Cost-efficiency of mixed 10-40-100Gb/s networks and elastic optical networks

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Abstract: We compare the cost-efficiency of optical networks based on mixed datarates (10, 40, 100Gb/s) and elastic technologies. We show elastic network bring up to 37% lower cost, in particular for high loads and dynamic scenarios.

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1. Introduction

Progress in technology of optical cross-connects (OXC) and the reach of long-haul transmission systems have enabled the development of core optical networks in which optical signals are never converted to the electrical domain at intermediate nodes of a path (transparent network) or only when deemed necessary for regeneration or grooming purposes (translucent networks). These architectures are significantly cheaper and more energy-efficient than the opaque networks that preceded them.

Translucent networks may transport demands over widely different length scales and optical signals may thus experience very different amounts of physical impairments (ASE noise, filtering from cascaded OXC, non-linearities). Combining low-capacity long-reach channels with high-capacity short-reach channels has proven itself an efficient way of handling these various length scales as well as the wide range of capacity demands (from tenths to tens of Gb/s) [1].

Mixed-rate networks relying on different technologies for each datarate have been extensively studied and deployed, for instance using 10Gb/s On-Off Keying (OOK) and 40Gb/s Differential-Phase Shift Keying (DPSK). These networks benefit fully from the price erosion of mature technologies, in particular the very low cost of low-datarate connections. However, they leave very little place for reconfiguration [2] and conflicting requirements between different generations of technologies make it hard to use all datarates at their full potential jointly [3].

On the other hand, other network models, which we refer to as “elastic optical networks”, propose to use a single type of rate-tunable technology to handle all types of connections. Using a single type of technologies simplifies the design of network and allows optimal sharing of resources in dynamic networking scenarios, though at the cost of a high price per piece of equipment[4][5].

Benefits of elastic technologies have been studied with a number of metrics such as number of interfaces or occupied bandwidth [4]. In this article, we present what is to our best knowledge the first analysis of elastic optical networks in terms of cost and compare to the cost of mixed rate optical networks for static and restorable networks.

2. Network model and planning algorithms

We consider a 28-node European network comprising 41 bidirectional links with one fiber per direction. Each fiber is made of SMF spans carrying up to 80 wavelengths spaced by 50GHz in the C-band. Enough demands are drawn between randomly selected node pairs to generate traffic matrices with 5 to 20Tb/s loads. The capacity of demands is normally distributed with mean 60Gb/s and standard deviation 20Gb/s.

We consider in this cost study only the cost of opto-electronic interfaces (emitters, receivers and regenerators), which is generally seen as the main cost center of optical layers.

We consider mixed-rate networks based on 10Gb/s OOK, 40Gb/s DPSK and 100Gb/s Polarization-Division-Multiplexed Quadrature Phase Shift Keying (PDM-QPSK) with coherent detection. The price of interfaces is assumed to be 1, 3 and 6 respectively, which is balanced between mature and bleeding-edge cost models [1][2]. The transparent reach available is assumed to be 3000, 1600 and 800km for 10, 40 and 100Gb/s respectively. In this study we choose to mitigate the deleterious effect of OOK channels on 100Gb/s channels [3] by routing the three datarates in three separate bands, with 40G channels acting as buffer between 10 and 100G wavelengths. The width of each band is the same on all links of the network and is determined by the routing algorithm (see infra). No guard band is assumed between bands.

For the elastic network solution, we consider interfaces derived from 100Gb/s PDM-QPSK interfaces. These interfaces can take advantage of the versatility of the emitter structure and signal processing capabilities at the receiver to transmit at 25 and 50Gb/s by restricting the number of polarization and phase states used per symbol[4].

The price of such interfaces is expected to be very similar to the price of 100Gb/s interfaces. Rate-tunability slightly increases the complexity and hence the price of the interface. But a single interface for all rates also brings economies of scales and fast price erosion. We thus chose the cost of elastic interfaces to be 6α with α is close to 1. The transparent reach available at 25, 50 and 100Gb/s is assumed to be 3000, 2400 and 1200. The 400km increased reach of 100Gb/s in this scenario is due to the combined effects of (i) the absence of OOK channels in the fiber[3], (ii) the absence of dispersion management, lowering slightly the noise figure of optical amplifiers and improving the resistance to non-linearities [6]. Cost and reaches for both network solutions are summed up in table 1.

