A Hybrid Control Architecture for Connection Management in Translucent WDM Networks

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Abstract—Translucent WDM networks use a set of sparsely but strategically placed 2R or/and 3R regenerators to overcome physical impairments and wavelength collision introduced by fully transparent networks. In this paper, we concentrate on the study of control architectures and management approaches for connection establishment in translucent networks. A hybrid OCP (optical control plane) has been proposed, which needs the extensions of both routing and signaling protocol. In hybrid OCP, we combine the best features of routing based information updating and signaling based data collection and path evaluation, in order to achieve better performance. Simulations are conducted to compare hybrid OCP with two existing control architectures: signaling based OCP and routing based OCP. Numerical results show that hybrid OCP keeps a lower blocking probability than the other approaches, and also minimize the stability and scalability problems under various traffic conditions.

Index Terms—DWDM, GMPLS, optical control plane, physical impairments, translucent optical network

I. INTRODUCTION

Optical transport is evolving from traditional opaque networks toward all-optical transparent networks. The absence of electronic regenerators in transparent WDM networks contributes significantly to reduce the overall network cost. However, physical impairments (such as ASE noise, PMD, crosstalk, nonlinear effects, etc.) will accumulate along the transparent lightpath, which may degrade optical signal quality in long-haul transmission systems and make the data unrecognizable at the receiver. Thus, the transmission reach of signals in transparent networks is limited [1].

Translucent WDM networks use a set of sparsely but strategically placed 2R or/and 3R regenerators to overcome physical impairments and wavelength collision introduced by fully transparent networks [2]. Rather than purely electronic or purely optical, a translucent WDM network is a compromise between all-electronic switching and all-optical switching [1]. Extensive studies indicate that even if only a few regenerators are employed, translucent networks can achieve elegant service provisioning performance close to all opaque networks, but much better than that of fully transparent networks [3-5].

In [1], S. Gangxiang presents the survey of recent research advances in planning and operation of translucent networks. But few studies concentrate on translucent connection establishment and management approaches in real WDM networks.

In ASON networks, Generalized Multi-Protocol Label Switching (GMPLS) is an implementation of the control plane (CP) to facilitate the establishment of Label Switched Paths (LSPs), involving signaling, routing, and resource management functions and protocols. But standard GMPLS does not take into account the physical impairments and regenerator employment of real optical networks, and also need some extensions to support the automatic setup/teardown of translucent connections. The extensions involve: 1) Data (resources related data and physical data) collection or updating. Resource related data includes the wavelengths state of the links and the resource (such as 3R regenerators, transmitters and receivers) state of the nodes, where physical data include the physical impairments (PI) introduced by the links/nodes. 2) Lightpath quality estimation (LQE). To guarantee the quality of signal, the accumulated physical impairments of each transparent segment on translucent path must be estimated and compliant with an acceptable range of required QOS. 3) Dynamic translucent path routing and resource assignment.

In previous study [6-8], Routing based OCP and signaling based OCP have been proposed and compared for impairment-aware transparent networks. In this article, we extend them for translucent WDM networks. The first approach (routing based) introduces resource related (RR) data and physical impairments into the routing protocol i.e. OSPF-TE. By flooding Link & Node State Advertisements (LNSAs), all the nodes update their Global RR and PI Database (G-RRD & G-PID) in addition to the basic TE database (B-TED) which gives them a complete view of the whole network. Considering LQE and regeneration allocation strategy, the source node can find the proper translucent route for a connection request while standard RSVP-TE signaling is used for translucent path establishment. The second approach (signaling based) extends RSVP-TE protocol instead. Each node can select a route based on standard OSPF-TE without knowledge of G-RRD and G-PID. Then the availability of the calculated optical path is estimated and 3R regenerators are deployed on a hop-by-hop
Combining the best features of routing based OCP and signaling based OCP, we have proposed hybrid OCP. In this approach, we divide the data into 2 classes: static data and dynamic data. Static data (such as link attenuation, residual dispersion, link weight and so on) is the information with static nature which is stored in the local database and updated in a routing based manner; while dynamic data (such as wavelength state per link, crosstalk noise per path, and so on) is the information which changes frequently with the setup/teardown of translucent path and being collected in a signaling based manner. Each node only contains Simplified G-RRD and G-PID (SG-RRD & SG-PID) and updates the database by LNSAs. The SG-RRD & SG-PID include static global data. When a connection request arrives, the source node can find the proper route according to the information in SG-RRD & SG-PID, while RSVP-TE is extended for data collection and translucent path establishment.

