Research on the multicast mechanism based on physical-layer-impairment awareness model for OpenFlow optical network*

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A physical-layer-impairment (PLI)-awareness based optical multicast mechanism is proposed for OpenFlow controlled optical networks. This proposed approach takes the PLI models including linear and non-linear factors into optical multicast controlled by OpenFlow protocol. Thus, the proposed scheme is able to cover nearly all PLI factors of each optical link and to conduct optical multicast with better communication quality. Simulation results show that the proposed scheme can obtain the better performance of OpenFlow controlled optical multicast services.
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The great progress of software defined network (SDN) technologies has already brought bright future for optical networks[1]. A great effort has been made to develop the software defined optical network (SDON) by the open networking foundation (ONF)[2,3]. The concept of SDON adopts the separation between control plane and transport plane through the logically centralized control plane[4].

In OpenFlow based optical networks, the optical multicast suffers from various kinds of physical-layer-impairments (PLIs), especially due to the ever-enlarged scale and the ultra high speed of SDON. These PLIs include amplified spontaneous emission (ASE), four wave mixing (FWM) and other impairment caused by optical switching[5]. All these PLI factors would results in worse optical signal-to-noise ratio (*OSNR*), bit error rate (*BER*), blocking probability, packet loss rate and so on. Great efforts have been made to deal with the problems caused by PLIs[6-10]. Ref.[7] proposed a new algorithm employing inverse multiplexing (IM) to account for the impairment-aware dynamic lightpath establishment problem with the cost of additional network resource usage. In Ref.[8], a novel approach for constructing a reachability graph of the physical network has been presented, considering PLIs and regenerators. Moreover, the dynamic impairment aware routing and wavelength assignment (IA-RWA) heuristic algorithms were also presented, which introduce impairment awareness in optical transparent links without deploying any additional regenerators[9]. However, those approaches are far from ideal, since they fail to consider those nonlinear PLI factors, and their theoretical results are still not so accurate. Therefore, the awareness ability of optical PLIs with better accuracy and deficiency is in urgency for the OpenFlow controlled optical multicast to make sure the optical communication quality.

For overcoming these problems caused by PLIs, a PLI-awareness based optical multicast mechanism is proposed in OpenFlow controlled optical network in this paper. Different from traditional approaches mentioned above, this proposed mechanism is able to build the PLI-awareness models including linear and nonlinear factors. Moreover, this proposed scheme can consider PLIs much more comprehensively in optical multicast. This function is able to make sure the communication quality with stronger robust and efficiency in OpenFlow controlled optical network. Simulation results show that the proposed mechanism can obtain better performance of optical multicast controlled by OpenFlow.

In general, an OpenFlow based optical network mainly consists of one OpenFlow controller and a number of optical network elements (ONEs) in which an OpenFlow agent (OA) is embedded. The typical architecture of the OpenFlow controlled optical network is depicted in Fig.1.

The controller is used to control these ONEs. And each ONE is logically equipped with its own OA. And the OA is responsible for maintaining communication between controller and ONE through the extended OpenFlow protocol. Moreover, the main functions of OA are compiling controller-to-switch messages to hardware instructors and reporting optical layer status to controller.

Under the condition of OpenFlow based all-optical network, the control operation of optical multicast is centralized in the OpenFlow controller. Deep studies have been conducted in the field of optical multicast under the

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SDN environment. Ref.[11] proposed an efficient overlay multicast provisioning (OMP) mechanism for dynamic multicast traffic grooming in overlay Internet protocol and multiprotocol label switching (IP/MPLS) over wavelength division multiplexing networks. In Ref.[12], a hybrid (optical and electrical) approach using physical layer optics has been reported to accelerate traffic delivery for each pattern. Ref.[13] also demonstrated an OpenFlow based unified control plane for the IP-over-label optical burst switching network, where the coordinative cross-layer multicast service can be realized to improve the network flexibility and the resource utilization efficiency.

