Physical impairments awareness based virtual network mapping strategy of elastic optical networks

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As virtual networks services emerge increasingly with higher requirement of flexibility and robust, great complex challenges caused by physical-layer impairments are presented to the elastic optical networks (EON). Aimed to solve this problem, this paper proposes a physical impairment awareness based virtual network mapping stragegy of EON. The physical impairments awareness model is established, including both of linear factors and nonlinear ones. On this basis, this paper proposes a virtual network mapping strategy with detailed procedures, combined with node importance factors during the virtual network mapping procedure. Test results show that the proposed approach is able to reduce blocking rate and enhance services supporting ability of EON.

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The rapid development of software defined network (SDN) technologies makes the elastic optical network (EON) strong candidate of the next generation intelligent optical network[1]. Benefiting from great progress of optical communications, the EON makes full use of orthogonal frequency division multiplexing (OFDM) in the optical field. By introducing new types of optical devices with variable bandwidth ability, the EON can provide great support to virtual network services[2]. 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 general, the virtual optical network (VON) is composed by virtual nodes and virtual links. And the virtual network mapping operation is to allocate optical layer network resources, which is also limited by spectrum consistence and physical impairments[3,4]. With ever increasing scale of virtual network services, physical impairments of the optical layer network are of great importance in EON, which may lead to serious blocking rate of virtual network services.

Therefore, it is necessary for the EON to actively take optical impairments into consideration to grantee service performance of virtual network mapping operation[5,6]. To solve the blocking problem of virtual network mapping, several related typical researches have been made during recent years. The traditional mapping method was proposed in Ref.[5], with highly efficient survival mapping approach. And Ref.[6] adopted genetic algorithm to reduce occupied spectrum to deal with static multicast services mapping. And the spectrum consecutiveness-opaque VON mapping algorithm was presented by Ref.[7]. Moreover, the so-called consecutiveness based local resource capacity K shortest-path-first fit algorithm is used in Ref.[8]. However, the blocking problem caused by various optical impairments is still in need to make sure the supporting ability of EON.

Aimed to solve the virtual network mapping blocking problem caused by various optical impairments in the EON, this article proposes a physical impairments awareness based virtual network mapping strategy in EON. In this article, a physical impairments model is established, which takes various optical impairments, node importance degree and other factors together into consideration. Moreover, this physical impairment awareness based virtual network mapping strategy is proposed with detailed procedures. Thus, system performance of the network virtual mapping can be greatly improved in the EON, which shows great feasibility and efficiency of the proposed approach, with better mapping success and total efficiency of the whole network system.

Generally, physical impairments will accumulate during the optical signal transmission, which mainly comes from amplified spontaneous emission (ASE), crosstalk and four-wave mixing (FWM)[9,10]. Thus, a physical impairments awareness model of each link between optical nodes is set up, which includes various main impairments factors. In this physical impairments awareness model, the final optical signal-to-noise ratio (*OSNR*) of a single link can be obtained by calculating the signal power gains and noise power[11].

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Firstly, the noise power caused by the optical switch is given as

$$N_{\mathrm{switch}}=\varepsilon\sum_{i=1}^{n}P_{\mathrm{switch},i}\left(\lambda\right),\tag{1}$$

where $P_{\mathrm{switch},j}$ represents the power of wavelength λ from other fibers in the OSN, and ε is the isolation factor. Then, the gain and the noise of ASE must be taken into consideration in Eq.(2). In detail, $F_{\mathrm{amplifier}}$ is the noise factor and $G_{\mathrm{amplifier}}$ is the gain of amplifier in the link, P_0 is the bandwidth of fiber, h is the Planck constant and f is the frequency:

$$\begin{cases}N_{\mathrm{ASE}}=\dfrac{F_{\mathrm{amplifier}}\cdot G_{\mathrm{amplifier}}\cdot h\cdot f}{2}\\ G_{\mathrm{amplifier}}=\dfrac{G_0}{1+P_{\mathrm{out}}/P_{\mathrm{max}}}\end{cases}.\tag{2}$$

Eq.(3) gives the optical signal loss of the fiber link, in which α is the fiber attenuation factor and d is the distance of the fiber link:

$$L_{\mathrm{fiber}}=\mathrm{e}^{-\alpha\cdot d}.\tag{3}$$

$N_{\mathrm{FWM},i}$ is the FWM impact from another wavelength i within the same fiber and N_{FWM} is the sum of $N_{\mathrm{FWM},i}$ in Eq.(4):

$$N_{\mathrm{FWM}}=\sum_{i=1}^{n}N_{\mathrm{FWM},i}\left(\lambda\right).\tag{4}$$