Section 2 of this paper provides details of hybrid OCP. In section 3 simulations are conducted for the comparison of hybrid OCP and the other solutions. Numerical results show that both routing based OCP and signaling based OCP have their own advantages as well as limitations, and hybrid OCP can achieve better performance than the others. Section 4 concludes this paper.

II. HYBRID OCP FOR TRANSLUCENT WDM NETWORKS

As mentioned in previous study [6, 7], both routing based OCP and signaling based OCP have the advantages as well as limitations.

In routing based OCP, the main advantage is that the translucent route is globally optimized and determined at the source node according to the information in G-RRD & G-PID, leading to higher resource utility and shorter setup delay. However, due to misalignment and routing protocol convergence time in case of network changes (topology, link/node resource availability, physical impairments of link/node), the G-RRD & G-PID cannot be guaranteed to reflect the real network status [7]. Especially for large network with bursting traffic (with higher arrival rate), the network status changes frequently but the database cannot be updated in time, so outdate information in G-RRD & G-PID will lead to higher resources collision [9] and incorrect lightpath quality estimation. Another disadvantage of this approach is that in the case of large network, a significant amount of information need to be updated by flooding LNSAs, which causes stability and scalability problems.

In signaling based OCP, The main advantage is that it handles better frequent changes of network status, and no global flooding is required, thereby minimizing scalability problems [7, 9]. However, due to the lack of knowledge about the whole network, the routes computed at the source take no consideration on resources state and physical impairments along the path, leading to higher blocking probability and longer setup delay. Another disadvantage is that a huge amount of information needs to be carried in signaling message, which will dramatically increase signaling load.

Combining the best features of these two approaches, hybrid OCP has been proposed in this paper to achieve better performance. In this approach, some extensions to the current GMPLS routing protocol (OSPF-TE) need to be implemented with the aim of carrying PI and RR information besides traditional TE attributes just as in routing based OCP. But each node only maintains SG-RRD & SG-PID instead of G-RRD & G-PID. SG-RRD contains resources utilization weight of each link/node rather than the accurate resources state, while SG-PID only contains static physical impairments of the whole network. The information in SG-RRD & SG-PID is updated by flooding LNSAs. Traditional GMPLS signaling protocol such as RSVP-TE also needs to be extended for data collection as in signaling based OCP. It performs on-line estimation of the signal quality and regenerator allocation during the translucent path setup process. The label object in standard RSVP-TE protocol also needs to be extended by allowing the representation of not only traditional GMPLS labels, but also labels which identify node resources, such as 3R regenerators, optical transmitters and receivers.

When the connection request arrives at the source node, first a K-HW-SPF (k hybrid weight shortest path first) route
computation algorithm [5] is implemented to provide up to k possible routes according to the information in SG-RRD & SG-PID. Then the calculated routes are passed to RSVP-TE extension module, and parallel transmitted by k Path messages [8]. In the forward direction, every traverse node, before propagating the Path message, update the collected data by adding its own dynamic parameters and resources state to the corresponding objects of RSVP message. At the same time, regenerator allocation strategy is implemented for signal quality estimation and regenerator allocation. At the destination, the node picks the first incoming Path message and queues the other arriving. This has the advantage that in case of a ResvErr the destination node can immediately issue the next Resv message along another path.

In this section, first we introduce the LQE module used in our simulations. Then the trace-forward strategy for signaling based regenerator allocation is presented. Finally, we analyze the advantages of adopting hybrid OCP.

A. LQE module

The Lightpath Quality Estimation (LQE) module is used to model the impairment effects, and compute the impairment accumulations along the candidate path, then verify the quality of the lightpath under certain physical constraints. If the lightpath can satisfy the signal quality requirements, the connection will be admitted using this candidate lightpath. Otherwise, the lightpath will be rejected.

The impact of transmission impairments on the quality of signal and routing strategy is extensively studied in [3, 7, 10-16] for impairment-aware transparent WDM networks. In this paper, we only consider four impairments: ASE noise, crosstalk, residual chromatic dispersion (RD), PMD. We only present the flowchart of LQE in Fig. 2. The mathematical functions are not described in this paper.

