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.

I. 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.

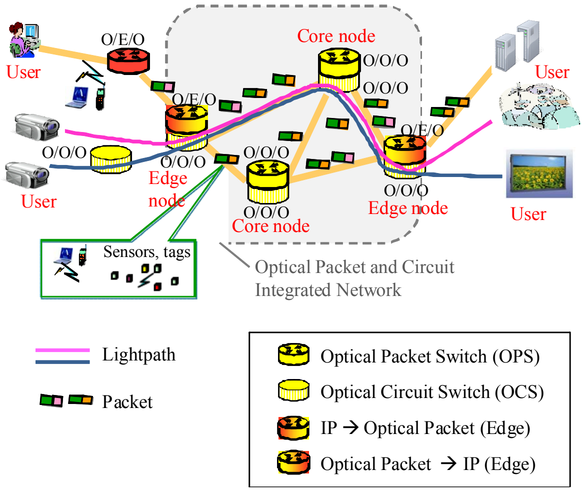


Fig. 1 Concept of OPCI network.

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 equipts a 4 x 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 optical 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 interlocked 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.

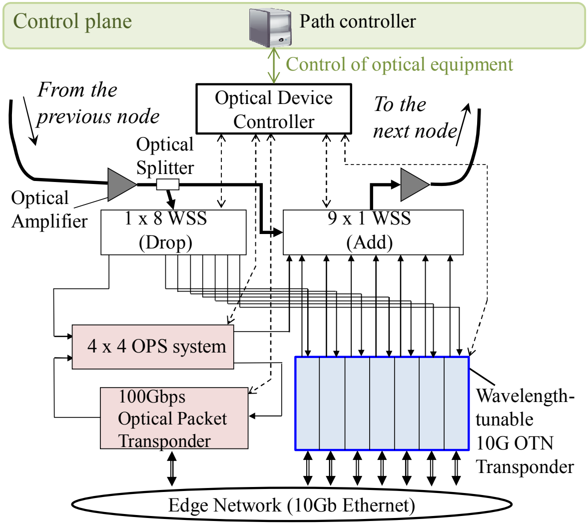


Fig. 2 Block diagram of OPCI ring network node.

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 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

