The Multiple Path Protection of DWDM Backbone Optical Networks*

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Primary transmission protection technology is based on the characteristics of SONET/SDH protection mechanism which provides two fiber path rings. A serious problem may arise in the architecture when two fiber links are simultaneously broken. Mesh protection networks can support many protection paths to address above issue, but the key components of optical cross-connect (OXC) or photonic cross-connect (PXC) are expensive for network providers. Therefore, this study proposes a novel protection mechanism with a low-cost equipment of optical protection switching (OPS) for building a multiple path protection architecture on DWDM backbone network. The proposed mechanism is named the double 8-type OPS back to back protection mechanism. It can support eight protection paths to improve the issues of the low-path 1 + 1 dedicated ring and expensive mesh protection networks. This experiment demonstrates the automatic protection switching (APS) simulation tool, and the proposed mechanism could satisfy all demands of protection standard (*e.g.*, the protection switching within 50 ms).

Keyword: OPS, DWDM, multiple-path protection, SONET/SDH, ring network

1. INTRODUCTION

The transmission bandwidth of telecom networks has growing dramatically in recent years. With this growing bandwidth, and the growing number of subscribers, the network restore forces are also growing and become more important. The large bandwidth of optical fibers has made the fibers attractive for high-speed networks, and the use of dense wavelength division multiplexing (DWDM) allows the aggregation of channels onto a single fiber without the need of high-speed optoelectronic devices for end-users [1-4]. It is the simplicity of this multiplexing scheme that permits relatively easy access to the fiber's bandwidth, which is the underlying reason for DWDM playing a major role in the expansion of optical networks. However, the existence of many independent data channels over the fiber infrastructure could lead to problems of failure, as the amount of bandwidth lost by a component or cable failure is now much larger than what would have been lost in a traditional network. This is why extra effort must be spent in analyzing optical DWDM networks and in finding ways to protect them against failures [5-8].

Currently the DWDM backbone network protection still adopts the traditional 1 + 1 dedicated path protection, which builds two fiber rings to increase the network survivability, *i.e.*, working path and protection path [9-11]. The O-BLSR (MS-SPRING) or O-UPSR (SNCP) of SONET/SDH protection can support two path fiber routing trans-

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missions to avoid an optical fiber from breaking off, however, sometimes two fiber paths would break simultaneously in a network. The restoration and repair time of cut fibers is lengthy. Although many researches of mesh protection [12, 13] have addressed the above issue, the switch equipments (*e.g.*, optical cross-connect (OXC), and photonic cross-connect (PXC)) are expensive for network providers.

Therefore, how to design a multiple-paths protection architecture with a low-cost equipment to improve the 1 + 1 protection architecture of a DWDM backbone network is a very important issue. In this paper, a low-cost and rapid multiple-path protection DWDM backbone network is proposed and implemented. The OPS operation model for the proposed protection structure is presented in section 2. The DWDM general protection type is described in section 3. Section 4 presents a multiple-path protection mechanism. Section 5 describes the simulations, testing results and further discusses the proposed architecture. Finally, a few concluding remarks are given in section 6.

2. THE OPS OPERATION MODEL

In this proposed protection architecture, each node is installed an optical protection switching (OPS) for building the protection policy. The structure of OPS mainly divides two parts: transmitter side and receiver side. The description of them is as follows:

- **Transmitter-side**

The transmitter-side structure of the OPS is shown in Fig. 1. When an optical signal comes from the upstream nodes, a small portion of incoming optical power (INcom) is separated into the photo diode (PD). The small portion of optical power is converted to be an electronic signal for detecting the incoming optical power value. The INcom signal and optical supervisory channel (OSC) signal are combined into the fiber with a coupler to connect the working path (OUTw) and protection path (OUTp).

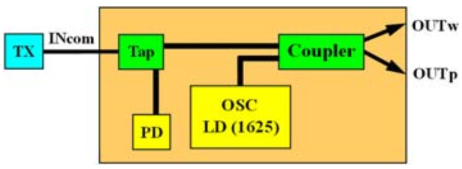


Fig. 1. The transmitter-side structure of OPS.

TS0	TS1	TS2	TS3	…………	TS14	TS15	TS16	…………	TS31

TS0: FAS (Frame alignment signal) TS1: E1 (Order wire channel)
TS2: F1 (User define channel) TS3 ~ TS14: D1 ~ D12 (DCC Channel)
TS15: E2 (Order wire channel) TS16 ~ TS31: Reserve channels

Fig. 2. The frame format of OSC.

