Recovery Scheme through Protection Switching in Neighbouring-Line Sharing for Fibre-to-the-Home Application

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***Abstract*— Optical-fibre line failure is a significant problem that must be addressed due to the many demands of high-capacity data access. Here, we propose a novel protection method for switching devices with neighbouring-line sharing using a proposed recovery scheme. We also developed and investigated this recovery scheme for Fibre-to-the-Home (FTTH) technology application. A protection-switching device called a Customer-Access Protection Unit (CAPU) is a reliable optical-protection switching module that is included in smart and controllable FTTH networks. The CAPU provides a platform for the customer to perform fast self-restoration at their home. The approach used is based on protection switching within a network system to protect against fibre failures in the drop region. A comparison of the simulation and experimental results shows the developed protection-switching scheme was successful. Performance comparisons between the analytic methods (experimental and simulation) showed only small deviations of the value were found.**

***Index Terms*—CAPU, BER, FTTH**

I. Introduction

There are many different approaches related to the protection scheme and they should be used to protect against cable or equipment failures in access networks. Four types of protection architectures are discussed in [1] based on ITU-T G.983.1, as shown in Figure 1. Figure 1(a) represents the first type of protection scheme that introduces a second fibre cable and a fibre switch. In this architecture, when the fibre breaks, the spare fibre is used as a backup link. Figure 1(b) shows the second architecture that specifies the full duplication of the Passive Optical Network (PON) architecture. The third ITU-T architecture showed in Figure 1(c) has redundant Optical Line Terminator (OLT) systems when the primary OLT is functioning normally, and the secondary is used as a cold standby. Figure 1 (d) proposes the independent duplication of the branch line and the common lines. However, in a previous study, we proposed an access network with Ethernet Passive Optical Network (EPON) interfaces without cold standby active equipment [1], which minimised cost. The previous study also utilised a protection control unit with an N:2N optical switch installed in a central office (CO). There are two options for protection suggested in [2]. The first is achieved by duplicating the transceivers and installing new fibre to create a disjointed path to the end user. The second adds an entire access network if a certain group of customers' demands higher availability. However, doubling the number of transceivers at both ends and having two disjointed fibre paths is less cost effective for the network system.

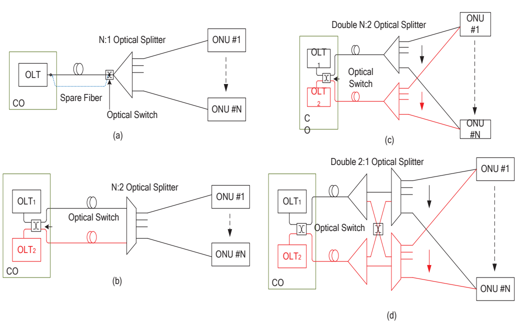

Figure 1: Proposed protection scheme ITU; (a) EPON protection architecture 1 recommended by ITU-T (b) EPON protection architecture 2 recommended by ITU-T (c) EPON protection architecture 3 recommended by ITU-T (d) EPON protection architecture 4 recommended by ITU-T

Another focusing technique uses protection switching against fibre breaks using a secondary fibre. Here, an automatic protection switching is performed independently by each Optical Network Unit (ONU) in a distributed manner. If the fibre breaks, the local-area network (LAN) transmission will not be received at the ONU, which indicates that a fibre break occurred [3]. The protection mechanism proposed in [3] enabled multiple adjacent ONUs to be simultaneously protected by a single ONU, utilising its maximum available bandwidth. Most of the proposals choose the alternative path line to carry the optical signal when the failure occurs in the other line [4].

II. Recovery Scheme And The Customer- Access Protection Unit

Our linear protection scheme (topology tree) suggests the use of a PON using a single port at the central office (CO) to provide access to n users in a 1:N ratio of the optical part of the network. The split ratio can be adjusted from 1:2 to 1:64, although, the ratios of 1:32, 1:16, or 1:8 are commonly used. The PON uses a WDM multiple-data stream carried over a single fibre. For the proposed dedicated protection scheme, each ONU is connected by an optical splitter (at a drop region). The optical splitter output is connected to the fibre lines. Every working line is duplicated, and the protection line is used as an alternative route in the event of any fibre failure, as depicted in Figure 2. The optical switches are used to divert the optical signal path. Each output port of the optical splitter is connected to the optical switch to select between two lines depending on whether the working line or protection line is used to carry the signal. The protection line is then connected to a 2 × 2 optical switch in which the output of the optical switch is connected to the optical switch input port for the neighbouring protection line.

