Comparison of Hybrid WDM/TDM Passive Optical Networks (PONs) with Protection

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Abstract *We present the evolution of PON protection and compare reliability performance related to investment and management cost for some representative cases. Our results can indicate the most cost efficient architectures.*

Introduction

Passive optical networks (PONs) are considered as a promising solution for broadband access. Meanwhile, fault management within the network becomes more significant due to the increasing demand for reliable service delivery. Therefore, a lot of work has been devoted to explore protection schemes for PONs (see e.g. [1-4]). On the other hand, access network providers need to keep capital and operational expenditures (CAPEX and OPEX) low in order to be able to offer economical solutions for the customers. Improving network reliability performance by adding redundant components and systems is expensive and thus, not always very suitable for cost-sensitive access networks. In addition, to cope with the increasing demand for broadband services in a cost-efficient way, a smooth migration from TDM-PON to hybrid WDM/TDM PON is envisaged for near-future deployment.

Therefore, in this paper we review the evolution of protection schemes for PONs and study reliability and availability of some representative protection architectures for hybrid WDM/TDM PON and compare their cost efficiency in relation to the reliability performance.

Evolution of PON Protection Schemes

The evolution of protection schemes for PONs can be divided into three phases. In the first one, the standard protection architectures were defined by ITU-T [1] around a decade ago. They are based on duplication of the network resources and are referred to as type A, B, C and D. In Type A only the feeder fiber (FF) is redundant. Type B protection duplicates the shared part of the PON, i.e., FF and optical interfaces at the OLT. In Type B the primary optical interface at OLT is normally working while the second one is used as a cold standby. Type C represents 1+1 dedicated path protection with full duplication of the PON resources. In Type C both the primary and secondary interfaces are normally working (hot standby), which allows for very fast recovery time. Type D protection specifies the independent duplication of FF and distribution fibers (DFs) and thus, it enables network provider to deliver services for different users with different reliability performance. Obviously, the ITU-T standard Type C and Type D with full protection offer a relatively high reliability performance but unfortunately they require duplication of all network resources (and investment cost) to realize the protection, which may result in CAPEX that is too high for the cost-sensitive access networks. Therefore, in the second phase of the PON protection scheme evolution the effort was put on development of cost-efficient architectures in order to decrease the deployment cost. In [2-4] two neighbouring ONUs protect each other using the interconnection fibers (IFs). In this way, the investment cost for burying redundant DFs to each optical network unit (ONU) can be saved and, consequently, the CAPEX can be reduced.

Following the trend of minimizing the cost per subscriber the third (future) phase of PON protection schemes evolution should migrate towards the reduction of OPEX. Meanwhile, OPEX is related to both protection architecture and maintenance strategy. With this in mind, in the following sections we compare CAPEX and OPEX related results along with the reliability performance of some representative PON architectures: the unprotected scheme, four standard protection schemes [1] and two novel protection schemes proposed in [3] and [4].

Reliability vs. Cost

To make our analysis more general, we consider two typical PON deployment alternatives referred to as collective and dispersive cases. The collective case corresponds to areas with relative dense population of users while the dispersive case is applied to sparsely populated areas. Consequently, for the collective case we assumed 19.5 km long FF, 0.5 km long DFs and 0.2 km long IFs while for the dispersive case it is assumed that FF is 15 km long, DFs are, 5 km long and IFs are 2 km long. For Type D, we

Schemes		Connection Unavailability ($x10^{-5}$)		MDT (min/year)		CAPEX per user (US$)		CRM	
		Collective	Dispersive	Collective	Dispersive	Collective	Dispersive	Collective	Dispersive
Unprotected		27.7568	27.7568	145.89	145.89	4527.6	35915.8	46.30	57.69
Type A		1.2379	7.3910	6.51	38.85	5061.6	36326.7	4.15	8.95
Type B		1.0667	7.2198	5.61	37.95	5101.8	36366.9	4.09	8.82
Type C		0.0077	0.0077	0.04	0.04	9055.2	71831.5	3.96	4.86
Type D	D_1	0.0072	0.0048	0.04	0.03	9108.0	71884.3	3.96	4.86
	D_2	0.9168	7.0699	4.82	37.16	5102.0	36367.1	4.03	8.70
Scheme [3]		0.6739	0.6717	3.54	3.53	5378.7	43071.4	3.97	4.93
Scheme [4]		0.5119	0.5097	2.69	2.68	5408.5	43101.2	3.91	4.86

TABLE 1: Results of Connection availability vs. CAPEX

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assume that one half of users is fully protected (Type D_1) while the second half is partially protected (Type D_2). Furthermore, in our comparison we consider hybrid WDM/TDM PON architectures with 16 TDM-PONs and 16 ONUs per TDM-PON (i.e. 256 users). .

