COST VERSUS RELIABILITY ANALYSIS OF NEW TREE-BASED HYBRID PROTECTION ARCHITECTURE FOR OPTICAL CODE DIVISION MULTIPLE ACCESS SYSTEM

Waqas, A. Imtiaz[1], Yousaf Khan[1], Syed Waqar Shah[2]

ABSTRACT

Conventional optical code division multiple access (OCDMA) system for passive optical network (PON) has limited applications in providing protection to network components. This increases the overall downtime of PON, and reduce its feasibility for deployment at the access domain. Therefore, it is imperative to design an economical system that should be able to provide fault detection and restoration at both feeder and the distribution level. This paper focuses on design and analysis of a novel tree-based hybrid protection architecture for OCDMA system in order to make it economical and reliable for deployment at the access domain. It is observed that the proposed protection architecture provides desirable (5 nines) connection availability along with minimum cost as compared to existing tree based protection architectures.

KEYWORDS: *optical code division multiple access, spectral amplitude coding, protection, cost, reliability*

INTRODUCTION

Passive optical network (PON) is an access technology, which utilize passive components between central office (CO) and subscriber premises to provide high bandwidth services. PON contain an optical line terminal (OLT) at the CO. Traffic from OLT is forwarded towards the access domain through a long feeder fiber (FF). End-face of the FF is connected to remote node (RN), which houses a 1:N optical coupler (OCP). Outputs from the passive OCP are connected with shot span distribution fibers (DFs), which serves as light-wave medium between RN and optical network units (ONUs). Support for high data rates and large number of subscribers have significantly increased the feasibility of PON for the implementation of optical fiber based communication in access domain[1-2].

Adaptation of PON requires efficient delivery of information from OLT to ONUs. Therefore, it is imperative to utilize an effective multiple access technology, which can provide maximum capacity in regards to data and the number of subscribers simultaneously accessing the medium[2]. Optical code division multiple access (OCDMA) technology is foreseen to provide the required capacity, owing to its significant advantages like, asynchronous nature, minimum delay, simultaneous access of multiple subscribers without contention, built in security, and support for high data rates[3].

Deployment of OCDMA system in access domain is limited by the absence of protection mechanism throughout the network. To the best of our knowledge, OCDMA does not provide any protection between OLT and ONUs. Therefore, it is necessary to develop a suitable protection architecture, which can provide desirable connection availability at minimum possible cost. ITU-T G.983.1 protection architectures can be considered for the survivability enhancement of conventional OCDMA systems, since they are based on tree topology. ITU-T G.983.1 provide four standard protection architectures by varying redundancy at feeder and distribution level respectively[1,4,5].

Type A and B protection architectures protects the feeder level only. Whereas type C, and D provides maximum connection availability by duplicating the entire PON. However, they are not suitable for deployment at the access domain; because type A and B protection schemes fail to protect the distribution level, which deteriorates their overall connection availability. This significantly increases the downtime per year that elevates the overall operational expenditure (OPEX) of PON. Type C and D solution on the other hand duplicates entire PON, which consumes an extensive amount of capital expenditure (CAPEX) during the deployment of PON. Various hybrid architectures are also provided for reliability enhancement[5-8], however the use of a suitable protection architecture with desirable connection

1 Department of Electrical Engineering, IQRA National University, Peshawar, Pakistan
2 Department of Electrical Engineering, University of Engineering and Technology, Peshawar, Pakistan

availability and minimum cost is still an open issue.

This paper proposes a novel tree-based hybrid protection architecture for OCDMA based PON, which ensures efficient detection and restoration of faults throughout the network. Moreover, the proposed architecture is designed to minimize the CAPEX and OPEX through maximum protection, simplified architecture, and minimum downtime per year. The proposed system is thoroughly analyzed for feasibility of deployment at the access domain, in terms of cost and reliability. It is observed that the proposed protection architecture requires minimum cost and provides desirable connection availability as compared to the existing ITU protection standards.

Rest of the paper is organized as follows. Section 2 provides a detailed analysis about design of the proposed tree-based hybrid protection architecture for SAC-OCDMA system, which is followed by detailed cost and reliability analysis in Section 3. The paper is finally concluded in Section 4.

