Dynamic fragments awareness based virtual network mapping strategy of elastic optical networks

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As virtual networks services emerge increasingly with higher diversification, the issue of spectrum fragments presents great challenge to the elastic optical networks (EON), especially under heaven services burdens. Aimed to solve this problem, this article proposes a dynamic fragments awareness based virtual network mapping (DFA-VNM) strategy of elastic optical network. In this proposed approach, the dynamic fragments awareness model of it is established, which takes available bandwidth demand and spectrum fragment degree into consideration. Moreover, the dynamic fragments awareness based virtual network mapping strategy makes full advantage of real-time fragments awareness result to conduct virtual network service mapping operation with less fragments and lower blocking rate. Testing results show that the proposed approach is able to improved services supporting ability of EON.

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Under great progress of optical communications technologies, the elastic optical network (EON) has achieved massive development by making full use of the orthogonal frequency division multiplexing (OFDM) in the optical field[1,2]. As new types of optical devices are equipped with variable bandwidth ability, the EON can provide stronger support to virtual network services[3,4]. As one kind of newly emerged technologies, the network virtual technology allows various logically isolated networks to share the same optical layer network and physical resources.

In fact, the virtual network mapping function is to allocate optical layer network resources for various kinds of virtual services, under the limitation by both spectrum consistence and continuity. With ever increasing demands from virtual network services, the spectrum fragment of the optical layer network is one of serious issues and this unavoidable problem of the EON may result in serious service blocking rate and low utilization of optical resources.

Therefore, it is of great importance for the EON to take spectrum fragments problem into consideration to provide support to virtual network mapping operation[5-7]. To solve the problem mentioned above, several related typical researches have been made during recent years[8-12]. In Ref.[8], the pre-configured backup resources method is proposed, together with the group survivable virtual network embedding algorithms, to achieve the best mapping result and to dynamically adjust work or protection resources. However, this approach may result in low utilization spectrum. Ref.[9] mainly focused on the remapping method, where those related virtual nodes and links suffered from link failure were migrated and remapped. But low remapping successive rate can be caused when resources are not so enough. The shared protection is considered in Ref.[10] to map virtual network into optical layer network with higher virtual network survivability and lower optical network blocking rate. But the low shared degree problem of protection bandwidth is still there. Ref.[11] also presented a shared protection mapping optimization algorithm to reduce protection cost, but it still failed to take the spectrum fragmentation problem of EON into consideration. Therefore, there still exists the unavoidable issue of optical spectrum fragments in the elastic optical network system, caused by bandwidth diversification of newly emerged virtual network services.

Aimed to solve the mapping failure problem of virtual network caused by the spectrum fragment in the elastic optical network, this article proposes a dynamic fragments awareness based virtual network mapping algorithm for EON. In this article, the dynamic fragments awareness model of virtual optical network is established, which takes both spectrum fragments degree and available re-

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sources into consideration, together with real-time bandwidth demand of newly arrived virtual network service. Moreover, the dynamic fragments awareness based virtual network mapping (DFA-VNM) scheme is able to predict dynamically the fragment degree after nodes mapping and conduct the links mapping with less fragments and shortest physical path. The definition of dynamic fragment degree is given and detailed procedure is also depicted in this article. Thus, system performance of the network virtual mapping can be greatly improved in the EON. Finally, testing result can show great feasibility and efficiency of the proposed approach, with better successive rate and bandwidth utilization rate of the whole elastic optical network.

As Internet multiple services soars in recent years, most services blocking events are mainly caused by spectrum fragments problem in the EON, under condition of diversified services requirements. Within the research of virtual network mapping over EON, this issue must be taken into consideration. With the aim to cope with this fragments problem, the fragment awareness model is necessary to depict the fragment situation not only link ant node fragment conditions, but also the one of path and even the whole EON.

Therefore, the conception of dynamic fragment rate (FR) is firstly defined and related model is established in this section, which includes both FR of link and that of node in EON. The spectrum consistence degree is firstly defined as r_f in Eq.(1)

$$r_f = f_i \cdot f_{i+1}. \tag{1}$$

When the frequency i is occupied, f_i=1 in this formula. Otherwise, f_i=0.