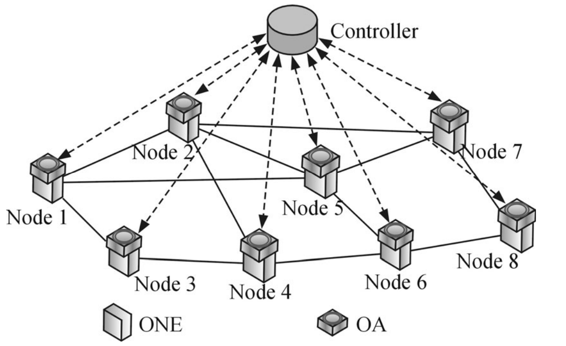

Fig.1 Architecture of OpenFlow based optical network

However, existing optical multicast approaches in OpenFlow controlled optical network still ignore these factors of PLIs. Therefore, it is necessary for the OpenFlow based optical network to take the impact of PLIs into consideration, and new awareness model of PLIs is needed to be built in the OpenFlow controller.

Aimed to solve the degradation problem of optical multicast in OpenFlow controlled high-speed optical network, a PLI-awareness model based optical multicast scheme is proposed, together with a whole new PLI-awareness model.

In this proposed PLI-awareness model based optical multicast scheme, one of key issues is the signal impairment collecting module. And each OA in ONE is equipped with this module. Thanks to these advanced optical performance monitoring technologies[14,15], the signal impairment collecting module enables each OA to be aware of various kinds of parameters of optical signal from ONE. Thus, those PLIs are allowed to be transformed into a concentrated PLI-awareness model.

On this basis, a so-called PLI-awareness module is designed and placed in the OpenFlow controller, where the PLI-awareness database is included in the PLI-awareness module. The PLI-awareness database keeps all PLI parameters of the whole optical network. During the initiation of the OpenFlow based optical network, the controller collects the related values of optical PLIs from each OA, through extending FLOW_MOD and FERTURES_REPLY messages.

When receiving the connection request of multicast services, the controller firstly computes a virtual light-tree. Then, the PLI-awareness module calculates the end-to-end PLIs weighted value along all branches in the virtual light-tree according to the PLI-awareness database, and the judgment is made according to the threshold. If the end-to-end PLI value fails to satisfy the demand, another new virtual light-tree will be computed until the end-to-end PLI value is able to match the *BER* requirement for successful optical multicast. Thus, the controller will control all related ONEs to conduct the establishment of virtual light-tree through involved OAs, by using the extended FLOW_MOD and FERTURES_REPLY messages.

Generally, PLIs will accumulate during the optical signal transmission, which mainly comes from ASE, crosstalk and FWM[14,15]. Thus, a PLI comprehensive awareness model of each link between ONEs is setup, which includes various main impairment factors. In this PLI comprehensive awareness model, the final *OSNR* of a single link can be obtained by calculating the signal power gain and noise power.

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

$$N_{\text{switch}} = \varepsilon \sum_{i=1}^{n} P_{\text{switch},i}(\lambda), \quad (1)$$

where $P_{\text{switch},i}$ represents the power of wavelength λ from other fibers in the ONE, and ε is the isolation factor. Then, the gain and the noise of ASE must be taken into consideration, which are shown as

$$\begin{cases} N_{\text{ASE}} = \dfrac{F_{\text{amplifer}} \cdot G_{\text{amplifer}} \cdot h \cdot f}{2} \\ G_{\text{amplifer}} = \dfrac{G_0}{1 + P_{\text{out}}/P_{\text{max}}} \end{cases}, \quad (2)$$

where $F_{\text{amplifier}}$ is the noise factor, $G_{\text{amplifier}}$ is the gain of amplifier in the link, G_0 is the bandwidth of fiber, h is the Planck constant, and f is the frequency.

The optical signal loss of the fiber link is given as

$$L_{\text{fiber}} = \mathrm{e}^{-\alpha \cdot d}, \quad (3)$$

where α is the fiber attenuation factor, and d is the distance of the fiber link.

