Spectrum Continuity Awareness for Virtual Network Construction in Elastic Optical Networks

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Abstract

With network virtualization technology, network resources are managed efficiently because multiple virtual networks (VNs) can be constructed over a shared physical network. On the other hand, Elastic Optical Networks (EONs), with its variable spectrum grids, can use the spectrum efficiently because the spectrum can be allocated at a subwavelength level. A VN can be constructed over an EON if there are enough available network resources and if the spectrum contiguity constraint is satisfied. In this paper, we consider the case where network operators do not use network convertors in order to reduce network costs. In this situation, an additional constraint called spectrum continuity has to be satisfied. Therefore, we propose a VN over EON construction algorithm which satisfies both the spectrum continuity constraint and uses spectrum splitting if there are not enough link resources. We evaluate the effectiveness of the proposed method by simulation for the NSFNET topology and discuss its results.

1. Introduction

With network virtualization technology, network resources are managed efficiently because multiple virtual networks (VNs) can be constructed over a shared physical network [1]. When a VN construction request arrives, node mapping and link mapping are performed. In node (link) mapping, the requested virtual node (link) resources are mapped by allocating physical node (link) resources if there are enough available resources. Since, physical network resources are limited, it is important to design an efficient VN construction algorithm in order to construct as many VNs as possible.

Optical networks are high speed networks where data is transmitted as an optical signal through channels called spectrum grids. In fixed grid optical networks, optical signals in the form of wavelengths are transmitted through spectrum grids with a predefined size. Here, the size of a grid as been set to 50GHz as per the standards defined by the International Telecommunication Union (ITU) [2].

However, having a grid that has a fixed size may result in inefficient spectrum utilization if the required bandwidth is not a multiple of 50 GHz [3], [4], [5]. As a cost-effective solution, elastic optical networks (EON) have been proposed.

In contrast to fixed grid optical networks, the spectrum in EONs can be allocated at a subwavelength level, where the spectrum unit is called frequency slot (FS). Furthermore, the size of the spectrum grid is variable because optical transponders that allow transmitting, receiving and switching optical signals at multiples of FSs are used [6]. Therefore, EONs can use the spectrum more efficiently and flexibly without adding more bandwidth. Hence, in this paper, we consider elastic optical networks (EON) as the physical network for VN construction.

When constructing a VN over EON, node mapping will succeeds the number of available physical CPU resource slots is larger than or equal to the requested virtual node resources [7], [8]. On the other hand, in link mapping, FSs at physical links are allocated by establishing a connection called a lightpath, which is established between two physical nodes. Link mapping succeeds if the lightpaths between the mapped physical nodes are established successfully. Here, a lightpath can be established if the number of available FSs is greater than or equal to the requested one [9], [10], [11]. In addition, the spectrum contiguity has also to be satisfied. In the spectrum contiguity constraint, the available FSs have to be allocated adjacently in the spectrum at each link of a lightpath. In this paper, we consider the case where network operators do not use network convertors in order to reduce network costs. In this situation, an additional constraint called spectrum continuity has to be satisfied. Here, the same FSs have to be allocated at each link of the lightpath.

In the literature, several techniques for VN construction over EON have been proposed. In [12], two algorithms have been proposed where one algorithm maximizes the utilization of FSs and the other minimizes the blocking rate of VN requests. In [13], the proposed method constructs VNs by minimizing the network cost in the case where the traffic is known in advance. In [14], the authors have presented a load-balancing algorithm in order to resolve the fragmentation issue that occurs in EON because some FSs cannot be used by VNs if the number of adjacents is too small for VN requests.

In this paper, we propose a spectrum continuity aware algorithm for VN construction, where the objective is to decrease the blocking rate of VN requests by performing spectrum splits. In this algorithm, a VN is constructed if node mapping and link mapping succeed under the spectrum contiguity and continuity constraints. If node mapping fails, the VN request is blocked. If node mapping succeeds and link mapping fails, spectrum splitting is executed. Here, the required FSs are allocated by establishing two lightpaths through different paths and a VN is constructed. If there are not enough available FSs at other paths, the VN request is blocked. We evaluate the performance of the proposed method with Monte Carlo simulation in NSFNET and investigate its effectiveness.