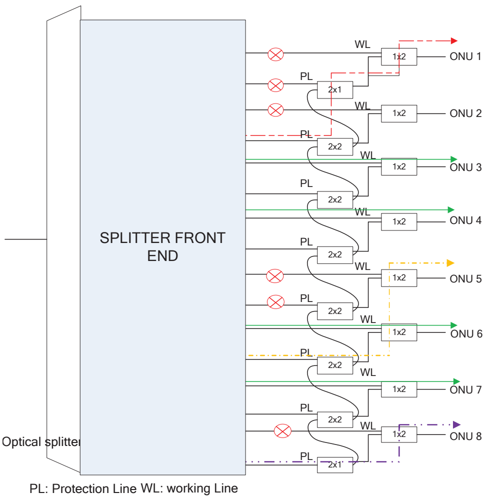

Figure 2: Restoration schemes that has been proposed at the drop region section

This mechanism continues until the last route in the optical splitter. Next, every working line connected to the ONU is also connected to the second optical switch before entering the ONU. The second optical switch in each line is used to redirect the data path to return to the original ONU if the neighbouring protection line is activated to carry the data. A recovery scheme using optical switches is used to change the path when a fibre failure is reported. The path is activated depending on the type of the fibre failure. Two optical switches are placed in the transmission line that are partially a product of the splitter and placed inline before entering the optical network unit (ONU).

The optical switch is activated when a failure occurs in the working line, and the proposed protection scheme consists of dedicated protection and shared protection. In this scheme, a dedicated protection is activated when a breakdown occurs in a line, whereas available shared protection is activated when a fibre failure occurs in two adjacent lines. Priority is given to the working line, and if the working line fails, then the protection line is activated. Depending on the order of the failure, the optical signal is diverted according to the restoration mechanism proposed in this study. The failure analysis described in this study involves four types of fault conditions.

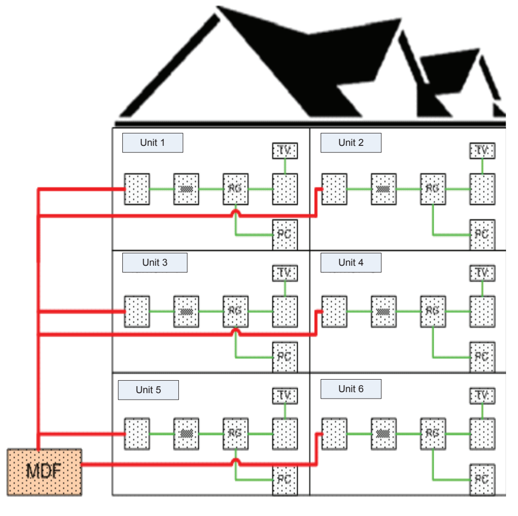

Figure 3:The application example of CAPU connections in apartment building

A protection-switching device known as a Customer-Access Protection Unit (CAPU) is used as an optical protection switch to divert the optical route in the event of failure. The CAPU prototype is in line with the development of smart FTTH networks in laboratory studies [5]. The protection-switching components consist of optical switches (2 × 1 and 2 × 2), an interface circuit and a microcontroller that are connected to the Ethernet. Figure 4 depicts the restoration-scheme architecture and shows that the front end of the protection switching hardware is placed in a centralised system and the CAPU is at the other end of the protection switch (highlighted region). The second optical switch, which contains 2 × 1 optical switches, is connected to the working line, and a 2 × 2 optical switch is connected to the protection line. A signal wavelength of 1,550 nm (downstream) enters the line at the feeder region. The protection scheme proposed shall be applied in high-rise building, apartment and small outlet building, etc. Figure 3 represents the placement of CAPU device and the protection schemes in such an apartment building.

