A Dynamic VONE Algorithm Considering Topology For Hybrid Services in SDM-EON

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***Abstract*—This paper propose a dynamic Topo VONE algorithm considering the VON requests' topology. Simulation results show that our algorithm can optimize band blocking probability, spectrum utilization and reduce the waste of computing resources.**

***Index Terms*—Virtual optical network, multi-core optical fiber, space division multiplexing, network profit**

I. INTRODUCTION

With the continuous growth of network service traffic, the capacity of Single-Core Fiber has reached its Shannon limit. As one of the solutions, Space division multiplexing (SDM) could be a promising technology to further expand optical fiber capacity with a multi-core fiber (MCF) [1]. SDM technology has been incorporated with EONs to accommodate the proliferation of high bandwidth traffics. The technology places several cores in each fiber link, and each core contains multiple modes to enhance the fiber capacity. Another constraint is network ossification, the internet is facing the issue of not able to meet the difficulties brought about by new services due to the lack of cooperation between Internet service providers. Network virtualization technology has become a potential answer to this problem [2]. With optical network virtualization, which is based on the concept of infrastructure as a service (IaaS), network operators can efficiently offer the network resources of their networks to users and applications[3]. The Virtual Optical Network Embedding (VONE) process determines how virtual network requests are mapped to physical facilities[4], such as physical nodes and fiber links.

Recently, researchers have been developing virtual networks embedded in substrate networks to utilise resources more efficiently and effectively. To complete the virtual optical network embedding in EON, it is necessary to consider the resource allocation of physical nodes and links [5] when simulating the VONE in a static scenarios. In the SDM-EON scenario, allocation of the same spectrum slots in the adjacent cores generates inter-core crosstalk (XT), which then degrades the quality of optical signal. Thus, the generation of XT must be considered for VONE in SDM-EON[6]. When it comes to solving the problem of high resource consumption of virtual network mapping, previous works have used integer linear programming to implement VONE resource allocations in static scenarios.

Various existing studies have been embedding VON in SDM-EON in a static scenario, and using the traditional two-stage embedding algorithm (where node embedding and link embedding are separated). As to our knowlegde, only a small number of works have considered the dynamic scenario of VON embedding or used an one-stage algorithm to solve the resource allocation for hybrid services. Hybrid services indicated that each batch of requests contains both general requests, which indicate traditional optical routing requests, and VON requests. Then we use Poisson distribution to simulate their arrival to the nodes.To solving the VONE problems, the traditional two-stage(named as Traditional VONE) method may map some substrate nodes that are far away from each other, so when the VON request's topology is a cycle, such method will waste a lot of computing and communication resource. In this work, we consider the topology of VON requests and substrate network, and propose an one-stage VONE algorithm(named as Topo VONE). Simulative numerical results show that Topo VONE algorithm outperforms the benchmark algorithm(Traditional VONE) in terms of band blocking probability and spectrum utilization, and our algorithm can also avoid the waste of computing and communication resource in VONE procedure.

II. NETWORK MODEL AND CONSTRAINT

A. Network Model

In VONs embedding model, a substrate SDM-EON is described as a weighted directed graph $G^s(N^s, L^s, C^s, F^s, O^s)$,where N^s, L^s, C^s, F^s and O^s represent a set of physical nodes, a set of physical links, a set of fiber cores, the number of frequency slots on each fiber core, and the available capacity of the computing resources at each physical node. $R(R^g, R^v)$is the set of requests that need to be placed in substrate network G^s, where $R^g(s_n, d_n, St, Du)$ represent the general requests, s_n is source node of the request, d_n is destination node of the request, st, Du is the start time and duration of the request. And $R^v(N^v, L^v, O^v, F^v, St, Du)$ represent the VON requests, where N^v is the set of virtual nodes, L^v is the set of virtual links,F^v and O^v is the requirement of the frequency slots and computing resources of VON request R^v.The SDM-EON architecture is illustrated in Fig.2, where each optical switching node that includes optical transponders and each fiber link has multi-core fibers (Shown in Fig.1). Fig.3 shows two different topology types of VON requests. From Fig2 and Fig3, we can notice that if we use node$\{B, C, G\}$ to embed the VON request$\{v1, v2, v3\}$, we only need 3 substrate links, but if we use node$\{A, F, C\}$, we need 5 links instead. That why we propose a one-stage algorithm to avoid this waste of resources. The algorithm is detailed in the next section.

