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Design Analysis of Protection and Restoration Scheme Utilizing Photo Diode and Switch Array in FTTH Distribution Segment

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ABSTRACT

The delivery of high speed broadband services is no longer an imagination. Most of the service providers and telecommunication operators around the world are deploying Fiber to the Home (FTTH/x) technology in the access network segment that could enable the broadband services to reach their subscribers in split seconds. With this deployment, there is also a need for the network to be reliable and robust enough so that the subscribers will enjoy uninterruptible services. Hence, the idea of protection and restoration come in place along with the deployment activity. In this paper, a protection and restoration technique will be described, particularly within the distribution side of the Passive Optical Network (PON) network. In order to realize this idea, enhancement and appropriate modifications has been made to the existing prototype modules, namely Access Control System (ACS), Multiple Access Detection System (MADS) and Customer Access Protection Unit (CAPU) modules, and a new module has been proposed and developed with a simpler but effective protection and restoration function. In this concept, the main controller for this purpose is located at the last stage of splitter segment while the protection and restoration module is integrated with the Customers Premises Equipment (CPE), or simply known as Optical Network Unit/ Terminal (ONU/T, will be referred as ONU). To prove the functionality and system reliability, a simulation has been executed based on the design and defined architecture to analyze on the optical and signal performance. With this configuration, the distribution side network protection and restoration could be implemented with an acceptable optical power budget without affecting the quality of each subscriber’s link.

Key words: Fiber to the Home, Protection, Restoration, Distribution, Survivability.

Introduction

The progress in the optical network communication has improved tremendously through the years. Be it in the backbone, core network or access region, the technology of optical communication is the preferable choice, especially when the service providers are dealing with a high bandwidth demand. Along that line, Passive Optical Network architecture has also been developed in 1990s starting from Full Service Access Network working group (FSAN) followed by ITU with the APON, BPON and the GPON (ITU-T G.984) standards. In 2004, IEEE 802.3 Standard has been completed by IEEE working group, where it uses Ethernet packet for communication. These standards are the major component that makes the Fiber to the Home (FTTH) available at present time.

Nowadays, most of the countries in the Asian region are moving towards Fiber to the Home (FTTH) solution for the high speed broadband deployment. Japan, Korea and China are well known for the successful implementation of FTTH with comprehensive applications or contents for their subscribers. In Malaysia for example, under the High speed Broad band initiative lead by Telekom Malaysia (TM), the deployment has started in 2010, providing triple play services (data, voice and video) to the subscribers (TM, 2011).

FTTH is utilizing PON architecture, could be seen as a cost effective solution, at this moment of time for delivering high speed broadband services in the access network region.

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Furthermore, it is also supported by the advantages of fibers over copper network such as the ability to carry high bandwidth, immunity to electromagnetic interference (EMI), longer reach and ease of installation (Bates, 2002).

As depicted in Figure 1, FTTH mainly deployed as a Point to Multipoint concept (P2MP) with the head end, Optical Line Terminal (OLT) located in the Central Office (CO) and the signal or services are distributed using a passive optical splitter to each subscriber.

Nevertheless, the evolution of FTTH technology does not stop there; researchers around the world are also finding ways to enhance FTTH technology with higher speed, wavelength multiplexing based PON method, interoperability and security as well as protection and restoration issues.

With reference to the points above, typically four level of FTTH protection or redundancy scheme has been defined by ITU-T, could be summarized as depicted in Figure 2.

Based from this concept, researchers are exploring various methods for protection and restoration mechanism. (Keyong et al., 2007) has proposed a hybrid protection architecture utilizing 2 pairs of splitter and AWG to support redundancy PON port at both OLT and ONU. This is to ensure that the availability of the PON network and devices is guaranteed.

(Zhen et al., 2010) also proposed both feeder and distribution protection with modification to the OLT and ONU architecture to suit the protection strategy. Two NxN optical splitters are used for both sections and it would also enable the ONU to have a direct communication between one another.

In the WDM-PON environment a study has also been made, where an optical switch is introduced in the ONU for a self restore process to the next linked ONU in the same tree. Proper wavelength assignment has made the protection mode more flexible since the wavelength from the failed ONU link could use the next link without traffic collision (Yeh, 2010).
Protection and restoration is one of the major issues that need to be addressed by the service providers in order to meet the agreed Service Level Agreement (SLA) with the customers. This would also affect the effectiveness of the operation and maintenance process.

