POLITECNICO MILANO 1863

SCUOLA DI INGEGNERIA INDUSTRIALE E DELL'INFORMAZIONE

EXECUTIVE SUMMARY OF THE THESIS

Protection in Advanced PON architecture with minimum trenching cost

TESI MAGISTRALE IN TELECOMUNICATION ENGINEERING – INGEGNERIA DELLE TELECOMUNICAZIONI

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1. Introduction

In the past years, Passive Optical Network (PON) has become a widespread solution to provide broadband access connectivity at relative low cost. Latest evolution of PON technology allows to transmit data at higher rates (up to 50 Gbit/s) and at longer distances to the users (up to 40 km), enlarging the set of possible applications of PON architecture. However, traffic patterns of new services require certain modifications of PON architecture, referred to as Advanced PON [1].

Advanced PON physical topology is similar to the state-of-the-art PON (see Figure 1) and consists of an Optical Line Terminator (OLT) connected to the core network, the Remote Node (RN), which splits the signal between the end users, the Feeder Fiber (FF), that links the OLT and the RN, the Optical Network Units (ONUs) that are the end users, and the Distribution Fiber (DF), that connects each ONU to the RN.

The major innovation of Advanced PON is the possibility to have direct communication between the ONUs. In traditional PON direct communication can be established only between the OLT and ONU, but there is no possibility to have a communication that originates in one ONU and is terminated directly at another ONU.

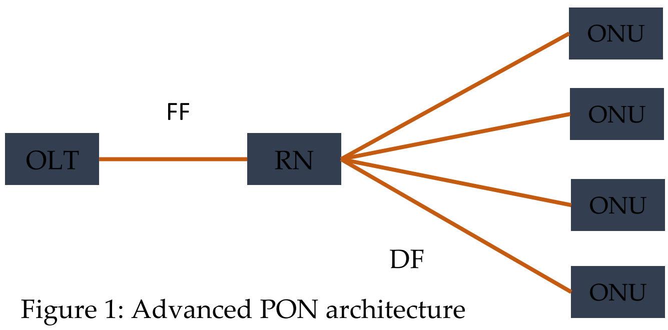

Figure 1: Advanced PON architecture

Several new services (e.g., 5G fronthaul) require inter-ONU communication with low latency, making detours through the OLT impractical and making Advanced PON a relevant candidate. In advanced PON, the internal architecture of the RN is modified to allow ONUs to directly communicate, avoiding the need for an optical-electronic-optical conversion at the RN and so establishing a so-called “local interconnect” between ONUs (i.e., a logical topology among ONUs), while still exploiting the existing PON architecture.

Since the new services envisioned for advanced PON have strict availability requirements, it is important to study how to extend the existing PON protection scenarios to protect traffic between ONUs. To the best of our knowledge, there have been no attempts to analyze protection in Advanced PON, so in this work we propose and analyze two protection schemes for local interconnects.

As trenching cost dominates the cost of network deployment [2], we propose an ILP model that maps primary and backup optical fibers in Advanced PON to the candidate trenches while minimizing trenching and fiber costs.

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2. Local interconnects

In this work we consider three types of local interconnects, i.e., one-to-any, any-to-few, any-to-any. In one-to-any scenario (see Fig. 2), there is only one ONU, tipically representing the macrocell (MC), that needs to exchange traffic with all other ONUs. This scenario is suitable, e.g., for communication between the Distribution Unit at a MC and Radio Units at ONUs in 5G Radio Access Network (RAN).

