Long Reach PON Management and Protection System Based on Optical Coding

Maged Abdullah Esmail and Habib Fathallah, member IEEE, OSA
Electrical Engineering Department
King Saud University
Riyadh, Saudi Arabia
hfathallah@ksu.edu.sa

Abstract—**We propose a fault management and protection system for the ring-and-spur long reach PON. We exploit an adapted, enhanced performance, and inexpensive passive optical components in the field and electronic switches in the central office (CO). Our system allows detecting and localizing not only faulty segments but also faulty nodes, hence alleviating the false alarm probability encountered in previous systems. We show that using ring duplication protection in LR-PON can save half the cost compared to full duplication protection with relatively high reliability (99.9925). We derive an expression for the upper bound notification and recovery times. Moreover, we found that our system can recover from a fault in about 0.5ms as an upper bound.**

Keywords- Long reach PON; fault management; protection; network reliability; optical encoder; recovery time.

I. Introduction

Long-Reach Passive Optical Network (LR-PON) has been proposed as a cost-effective solution for next generation broadband optical access network. LR-PON span extends to 100km and beyond. This supports more customers by exploiting wavelength division multiplexing (WDM) technology. Fig. 1 illustrates the general architecture of the ring-and-spur WDM/TDM LR-PON. The ring section interconnects the optical line terminal (OLT) in the central office (CO) to a number of remote nodes (RNs) by optical fibers. The distribution section runs from the RN to the optical network units (ONUs) through the power splitter/combiner (PSC).

Any fault in the network physical layer, especially the ring, will cause high data loss, customer dissatisfaction and complaints. Hence, an efficient management system for fault detection and then protection is highly required. Most of the conventional survivability approaches of fault management in optical networks rely on diagnosis in higher layers, based on the status reports collected from various checkpoints on the managed optical networks. However, this would impose excessive overhead in the network signaling as well as in the network management system (NMS). It is recommended that fault detection takes place at the layer closest to the fault, which is the physical layer for optical networks [1]. This facilitates the network protection and restoration.

This research was done with the support of The National Plan for Science & Technology (NPST) program by King Saud University, Saudi Arabia, Project Number 09-ELE667-0. The authors acknowledge *Prince Sultan Advanced Technologies Research Institute* (PSATRI), *Saudi Telecommunication Company* (STC) and King Abdul Aziz City for Science and Technology.

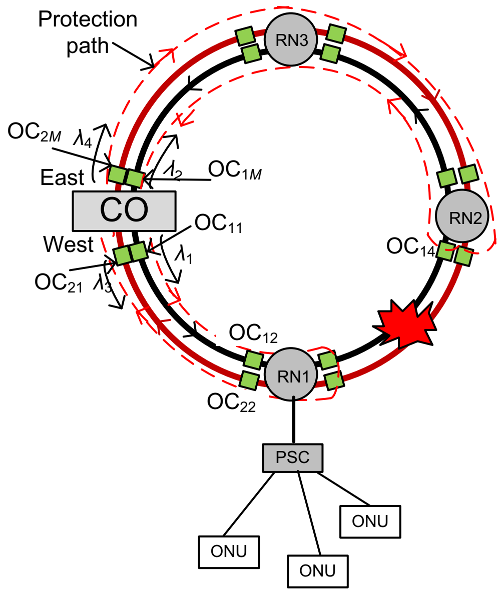

Figure 1. Double ring protection for ring-and-spur LR-PON.

In this paper, we propose a management and protection system that uses passive components in the field. This system can identify and localize any fault in the ring and then notify the CO to initiate the protection process. Instead of using active monitors in the RNs, our system uses passive components for the monitoring. Hence it reduces the capital expenditure (CapEx) and operational expenditure (OpEx). Using passive components in the field to protect the ring failure is reported in [2, 3]. These approaches detect a fault based on monitoring the upstream data wavelengths in the CO. However, this leads to high false alarm probability. For example, a fault in RN_i will cause loss for upstream waveband Λ_i from RN_i. When the CO detects this miss, it will interpret it as a fault in the ring segment between RN_i and RN_{i+1}. This leads to wrong protection and increases the OpEx by dispatching technicians to fix faults in wrong locations. Our NMS overcomes this issue by monitoring also the RNs, not only the ring segments.

