwise, the embedding fails, and we update the number of unsuccessfully embedded virtual networks $\aleph \leftarrow \aleph + 1$.

4. SIMULATION RESULTS

First, we introduce simulation settings. We then analyze the performance of our design under various conditions.

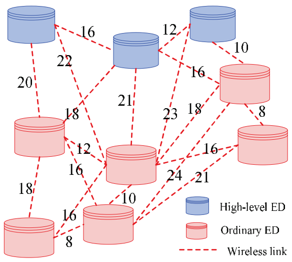


Figure 5: Test topology for each ED group.

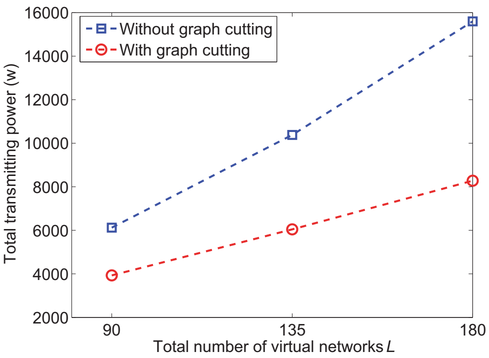


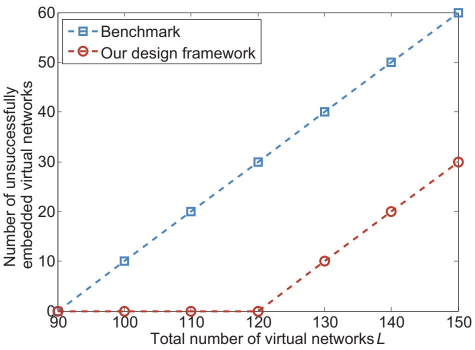
Figure 6: Total number of virtual networks vs. total transmitting power.

4.1 Simulation settings

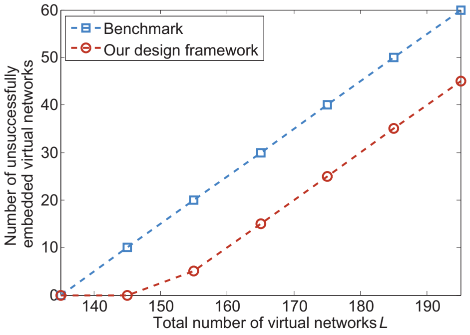
Our test optical-wireless network has 3 groups, each of which owns 3 high-level EDs and 6 ordinary EDs (i.e., $n = 3, M = 3, P = 6$). In the internal structure of each ED group shown by Fig. 5, the number beside the wireless link (u, v) is the pre-determined $P_u(v)$. To emulate a semi-real environment in Fig. 5, these EDs are randomly deployed in each group, according to the principle mentioned in subsection 2.1. Obviously, a longer physical distance—between two linked EDs u and v—corresponds to a larger $P_u(v)$. In addition, the initial radio bandwidth per wireless link is assumed to be rich. For the virtual network $vn(s, \phi, wb, c)$ processed by a single ED group, $|\phi| = 2$, $c = 1$ and $wb = 1$. We let $|\phi| = 2$ to ensure that the total number of virtual nodes—owned by the virtual network $vn(s, \phi, wb, c)$—can not exceed the total number of ED groups, i.e., $(1 + |\phi|) \leq n$. The wavelength capacity is $ba = 6$ which is a half of a small wavelength granularity OC-12.

4.2 Simulation results

First of all, given the initial computing capacity of each high-level ED $SC_h = 20$, we analyze the reduction of transmitting power using graph cutting when embedding virtual networks. It could result in an unfair situation where few virtual networks are successfully embedded—with the bad use of wireless resources—but the design has a low total transmitting power. For this end, we determine the maximum number of successfully embedded virtual networks $N_1^{\max}$ based on Eq. (4). Such that, whether with or without graph cutting, all virtual networks can be successfully embedded onto a single ED group. Then, we have $N_1^{\max} = (n \cdot P \cdot SC_l)/(c \cdot |\phi|) = 90$ when $SC_l = 10$, $N_1^{\max} = 135$ when $SC_l = 15$, and $N_1^{\max} = 180$ when $SC_l = 20$ (see the horizontal axis of Fig. 6). The total transmitting power is evaluated by Eq. (5). Simulation results show that the graph cutting can reduce the total transmitting power with an improvement ratio of 42%. This is reasonable because we simplify the graph for each ED group by reserving only the wireless link with a lower $P_u(v)$ weight.



(a) $SC_l = 10$



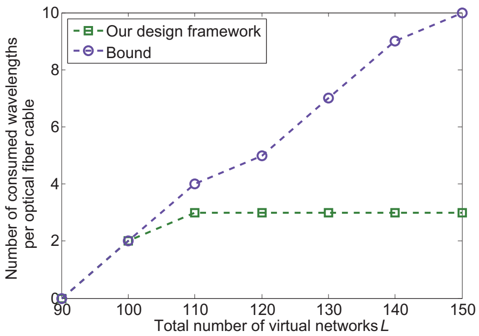
(b) $SC_l = 15$

Figure 7: Number of unsuccessfully embedded virtual networks vs. total number of virtual networks.