The fragment rate $V_{\mathrm{FR\_link}}$ of each link in EON is also defined as

$$V_{\mathrm{FR\_link}} = 1 - \frac{\sum_{l=1}^{n_{\mathrm{link}}} \left(f_l \cdot f_{l+1} \right)}{n_{\mathrm{link}}}, \tag{2}$$

where n_{link} is the number of frequency slots in link. On the basis of Eq.(2), $V_{\mathrm{FR\_node}}$ of each node in EON can be also defined in Eq.(3), where S_{node} is the set of neighbour links around node and D_{node} is the total number of neighbour links.

$$V_{\mathrm{FR\_node}} = \frac{\sum_{l \in S_{\mathrm{node}}} \left(1 - V_{\mathrm{FR\_link}} \right)}{D_{\mathrm{node}}}. \tag{3}$$

Furthermore, the relative fragments rate can be defined as Eq.(4), which means the difference degree after the new service is allocated upon this node.

$$V_{\mathrm{RFR\_node}} = V'_{\mathrm{FR\_node}} - V_{\mathrm{FR\_node}}. \tag{4}$$

Moreover, the fragments degree $V_{\mathrm{FR\_path}}$ of path L can be gained.

$$V_{\mathrm{FR\_path}} = \sum_{\mathrm{link} \in L} \left(1 - V_{\mathrm{FR\_link}} \right). \tag{5}$$

Thus, the difference value $V_{\mathrm{FRD\_path}}$ of path fragments is given in Eq.(5), in which the $V'_{\mathrm{FR\_path}}$ is the one after a new service is allocated upon this path.

$$V_{\mathrm{FRR\_path}} = V'_{\mathrm{FR\_path}} - V_{\mathrm{FR\_path}}. \tag{6}$$

Therefore, the fragments rate of each node and link and even path, all can be obtained using this theoretical model. And this model will be refreshed, when any service connection is established or released.

Additionally, to deal with this fragment problem, there exist two approaches, where one is to conduct the defragmentation and the other is to improve the resources allocation operation of elastic optical networks. And the later one is adopted in this paper.

In general, the virtual network mapping can be divided into two parts which are the virtual node mapping and the virtual link mapping[13-15]. As limited conditions, every virtual node must be mapped onto only one physical node, and the spectrum consistence and continuity must be sure for every virtual link, where allocated spectrum slots of physical path should satisfy the bandwidth demand of virtual service. However, the fragment problem due to frequent virtual network mapping cannot be ignored. Based on the fragments awareness model defined above, this section proposed a novel virtual network mapping scheme with lower fragments degree during the virtual network mapping operation.

The main idea of the DFA-VNM scheme coms from that: Both physical network topology and spectrum utilization information of the whole EON system are collected, including all nodes and links. And detailed fragments condition is also computed. Thus, the elastic optical network is able to conduct virtual network mapping operation with minimum fragments, according the optical spectrum fragments model proposed in this paper.

In this article, the typical virtual network mapping example can be depicted by Fig.1, where the virtual network is (a-b-c) and corresponding nodes and links of EON include (2-1) and (1-5-6). In fact, each virtual network is independent logically from each other. For example, virtual network (2-6) and virtual network (3-5) have no directly relations between them.

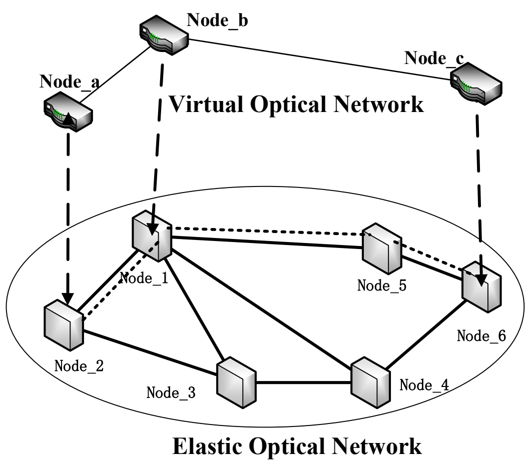

Fig.1 Virtual network mapping of EON

As is shown in Fig.2, the new spectrum slots are also arranged for this virtual network service request, with the least fragments produced.