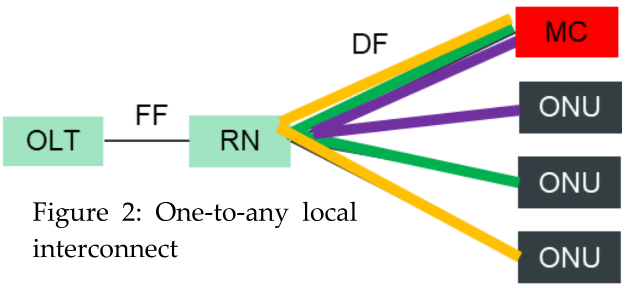


Figure 2: One-to-any local interconnect

In any-to-few scenario (see Fig. 3) the application built upon the advanced PON requires each ONU

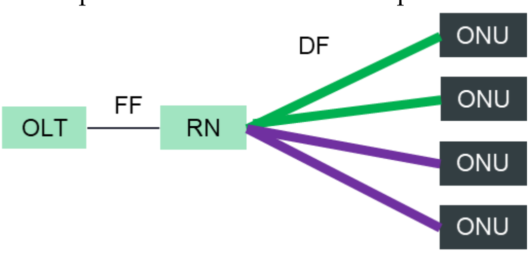


Figure 3. Any-to-few local interconnect

to exchange traffic with a limited number of neighboring ONUs, such as, e.g., for an inter-cell interference mitigation communication.

In any-to-any scenario (see Figure 4) each ONU communicates with each other ONU, e.g., as in an inter-data-center traffic exchange, where each ONU is located in a different DC area.

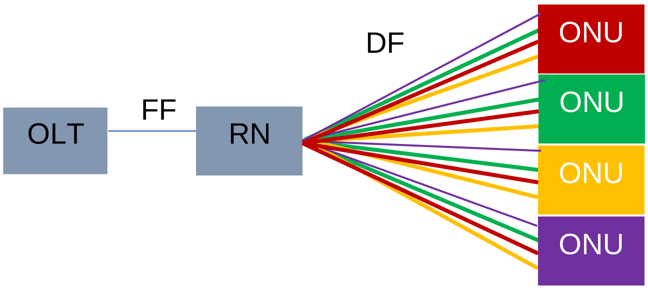


Figure 4. Any-to-any local interconnect

3. Protection in local interconnects

PON protection has been investigated by the research community. Four protection schemes, often referred to as protection type A, B, C, D, have been proposed, that guarantee different levels of protection by duplicating different equipments of the network. In protection type A (Fig. 5) the only duplicated elements are the FF and DF. In protection type B (Fig. 6) also the OLT is duplicated. In protection type C (Fig. 7), the whole OLT-FF-RN-DF section is duplicated for users that require high level of protection. Finally, in protection type D (Fig. 8) an additional fiber connects the backup OLT with the working RN and the working OLT with the backup RN in order to guarantee a higher level of protection for all PON users.

To protect DF section at minimal cost, existing work has investigated on how to find a layout of primary and backup DF fibers that minimizes the total trenching distance, assuming that trenching cost dominates PON deployment cost.