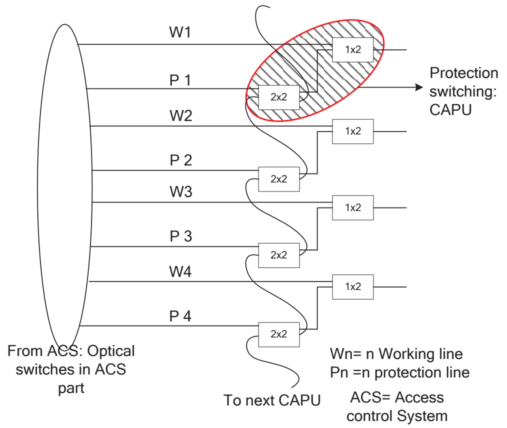

Figure 4: CAPU will be placed right before the end user

III. Simulation And Experimental Setups

The output power for each failure situation is measured by an optical power meter at each CAPU output port to determine the dynamic range of this test-restoration system for a wavelength of 1,550 nm. A 20 dB gain amplifier was used in an Erbium Doped Fiber Amplifier (EDFA) with an input power of -10.8 dB. The simulations were conducted using the Optisystem software based on the recovery test-system architecture in Figure 5, and the components were selected based on the theoretical product specifications. Each ONU is connected to the output of two optical splitters (a working line and a protection line) by two optical switches, as shown in Figure 5. The optical signal passing through the splitter enters the 1× 2 optical switch and the 2 × 1 optical switches.

Table 1 depicts the component specifications used in the simulations. A simulation platform corresponding to the FTTH test setup was developed to analyse the system's performance theoretically.

Table 1
Insertion loss according to components used in simulation

Devices/Components	Insertion loss 1550nm
Optical fiber (SMF-28)	0.20 dB/km
ACS prototype	10.6 dB
EDFA	20 dB
1x2 and 2x2 Optical switch	1.2 dB

Figure 6 shows a simulation platform developed according to the setup used to test failure scenarios at the feeder section. The feeder consisted of a 1,550 nm source, an EDFA, feeder fibre and ACS components. Figure 7 shows the layout of the optical components involved in the distribution and consists of a CAPU (recovery scheme) and an ONU. The optical components and devices used in the simulation platform were developed in parallel with the theoretical values used in products such as commercial hardware.

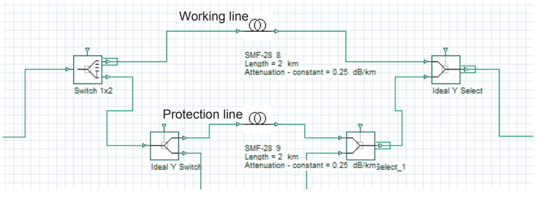

Figure 5: Protection mechanisms that used an optical switch in order to connect to working line and protection line

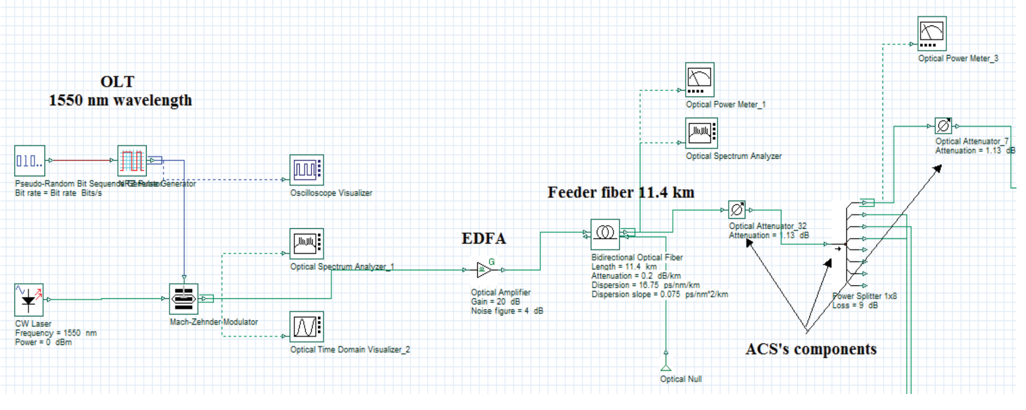

Figure 6: Optical components arrangement at the feeder region that refers accordingly to the FTTH test recovery site