To support the protection policy, a frame format of OSC is shown in Fig. 2. The FAS field is confirmed for the signal synchronization. The TS1 and TS15 fields are used for voice communication channels. The F1 field is a free channel for users. D1 ~ D12 fields represent the data communication channels. Finally, the TS16 ~ TS31 fields are the reserved channels.

• **Receiver-side**

The receiver-side structure of the OPS is shown in Fig. 3. The incoming optical power signal (INw) can be detected by the OSC in real-time. When its optical power is lower than the initial threshold, the optical switch port is switched to the protection path (INp) to guarantee the network reliability. It is worth noting that the detection time of the lower optical power signal (INw) must be sustained for 50 ms according to the protection standards, to void an error decision in switching.

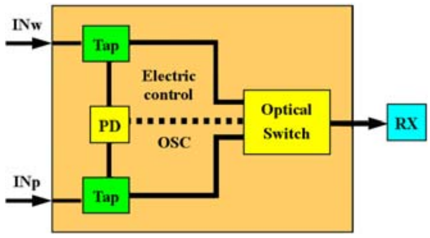


Fig. 3. The receiver-side structure of OPS.

Here, there are three different kinds of operation modes in OPS that can be selected for the network management. These operation modes are described as follows:

- AUTO: this model is an auto reserve type. When the signal loss of INw is large, the unusual time is more than 50 ms, and the optical switch is able to switch the INp port. When the working fiber has been reconstructed, the optical switch will return to connect the INw port.
- SEMI-AUTO: this model is a semi-automatic switch type. This model can automatically switch to INp port when the working path is cut, however, the optical switch cannot return to connect the INw port, even if the working fiber has been repaired.
- MANUAL: this model is a manual operation type. When the working path is cut or repaired, the network management must operate the optical switch port to select received the incoming optical signal of INp or INw via SNMP management.

The operation configuration of OPS is shown in Fig. 4. The significance of input/output symbols and the system parameters range of OPS are listed in Tables 1 and 2. The insertion loss of OPS only consumes about 1.2 dB by power meter.

3. DWDM GENERAL PROTECTION TYPE

When the loss of incoming optical power (INw port) of OPS or the optical signal power is seriously degraded for some important channels, these irregular phenomena can be detected by the OSC channel. Once a fault is detected the optical switch switches

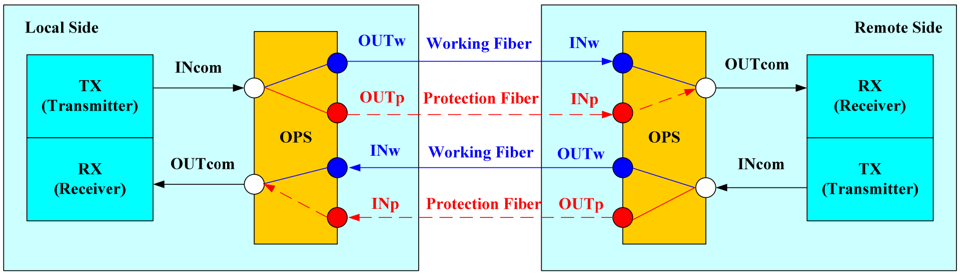


Fig. 4. The OPS operation configuration.

Table 1. The significance of input/output symbols of OPS.

Symbol	Significance
OUTcom	Local optical receiver plug
INcom	Local optical transmission plus
INw	Receiver remote optical transmission (working path) plug
INp	Receiver remote optical transmission (protection path) plug
OUTw	Transmission to remote receiver (working path) plug
OUTp	Transmission to remote receiver (protection path) plug

Table 2. The system parameter ranges of OPS.

	Item	Min	Typical	Max
Transmitter-side	Operating wavelength (nm)	1310 ± 20 & 1550 ± 20		
	Input power range (dBm)	– 15		3
	OSC wavelength (nm)	1595	1625	1655
Receiver-side	Operating wavelength (nm)	1310 ± 20 & 1550 ± 20		
	Input power range (dBm)	– 35		1
	Switch level (dBm) Setting range (Res = 1)	– 29		– 5
	Restoration time (ms)			50

form the INw port to the INp port for executing network protection. In addition, to ensure the OPS has a correct protection mechanism, there are many important system parameters requirements necessary to conform. They are listed as follows:

- Switch over time within 50 ms to minimize the impact to the service.
- Both the working path and protection path are supervised by the OSC channel in real-time.
- DWDM side (MUX/DMUX): the received power is set at power ranges (0 ~ – 18 dB).
- Client side: the received power of optical transponder unit (OTN) is set at power ranges (– 3 ~ – 18 dB).
- OPS switching level: the value is set according to the OUT and client equipment sensitivity.