2. DESIGN OF TREE BASED HYBRID PROTECTION ARCHITECTURE

Since, OCDMA system provides broadband services to the access domain, therefore it is imperative to design a protection scheme that can offer maxmimum connection availability at minimum cost. In this regard, cost and relaibilty of idividual component in OCDMA system is analyzed to determine the component with higher cost and need for protection. Table 1[5,8,9] shows that OLT requires highest cost (12100 $) among basic PON component. Moreover, cost (4000 $ for 25 km) of fiber is also of critical concern, since redundant light-wave paths are utilzed to provide protection at feeder and the distribution level. This might as well increase the deployment cost of OCDMA PON beyond the reach of common end user.

Moreover, it is observed from Table 1 that fiber at both feeder and distribution level provides the lowest connection availability as compared to other components of the network. Therefore, it is imperative to provide the necessary protection for fiber in order to ensure desirable connection availability of the proposed architecture.

Based on aforemnetioned analysis, a novel protection architecture is designed for OCDMA system, which empahizes on protecting feeder and distribution fiber. Moreover, special considertaion is given to negate fiber duplication to minimize the deployment cost. Figure 1 shown implemetation of the proposed tree-based hybrid protection architecture, which consists of OLT at the CO. OLT contain multip broadband soruces (BBSs) that generate required optical signal at different wavelengths. Thus, the proposed system utilize wavelength multiplexed OCDMA inorder to support large number of subscribers. End-face of each BBS is fed into an optical encoder, which translates the binary 0's and 1's, in coding scheme, to desired spectral representation. Output of each encoder is fed into Mach-Zhender Modulator (MZM), which modultes data of individual subcriber with non-return to zero (NRZ) line coding scheme. Output of MZM is connected with an optical circulator (OC_{co}) that splits the traffic for OLT receiver module and the access domain.

End-face of the OC_{co} is connected to an erbium dopped fiber amplifier (EDFA), which apmlies the

Table 1. Unavailability and cost of PON components

PON Components	Unavailability	Availability	Cost ($)	Energy Consumption
OLT	5.12e^-7	99.9999%	12100	20 W, 25 W with EDFA, 2 W (standby)
ONU	1.54e^-6	99.9998%	350	1 W, 0.25 W (standby)
Optical Circulator	3e^-7	100 %	50	
Optical Switch	1.2e^-6	99.9999%	50	
1:2, 2:2 OCP	3e^-7	100%	50	
1:N, 2:N OCP	7.2e^-7	99.9999%	800	
Fiber (/Km)	1.37e^-5	99.9986%	160	

encoded spectrums to a desired value. Output of EDFA is further conencted to an optical switch (OS_{co}) as shown in Fig. 1. OS_{co} provides the required redundancy at feeder level by swithcing between primary and secondary FF respectively. Under normal conditions, OS_{co} is at port 1 and all traffic is transmitted over the primary FF (FF_p). In case of failure, OLT medium access control (MAC) layers flips the switch towards port 2, which restores the flow of traffic between OLT and ONUs through secondary FF (FF_s). Two SMFs (FF_p,FF_s) are employed in this architecture to ensure maximum connection availability at the feeder level.

Output of both fibers is connected to a 2:N bidirectional OCP_{RN}, which feed individual DFs. End-face of each DF is fed into ONU through a 1:2 OCP_{onu} as shown in Fig. 1. This coupler is used to provide redundancy at the distribution level by forming a protection ring (PR) between adjancet ONUs. Port 2 of the OCP_{onu} is fed into an OS_{onu}, whereas port 3 extends the PR towards the neighbouring ONU. Under normal mode of

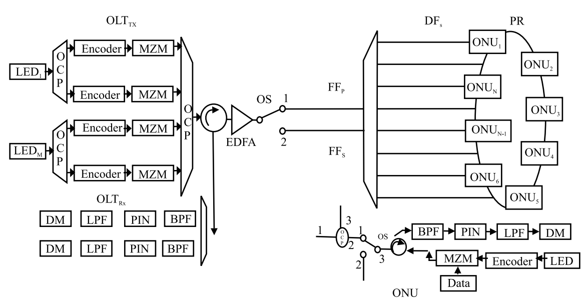


Figure 1. Proposed tree-based hybrid protection architecture for OCDMA system

operation OS_{onu} is at port 1 and all traffic is handeled through respective DF. In case of failur ONU MAC layers flips the switch position and restores the flow of traffic through redudant PR.

