Reliability and Cost Benefit Analysis of Protection Schemes for Passive optical Fiber Network

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Abstract—This paper gives a model for finding the reliability and cost of passive optical fiber networks (PONs). Mathematical modeling of various PONs has been done using to determine the cost and reliability for deployment at the access domain. It is observed that there is a trade-off between cost of protection and the reliability level that we attain from adding redundancy, as duplication in PON network can be expensive. The base data regarding the reliability has been collected from one network and single manufacturer as currently there are very limited numbers of operator in Pakistan providing INTERNET service using passive optical fiber network. The model developed in this paper can be used by any Internet service provider to measure the reliability of the network and cost in order to install any protection to their PON. This research provides a tool or a model for any ISP to analyze the effectiveness of the protection schemes before installing it and finalizing their decision as protection in optical network is expensive.

Index Terms—Passive optical network; Protection; Deployment cost; Reliability block diagram

I. INTRODUCTION

Passive optical network is a point to multipoint telecommunication network that uses passive elements to provide FTTH service in an area of 25 Km. During the last decade PON has emerged as a promising technology to fulfill the need of high speed data and provide service to a large number of subscribers thus this network provides a great business opportunity [1]. Many other broadband services are in market such copper based digital subscriber line (DSL) and wireless broadband service but PON supersedes them in terms of reliability and quality of service.

There are two basic types of fiber networks. Active networks and Passive Optical networks, Active networks uses electrical powered equipment at remote locations, which can be difficult to manage due to the shortage of power in many areas around the globe [2]. Passive optical network offers an advantage as it provides its service with using any active elements at its remote locations. However fault management is well known crucial aspect in any network so a better fault management or protection for core and access network in taken into consideration to insure and uninterrupted and reliable end to end service [3]–[5].

But there is a tradeoff between reliability and cost of the protection, the model is this paper has been developed for this purpose so that the system cost can be kept low and the operators can select the protection that offers a better reliable service while keeping the system cost low [6]. The updated versions of PONs offer up to 10Gbps data flow also known as GPON any down time of network can result in a huge loss of data [7].

II. PROTECTION AND NETWORK TOPOLOGY

There are two common topologies for passive optical networks namely tree and ring. In tree topology optical signal is sent from Optical Line Terminal (OLT) via Feed Fiber (FF) and then distributed at splitter towards their designated Optical Network Unit(ONU) through Distribution Fiber (DF), shown in Fig a. In simple ring architecture OLT is connected to multiple splitters through a single fiber, and the splitter distributes the signal towards their designated ONUs [8], [9].

While installing protection it is viable to consider the network topology, there are two main resources that need to be protected that are fiber links and active components such as OLT [10]. Protection in PON is usually achieved by light path diversity i.e. fiber link duplication as shown in Fig. 1. The protection can be of two types N+N and 1: N. In N+N there is a separate redundant fiber for every main fiber. In 1: N Protection there is a single stand by fiber for all the main fibers. N+ N and 1: N protection types are shown in fig c and fig d respectively [3], [11], [12].

Mostly PONs networks are designed using tree topology as it can cover a large compared to ring architecture [13].

III. PASSIVE OPTICAL NETWORKS AND EFFECTIVE MODELS

In our study we analyze four protected Passive optical fiber networks proposed by ITU-T [14] as shown in Fig. 2. Type A is a most basic type of passive optical network architecture and it offers 1+1 protection in Feed Fiber only. Type B second OLT is in sleep mode that is triggered by an automatic switch in case the first OLT malfunctions. Type C offers network duplication from OLT to ONU one half of the network both the parts will be in active mode carrying half of the traffic on each if one half fails the while traffic is shifted on second half. In type D network from OLT to 1:2 splitters will be in sleep mode. The ITU stand type C and type D offers very reliable service but unfortunately the whole network has to be duplicated in these two architectures [15].

These graphical representations are the block diagrams of effective and protected passive optical networks. In our study failure is considered a scenario in which the connection between OLT and ONU is broken. Each block in these diagrams has two functional states i.e. operating or failed. These systems are considered in working states if at least one path that
starts from OLT and goes till ONU without passing through any failed hardware or component [16]. The block diagrams are represented in series and parallel combination. A single component fails in series combination that path will go down, if a parallel path is available transmission will be uninterrupted other will ISPs will face complete network outage [17].

IV. DATA AND ASSUMPTIONS

In this data we measured the unavailability of a component by using the following equation [18]

\[
U_{\text{availability}} = 1 - \frac{MTTR}{MTTR + MTBR}
\]  

Where MTTR, and MTBR represent the mean time to repair, and mean time between repair respectively. The result was than subtracted from 1 that gave us the unavailability of that component. It must be noted that the MTTR depends upon the operators and their SOPs. The unavailability of the components in our scenario has been taken from working equipment that is operation for 6 years.