B. VON Embedding Constraint

In this network nodel, VONE can be decomposed into three sub problems: node mapping , link mapping and core allocation, each of them have several constraints. Node mapping constraints contains:

$$\sum_{s \in N^s} \rho^r_{v,s} = 1 \quad \forall v \in N^v, \forall r \in R^v \tag{1}$$

$$\sum_{v \in N^v} \rho^r_{v,s} \leq 1 \quad \forall s \in N^s, \forall r \in R^v \tag{2}$$

$$\sum_{r \in R^v} \sum_{v \in N^v} O^v \leq O^s \quad \forall v \in N^v, \forall s \in N^s, \forall r \in R^v \tag{3}$$

Equation(1) (2) ensure that each VN is embedded into just one substrate node, and Equation(3) ensure the embedded substrate node has sufficient computing capacity to handle the VON request. Link mapping constraints contains:

$$\alpha^r_{e,(s,d)} + \alpha^r_{e,(d,s)} \leq 1, \forall r \in R^v, \forall e \in L^v, \forall s, d \in N^s \tag{4}$$

$$f^r + F^r_v - 1 \leq F^s \quad \forall r \in R^v \tag{5}$$

$$f^r + F^r_v - 1 = I^r_{fs} \tag{6}$$

Where $\alpha^r_{e,(s,d)}$ is a binary variable indicated whether a link of a virtual network is mapped into a substrate link or not, f^r and I^r_{fs}represent the start index and the maximum index of the frequency slots allocated to the service requestR^v. Equation(4) guarantee link-disjoint principle, Equation(5) guarantees a mapped substrate link has enough frequency slots capacity to accommodate mapped requested frequency slots, and Equation(6) describes the maximum index of the frequency slots,

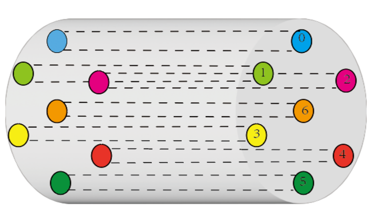


Fig. 1. A multicore fiber with seven cores.

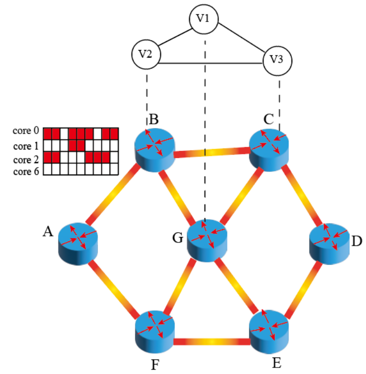


Fig. 2. An architecture of VON over SDM-EON.

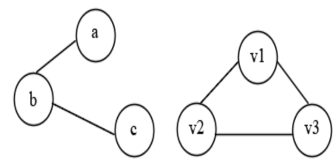


Fig. 3. An example of VON requests with different topology.

which represents the principle of frequency continuity. Core allocation constraints contains:

$$\begin{gathered} When \quad \beta^{r_1}_{c,(s,d)} + B^{r_2}_{c_{adj},(s,d)} = 2, \\ then \quad f^{r_1} - f^{r_2} \geq F^{r_2}_v \\ or \quad f^{r_2} - f^{r_1} \geq F^{r_1}_v \\ \forall r_1, r_2 \in R^v, \forall c \in C^s, \forall s, d \in N^s \end{gathered} \tag{7}$$

Where $\beta^r_{c,(s,d)}$ is a binary variable indicated the request r is allocated to core c or its adjacent core. Eq(7) can avoid the overlapping of the frequency slots when two different requests are allocated to two adjacent cores.