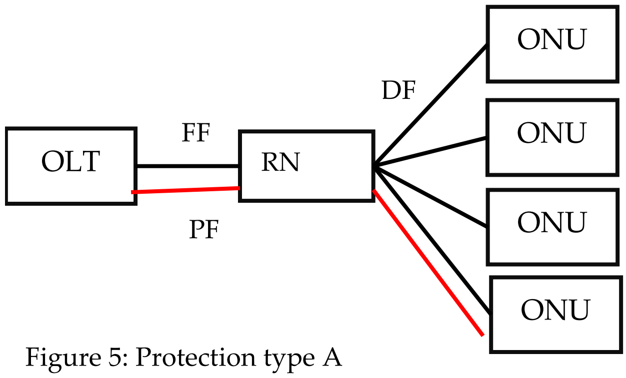


Figure 5: Protection type A

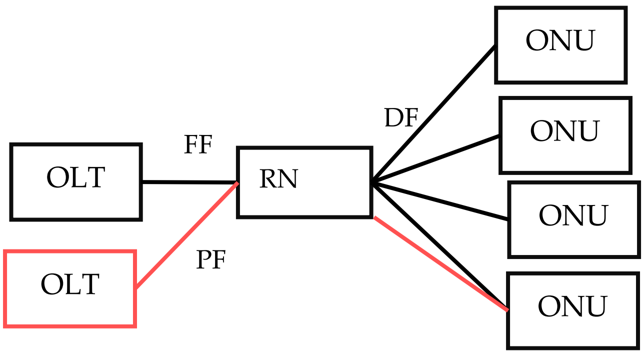


Figure 6: Protection type B

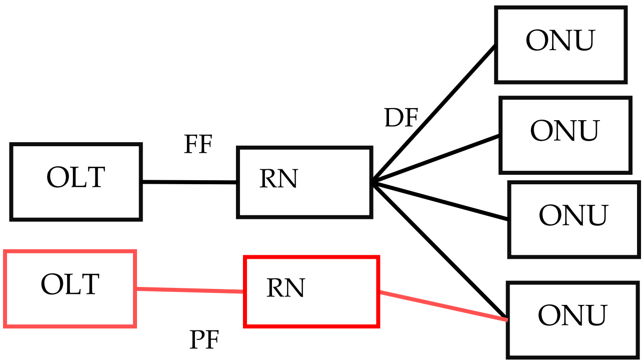


Figure 7: Protection type C

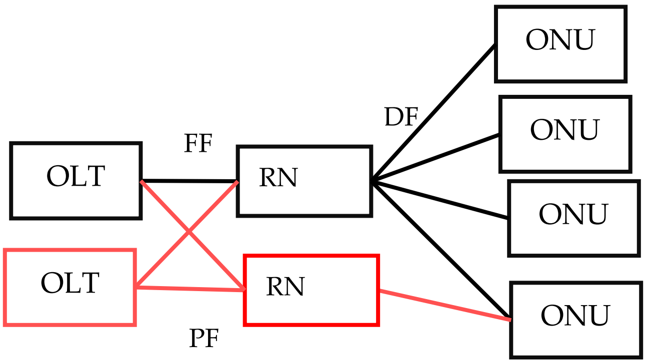


Figure 8: Protection type D

Protection types A-D have been traditionally developed to protect OLT-ONU traffic. Considering new applications envisioned for Advanced PON, these protection strategies must be extended to protect inter-ONU traffic in the local interconnect.

In this work we present and analyze two protection schemes, shown in Fig. 9, for inter-ONU communications: *i*) RN-ONU protection and *ii*) ONU-ONU protection. The first scheme duplicates two link-disjoint fiber paths that connect the RN with the ONU. The second scheme places a backup fiber path that connects the communicating ONUs. ONU-ONU protection is expected to have shorter backup paths and also less active ports at the RN. The ONU-ONU protection allows either to serve higher number of ONUs with the same RN or reduce splitting ratio and reach longer distances between the RN and the ONUs. Also, ONU-ONU protection makes local interconnect resilient to RN failures, as backup paths do not pass through it. However, for the same reason, ONU-ONU protection is inconsistent with protection types C-D, and OLT-ONU traffic cannot be protected against RN failure.

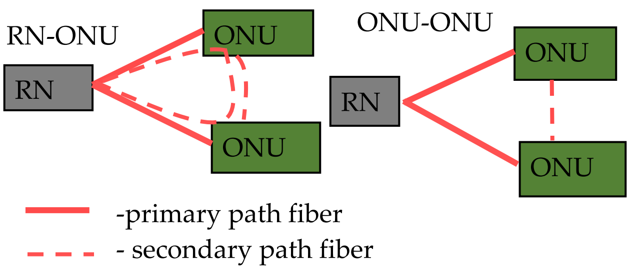


Figure 9. RN-ONU and ONU-ONU protection

For a fair comparison of the two schemes, they must guarantee the same level of protection. In Fig. 10a we show that, if working fibers of the two ONUs share the same trenching, and ONU-ONU protection is used, if that trenching becomes compromised, ONUs cannot connect the OLT. Conversely, in Figure 10b we show that OLT-ONU traffic is not affected if RN-ONU protection is used.

