Value Analysis Methodology for Flexible Optical Networks

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Abstract: A methodology for the estimation of the value of flexible networking in comparison with standard WDM solutions is presented, and specifications for the cost of the required flexible transponders and WSSs are extracted.
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1. Introduction

Telecom operators are facing today a two-fold challenge with traffic increasing almost 50% per year while capital and operational expenditures constrain the future infrastructure upgrades. Recent research advancements propose new transmission schemes for the future core networks to cope with the high-capacity requirements. “Flexible”, “elastic”, “tunable”, “gridless” or “adaptive” are few examples of the terms used by the research community to describe solutions that migrate from the fixed WDM single line rate (SLR) systems to systems with improved and heterogeneous transmission characteristics [1]. These solutions may be categorized into two broad groups; one refers to single-carrier systems [2] while the other includes multi-carrier ones based on Orthogonal Frequency Division Multiplexing (OFDM) [3]. Single-carrier solutions offer rigid granularity typically mixing 2-3 predetermined data rates that may be allocated in a fixed or adaptive manner [4]. On the other hand, the multi-carrier solutions introduce a high-degree of flexibility on the spectrum level, utilizing a variable number of low data-rate OFDM subcarriers [3] to effectively adjust the aggregate rate. This work focuses on the multi-carrier OFDM-based solution, further denoted as *spectrum-and-rate-flexible* (SF).

Focusing on the importance of spectrum as a resource, we have studied the problem of path and spectrum allocation in an optical OFDM-based network. In [5] we introduced and proposed solutions for the problem of the Routing, Modulation Level and Spectrum Allocation (RMLSA), equivalent to the typical Routing and Wavelength Assignment (RWA) problem of traditional WDM networks. Overall, recent works [6] that studied the performance of flexible networks over the traditional SLR architecture, showed superior performance that justifies the great attention received from the industry.

Nevertheless, to realize the level of flexibility of the multi-carrier solutions, new network and transmission elements need to be introduced in the optical transport, implying extra capital investment. Software-defined transponders [7] and bandwidth-flexible optical nodes [8] employing spectrum flexible WSSs (SF-WSS) are the key enablers for the implementation of this architecture. So far though, few works have addressed this transition from an economic point of view and have studied only specific aspects. The authors in [2] focused their study on the comparison of a mixed-line-rate network with a network employing a single, rate-adaptive transmitter that may offer 25/50/100Gbps, while [9] compared the CapEx of a 10/40Gbps network to a solution based on OFDM transponders.

In this work we introduce a methodology to explore the conditions under which the vision of flexible networking makes a good business case and discuss the cost implications stemming from the required capital investment in correlation with the gained spectrum optimization. This methodology is applied here to investigate how the spectrum savings in a SF network can overcome the added cost of the equipment and compared that to a SLR networking solution. It was found that in order to justify the infrastructural transition to the SF network, the required equipment may cost up to approximately 25% more than that of a SLR.

2. Methodology

The key metric considered in our previous work [5] is the “spectrum saving” resulting from the optimized packing of the connections in the frequency domain when the capabilities of OFDM technology are used, as opposed to traditional fixed-grid WDM networks. We expect that spectrum savings could be utilized for the provisioning of new traffic and/or revenue generating services. To translate the spectrum savings to a measurable entity, we introduce the cost of a "dark" 50GHz channel slot $c_{wavelength}$. This definition of a 50Ghz channel slot corresponds only to the cost of the link infrastructure (equipment/fiber) to support a 50GHz channel and excludes any cost associated with "lighting-up" this channel. We model the total cost of a system considering three main cost contributions. The first is related to the cost of the transponders, the second is related to the cost of the node equipment and the third is related to the number of “dark” 50GHz channel slots that are utilized and are associated only with the link infrastructure cost. In this study we used this approach to model the cases of a 100 Gbps SLR

WDM network and that of a SF network:

$$Cost_{SLR} = n_{SLR\text{-}100G} \cdot c_{100G} + n_{WSS} \, . c_{WSS} + n_{SLR\text{-}wavelengths} \cdot c_{wavelength} \quad (1)$$

$$Cost_{SF} = n_{SF} \cdot c_{SF} + n_{WSS} \, . c_{SF\text{-}WSS} + n_{SF\text{-}slots\text{-}to\text{-}wavelengths} \cdot c_{wavelength} \quad (2)$$