To ensure network survivability and continuous service delivery, initial study on the protection and restoration scheme and its prototype module have been developed, however in order to implement those in the actual network, some modifications and enhancements have to be done as to suit the actual PON requirements.

This paper will focus particularly on the distribution network’s protection and restoration method with respect to the developed prototype modules. A review on the prototype will be conducted with a suggestion for improvement in order to suit the requirements.

Materials and Methods

In order to implement protection and restoration function in the distribution side, three prototype modules have been developed. These modules are interconnected between one another during operation. The descriptions are as follows:

Access Control System (ACS):

ACS is the main block that will control the protection and restoration mechanism. It is located at the last stage of distribution level, could be in an optical distribution cabinet or fiber distribution house/room. The distribution side optical splitter is integrated in this module and will be coupled with the optical switches for the working and protection link. Each optical switch set will also be connected to its neighboring switch for shared protection purpose. The optical switches’ operation will be controlled by a microcontroller; in this design PIC18F97J80 by Microchip is used.

In addition, a wavelength selective coupler (WSC) is also being used to combine with another set of optical switch that has the same dimension as the main distribution optical splitter for an in-line link monitoring function. Hence, other than protection and restoration function, it will also has the ability to monitor each customer’s link (Premadi et al., 2009; Ab-Rahman et al., 2009).

Multiple Access Detection System (MADS):

MADS is the detector that feed the detection result to the ACS for protection and restoration operation to be successfully executed. It is placed at the customers premise together with the CAPU device. It is connected in series with the working and protection link. For detection function, 10% from the 1550nm wavelength of downstream optical signal will be extracted and sent to a circuit that will translate it to an electrical signal to indicate the link status (working or broken). This signal will be sent to the ACS for the protection and restoration scheme activation (Mastang et al., 2009).
Customer Access Protection Unit (CAPU):

CAPU is the final block of this system before reaching the ONU. CAPU has a pair of switch that could switch the optical link to ensure network survivability. One of the output links will be connected to the ONU and the others for working, protection and shared (with the neighbours) protection links connection. The switching operation is controlled by the ACS based from the signals sent by the MADS (Ab-Rahman et al., 2009) (Aziz et al., 2009).

Fig. 5: CAPU block diagram.

Apparently, all of these modules need a 12V DC power supply to operate. However, this is for the switching and communication purposes only. It does not affect nor modify the data packets to and from the OLT or ONU.

Fig. 6: The distribution side protection and restoration modules arrangement.

Each customers/ ONU will be connected with a pair of fiber optic cables from the ACS. On the neighboring side, the ONU will be interconnected through a single core of fiber cable that will be used for shared protection scheme.
The fundamental operation of this architecture is based on the downstream signal detection; in particular the overlay broadcast video signal using 1550 nm wavelength.

During operation mode, if the MADS could not detect the video signal, an alert signal will be send to the ACS. Then, ACS will instruct the required optical switch set to switch to the defined protection link. In this case, the communication between ACS and CAPU is through the 10Mbps Ethernet port of the PIC18F97J80 chip.

Enhancement and Modification:

With reference to the discussion on the previous section, it is observed that the setup would cause drawbacks for actual PON system deployment. However, it could be optimized accordingly for actual field deployment. The key points could be described as below;

a. ACS complexity
   - The integration of the second optical splitter and WSC for in-line monitoring will cause the optical power level to drop drastically. This will affect the performance, and distance of the customers that could be served.

b. Power issue
   - Different set of power adaptors are needed for MADS, CAPU and ONU. Hence, this would burden the customer and impractical installation process.

c. Management communication link
   - The communication link for ACS and MADS is through the fixed line Ethernet link. This would cause an additional copper cable link installation and could incur additional installation cost.

d. Limitation of sharing the protection network
   - The sharing of protection link with the neighbour’s will also cause the received optical power drop as well as latency. There should be a control as to what level should the sharing link should be utilized.