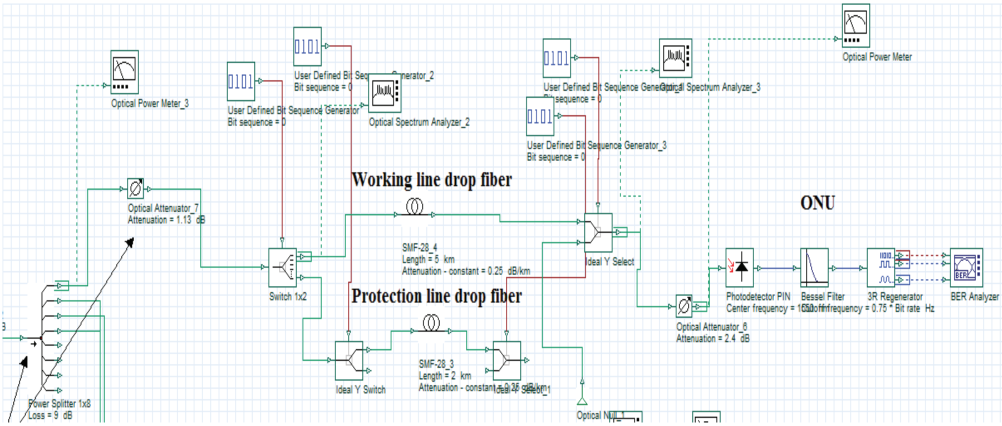

Figure 7: Optical components at distribution part to achieve an output power and BER analysis

In our laboratory, we took measurements to investigate the CAPU insertion-loss specification and the output power according to the recovery scheme at the FTTH test. Based on the experimental setup, the insertion loss for the 1 × 2 and 2 × 2 optical switches (CAPU) was measured using an optical power meter. Figure 8 shows that each CAPU has two inputs, one each from the W_n line and the P_n line. When the laser source was injected into the W_n line, the 1 × 2 optical switches in the prototype CAPU were adjusted to direct their paths, and the output power is found at Output B. If the laser source was injected into the P_n line, then the 2 × 2 optical switch was set to a cross path, and the 2 × 1 optical switch was located on a path to receive signals from the protection line. Therefore, if the laser source was injected into the P_n line, the signal then went through two optical switches in each prototype CAPU.

The next stage of testing was performed by connecting the CAPU to the FTTH test setup. A prototype experiment was conducted at the FTTH testing facility to test the quality of the receiving signal and the output power obtained at each output port of the CAPU prototype. The simulated and experimental outputs were then compared. When the laser source was switched on, the signal receiver in the ONU was obtained, and the results from the optical power meter showed differing orders of failure. Under normal conditions without the fibre failure, a video signal with a 1550 nm wavelength will pass through six lines containing three CAPUs. In the first-order failure experimental setup, the optical switches in the prototype ACS were moved to the protection line, and one failure was detected in the working fibre line. In this simulation, a wavelength of 1550 nm was used as a source to measure the output power.

Similar measurements of fibre failure were found for the second-order and third-order failures. Optical power attenuation was found when the signal was diverted to several lines (as in the recovery scheme). The output power was measured in each CAPU output according to the failure restorations.