Mixed-rate network

Datarate (Gb/s)	Price (a.u.)	Reach (km)
10	1	3000
40	3	1600
100	6	800

Elastic network

Datarate (Gb/s)	Price (a.u.)	Reach (km)
25	6α	3000
50		2400
100		1200

Table. 1: Cost and reach estimation model of interfaces in mixed-rate and elastic networks. Mixed-rate prices follow trends of [1][2]

Routing and wavelength allocation (RWA) is performed with a heuristic derived from [7]. For each node pair, the heuristic considers all combinations of two datarates eligible to route the capacity demand between the node pair (e.g in a mixed-rate network, a 50Gb/s demand can be routed through 5x10Gb/s, 1x40Gb/s+1x10Gb/s or 1x100Gb/s). For each eligible combination, the algorithm finds a path for each wavelength and determines the number of required interfaces to add, drop and regenerate the signal according to the reach available to each datarate. The traffic computes the quantity $W=\sum_r \beta(r)C(r)N_{TSP,r}$ where r runs over the available datarates, $C(r)$ is the cost of an interface at rate r and $N_{TSP,r}$ is the number of required interfaces at rate r and $\beta(r)$ is rate-dependent weight . In elastic solutions, $C(r)$ is independent of r and equal to 6α. The heuristic then selects for each demand the combination of datarates minimizing W. When the network load is low and congestion is not an issue, $\beta(r)$ is chosen equal to 1 and W is thus the cost of routing a demand with a given combination of datarates. When blocking may occur, $\beta(r)$ is iteratively changed to $\beta(r)=(r_{min}/r)^{\varepsilon}$, $\varepsilon>0$ (r_{min} is the minimum available datarate) until blocking disappears to favor high-datarate channels and thus reduce the bandwidth usage.

In restorable network scenarios, the algorithm also determines the number of required spare interfaces and wavelength needed to make the network resilient to all single link failures following the procedure detailed in [7].

For mixed-rate networks, the number of lightpaths required at 10, 40 and 100Gb/s is first computed through minimization of W per node-pair and demands are then re-routed so as to respect the per-band channel allocation.

3. Results

We first consider completely static network scenarios and the total cost of the network as a function of traffic load for both mixed-rate and elastic solutions. The results are shown in Fig. 1(a), where the cost of elastic solutions is presented for values of α between 0.8 and 1.2. We also show in Fig. 1(b) the breakdown of the required interfaces in terms of data-rates for mixed-rate network and their total number for elastic networks.

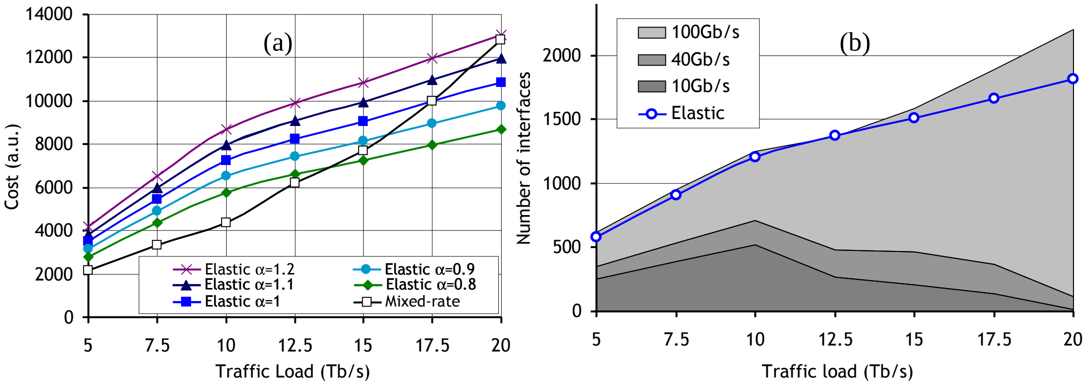

Figure 1: (a) Cost versus traffic load for static mixed-rate and elastic networks (b) Rate distribution interfaces for mixed-rate networks and total number of interfaces for elastic networks.

