Management Architecture against Hardware Failures in an Optical Packet and Circuit Integrated Network

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Abstract—We design and develop architecture against hardware failures arisen on an optical packet and circuit integrated (OPCI) network. The control plane regularly collects hardware failures’ information from the data plane, automatically notifies the failures to the management plane (M-plane), and recovers the status of path usage. For the M-plane, we develop and install a management system based on a hierarchical management model constructed as a relational database to visually manage various OPCI network elements and their correlative relationships over multiple layers. The M-plane contributes to faster discovery of resources affected by hardware failures than the existing OPCI network without any management systems. In verification experiments, we show that hardware failures and resources affected by the failures are successfully displayed on the management window. Besides, the empirically-estimated time to detect a hardware failure and specify affected resources indicates indispensability of the M-plane in that the network administrator can work on recovery operations much faster and earlier and enhance availability of the OPCI network.

Keywords—Optical Network; Packet Switching; Circuit Switching; Failure; Network Control; Network Management.

1. INTRODUCTION

Recently, to provide both optical packet switching (OPS) [1] and optical circuit switching (OCS) [2] on the same wavelength-division-multiplexing (WDM) infrastructure with a finite bandwidth, we have been developing an optical packet and circuit integrated (OPCI) network as a high-speed metro/core network infrastructure [3]–[5]. Figure 1 shows the concept of OPCI network, in which separate wavelength bandwidths are dynamically allocated to OPS and OCS. Consumers can flexibly select bandwidth-shared large-capacity OPS services or bandwidth-guaranteed high-quality OCS services depending on their demands on a common fiber infrastructure, which meets the objective of Future Networks [6]. Telecommunications carriers receive benefits of energy-efficient large-capacity data transmissions due to optical technologies. Here, a lightpath or an optical path is defined as each end-to-end occupied wavelength in the OCS resources. We apply statistic multiplexing to the OPS, which realizes asynchronous and random access to the network. Networks providing both packet switching and circuit switching are investigated also in other research projects [7]–[9], and thus receive much attention in the world.

In case some failures of hardware (e.g. fiber links or optical equipment) occur on the data plane (D-plane) of OPCI network, we require the network administrator to discover the failures and recover the network as fast as possible. Hence, the OPCI network is obliged to equip management plane (M-plane) especially to manage association among various OPCI network elements and visualize failures and resources affected by the failures soon. However, our OPCI network in [3]–[5] has not equipped such M-plane. With M-plane, when some failures occur, the network administrator will not need to manually look into the status of various network elements one by one on the control-plane (C-plane).

General network management is based on a vertically-integrated architecture in which each of various network services such as transport, circuit-switching, packet-switching, and VPN, and uses its own network management system. Meanwhile, management for MPLS/GMPLS has been already standardized [11]–[13], and its elements include management information base (MIB) related to traffic engineering. In MPLS/GMPLS networks, various network elements over multiple layers can be managed effectively by a hierarchical model constructed as a relational database (RDB). In our OPCI network, multiple service layers (optical equipment, wavelength resources, OPS and OCS) are cooperated with each other on a common fiber infrastructure, and various network elements at multiple layers are closely associated with each other. In such a network, the network administrator is obliged to unify management of such OPCI various network elements.
and their association over the multiple service layers. Thus, as 
in the case of MPLS management, a hierarchical management 
model is suitable for our OPCI network.

In this paper, we design and develop architecture against 
hardware failures arisen on the D-plane of OPCI network. The 
C-plane regularly collects hardware failures’ information from 
the D-plane, and the C-plane notifies the failures to the M- 
plane and recovers the status of path usage. The M-plane 
manages the failures’ information, and automatically and 
visually displays it on the management window. For the M- 
plane, we develop and install a management system based on a 
 hierarchical management model constructed as a RDB to 
comprehensively and visually manage various OPCI network 
elements and their correlative relationships over multiple layers. 
The multiple layers include optical transport, wavelength 
resources, OPS and OCS layers for the WDM-based OPCI 
network. When some hardware failure occurs, the network 
administrator not only receives the failure message but also 
promptly and simultaneously specifies both OPS and OCS 
resources affected by the failure. This is due to management of 
the correlative relationships among OPCI network elements. In 
verification experiments, we show that hardware failures and 
resources affected by the failures are successfully displayed on 
the management window. Besides, the empirically-estimated 
time to detect a hardware failure and specify affected resources 
indicates indispensability of the M-plane in that the network 
administrator can work on recovery operations much faster and 
earlier and enhance availability of the OPCI network.