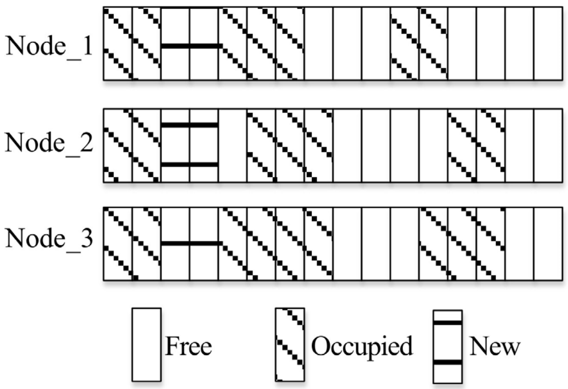

Fig.2 Spectrum slots mapping of EON

Generally, the virtual node mapping result will greatly affect the link mapping operation. This scheme takes the fragments condition as the main factor and chooses the right physical node with the least fragment for virtual node mapping. The virtual node mapping procedure is depicted as follows.

Step 1: Receiving newly arriving virtual network request which includes number of virtual nodes, number of virtual links and virtual bandwidth;

Step 2: Collect topology and resource information from the whole elastic optical network;

Step 3: Delete all nodes without enough service provision ability and form the available node set S_{node};

Step 4: Compute node fragment rate according to Eq.(3) for each physical node in S_{node};

Step 5: If there exists no physical node with enough service provision ability, reject this virtual network request; otherwise, turn to Step 6;

Step 6: Compute the difference degree of each node in S_{node} according Eq.(4) and select the right node using

$$R_{\text{RFR\_node}} = MIN\left(R_{\text{RFR,node\_1}}, R_{\text{RFR,node\_2}}, \cdots, R_{\text{RFR,node\_N}}\right); \qquad (7)$$

Step 7: Map the virtual node $V_{\text{node\_}i}$ into the physical node with minimized $R_{\text{RFR\_node}}$ value;

Step 8: Update information of related virtual node and physical node of EON;

Step 9: Turn to the next virtual node and repeat Step 4, until all virtual nodes have already been mapped;

Thus, the node mapping procedure is completed.

Following the node mapping operation, the virtual link mapping is also conducted, by using the shortest path to reduce unnecessary fragments. And the virtual link will be mapped into the physical path with minimum relative fragments rate. The virtual link mapping procedure is also given as follows.

Step 1: Delete all links without enough available bandwidth and form the available node set S_{link};

Step 2: Compute the physical link comprehensive factor according to Eq.(2) for each physical link;

Step 3: Adopt the Dijkstra routing algorithm to compute several physical paths with the shortest hops for virtual link $V_{\text{link\_}ij}$;

Step 4: Select the physical path with the least $V_{\text{RPR\_path}}$ according to Eq.(8) and map the virtual link upon this physical path

$$R_{\text{RFR\_path}} = MIN\left(R_{\text{RFR,path\_1}}, R_{\text{RFR,path\_2}}, \cdots, R_{\text{RFR,path\_k}}\right); \qquad (8)$$

Step 5: Update related information of all link fragments rate of physical topology;

Step 6: Update resources information of related physical links of EON and turn to the next virtual link, until all virtual links have already been mapped successively; otherwise, turn to the Step 1;

Step 7: The link mapping procedure is finished.

After that, the DFA-VNM can be well prepared for the elastic optical network system.

To evaluate the proposed fragments awareness based virtual network mapping algorithm, the simulation is conducted in this section, where the simulation environment is constructed by NS3 network simulation software tools and the NSFnet topology is adopted. And this simulated software defined optical network mainly consists of 32 nodes and 41 links, where each link contains 150 slots. The message delivery delays in each link are 1 ms. In this simulation, services requests are generated by C++ based clients for each optical node and the simulation is repeated 20 times. Connection requests follow the Poisson distribution and are uniformly distributed across the network with an arrival rate of 100/s. And the number of virtual nodes is distributed within [3~5] randomly and the duration of services time follows the negative exponential distribution.