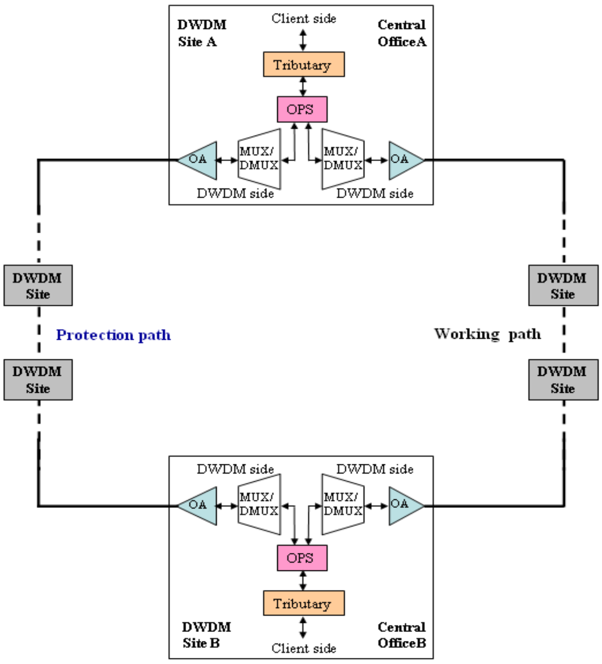


Fig. 5. When the working path fiber is cut, the DWDM site-A and DWDM site-B of OPS are switched to the protection path. (Channel Protection)

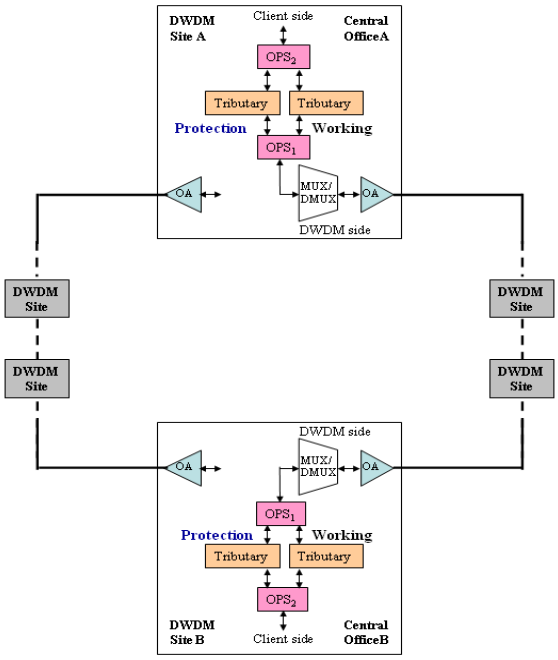


Fig. 6. When the working tributary card has a failure, OPS_1 and OPS_2 are switched to the protection tributary card. (Client Protection)

There are four different kinds of protection mechanisms that can be selected in this protection architecture, such as channel protection, client protection, channel/client protection, and fiber protection. These protection mechanisms are described as follows:

- **Channel Protection Mechanism**

In this mechanism, the DWDM side has two MAX/ DMAX, as shown in Fig. 5. When the working path fiber is cut, the DWDM site-A and DWDM site-B OPS are switched to the protection path for achieving a good communication quality for traffic load.

- **Client Protection Mechanism**

In this client protection mechanism (see Fig. 6), the DWDM site has one path, one MUX/DMUX, and are two tributary cards. When the working tributary card fails, the OPS_1 and OPS_2 are simultaneously switched to the protection tributary card to ensure communication reliability.

