Homing Architectures in Multi-Layer Networks: Quantifying the Effect of ODU Switching

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Abstract: Alternative homing architectures can lead to significant cost reductions. Using linear programming we quantify these reductions for IPoWDM and IPoOTN networks under a multi-layer consideration for a reference network topology and varying traffic demand.

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1. Introduction

As the pressure to drive down network costs increases without compromising the stringent availability requirements imposed by service Level Agreements (SLAs), the development of advanced techniques to optimize the interaction between network layers becomes a necessity. To this end multi-layer networks have been investigated, influencing network design and provisioning [1]. The requirements of high quality of service (QoS) lead to the elimination of single points of failure (SPoF). As a result, network elements and connections are often duplicated. The interconnection of core networks with metro/access networks becomes crucial, resulting in the attachment of services at two different network elements. This redundancy, which is introduced through such configurations, opens the path for investigation of resource efficient homing architectures, where homing is defined as the interconnection of an access router to a core router.

Various homing architectures are studied and compared in [2]. A qualitative evaluation, as well as a classification of homing architectures in multi-layer networks is offered in [3]. A generic multi-layer multi-homing model is proposed in [4], where the tradeoffs between the network equipment cost and availability are quantified for homing architectures deploying optical cross connects (OXCs). Unlike previous literature, in this paper we study the influence on the optimal CAPEX for network equipment for homing architectures deploying electrical cross connects (EXCs) provided by optical data unit (ODU) switching technology. We identify not only the tradeoffs occurring between different homing architectures when EXCs are deployed, but also the influence of this replacement within each architecture. The paper is organized as follows. In Section 2 different homing architectures are briefly presented. Section 3 discusses the conducted case studies and Section 4 provides the conclusions.

2. Homing Architectures

In [3] homing architectures are classified according to their characteristics. In the following the studied architectures will be briefly presented under a multi-layer consideration. We first consider the dual homing case. In this architecture two core routers are deployed in each site and every access router maintains connections to both of them. This architecture is highly robust against single core router failures. Fig. 1(a) depicts the equipment interconnections, where the continuous and dashed lines represent separate IP planes.

Completely eliminating the redundancy on the router level for the edge traffic leads us to single homing architectures. Each access router is directly connected to the only core router deployed in each site (Fig. 1(b)). As a result, there is no possibility to survive a core router failure without the loss of edge traffic at the failed router site.

The third studied homing architecture is referred to as dual homing with shared backup router resources. The additional required IP level resources (i.e. IP router ports, IP line cards) in order to provide protection against core router failures can be allocated to routers already carrying traffic in the failure-less case or to separate shared backup routers. This approach can be viewed as a network-wide pool of resources, which is shared by the failed entities. An instance of this architecture is depicted in Fig.1(c). Note that in this case the shared router resources are provided by one separate router. In case of a core router failure, the cross connects (OXC/EXC) establish connectivity with the shared router as the access routers are connected to the core routers through the cross connects. Note that depending on the core router availability values, additional shared backup routers could be required in order to achieve the desired network availability.

Depending on whether OXCs or EXCs are deployed, the dual homing architecture cases are referred to as DH+OXC and DH+EXC respectively. In a similar manner the two flavors of the single homing (/shared backup router resources) architecture are referred to as SH+OXC (/SBRR+OXC) and SH+EXC (/SBRR+EXC) respectively.

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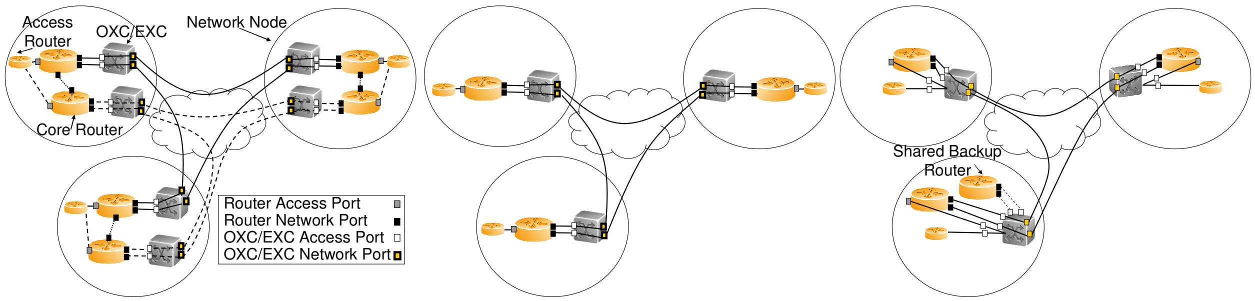

(a) (b) (c)

Fig. 1. Homing Architectures. (a) Dual homing , (b) Single homing, (c) Dual homing with shared backup router resources.