C. Objectives

Our objectives includes: Minimizing the bandwidth blocking probability (BBP) of VON requests, maximizing the utilization of spectrum resources, and minimizing the average hops of virtual link mapping in VON embedding. The blocking bandwidth probability,utilization of spectrum resources and average hops of virtual link embedding are computed by:

$$\frac{\sum_{k \in Block} F^k_v}{\sum_{r \in R^v} F^r_v} \tag{8}$$

$$\frac{\sum_{l \in L^s, c \in C^s} M^s}{\sum_{l \in L^s, c \in C^s} F^s} \tag{9}$$

$$\frac{\sum_{r \in R^v} H^r}{Count(R^v)} \tag{10}$$

TABLE I
VARIABLES

Variable name	Variable description
$O_\lambda^s \quad \lambda \in N^s$	represents the remain computing resource of the substrate node λ
$\omega_l^s \quad l \in L^s$	ω_l^s represents the capacity of link l to accept the new requests $R(R^g, R^v)$
$c_i^l \quad c \in C^s$	c_i^l is a binary variable. If the frequency slots of link l at index i is occupied by any two cores in core c and its two adjacent cores, then $c_i^l = 0$, otherwise $c_i^l = 1$
$Topo_{R^v}$	$Topo_{R^v}$ is a binary variable. If topology of R^v is a cycle, then $Topo_{R^v}$=1, otherwise $Topo_{R^v}$=0

Where M^s is a binary variable represent the occupied frequency slots in each substrate link, H^r represent the hop number of the substrate links which used to embed the VON request R^v, and $Count(R^v)$ indicated the number of VON requests.

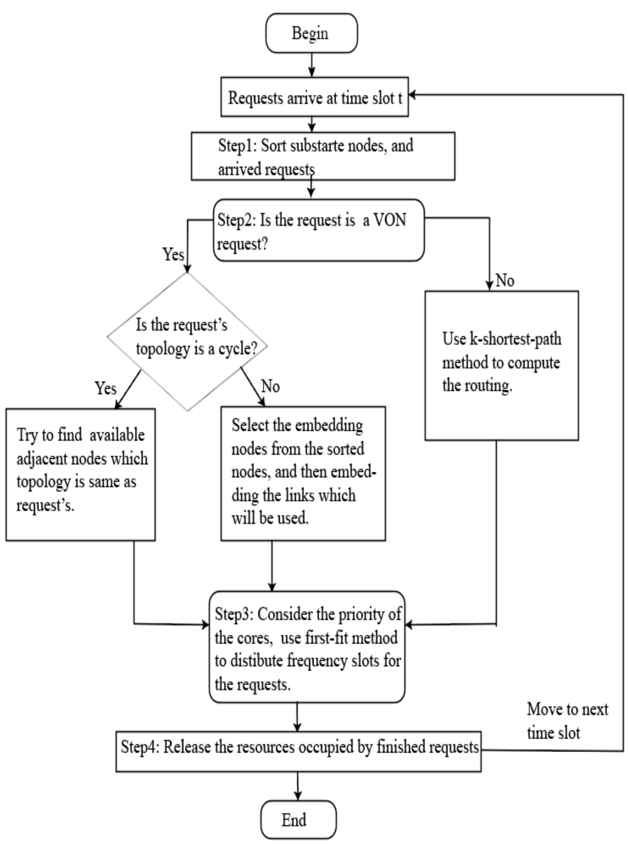
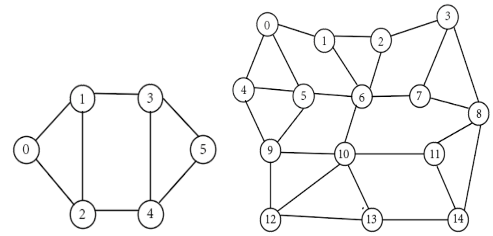


Fig. 4. Flowchart of algorithm.

III. DESIGN METHOD FOR VON EMBEDDING

The traditional VON mapping algorithm uses a two-state virtual network embedding framework (substrate node embedding, and substrate link embedding), but using this algorithm will lead to more substrate links are embedded , which may waste the spectrum resources. In this paper, We proposed a new synchronization embedding algorithm with considering the hybrid requests in SDM-EON and the topology of VON requests . Some variables are showed in Table 1, these variables are computed by:



(a) A 6 nodes network. (b) A 15 nodes network.

Fig. 5. Simulation environment

$$O_{\lambda,current}^s = O_{\lambda,origin}^s - \sum_{r \in R^v} O_{r,\lambda}^v \quad \forall \lambda \in N^s \tag{11}$$

$$\omega_l^s = \sum_{c \in C^s} \sum_{i=0}^{n} c_i^l \tag{12}$$

The synchronization VON embedding algorithm has four steps, these steps are described in flowchart Fig.4, which corresponding to algorithm 1,2,3 and 4. (These four steps are shown in appendix)

According to step1, we can select the requests that arrive at time slot t and get the sorted nodes and links which are prepared for VON embedding. Step2 is to select the substrate nodes and links for VON embedding requests, and it also compute the shortest route for general requests. Step3 is to select the assigned core and frequency slots, then embedding the virtual nodes, links and occupy the resource of the substrate network. Step4 is to release the resources which are occupied by the time-out requests so that this substrate network can handle more requests which arrival at next time slot.