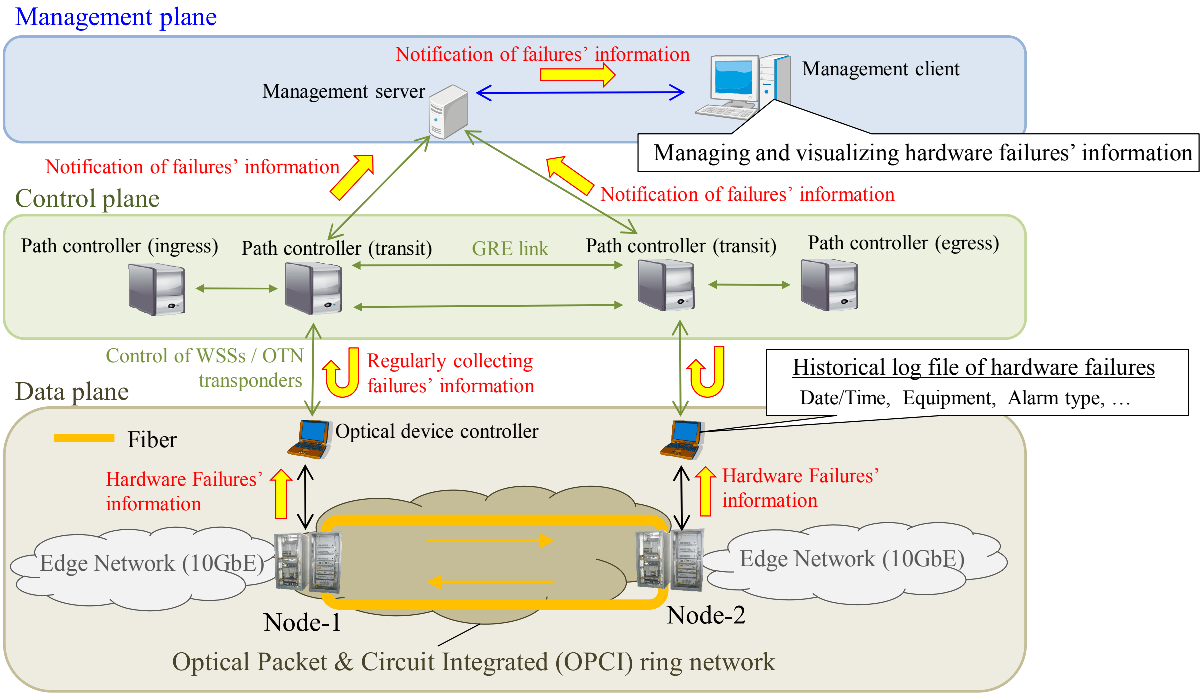
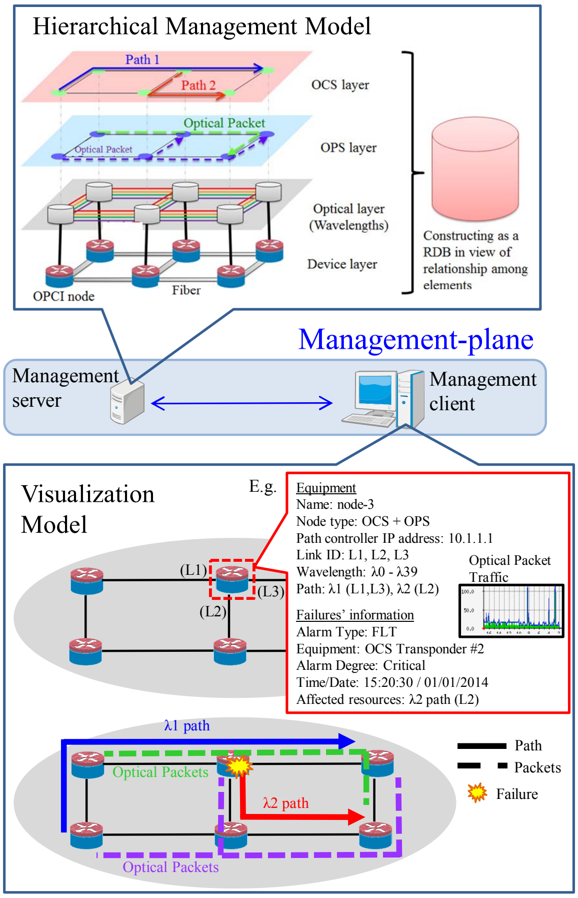


Fig. 3 Schematic view of architecture of D-/C-/M-planes.

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. Since we cannot wreck optical equipment, the device controller generates a pseudo *FLT* message in this work