II. OPCI NODE FOR RING TOPOLOGY

In [4], we have developed OPCI nodes for ring networks, of 
which a block diagram is shown in Fig. 2. We use 40 
wavelengths with 100GHz interval in C-band. Each node is 
capable of stable, simultaneous transfer of 100 Gbps (10 Gbps 
× 10 wavelengths) optical packets and seven 10-Gbps optical 
transport network (OTN) path signals (OTU2e frame [10]). In a 
node, we employ two wavelength selective switches (WSSs) 
each of which is for multiplexing (adding) or demultiplexing 
(dropping). As to OPS, each node equips a transponder, and 
also equips a 4 × 4 OPS system consisting of an optical packet 
switch and an optical packet header processing controller for 
forwarding and buffering. Each transponder of OCS and OPS 
has a 10Gbe interface for edge networks. Each node installs an 
device controller as equipment on the D-plane, which 
directly changes the configurations of OPS and OCS 
equipment by means of Transaction Language 1 (TL1). The C- 
plane executes three distributed OCS control functions: 
signaling for OCS, routing for OCS and dynamic resource 
allocation to OPS/OCS which are interleaved with each other 
[5]. In the signaling process, every time each node transfers a 
signaling message, the control system on the C-plane sends 
request of controlling the WSSs and/or the OTN transponder to 
the optical device controller by means of a proprietary 
protocol. The optical device controller automatically obtains 
hardware failures’ information from optical equipment.

III. D-/C-/M-PLANES AGAINST HARDWARE FAILURES

Figure 3 shows a schematic view of architecture of D-/C-/ 
M-planes. We do not focus on edge networks in this paper. As 
to OCS, we target at loss of signals (LOS) arisen from the OTN 
transponders, and also target at equipment faults (FLT) arisen 
from the OTN transponders and WSSs. Note that each LOS 
message only arises from the corresponding OTN transponder 
equipped in the egress node of the related path because OCS 
provides transparent lightpaths which do not go through any 
OTN transponders at transit nodes. When a hardware failure 
occurs on the OCS D-plane of OPCI network, the related 
equipment (i.e. the OTN transponders and/or the WSSs) 
automatically notifies the failure to the optical device controller. 
The optical device controller updates its historical log file of 
failures. The log file records failures’ information such as 
date/time, equipment where the failure’s message arises, alarm 
type (i.e. LOS or FLT). Other attributes are not expressed in the 
scope of this paper. In the path controllers on the C-plane, we 
implement a function to regularly monitor and collect hardware 
failures’ information from the log files in the optical device 
controllers; we can set the time interval to regularly collect the 
information, T, which is set to 10 seconds in this work. (Note 
that, if we set T to a much shorter value (e.g. 1 second), the 
hardware failures’ information can be instantly delivered from 
the optical equipment to the management client.) If there is 
some updated failures’ information, firstly each path controller 
transforms failures’ information collected from the optical 
device controller to a message format suited for management, 
which is compliant with the standard message format in SNMP. 
We use SNMP-TRAP version 2c [14], and notify failures’ 
information to the M-plane. Then, the path controller requests 
the ingress node to release the path related to the failure, and 
the ingress node sends a path release message to the egress 
ode node on the path route. After releasing the path, in each node, 
signaling and routing protocols for OCS update their databases 
to recover the status of path usage on the C-plane. The optical 
device controller in Fig. 2 has a function to tune the 
wavelengths transmitted from OTN transponders, but does not 
have a function to turn off the transponders. Hence, a LOS 
message arises from an OTN transponder also when the related

![Block diagram of OPCI ring network node.](image)
optical connection is deleted in a WSS in the case of normal path release; in order to deal with this issue, in advance of sending request of path release to the ingress node, the relevant node checks if the relevant path has been already released or is remaining. Only when the relevant path is remaining, the node notifies the LOS from the C-plane to the M-plane and sends request of the path release to the ingress node. With regard to the case of FLT, the processing on the C-plane is slightly different from the one in the case of LOS. If an OTN transponder breaks down, only the path with the corresponding wavelength going through the transponder needs to be released: If a WSS breaks down, all of the paths going through the WSS need to be released regardless of the wavelengths. Each node has a failure’s flag for each link interface in order not to establish paths related to broken equipment. The flag is set to ‘1’ when FLT arises; it is set to ‘0’ when related equipment is in normal status.

