

Target cost for Sliceable Bandwidth Variable Transponders in a Real Core Network

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Abstract: Elastic Optical Networking (EON) is a solution that promises to improve infrastructure utilisation by implementing flexible spectrum allocation with small spectrum slots instead of the rigid 50-GHz fixed grid of current DWDM deployments. This new EON flexible grid supports Bandwidth Variable Transponders (BVT) that can tune their bit rate and bandwidth dynamically with a trade off between reach and capacity. However, when BVTs need to transmit at low bit rates, part of their capacity is wasted. Therefore, the Sliceable Bandwidth Variable Transponder (SBVT) has been proposed, which can provide even higher levels of elasticity and efficiency to the network. SBVTs enable transmitting from one point to multiple destinations, changing the traffic rate to each destination and the number of destinations on demand.

The aim of this work is to identify the target cost of 400 Gb/s and 1 Tb/s SBVTs to reduce, by at least 30%, transponder costs in a core network scenario. This target cost is calculated in relation to estimations for non-sliceable transponders of 400 Gb/s and 1 Tb/s. In light of our results, cost savings of 30% are feasible for 1 Tb/s transponders in the next nine years with a higher cost than non-sliceable transponders. Savings of 30% for 400 Gb/s case are possible in the short-term before 1 Tb/s SBVTs can appear in the market. Feasibility of such savings with a target cost higher than current non-sliceable transponder shows that SBVT can be a reality.

Keywords: Sliceable Bandwidth Variable Transponder, Elastic Optical Networks.

1 Introduction

The ever increasing demand for transmission capacity and higher signal speeds is driving the development of advanced technologies that allow a better use of deployed resources as well as an increase in transport rates. On the other hand, Telecom operators are facing strong pressures on capital and operational expenditures, so that emergent technologies will only be adopted if they are economically feasible [1].

Existing DWDM systems divide the C-band optical spectrum into discrete bands, spaced usually by 50 or 100 GHz, and standardised by the ITU. A transponder provides an individual wavelength carrying a client demand (which might be Ethernet or OTN, and might have a payload of anything up to 100 Gb/s), which can be accommodated in just one of these bands. This means that the resulting DWDM network is somewhat inflexible to changes in bandwidth demand. Although further transponders can be installed to cope with additional demands, this is a very slow process that can typically take many weeks due to the great deal of manual processes involved, e.g. placing the order for a new transponder,

conducting the necessary installation and provisioning, testing, etc. Also, future high bit rate transponders, such as 400 Gb/s and above, are expected to utilise wider bandwidths than the current 50GHz grid. Therefore, current infrastructure would not be able to support them. Therefore, large bandwidth demands would have to be divided up so that they can be carried over the fixed grid.

Elastic Optical Networks make it possible to use the optical spectrum in a more flexible way. For instance, variable-size spectrum slices can be defined and allocated depending on the bandwidth requirements of individual channels. The ITU-T has recognised the requirement for a spectrum allocation scheme that provides more flexibility than the conventional 50-GHz grid. Therefore, the revised G694.1 recommendation considers a flexible DWDM grid with 12.5-GHz frequency slot granularity and 6.25-GHz central frequency granularity [2]. The EON approach advocates the use of new building blocks for an extended flexibility on resource assignment (be it capacity or spectrum) and an optimized use of the network capacity. The main blocks of EON are the flexible grid ROADMs and the Bandwidth Variable Transponder (BVT). Flexgrid ROADMs can filter signals with a granularity of 12.5GHz, instead of 50 GHz like in current WDM systems. BVTs can adjust their transmission rate to the actual traffic demand, by expanding or contracting the bandwidth of an optical path (i.e. varying the number of subcarriers) and by modifying the modulation format. Several experiments have demonstrated the feasibility of EON [3] and BVT [4]. There are studies have shown the potential to reduce cost and increase infrastructure utilisation of BVTs [5, 6].

Sliceable Bandwidth Variable Transponder (SBVT) enables transmitting from one point to multiple destinations, changing the traffic rate to each destination and the number of destinations on demand. This new architecture can achieve savings in network operators [7]. The objective of this paper is to find which is the required target cost of 400-Gb/s and 1-Tb/s SBVTs that would reduce transponder costs in a real core network scenario by at least 30%. The target cost requirements are calculated in comparison to those achievable by 400-Gb/s and 1-Tb/s transponders that are not sliceable.

