A Framework on Feature Interactions in Optical Network Protocols

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Abstract. This paper studies the feature interaction problems in optical network protocols. A framework is defined, in which the basic services needed by optical network protocols are discussed, and the feature interaction problems in optical network protocols are analyzed. Especially, the interactions occurred in or between the control and management protocols of optical networks are firstly studied in this paper and some guidelines to detect and resolve these problems are proposed.

1 Introduction

Nowadays fiber optics is being widely used for establishing telecommunication networks as well as data communication networks throughout the world because of its high bandwidth and very low received bit error rate [1]. ASON (Automatic Switched Optical Network) is the core optical networks with high-speed, high-bandwidth, flexibility and reliability to meet the demands for capacity, speed and survivability from applications such as video, audio and the other emerging ones [2].

ASON consists of a number of Optical Cross-connects (OXCs), each of which consists of a switching fabric and a separate control plane processor. The control plane processors in an ASON, communicate with each other over data communication network whose control and management tend to be IP centric. Switching fabrics of OXCs forms the data plane of ASON, and the topology of control plane and data plane need not be identical. The architecture of ASON is different from the traditional telephone networks in that its control plan can run over IP networks which provides transparent connectivity between two nodes in the network, while equipments in traditional networks can only communicate with their physical neighbors. The differences between IP network and traditional telephone network described in [3] also exist between ASON and the traditional telephone network, so does the impact of these differences on the feature interaction problems.

But different from the traditional Internet, the services of optical networks are provided by the cooperation of both control plane and data plane which can be physically separated with each other and have fairly different characteristics and features. The IP-centric control plane and connection-oriented data plane make the operation of ASON have the characteristics of both PSTN and Internet software and become more complicated. The standardization of optical control plane protocols is still undergoing and most of the services provided by ASON are still proprietary, the feature interaction problems in optical network have not been studied yet. In this paper, we define a framework for feature interaction problems in optical network management protocols.

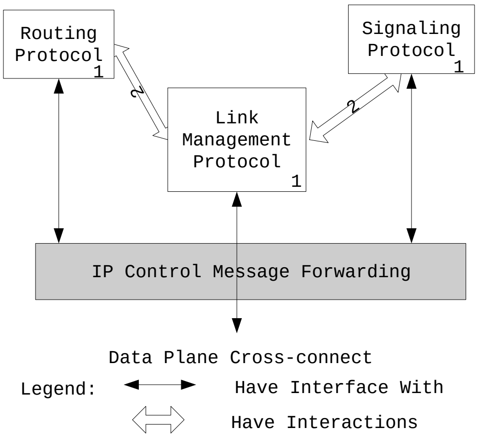

Figure 1: Control Plane Architecture

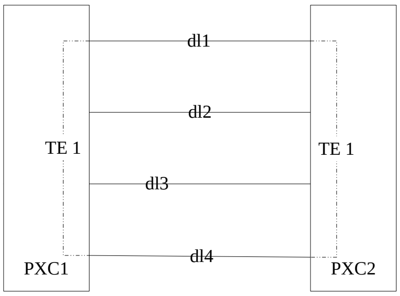

Figure 2: Relationship between TE Link and Data Link

This paper is organized as follows: section 2 introduces the framework of optical network control and management, in section 3, the feature interactions in optical network are analyzed. The techniques to detect and resolve the feature interaction problems in optical network are introduced in section 4 and this paper concludes in section 5.

2 Model of System and Services

In this section, we define the kernel functions provided by optical networks at first, then briefly introduce the intelligent features of optical network protocols and their relationship.

2.1 Kernel Functions of ASON

In ASON, the data plane and control plane can be separated and each has its own topology such that ASON is taken as two layers: optical transport layer and protocol control layer. Optical transport layer provides the management of the hardware equipment, handles the signals from the hardware and generates indication to upper layer protocols. Protocol control layer increases the intelligence of ASON, provides the functions such as resource discovery, connection management, topology/state dissemination.

Different transport equipment has different capabilities such that services provided by data plane to control layer protocols are different. The generic data link layer and physical layer features have been defined in ITU-T X.211 and X.212, which can be defined as the basic services provided by data plane. The capabilities of SONET/SDH equipment, specified by ITU-T G.780 series, are also the basic services provided by data plane when analyzing the control and management protocols of optical networks. Of course, only part of these capabilities are needed by a specific protocol.

Figure 1 illustrates the simple architecture of a control plane node. It shows that routing and signaling protocols only need the kernel functions provided by IP control module, but protocols that fulfill the resource management functions need to interact with the cross-connect hardware. So the kernel functions needed by optical network management protocols and provided by optical transport layer and protocol control layer are different with respect to the protocols for different purpose.