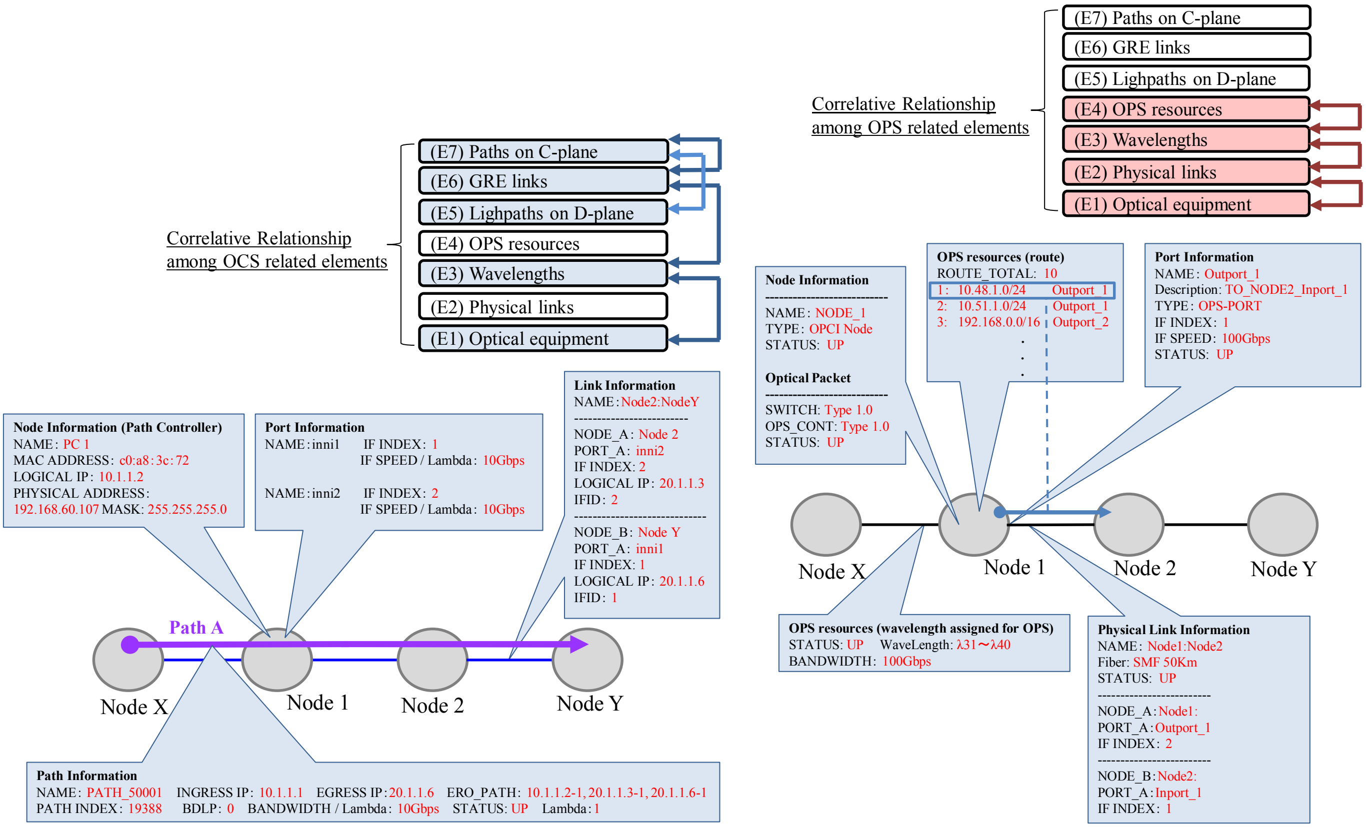
On the other hand, as to OPS, we target at *FLT* arisen from the optical packet transponder and OPS system. The *FLT* messages arise from the node in which the equipment has broken down. OCS control messages such as signaling and routing messages are transferred by means of optical packets within the 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, we generate a pseudo *FLT* message on the C-plane and it is automatically notified to the M-plane by means of SNMP-TRAP version 2c. Then, the node where the failure occurs sends request of releasing the relevant path to the ingress node, and the ingress node sends a path release message to the egress node on the route of the path.



Equipment
Name: node-3
Node type: OCS + OPS
Path controller IP address: 10.1.1.1
Link ID: L1, L2, L3
Wavelength: λ0 - λ39
Path: λ1 (L1,L3), λ2 (L2)

Failures' information
Alarm Type: FLT
Equipment: OCS Transponder #2
Alarm Degree: Critical
Time/Date: 15:20:30 / 01/01/2014
Affected resources: λ2 path (L2)

Fig. 4 Hierarchical management model and visualization model.



(a) OCS

(b) OPS

Fig. 5 An image of management of OCS and OPS related information.

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 related information and OPS related one. 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

