OSNR comprehensive-awareness model based lightpath control scheme in an OpenFlow controlled all-optical network*

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To enhance the communication quality of OpenFlow controlled all-optical networks, an optical signal-to-noise ratio comprehensive-awareness (OSNR-CA) model based lightpath control scheme is proposed. This approach transforms main physical-layer optical impairments into OSNR value, and takes this comprehensive OSNR value of the optical signal along the lightpath into consideration, when establishing the lightpath for the connection request using OpenFlow protocol. Moreover, the proposed scheme makes full advantages of the OSNR monitoring function in each node, and assigns the lightpath according to the comprehensive-OSNR value by extending messages of OpenFlow protocol, in order to guarantee the reliable establishment of the lightpath. The simulation results show that the proposed scheme has better performance in terms of packet loss rate and lightpath establishment time.
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The OpenFlow technology is one of main trends of software defined network (SDN)[1]. The OpenFlow network architecture includes several OpenFlow switches, one controller, a secure channel that interconnects the switch with the controller, and the OpenFlow protocol for communication between switches and controller[2]. As a typical demonstration, ref.[2] has reported an OpenFlow-based wavelength path control for lightpath provisioning in transparent optical networks.

However, the scale of optical network is enlarged greatly, and the traffic of data packets is also soaring rapidly. Thus, the optical signal is unavoidable to suffer from various physical-layer impairments (PLIs), which would lead to the worse communication quality. These PLIs include amplified spontaneous emission (ASE), polarization dependent loss (PDL) and channel uniformity (CU)[3]. Great efforts have been made to deal with the problems caused by PLIs. A bi-dimensional quality of service (QoS) differentiation framework, which considers the PLIs and the set-up delay as well as the impact of the former on the latter, was reported[4] to implement service differentiation in transparent optical networks. The impairment-awareness routing and waveband assignment for efficient optical transport networks were presented[5], which achieved significant improvement in both impairment satisfaction rate and total network cost. The deep researches on impairment-awareness optical networking were conducted[6] by using cross layer communication. Following this trend, the OpenFlow controlled all-optical network will still face increasing optical signal impairment of physical layer. Therefore, the awareness ability of optical signal impairment is needed urgently for OpenFlow controlled all-optical network to improve its performance.

In this paper, an optical signal-to-noise ratio comprehensive-awareness (OSNR-CA) model based lightpath provision scheme is proposed, which makes full use of optical performance monitoring technologies, and is able to transform those optical impairments into a so-called comprehensive-OSNR awareness model. This function is able to establish the lightpath in OpenFlow controlled all-optical network. The simulation results show that the proposed approach is able to greatly reduce the packet loss rate of lightpath provision.

With the development of optical performance monitoring technology, it provides more efficient ways to detect various parameters of optical signal and resolve the degradation problems caused by PLIs.

Generally, there are two model categories of PLIs, which are the OSNR model and the Q-value model. On one hand, the OSNR and the polarization mode dispersion (PMD) are combined together in routing computation and wavelength allocation in Ref.[7], while ref. [8] deals with OSNR and PMD separately and judges the

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usability of lightpath by comparing these two factors in terminal node. On the other hand, for the Q-value model, the ASE and the PMD can be both considered and transformed into bit error rate to judge the usability of lightpath[9]. Furthermore, Q-value factors based routing table for connection establishment has also been reported[10].

Under the condition of OpenFlow based all-optical network, the control operation of lightpath is centralized in the OpenFlow controller. Therefore, the impact of PLIs must be taken into consideration, and new awareness model of PLIs is necessary to be built in the OpenFlow controller.

In the OpenFlow controlled all-optical network architecture, there is a single NOX controller to control a number of optical network elements (ONEs). Each ONE is logically equipped with its own OpenFlow agent. The agent is responsible for maintaining communication between controller and ONE through the extended OpenFlow protocol, and its functions include compiling controller-to-switch messages to hardware instructors and reporting optical layer status to the controller. The architecture of the network is shown in Fig.1.

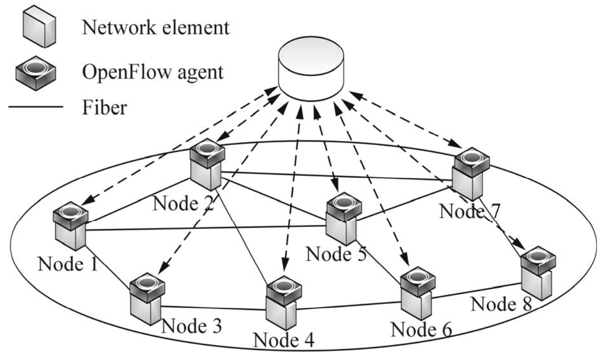

Fig.1 Architecture of OpenFlow based optical network

Moreover, each ONE is equipped with optical signal impairment collecting module, benefiting from advanced optical performance monitoring technology. Thus, it is convenient for the OpenFlow agent to be aware of various kinds of parameter values of optical signal from ONE. Additionally, those PLIs can be transformed into OSNR model in the OpenFlow controller. Therefore, an OSNR-CA model is designed and embedded in the OpenFlow controller.