To equalize two protection schemes, we request that in case of ONU-ONU protection working fibers must be link disjoint. This way, if a working fiber of one ONU is cut, primary fiber of the other ONU is used to connect to the OLT. This additional constraint significantly affects the solution space for DF protection, especially when multiple ONUs must be connected.

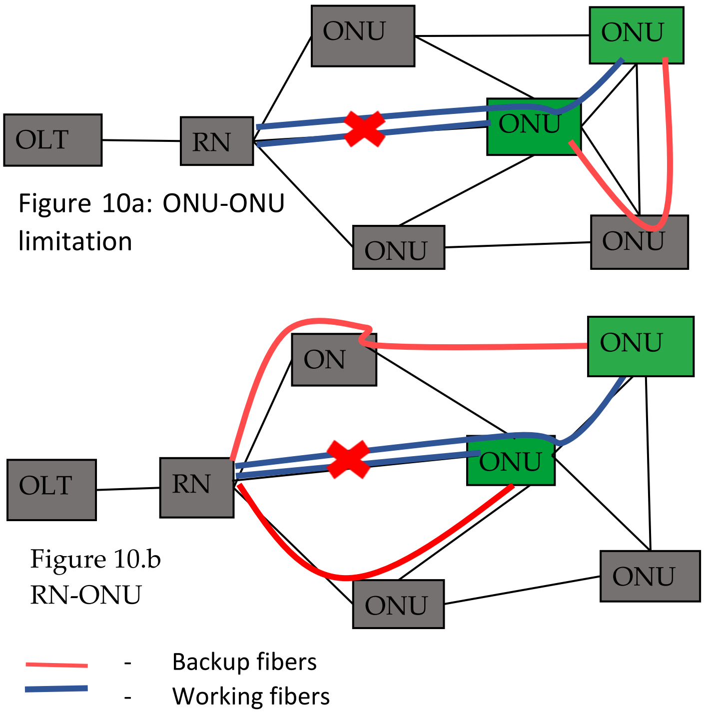


Figure 10a: ONU-ONU limitation

Figure 10.b RN-ONU

Figure 10. Link disjointness condition for ONU-ONU protection

4. Mathematical formulation of RN-ONU and ONU-ONU protection

We propose an algorithm for selecting the set of possible trenches and an ILP model that maps primary and backup fibers to the candidate trenches and minimizes total trenching costs and total fiber length.

4.1. Problem statement

Given the set of ONUs and the location of the RN, we must *find* trenches over which to map the working and the backup fiber paths to *minimize* the trenching and fiber costs, *so that* each ONU is connected to the RN, working and backup paths are disjoint, the maximum length between RN and ONU is limited and, in case of ONU-ONU protection, primary paths between two connected ONUs are link disjoint.

To solve this problem we adopt a two step approach: firstly we apply the algorithm to generate the candidate trenches topology and after we solve the ILP that selects which set of trenches minimize the total trenching costs and total fiber length.

4.2. Candidate trenching topology generation

To find a planar topology of candidate trenches, we use Delaunay Triangulation (DT). DT takes as input the locations of the ONUs we need to connect to the RN and outputs a maximum planar partition, which means that no trench can be added to the graph while keeping it planar. This type of topology is a god model for urban fiber deplyments. It is generated so that for each triangle identified by three links of the DT, there is no other nodes of the DT that are included in the circle that circumscribes the triangle.
The algorithm is based over the "void circle test" and on the "arc flip". The void circle test verifies if a node D is in the circle that circumscribes a triangle ABC or not: it takes as input the coordinates of the four nodes and computes the determinant of the following matrix:

$$\begin{vmatrix} X_A & Y_A & X_A^2+Y_A^2 & 1 \\ X_B & Y_B & X_B^2+Y_B^2 & 1 \\ X_C & Y_C & X_C^2+Y_C^2 & 1 \\ X_D & Y_D & X_D^2+Y_D^2 & 1 \end{vmatrix}$$