The remaining of this paper is organized as follows. Section 2 introduces the concept of Sliceable Bandwidth Variable Transponder and possible architectural implementations. Section 3 presents architectures interconnection SBVTs and client equipment. Section 4 describes the case study and Section 5 shows the results. Finally, Section 6 concludes this paper and proposes further work.

2 Sliceable Bandwidth Variable Transponder architecture and definition

BVTs are able to tune their bandwidth by adjusting their transmission bitrate or modulation format, as depicted in Figure 1(a). BVTs support high-speed transmission using spectrally efficient modulation formats, e.g. 8PSK, 16QAM, 64QAM, for short reach connections. Also, long-reach connections are supported using more robust but less efficient modulation formats, e.g. QPSK, BPSK. Therefore, BVTs are able to trade off spectral efficiency and transmission reach [8].

There have been several demonstrations of bitrate-variable transmitters where the number of subcarriers or the modulation format is adapted to achieve the desired bitrate and spectral efficiency [3, 4].

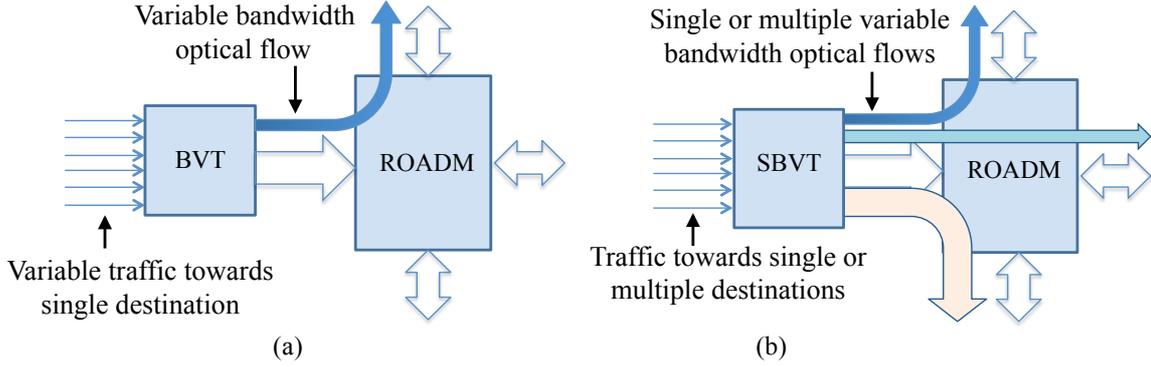


Figure 1. Illustration of the functionalities of (a) bandwidth variable transceiver (BVT) and (b) sliceable bandwidth variable transceiver (SBVT).

However, when a high-speed BVT is operated at lower than its maximum rate, e.g. due to required reach or impairments in the optical path, part of the BVT capacity is wasted. In order to address this issue the Sliceable BVT (SBVT) has been proposed [9]. A SBVT is able to allocate its capacity into one or several optical flows that are then transmitted to one or several destinations, as illustrated in Figure 1(b). Thus, when an SBVT is used to generate a low bit rate channel, its remaining capacity can also be exploited for transmitting other independent dataflows.

From the point of view of higher layers, an SBVT may be viewed either as a high-capacity BVT or as a collection of multiple logically/virtually independent lower-capacity BVTs, depending on the mode of operation. Possible BVT and SBVT configurations utilizing Nyquist WDM are shown in Figure 2 [9].

