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Abstract: This paper presents a novel GMPLS-based fault management architecture for OULSR rings tested in the ADRENALINE testbed. Experimental results show an optical protection delay of 45ms using SNMP-based monitoring and IP/control restoration delays around 2100ms.

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1. Introduction

Most of current metropolitan area networks are based upon fiber-ring architectures, as evidenced by the proliferation of multi-level SONET (SDH) rings. Given this large, entrenched base of ring topologies and the extensive experience operators have gained in operating SONET ring networks, it seems logical to plan for a migration to equivalent dynamic optical ring architectures based upon recent advances in optical networking technologies such as WDM, reconfigurable OADMs and OXCs, capable of providing high-bandwidth, end-to-end optical connections. On the other hand, network operators have become well-accustomed to the fast, timely recovery capabilities provided by SONET automatic protection switching (APS) that can achieve service recovery within 50ms after a fault event. Thus, these features must be kept in the new optical ring architectures.

As long with increasingly MPLS-based client router networks, intermediate metro/regional networks are expected to evolve to similar IP-based architectures. However, the emerging IP-based GMPLS framework for optical networks is largely based upon optical mesh networks. Although some might state that rings are special cases of meshes, technically speaking, the various intricacies of ring networks require special attention in the GMPLS framework, such as the Optical Multiplex Section (OMS) protection scheme, which is not supported by the GMPLS recovery framework [2,3]. GMPLS only supports Optical Channel (OCh) resilience, that is, on a per LSP basis for end-to-end or segment. The objective of this paper is to propose an experimental enhancement to GMPLS recovery schemes for fault management in OULSR in order to provide service recovery within 50ms (SONET-like) after the fault event. Performance evaluation, in terms of recovery time, has been carried out in the ADRENALINE testbed.

2. ADRENALINE testbed. General Overview.

The ADRENALINE testbed (http://www.cttc.es/adrenaline) is based on an ASON/GMPLS network constituted by a metropolitan DWDM ring with three dynamically reconfigurable OADMs and a GMPLS-based control plane. The optical transport network is composed by an Optical Unidirectional Line-Switched Ring (OULSR, also named OMS-DPRing). It utilizes two counter-rotating fibers, one for working lightpaths (clockwise) and the other for protection lightpaths (counter-clockwise). The protection fiber basically provides an alternate fiber path between two nodes experiencing a fiber cut. In such a case, all the lightpaths passing through the failed link (line) must be jointly switched (OMS) over the protection fiber at both adjacent OADMs using 2x2 optical switches. The optical switches employed in the experimentation have a switching delay around 10ms.

ADRENALINE's control plane is based on GMPLS RSVP-TE signaling for dynamic wavelength reservation and lightpath provisioning, and GMPLS OSPF-TE routing for network topology and optical resources dissemination. Each node is equipped with an Optical Connection Controller (OCC) implemented on a Linux platform with two 1GHz processors, acting like IPv4 router. Each pair of nodes communicates through the use of a single IP control channel implemented with full duplex Fast Ethernet links transported in-fiber (35Km) out-of-band at 1310nm. Note that after a link failure, the IP control channel between a pair of nodes also fails, therefore there is no control channel for recovery-related information and message exchange. Finally, each OCC has also an SNMP agent for communicating with management entities and a Connection Control Interface (CCI) for communicating with the optical node's hardware. A more detailed description of ADRENALINE's architecture can be found in [1].

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3. Enhanced GMPLS fault management.

Fault management includes detection, localization and recovery of failures. Fault detection is handled at the physical layer. One measure of fault detection is simply detecting the loss of light (LOL) of the incoming fiber. This is appealing for transparent devices without optical-electrical conversion because of its speed and simplicity. In the experimentation we have employed an SNMP-based, all-optical transport monitor that taps 1% of the received power. The monitor sends a threshold-crossing alarm to the OCC's SNMP agent in case of power attenuation. The sweep of monitoring is 10ms and the signal attenuation level is 20dB.