Next, we introduce background information in section 2 and summarize some related work on spectrum splitting in section 3. In Section 4, we explain our system model and our proposed method

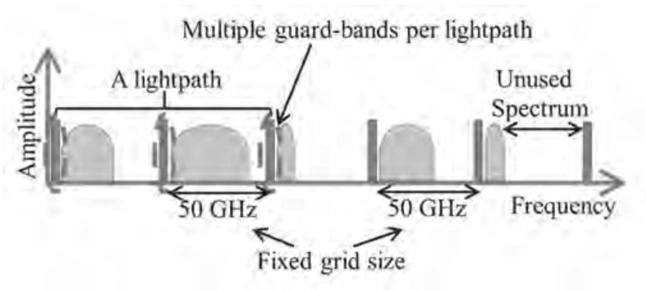


Figure 1. Comparison of spectrum grids.

in section 5. Numerical results are shown in Section

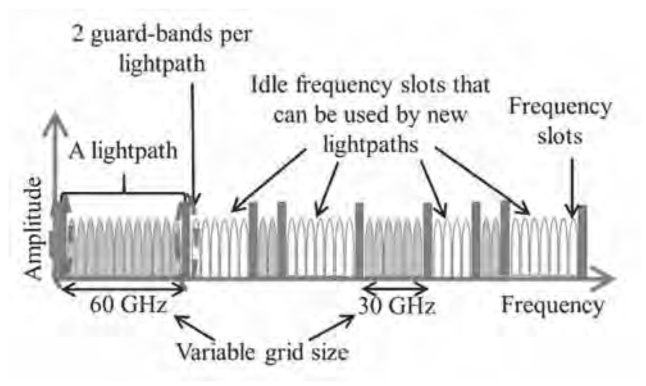
(a) Fixed grid optical networks.

(b) Elastic optical networks.

6, and conclusions are presented in Section 7.

2. Background

2.1 Elastic Optical Networks



In this subsection, we explain how the spectrum grid is utilized in EON. Figure 1 illustrates the differences between EON and fixed grid optical networks in terms of the utilization of the optical spectrum.

As illustrated in Figure 1 (a), the size of the spectrum grid for fixed grid optical networks is always 50 GHz, meaning that it is fixed. Therefore, if the required bandwidth is not a multiple of 50 GHz, the spectrum grid is not fully utilized. For example, if the required bandwidth is 80 GHz then two grids will be used. Here, one 50 GHz grid is fully utilized while in the other grid only 30 GHz are used. Therefore, in this example, 20 GHz of spectrum are wasted because it cannot be used by other users. In addition, a guard-band is needed between adjacent grids even when these grids are used by the same lightpath, hence, in fixed grid

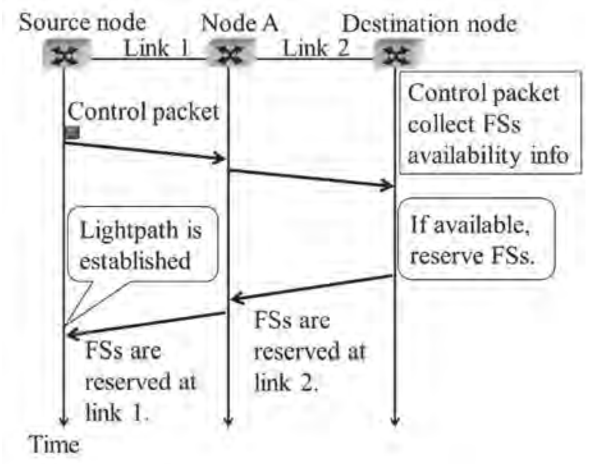


Figure 2. Lightpath establishment in EON.

optical networks, the spectrum grid is not used efficiently.