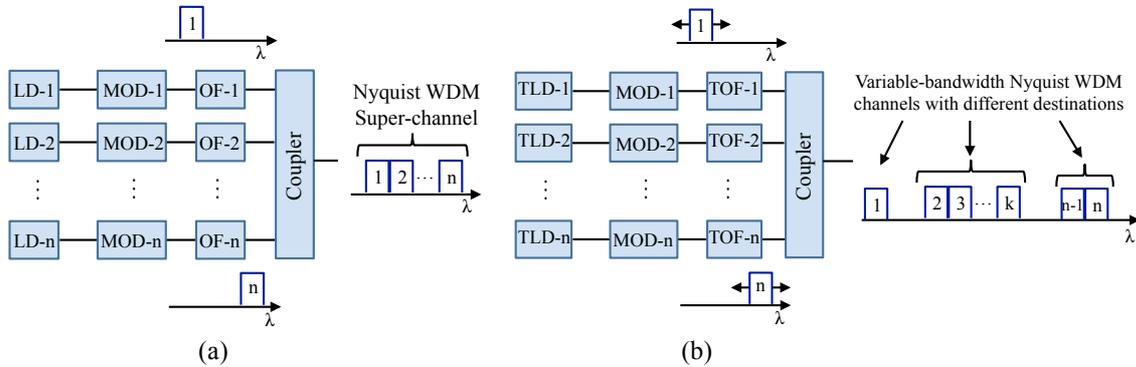


Figure 2: Configurations based on Nyquist WDM: (a) Bandwidth Variable Transceiver and (b) Sliceable Bandwidth Variable Transceiver

The BVT, shown in Figure 2(a), comprises multiple light sources, modulators, quasi-ideal optical filters and a coupler. Multiple light sources, with a spacing very close to the Nyquist limit, are independently modulated, filtered and coupled together in order to generate a multicarrier super-channel. The super-channel bitrate and bandwidth can be tuned by changing the modulation format (and carrier spacing) or by turning off unused carriers. The same configuration can be used to construct a SBVT by making the light sources and optical filters tuneable. Thus, one or more carriers can be selected and utilised for transmission towards different destinations using different spectral bands, as shown in Figure 2(b). The number of carriers used for each optical flow is determined by the required channel bit rate.

Based on commercially available technologies is possible to implement SBVT. Figure 3 depicts an example for a 400Gbps SBVT. Thanks to Photonic Integrated Circuits (PIC), it is possible to have multiple carriers in the same component [10]. Modulation

formats can be programmed externally for each of the carriers. This example is based on carriers of 100Gbps, which are transmitted using DP-QPSK. Next section presents different proposals for interconnect routers and SBVTs. To have lower granularities in the client interfaces, OTN or Ethernet switching is required.

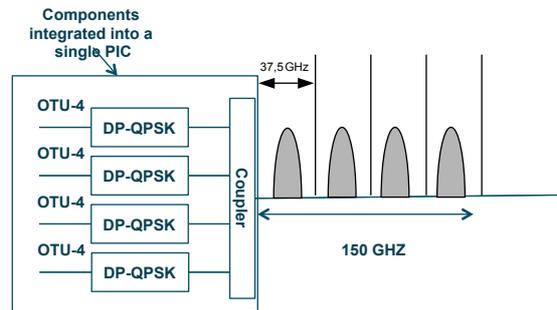


Figure 3: Example SBVT based on state of the art technologies

3 SBVT architectures involving multiple layers

Although SBVTs are based on a flexible optical signal generation mechanism that supports the sliceable feature, this is not the only requirement for SBVTs to work. For instance, the interface between the client equipment (mainly routers) and SBVT must also be flexible to allow SBVT to take different aggregate traffic flows and send them in different directions, without requiring manual reconfiguration of the connectivity between the systems. There are several approaches to achieving such flexibility:

- Using an OTN cross-connect between the router and SBVT.* This cross-connect can take multiple router links and multiplex them into a single payload that will be served to the SBVT for transmission to a specific remote destination. Note that this approach adds a separate switching layer to the solution, which should not be needed given the router can perform the traffic switching function. Moreover, it still leaves the same fundamental questions open: how does the OTN cross-connect connect to the router in a flexible manner and how does it connect to the SBVT in a flexible manner? This architecture is shown in Figure 4-a.
- Using multiple 100GE links between the router and SBVT.* Assuming the SBVT granularity is in multiples of 100GE, this approach can use existing router gear and allow SBVT to map N 100GE links into a single payload for transmission, e.g., a higher order ODU container. For example 3 100GE links can be multiplexed together into a 300G ODUflex frame and shipped in a 300G OTUflex container (Figure 4-b).
- Using a channelized OTN interface between the router and SBVT.* The router places traffic in flexible ODU containers. Assuming SBVT is configured the same way, it just needs to map each ODU container onto a super-channel. This approach also allows the router to exploit more flexible Ethernet frames based on MACflex concepts (an Ethernet frame that allows for any line rate instead of the fixed 40GE, 100GE, 400GE etc.), instead of fixed 100GE as in case b). As depicted in Figure 4-c, if 300G should be used to connect a pair of routers, the router can generate a 300G MACflex frame and map it into a 300G ODUflex. This will be carried in the 1T OTU interface between the router and the SBVT together with other channels to other destinations. SBVT will extract the 300G ODUflex and map it into a 300G OTUflex for shipment over a super-channel.
- Using VLANs in an Ethernet i/f between the router and SBVT.* In this case the channelization of the interface between the layers is done via VLANs, where each VLAN represents a different remote destination. The issue with this approach is that