Output of the switch is connected with ONU receiver module, which consists of single bandpass filter that recovers the non-overlapping encoded chip only. This technique significantly elevates the performance by negating multiple user ineterference (MUI) and associated phase induced intensity noise (PIIN) at receiver[10-12]. Output of the bandpass filter is fed into PIN photodiode that coverts the signal from optical to electrical domain. Electrical signal is forwarded towards the low pass Bessel filter followed by the decision making circuit at each ONU.

3. COST VS. RELIABILITY ANALYSIS

3.1. Reliability Analysis

Reliability analysis determines the overall connection availability of protection architectures in order to determine a suitable architecture with minimum downtime per year. If i represent the number components, and i*u* is the unavailability of each optical component, then overall connection availability is given by[5]

$$A = 1 - \sum_{i=1}^{m} i_u \qquad (1)$$

Connection availability is determined by referring to reliability block diagram (RBD), which is a technique of arranging system components in series and parallel combination based on protection. Figure 2 shows RBDs of ITU, and the proposed protection architecture where each component is connected in series or parallel combination between CO and the subscriber premises. Series arrangement represent the unprotected section of network.

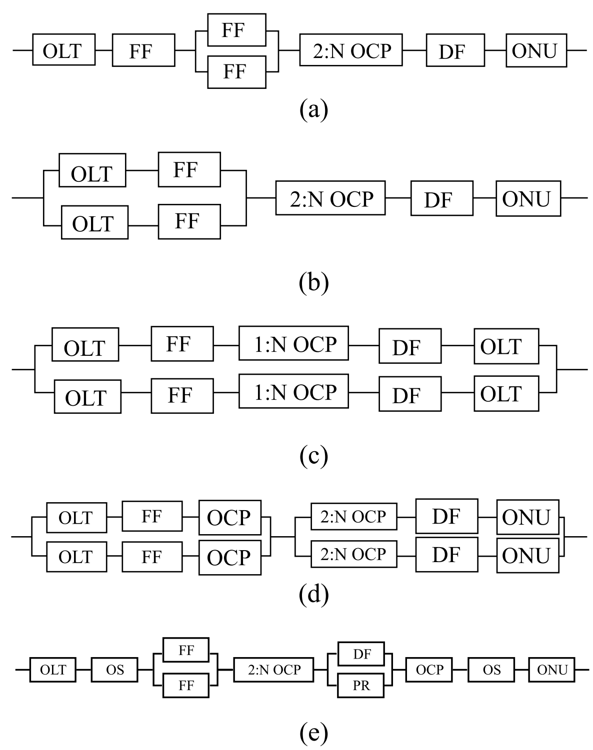


Figure 2. RBDs for (a) Type A (b) Type B (c) Type C (d) Type D (e) Proposed protection architectures

Whereas, parallel arrangement is used to represent the redundant components of protection architecture[5].

Now, connection availability of each protection architecture based on RBDs can be written as

$$A_A = 1 - [OLT_u + OS_u + (FF_u \times FF_u) + 2{:}\,N\,OCP_u + DF_u + ONU_u] \quad (2)$$

$$A_B = 1 - [(OLT_u \times OLT_u) + (FF_u \times FF_u) + 2{:}\,N\,OCP_u + DF_u + ON_u] \quad (3)$$

$$A_c = 1 - [(OLT_u \times OLT_u) + (FF_u \times FF_u) + (1{:}\,N\,OCP_u) + (DF_u \times DF_u) + (ONU_u \times ONU_u)] \quad (4)$$

$$A_D = -\,1\,[(OLT_u \times OLT_u) + (FF_u \times FF_u) + (OCP_u + OCP_U) + (2{:}\,N\,OCP_u \times 2{:}\,N\,OCP_u) + (DFu \times DFu) + (ONU_u \times ONU_u)] \quad (5)$$

$$A_P = 1 - [(OLT_u + OS_u + (FF_u \times FF_u) + 2{:}\,N\,OCP_u + (DF_u \times PR_u) + OCP_u + OS_u + ONU_u] \quad (6)$$