On the other hand, as shown in Fig. 1 (b) for EON, the spectrum can be allocated per FS unit. In addition, if a lightpath uses multiple grids, only two guard-bands are needed. As a result, the optical spectrum can be utilized more efficiently in EON.

2.2 Lightpath Establishment in EON

In EON, data is transmitted all optically. This means that the optical signal remains in the optical domain from source to destination, and the Optical/Electrical/Optical (O/E/O) conversion is not performed at intermediary nodes, hence providing an ultra-fast data transmission. Moreover, in EON, a connection, called a lightpath, has to be established prior to data transmission. When a lightpath establishment request between a source and a destination node arrives, the following four steps are performed (see Fig. 2):

Step 1: Signaling

A ligthpath establishment request arrives at the source node with a required number of FSs and a destination node. Next, a path between the source and destination node is computed. Then, a control packet is sent along the computed path from source to destination. At each link along the path, the control packet collects information on the number of idle FSs and its positions in the spectrum.

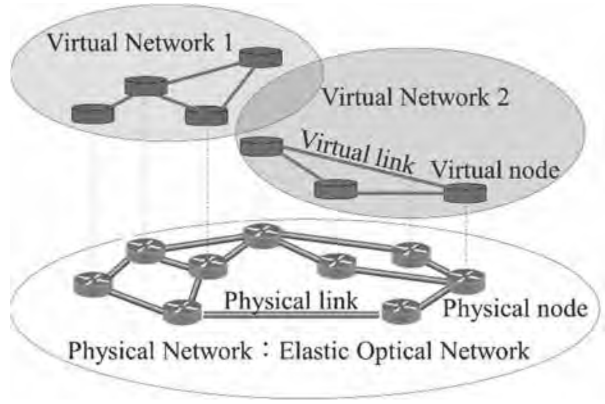


Figure 3. VN construction over EON.

Step 2: Reservation of FSs

When the control packet arrives at the destination node, the number of idle and contiguous FSs are checked for each link, based on the information included in the control packet. At this step, at each link, a number larger or equal to the requested FSs have to be:

- Idle
- Contiguous (adjacent in the spectrum) to satisfy the spectrum contiguity constraint.
- Continuous (the same FSs have to be utilized along all links in the lightpath) to satisfy the spectrum continuity constraint.

If the above three conditions are true, the FSs are reserved at each link and a lightpath is established. Otherwise, it is blocked.

Step 3: Data Transmission

At the end of step 2, if a lightpath has been established, then data is transmitted continuously and all optically from source to destination.

Step 4: Lightpath Termination

After all data is transmitted, all the reserved FSs are freed and the lightpath is released.

2.3 Virtual Network Construction over EON

In this subsection, we explain how VNs are constructed over EON. Figure 3 illustrates how multiple VNs are constructed over EON as a shared physical network. A VN is constructed based on the information in a VN construction request, which includes the number of required links, FSs (link resources) and CPU resource slots resources (node resources). Here, the requested node resources are allocated to available nodes in EON (node mapping) if the number of idle node resources is larger than that of the VN request. On the other hand, in link mapping, the requested link resources are mapped to available links in EON by establishing lightpaths between the mapped nodes if the three conditions mentioned in subsection 2.2 Step 2 are true.

If both node mapping and link mapping succeed, then a VN is constructed. Otherwise the VN construction request is blocked.

3. Related Work

Next, we introduce some related work on spectrum splitting. In [15], the authors propose spectrum splitting for constructing VNs over fixed grid optical networks. Here, spectrum splitting is utilized to split a virtual link into multiple paths for embedding many VNs, if the available amount of link resources is smaller than the amount of requested link resources. However, the proposed algorithm cannot be used for constructing VNs over EON because the spectrum contiguity constraint has not been considered.

For lightpath establishment in EON, spectrum splitting algorithms have been proposed in [16], [17], [18] and [19]. Here, spectrum splitting is used to split a single traffic demand into multiple lightpaths along the same link. However, these proposed algorithms are for lightpath establishment and cannot be used for VN construction over EON because node resources have not been considered.