it requires SBVT to understand the Ethernet frame, effectively turning it into an L2 device and adding unnecessary complexity to it.

Although explanation of previous architectures is focus on SBVTs, similar ideas apply to the case of BVTs. If a router with a 1Tbps is connected via a single port to equipment with 10 BVTs of 100Gbps. An OTN or an Ethernet switch is required to split the terabit interface to each BVT (like in Figure 4-a and Figure 4-d). If OTN or Ethernet interfaces are used (Figure 4-b or Figure 4-c), a direct mapping is done with each of the BVTs. Consequently, this work is focus on the cost of the transponders assuming that architectures are similar.

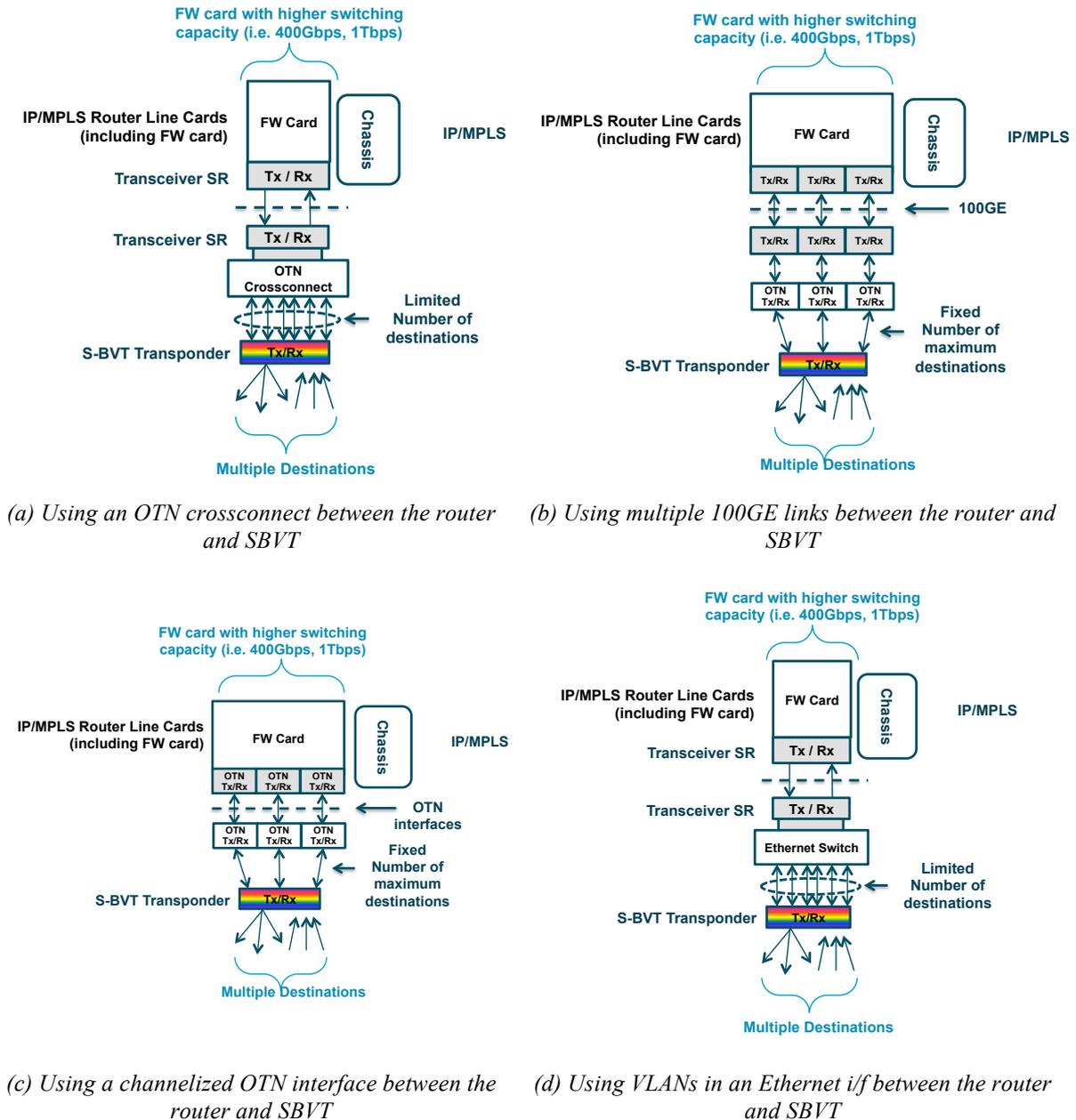


Figure 4: Architectural option for interconnecting routers and SBVTs

4 Case Study definition

The objective of this study is to calculate the cost that a SBVT should have in order to achieve a percentage cost reduction in transponders for a backbone network. To this end, two node models are compared: (a) current model without sliceable transponders and (b)