$N_{\text{FWM},j}$ is the FWM impact from another wavelength j within the same fiber, and N_{FWM} is the sum of $N_{\text{FWM},j}$ expressed as

$$N_{\text{FWM}} = \sum_{j=1}^{n} N_{\text{FWM},j}(\lambda). \quad (4)$$

Considering the optical signal power and the noise power mentioned above, the optical signal power and the noise power of the link can be obtained as

$$P_{\text{link}} = \frac{G_{\text{amplier}}}{L_{\text{switch}} L_{\text{mux}} L_{\text{demux}} L_{\text{fiber}}} P_{\text{in}}, \quad (5)$$

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

Thus, the *OSNR* of the link can be get as

$$V_{link} = {P_{link}}/{N_{link}} . \quad (7)$$

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

For implement, the proposed scheme is divided into two parts: the initiation procedure and the working procedure. The detailed initiation procedure of the PLI-awareness based optical multicast mechanism is described in Fig.2.

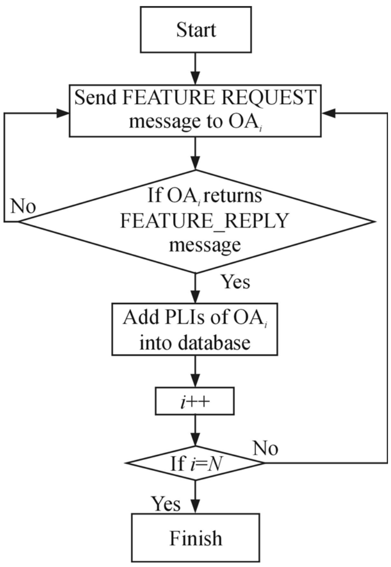

Fig.2 Flow diagram of PLI-awareness initiation procedure in controller

After the initiation of the proposed scheme is finished, the PLI-awareness based optical multicast is ready to work. The working procedure of the proposed optical multicast scheme is given as follows:

Step 1: After receiving the multicast connection request directly from the client, the OpenFlow controller conducts the light-tree computation according to the PLI-awareness database.

Step 2: After the light-tree computation, the OpenFlow controller calculates the final PLIs weighted value of the whole multicast-tree using the PLI-awareness model by Eqs.(1)—(7).

Step 3: The OpenFlow controller judges the usability of the light-tree by comparing the final PLIs weighted value with the threshold.

Step 4: If the PLIs weighted value satisfies the demand, turn to Step 5; otherwise, turn to step 7.

Step 5: The OpenFlow controller sends the OPENFLOW_MOD message to all involved OAs along the light-tree, which can figure the network element to set up the light-tree.

Step 6: All involved OAs will return FEATURE_REPLY messages to the controller. Thus, the lightpath is successively established.

Step 7: The controller recalculates another path and turn to step 2. If there is no usable light-tree, the multicast connection request is blocked by OpenFlow controller.

For evaluating the proposed scheme, an OpenFlow controlled all-optical network simulation platform is build, which consists of one OpenFlow controller, 14 ONEs and 21 bidirectional fibre links. In this simulation, the NSF net topology is adopted. Moreover, the multicast service request follows the Poisson distribution, and its duration keeps the negative exponential distribution.

This simulation comparison is conducted among three kinds of approaches. For convenience, case_1 and case_2 represent the OpenFlow controlled optical multicast with and without PLIs awareness, respectively. And case_3 is the traditional generalized multiprotocol label switching (GMPLS) controlled optical multicast. The simulation comparison mainly focuses on the performances of *BER* and average connection establishment time, and the results are shown in Figs.3—5.

