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A Study of Equipment Protection for High Availability of Control and Data Planes in Photonic Cross-Connect

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Abstract A photonic cross-connect with 1+1 redundant supervisory cards and optical switches to minimize any system outage has been developed. We show the resulting improved protection time as evaluated on a live prototype.

1. Introduction

In order to help meet the network needs arising from the continuous growth of Internet traffic, photonic cross-connects (PXCs) are under widespread investigation [1-3], as a PXC is able to provide bit-rate free and format-free switching. The switch structure and its control system are much simpler than those of a digital cross-connect due to its complete lack of O/E/O conversions. However, an optical switch failure would cause all the transmission channels through it to fail. Therefore, the reliability of the optical switches is an important factor in the stable operation of carrier-grade networks.

In this paper, we report a PXC prototype with 1+1 redundant supervisory cards and optical switches for high availability network operation. The protection was carried out without any disconnection of live traffic. The protection time of the 1+1 protected optical switches was 9.5 ms when seven paths were disconnected simultaneously due to a simulated optical switch failure. The resulting improved system outage is also discussed.

2. 1+1 Redundant Supervisory Systems

An uninterrupted supervisory system is mandatory for PXC based optical networking, to minimize the recovery time if a system failure occurs. Any failure in a supervisory card should be recovered rapidly via some form of redundant architecture. Moreover, any failure in a supervisory card and any failures in its related elements, e.g. the control bus, control lines, and the connections between the control and management planes, should not affect live traffic. Fig. 1 shows the architecture of the PXC's 1+1 redundant supervisory system. Not only the supervisory cards, but also the control buses for the optical interface (I/F) cards and the control lines for the optical switches, have a 1+1 architecture. The connection between the control and management planes also has 1+1 redundancy.

(1) 1+1 redundant supervisory cards

The working supervisory card passes a range of signalling information and data to the standby card, e.g. the used and unused ports, optical powers and power loss thresholds at each input/output port of the optical switch, in addition to a range of alarms, via a high availability (HA) link. The HA link also has 1+1 redundancy. If the working card fails, the standby card is promptly activated. The conditions in the data plane are preserved and no live traffic is disconnected.

(2) 1+1 redundant control buses for optical I/F cards

The 1+1 redundant control buses are used to supervise the optical I/F cards, one being the working bus and the other being the standby. Each optical I/F card is informed which is the working bus via two specific signal lines connected to the supervisory cards. The standby supervisory card receives information from the optical I/F cards, but sends nothing unless the working bus has failed.

(3) 1+1 redundant control lines for optical switches

The 1+1 redundant optical switches are controlled by cross-connected 100BASE-T cables. If a failure occurs in the working control line, the supervisory card immediately checks whether the standby line can connect correctly prior to activating the standby control line, in order to avoid any unwanted session conflict.

(4) 1+1 redundant connections to control & management planes

The connection between the control and management planes also has 1+1 redundancy. When the standby supervisory card is activated, it starts to use the same IP address as the working card in order to conceal the protection action from the control and management planes.

We evaluated the protection using a live prototype PXC. We intentionally caused failures by generating forced error signals or disconnecting control lines by hand. In each case, the supervisory system was successfully restored without any unwanted conflict. The data planes were also maintained and no live traffic was disrupted.

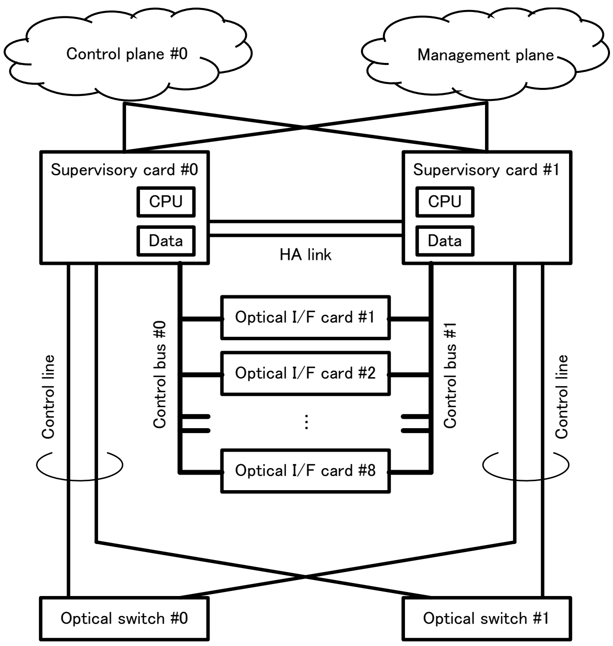

Fig. 1: PXC architecture with multiple 1+1 redundancy.

3. 1+1 Redundant Optical Switches

Fig. 2 illustrates the connections between the optical I/F cards and optical switches with 128x128 input/output ports.