The basic principle of the OSNR-CA model based lightpath control scheme is as follows. With receiving service connection request from client, the controller firstly computes a so-called virtual lightpath. Then, the controller collects related values of optical PLIs from each OpenFlow agent along the virtual lightpath by using extended FLOW_MOD and FERTURES_REPLY messages. Later, the total OSNR of the whole virtual lightpath is calculated, and the judgment is made according to the OSNR threshold. If the total OSNR fails to satisfy the demand, another new virtual lightpath will be computed, until the total OSNR is able to match the requirement for successful lightpath establishment. Then, the controller will trigger all the related ONEs to construct the setup of lightpath through OpenFlow agents by using the extended FLOW_MOD and FERTURES_REPLY messages.

With the maturation of optical performance monitoring technology, the approach for obtaining PLIs has been greatly enriched, which makes it feasible to build related mathematical model for these PLIs[11,12]. In the non-ideal optical network, these PLIs can be divided into two categories of linear impairments and nonlinear impairments.

In this paper, the OSNR model is adopted for those PLIs, and various kinds of PLIs can be transformed into the OSNR model. The OSNR value considered ASE can be obtained as

$$OSNR_{\text{out}} = -10\lg\left[10^{-\frac{P_{\text{in1}}-NF_1-10\lg(hvB)}{10}}\right] + \sum_{x=2}^{X} 10\lg\left[10^{-\frac{P_{\text{in}x}(x)-NF_x-10\lg(hvB)}{10}}\right], \quad (1)$$

where $P_{\text{in}x}$ is the input power of optical amplifier x, NF_x is the noise factor of amplifier x, v is the working frequency of lightwave, h is the Planck constant, B is the bandwidth, and X is the total number of amplifiers. Then the OSNR degradation due to PDL is given as

$$OSNR_{\text{PDL}} = \sqrt{\frac{8}{3\pi}}\left(\sum_i PDL_i^2\right)^{\frac{1}{2}}, \quad (2)$$

where the PDL_i is the PDL value of optical device i, and the OSNR degradation caused by CU can also be got through

$$OSNR_{\text{CU}} = CU_1 + CU_2 + \ldots + CU_n, \quad (3)$$

where the CU_i represents the CU value of optical element i. Thus, the total OSNR model can be drawn by combining Eqs.(1)–(3) as

$$OSNR_{\text{total}} = OSNR_{\text{out}} - OSNR_{\text{CU}} - OSNR_{\text{PDL}}. \quad (4)$$

Thus, the OSNR-CA model can be well achieved.

The extension of OpenFlow protocol to optical domain should be made to realize this proposed OSNR-CA model based lightpath control scheme. The protocol extension is based on Flow_Mod and Feature_Request/Reply messages, as shown in Fig.2.

It is shown in Fig.2 that extra fields are added after the original OpenFlow 12-tuple as fields from packets used to match flow entries. Here, the “Flow” means a wavelength or a sub-wavelength, rather than a number of packets. The “Wavelength” field is used to denote the occupied wavelength. The “Port *i*” and “Port *j*” fields indicate physical port connection with neighbour ONEs, and these two fields are responsible for topology-discovery function for NOX controller. The “Flow

ID” indicates various applications, and each one occupies a designated lightpath.

Ingress port	…	TCP/UDP src port	TCP/UDP dst port	Weve-length	Port *i*	Port *j*	Flow ID

Fig.2 Extended fields to match the flow entries

The detailed procedure of the normalized OSNR-CA based lightpath provision scheme is described as follows.

Step 1: With receiving the connection request directly from the client, the OpenFlow controller conducts path computation for this connection request.

Step 2: After the path computation, the controller sends FEATURE_REQUEST messages to all OpenFlow agents involved along the commutated path to require the normalized-OSNR value.

Step 3: Each involved OpenFlow agent obtains PLIs and calculates the normalized-OSNR value.

Step 4: Each involved OpenFlow agent reports the FEATURE_REPLY message to the OpenFlow controller.

Step 5: The OpenFlow controller calculates the final value of OSNR using the OSNR-CA model by Eq.(4), and judges the usability of the lightpath by comparing the final OSNR value with the threshold.

Step 6: If the final OSNR value is good enough, turn to step 7; Otherwise, turn to step 9.

Step 7: The OpenFlow controller immediately sends OPENFLOW_MOD messages to all involved OpenFlow agent, which will configurate the ONEs to set up the lightpath.

Step 8: All involved OpenFlow agents return FEATURE_REPLY messages to the controller. Thus, the lightpath is successively established.

Step 9: The controller recalculates another path and step 2 is turned to. If there is no usable lightpath, the connection request is blocked by OpenFlow controller.

To evaluate the proposed scheme, an OpenFlow controlled all-optical network simulation platform with an NOX controller, a client, 14 ONEs and 21 bidirectional fiber links is built, where the NSFnet topology is adopted. The client is responsible for producing connection requests, where the connection request comes with the Poisson distribution and its duration keeps the negative exponential distribution. The main parameters for simulation are given in Tab.1.