IV. NUMERICAL SIMULATION

We use two different networks which have 6 nodes and 15 nodes separately, as shown in Fig.5.The general light path and VON requests are shown in Fig.6. These requests arrive to

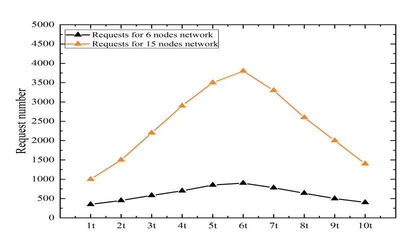


Fig. 6. Simulation of requests

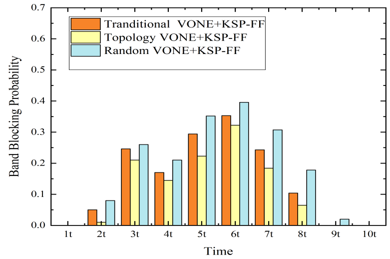


Fig. 7. BBP of 6 nodes network.

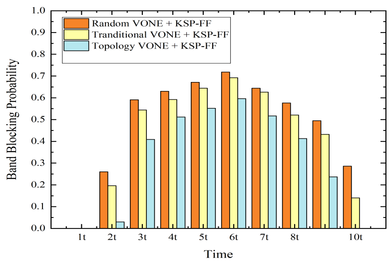


Fig. 8. BBP of 15 nodes network.

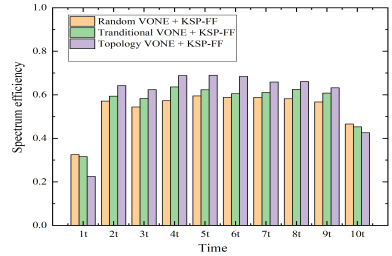


Fig. 10. Spectrum efficiency of the big net.

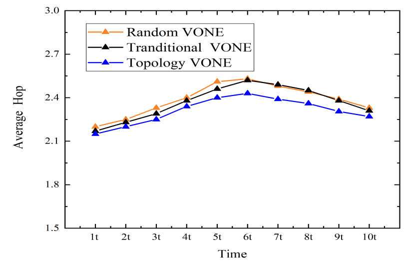


Fig. 11. Request's average hop in the small net.

the substrate nodes following a Possion distribution. We use *Random VONE, KSP-FF* as a benchmark algorithm, where KSP and FF stand for K-shortest paths and first-fit algorithm.

In this paper, we propose a new VONE algorithm based on the network topology and VON requests' topology, which named as *Topology VONE* and compare with the *Traditional VONE* algorithm in these two different network. As two benchmark algorithms, *Random VONE* uses the random method to select the embedding nodes and links, and *Traditional VONE* uses the two stage method to select the embedding nodes and links. Fig.7 and Fig.8 depict the band blocking probability by using these three different algorithms to accept the requests in the network,from which we can learn that using *Topology VONE* can reduce the BBP of the current requests significantly. In the 6-nodes network, at the peak of request's traffic, using *Topology VONE* can improve 37.6% BBP of the *Random VONE* and 24.2% BBP of the *Traditional VONE*, compared to the increases of 21.5% and 17.7% in the 15-nodes network. Fig.9 and Fig.10 show the spectrum efficiency by using these three algorithms, when the network is overloaded, using *Topology VONE* can provide a higher spectrum efficiency since it can accept more requests, these improvements are 19.2%, 13.4% in the 6-nodes network and 21.1%, 16.9% in the 15-nodes network. Fig.11 and Fig.12 explain the average hop of each request by using these three algorithms, this prove that using *Topology VONE* method can reduce the VON requests' embedding average hop significantly in the 15-nodes network, which justifies that under our approach it is possible to use less substrate nodes and links when implementing VON embedding.