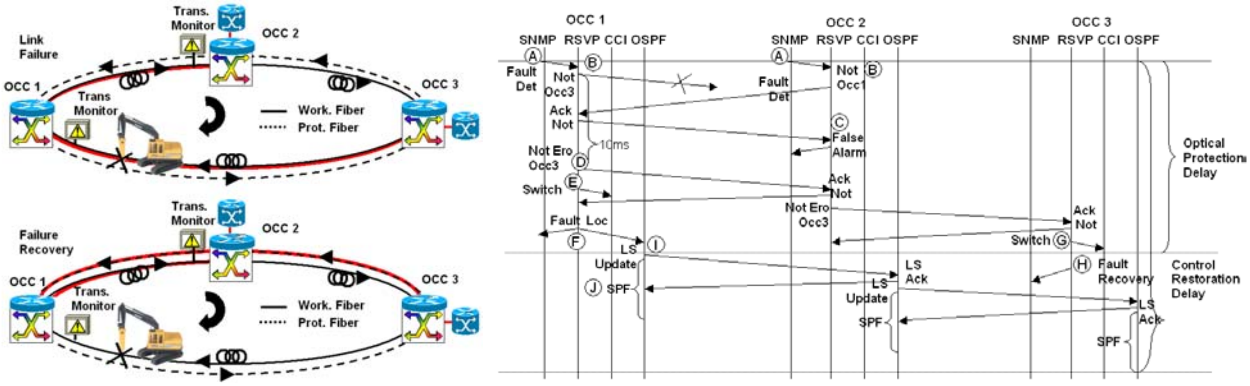


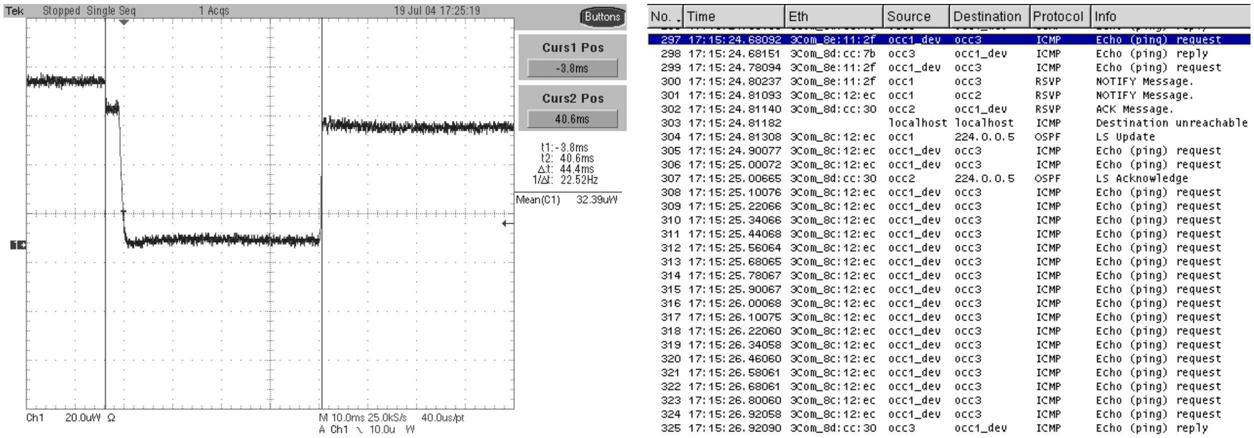
Fig. 1.a) Example of fault link in ADRENALINE testbed. 1.b) Proposed GMPLS fault management for OULSR

Fault localization requires communication between nodes to determine where a failure has occurred. LOL propagates downstream along the connection path and therefore all downstream nodes may detect the failure. Let us consider the example of Figure 1.a, based on the ADRENALINE testbed. In this example there are working lightpaths traveling from node 3 to node 2 passing through node 1. Therefore, if the link between node 1 and node 3 fails, the SNMP-based monitors located at nodes 1 and 2 will report the alarm to OCC1 and OCC2's SNMP agents, respectively. GMPLS introduces a new protocol called Link Management Protocol (LMP), which runs between adjacent nodes, responsible for establishing control channel connectivity as well as failure localization. LMP sends Channel-Status messages between adjacent nodes, therefore it requires a control channel maintained separately for the data-bearing channels. In ADRENALINE, the signaling is in-band, thus when a fiber link occurs it affects both control and data channels. Therefore, LMP does not work correctly in this network context. To overcome this, we propose to use the GMPLS RSVP-TE signaling also for fault localization using a Notify message that differs from the one specified by the IETF [2,3,4].