2.2 Features of Optical Network Protocols

Given the kernel functions of ASON, which are provided by the IP control message forwarding and the data plane, lots of features can be developed to increase the intelligence of ASON. As indicated in figure 1, control and management features of ASON are provided by three kinds of protocols, that is,routing protocol, link management protocol and signaling protocol.

The routing protocol provides the functions to collect, disseminate network resource and topology information, which is maintained by link management protocol. The link management protocol manages local resource and summarizes it for traffic engineering (TE) purpose. The TE link information can be used by routing protocols to generate their Link State Advertisements (LSAs); it also maps TE links and control channels which can be used by signaling protocols to set up a Label Switched Path (LSP). Based on the topology or network resource information learned by routing protocol, a path can be calculated for a connection request and signaling protocol is used to create, maintain, restore, and delete the connection. As a result of processing of the signaling protocol messages, the state of local resource can be changed, that is, connections can be established or removed, corresponding to allocation or deletion of resources. In the whole architecture, link management protocol provides the fundamental functions to support routing and signaling protocols.

All the features of optical network protocols are being standardized by IETF under the umbrella of GMPLS framework [5]. Link Management Protocol (LMP)[6], enhancements to OSPF/IS-IS, and enhancements to RSVP/CR-LDP are the most promising protocols to provide these features to optical network.

3 Feature Interactions in Optical Network Protocols

The ever-increasing features of optical network protocol and its openness in control plane invariably result in many new feature interaction problems. As indicated in figure 1, feature interactions of optical network protocols can occur in a single protocol as shown at location 1, or between different protocols as shown at location 2. The latter case is usually referred to as protocol interactions and not strictly be *feature* interactions [3]. Intelligence of ASON is provided by the cooperation of several protocols, such that all the features provided by protocols are also features of ASON intelligence. From the level of ASON intelligence, we define that when the presence of a feature of a protocol results the behavior of another protocol different from what is desired when they are designed independently, feature interactions between different protocols occur.

Feature interactions in ASON is classified into two categories: feature interactions between the features of a single protocol and feature interactions between the features of different protocols. For each category, we illustrates the scenarios that will result in the feature interactions in the following. Table 1 summaries the reasons of these feature interactions and possible resolution techniques.

3.1 Interactions Between Features of a Single Protocol

To reduce the number of protocols running in networks, there is a tendency to extend existing protocols to provide new services rather than to develop new protocols. So more and more features can be developed via the same suite of messages or some new messages are added to

Table 1: Feature Interactions in Optical Network Protocols and Their Resolution Techniques

Resolution Reasons of FIs	Policy Definition 4.2	Behavior Restriction 4.3	Advanced Scheduling 4.4	On Line Control 4.5
Coexistence of incompatible multiple capabilities 3.1.1	✓			✓
Requirement violation 3.1.2		✓		
Race condition 3.2.1			✓	
Single trigger event and multiple inconsistent responses 3.2.2	✓			
Performance degradation 3.2.3	✓			

the existing protocol to provide new functions. These features of a single protocol can interact with each other.

3.1.1 *Feature Interactions in Label Distribution Protocol*

Label distribution protocol defines a set of procedures by which one Label Switched Router (LSR) informs another of the meaning of labels used to forward traffic between and through them [4].

LDP provides two label advertisement modes, Downstream on Demand mode and Downstream Unsolicited mode, for each interface on an LSR to initiate mapping requests and mapping advertisements. It is possible for neighboring LSRs with different advertisement modes to get into a live lock situation where everything is functioning properly, but no labels are distributed.

3.1.2 *Feature Interactions in Link Management Protocol*

The features of LMP include: control channel management, link property correlation, link connectivity verification, and fault management. It is required that when a TE link becomes up, any data link in up/free state in the TE link can be allocated to a request. The requirement can be satisfied when only link property correlation and control channel management features are invoked in LMP. But when link connectivity verification process is added, the property fails to hold sometimes.