These issues are being addressed accordingly where the ACS has been simplified to meet the protection and restoration technique and optical power requirements. Figure 7 shows the block diagram of the elements in the ACS. In this design, the optical splitter is connected to the optical switch pair that provides a working and protection link for each user. There is also links to and from each optical switch pair for sharing the neighbouring protection link should the main one failed.

ACS is the main controller unit integrated with the optical splitter for distribution purposes. The splitter dimension could vary from 4 to 64 links, depending on the network requirement. This setup is using a 1X4 optical splitter and each user’s link will utilize a pair of optical switches that is interconnected with one another, as in Figure 7.

During operation the microcontroller in the ACS and ONU protection module will be communicating between one another through the Ethernet link or GSM module. ACS will control the protection and restoration mechanism by means of observing the commands sent by ONU’s protection and restoration module. It will map the current state of switches for each of the ONU links and instruct them to a predefined protection state.

![ACS block diagram](image)

**Fig. 7:** ACS block diagram.
Fig. 8: System’s conceptual block diagram.

On the other hand, the ONU’s optical interface has also been designed to cater for this architecture. This means that each ONU will have at least 2 links, for working and protection link as well as the shared neighbour’s protection link. As depicts in Figure 10, ONU is designed with the protection and restoration modules and links in the same casing.

Detection Circuit:

In this design a photodiode is used for checking the availability of the downstream optical signal by tapping 5% of the downstream optical signal power. It is placed in series prior the ONU optical input.

Photodiode works in reverse biased mode and has a photo detector that will generate current in the circuit when the light or the downstream optical signal source falls on it. Alternately, there will be no current through it if there is no light being detected. In addition to this, a comparator is used to provide a distinctive high or low output level to the controller module. The comparator consists of an inverting and non-inverting input as well as an output pin. In principle, it works by comparing both input levels where the output will remain high as long as the non-inverting input is on higher potential than the inverting one.

As shown in Fig. 9, this circuit will provide a high (3V) or low (0V) voltage output from the comparator to the controller module, indicating the presence of the downstream optical signal.

Protection and Restoration Circuit:

As for the protection task, two optical switches are connected as in Fig. 10.

In this design, a 1x2 and 2x2 switch is used. The optical path in the switch circuit will depend on the switch state, either straight or cross mode. Both switches will be controlled by the controller module that obtained the optical signal status from the photodiode.

The switches used are from Omron with a typical insertion loss value of 0.8 dB and 2.3ms of switching time (Omron).
For controlling purposes, microcontroller chip is used. Both detector and switches circuit is connected to this chip. The microcontroller module used in this design is PIC18F97J60 by Microchip Technology Inc. This chip could be considered a simple yet effective computer-on-chip solution with an integrated Ethernet controller. In addition, other major features included in this model are, the I/O ports, memory for program and data storage, watchdog circuit as well as the analogue to digital converters. The details operation of this chip will not be discussed in this paper.

However, in principle, both chips (at the ACS or ONU) will handle the switch state and protection and restoration scheme. The communication between these chips is through the Ethernet port/GSM module. This is to ensure that the switch state at both sides of the device is in synchronous for an optical network link could be established.

Results and Discussions

The enhanced customer premise equipment protection and restoration system is simulated using ‘OptiSystem’ simulation software by Optiwave Software Company. The concept described in the previous section will be simulated and the results are analyzed and discussed in this section.

These results will show the feasibility and limitation of the solution for actual network implementation.

One of the major issues that need to consider in any optical communication system is the optical power budget, and by implementing this solution, it needs to be ensured that the received signal is within the ONU sensitivity range for a functional optical communication link. The downstream 1490nm wavelength signal from the OLT will be measured at the ONU optical port. This signal is always available within the same splitter output ports if there is a connection to the OLT PON port, regardless of the ONU status in the network. Since the concept of this solution is based on this signal for detection and making a decision as to where the protection and restoration switch should be set to, the optical characteristics will be examined.

In typical FTTH deployment, the feeder cable is longer than the distribution cable and will be laid as far as possible before reaching the distribution splitter. Hence, the resulting signal shows the power reading at the ONU input port with different of the feeder cable’s length. In addition to that, the receive power by the ONU is also being analyzed with respect to the distribution segment distance. Finally, the number of optical splitter dimension in the distribution network is also simulated in order to analyze the maximum splitting ratio that the system could tolerate.