Considering both optical signal power and the noise power mentioned above, the optical signal power and the noise power of the link can be obtained in Eqs.(5) and (6):

$$F_{\mathrm{link}}=\frac{G_{\mathrm{amplifier}}}{L_{\mathrm{switch}}L_{\mathrm{mux}}L_{\mathrm{demux}}L_{\mathrm{fiber}}},\tag{5}$$

$$N_{\mathrm{out}}=\frac{G_{\mathrm{amplifier}}}{L_{\mathrm{switch}}L_{\mathrm{mux}}L_{\mathrm{demux}}L_{\mathrm{fiber}}}\left(N_{\mathrm{in}}+N_{\mathrm{switch}}+N_{\mathrm{ASE}}\right)+\frac{G_{\mathrm{amplifier}}}{L_{\mathrm{mux}}L_{\mathrm{demux}}}N_{\mathrm{FWM}}.\tag{6}$$

Thus, the *OSNR* value of the link can be got by

$$V_{\mathrm{link}\_ij}=P_{\mathrm{in}}\frac{F_{\mathrm{link}\_ij}}{N_{\mathrm{link}\_ij}}.\tag{7}$$

Therefore, this physical impairment awareness model of optical link is set up, which includes ASE, FWM, attenuation and cross-talk. Moreover, this physical impairment model considers both of linear and nonlinear and transforms them into *OSNR* value, and makes it convenient to compute their impacts using mathematic method with better accuracy, which provides the theoretical basis to the physical impairment awareness based virtual network mapping mechanism.

Based on the physical impairment awareness model mentioned above, this section proposed a novel VON mapping strategy.

The VON mapping operation can be divided into two stages that are the node mapping and the link mapping[12]. And the node mapping includes the virtual node sorting, physical node sorting and assignment of physical node for virtual node using related algorithm[13]. Following the node mapping result, the link mapping can provide corresponding physical light-path for virtual link from the physical network, under some limited conditions.

This proposed physical impairment awareness based VON mapping strategy introduces the *OSNR* awareness result into both node mapping and link mapping operation. By combining the node importance degree and bandwidth availability into consideration, weight value is computed and given for each physical node and link. Fig.1 depicts the VON mapping operation.

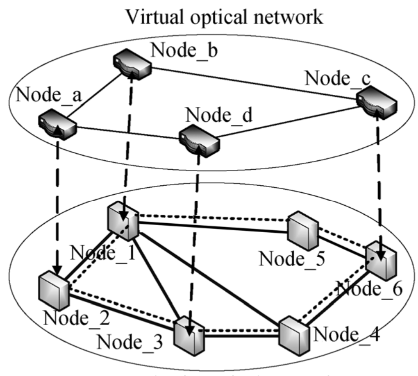

Fig.1 VON mapping

In Fig.1, each virtual node is mapped to (Node_1, Node_2, Node_3, Node_6), and virtual link (a-b) is mapped to (1-2) and virtual link (b-c) is to (1-5-6), etc.

The node mapping result will greatly affect the link mapping operation[14]. The important degree of optical nodes must be taken into consideration.

The node importance is introduced in this section, and the weighted adjacent matrix is defined as

$$\boldsymbol{A}\left(G\right)=\left[\frac{V_{\mathrm{link}\_ij}}{MAX\left(V_{\mathrm{link}}\right)}\right].\tag{8}$$

Then the impact factor R_{node_i} of virtual network disruption caused by optical node failure is also defined, which is depicted by

$$R_{\mathrm{node}\_i}=1-\frac{\ln\left(\dfrac{1}{N}\displaystyle\sum_{\mathrm{node}\_j}^{N}\mathrm{e}^{\lambda_j(G-\mathrm{node}\_i)}\right)}{\ln\left(\dfrac{1}{N}\displaystyle\sum_{\mathrm{node}\_j}^{N}\mathrm{e}^{\lambda_j(G)}\right)},\tag{9}$$

where $\lambda(G)$ is the rank of matrix $\boldsymbol{A}(G)$, while the $\lambda(G\text{-node}\_i)$ is the rank of matrix $\boldsymbol{A}(G\text{-node}\_i)$ which means the adjacent matrix of optical network without node_*i*.

Thus, the procedure of the virtual nodes mapping is depicted as follows.

Step 1: Compute importance factor of each node all over the EON, according to Eq.(9);

Step 2: Obtain requirement parameters of newly arrived virtual network service, including virtual node number, virtual link number and virtual network bandwidth;

Step 3: Form the pre-mapping set Snode by deleting nodes without enough bandwidth;

Step 4: Conduct pre-mapping by mapping node_*i* to each node of Snode and calculating variance R_{node_i} using

$$\begin{cases} R_{\text{node}\_i}=\sqrt{\dfrac{\sum_{j=1}^{N}\left(R_{\text{node}\_j}-R_{\text{node\_avg}}\right)^2}{N}} \\ R_{\text{node\_avg}}=\dfrac{\sum_{j=1}^{N}R_{\text{node}\_j}}{N} \end{cases}; \tag{10}$$

Step 5: When node_*i* satisfies Eq.(11), the virtual node is mapped into the optical node_*i*

$$R_{\sigma,\text{node}\_i}=MIN(R_{\sigma,\text{node\_1}}, R_{\sigma,\text{node\_2}},\dots R_{\sigma,\text{node}\_N}); \tag{11}$$

Step 6: Update the $A(G)$ and turn to step 3, until all virtual nodes finish the mapping operation.