Figs.3 and 4 show the *BER* performances of three cases with the average number of hops of 6 and the average load of 0.6 Erlang, respectively. Obviously, case_1 achieves the best result in term of *BER* among these three cases. That is because case_1 can make sure the optical signal quality of the end-to-end optical multicast-tree, which is enhanced by PLI-awareness function. On the other hand, the end-to-end communication quality of both case_2 and case_3 still suffers from optical signal degradation caused by PLIs. As the proposed scheme can be fully aware of the optical physical layer channel, the *BER* can be efficiently reduced, even under condition of high traffic load. Therefore, case_1 can achieve the best performance with much lower *BER* compared with other two cases.

In Fig.5, case_3 shows the worst performance to set up end-to-end lightpath, while case_1 and case_2 can finish their operation with much shorter time. The worst result of case_3 is because of the consequent processing approach taken by traditional GMPLS controlled optical network, in which the multicast-tree setup is set up node after node along the route using resource reservation protocol-traffic engineering (RSVP-TP). Different from the distributed manner of case_3, both case_1 and case_2 benefit from the centralized controlling using OpenFlow protocol, and the multicast-tree is established parallel among all involved nodes at the same time. Thus, the time taken by case_1 and case_2 can be greatly saved for the establishment of multicast-tree. Moreover, case_1 still takes a little more time compared with case_2. That is because case_1 needs to calculate the appropriate multicast-tree by OpenFlow controller to overcome the impact from PLI factors.

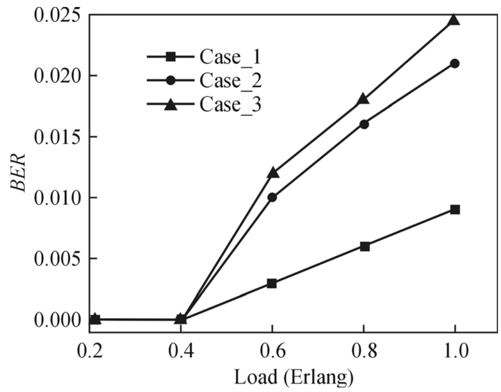

Fig.3 Comparison of *BER* (with 6 hops) for three cases

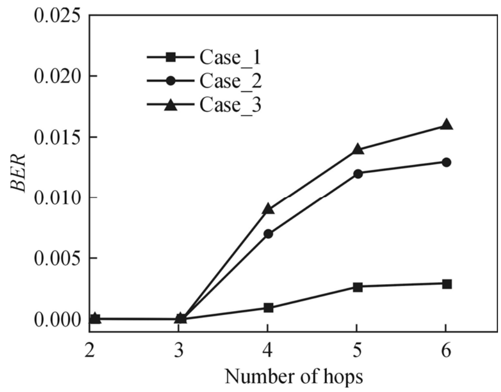

Fig.4 Comparison of *BER* (with 0.6 Erlang) for three cases

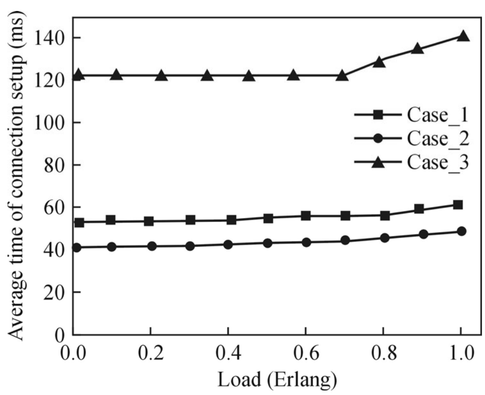

Fig.5 Comparison of connection establishment time for three cases

In this paper, a PLI-awareness based optical multicast mechanism controlled by OpenFlow protocol is proposed. This proposed approach builds a PLI-awareness model for the optical signal along the multicast light-tree, and fully considers these PLI factors when establishing the lightpath for the optical multicast using OpenFlow protocol. Moreover, the proposed mechanism makes full use of the optical signal monitoring function in each node to realize this PLI-awareness function for guaranteeing the reliability of the optical multicast. Simulation results show that the proposed scheme is able to get better performances in terms of *BER* and optical multicast-tree establishment time.

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