- **Channel/Client Protection Mechanism**

In the channel/client protection, both the DWDM side and tributary side have working and protection cards to execute the protection mechanism as shown in Fig. 7. This protection mechanism has two protection methods. In the channel protection mechanism, the DWDM site-A of OPS and DWDM site-B of OPS are simultaneously switched to the protection path when the working path fiber is cut. In the client protection mechanism,

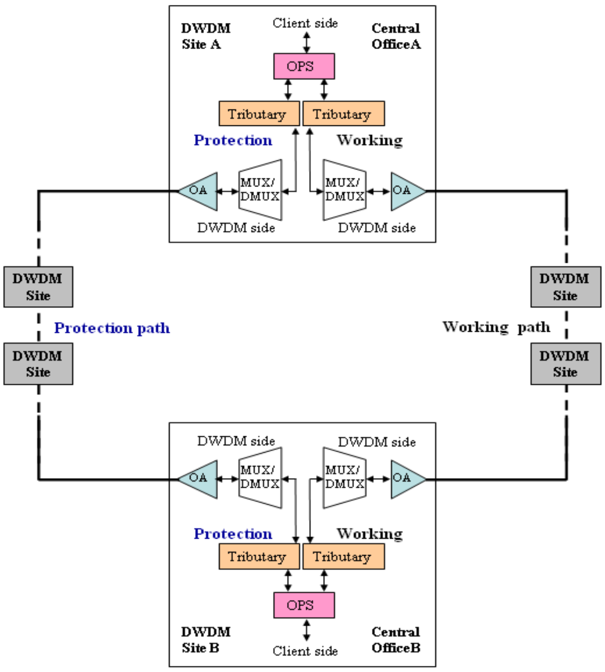


Fig. 7. When the working path fiber is cut or working tributary card has a failure, OPS switches to the protection path and the protection tributary card. (Channel/client protection)

the DWDM site-A of OPS and DWDM site-B of OPS can be switched to the protection tributary card to avoid the traffic load being broken.

- **Fiber Protection Mechanism**

In the fiber protection mechanism, if the working fiber is cut, the traffic can be automatically switched to the protection fiber. This protection mechanism is able to protect all channels to guarantee the communication quality. Here, the characteristic of protection fiber in length and power budget is similar the working fiber [14] to avoid error detection of all OPS. Naturally, the influence of the insertion loss in OPS is also considered. The illustration of protection mechanism is show in Fig. 8.

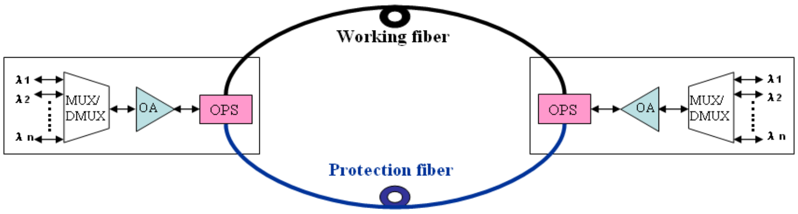


Fig. 8. When the working fiber is cut, the traffic can be switched to the protection fiber automatically. (Fiber protection)

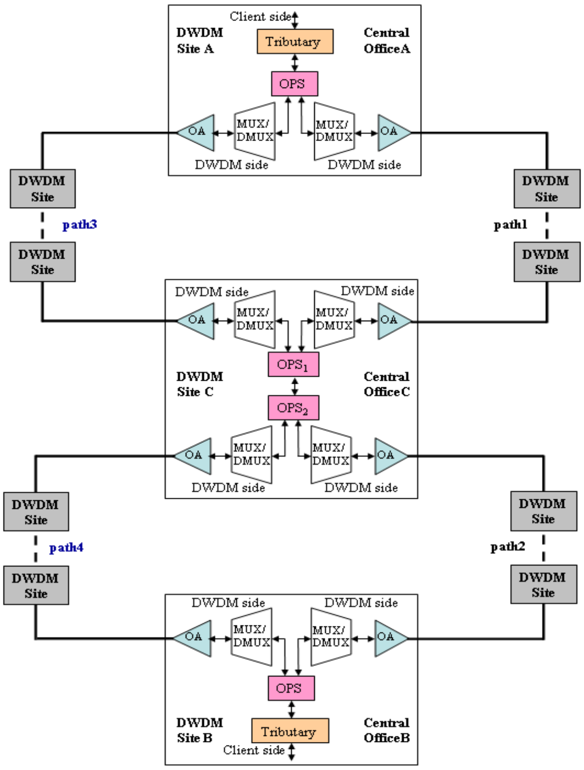


Fig. 9. 8-type OPS back to back connection protection.