1) Connection availability vs. CAPEX

We compare availability of a connection between OLT and ONU for unprotected, Type A-D [1] and protection schemes in [3] and [4]. We assume that the failures of difference components are independent and we apply models in [5] and reliability data in [3] for connection unavailability calculations. Furthermore, for each scheme we evaluate CAPEX per user based on cost of burying fiber of 7000 USD per km and component cost given in [3]. We also define cost-reliability measure (CRM) [6]:

$$CRM = \{\log(CAPEX\ per\ user)\} / Q_A$$

where Q_A [6] represents the reliability measure and is related to connection availability. It can be seen that the smaller CRM the better since it corresponds to higher efficiency of deployment cost for the achieved reliability improvement.

Table 1 shows our results for connection unavailability, mean down time per year (MDT), CAPEX per user and CRM. It can be seen that Type C, D_1 and schemes [3] and [4] can offer very high connection availability (higher than 99.999%, i.e., 5 nines) in the both dispersive and collective cases. However, comparing CAPEX per user and CRM shows that schemes [3] and [4] are much more cost efficient than Type C and D. Furthermore, as expected, connection unavailability and MDT in Type A, B and D_2 are much better in the collective case than in the dispersive case. It is because in the dispersive case DFs are much longer than in the collective case and the unprotected DFs in Type A, B, and D_2 can significantly deteriorate the connection availability. Consequently, in the collective case, connection availability close to or higher than 5 nines can be achieved in Type B and D_2. Thus, our results reveal that in order to achieve high connection availability in dispersive case, all fiber links should be protected while for the collective case it can be sufficient to protect only the shared parts of PON.

2) OPEX related results

Usually, service interruption penalty and failure reparation process are the most costly parts of OPEX. It should be noticed that the mean downtime per year doesn't correspond to the real downtime experienced by a client since if the failure occurs during the contracted period the service interruption will be much longer than MDT while if the failure will not occur no service interruption will be noticed. Therefore, in order to reflect the difference in service interruption penalty between the considered PON architectures, we compare the probability of service interruption for a client during his contracted period of 5 years. We also compare the expected number of failures in the network during 5 years in order to address the cost related to the reparation process.

Schemes		Probability of service interruption		Expected number of failures	
		Collective	Dispersive	Collective	Dispersive
Unprotected		41.50%	41.50%	6.8	35.5
Type A		19.80%	24.00%	7.3	35.9
Type B		18.70%	22.90%	7.5	36.0
Type C		17.20%	17.20%	13.7	70.9
Type D	D_1	15.60%	12.10%	10.6	53.5
	D_2	18.60%	22.80%		
Scheme [3]		19.20%	16.10%	10.8	45.1
Scheme [4]		18.60%	15.50%	10.8	45.0

Table 2: OPEX related results for 5 years period

The OPEX related results are shown in Table 2. Our calculations are based on models in [5] and the reliability data in [3]. In the collective case, the probability of service interruption is similar in all the considered protection schemes due to the relatively short DFs. In all considered protection schemes users can expect with more than 80% probability that the service will not be interrupted during 5 years compared with 58.50% for the unprotected system. On the other hand, in the dispersive case the probability of service interruption is different for each protection scheme. The probability lower than 20% is obtained for Type C, D_1 and schemes [3] and [4] while for Type A, B and D_2 this probability is much higher. Furthermore, Type C has the largest expected number of failures in a time period of 5 years (and consequently highest expected cost related to the reparation process) due to the full duplication of all resources. In contrast, schemes [3] and [4] have much lower expected number of failures than Type C while probability of service interruption in both of collective and dispersive cases is similar. Comparing probability of service interruption and the expected number of failures it can be observed that schemes in [3] and [4] are still the best ones with respect to OPEX related to reparation actions and service interruption penalty ns. A more quantitative OPEX study can be performed based on specific input data such as the penalty signed in service level agreement, local salary for the reparation etc.

Conclusions

In this paper we present the evolution of protection schemes and compare their reliability performance in relation to the CAPEX and OPEX parameters. Our results reveal that for 5 nines connection availability in the areas with relative dense population of users (i.e., in the collective case) it can be sufficient to protect only the shared parts of PON while in the sparsely populated areas (dispersive case) all fiber links should be protected. Therefore, in terms of OPEX and CAPEX efficiency related to the reliability improvement Type A, B and schemes [3] and [4] perform well in the collective case while in the dispersive case only schemes [3] and [4] can be recommended.

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