In [20], path splitting for VN construction over EON has been proposed and numerical results show that the VN request blocking probability has been significantly reduced. Here, four schemes for node mapping have been considered. For link mapping, the shortest path between the mapped nodes, is computed. If there are no available FSs, path splitting is performed. Here, part of the requested FSs are assigned at links in the shortest path and the remaining FSs at links in alternative paths. However, this method considers the case where spectrum conversion is allowed, hence VNs are constructed without satisfying the spectrum continuity constraint. Therefore, it cannot be used in cases where the spectrum continuity is required.

From the above, we conclude that spectrum splitting has been proposed in cases of VN construction over fixed grid optical, for lightpath establishment in EON, and for VN construction over EONs that do not require spectrum continuity.

It is important to consider spectrum continuity because it provides an important cost saving for network operators. Therefore, in this paper, we propose a VN construction algorithm over EON that uses a continuity aware spectrum splitting.

4. Spectrum Continuity Aware Spectrum Splitting

In this section, we propose a spectrum continuity aware algorithm for VN construction, where the objective is to decrease the blocking rate of VN requests. In this algorithm, a VN is constructed if node mapping and link mapping succeed under the spectrum contiguity and continuity constraints.

4.1 Network Model

In this subsection, we explain our network model for the construction of VNs over EON.

We consider our physical network (EON) denoted as a graph G_p (N_p, L_p) where N_p is the set of physical nodes and L_p is the set of physical links. The maximum number of physical nodes is N and the maximum number of physical links is L. The i^{th}

(i=1, …, N) physical node is denoted as $n^i_p \in N_p$ and the number of CPU resource slots for n^i_p is denoted as C. We define the j^{th} CPU slot at node n^i_p as $c^i_n(j)$, which is equal to 0, if the j^{th} CPU slot at node n^i_p is idle, and 1 if it is used.

In addition, the i^{th} (i=1, …, L) physical link is denoted as $l^i_p \in L_p$, and the total number of FSs for link l^i_p is denoted as M. Here, we define the j^{th} FS at link l^i_p as $m^i_n(j)$, which is equal to 0, if the j^{th} FS at link l^i_p is idle, and 1 if it is used.

In this network, a VN is constructed based on the information of a VN request. Let us represent a VN as a graph G_v (N_v, L_v) where N_v is the set of virtual nodes and L_v is the set of virtual links. The v^{th} virtual node is denoted as $n_v \in N_v$, and the v^{th} virtual link is $l_v \in L_v$. A VN request contains information about the required number of nodes k, number of CPU resource slots c_v, and number of FSs m_v. We assume that $k \leq N$. In terms of node resources, c_v $(c_v \leq C)$ is the number of required CPU resource slots for virtual node $n_v \in N_v$. For link resources, m_v $(m_v \leq M)$ denotes the number of required FSs for virtual link $l_v \in L_v$.

A VN is constructed if the requested virtual nodes can be mapped to the physical nodes (node mapping) and virtual links to the physical links

$$A(n_v) = n^i_p, \quad n_v \in N_v,\ n^i_p \in N_p, \qquad (1)$$

(link mapping). We denote node mapping as follows:

Here, a virtual node is mapped to only one physical node, if there are enough available CPU resource slots at the physical node.

On the other hand, link mapping is denoted as:

$$A(l_v) = l^i_p, \quad l_v \in L_v,\ l^i_p \in L_p, \qquad (2)$$

A virtual link may be mapped to one or more physical links if there are enough idle FSs, which are contiguous and continuous at each link.

4.2 Overview

In this subsection, we give an overview of the proposed method. We assume that a VN request arrives at an EON with information about the required number k of virtual nodes, the number c_v of CPU resource slots for each requested node, and the number m_v of FSs at each link. Based on the VN request information, CPU resource slots are allocated at all the mapped nodes. Furthermore, lightpaths are established between each pair of mapped nodes with m_v FSs at each link of the lightpath.

A VN is constructed according to the following steps (see Fig. 4).