If the determinant is greater than zero the point is included in the circle. If the point is in the circle the arc flip is applied to change the set of triangle, so obtaining a triangle which do not include points: the two tringles composed by the four points A, B, C, D are identified by the four edges of the quadrilateral ABCD and by one diagonal, the arc flip consists in exchanging the diagonal selected with the other one.
Now that we have defined the "void circle test and the "arc flip" it is possible to define the algorithm that starts taking three random points from the set of nodes and adding the edges of the triangle that is identified by the three points to the DT. Then we go on adding one node at a time and maintaining the planar condition by the void circle test and the arc flip.

Algorithm 1 generation of the DT algorithm

1: Add three random nodes and the edges between them to the DT
2: Add a random node v to the DT and identify the triangle T_i that contain it
3: Add the edges that links v with the vertex of T_i to the DT
4: Apply the void circle test on each triangle of the graph and if it is not verified apply the arc flip
5: If there are other nodes to add return to point 2 otherwise return the DT

4.3. ILP model

The ILP takes as inputs the topology generated as described in the Section 4.2 and the set of working and backup fiber demands, giving as output the total cost of trenches used to map the working and the backup fibers for all the demands and the total fiber length. The objective function of the ILP minimizes the total trenching distance, the total fiber distance and the total working path length, each of them with its relevance weight. The solution of the ILP has to respect the flow constraint, which guarantees that the fiber for a given request starts in its source and ends in its destination, and this for both the working and backup demands. At the same time the constraints that must be respected are that the fiber length of each distribution fiber does not exceed the maximum allowed distance, assumed to be 40 Km, and the link disjointness condition which guarantees that the working and backup fiber are geographically separated and, in case of ONU-ONU protection, that the working fibers of two ONUs that require protection for their local interconnects, are link disjointed.

In RN-ONU protection backup fibers start at the RN and end at an ONU, while working and backup paths must be link disjoint in ONU-ONU protection backup fibers start and end at ONUs, while working paths of both ONUs and backup path must be disjoint.

Equations can be found in the thesis.

5. Numerical results

We compare RN-ONU and ONU-ONU protection in terms of total trenching distance, total working fiber length and total backup fiber length, using different topologies.

We use RN-ONU protection as a reference scheme and plot the percentage increase in the listed metrics for the ONU-ONU protection for the different local interconnect scenarios. We generate 5 random traffic matrices for each topology to average the results. We also investigate different % of protected ONUs.

Figure 10 shows that ONU-ONU protection requires higher total trenching distance, especially in any-to-few and any-to-any local interconnects. Figure 11 shows that ONU-ONU protection also requires higher total working fiber length, especially in any-to-few and any-to-any scenarios, due to disjoint primary paths condition. However, as expected, ONU-ONU protection generally requires shorter backup fibers.