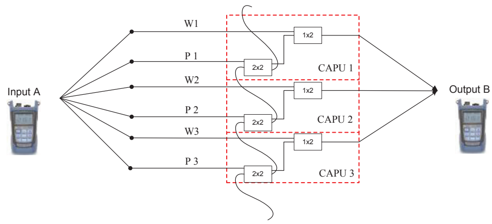

Figure 8: Insertion loss measurement for 3 CAPU prototypes with 6 input port

IV. RESULTS ANALYSIS

A. Simulation Result

The simulation approaches used in this study were described in the previous section. The simulations were conducted to obtain the output power according to the recovery scheme under different failure orders and to evaluate system performance at a sensitivity of -25 dBm. An eye-diagram analysis was used to evaluate the system performance under the recovery scheme. Figure 9 shows the output power at wavelengths of 1490 nm and 1550 nm, with fibre-attenuation coefficients of 0.25 dB/km and 0.20 dB/km, respectively. The output power at each receiver is at a total distance of 20 km. We found that output power decreased linearly with the fibre attenuation constant beginning at 0.20 dB/km to 0.25 dB/km. A third-order failure had a lower power output than the other failure situations, with the lowest values at -16.172 dBm (1550 nm) and -16.742 dBm (1490 nm).

Figure 10 shows the effect of changes in the maximum Q factor over time (bit period), where the best quality is obtained with the highest Q factor under normal circumstances. A third-order failure resulted in the lowest curve, and the Q factor decreased from 205.039 (normal conditions) to 47.6403 (third-order failure). The standard value for the minimum acceptable Q is six. Eye diagrams can be used to visualise how the waveforms send multiple bits of data can potentially lead to errors in the interpretation of those bits. Figure 11 represents the amplitude (a.u.) over one bit period for different failure orders. The high value of Q, better the quality of the system and resulted to clear eye diagram.

B. Experimental Results

The output power results measured at Output B for the three CAPUs are shown in Table 2 for a wavelength of 1550 nm. The insertion loss represents the dissipated power measured by the meter at the Output B (see Figure 8). The average insertion loss for a 1 × 2 optical switch was -1.66 dBm (1550 nm), close to the theoretical value of 1.2 dB given in the product specification. For both the 2 × 1 and 2 × 2 optical switches (CAPU), with source injection into the P_n line, the average insertion loss for the three CAPU was approximately -2.54 dBm (1550 nm). In the experiment with the FTTH recovery test setup, output power was measured for different failure orders and different fibre lengths.

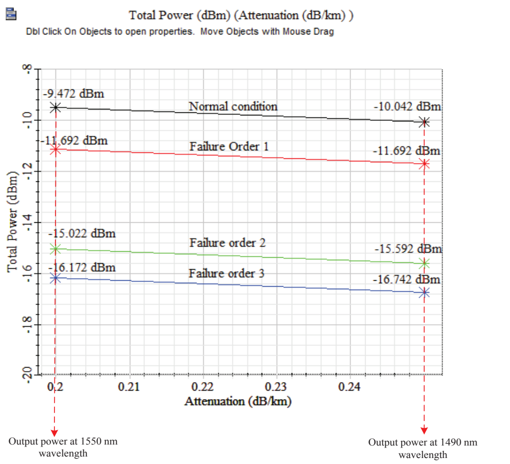

Figure 9: Output power at different failure orders for 1550 nm and 1490 nm wavelength

Table 2
Insertion loss for 3 CAPU from experimental results

Number of CAPU	Fiber line	Insertion Loss of 1550 nm wavelength
CAPU 1	W1	-1.37
	P1	-2.57
CAPU 2	W2	-2.12
	P2	-2.54
CAPU 3	W3	-1.48
	P3	-2.51