The feeder fiber length is varied from 5km to 30km, while the distribution fiber is set to 1km. The result in Figure 11 shows that by introducing these components in the network the received optical power at the ONU is still within the typical sensitivity range for deployment; i.e. -26 dBm. However, the received power is decreased gradually from -11.53 dBm at 5km to -16.53dBm at 30km. This loss is also contributed by the fiber cable itself where with G.652D cable will introduce an attenuation of approximately 0.2 to 0.25 dB/km.

Furthermore the graph is extrapolated to more than 30km and the received power is plotted with respect to the length (indicated by the thick dotted line on the graph) of a longer feeder cable. The extrapolation is based on the linear graph formula;

\[ y = mx + b \]
where; $m$ is the gradient of the slope, $b$ is the point where the graph crosses the $y$ axis, and $x$ and $y$ is the variable representing cable length and received power respectively.

From here it is found that the line will cross the $y$ axis at $-10.531$ dBm, which can also be seen as direct connection, while the slope constant is $-1$. The point will pass the $-26$ dBm level is at 80km. Hence we could see that there is a sufficient optical power buffer within the standard 20km range for the operation of OLT and ONU through the modules.

![Graph showing power distribution vs length](image)

**Fig. 11:** The result of varying the feeder cable length with respect to the received optical power on the working link.

Next, the result of varying the distribution segment length and the effect of selecting different protection link scheme. In this simulation, the feeder cable is fixed at 15km, and the distribution link is varied from 1km to 10km. Apparently, this is to simulate the generic deployment range of FTTH network. Since the standard maximum range of FTTH network is 20km, the reading is measured at 5km, where the working link has the highest optical power measurement at $-14.53$ dBm, on the other hand, the lowest reading is for shared User’s 3 protection link which is $-23.33$ dBm. Based from formula (1), the graph slope in Figure 12 it can be summarized that the rate of power reduction is approximately 0.2 dBm/ km. While the Q factor in Table 1, shows at maximum distance of 20km (5km of distribution link, and 15km of feeder link), the system is capable to utilize up to the first neighbour’s protection link ($Q = 14.9$) in case the working and main protection link are broken. The values for another two neighbouring protection links are considered marginal and not suitable to be utilized for this purpose. The acceptable Q value for a successful digital communication system is at least 6 (which could produce BER equal to $10^{-9}$) (Ab-Rahman et al., 2011).

![Graph showing Q factor vs distribution length](image)

**Fig. 12:** Result of varying the distribution fiber length for all links.

<table>
<thead>
<tr>
<th>Link Type</th>
<th>Q Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working</td>
<td>41.2</td>
</tr>
<tr>
<td>Protection</td>
<td>24.1</td>
</tr>
<tr>
<td>Sharing Neighbour 1</td>
<td>14.9</td>
</tr>
<tr>
<td>Sharing Neighbour 2</td>
<td>9.1</td>
</tr>
<tr>
<td>Sharing Neighbour 3</td>
<td>6.1</td>
</tr>
</tbody>
</table>

**Table 1:** Q Factor when using different level of protection link measured at 5km.

As stated above, the final experiment is to observe the number of distribution network splitting ratio that the system could handle. For each of the protection and restoration level, the splitting ratios are varied from 2 until 64 splits. Figure 13 summarizes the optical power value as seen by the ONU with this variation.
The received power is reduced gradually as the splitting and protection and restoration level is increased. This is due to the loss induced by the splitter itself, where for each multiple of two splits will incur approximately 3 dB loss. Moreover, as the level of protection and restoration is increased, the light signal is also need to go through more optical switches in the ACS as well as ONU.

In theory, referring to the general sensitivity value of -26 dBm, the maximum splitting of 8 or less will allow utilizing shared protection up to the third neighbour. If the number of splitting is increased, the level of protection and restoration level is decreased, i.e. fall below the red line.

However, in practical, the quality of the received signal needs to be considered together with the received optical power. Hence, Table 2 shows the BER and Q value of the allowable splitting ratio and shared protection level that could be implemented. As with the power pattern, these values are also decreasing as the split and protection level is increased.