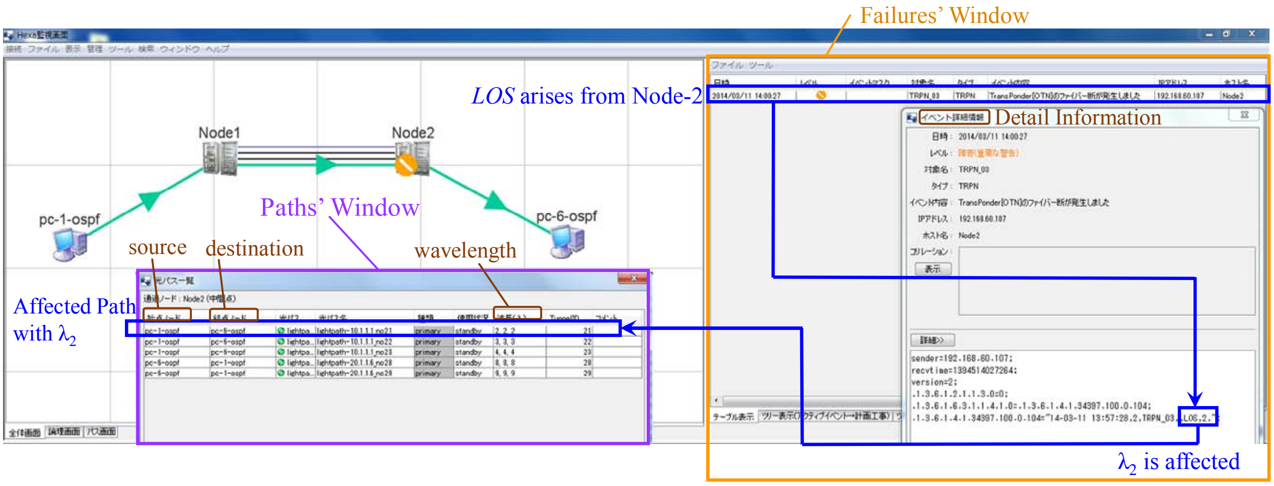


Fig. 6 Result of verification experiment in the case of *LOS*.

links. 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

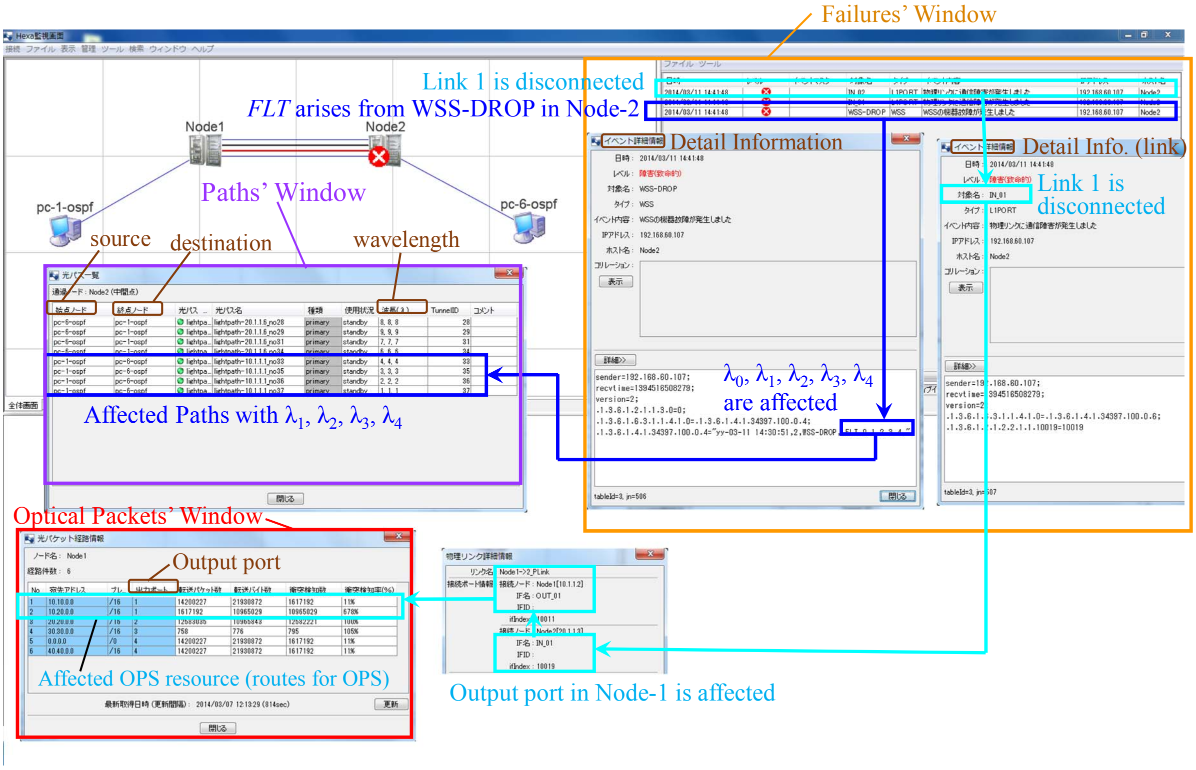


Fig. 7 Result of verification experiment in the case of *FLT*.