Figure 3 shows the overall connection availability of proposed tree-based hybrid protection architecture in comparison with existing ITU solutions. Highest connection availability is provided by both type C, and D protection architectures, where each component at feeder and distribution level is protected by redundant component. While type A, and B architectures yield the lowest connection availability since no protection mechanism is delivered at the distribution level. Figure also shows that the proposed hybrid protection architecture provides desirable (acceptable) connection availability (5 nines)

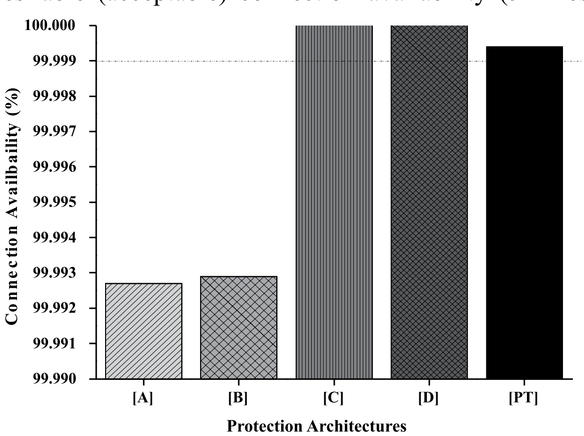


Figure 3. Connection availability analysis of proposed architecture in comparison with ITU schemes

through protection at fibers. For further investigation regarding feasibility of selected protection schemes, cost analysis is performed in the following section.

3.2. Cost Analysis

This section analyzes the performance of tree-based hybrid protection architecture in comparison with existing solutions through cost analysis technique from[5,9]. Network cost consists of two basic components namely CAPEX and OPEX. CAPEX includes the cost of optical components (including fiber) that is required to build the basic network architecture. OPEX on the other hand consist of multiple parameters including reperation cost, service interruption penalty cost and enrgy consumption cost etc. Cost figure is an improtant parameter that determines the most suitable architecture in terms of cost for a specific life span.

Following specification are considered for fair analysis of the proposed protection architecture in comparison with ITU-T G.983.1 tree-based protection standards.

- Analysis is performed for residential subscribers only.
- Length of feeder and distribution fiber is 20 and 5 km respectively.
- Length of redundanct protection ring in the proposed architecture is 1 km between adjancent nodes.
- Four PONs are considered with 16 subscribers per PON.
- Cost of burying fiber is ignored due to high variation between suppliers and localities.
- Cost of standard OLT and ONUs is similar to that of OCDMA based OLT and ONUs.
- Life span of the network is taken to be 20 years.
- Salary of reperation team is 1000 $/hour.
- Cost of per unit electricity is 0.25 $/kWh.

- Service interruption penalty cost is ignored, since the analysis is performed for residential customers only.

In order to determine the CAPEX of proposed architecture and ITU-T G.983.1 solutions, each network is divided into three parts. First part consist of components at the CO including OLT, OCPs, OSs, etc., second part contain FF and RN, whereas thrid part comprises of basic component in the distribution network including DFs, OCP, OSs, and ONUs. Thus, the CAPEX equations for existing ITU standards and the proposed protection architecture can be written as, where 4 represent the number of OLT ports (number of PONs).

CAPEX equation from 7-11 are based on RBDs, where 4 OLT ports and four OCPs are used in each architecture to support 16 ONUs per PON. Moreover, the cost of fibers at feeder and distribution level is determined by multiplying the length of fiber with the number of fibers, and the cost of per km fiber at both levels.

$$C_A = [(OLT \times 4) + OS + (2 \times 20 \times FF) + (4 \times 2:N\ OCP) + (5 \times 64 \times DF) + (64 \times ONU)] \quad (7)$$

$$C_B = [(2 \times 4 \times OLT) + (2 \times 20 \times FF) + (4 \times 2:N\ OCP) + (5 \times 64 \times DF) + (64 \times ONU)] \quad (8)$$

$$C_C = [(2 \times 4 \times OLT) + (2 \times 20 \times FF) + (4 \times 2 \times 2:N\ OCP) + (5 \times 64 \times 2 \times DF) + (64 \times 2 \times ONU)] \quad (9)$$

$$C_D = [(2 \times 4 \times OLT) + (2 \times 20 \times FF) + (4 \times 2 \times OCP) + (4 \times 2 \times 2:N\ OCP) + (5 \times 64 \times 2 \times DF) + (64 \times 2 \times ONU)] \quad (10)$$