node with SBVT (Figure 5). Previous architectures to interconnect client equipment and SBVT are possible choices for implementation, but they are out of the scope of the paper. The main difference between both models is that the non-sliceable transponder model requires least one interface for each destination, while the SBVT transponder reuses hardware and optical spectrum to transmit to multiple destinations.

We consider coherent modulation formats in the model without sliceable transponders (40Gb/s, 100Gb/s, 400Gb/s and 1Tb/s), while 400-Gb/s and 1-Tb/s SBVTs are used for the second model. Let us remark that the maximum traffic rate is the same in both models. Therefore, when studying 400 Gb/s SBVT model, there are no 1-Tb/s transponders in the non-sliceable transponder model.

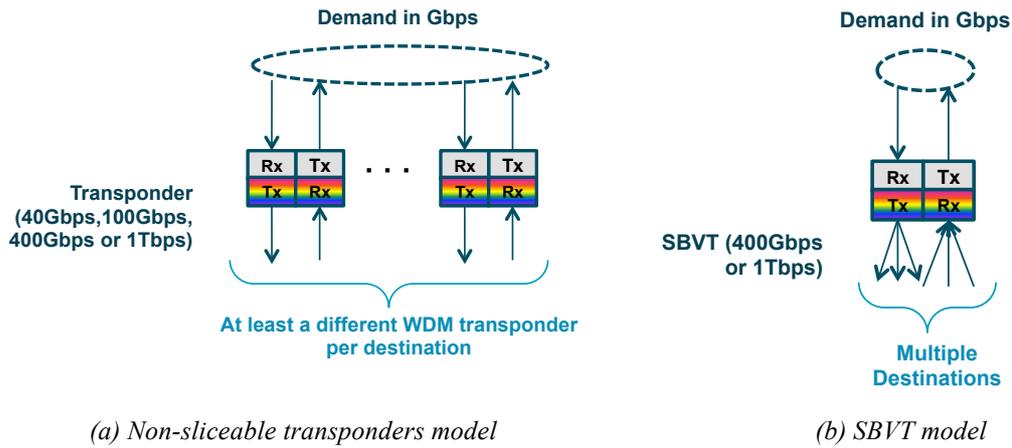
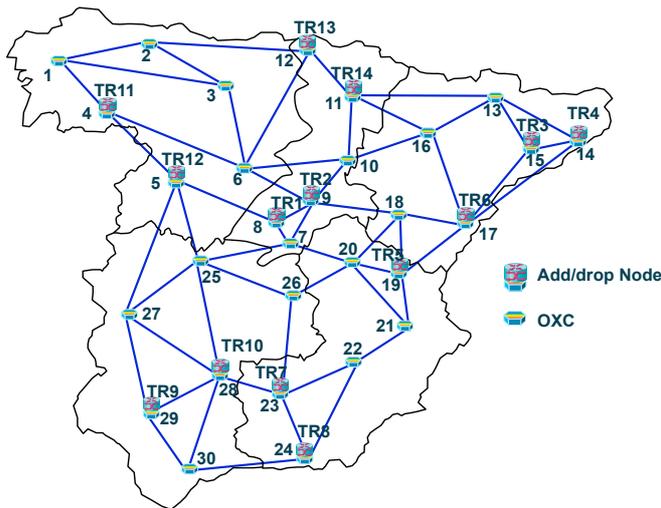