Although Fig. 2 depicts only one input/output port in each optical I/F card for ease of visualization, each optical I/F card in fact has sixteen input/output ports. We concentrate on the traffic flow through optical I/F #i, #j and #k as follows: (1) the input optical signals are split by couplers at the optical I/Fs (#i and #j/#k) and launched into the working and standby optical switches; (2) the duplicate signals are switched and launched into each optical I/F (#j/#k and #i), where the optical 2x1 switch selects one of the redundant signals. Optical power monitors are fitted at both input and output ports in order to distinguish a loss of light from an optical switch failure.

In the case of bi-directional label switched paths (LSPs) through #i and #j or #i and #k, the supervisory card sends a command to the 1+1 optical switches and the optical 2x1 switches to establish the paths, i.e. route A or C as working path and route B or D as protection path. If the working optical switch fails, the optical 2x1 switches in optical I/Fs (#i and #j/#k) are released, and the paths are bridged to route B or D. In the case of 1+1 dedicated protection with LSPs from #i to #j and #k and vice versa, the supervisory card sets up routes A and D.

We evaluated the protection time for an optical switch failure using the live prototype PXC. We intentionally caused seven simultaneous failures in the fiber connections between the optical I/F card and the working optical switch to demonstrate the effect of an optical switch failure. Fig. 3 shows the measured 1+1 protection times for the failure. The maximum protection time was 9.5 ms. The protection time increases progressively by port number. This is because the supervisory card queues the optical 2x1 switches one at a time.

We discuss here the protection time of the architecture developed. If a hardware failure occurs, it could take some time before the supervisory system detects and restores the fault. This may depend, for example, on the frequency with which signals are sent, on the speed of fault detection and system notification in the hardware, and on the time it takes for the system to gather all the fault information from the various signals, correlate it, and then wait to avoid instability. The protection time T_{pro} is given by [4]

$$T_{pro} = \tau_{det} + \tau_{hold} + \tau_{notify} + \tau_{rec\_ope(s/w)} + \tau_{rec\_ope(h/w)}, \quad (1)$$

where τ_{det}, τ_{hold}, τ_{notify}, $\tau_{rec\_ope(s/w)}$, and $\tau_{rec\_ope(h/w)}$ are respectively hardware fault detection time, hardware hold-off time, software fault notification time, and software and hardware recovery times. Here, τ_{det}, τ_{hold}, and τ_{notify} were set to 0.1 ms, 0 ms, and 5 ms at a maximum. $\tau_{rec\_ope(s/w)}$ and $\tau_{rec\_ope(h/w)}$ take 0.4 ms and 4 ms, respectively.

4. Outage Estimation for 1+1 Redundant System

We discuss outage of the 1+1 redundancy architecture. Here we assume the respective failure rates (FITs) of the supervisory card and the optical I/F card to be approximately 200 and 100. These values are estimated from the service records of similar field proven cards. The optical switches' FIT rate is an intentional worst estimate of 20,000. The mean times to repair (MTTRs) are estimated at about 4 hours for optical switch replacements and less than 1 sec for supervisory card protection. The data plane outages with and without redundancy are calculated to be 13 sec and 42 min per year. The control plane outages with and without redundancy are calculated to be respectively 1.8 ms and 25 sec per year. The 1+1 redundancy enables highly reliable operation for carrier-grade networks.

5. Conclusion

We have developed a 1+1 protection based redundancy system for a photonic cross-connect for high availability network operation. The protection of the redundant supervisory cards was carried out without any disturbance to live traffic, and the protection time of the 1+1 protected optical switches was 9.5 ms when seven paths were disconnected simultaneously due to a working optical switch failure.

References

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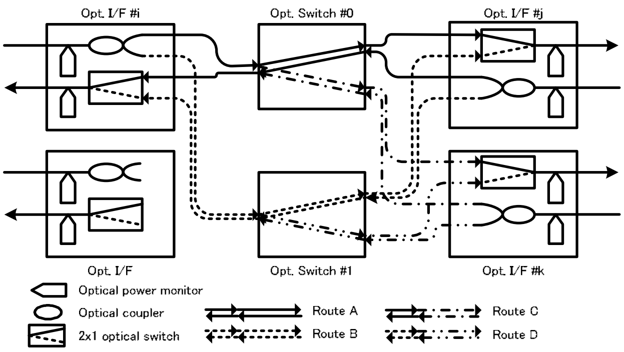

Fig. 2: Optical I/F card and optical switch connections.

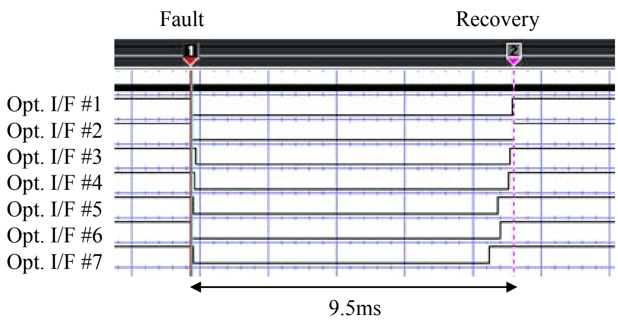

Fig. 3: Time to protect seven optical paths by 1+1 redundant optical switches.