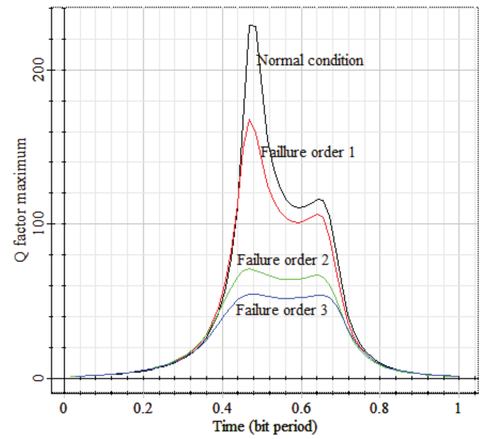

Figure 10: Q factor maximum in different failure situations over the bit period

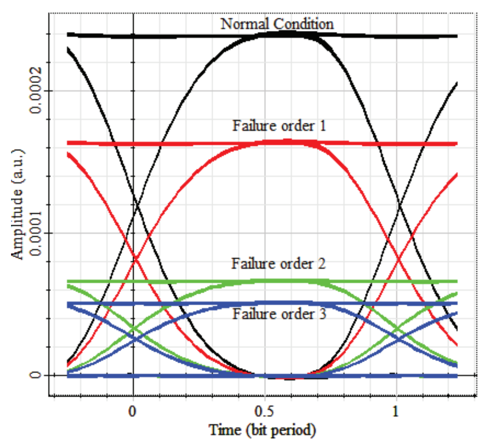

Figure 11: Amplitude (a.u) of eye diagrams for different failure situations

C. Comparison of Results

A simulation of the overall maximum-distance accessibility according to the failure conditions was performed accounting for the theoretical insertion losses of the optical switches. A measurement of the actual insertion loss was obtained from the experimental results (see Table 2). An insertion loss of 2.54 dB (1550 nm) was found, and the maximum distance that can be achieved given the insertion loss was thus obtained. Figure 12 shows the Q factors of the fibre lengths under the 4 studied conditions. We found that the maximum Q factor decreased exponentially with fibre length depends on the failure order. For the same length (km) of fibre, MaxQ value decreases when higher levels of failure due to the insertion loss that vary from failure order. The insertion loss considered here was 2.4 dB according to the theoretical values. The maximum fibre length is that which can be achieved with the minimum acceptable Q factor of ~6.

Table 3 shows the maximum distance achieved for the two conditions according to the theoretical values and the actual insertion loss of the optical switch (CAPU). The comparison done to see product theory loss and real loss of CAPU in order to achieve maximum distance of fibre length if CAPU is utilized in FTTH. The deviation of the actual distance (the insertion loss of the experimental distance) was less than the distance derived from the theoretical dissipation of the products (2.4 dB). On average, the reduction in the insertion loss of the optical switches was 10.7% for all failure conditions over the maximum distance (compared to the theoretical product values).

Table 3
Comparison of fiber distance to achieve maximum distance insertion loss according to product theory and real loss

	Maximum distance achieved from simulation	
Failure Conditions	Product theory loss	Real loss
Normal situations	95 km	94 km
Failure order 1	87.8 km	86.6 km
Failure order 2	68.7 km	66.4 km
Failure order 3	61.8 km	59 km

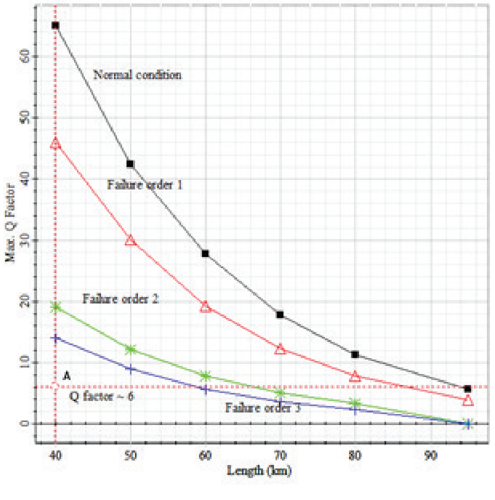

Figure 12: Maximum fiber lengths that can be achieved according to Q factor value for various failure orders in -25 dBm

Apart from the loss caused by the hardware used, the output power was also greatly influenced by the cleanliness of the connector. Impurities found in many optical connectors can result in power attenuations. The power output was measured in each CAPU output according to the failure restorations.

V. Conclusion

We compared the performance of recovery-scheme mechanisms based on four failure conditions in both simulations and experiments. Since different types of failures can occur in an optical signal route, the output power and fibre length that can be achieved also differ. For each type of recovery mechanism, we used both dedicated and shared protections. The continuous survival of the EPON is necessary to provide seamless service and to ensure network reliability. In our scheme, a single failure in the line activates the dedicated protection, whereas the shared protection is activated when both fibres (working and standby fibres) fail. The BER characteristics were measured at 1.25 Gb/s, and no degradation was observed; this was confirmed by a comparison of the simulated results with those obtained from the systems without restoration elements.

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