Figure 5: Models for the study with and without SBVT

A network model based on the Spanish backbone is used for this study (Figure 6) [11]. The network is made up of 20 edge nodes that aggregate traffic from transit and access routers and forwards it over wavelength channels requested to the photonic mesh. In this analysis OXCs are assumed to switch the optical channels in an elastic manner, but they do not have any influence on transponder requirements, as they do not implement transponders themselves. We assume that there is enough optical resources in both situations with and without SBVTs and the objective of this work is to reduce the investment in transponders.

The initial traffic matrix is created based on information for the Telefonica backbone network in 2012. The link dimensioning is done using an over-dimensioning factor of 30%. For instance, given a traffic demand of 35 Gb/s, links are dimensioned for 45.5Gb/s (35Gb/s x 1.3). Traffic is incremented yearly by a 50% factor in order to compare the cost performance of the different architectures proposed over the next 10 years. In order to assess the cost of non-sliceable model, the STRONGEST cost model is used in this study [12]. Table 1 contains information about the relative unit cost used for the non-sliceable transponders of different bit rates.



TxP parameters	Cost
40Gb/s, 2500km, 50 GHz	6
100Gb/s, 2000km, 50 GHz	15
400Gb/s, 75GHz, 500km	22
1000Gb/s, 175GHz, 500km	25

Figure 6: Reference network based on Spanish national backbone [11]

Table 1: Non-sliceable transponders cost [12]

5 Results

Figure 7 shows the target cost of the SBVT (bars) to achieve 30% overall savings in transponder costs for 400-Gb/s and 1-Tb/s SBVTs across the whole network. The cost for non-sliceable transponders is also shown in Figure 7, to illustrate that in some instances this 30% overall savings are possible even when unit cost of SBVT are higher than the cost of non-sliceable transponders.

Figure 8 shows the possible cost increment of SBVT in comparison with non-sliceable transponder cost. The target cost of 1-Tb/s SBVT steadily increases for the next three years to reach a peak of 140% the cost of a non-sliceable transceiver in 2015 (a total traffic demand of 12.5 Tb/s). For 400 Gb/s, the peak target cost is reached in 2013 (a total traffic demand of 5.5 Tb/s) and then it steadily drops so that in 5-6 years the cost of the 400-Gb/s SBVT should be similar to the cost of a fixed grid transponder to achieve overall 30% savings in the network. Therefore, when the price of 400 Gb/s SBVTs approaches the price of non-sliceable transponders, it would make sense to migrate some nodes to 1 Tb/s SBVT. Finally, we should note that we have not applied any discount or price degradation in our model, so costs remain the same along time. It is reasonable to expect decreasing non-sliceable 400 Gb/s and 1Tb/s transponder costs.

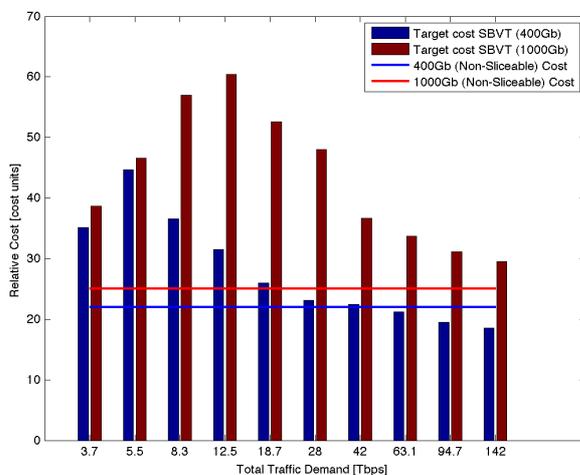


Figure 7: Target cost for SBVT (400Gb/s and 1Tb/s) and reference costs for non-sliceable transponders