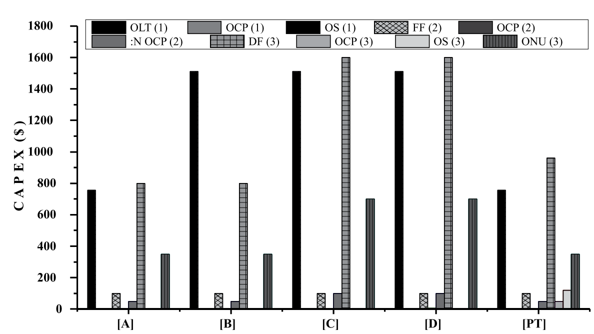
$$C_P = [(4 \times OLT) + OS + (2 \times 20 \times FF) + (4 \times 2:N) + (5 \times 64 \times DF) + (64 \times PR) + (64 \times OCP) + (64 \times OS) + (64 \times ONU)] \quad (11)$$

OPEX includes both reperation and energy consumption of optical component in selected network architectures. Reperation cost is computed by multiplying the downtime of each protection architecture with per hour salary of reparing team. Whereas, energy consumption of each component is compouted by multipying energy consumption in Table 1 with total life span and cost of elecritcity per kWh.

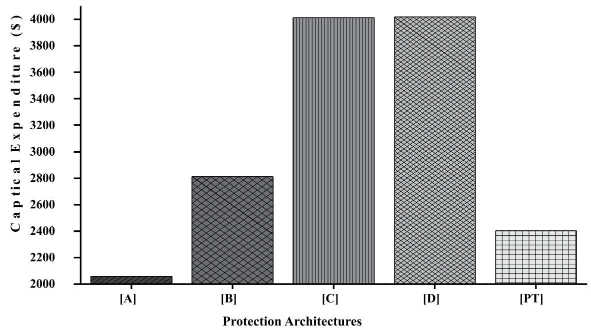
Overall CAPEX is divided by total number of subscribers (64) to determine the per user cost of deployment. Figure 4(a) shows the cost of individual component for the proposed protection architecture and existing solutions. It is observed that maximum cost is required by OLT at the transmitter module followed by DFs, that serves individual subscriber. Figure also shows that the proposed protection architecture requires minimum cost for implementation of the DFs (including PR) through its efficient star-ring architecture. Figure 4(b) represent the per subscriber CAPEX of the proposed architecture in comparison with existing ITU-T schemes. OPEX analysis is presented in Fig. 4(c), which indicates that type A, and B requires maximum reperation cost, since they suffer from maximum downtime (52.56 min/year). It is also observed that the proposed architecure along with type C, and D requires minimum OPEX due to desirable connection availbility, which reduce to downtime to (5.26 min/year). Moreover, utilization of minimum components in the proposed architecture for desirable redundancy consumes less energy which further reduce the OPEX consumed during selected life span.

Figure 4 shows the total cost including CAPEX and OPEX of ITU protection schemes in comparison with the proposed hybrid tree based protection architecture. It can be osberved that the proposed architecture requires minimum total cost as compared to ITU scheme. It is evident from the fact that proposed tree based hybrid protection architecture provides 5 nines connection availability at minimum components along with no fiber duplication at the distribution level. This significantly reduce the CAPEX and OPEX as compared to type C and B with same connection availability.

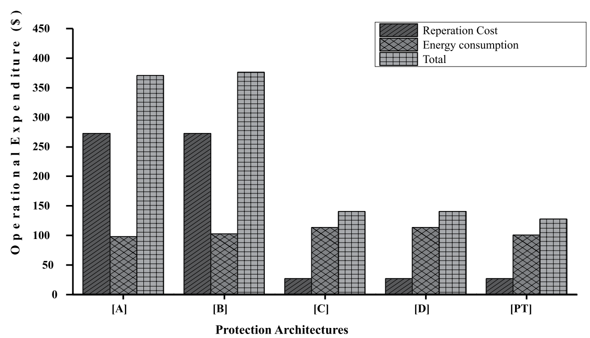
Cost vs. Reliability analysis shows that the proposed tree-based hybrid protection architecture is most efficient in terms of cost and reliability. Although highest



(a)



(b)



(c)