Step 1: A new VN request arrives with the required number of nodes k, CPU resource slots cv, and m_v FSs enough.

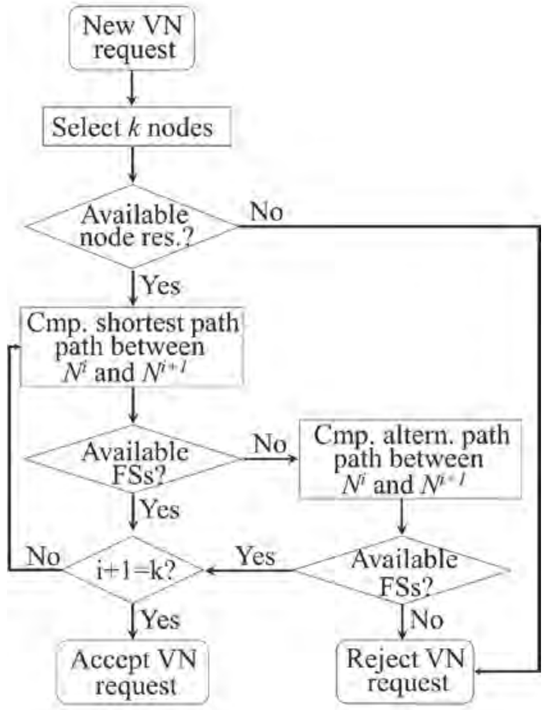


Figure 4. Flow chart of the proposed method

Step 2: In this step, k nodes which have the highest number of idle CPU resource slots are selected. These nodes are denoted as $(N^1,\ldots,N^i,\ldots,N^k)$.

Step 3: If the number of idle CPU slots is larger or equal to c_v at each selected node, go to Step 4. Otherwise, go to Step 9.

Step 4: Compute the shortest path between N^i and N^{i+1}.

Step 5: If the number of idle, contiguous and continuous FSs is larger than or equal to m_v at all link of the shortest path between N^i and N^{i+1}, go to Step 6. Otherwise, go to Step 7.

Step 6: If $i+1=k$, go to Step 10. Otherwise, increment i by 1 and go to Step 4.

Step 7: Spectrum splitting is executed because there are not enough idle, contiguous and continuous FSs at each link of the shortest path. Therefore, an alternative path with the fewest common links with the shortest path is computed between N^i and N^{i+1}.

Step 8: If there are enough idle, contiguous and continuous FSs at each link of the alternative, go to Step 6. Otherwise, go to Step 9.

Step 9: The VN request is blocked.

Step 10: The VN request is accepted. Here, cv CPU resource slots will be allocated at each of the selected k nodes, and m_v FSs will be allocated at all link for each established lightpath.

4.3 Spectrum Splitting

In this subsection, we explain Step 7. As explained in subsection 4.2, Step 7 is performed if there are enough idle CPU resource slots but not enough available FSs. Here, spectrum splitting is executed because the number of idle, contiguous and continuous FSs at each link along the shortest path between N^i and N^{i+1} is smaller than m_v which is the number of requested FSs. In this step, an alternative path is computed in order to perform spectrum splitting. Let us denote m_v^{sp} as the maximum number of idle, contiguous and continuous FSs that is common to all links of the shortest path. Therefore, the remaining number of FSs to be reserved at each link of the alternative path, denoted as m_v^{al}, is defined as:

$$m_v^{al} = m_v - m_v^{ps}, \quad m_v^{al}, m_v^{ps} > 0, \qquad (3)$$

At first, all possible paths between N^i and N^{i+1} are computed. Then, a path which has the smallest number of common links with the shortest path is selected as the alternative path. If there are multiple candidate paths, the paths with the smallest number of hops is selected. Next, as explained in Step 8, the FS availability at each link along the alternative path is checked. Here, spectrum splitting succeeds if the number of idle, contiguous and continuous FSs at each link along the shortest path between N^i and N^{i+1} is larger than or equal to m_v^{al}. The VN request is accepted if there are enough idle CPU resource slots and enough available FSs over both the shortest path and the alternative path. Finally, c_v CPU resource slots are allocated at N^i and N^{i+1}, and two lightpaths (one for the shortest path and another for the alternative path) are established between N^i and N^{i+1}. If the above conditions are not satisfied, the VN requested is blocked.

