Techno-economic Analysis of a Dynamic Impairment-Aware Optical Network

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Abstract: We quantify the performance of impairment-aware networking in terms of capital and operational expenditures and compare it to an impairment-unaware solution in the presence of nodes that bear different degrees of flexibility.

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1. Introduction

When planning or upgrading a long haul core network it is important to optimize investments by balancing the cost and frequency of equipment installations. Previous work has shown the economic benefits of transparent networking, with Capital Expenditures (CapEx) savings up to 50% by avoiding unnecessary optical-electronic-optical (O/E/O) conversions [1] and significant Operational Expenditures (Opex) savings due to the minimal power consumption of photonics [2]. However in a transparent network as the physical-layer impairments accumulate, the quality of transmission (QoT) degrades and therefore error free detection of the optical signal can be achieved only for a finite distance [3]. In this context Impairment Aware (IA) transparent networks make maximum use of the optical reach as this leads to lower blocking rates and more efficient utilization of resources.

In addition to the photonic switches that effectively enable transparency, reconfigurable optical switching components are adopted due to their flexibility to support dynamic traffic in a cost-effective manner [4]. Reconfigurable optical networks allow operators not to over-provision their network with equipment meant to serve future variations in traffic. In this work we study CapEx and OpEx reductions achieved by an IA networking solution under the flexibility constraints of different node architecture and show that the IA solution achieves better resource optimization when compared to an Impairment Unaware (IUA) solution without QoT considerations.

2. Methodology

To assess the IA network planning, we dimension a reference network, comprising of 14 nodes and 23 bidirectional links, using the offline IA Routing and Wavelength Assignment (IA-RWA) algorithm proposed in [5]. The IA-RWA algorithm is compared to an IUA method that does not consider any physical-layer constraints. The two algorithms are fed with the same traffic matrices and their output (essentially the lightpaths that serve the traffic demands) is used to calculate the capital and operational costs, by adding the required component costs (amplifiers, add/drop terminals, transponders, network interfaces) of each solution. The IUA-RWA algorithm that was employed stems from the IA-RWA algorithm, yet only taking into account the wavelength availability and continuity constraints. The output of the IUA algorithm is checked afterwards for feasibility by the same QoT estimator used by the IA-RWA algorithm. To quantify the planning solutions of the two RWA approaches we assume that the network is equipped with 80-channel line systems. If the 80-channel system is exhausted in terms of resources, a parallel line system is installed.

Additionally, the analysis is performed for four (4) different types of node architectures that differ in terms of flexibility (bearing or not the features: directionless, colorless, contentionless). The cost of the different architectures depends on their physical implementation, presented in detail in [6]. The CapEx and OpEx model for the various node components and the capabilities of the four node architectures are summarized in Table 1. It is based on [6] and updated through a survey of the most recent list prices published by component manufacturers and system vendors [7].

Table 1: Component CapEx, Network-related Opex and node capabilities [7]

Equipment	Relative cost	Power consumption [W]	Mean Time Between Failures
Long reach 10G Transponder	1	30	250,000
EDFA, double stage	1.33	25	500,000
EDFA, single stage	1	15	500,000
1x4 WSS (80 channels)	2.35	30	300,000
1x8 WSS	4.7	40	300,000
1x20 WSS	7.05	50	300,000
1x40 WSS (not commercially available)	10.58	60	150,000
Splitter(cost per port)	0.05	-	-
Combiner(cost per port)	0.13	-	-
AWG	0.7	-	-
Casing Node	2.5	-	-
Casing Network Interface	1-4	2-8	-
Casing AWG	0.5	-	-
Floorspace (Cost per square meter per year)	0.27	-	
Power (Cost per kW per year)	0.79	-	-
Repair cost per WSS failure	0.2	-	-
Repair cost per Transponder failure	0.1	-	-
Repair cost EDFA double/single stage	0.1	-	-

Node type	Directionless	Colorless	Contentionless
R-OXC6	no	no	yes
R-OXC4	no	yes	no
R-OXC3	yes	yes	no
R-OXC2	yes	yes	partly