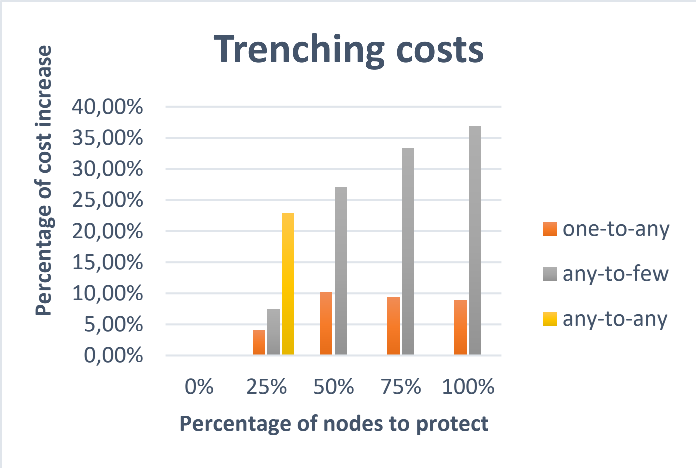
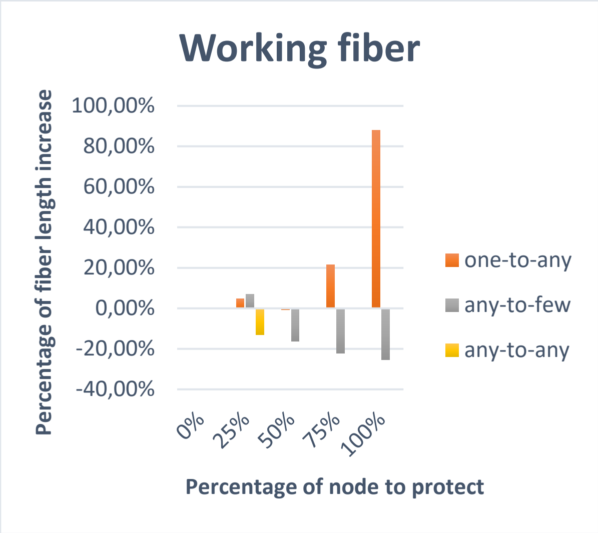


Figure 10: Trenching costs



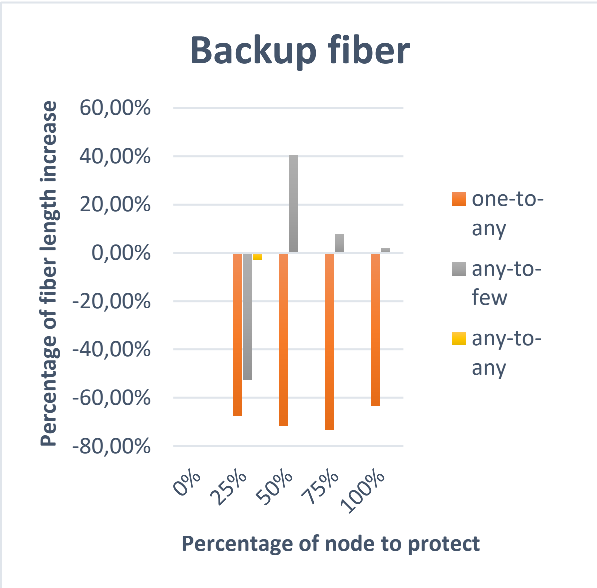


Figure 11: Working and backup fiber length

6. Conclusion

We have proposed and analyzed two protection schemes for ONU-ONU traffic protection in Advanced PON, i.e., RN-ONU and ONU-ONU protection. We have developed an ILP model that maps primary and backup optical fibers to the candidate trenches while minimizing trenching cost. Finally, we have compared two protection schemes in terms of their cost in different network scenarios and % of protected users.

Numerical results show that ONU-ONU protection leads to an increased trenching costs for all the network scenarios. However, cost increase in the one-to-any scenario is below 10%, so that ONU-ONU protection can still be considered by the network operators due the benefits that come with the lower RN degree.

References

[1] P. Thomas, “Advanced PON Architectures,” in *Springer Handbook of Optical Networks*, Stuttgar, Germany, Springer Nature, Mukherjee B., Tomkos I., Tornatore M., Winzer P., Zhao Y., pp. 753-788.

[2] J. Chen, M. Mahloo, A. Dixit, D. Colle e M. Pickavet, *“Efficient Protection Schemes for Hybrid WDM/TDM Passive Optical Networks”*, Ghent, Belgium: Department of Information Technology Ghent University-IBBT.

[3] ITU-T Rec. Series-G Supplement 51, *“Passive optical network protection considerations”*, vol. 171, Geneva, 2016, p. 737–738.