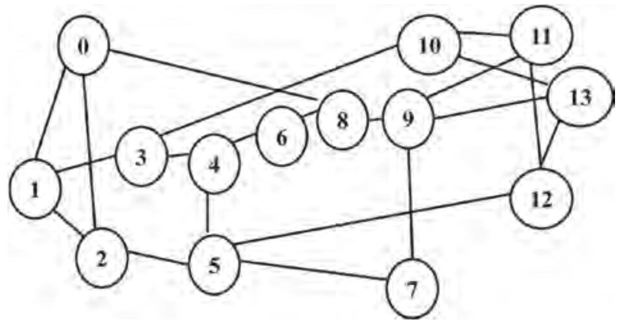


Figure 5. The NSFNET Topology.

5. Numerical Results

In this section, we evaluate the performance of our proposed method by Monte Carlo simulation for the NSFNET topology shown in Fig. 5. In this topology, the number N of nodes is 14 and the number L of links is 21. The number M of FSs at a link is 64, and the number C of CPU resource slots is set to 64 at each node. We assume that VN requests arrive at an EON according to a Poisson process with rate λ [Requests/ms], and the utilization time of a VN follows an exponential distribution with rate 1.0.

We compare the performance of our proposed method with two conventional VN construction methods under spectrum contiguity and continuity constraints. In the node mapping of both conventional methods, all required nodes of a VN request are selected at random. The first method denoted as “EON” constructs VNs over EON without performing spectrum splitting, hence if there are no available FSs, the VN request is blocked. Whereas the second method denoted as “EON SS” performs spectrum splitting if there are not enough available FSs at each link of a lightpath.

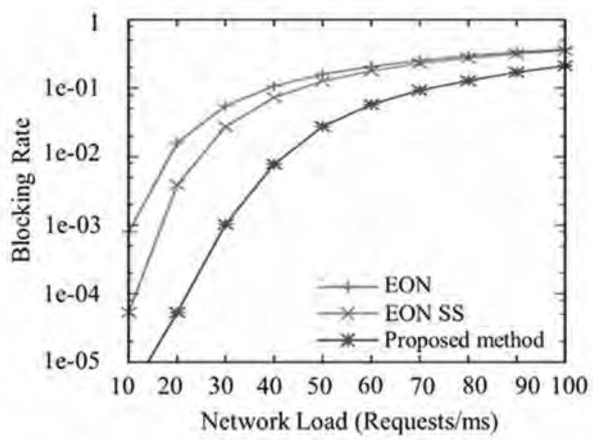


Figure 6. Blocking rate vs. network load.

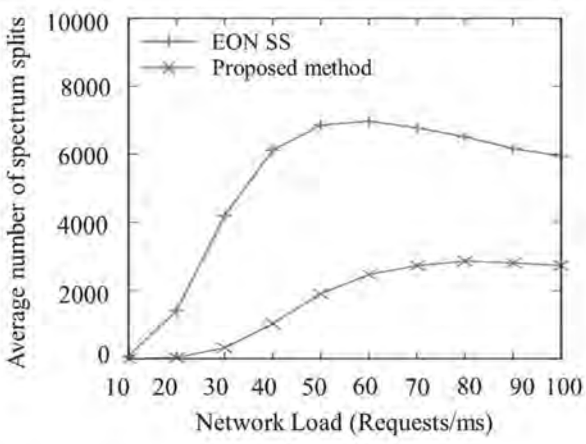


Figure 7. Spectrum splits vs. network load.