At low network loads we find as expected that mixed-rate solutions are very cost-efficient: they require marginally more interfaces than elastic networks but a large part of these interfaces are very low-cost 10Gb/s cards. We notice that for the choice of costs and reaches of this study, 40Gb/s connections are rare with the RWA tool preferring either cheap 10Gb/s connections or targeting directly high-capacity 100Gb/s solutions. When the traffic load increases, the cost benefit of mixed-rate solutions slowly vanishes, through two combined effects. Firstly, the necessity to route different datarates in separate bands of the spectrum wastes part of this spectrum. This requires to preferentially select high-datarate, and thus expensive interfaces, to avoid blocking as shown by the rapid increase in the volume of 100Gb/s interfaces in Fig 1(b). Secondly, high-datarates wavelengths in mixed-rate scenarios have a fairly short reach and thus necessitate frequent opto-electronic regeneration, further adding to the cost of the solution. Elastic solutions become more cost-efficient than mixed-rate solutions for high traffic loads (above 14Tb/s for $\alpha=0.8$, 14Tb/s for $\alpha=1.2$). For $\alpha=1$, we find up to 15% better cost efficiency for elastic networks at high network load.

In reconfigurable networks, the benefits of elasticity become more significant. We show in Fig 2 the cost of a restorable network versus traffic load. In elastic networks, the same spare interfaces can be used to restore wavelength at any of the available datarates while for mixed-rate scenarios, different spare interfaces must be provisioned for different datarates, thus requiring a higher number of spare resources [7].

In restorable networks, it is also worth noticing that some of the spectrum must be saved for the re-routing of restored wavelengths. This has two effects: firstly it forces the RWA process to preferentially target high-datarates to free up part of the spectrum, which means an increased need for regeneration, in particular in mixed-rate scenarios. The selection of high datarates is clearly shown in Fig 2(b) where low-datarate interfaces are almost never used for network loads above 15Tb/s. Secondly, in mixed-rate scenarios, spectrum must be saved for restoration purposes in each of the three spectral bands while some of this bandwidth can be mutualised in elastic networks.

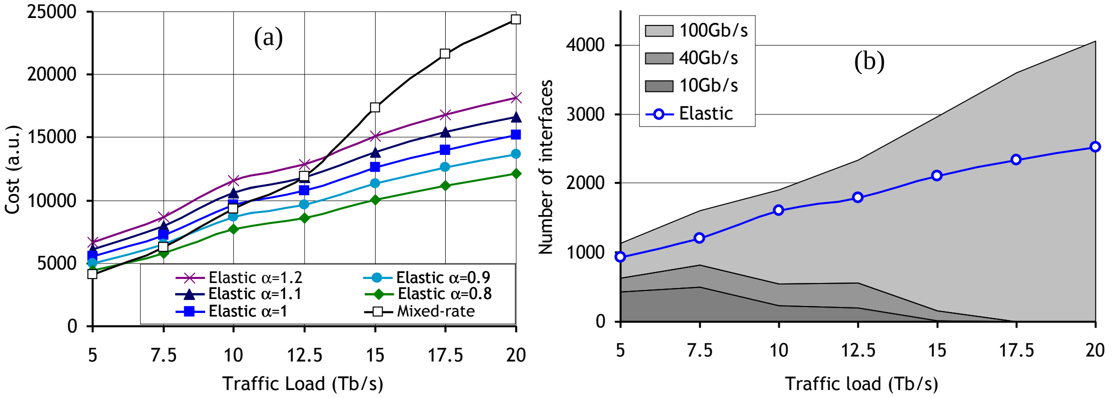

Figure 2: (a) Cost versus traffic load for restorable mixed-rate and elastic networks (b) Rate distribution interfaces for mixed-rate networks and total number of interfaces for elastic networks.

The combination of these effects makes elastic optical networks more cost-efficient for all but the lowest traffic loads. Elastic networks indeed require much fewer interfaces (20 to 35%) at only limited increase of the cost per interface compared to 100Gb/s interfaces. The cost benefits of elastic networks increase rapidly as the traffic load goes up, reaching 37% at 20Tb/s for $\alpha=1$.

4. Conclusion

We have compared the cost-efficiency of 10/40/100Gb/s mixed-rate and 25/50/100Gb/s elastic architectures for translucent transport networks. We have investigated the trade-offs between price of interfaces, reach and reconfigurability. We have shown that despite the high price of individual interfaces, elastic solutions can be more cost-efficient than mixed-rate solutions because of the better compatibility between different datarates, increasing the reach of channels and simplifying the wavelength allocation. In reconfigurable networks such as restorable networks, the benefits of elasticity are further increased. For the cost model considered here, we find that elastic networks can bring up to 37% reduction in the cost of a network.

5. References

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