In the above equations, n denotes the number of the elements that are considered and c the corresponding cost of each element. To perform an illustrative comparison of the SLR and the SF network we have used the following cost values. We have assumed the cost of the 10 Gbps transponder equal to c_{10G}=2K € and we set the targeted cost for the 100Gbps transmitter $c_{100G}=6 \cdot c_{10G}$. It was also assumed that the transmission distance of the 100Gbps transponder is equal to 800 Km. The SF transponder has two flexibility degrees: (a) the spectrum, in terms of the number of 12.5 GHz subcarriers that it uses, and (b) the modulation format of the subcarriers, as a function of the transmission distance. To have a fair comparison it was assumed that the SF transponder can utilize up to four subcarriers of 12.5 GHz each. The corresponding transmission distance limits of the SF transponder was set equal to that assumed for the 100Gbps WDM transponder, so that if all four subcarriers are utilized, the SF transponder can transmit 100 Gbps to 800 Km. The achieved transmission distance varies with the selected modulation level assuming a decrease by half of the transmitted distance when the level doubles.

The SLR WDM networks utilize fixed grid wavelength selective switches (WSSs), assuming 50 GHz ITU-grid, with corresponding cost c_{WSS}, while the SF network needs to employ SF-WSS with corresponding cost $c_{SF\text{-}WSS}$. The basic switching capability of the SF-WSS was assumed to be 12.5 GHz. We set the corresponding cost of a conventional fixed-grid WSS c_{WSS}=12 K€, and the corresponding cost of the flexible SF-WSS to be variable and range between 0% and 100% over the cost of the conventional fixed-grid WSS.

In our analysis we considered as reasonable range for the cost of a "dark" 50GHz channel slot $c_{wavelength}$ to be 10K€ to 100K€. In our opinion and based on feedback we got from carrier's carriers and network operators, this cost range is justifiable. The typical range of prices for leasing a dark-fiber infrastructure (which of course excludes also the cost of transponders and optical nodes) is 1-3 € per meter for a long-term IRU (15-20 years). Considering that in a national scale network the average length of a light-path is several hundred of kilometers, one can easily deduce that the cost of leasing the corresponding dark fiber (with potential to carry 80 channels in 50GHz slots) is within a couple of million €. Therefore, the equivalent average link equipment/fiber related cost estimate we got for a 50GHz channel slot is within the range we have assumed to consider in our analysis. However, we would like to emphasize the fact that the wholesale leasing price of a fully operational 50GHz channel slot (for either 10Gb/s or 40Gb/s channel speeds which are currently available by some operators) is significantly higher (since this market is unregulated and not many companies can offer such wavelength services) than the cost range of a "dark" 50GHz channel slot we considered in our calculations. To be more precise, the price of a fully operational 50GHz channel slot (carrying 10Gb/s or 40Gb/s) ranges between 20K-60K € per month or 2M-6M € for a 20-year long-term leasing.

3. Results

To examine the performance of the proposed networking solutions we have assumed the nation-wide DT network consisting of 14 nodes and 46 directed links. We used the realistic traffic matrix of the DT network for 2009 and we scaled it up to 10 times to obtain traffic ranging from 3.6 Tbps up to 36 Tbps, respectively. We assumed directionless, colorless, and contention-less nodes that require in total 92 WSS elements.

Fig. 1 presents the utilization of spectrum and the savings in terms of 50 GHz slots of the SF network as opposed to the 100 Gbps SLR system. These results were produced by applying the algorithm of [5], using the SF transponder and transmission distance assumptions that are considered in this study.

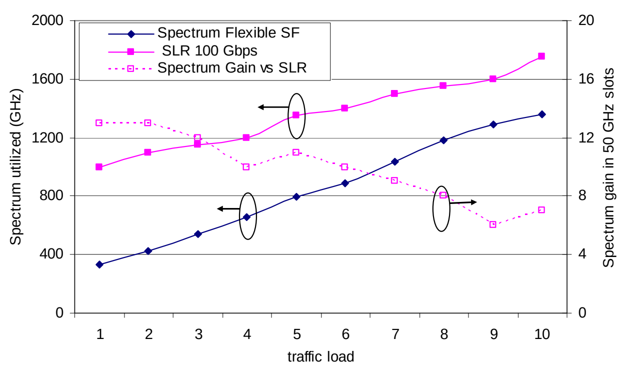

Fig 1. Spectrum utilization and spectrum gain (in 50GHz slots) of the SF network as opposed to a SLR 100 Gbps system for different traffic loads.