According to the IETF, the Notify message provides a mechanism to inform non-adjacent nodes of LSP (lightpath) related events. Moreover, the Notify message is generated if requested by the corresponding LSP, through the insertion of a Notify Request Object in the Path or Resv messages to indicate the address of a node that should be notified on an LSP failure. Finally, to support reliable delivery of the Notify message, an ACK message is used to acknowledge the receipt of the Notify. In our approach, we use the Notify message without the Notify session list, that is, without any reference to any LSP session, since we work on an OMS resilient scheme instead of an OCh scheme. Therefore, continuing with the previous example (Figure 1.b), the OCC's SNMP agent sends a "Fault Detection" alarm to the GMPLS RSVP-TE agent (step A). Once the RSVP-TE agent receives this alarm, it generates a Notify message with reliable message delivery encapsulated in an IP packet whose destination is equal to the remote node address of the failed link (step B), that is, for OCC1 a Notify message to OCC3 would be generated, and for OCC2, to OCC1. After that, the RSVP-TE agent will wait for 10ms to receive the Notify ACK message from the remote OCC. Upon reception of the ACK message, the RSVP-TE agent sends an alarm to the SNMP agent indicating "False Alarm", in order to defuse it (step C). Not receiving the Notify ACK message means localization of the failed link. In this paper, the 10ms timeout for receiving the ACK is enough even for high traffic loads, taking into account that generally the ACK messages in the experimentation are received in less of 1ms.

Once the failure has been detected and localized, the nodes responsible for fault recovery must be notified and repair procedures must be initiated ("Fault Notification", steps D to I). In an OULSR network, the pairs of nodes involved in the repair procedures are the node that has localized the failure (OCC1 in Figure 1.b) and the adjacent node to the failed link (e.g OCC3). In our example, OCC1 must notify OCC3 about the failed link so that OCC3 can start the repair procedures, without using the failed IP control channel. In this paper we propose an enhancement to the Notify message introducing an Explicit Route Object (ERO) that specifies a strict path to the adjacent node in the opposite direction to the failed link, that is, following the example, OCC1 would send a Notify message to OCC3 with an ERO composed by OCC2's and OCC3's IP addresses, and targeted to OCC2's IP address (step D). Note that this Notify message must be processed hop-by-hop by all the intermediate nodes. This differs considerably from [4], which specifies that Notify messages are not processed at intermediate nodes.