3. Results

We consider a traffic load scaling from 0.8 to 1.1, where load 1 corresponds to a traffic matrix with one 10-Gb/s connection request per pair of nodes (i.e. 182 lightpaths for the 14-node reference network). The CapEx results with respect to the induced traffic load for R-OXC6 are depicted in Fig. 1 (left). For load 0.8, the two methods yield the same CapEx as both can serve the traffic with the 80 available channels. As the load increases, the cost of the IA network solution rises slightly due to the number of transponders, related to the increased number of demands, but it can still serve all of the demands on a single 80 channel line system. The IUA algorithm, however, requires more than 80 channels to accommodate the traffic, leading to a significant increase in CapEx. To resolve the physical blocking an extra parallel line system is installed, which translates to a cost increase of around 60% when compared to the IA counterpart. Fig. 1 clearly shows that the IA solution outperforms the IUA one in CapEx and the respective difference is directly proportional to the extra equipment that is required to serve the traffic without any blocking. The IUA solution does not consider the QoT in the lightpath computation and therefore the routing and channel allocation is not optimized. As a consequence, the IUA approach calls for a capital investment sooner than the IA one as the traffic increases. The two methods were also assessed in terms of CapEx assuming R-OXC4 (Fig. 1 right). The overall higher computed cost for R-OXC4 when compared to R-OXC6 is due to the increased flexibility of the node.

Fig. 2 illustrates the relative cost for the four architectures for load 0.8 (left) and load 1.1 (right). The cost is driven primarily by the number of add/drop terminals and the network interfaces. As a consequence, regardless of the traffic load the most flexible node, i.e. R-OXC2, appears as the most costly. In the OpEx estimations, the repair costs
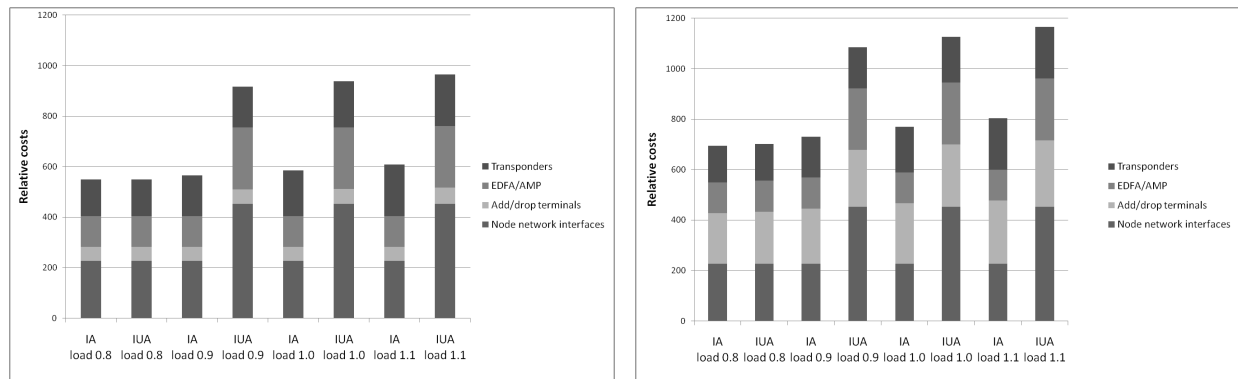