This simulation comparison mainly focuses on performances of the blocking rate and the utilization rate of network resources. The comparison is made among the largest computing resources requirement versus the largest computing resources provisioning (LCLC)[16], FA-VNM[17] and the proposed DFA-VNM in this article. And comparison results are given by Fig.3 and Fig.4.

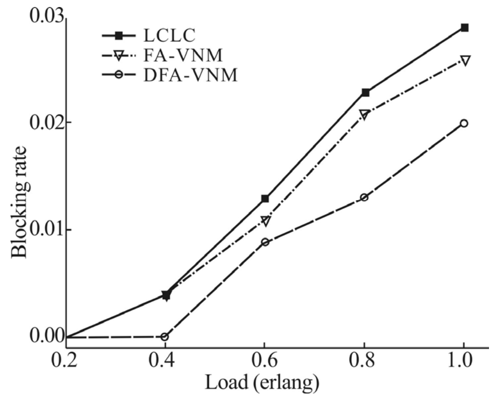

Fig.3 Comparison of blocking rate

The comparison of the blocking rate is given in Fig.3. Obviously, the LCLC shows the worst result in term of blocking rate when compared with FA-VNM and DFA-VNM. That is because LCLC fails to provide more optical resources available for the virtual network service under various limits. Moreover, both LCLC and FA-VNM have the same blocking rate performance partly under low traffic load, because their spectrum fragments are at the same degree under this condition. In comparison, the DFA-VNM can achieve the best performance, enhanced by the dynamic fragment awareness function. Thus, the QoS quality of EON with LCLC still suffers greatly from spectrum fragments problem. As the proposed DFA-VNM scheme can be fully aware of those spectrum fragments of EON to avoid of producing unnecessary fragments, the blocking rate can be efficiently improved by the DFA-VNM, even under condition of high traffic load. Because the virtual link mapping method of the DFA-VNM can directly save network resources of EON, the system can provide support to more service request. Thus, the blocking rate can be further improved by this DFA-VNM scheme.

As shown in Fig.4, both LCLC and FA-VNM work with worse performance on resource utilization rate, while the DFA-VNM can achieve better result. When the traffic load is very low, the FA-VNM and the DFA-VNM show the same utilization rate, because both schemes are equal on theory in this condition. As the traffic load soars, the DFA-VNM produces less fragments, which means this proposed algorithm can actively allocate resources with higher efficiency. As network resources can be saved greatly by the proposed DFA-VNM, better utilization rate of network resources can be achieved.

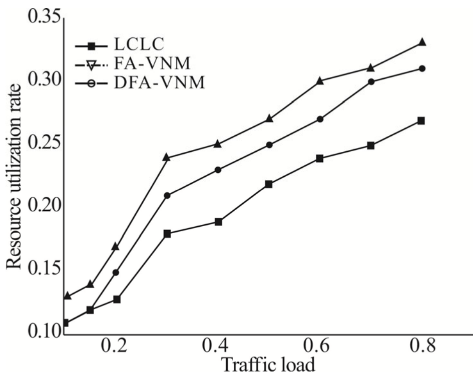

Fig.4 Comparison of resource utilization rate

Comparison of average performance is given by Tab.1. The DFA-VNM has better blocking and utilization performances, while its delay time is between LCLC and DFA-VNM. That is because of the complexity brought by DFA-VNM to be aware of real-time fragments condition of the whole EON.

Tab.1 Performance comparison

Scheme	Average blocking	Average utilization	Average delay
LCLC	1.38%	19%	94 ms
FA-VNM	1.24%	21%	75 ms
DFA-VNM	0.84%	23%	79 ms

Over all, it can be drawn that the DFA-VNM scheme is able to greatly improve the blocking rate of services and the utilization rate of network resources.

Aimed to improve virtual network mapping efficiency for multiple Internet services with less spectrum fragments in elastic optical network, this paper proposed a so-called fragments awareness based virtual network mapping algorithm in the EON. This proposed fragment-awareness model taken spectrum fragments conditions into consideration. Moreover, a novel virtual network mapping algorithm was also proposed and designed based on this fragment awareness model. Simulation results showed that the proposed scheme was enabled to provide support to services-oriented virtual network mapping of elastic optical networks in terms of bandwidth blocking rate and resources utilization rate performances.

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