For example, in figure 2, four data links are configured to a TE link. The initial state of TE link is Init, which is changed to up when at least one data link in the TE link becomes up. When link connectivity verification is not invoked, both TE link and data link state are changed to up when link property correlation completes its operation. But when link connectivity verification process is invoked in the nodes, link connectivity verification process can change the state of data link to up once it finishes verification process. For example, in figure 2, the state of dl1 is changed to up when link connectivity verification finishes its operation, so the state of TE link 1 is also changed to up. In this case, dl1 can not be allocated to a request though dl1 and the TE link including dl1 are both in up state, because the properties of dl1 has not been exchanged yet, and the incompatible properties in both sides of the dl1 can result in the failure of the path set up. The inconsistent operation of link connectivity

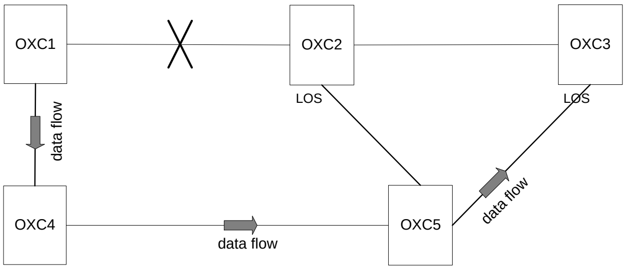

Figure 3: Interactions between Fault Detection and Path Restoration.

verification and link property correlation makes them interact and result in the violation of the requirement.

3.2 Interactions between Features of Different Protocols

3.2.1 *Feature Interactions between Path Setup and Link Connectivity Verification*

Both LMP and LDP can change the state of a data link between two OXCs. For an up and free data link, LDP can request LMP to change its state to be allocated once a lightpath is set up along the data link; link management protocol can change its state to test if it needs to monitor the status of the link. Interaction occurs when LDP gets an up/free data link whose state is changed to test before LDP succeeds its operation and changes the data link to be allocated.

The communication of two protocols in optical control plane is usually asynchronous and interaction can be resulted by the race conditions among the operations of different protocols. To be more clarified, consider that LDP and LMP are two processes. LDP sends a request to LMP to get an up/free data link, and LMP response LDP with an up/free data link with the attributes of the data link. LDP checks that the attributes of the data link is compatible with the lightpath requirement, it sends LMP an indication to set the state of the data link to be allocated. But before LDP sends the indication to LMP, the monitor timer of LMP expires and the state of data link returned to LDP is changed to test by the link connectivity verification function of LMP. If LMP discards the indication of LDP, the lightpath set up by LDP is not usable for it's illegal to transmit traffic while a data link is under test. If LMP accepts the indication of LDP and stops the test process, the incomplete monitor process can result a data link to be down. Such a dilemma indicates that interactions occur between path setup function of LDP and link connectivity verification function of LMP.

3.2.2 *Feature Interactions between Fault Detection and Path Restoration*

Several layers in optical networks, such as physical layer, data layer, network layer and service layer, have their own fault management mechanisms, each focusing on a different aspect. These fault mechanisms can interact with each other, especially when fault occurs in lower layer and the fault mechanisms in all upper layers are triggered. Some inconsistent behaviors in different layer can result in the failure of some features.

Figure 3 shows a network composed of several optical cross-connects. Before errors occur between oxc1 and oxc2, user traffic is transmitted along the primary path oxc1, oxc2 and oxc3. When fault occurs between oxc1 and oxc2, the fault can be detected by oxc2 and oxc3 as a result of loss of light. In this case, several fault management mechanisms can be triggered. If LMP is running on each node, fault localization process of LMP will be triggered to identify the location of the fault; if 1:n or 1+1 protection mechanism is deployed to the primary path, the protection mechanism can be triggered to recover the user traffic from the fault. If the protection mechanism is triggered and completes its operation before fault localization finishes its function, the fault localization feature of LMP fails to hold. Because when restoration mechanism is triggered, the user traffic is switched to path oxc1, oxc4, oxc5 and oxc3, there is no traffic carried along the primary path at this case. Fault localization process of LMP has supposed that the user traffic is always carried along the primary path such that it can find oxc1 is ok and oxc2 has detected the loss of signal, then decide that fault occurs between oxc1 and oxc2. With the user traffic switched over to the protection path, both oxc1 and oxc2 detect the loss of signal, so it cannot decide the location of the fault.

3.2.3 *Feature Interactions between Routing and Link Management Protocols*

In optical network, when a lightpath is set up and torn down, the status of all the involved channels is changed from being available to occupied and vice versa, such a network resource information is flooded throughout the control plane by routing protocols. Link management protocol maintains the status of channel status and triggers the flooding of the resource information once it is changed.

With a large number of links between two devices, flooding information of routing protocols will become tremendous, which can lead to control network congestion and instability. Link management protocol bundles these links into TE links, it triggers routing protocol to flood resource information until the resource change reaches certain points. But too infrequent flooding makes the network resource information inaccurate in each node, which can result in the inefficient utilization of the network resource and degrade network performance.