Thus, each node must store two complementary routes, one for each adjacent node, that can be manually configured or learned dynamically by the OSPF-TE. Once OCC3's RSVP-TE agent receives the Notify message it configures the local OMS' 2x2 optical switch, through the CCI interface, in order to switch the working traffic over the protection fiber (step G), and sends an alarm to the SNMP agent reporting "Fault Recovery" (step H). In the same way, once OCC1's RSVP-TE agent sent the Notify message, it configures the local optical switch (step E) and sends an alarm to the SNMP agent and to the GMPLS OSPF-TE agent reporting "Fault localization" (step F). Experimental tests have shown that optical protection delay, that is, the time during which the working lighpahts do not have service is about 45ms (Figure 3.a), which is comparable to the SONET recovery levels.



```
No.  Time            Eth               Source     Destination  Protocol  Info
297  17:15:24.68092  3Com_8e:11:2f     occ1_dev   occ3         ICMP      Echo (ping) request
298  17:15:24.68151  3Com_8d:cc:7b     occ3       occ1_dev     ICMP      Echo (ping) reply
299  17:15:24.78094  3Com_8e:11:2f     occ1_dev   occ3         ICMP      Echo (ping) request
300  17:15:24.80237  3Com_8e:11:2f     occ1       occ3         RSVP      NOTIFY Message.
301  17:15:24.81093  3Com_8c:12:ec     occ1       occ2         RSVP      NOTIFY Message.
302  17:15:24.81140  3Com_8d:cc:30     occ2       occ1_dev     RSVP      ACK Message.
303  17:15:24.81182                    localhost  localhost    ICMP      Destination unreachable
304  17:15:24.81308  3Com_8c:12:ec     occ1       224.0.0.5    OSPF      LS Update
305  17:15:24.90077  3Com_8c:12:ec     occ1_dev   occ3         ICMP      Echo (ping) request
306  17:15:25.00072  3Com_8c:12:ec     occ1_dev   occ3         ICMP      Echo (ping) request
307  17:15:25.00665  3Com_8d:cc:30     occ2       224.0.0.5    OSPF      LS Acknowledge
308  17:15:25.10076  3Com_8c:12:ec     occ1_dev   occ3         ICMP      Echo (ping) request
309  17:15:25.22066  3Com_8c:12:ec     occ1_dev   occ3         ICMP      Echo (ping) request
310  17:15:25.34066  3Com_8c:12:ec     occ1_dev   occ3         ICMP      Echo (ping) request
311  17:15:25.44068  3Com_8c:12:ec     occ1_dev   occ3         ICMP      Echo (ping) request
312  17:15:25.56064  3Com_8c:12:ec     occ1_dev   occ3         ICMP      Echo (ping) request
313  17:15:25.68065  3Com_8c:12:ec     occ1_dev   occ3         ICMP      Echo (ping) request
314  17:15:25.78067  3Com_8c:12:ec     occ1_dev   occ3         ICMP      Echo (ping) request
315  17:15:25.90067  3Com_8c:12:ec     occ1_dev   occ3         ICMP      Echo (ping) request
316  17:15:26.00068  3Com_8c:12:ec     occ1_dev   occ3         ICMP      Echo (ping) request
317  17:15:26.10075  3Com_8c:12:ec     occ1_dev   occ3         ICMP      Echo (ping) request
318  17:15:26.22060  3Com_8c:12:ec     occ1_dev   occ3         ICMP      Echo (ping) request
319  17:15:26.34058  3Com_8c:12:ec     occ1_dev   occ3         ICMP      Echo (ping) request
320  17:15:26.46060  3Com_8c:12:ec     occ1_dev   occ3         ICMP      Echo (ping) request
321  17:15:26.58061  3Com_8c:12:ec     occ1_dev   occ3         ICMP      Echo (ping) request
322  17:15:26.68061  3Com_8c:12:ec     occ1_dev   occ3         ICMP      Echo (ping) request
323  17:15:26.80060  3Com_8c:12:ec     occ1_dev   occ3         ICMP      Echo (ping) request
324  17:15:26.92058  3Com_8c:12:ec     occ1_dev   occ3         ICMP      Echo (ping) request
325  17:15:26.92090  3Com_8d:cc:30     occ3       occ1_dev     ICMP      Echo (ping) reply
```

Fig. 3.a) Optical Protection delay (Com. Signal Analyzer). 3.b). IP/Control Restoration Delay (Network Analyzer)

When the OSPF-TE agent receives the "Fault localization" alarm, the dynamic IP layer restoration schemes start, since both the topology of the control and transport plane have been affected by the failure. With dynamic routing, reachable active OCCs are found dynamically by exchanging (between adjacent routers) control messages that are used to update the OCC's routing tables, thus enabling IP packets to be dynamically rerouted around link and node failures. Therefore, once the OSPF-TE agent receives the alarm reporting the fault in the network, it propagates the occurred changes to its neighboring routers using the Link State Update messages (step I). Then, SPF recalculates the affected routes and updates its routing tables (step J). In our example, once OCC3 has recalculated the new routes, the control plane is reestablished, being ready for new optical connection requests. In this experimentation, an estimation of the control restoration delay has been obtained through pings each 100ms from OCC1 to OCC3. Results shows that the control plane is out-of-service only around 2100ms, due to the elimination of the OSPF-TE HELLO messages used for detecting faults in the network. Figure 3.b shows a capture of a network protocol analyzer, in which the ICMP Ping request (from OCC1) and reply (from OCC1) are shown. This figure also shows the rest of control messages (signaling and routing) employed for the transport and control plane resilience.

Conclusions

This paper has proposed a novel GMPLS-based fault management architecture for OULSR networks that has been tested in the ADRENALINE testbed. The performance shows that the optical protection delay can be achieved in 45ms using a SNMP-based monitoring, thus being comparable with SONET's quality standards. Moreover the IP/control restoration delay has been achieved in 2100ms, which is considerably inferior to the tens of seconds characteristic of IP dynamic routing.

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