B. Trace-forward strategy

In translucent networks, the translucent path is composed by a number of transparent regeneration segments. The regenerator allocation can be implemented either in a distributed manner (DRA) hop-by-hop or in a centralized manner (CRA) at the destination. In CRA, regenerator allocation strategies such as Fragmentation (FS), Trace-back (TBS) [5] can be implemented to divide the path into consecutive transparent regeneration segments which are estimated by LQE module. One limitation of CRA is the high computational complexity due to iterative calling of LQE module at one node. Another problem is that Path messages must carry all the dynamic data to the destination for centralized resources allocation. In DRA, the computational task is distributed among the nodes along the path, and Path messages only need to carry the dynamic data of one regeneration segment, which will effectively reduce the load of signaling.

In DRA, when the Path message arrives at the intermediate node, it only carries part of collected data without knowledge of the information from the next to the destination. But in previous study [5], regenerator allocation strategies need a complete view of the whole path, which is not suitable for DRA. Thus, we have proposed a new strategy called Trace-forward for regenerator allocation.
allocation in a distributed manner. The flowchart of this strategy is shown in Fig. 3 (the figure only considers the case in the source/intermediate nodes. The case of the destination node is just a little different with the case in the intermediate node and not shown here). Pre-regeneration node denotes the end node of previous regeneration segment which has been determined. Pre-acceptable regeneration node denotes the node with available regenerators and acceptable lightpath quality from pre-regeneration node to this node.

When implementation, the parameters \( p_r \), \( p_a \), and \( w_{pa} \) can be carried by signaling Path messages.

In hybrid OCP, the main advantages involve: First, compared with signaling based OCP, routing algorithms such as K-HW-SPF can select better routes with more available resources according to the information in SG-RRD & SG-PID which will reduce the blocking probability caused by insufficient network resources on the selected route. Second, compared with routing based OCP, the signaling based data collection can get more accurate information. Thus, hybrid OCP is much more robust to inaccurate network status. Third, in this approach, dynamic data is collected and processed in a signaling based manner, while static data is stored in local database and updated in a routing based manner. On one hand, the data in SG-RRD & SG-PID do not change frequently, thus the problem introduced by LNSAs flooding and routing convergence time can be alleviated. On the other hand, only parts of data need to be carried in signaling message, which will reduce the overhead of signaling messages. Through this approach, we can minimize the stability and scalability problems. From the simulation results shown in the next section, we can see that hybrid OCP can achieve better performance than the other two approaches.

III. SIMULATIONS

In this section, the three approaches are evaluated through numerical simulations conducted in the extended version of AMSON simulator [17]. Section 3-A introduces the network model used in the simulations. Section 3-B presents some assumptions of the simulations. Simulation results and performance analysis are shown in section 3-C.

A. Network model

The network under study is a translucent WDM network, which consists of multiple nodes with regeneration capability connected by optical fibers in an arbitrary topology, as shown in Fig. 4. The physical parameters and constraints used in the simulations are not presented in this paper.

B. Assumptions

1) There are two fibers on each link transmitting in opposite directions. Each fiber contains 20 wavelengths. Each wavelength channel has the same frame format and digital rate 40Gbit/s.

2) There are enough add-ports and drop-ports for service access. 20% regenerators are employed in the network according to Nodal Degree Based (NDB) regenerator placement algorithm [5].

3) The unidirectional connection requests which follow Poisson distribution are uniform distributed among each node pairs, and the duration of each request is exponentially distributed with the same mean time. The number of connection requests tested in each simulation is 10000.

4) Random selection strategy is used for wavelength assignment in the simulations.

5) The topology of optical control plane is the same as data plane.

6) In the simulations, transmission delay is emulated by software. We also assume that the configuration time of optical devices at each node is uniformly distributed between 0.01 seconds and 0.02 seconds.

C. Performance analysis

The purpose of the simulations is to compare the three approaches from different aspects, such as blocking probability, the overhead of signaling messages, regenerator hops, and setup delay. We first compare the tolerance of each approach to inaccurate information under light traffic load and heavy traffic load. Then we show the gain and the cost of adopting hybrid OCPs compared with the other approaches. Finally, the setup time and average number of regenerators per path are simulated and analyzed.