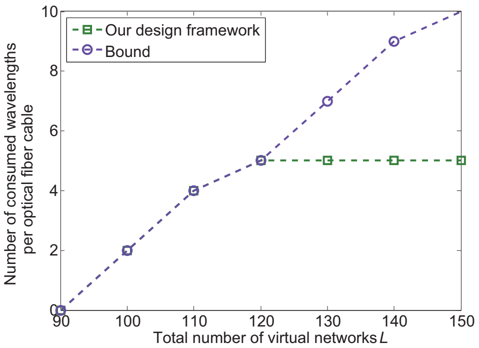
In Fig. 7, given the initial computing capacity of each high-level ED $SC_h = 20$, we compare our design framework and the benchmark neglecting the virtual network transformation, in terms of the total number of unsuccessfully embedded virtual networks $\aleph$. The benchmark is the traditional VNE in WMNs (e.g., [7]), but we identify the benchmark to support edge computing. In other words, the benchmark only allows the virtual network processed by a single ED group. The total number of virtual networks L starts from $N_1^{\max}$ determined in Eq. (4), i.e., L starts from $N_1^{\max} = (n \cdot P \cdot SC_l)/(c \cdot |\phi|) = 90$ when $SC_l = 10$. Thus, impossibly embedded virtual networks will emerge if $L > N_1^{\max} = 90$, and the virtual network transformation can be invoked in our algorithm. Similarly, L starts from 135 when $SC_l = 15$. A small $\aleph$ means a good VNE efficiency. Firstly, when $SC_l = 10$ in Fig. 7(a), $\aleph = 0$ only when $L = 90$ for the benchmark. While for our design framework, $\aleph = 0$ when $L = \{90, 100, 110, 120\}$ because we can further transform impossibly embedded virtual networks into new ones processed by ED groups. Starting from 130, $\aleph$ becomes larger than 0 for our design framework, due to the lack of computing resources owned by high-level EDs; but we also have a smaller $\aleph$ than that of the benchmark, and the improvement ratio of decreasing $\aleph$ is about 81%.

When $SC_l = 15$ in Fig. 7(b), the improvement ratio of decreasing $\aleph$ is 53% over the benchmark. There is an interesting point that the improvement ratio decreases with the increase of the initial computing capacity of ordinary EDs. In other words, although deploying a large number of high-capacity ordinary EDs, the VNE efficiency can not be further improved. This is because the efficiency of embedding the virtual network onto different ED groups is significantly affected by the limited computing capacity of high-level EDs. In summary, our algorithm performs best when $SC_h = 20$ and $SC_l = 10$, because it has the highest VNE efficiency with an appropriate deployment expenditure.

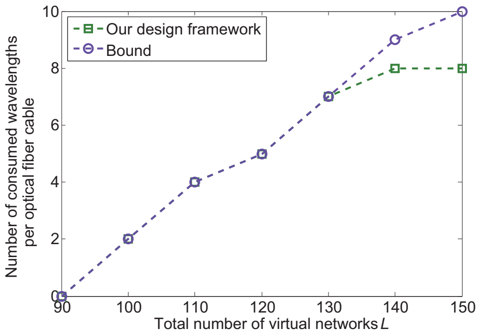
Given the initial computing capacity of each ordinary ED $SC_l = 10$, we compare the number of consumed wavelengths—deployed on each optical fiber cable—between our design



(a) $SC_h = 15$



(b) $SC_h = 20$



(c) $SC_h = 25$

Figure 8: Number of wavelengths per optical fiber cable vs. total number of virtual networks.

framework and the optimal solution with $SC_h = \{15, 20, 25\}$ in Figs. 8(a), 8(b), and 8(c), respectively. The number of wavelengths used by our design framework W becomes larger with an increasing value of L. With $SC_h = 15$ in Fig. 8(a), only when $L = 90$, the converge ratio between W and the optimal solution W_{bound} is 100%. While in Fig. 8(a), the converge ratio decreases if L is larger than 90. This is because that we can not serve more virtual networks due to the limited computing resources of high-level EDs, even using the transformation of virtual networks. However, we can narrow the gap between W and W_{bound} if a higher SC_h is given. Given $SC_h = 20$ in Fig. 8(b), when $L = \{90, 100, 110, 120\}$, the converge ratio is 100%. Given $SC_h = 25$ in Fig. 8(c), when $L = \{90, 100, 110, 120, 130\}$, the converge ratio is always 100%. This demonstrates the optimality of our design framework.

5. CONCLUSION

We proposed a novel design framework to perform the green VNE of collaborative edge computing in environment-friendly optical-wireless networks. Simulation results demonstrated that our design framework could successfully embed more virtual networks compared to the benchmark with an average improvement ratio of 77%, while a blind increase of ED computing capacity could not improve the VNE efficiency; our algorithm showed a good converge ratio between the actual number of wavelengths used per optical fiber link and a theoretical optimal solution, especially with a high initial computing capacity of high-level EDs. Since our solution has a lower transmitting power and consumes fewer wavelengths, the corresponding design complies with the principles of social, economic and ecological sustainability.

6. ACKNOWLEDGMENTS

This work was supported in part by the National Natural Science Foundation of China (Grant Nos. 61401082, 61471109, 61502075, 61672123, 91438110, U1301253), the Fundamental Research Funds for Central Universities (Grant Nos. N161604004, N161608001, N150401002).

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