Fig. 1: CapEx of IA vs. IUA for R-OXC6 (left); CapEx of IA vs. IUA for R-OXC4 (right).
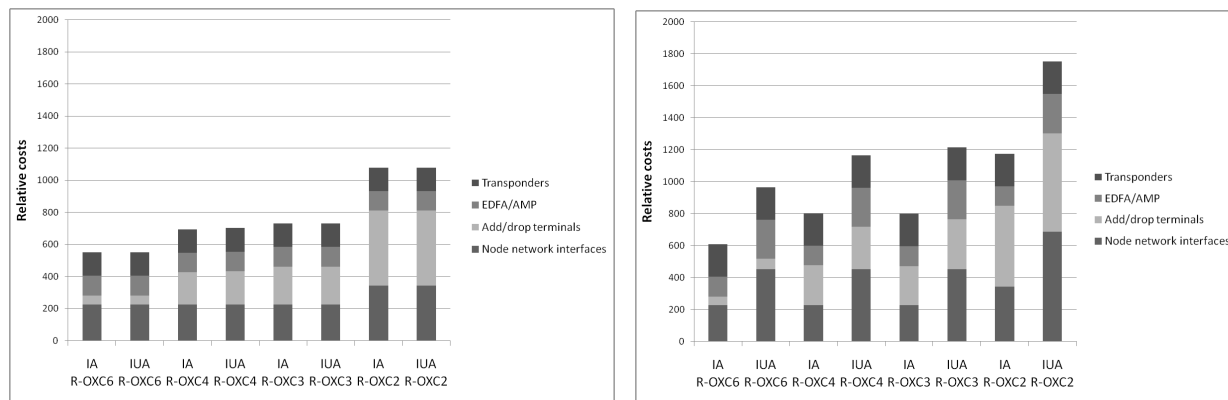
Fig. 2: CapEx of the different node architectures for load 0.8 (left) and load 1.1 (right).
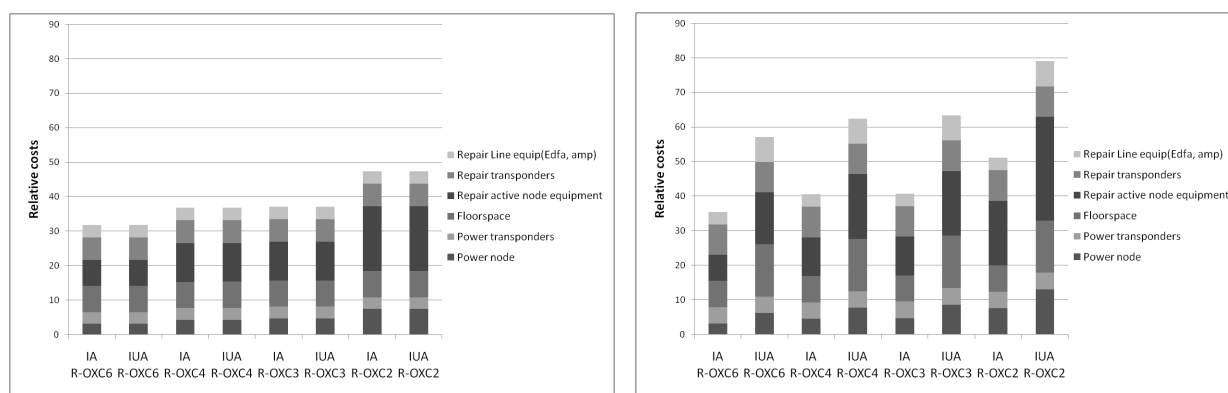

Fig. 3: OpEx of IA vs. IUA with R-OXC6 (left); OpEx of IA vs. IUA for load 1.1 (right)

and power consumption of the transponders are responsible for a slight increase for both cases when the traffic load increases (Fig. 3). Similar to the CapEx results, the sharp increase in the IUA case for loads higher than 0.8 is caused by the extra parallel line systems. Fig. 3 also depicts the computed OpEx for the four different node architectures. Overall the cost to repair the active node equipment accounts for the major part of the OpEx. The OpEx follows the same trend as the corresponding CapEx when considering the impact of the architecture and R-OXC6 incurs the lowest requirement in network-related OpEx. However, the cost of a flexible node (e.g. R-OXC2) may be counterbalanced by its superior performance under highly dynamic traffic conditions.

4. Conclusions

In this work we compared the resource optimization achieved by an impairment-aware network planning solution to a planning solution that is unaware of the signal QoT and showed that the optimization achieved by the former leads to capital and operational cost benefits. We also studied the role of the node architectures in the cost estimations and the results indicate that a flexible node induces higher network-related costs.

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