On the other hand, as to OPS, we target at FLT arisen from the optical packet transponder and OPS system. The FLT messages arise from the node in which the equipment has broken down. OCS control messages such as signaling and routing messages are transferred by means of optical packets within the wavelength resources dedicatedly allocated to OPS [3][5]. This means that faults of OPS related equipment cause discarding of OCS control messages, which results in failure of signaling processes. The optical device controller collects the OPS related equipment’s status by manual operation (clicking a button on a window by a GUI) and writes the status on a log file. Since we cannot wreck optical equipment, the device controller generates a pseudo FLT message in this work.

node sends a path release message to the egress node on the route of the path.

Fig. 3 Schematic view of architecture of D-/C-/M-planes.

Fig. 4 Hierarchical management model and visualization model.
On the M-plane, once the management server receives the failures’ information, the server updates the database of hardware failures and inform the management client of the update. The management client visually displays the management information registered in the server at all times. Once the management client receives the update, the client visualizes it on a management window by a GUI.

### IV. DETAILS OF THE M-PLANE

Figure 4 shows the management and visualization model on the M-plane. The M-plane consists of the management server and the management client. As illustrated in the upper side of Fig. 4, we construct a hierarchical management model in which there are four layers: device layer, optical layer, OPS layer, and OCS layer. This model is constructed as a RDB in view of the correlative relationship among the elements constituting the OPCI network. In the visualization model, the network administrator can visually manage nodes’ equipment including the path controller’s IP address, connected links, wavelengths, paths, optical packet traffic and resource (route), and failures. We set the time interval to collect the information to 60 seconds in order to avoid overflow of received information.

Figure 5 (a) and (b) show images of management of OCS and OPS related information. The network elements in the hierarchical management model include (E1) optical equipment such as transponders and switches, (E2) physical links, (E3) wavelengths, (E4) OPS resources (i.e. routes and wavelengths for OPS), (E5) lightpaths established on the D-plane, (E6) Generic Routing Encapsulation (GRE) links, and (E7) paths established on the C-plane. In this work, we assume that every physical link has only one GRE link for OCS. However, since one physical link may consist of multiple GRE links which have the same set of logical wavelengths, we include (E6) as an OCS related element.

As for OCS, (E1), (E3), (E6), and (E7) are associated with each other. Currently, we cannot directly obtain the D-plane’s lightpath information, but it is directly associated with the C-plane’s paths. Hence, by associating (E5) with (E7), we manage D-plane’s lightpaths indirectly. Since we assume every physical link has only one GRE link, (E6) is regarded as the link for OCS. Thus, for OCS, (E2) does not need to be managed and associated with other network elements. In “Node Information”, we can obtain the MAC address, and logical and physical IP addresses of the path controller of the node. In “Port Information”, we can get the interface index number and interface speed per wavelength of each physical port. In “Link Information”, we can obtain the nodes, logical IP addresses and interface IDs of the both ends of the GRE link. In “Path Information”, we can get the path index, source and destination nodes, path route, direction, bandwidth per wavelength, and in-use wavelength of the path.

On the other hand, as for OPS, (E1), (E2), (E3), and (E4) are associated with each other. Though the current management server cannot directly obtain the physical links’ information, the routes for OPS need to be associated with the...
Contrary to OCS, the OPS layer does not have GRE links in our OPCI network. Thus, in this work, we manually register the physical links in the database of management system. In “Node Information”, we obtain the version information of OPS system and IP address of OPS system. In “Port information”, we get the interface index number and interface speed of the physical port. In “OPS resource”, we obtain the route, wavelengths and bit-rate for OPS. In “Physical Link Information”, we obtain the nodes, port names and interface index numbers of the ends of the physical link.