II. Network Architecture and Reliability

Any network management and protection system should

take into account two critical factors: level of service reliability and network cost. Fig. 2 shows the reliability model illustrated by reliability block diagrams (RBDs) derived from the WDM/TDM LR-PON shown in Fig. 1. RBD is a graphical representation of the system reliability architecture and is a method of representing the effects of all possible configurations of functioning and failed components in the system. Fig. 2(a) shows the basic network RBD without protection. The RBD includes all the optical components and devices in the signal path from the CO to the ONU. This includes the OLT, ring fiber (RF), arrayed waveguide grating (AWG) in the RNs, distribution fiber (DF) from the RN to the PSC, PSC, drop fiber (DRF) from the PSC to the ONU and the ONU. Each component or device is represented by a box. Access network duplication RBD is similar to Fig. 2(b) but the access part is duplicated and optical switch (OS) is used to select between one of the two access networks. Ring duplication RBD is shown in Fig. 2(b) where two synchronous OSs are used to route the data on one of the two rings. Full duplication RBD is similar to Fig. 2(b) but with OLT and access section duplication (not shown here). We assume that a failure occurs when the connection between the OLT and the ONU is interrupted due to the failure of system components [4]. The system is functioning if there is at least one path that runs from the start to the end. The unavailability of a component x (U_x) corresponds to the probability that the component x is failed which is given as

$$Ux = 1 - \frac{MTBF}{MTBF + MTR} \quad (1)$$

where MTBF is the mean time before failure and MTR is the mean time to repair (MTR). The component x availability is Ax=1-U_x. Hence the full system availability is given as

$$A = 1 - \sum U_i \quad (2)$$

A detailed description of the system components' unavailability and cost obtained from [4] is given in Table 1 where N denotes the number of ONUs in each access network connected to RN. We assume that the ring length is 100km and the distance between any RN and the ONUs at the user premises (the sum of DF and DRF) is 10km. Moreover, we consider there are 32 RNs with 32 ONUs in each TDM access network. The deployment scenario that is considered here is a

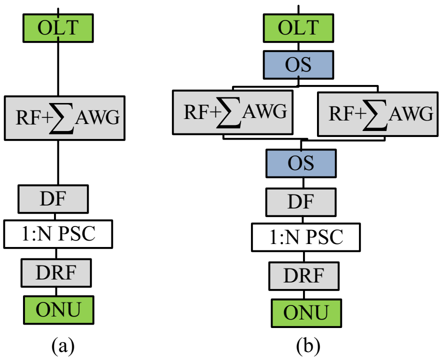

Figure 2. RBD for LR-PON protection architectures.

TABLE 1
COMPONENT UNAVAILABILITY AND COST [4]

COMPONENTS/DEVICES	UNAVAILABILITY	COST($)
OLT(WDM PON) 3.2Gbps	5.12E-07	40,000
ONU (TDM PON)	1.54E-06	350
1:N splitter	7.20E-07	800
Optical switch	1.20E-06	100
AWG	1.20E-6	1200
Fiber (/km)	1.37E-05	160
Burying Fibers (/km)	---	7000

TABLE 2
UNAVAILABILITY AND COST FOR LR-PON PROTECTION ARCHITECTURES

PROTECTION TYPE	UNAVAILABILITY	TOTAL COST ($)	COST/ONU ($)
No protection	7.93E-04	9,465,120	9,243
Access protection	7.24E-04	18,100,640	17,676
Double ring protection	7.42E-05	10,261,220	10,021
Full protection	2.92E-06	18,933,640	18,490

dense populated area (collective). In this scenario DF and DRF are 19.5 and 0.5km long respectively. Our results for the different architectures are shown in Table 2. It is shown that the total network cost of no-duplication is about 9.25$ millions with 99.9206% reliability. The access-region duplication cost is close to the full-duplication cost (≈18$ millions), but the reliability is just 99.9276% compared to 99.9997% for the full duplication. However the metro-ring duplication has relatively high availability, 99.9925%, and the cost is slightly higher than of the no-duplication architecture (10.3$ millions). Hence, it is clear that half the cost can be saved with high reliability if only ring duplication protection is used.