4. MULTIPLE-PATH PROTECTION

In the general protection mechanism, there are two fiber paths or two tributary cards for protection of the working fiber or the working tributary card. However, this protection only provides two paths protection. Therefore, in order to increase the protection paths, the above protection mechanism could be extended to a multiple-path protection mechanism. This multiple-path protection mechanism has two different kinds of protection architectures, the descriptions of protection action are as follows:

- **8-Type OPS back to back Protection Mechanism**

An OPS back to back connection protection is accomplished as shown in Fig. 9 to support four routing protection paths as follows:

(1) DWDM side-A → path1 → DWDM side-C → path2 → DWDM side-B.
(2) DWDM side-A → path1 → DWDM side-C → path4 → DWDM side-B.
(3) DWDM side-A → path3 → DWDM side-C → path2 → DWDM side-B.
(4) DWDM side-A → path3 → DWDM side-C → path4 → DWDM side-B.

This 8-type back to back OPS connection can provide double protection capacity over the traditional 1 + 1 protection mechanism.

- **Double 8-Type OPS back to back Protection Mechanism**

The double 8-type protection mechanism consists two 8-type OPS back to back protection networks, with parallel connections. The illustration of protection mechanism is show in Fig. 10. It can support eight protection paths, as follow:

(1) DWDM side-A → path1 → DWDM side-C → path2 → DWDM side-B.
(2) DWDM side-A → path1 → DWDM side-C → path4 → DWDM side-B.
(3) DWDM side-A → path3 → DWDM side-C → path2 → DWDM side-B.
(4) DWDM side-A → path3 → DWDM side-C → path4 → DWDM side-B.
(5) DWDM side-A → path5 → DWDM side-C → path6 → DWDM side-B.
(6) DWDM side-A → path5 → DWDM side-C → path8 → DWDM side-B.
(7) DWDM side-A → path7 → DWDM side-C → path6 → DWDM side-B.
(8) DWDM side-A → path7 → DWDM side-C → path8 → DWDM side-B.

This protection mechanism can maintain eight protection paths for DWDM backbone networks to more communication reliability. The flow chart of a double 8-type OPS back to back protection connection action is shown in Fig. 11.

5. SIMULATION AND TESTING RESULTS

To test the proposed protection mechanism, the simulation software named automatic protection switching (APS) in the ACTERNA ANT20 is used. The channel speed is operated at 2.5 Gb/s in the DWDM backbone network.

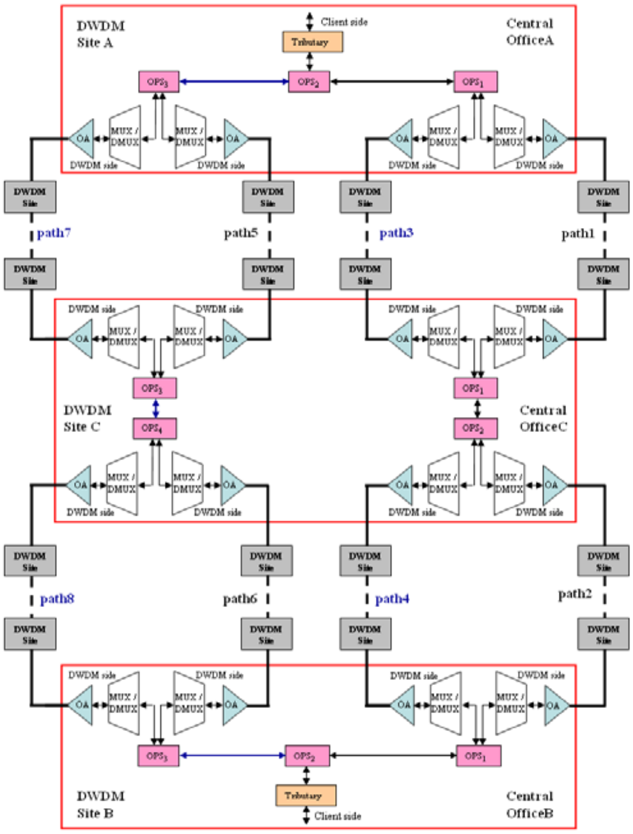


Fig. 10. Double 8-type OPS back to back connection protection.