V. VERIFICATION EXPERIMENT

We use an experimental setup which has the same structure as that illustrated in Fig. 3. On the C-plane, we assign IP addresses 10.1.1.1, 10.1.1.2, 20.1.1.3 and 20.1.1.6 to the path controllers of ingress, transit for Node-1, transit for Node-2 and egress, respectively. Note that their addresses are logical ones on the logical network consisting of GRE links. The path controllers are assigned physical IP addresses within the same subnet 192.168.60.0/24 to communicate with each other. We verify the processing of D/C/M-planes in the case that a LOS or a FLT of WSS-DROP occurs in OPCI Node-2.

Figure 6 shows the experimental result shown on the management window in the case of LOS. “pc-1-ospf” and “pc-6-ospf” correspond to the ingress and egress nodes in Fig. 3, respectively. Firstly, in OPCI Node-1, we disconnect the

![Fig. 6 Result of verification experiment in the case of LOS.](image)

Figure 7 shows the experimental result shown on the management window in the case of FLT. “pc-1-ospf” and “pc-6-ospf” correspond to the ingress and egress nodes in Fig. 3, respectively. Firstly, in OPCI Node-1, we disconnect the

![Fig. 7 Result of verification experiment in the case of FLT.](image)
We cannot wreck optical equipment, we generate the pseudo DROP in OPCI Node-2. As we explained earlier, since we evaluate the estimated times empirically required for three kinds of processes: The first process is detecting a hardware failure, the second one is specifying the cause of failure, and the third one is specifying resources affected by the failure. We assume that the system manages 10 OPCI nodes. In the first process, in the Non-MP, it takes 10 minutes for a user to detect the abnormal status of data communications, and 10 minutes for the administrator to receive the report of abnormal status from the user and notify the incident. The MP requires 1 minute to notify a hardware failure from the C-plane to the M-plane and detect the icon of failure displayed on the management window, and also requires 1 minute to perceive the brief summary of failure and confirm the detail of failure. In the second process, in the Non-MP, it takes 5 minutes for the network administrator to presume affected equipment by checking the status of links/wavelengths on the C-plane or OPS system, and 20 minutes to presume and specify the resources affected by the failure by logging on the path controllers one-by-one. The MP can visually check the information of affected equipment on the management window and specify the cause of failure within 5 minutes. In the third process, in the Non-MP, it takes 10 minutes for the network administrator to look into the status of routes and wavelengths of optical paths and/or optical packets on the C-plane or OPS system, and 20 minutes to presume and specify the resources affected by the failure by logging on the equipment one-by-one. The MP requires 1 minute to confirm the detail of failure, 1 minutes to specify the optical paths associated with the affected wavelengths by checking the paths’ window, and 1 minutes to specify the OPS resources associated with the affected links by checking the optical packets’ window. In this way, the MP can reduce the required time to around one-eighth in comparison to the Non-MP, and therefore, the network administrator can enhance availability of the OPCI network by installing the M-plane.

Table I Evaluation results of required time.

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<tr>
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<th>Non-MP [5]</th>
<th>MP</th>
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<tbody>
<tr>
<td>Detecting a hardware failure</td>
<td>20 minutes</td>
<td>2 minutes</td>
</tr>
<tr>
<td>Specifying the cause of failure</td>
<td>30 minutes</td>
<td>5 minutes</td>
</tr>
<tr>
<td>Specifying resources affected by the failure</td>
<td>30 minutes</td>
<td>3 minutes</td>
</tr>
<tr>
<td>Total</td>
<td>80 minutes</td>
<td>10 minutes</td>
</tr>
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</table>

VI. CONCLUSION

We have developed and installed RDB-based management functions against hardware failures arisen on the D-plane of OPCI network. With the M-plane, the time required for detecting a hardware failure and specifying resources affected by the failure can be reduced to around one-eighth, and thus, the network administrator can work on recovery operations faster and earlier and enhance availability of the network in comparison to the previous OPCI network without M-plane.

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REFERENCES