3. Case Studies

In this section we describe the performed case studies. The generic multi-layer multi-homing mathematical model given in a linear programming formulation, which is presented in [4], was applied enabling the calculation of the minimal network cost. The reference network used in our analysis is a 17-node Germany reference network, consisting of 26 links with an average length of 170 km [7]. The set of candidate paths used in the optimization is limited to the paths having a maximum of ten hops for every node-pair.

It is noted that the optimization gap is set to 5% (i.e. the obtained cost result is within 5% from the optimal value). The inter-node traffic demand is uniformly distributed between 0 and x Gbit/s for half of the node pairs, where x is dependent on the required average value. The remaining inter-node traffic demands are set to zero in order to keep the computational time in a tractable range. We consider transport link failures as well as core router failures and calculate the optimal cost over all failure cases. Two different options concerning router bypassing are implemented: (i) the establishment of a path bypassing all of the intermediate routers between node-pairs and (ii) the performance of intermediate grooming at all of the traversed nodes. Wavelength assignment is not considered due to the computational complexity and the minor incurring cost increase. Additionally, amplifiers and regenerators are not included in the conducted study as they are expected to have limited influence on the total costs (around 5%).

The network equipment cost values from the cost model provided in [6] are used except if stated otherwise. The equipment costs are relative costs that are normalized to the cost value of a 10G long haul (LH) transponder. Depending on the required capacity, the optimal router and EXC basic node as well as the degree of the OXC are selected independently for every network node. As for the router port cards, 10 X 1 gigabit Ethernet (GE) short reach (SR) interfaces are used on the tributary side and 40 Gb/s long reach (LR) GE interfaces are used on the trunk side. The OXCs, having an add-drop capacity of 100% and a capacity of the optical line system of 80 channels, incur a fixed cost and an additional cost related to the number of bidirectional fiber ports connected. The access interfaces of the OXCs are 40G LH transponders and there are no corresponding network interfaces. The access interfaces of the EXCs are 4 X 10 GE (1.40 cost units) and the corresponding network interfaces are colored LH STM-256/ODU3 (3.00 cost units). Finally for the shared router resources architecture additional 10G LH transponders (/10GE XFP LX) are required to interconnect the access routers to the core routers through the OXCs (/EXCs). Note that one separate shared backup router is deployed in the network.

In Fig. 2(a) and in Fig. 2(b) the CAPEX for network equipment is shown as a function of the average internode traffic demand for homing architectures deploying OXCs and EXCs respectively. It is observed that the network equipment costs follow an approximately linear relationship with the traffic demand. As it is expected the dual homing architecture requires the highest CAPEX - reaching 170% and 156% of the single homing costs for the OXC and EXC cases respectively. When comparing the shared router resources with the single homing architecture for the OXC case, an average relative difference of 17% is observed. This relative difference falls to 10% when EXCs are deployed as lower costs required for interconnecting the access routers to the core routers through the EXCs. Note that the shared backup router resources architecture would require marginal additional software costs.

In Fig.2(c) the two flavors (OXC/EXC) of the homing architectures are compared in terms of their relative CAPEX. We observe that for low traffic demand the EXC alternative outperforms the OXC one. However, this does not hold with traffic demand increase, where a higher wavelength utilization factor is achieved. Additionally, this is enhanced by the fact that the EXC basic node cost increases significantly with the carried traffic, while the OXC basic node cost scales with the degree of the node. Note that the break-even point between these two cases is dependent on the homing architecture. At an average internode traffic demand of 40 Gb/s the SH+EXC architecture is almost 20% more costly than the SH+OXC case, whereas the dual homing architecture is still at its break-even point. DH+OXC eventually outperforms DH+EXC, but for higher traffic demand. This is influenced by the traffic that is carried per router (with dual homing less traffic is carried), leading to higher wavelength utilization factors.