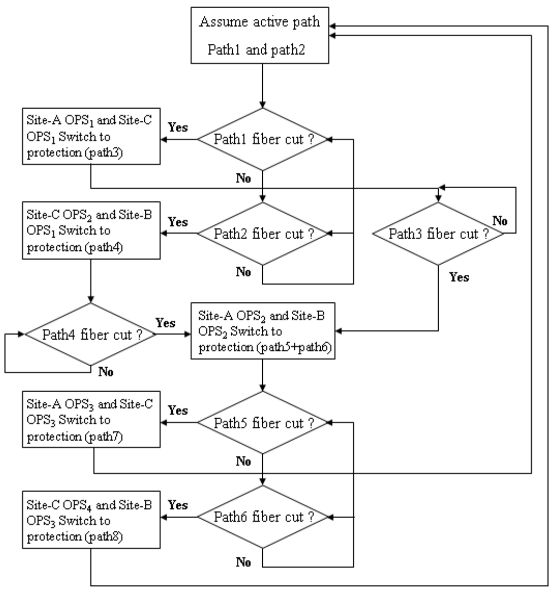
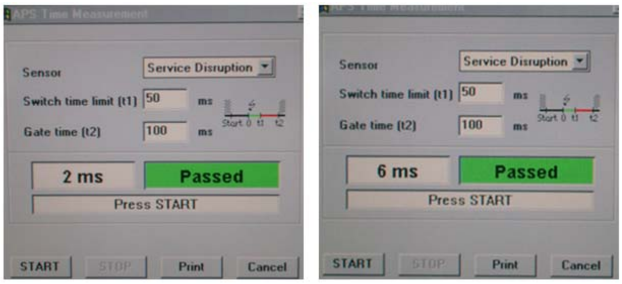
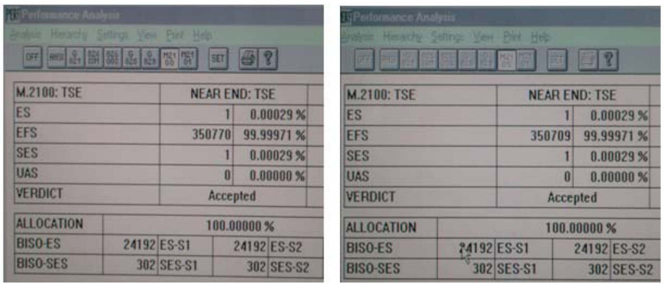


Fig. 11. The flow chart of a double 8-type OPS back to back protection connection.



(a) (b)

Fig. 12. (a) The test result of the switching time with the OPS manual switching; (b) The test result of switching time when the OPS fiber is cut.



(a) (b)

Fig. 13. (a) The ES test result with the OPS manual switching by the APS of ACTERNA ANT20; (b) The test result of ES when the OPS fiber is cut.

- **Manual Switch Testing**

The test uses the manual switching mode to examine the protection capacities of Figs. 5 to 10. Here, the INw port is switched to the INp port by SNMP management. The test results of the switching time, and the error seconds (ES), are shown in Figs. 12 (a) and 13 (a). The simulation results show that the switching time and ES are only about 2 ms and 1 (ES). This represents that this proposed mechanism can provide a rapid and low error protection system.

- **Fiber Cut Switch Testing**

In the test simulation, the OPS is operated as automatic models to understand the influence of fibers being cut, as shown in Figs. 5 to 10. The test results are shown in Figs. 12 (b) and 13 (b). From the figures display the switching time and ES is only 6 ms and 1 ES.

The above discussion makes it clear that double 8-type back to back connection protection mechanism has a more perfect protection capacity than do other protection mechanisms. The feature comparisons of these proposed protection mechanisms are summarized in Table 3. The proposed protection mechanism exhibits excellent protection capacity and low-cost equipment to maintain the communication reliability and quality for widespread users or important customers.

Table 3. Comparison of general DWDM backbone protection and double 8-Type back to back connection protection mechanism.

Protection Type	Path numbers	Tributary numbers
1 + 1 dedicated protection	2	1
Channel protection	2	1
Client protection	1	2
Channel and client protection	2	2
8-type back to back connect	4	1 or 2
Double 8-type back to back connection	8	1 or 2

6. CONCLUSION

Optical communications provide a huge bandwidth capacity on DWDM backbone networks, therefore, if the working fiber is suddenly cut, it is a serious problem for communication quality. Hence, how to enhance the network survivability is still a very important issue in DWDM backbone networks. This paper proposes a double 8-type back to back connection protection mechanism to improve the 1 + 1 dedicated protection mechanism (with only two protection paths) on DWDM backbone networks. The protection architecture requires simplified, rapid, and low-cost equipment with some passive optical components. It can support eight protection paths to more ensure communication reliability and quality. The simulation results also show that, the switching demands of this proposed protection mechanisms can satisfy protection standards, regardless of the system being operated as an automation or manual operation model. This protection mechanism can provide multiple-paths with a low-cost equipment to improve the disadvantages of the low-path 1 + 1 dedicated ring protection and expensive mesh protection mechanisms.

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