In our calculation we assumed that the distance between OLT at data center and ONU at customer premises to be 20 Km. Dispersive case scenario is used in these calculations in which feed fiber is 20 Km in length and distribution fiber is 5 Km in length [18], [19]. This modeling is done based on as system capable of transmitting 1 Gigabits per second (Gbps). It must also be noted that cost of the system installation maybe very different in different countries.

Below mentioned equations were developed for calculating the unavailability of each type of standardized network shown in Fig. 2.

\[
U_A = U_{\text{OLT}} + U_{sw} + (U_{FF} \times U_{FF}) + U_{2:N} + U_{DF} + U_{ONU}
\]  

\[
U_B = (U_{\text{OLT}} + U_{FF}) \times (U_{\text{OLT}} + U_{FF}) + U_{2:N} + U_{DF} + U_{ONU}
\]  

\[
U_C = (U_{\text{OLT}} + U_{FF} + U_{1:N} + U_{DF} + U_{ONU}) \times (U_{\text{OLT}} + U_{FF} + U_{1:N} + U_{DF} + U_{ONU})
\]  

\[
U_D = (U_{\text{OLT}} + U_{FF} + U_{1:2}) \times (U_{\text{OLT}} + U_{FF} + U_{1:2})
\]

\[
+ (U_{2:N} + U_{DF} + U_{ONU}) \times (U_{2:N} + U_{DF} + U_{ONU})
\]  


TABLE I: Unavailability and cost of optical components [18]

<table>
<thead>
<tr>
<th>Optical Components</th>
<th>Unavailability</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OLT 3.2 Gbps</td>
<td>5.12e-7</td>
<td>40,000</td>
</tr>
<tr>
<td>OLT 1.0 Gbps</td>
<td>5.12e-7</td>
<td>12,100</td>
</tr>
<tr>
<td>ONU WDM PON</td>
<td>1.54e-6</td>
<td>525</td>
</tr>
<tr>
<td>ONU TDM PON</td>
<td>1.54e-6</td>
<td>350</td>
</tr>
<tr>
<td>1:2 (2:2) Splitter</td>
<td>3.00e-7</td>
<td>50</td>
</tr>
<tr>
<td>1:N (2:N) Splitter</td>
<td>7.20e-7</td>
<td>800</td>
</tr>
<tr>
<td>Optical Switch</td>
<td>1.20e-6</td>
<td>100</td>
</tr>
<tr>
<td>Optical Fiber / Km</td>
<td>1.37e - 5</td>
<td>500</td>
</tr>
</tbody>
</table>
TABLE II: Deployment cost of ITU-T protection architectures

<table>
<thead>
<tr>
<th>PON Protection Type</th>
<th>Availability (%)</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A</td>
<td>99.99</td>
<td>23,350</td>
</tr>
<tr>
<td>Type B</td>
<td>99.993</td>
<td>42,850</td>
</tr>
<tr>
<td>Type C</td>
<td>99.9999992</td>
<td>46,500</td>
</tr>
<tr>
<td>Type D</td>
<td>99.999995</td>
<td>48,100</td>
</tr>
</tbody>
</table>

V. COMPARISON

We compared the unavailability found in above mentioned equations and deployment cost for the ITU-t standards provided in Table II.

It can be observed from Table II that Type C, and D require the maximum deployment cost, as compared to Type A, and B. It is evident from the fact that both former protection architecture duplicate entire network components to provide the required 5 nines protection. This significantly increase the cost of PON for a common end user. Therefore, a trade-off is made between the cost and deployment of these architectures in the cost sensitive PONs.

Furthermore, owing to the high cost of ITU-T 983.1 pure tree-based protection architectures, hybrid schemes are introduced to reduce the cost of deployment along with desirable connection availability [3], [4], [18], [20], [21]. These architectures utilize the combination of tree, ring, and star topology at different levels of the PON. Utilizing of each topology is strictly governed by the number of subscribers that the proposed PON can support, amount of data that can be transmitted, power budget and reach of the network. Consequently, both tree-star and ring based topologies can be utilized at feeder and the distribution level, depending on the network requirement. These topologies have proved to be much significant in terms of providing the required redundancy at minimum cost as compared to ITU-T 983.1 schemes.

VI. CONCLUSION

Different evolved versions of protected PON were presented in this research and we performed their effectiveness and cost analysis. It was found out that the protected PONs are much superior to non-protected PONs in terms of Reliability. Due to the increasing demands of a reliable broadband service the operators need to consider different protection schemes for their system to make them reliable. Analysis shows that the protected PONs are much more economical compared to unprotected PONs in term of operation. With the model proposed the operators can easily suggest a protection type for their network according to their need and economic condition. The installed protection schemes should be according to the customer type in that area such as for business customers they cannot afford any down time of the network so a more reliable network should be installed in that area.

REFERENCES