5.1 Effect of the network load on the blocking rate

In this subsection, we analyze the effect of the network load on the blocking rate. Figure 6 shows the overall blocking rate against the network load of the proposed method and that of the conventional methods denoted as “EON” and “EON SS”. Note that, “EON” and “EON SS” perform spectrum splitting if there are enough CPU resource slots but not enough available FSs. The main difference between these two methods and the proposed method is that the proposed method implements node mapping by selecting nodes with the most available CPU resource slots. Whereas in “EON SS”, nodes are selected at random.

From this figure, we find that the overall blocking rate for all schemes becomes large as the network load increases. Moreover, Fig. 6 shows that the blocking rate of the proposed method is

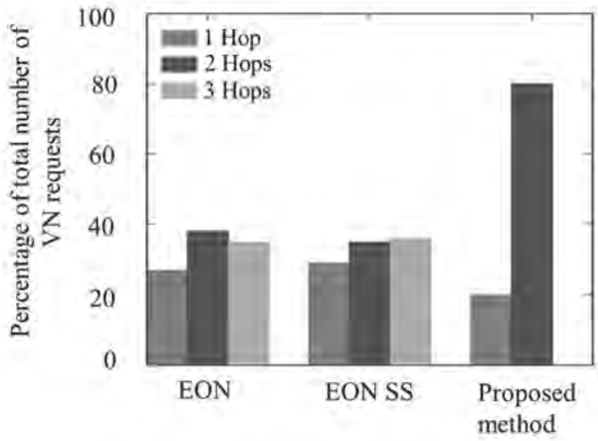


Figure 8. Number of VN requests per hops.

the lowest and that of “EON SS” is the highest. This is because our proposed method considers both the availability of CPU resource slots at link mapping and FSs availability in link mapping when constructing a VN. From the above results, we conclude that the proposed method can reduce the blocking rate significantly compared to the other two conventional methods.

5.2 Impact of the number of spectrum splits

Next, we investigate the impact of the network load on the average number of spectrum splits. Figure 7 shows the average number of spectrum splits against the network load for the conventional “EON SS” and the proposed method. From Fig. 7, we can see that the number of spectrum splits increases as the network load increases for both methods. Here, VN requests tend to get blocked more frequently when the network load increases because the network get congested and there are fewer available network resources for the arriving VN request.

In addition, the number of spectrum splits is the smallest for the proposed method and the largest for “EON SS”. This is because “EON SS” does not consider the amount of available computing resources at nodes at the node mapping stage when constructing a VN. In contrast, the proposed method constructs VNs by mapping nodes that have the highest available CPU resource slots.

Moreover, we notice that there is a peak in spectrum splits for both methods when the network load is about 60 requests per millisecond. Therefore, the number of spectrum splits is the smallest for the proposed method because the network resources are allocated more effectively.

5.3 Percentage of number of VN requests per hops

Finally, we investigate how node mapping and the use of spectrum splitting in link mapping affect the percentage of the number of VN requests per hops. Figure 8 shows the percentage of the total number of VN requests per hop for each of the conventional “EON”, “EON SS” and the proposed method. Note that we show in this figure the results of one hop, two hops and three hops. This is because in NSFNET the maximum number of hops between any pair of nodes is three. Figure 8 illustrates the case where the network load is 60 requests per millisecond. From this figure, we find that the percentage of the number of VN requests for one hop, two hops and three hops is almost the same for both the conventional “EON” and “EON SS” methods. However, for the proposed method, the percentage of the number of VN requests for two hops is the largest, followed by one hop and three hops. This is because, for the proposed method, nodes with largest available CPU resource slots are selected and mapped.

6. Conclusion

In this paper, we proposed a spectrum continuity aware algorithm for VN construction, where the objective is to decrease the blocking rate of VN requests. In this method, a VN is constructed if node mapping and link mapping succeed under the spectrum contiguity and continuity constraints. If node mapping succeeds and link mapping fails, spectrum splitting is executed, and a VN is constructed if there are available FSs at alternative paths. Otherwise, the VN request is blocked. We evaluated the performance of the proposed method by simulation for the NSFNET topology. From the numerical results, we found that the proposed method is effective in reducing the blocking rate. Thus, by using our proposed method, a larger number of VNs can be constructed over EONs.

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