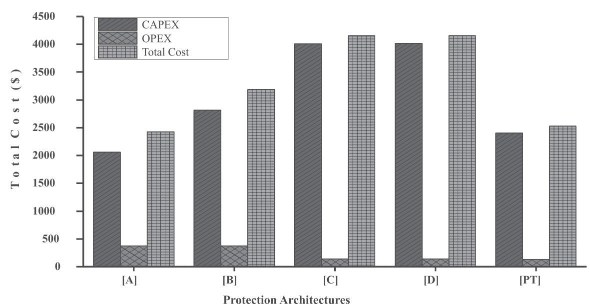


Figure 4. (a) Component wise CAPEX and (b) overall CAPEX (c) OPEX analysis

connection availability is provided by type C, and D of ITU standard. They require significant amount of CAPEX for duplicating every component throughout the network. Therefore, they are not feasible to implement the cost sensitive PON. The proposed protection architecute is a feasible solution, since it provides desirable connection availability through redundancy at both feeder and distribution level. Moreover, utilization of minimum components and high connection availability further reduce the cost of proposed tree-based protection architecture. Therefore, it is more efficient in terms of reliability and cost for deployment of OCDMA system at the access domain.

4. CONCLUSION

Cost and reliability are important parameters in network performance, since they determines the feasibility of deployment and affordability over network life span. This paper propose a novel protection architecture for OCDMA system and analyze its cost and connection availability in compariosn with existing soultions. CAPEX and OPEX is computed to determine the overall cost of the proposed architecture, in comparison with existing solutions, for the life span of 20 years. Furthermore, reliability of each architecture is determined to find the most suitable solution with high connection availability. Analysis shows that the poposed tree-based hybrid protection architecture provides desirable connection availability (99.9995%) at minimum cost per subscriber as compared to esixting solutions. Therefore, the proposed tree-based hybrid protection architecture is more feasible for the deployment of OCDMA systems at the access domain.

REFERENCES

1. *Davey, R.P., Grossman, D.B., and Rasztovits, M., 2009. "Long-reach passive optical networks". Journal of Lightwave Technology 27(3):273-291.*

2. *Wong, E., 2012. "Next-Generation Broadband Access Networks and Technologies", Journal of Light Wave Technology 30(24):597-608.*

3. *Ghafouri, S. H. and Karbassian, M., 2012. "Optical CDMA networks". Wiley. Chichester, West Sussex, U.K.*

4. *Wong, E., 2014. "Survivable architectures for time and wavelength division multiplexed passive optical networks". Optics Communications 325:152-159.*

5. *Wosinska, L., Chen, J. and Larsen, C., 2009. "Fiber Access Networks: Reliability Analysis and Swedish Broadband Market". IEICE Transactions on Communications 92(10):3006-3014.*

6. *Chen, H., Gan, C., Yin, M. and Ni, C., 2014. "A Single-Star Multi-Ring Structure of Self-Healing Wavelength Division Multiplexing Optical Access Network". Fiber and Integrated Optics 33:4-16.*

7. *Qiu, Y. and Chan, C., 2014. "A novel survivable architecture for hybrid WDM/TDM passive optical networks". Optics Communications 312:52-56.*

8. *Grobe, K., Roppelt, M., Autenrieth, A., Elbers, J. and Eiselt, M., 2011. "Cost and energy consumption analysis of advanced WDM-PONs". IEEE Communincation Magazine 49(2):25-32.*

9. *Jiajia, C. and Wosinska, L., 2007. "Performance Analysis of Protection Schemes Compatible with Smooth Migration from TDM-PON to Hybrid WDM/TDM-PON". in Optical Fiber Communication Conference.*

10. *Fadhil, H. A. and Aljunid, S. A., 2009. "Performance of random diagonal code for OCDMA systems using new spectral direct detection technique". Optical Fiber Technology 15: 283-289.*

11. *Abd, T. H. and Aljunid, S. A., 2011. "Development of a new code family based on SAC-OCDMA system with large cardinality for OCDMA network". Optical Fiber Technology 17:273-280.*

12. *Norazimah, M. Z., Aljunid, S. A. and Fadhil, H. A., 2011. "Analytical Comparison of Various SAC-OCDMA Detection Techniques". IEEE 2nd Conference on Photonics. Kuala Lumpur, Kata Kinabalu.*