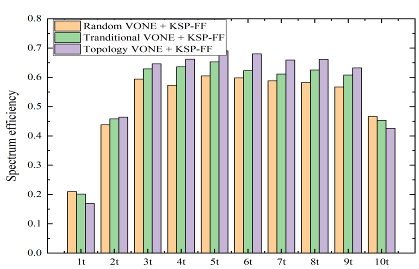


Fig. 9. Spectrum efficiency of the small net.

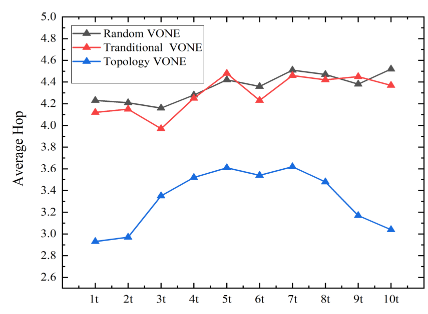


Fig. 12. Request's average hop in the big net.

V. Conclusion

In conclusion, this work introduces the designed method which takes into account of VON requests' topology for hybrid services, as well as the dynamic VON embedding procedure in SDM-EON. Numerical simulations showed that our new method can reduce the incidence of band blocking, improve spectrum utilization and use less substrate nodes and links in VON embedding procedure. Notably, our method can reduce 17.7% BBP and improve 16.9% spectrum utilization in the 15-nodes network.

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Appendix

Algorithm 1: VON embedding step 1

Input: $G^s, R(R^v, R^g), Time\ slot\ t$
Output: The sorted nodes, links and requests at time time slot t

Initialize $n_{sort} = \emptyset, l_{sort} = \emptyset, r_{sort} = \emptyset$
foreach $r \in R$ **do**
  if $r(St) = Time$ **then**
    Add r into set r_{sort}
      /* The requests are sorted by their type, handle VON requests first. */
  end
end
foreach $n \in N^s$ **do**
  Add n into the set n_{sort} and sort O_n^s from large to small.
end
foreach $l \in L^s$ **do**
  Compute w_l^s, add l into the set l_{sort} and sort w_l^s from large to small.
end

Algorithm 2: VON embedding step 2

Input: $r_{sort}, n_{sort}, l_{sort}$
Output: Embedding nodes and links for VON requests R^v, routing for general requests R^g

foreach $r \in r_{sort}$ **do**
  if $r \in R^v$ **then**
    if $Topo_r$ = *1* **then**
      Select a cycle in the substrate graph G^s, which satisfy $\forall n^s \in cycle, \forall n^v \in N^v \quad O_{n^s}^s \geq O_{n^v}^v$
    end
    else
      Select the first nodes from n_{sort}, according to l_{sort}, select the link adjacent to the first node, then select the second embedding node until all the embedding nodes are selected.
    end
  end
  if $r \in R^g$ **then**
    Using $r(sn, dn)$ compute the k-shortest-paths for request r, then select the route with the minimum distance and hop.
  end
end

Algorithm 3: VON embedding step 3

Input: Embedding substrate nodes N_r^s, links L_r^s and routes R_r $\forall r \in r_{sort}$

Output: The selected core and the start index of frequency slots, the number of success requests, substrate network G_{new}^s after resource allocation.

Initialize $count = 0$
foreach $r \in r_{sort}$ **do**
  if $r \in R^r$ **then**
    Embedding N_r^s, L_r^s, select a core from the highest priority group, using first-fit method to select and assign the start index of frequency slot, until the request is embedding successfully.
    if r *is success* **then**
      $count = count + 1$
    end
  end
  if $r \in R^g$ **then**
    The request route is R_r, select a core from the highest priority group, using first-fit method to select and assign the start index of frequency slot, until the request is successful
    if r *is success* **then**
      $count = count + 1$
    end
  end
end

Algorithm 4: VON embedding step 4

Input: $G_{new}^s, r_{sort}, Time\ slot\ t$

Output: The final substrate network G^s at $Time\ slot\ t$ after resource allocation and release

foreach $r \in r_{sort}$ **do**
  if $r(St) + r(Du) \ = \ t$ **then**
    if $r \in R^v$ **then**
      Release the frequency slots in the embedding links and compute resource of the substrate nodes for this VON request
    end
    if $r \in R^g$ **then**
      Release the frequency slots on the routing links.
    end
  end
end