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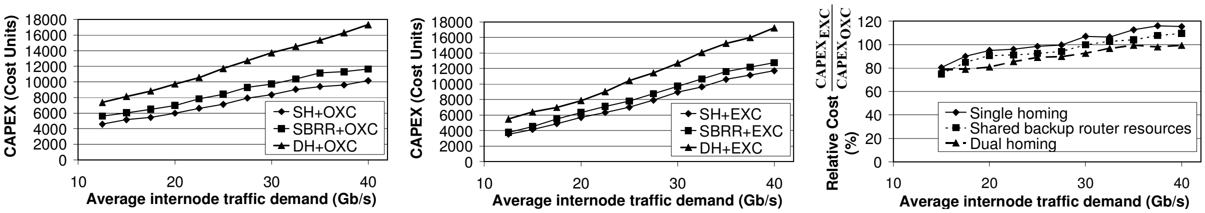
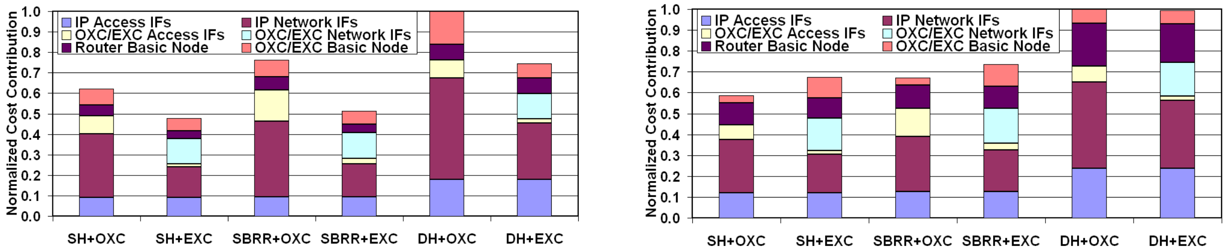


(a) (b) (c)

Fig. 2 (a) CAPEX for network equipment (normalized to the cost value of a 10G LH transponder) over traffic demand for homing architectures deploying OXCs, (b) As in (a) for homing architectures deploying EXCs , (c) For each homing architecture the CAPEX of the case deploying EXCs relative to the CAPEX of the case deploying OXCs is shown as a function of the traffic demand.



(a) For an average internode traffic demand of 12.5 Gb/s (b) For an average internode traffic demand of 40 Gb/s.

Fig. 3. The cost contribution of the network elements is shown for all homing architectures and for the deployment of OXCs or EXCs. The costs are normalized to the total CAPEX of the dual homing architecture deploying OXCs.

In Fig. 3 the normalized cost contribution of the different network elements is shown for all homing architectures. The costs are normalized to the total CAPEX of the dual homing architecture deploying OXCs. Fig. 3(a) and Fig. 3(b) correspond to an average internode traffic demand of 12.5 Gb/s and 40 Gb/s respectively. Hence, we can compare relative cost contribution of network equipment under different traffic load scenarios. We observe that for the high demand case the core router basic node contribution is significantly higher, in some cases exceeding double the relative cost contribution of the low demand case. This is caused by the extra costs arising due to multi-chassis configurations. The relative cost contribution of the OXC basic nodes is reduced to less than half in the high demand case as almost the same cost is distributed over higher total network CAPEX. It is interesting to observe that the relative cost contribution of the other elements remains relatively constant. Additionally, for low traffic demand significant savings in IP network interfaces (in the order of 50%) can be achieved by deploying EXCs.

At this point it is more obvious why the dual homing architecture is more expensive compared with the single homing case when OXCs are deployed. This is caused by the scaling of the EXC basic node costs with the traffic demand. In the dual homing case double the OXC basic node costs are required compared with the single homing case. When EXCs are deployed, single homing requires higher or equal or basic node costs than dual homing.

4. Conclusion

Increasing pressure for reductions in capital expenditures for network equipment necessitate the study of alternative network architectures. We examine three different homing architectures under a multi-layer consideration in two flavors (deploying OXCs or EXCs). Case study results show that the EXC and OXC alternatives of the shared backup router resources architecture require on average only 10% and 17% higher costs respectively than the single homing case, offering the possibility to restore edge traffic under all single core router failures. For low traffic demand the EXC flavor outperforms the OXC one (up to 30% CAPEX savings), whereas with significant traffic demand increase the roles are reversed. We find that the break-even point between these two flavors is dependent on the homing architecture, with dual homing requiring higher traffic demand to reach this point. Note that the requirement of dynamic optical channel setup is imposed by the OXC alternatives, increasing restoration times.

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