4 Feature Interactions Detection and Resolution Techniques in Optical Network

The causes of feature interactions in intelligent networks that are identified as limitations on network support, intrinsic problems in distributed systems and violation of feature assumptions[7], can also result in feature interactions in optical networks, such that the feature interaction resolution techniques developed in traditional telecommunication network can be applied to detect and resolve the problems in optical networks. But the interactions occurred in optical control and management protocols can result in much serious effect on the network operation, most interaction should be predicated before the deployment and more efficient resolution should be provided in run-time to prevent the service failure. Because of this, formal methods plays a much more important role in the design period to verify protocol properties, and some new methods are developed to resolve the interaction problems in run-time. We have used the automatic protocol validation tool Spin [8] to detect the feature interaction problem in the automatic neighbor discovery protocol [2] of optical networks and the on-going work is applying testing techniques to detect feature interaction problems.

4.1 Interaction Resolution by Policy Definition

Policy definition is much more important in protocol design and deployment of optical network protocols for its simplicity in solving possible interaction problems.

To solve the live lock between two LSRs operating in different label advertisement modes as indicated in section 3.1.1, a rule should be defined in an LSR operating in Downstream Unsolicited mode that an LSR operating in Downstream on Demand mode should not be expected to send unsolicited mapping advertisements. Therefore, if the downstream LSR is operating in Downstream on Demand mode, the upstream LSR is responsible for requesting label mappings as needed.

A single failure in optical networks can trigger the operation of multiple protocols with different behaviors, which results in the interactions between fault detection and path restoration in section 3.2.2. To solve this problem, a policy can be defined for the control path restoration process such that it can wait a period of time before beginning its operation. Such a policy is usually implemented by a timer in a real system.

4.2 Interaction Resolution by Behavior Restriction

For the interactions that are resulted by violation of the properties of a feature when adding or invoking a new one, behavior restrictions on the new features can solve them.

The invoking of link connectivity verification of LMP having violated the requirement of link property correlation as indicated in section 3.1.2 can be resolved by restricting the behavior of link connectivity verification. That is, when a data link passes the verification, its state is not changed to up until a link summary message on this data link is received and the property of the data link in both ends are checked to be compatible with each other.

4.3 Interaction Resolution by Advanced Scheduling Techniques

Many interactions in optical network protocols are resulted by the inconsistent operation on the shared resource. Data links in optical network are shared resource by all the protocols, and inconsistent operation on its state can result in the failure of some features, example given in section 3.2.1 is for this case.

A shared resource is usually associated with a resource management mechanism. Based on operation mechanism of the management system associated with a resource, the resource can be classified as: time-shared resource and space-shared resource. A space-shared scheduler executes a request for the resource by running it on a dedicated part of the resource when allocated; a time-shared scheduler starts its requests immediately upon its arrival and share resources among all jobs. Data link database can not be accessed simultaneously, so a space-shared systems can associate with it to handle its access request. The space-shared systems use resource allocation policies such as first-come-first-served (FCFS), shortest-job-first served (SJFS). This system must guarantee that once a request from a protocol has not been served completely, no other request can be adopted.

For the example given in section 3.2.1, the resource management system of the data link should be designed to control that once a read request has been received from LDP, and before receiving the response from LDP, no other access can be allowed to the same data link. If the data link database is implemented with shared memory instead of an independent database management system, a semaphore can be associated with each data link, and each protocol should get the semaphore no matter it needs to read or write the state of the data link. Once LDP gets the semaphore, it should not release it until it completes the operation on this data link.

4.4 On-line Detection and Resolution Techniques

Many on-line detection and resolution techniques can be applied to ASON. But to detect and resolve the interactions in control and management protocols in optical network, the speed and efficiency is of the first priority. In many protocols, interactions are detected by predication in design and resolved in run-time, that is, during design period, the possible interaction problems are predicated and some fields in the messages are reserved for negotiation to reduce the possible interactions in run-time. Such an on-line negotiation process can be used to solve many interactions resulted by the coexistence of multiple capabilities.

5 Conclusion

The feature interaction problems in ASON control and management protocols are very important for their severe impact on the network operation. We have proposed a framework and discussed the feature interaction problems in optical network management protocols. Our analysis shows that feature interactions can not only occur between features of a single protocol, but also occur between features of different protocols which can have much more serious effect on the network performance and operation. Some new resolution techniques which are particularly suitable for optical control and management protocols are proposed.

Adopting the characteristics of optical network control and management protocols to develop more techniques to detect and solve the feature interaction problems in optical networks is an interesting topic. What kind of techniques developed in traditional telecommunication network can be applied to optical network protocols and what's the barrier of using such techniques need further study.

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