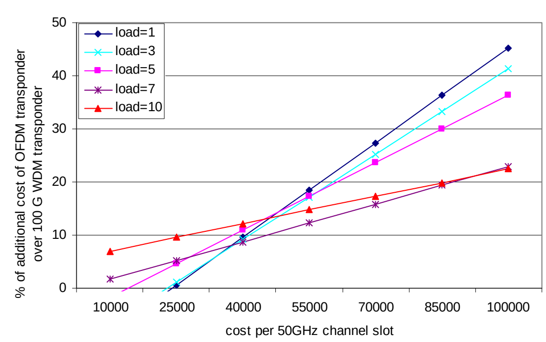

Fig 2. Percentage of additional cost of the SF transponder over the cost of the 100 Gpbs transponder as a function of the cost of the 50 GHz slot, for different traffic loads and 50% SF-WSS extra cost.

Figures 2-4 depict the main results of the current work. Fig 2 presents the percentage of the additional cost of the SF transponder over the cost of the 100 Gbps transponder, in order to achieve SF total cost equal to that of the SLR network. We graph the results for traffic loads equal to 1, 3, 5, 7 and 10 times the base traffic matrix of DT, assuming that the additional cost of the SF-WSS compared to the conventional 50GHz WSS is 50%. In Fig. 2 for instance, one may observe that for load=5 and for a cost $c_{wavelength}$=50K€ for a 50GHz channel slot, SF networking is preferable over SLR if the SF transponder costs 15% or less than that of the corresponding 100 Gbps transponder. From Fig. 2 we can see that SF networking is preferable over SLR network when the additional cost that is tolerable for the flexible transponder ranges between 10% to 45%, for a 50GHz channel slot ranging from 10K to 100K. Since according to Fig 1, the spectrum savings (i.e. 50GHz slots) are more pronounced for low traffic loads, the slopes of the graphs decrease as the load increases. Thus, for high values of $c_{wavelength}$, the extra SF cost that can be tolerated for lower loads is higher than that for higher loads.

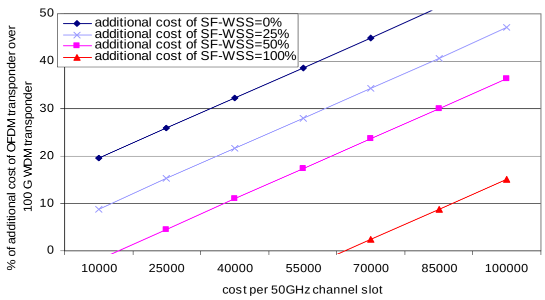

Fig 3. Percentage of additional cost of the SF transponder over the cost of the 100 Gpbs transponder as a function of the cost of the 50 GHz slot, for different SF-WSS extra cost percentages and for load=5.

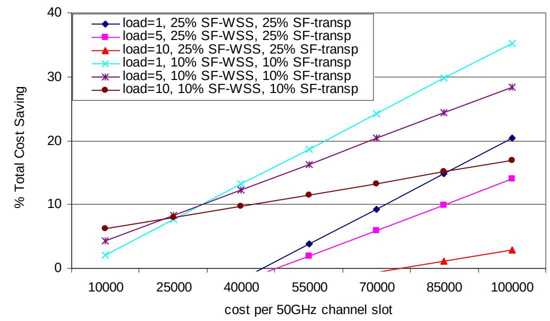

Fig 4. Percentage of total network cost saving as a function of the cost of the 50 GHz slot, for different SF-WSS and different SF-transponder values.

Fig. 3 illustrates the corresponding results for traffic 5 times the base traffic matrix and different values for the extra cost of the SF-WSS over the cost of a conventional 50GHz WSS. The cost of the SF-WSS could be considered quite high at present, however it stands to reason that in the future the SF-WSS cost would decrease and be comparable to that of a conventional WSS element.The SF network becomes significantly more cost efficient as the extra cost of the SF-WSS falls bellow 50%. For example from Fig. 3 we can observe that when moving from 50% to 25% extra SF-WSS cost, we can tolerate to spend 10% more for the SF transponders.

Fig. 4 illustrates the percentage of the total network cost saving of the SF over the SLR network. From Fig. 4 it is evident that the savings increase fast with the increasing cost of the 50 GHz slot. For 10% extra SF-WSS cost and for 10% extra SF-transponder cost the SF network achieves more than 10% saving for all examined loads.

It is emphasized that the results in figures 2-4 consider capital costs and do not account for any savings that may arise due to operational life-cycle cost savings associated with the capabilities of the flexible networks.

4. Conclusions

In this work we provided a methodology for the estimation of the value of flexible optical networking compared to standard single line rate WDM solutions. We applied our methodology for the case of OFDM-based flexible optical networks and we found under different examined conditions that if the additional network elements that are required to support their operation (flexible transponders and WSSs) cost up to 20-25% over the cost of their counter-parts for a fixed SLR system, then the additional investment may be justified justified.

Acknowledgements
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5. References

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