Ring duplication protection is shown in Fig. 1. Two rings are used, inner ring (primary) and outer ring (protection). In normal mode, the OLT transmits data on the inner ring (west) and nothing is transmitted in the outer ring (east). The 3dB coupler in the RN shown in Fig. 3 divides the upstream signals from the access network to both rings. In the inner ring, the multiplexed upstream signals will continue propagation toward the CO (east). In the outer ring, the multiplexed upstream signals take west direction. At the CO, the received signals in the inner ring (east) are chosen by switches whereas the received signals from the outer ring (west) are neglected.

III. FAULT MANAGEMENT SYSTEM

The NMS proposed in this paper is based on installing passive optical encoders at the end of each fiber segment between two RNs. The performance of these passive optical encoders have been demonstrated practically in [5] for monitoring standard tree architecture PONs. This NMS uses a waveband Λ_m from the U band recommended for troubleshooting, surveillance and monitoring purposes. In normal mode, the NMS sends monitoring pulses with duration T_s and wavelength λ_1 for inner ring and λ_3 for outer ring from the CO in west direction. Each optical encoder will generate and reflect a code by coupling part of the monitoring pulse. This reflected code will be received at the CO from the west and then decoded to

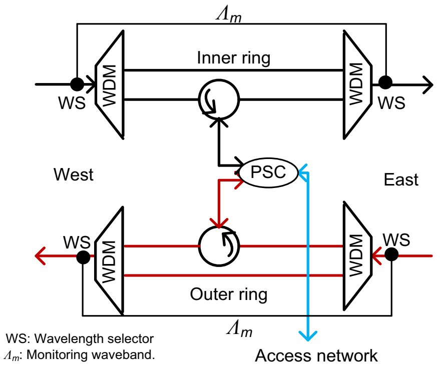

Figure 3. RN architecture.

determine the status of the fiber segments on both rings.

When double fault occur on both rings between two RNs as shown in Fig. 1, the optical code OC_{14} and OC_{24} are missed at the CO and then an alarm is generated. This alarm signal will control the switches in the CO to transmit data for RN_1 on the inner ring and its upstream data on the outer ring (west). It also transmits data for RN_2 and RN_3 on protection ring and upstream data on primary ring (east). Hence, in this way we successfully recover from this double fault scenario. However, the fault between RN_1 and RN_2 will block the monitoring pulses from propagating to RN_2, RN_3 and then to the CO. If another fault occurs between RN_3 and the CO, the NMS cannot detect this fault. Hence we need to send other monitoring pulses with different wavelengths (λ_2, λ_4) from east to both rings to completely monitor the network.

Sending two monitoring pulses on each ring from both sides with two different wavelengths requires using new type of optical encoders having the ability to generate and reflect a code toward the CO from any direction. We call these encoders symmetrical optical encoders (SOEs). The symmetric property comes from the fact that the generated codes from both sides are similar but have different wavelengths. Fig. 4 shows the FBG-SOE which is a modification of the FBG encoder in [5]. Sometimes the fault cause is not the ring segment but the RN itself. For example, if RN_1 in Fig. 1 is faulty, then the NMS will interpret this as a fault in the ring segment between RN_1 and RN_2. To solve this issue, we install another SOE after each RN so that we can determine the exact source of fault. If no code received from this new encoder, then we know that RN_1 is faulty.