Thus, the virtual node mapping is completed.

With the aim to reduce the accumulated physical impairments of each virtual link, the path weight is introduced into the virtual link mapping. This path-weight is depicted by Eq.(12), which gives higher priority to path with the maximum *OSNR* value:

$$W_{\text{Path}}=P_{\text{in}}\frac{\sum_{\text{link}_{ij}\in R_k}F_{\text{link}\_ij}}{\sum_{\text{link}_{ij}\in R_k}N_{\text{link}\_ij}}. \tag{12}$$

Thus, the procedure of the virtual links mapping is depicted as follows.

Step 1: Compute *K* paths with the highest path-weight W_{Path} by Eq.(12), in which these paths satisfy the hops limit;

Step 2: Compute the spectrum slot number that satisfies the virtual link;

Step 3: Choose the path pk and compute available spectrum block;

Step 4: Compute the *OSNR* value of the light path pk through the optical impairments model mentioned above;

Step 5: Judge the *OSNR* value according to the *ONSR* threshold and turn to Step 6; otherwise, turn to Step 3;

Step 6: The virtual link is mapped into path pk and record this successful mapping result.

To evaluate the proposed physical impairments awareness model based virtual network mapping strategy, the simulation is conducted in this section, where the simulation environment is constructed by NS2 network simulation software tools and the NSFnet topology is adopted. And this simulated EON consists of 32 nodes and 41 links with 8 or 16 wavelengths in it. And the VON service follows the Passion distribution and traffic load is generated by client software. Main parameters for simulation are given in Tab.1.

Tab.1 Main parameters for simulation

Parameter	Value
Link amplifier noise	7 dB
Node PDL	1.5 dB
Node noise	20 dB
Link amplifier PDL	0.5 dB
Output power of amplifier	1 dB
Symbol time	100/50 ps
Bite rate	10/40 Gbit/s
OSNR threshold	19 dB

Simulation comparison mainly focuses on performances of blocking rate and connection establishment time. And case_2 is the physical impairment awareness based virtual network mapping algorithm, while case_1 is the one without physical impairment awareness ability, under the condition that there are 8 wavelengths. Moreover, case_3 and case_4 are the same with 16 wavelengths in each link. Comparison results are given by Fig.2 and Fig.3.

The comparison of the blocking rate is made in Fig.2. Obviously, both case_2 and case_4 achieve worse result in term of blocking rate when they are compared with case_1 and case_3. That is because both case_2 and case_4 fails to make sure the optical signal quality of the VON under physical impairments limits. On the other hand, the case_1 and case_3 can achieve better performance, enhanced by the physical impairment awareness function. Thus, the QoS quality of VON in case_2 and case_4 still suffer from optical signal degradation caused by physical impairments. As the proposed scheme can be fully aware of the optical physical layer channel, the blocking rate can be efficiently reduced, even under condition of high traffic load.

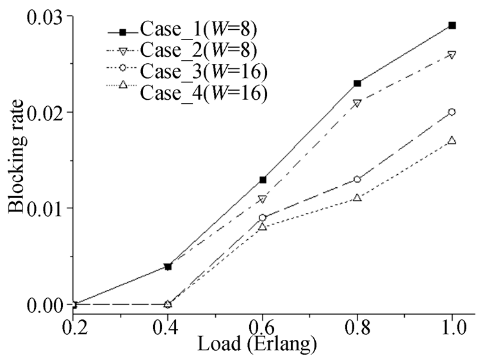

Fig.2 Comparison of blocking rate

In Fig.3, both case_3 and case_4 shows worse performance to finished VON mapping operation in term of time delay, while the case_1 and the case_2 can take much shorter time, due to the complexity of physical optical network with more wavelengths. Moreover, the case_1 still takes a little longer time when compared with case_2. That is because of the case_1 needs to compute the impact by physical impairments factors, as the cost of this optical impairment awareness function.

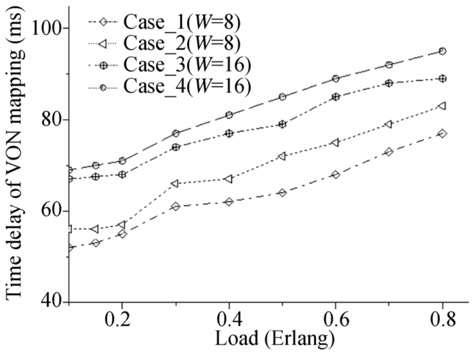

Fig.3 Comparison of VON mapping time

With the aim to improve virtual network mapping reliability for multiple Internet services, this paper proposed a physical impairments awareness model based virtual network mapping strategy in the software defined EON. This proposed physical impairment awareness model taken various node importance factors and link *OSNR* into consideration. On this basic, the VON mapping algorithm was also proposed and designed. Test results show that the proposed approach was able to support services-oriented virtual network mapping of EON.

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