Tab.1 Main parameters for simulation

Parameter	Value	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
Bit rate	10/40 Gbit/s	OSNR threshold	19 dB

Simulation comparison mainly focuses on the performances of packet loss rate and connection establishment time. Case 1 is the OpenFlow controlled lightpath provision with OSNR-CA model, while case 2 is the one without OSNR-CA model reported in Ref.[6], and case 3 is the traditional generalized multiprotocol label switching (GMPLS) controlled lightpath provision. The comparison results are given in Figs.3–5.

The comparison of the packet loss rate for three cases is shown in Fig.3. Obviously, the case 1 achieves the best result among these three cases. That is because the case 1 is able to make sure the quality of optical signal in the end-to-end lightpath, which is enhanced by OSNR-CA function. On the other hand, the case 2 and the case 3 fail to do so. In fact, the OSNR value of the whole lightpath in case 1 is greatly enhanced for the terminal node to receive data packets with the best performance among these three cases. As the OSNR value is improved greatly, the packet loss rate can be efficiently reduced, even under condition of high traffic load. Therefore, the case 1 can achieve the best performance with much lower packet loss compared with the other two cases.

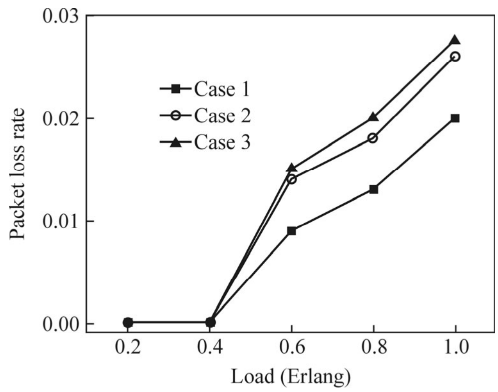

Fig.3 Comparison of packet loss rate for three cases

Fig.4 gives the comparison result on the average time of connection establishment. In Fig.4, the case 3 takes the longest time to set up end-to-end lightpath, while the case 1 and the case 2 can complete this operation with much shorter time. The performance result of case 3 is due to the consequent processing approach taken by traditional GMPLS controlled optical network, where the lightpath setup is built node after node along the route using resource ReSerVation protocol-traffic engineering (RSVP-TE). Different from case 3, both of case 1 and case 2 adopt centralized control using OpenFlow protocol, and the connection establishment is conducted parallelly between each pair of nodes. Thus, the times taken by case 1 and case 2 can greatly shorten the establishment of connection. It can be drawn from Fig.4 that the case 1 needs a little longer time compared with case 2. That is because it needs to collect OSNR values from each involved OpenFlow agent by NOX controller.

The comparison of blocking rate is shown in Fig.5, where the case 1 shows the highest blocking rate. That is because the virtual lightpath with OSNR value higher than threshold is rejected by OpenFlow controller in case 1, while the other two cases accept the connection requests without taking any PLI factor into consideration.

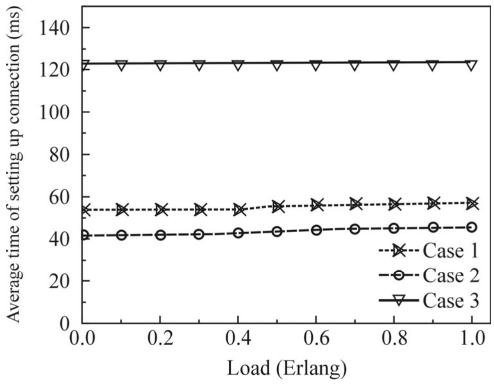

Fig.4 Comparison of connection establishment time for three cases

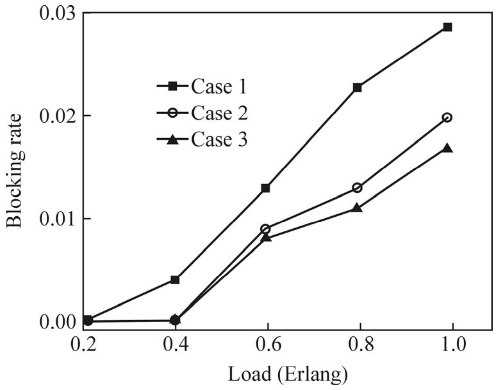

Fig.5 Comparison of connection blocking rate for three cases

In this paper, an OSNR-CA model based lightpath control scheme is proposed for all-optical networks controlled by OpenFlow protocol. This proposed approach takes the OSNR value of the optical signal along the lightpath into consideration when establishing the lightpath for the connection request using OpenFlow protocol. Moreover, the proposed scheme makes full advantages of the OSNR monitoring function in each node, and assigns the lightpath according to the OSNR value by extending messages of OpenFlow protocol, in order to guarantee the reliable establishment of the lightpath. Simulation results show that the proposed scheme is able to get better performance, such as the packet loss rate and the lightpath establishment time.

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