IV. Upper Bound Notification and Recovery Times

The notification time is defined as the time elapsed between a failure in the physical layer of the network and the

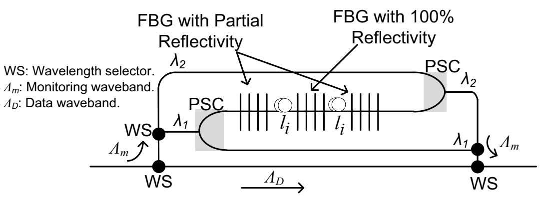

Figure 4. SOE architecture.

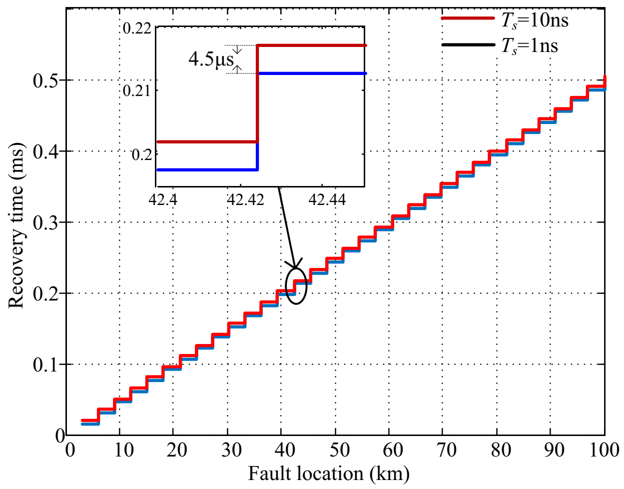

Figure 5. Recovery time versus fault location.

localization of the fault by the NMS. The monitoring pulses are transmitted with time delay between them equals the code duration T_c to avoid overlap between successive pulses. Hence the upper bound notification time is given as

$$T_N \leq T_r / 2 + T_c + T_p \qquad (3)$$

where T_r is RTT for a pulse to cross the ring forward and backward, and T_p is the processing time taken by the NMS to decode, localize and generate an alarm. The recovery time depends on the type of the switches in the OLT. If the switches are optical, the delay time is about 10ms, which is high compared to electronic switch that has time delay in nanosecond. The upper bound recovery time is given as

$$T_R \leq T_N + T_{sw} \qquad (4)$$

where T_{sw} is the time delay of the switch. So the recovery time is dominated by the RTT. Fig. 5 shows the simulation result for the recovery time as a function of the fault location in 100km ring length. We assumed there is 32 equidistant RNs and OCs with pulse duration T_s=1ns and 10ns. We also neglected the processing and switching times because they are very small compared to the RTT and code duration. The results show that using wider pulses in order to increase the code power from 1ns to 10ns will increase the recovery time by 4.5µs. The simulation also shows that the maximum recovery time is about 0.5ms for a code located at the end of the ring.

Conclusion

We proposed a passive fault management and protection system based on using passive optical encoders for ring-and-spur LR-PON. We found that ring duplication protection can reduce the cost to half compared to full duplication with high reliability. We also show that our management and protection system can localize the exact location of fault compared to other proposed systems that can make false alarms. We found that the recovery time can take about 0.5ms as an upper bound.

References

[1] M. Maier, Optical Switching Networks, 1st ed. New York, USA: Cambridge University Press, 2008.

[2] D. Seol, E. Jung and B. Kim, "A simple passive protection structure in a ring-type hybrid WDM/TDM-PON," *The 11th Int. Conf. on Advanced Com. Techn*., Phoenix Park , Feb., 2009, pp. 447 -449.

[3] D. Seol, E. Jung and S. Lee , "Passive protection in a long-reach WDM/TDM-PON," *The 9th Int. Conf. on Opt. Internet*, Jeju , 2010.

[4] L. Wosinska, J. Chen and C. Larsen," Fiber Access Networks: Reliability Analysis and Swedish Broadband Market" *IEICE Trans. on Com.*, vol. E92.B, no. 10, pp. 3006-3014, Oct., 2009.

[5] M. Rad, H. Fathallah, S. LaRochelle, and L. Rusch, "Experimental Validation of Periodic Codes for PON Monitoring," *IEEE Globecom Conf.* , Honolulu, HI, 2009, pp. 1 - 7.