optical fiber directly connected to the OTN transponder port-3 (associated with λ_2) only at the sending interface. When it is disconnected, the *LOS* message arises from Node-2 because the optical signals sent from Node-1 cannot reach Node-2. The icon of orange circle is automatically visualized on the Node-2. The management client automatically visualizes the textual information including the date/time, the equipment where the failure occurs and the alarm type on the failures' window. We can see that the resource (i.e. λ_2) affected by the *LOS* is clearly specified on the failures' window; we also specify the path affected by the *LOS* by checking the paths' window. These are due to the fact that the elements "optical equipment", "wavelegnths" and "C-plane's paths" are associated with each other in the correlative relationship in the RDB. In this case, the path with λ_2 of which the source and destination nodes are pc-1-ospf and pc-6-ospf, respectively, is affected by the *LOS*. Note that, in Fig. 6, the wavelength is displayed as "2, 2, 2". This is because the M-plane manages the in-use wavelength in each link on each path. The failures' information and affected resources are recorded in the failures' log file and can be displayed on the window at any time. On the C-plane, the path controller sends request of release of the related path (λ_2 path in the downstream direction) to the ingress node. We confirmed that the path controller successfully released the path.

Figure 7 shows the experimental result shown on the management window in the case of *FLT* arisen from the WSS-DROP in OPCI Node-2. As we explained earlier, since we cannot wreck optical equipment, we generate the pseudo *FLT* message on the C-plane. In this experiment, we use λ_0, λ_1, λ_2, λ_3 and λ_4 for paths in the downstream direction (from pc-1-ospf to pc-6-ospf), and λ_5, λ_6, λ_7, λ_8 and λ_9 for paths in the upstream direction (from pc-6-ospf to pc-1-ospf). Note that *FLT* arisen from WSS-DROP in Node-2 affects the paths in the downstream direction. We can see that the resources (i.e. λ_0, λ_1, λ_2, λ_3 and λ_4) affected by the *FLT* are clearly specified on the failures' window; we specify the path affected by the *FLT* by checking the paths' window as in the case of *LOS*. In this case, the paths with λ_1, λ_2, λ_3 and λ_4 are affected by the *FLT*. The failures' information and affected resources are recorded in the failures' log file in the management client and can be displayed on the window at any time. On the C-plane, the path controller sends request of release of the related paths (paths with λ_1, λ_2, λ_3 and λ_4 in the downstream direction) to the ingress node. We confirmed that the path controller successfully released the path. Meanwhile, when the *FLT* arises from WSS-DROP in Node-2, the management system also displays the link affected by the *FLT*. In Fig. 7, since we can see that the link directly connected to the output port in Node-1 is affected, we can specify the OPS resource (i.e. route for OPS) affected by the *FLT*. These are due to the fact that the elements "optical equipment", "physical links" and "OPS resources" are associated with each other in the correlative relationship in the RDB. In this way, we can simultaneously specify both OCS and OPS resources affected by hardware failures.

We evaluate the time required to detect a hardware failure and specify resources affected by the failure. Table I shows the evaluation results of the OPCI network without the M-plane (*Non-MP*) [5] and the one with the M-plane (*MP*). 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 by use of CLI, and 25 minutes to specify the cause of failure by looking into the status of various elements with 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.

	Non-MP [5]	*MP*
Detecting a hardware failure	20 minutes	2 minutes
Specifying the cause of failure	30 minutes	5 minutes
Specifying resources affected by the failure	30 minutes	3 minutes
Total	80 minutes	10 minutes

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.

ACKNOWLEDGMENT

The authors would like to thank Mr. Tsunemasa Hayashi for his contributions in the early stage of this work, and Mr. Wei Ping Ren, Mr. Takahisa Uemura and Mr. Ryo Mikami for their technical supports on this work.

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