The suitable value that could be achieved using this system is with a 1x8 split and using the first neighbour for protection link sharing. As shown in Table 2, the value at this point is BER = 1.76E-11 and Q = 6.6228. This value full fills the requirement for the generic allowable level of successful transmission system. The OLT and ONU communication might fail or encounter problems should the splitter and protection level is increased. This is because of the distorted and unrecoverable signal by the OLT and ONU due to optical power loss and different path and optical components that the signal has to travel in each condition, as represented by the reduction in Q value and BER as we move across the table to the right hand side.

Table 2: BER and Q Factor with respect to splitting ratio and protection level.

<table>
<thead>
<tr>
<th>Split/Level</th>
<th>Working BER</th>
<th>Working Q</th>
<th>Protection BER</th>
<th>Protection Q</th>
<th>Sharing N1 BER</th>
<th>Sharing N1 Q</th>
<th>Sharing N2 BER</th>
<th>Sharing N2 Q</th>
<th>Sharing N3 BER</th>
<th>Sharing N3 Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>1X2</td>
<td>0</td>
<td>69.704</td>
<td>0</td>
<td>48.9928</td>
<td>7.22E-172</td>
<td>27.922</td>
<td>1.22E-80</td>
<td>8.7691</td>
<td>1.23E-37</td>
<td></td>
</tr>
<tr>
<td>1X4</td>
<td>1.20E-247</td>
<td>33.589</td>
<td>1.89E-128</td>
<td>24.0829</td>
<td>5.55E-39</td>
<td>13.007</td>
<td>2.14E-18</td>
<td>8.6709</td>
<td>3.60E-09</td>
<td></td>
</tr>
<tr>
<td>1X8</td>
<td>6.28E-71</td>
<td>17.768</td>
<td>8.56E-36</td>
<td>12.4338</td>
<td>1.76E-11</td>
<td>6.6228</td>
<td>4.98E-06</td>
<td>6.6228</td>
<td>0.000156</td>
<td></td>
</tr>
<tr>
<td>1X16</td>
<td>5.86E-20</td>
<td>9.0715</td>
<td>1.22E-10</td>
<td>6.30055</td>
<td>0.00036547</td>
<td>3.3773</td>
<td>4.4177</td>
<td>4.4177</td>
<td>0.00156</td>
<td></td>
</tr>
<tr>
<td>1X32</td>
<td>1.91E-06</td>
<td>4.6206</td>
<td>0.0006183</td>
<td>3.22985</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1X64</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Finally, the eye diagram in Figure 14 shows three level of protection and restoration method with different splitting ratio for each scenario. For all scenarios, the eye opening is excellent for 1X2 splitter, and starts decreasing as the splitting increased, where it is totally closed at 32 splits. The minimum condition that the system could function as mentioned above is in Figure 14 (B). This is the maximum level and split that could allow the communication between OLT and ONU through this system. Comparatively, the third neighbour protection link is not suitable to be used in the deployment due to the signal distortion that represented by the lower amplitude value.

Conclusion:

In an effort to provide network survivability to FTTH-PON, a protection and restoration methodology has been developed and described from the concept, architecture and design as well as the simulation results. By designing an array of optical switch in both distribution optical splitter and ONU, an FTTH-PON distribution side protection and restoration scheme could be established. The usage of inline taper and photodiode could enable the optical monitoring function to trigger the protection and restoration function. Considering the optical power penalty caused by the solution as well as other PON components, the suitable implementation is by using eight splitting ratio with the sharing of the first neighbour’s protection link (should the main protection link failed) within the standard FTTH PON range.
Fig. 14: (A) Eye diagrams for working link with different splitting ratio and Q factor value, (B) Eye diagrams using Neighbour 1 protection link with different splitting ratio and Q factor value, (C) Eye diagrams using Neighbour 2 protection link with different splitting ratio and Q factor value.

References


Omron, Omron Datasheet, 1x2 and 2x2 Optical Switch P1S.

TM, M.C., TM'S UNIFI HIGH SPEED BROADBAND SERVICE REACHES MORE THAN 750,000 PREMISES PASSED 5 January 2011; Available from: http://www.tm.com.my/ap/about/media/press/Pages/TM%E2%80%99SUNIFIHIGHSPEEDBROADBANDSERVICEREACHESMORETHAN750,000PREMISESPASSED2.aspx.