In order to evaluate the impact of inaccurate information on the three approaches, the simulations are conducted with different traffic load and arrival rate. Assuming that the LNSAs processing delay is uniformly distributed between 3 seconds and 5 seconds at each node. Once LNSA is sent, it will collect all the changed information into one packet. Fig. 5(a) shows the blocking probability of each approach changing with arrival rate under light traffic load (200 Erlang). When arrival rate is low (normal traffic), routing based OCP has a little better blocking probability than signaling based OCP, because of...
globally optimized route selection with consideration of resources utility and physical impacts. Hybrid OCP has the best performance because of the combination of routing based route selection and signaling based information collection and resources allocation. When arrival rate grows high (bursting traffic), the blocking probability of routing based OCP increases very quickly to an intolerable degree (nearly 20%), while signaling based OCP and hybrid OCP remain the blocking probability almost unchanged. The high blocking probability of routing based OCP is mainly caused by inaccurate information, which can be alleviated by signaling based information collection. When traffic load is high (350 Erlangs), the influence is more obvious as shown in Fig. 5(b). Therefore hybrid OCP is much more robust to inaccurate information compared with routing based OCP, while maintains the lowest blocking probability of all.

When adopting hybrid OCP, k-parallel signaling can be used with K-HW-SPF [5] to achieve lower blocking probability at the cost of more signaling Path messages. In order to evaluate the gain and the cost of k-parallel strategy, simulations are...
conducted under different traffic load with normal arrival rate (arrival rate = 0.1/s). Fig. 6(a) shows the blocking probability of hybrid OCP with different k value under different traffic load. The blocking probability will decreases as k increases, especially when k changes from 1 to 3. But when k increases to 5, the approach just has a slightly better performance compared with k=3. When traffic load is low, the blocking probability of 3-H-OCP is nearly 40% better than that of 1-H-OCP. As traffic load grows high, 3-H-OCP can achieve 2 percent reduction on blocking probability compared with 1-H-OCP. Fig. 6(b) shows the total number of signaling Path messages sent/received in the whole network for different approaches under low traffic load (200 Erlangs with 10000 requests). RB-OCP (routing based OCP), SB-OCP (signaling based OCP) and 1-H-OCP (hybrid OCP with k=1) have the similar number of Path packets. But the number of Path messages sent/received in 3-H-OCP is over three times more than that of 1-H-OCP, while that is nearly 2 times more in 5-H-OCP compared with 3-H-OCP. This is because that k-parallel signaling needs probe multi-paths with more hops to guarantee lower blocking. So an inappropriate k value will dramatically increase the overhead of signaling.

Fig. 7(a) compares the setup delay for different approaches under normal traffic (arrival rate = 0.1/s). Routing based OCP has the shortest setup delay because of source-initiated resource reservation. Signaling based OCP and 1-H-OCP has the similar setup delay which is nearly 0.02 seconds more than that of routing based OCP, because of destination-initiated resource reservation. The setup delay of K-H-OCP is a little more as k increases, which is caused by the excessive time of setup-attempt. Fig. 7(b) shows the average number of regenerators per path for different approaches under normal traffic (arrival rate = 0.1/s). When traffic load is low, all approaches have the similar number of regenerators per path. When traffic load increases, routing based OCP uses less regenerators for each path, while signaling based OCP and 1-H-OCP remain the number nearly unchanged. But in K-H-OCP (k > 1), it needs more regenerators for each path to overcome wavelength contention and physical impairments, so to achieve lower blocking probability compared with other approaches. Therefore, K-H-OCP (k > 1) has the lowest blocking probability, but at the cost of longer setup delay and more number of regenerators for each path.

IV. CONCLUSIONS

In this paper, we have studied the problem of extending GMPLS protocol stack to support translucent WDM networks. An existing routing based approach modifies the routing protocol to get an up-to-date picture of the whole network for the purpose of translucent path computing. Another signaling based approach is based on extending the signaling protocol to collect data and determine the proper translucent path in a distributed manner. Combining the best features of routing based information updating and signaling based data collection, hybrid OCP has been proposed to improve network performance. With appropriate k-parallel signaling, hybrid OCP can achieve lower blocking probability and minimize scalability problems. The gain and the cost of adopting hybrid OCP are presented in the simulations.

Simulations results show that routing based OCP is more adapted to static networks, while signaling based OCP performs better on dynamic networks. Hybrid OCP can conquer the limitations of both approaches and achieve the best performance under various network conditions. Therefore it is a suitable solution for connection management in translucent WDM networks.

REFERENCES