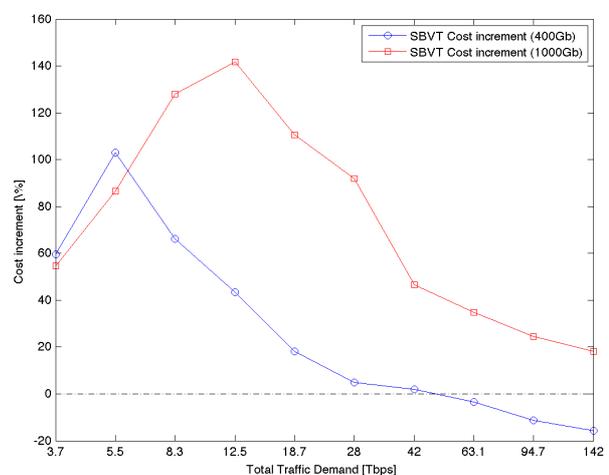


Figure 8: Cost increment of the SBVT (400Gb/s and 1Tb/s) in comparison with non-sliceable transponders

In addition to the target costs for 30% overall savings, we have also studied the maximum overall savings that can be achieved when SBVT costs are the same as those of non-sliceable transponders. To this end, we have computed transponders costs across all the network using non-sliceable transponders in three scenarios: (1) no savings, (2) 30% savings and (3) 50% savings. On the other hand, we have computed the required number of SBVTs to handle the same capacity and multiplied this number by the cost of non-sliceable transponders. Figure 9(a) and 7(b) show the results for 400 Gb/s and 1 Tb/s cases, respectively.

In light of these results, we can say that 50% savings is not possible in the case of 400 Gb/s, as shown in Figure 9(a). In the case of 1 Tb/s, more than 50% savings could be possible if the technology were available before 2018 (or when 42 Tb/s traffic is reached).

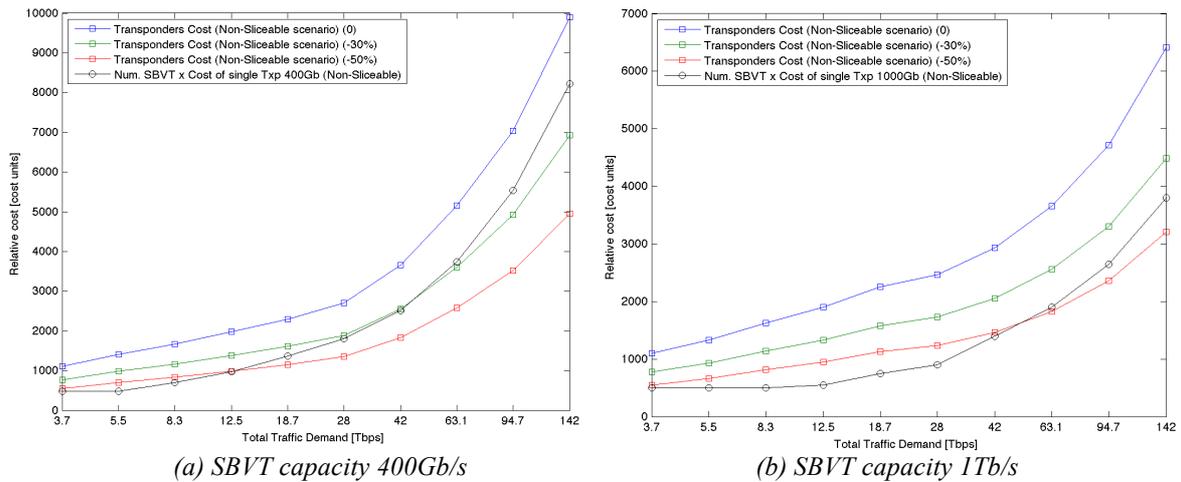


Figure 9: Comparison of transponders cost for Non-Sliceable model without savings and with 30% and 50% and minimum cost of SBVT

6 Conclusions and further work (TID)

SBVT enables transmitting from one point to multiple destinations, changing the traffic rate to each destination and the number of destinations on demand. Although there are not commercial implementations, there are some architecture proposals, which shows its feasibility.

In this paper we present results of the target cost of 400 Gb/s and 1 Tb/s Sliceable Bandwidth Variable Transponders to reduce in a 30% transponders cost in a core network scenario. In light of the results, savings of 30% in transponder cost are possible using 400Gb/s and 1Tb/s interfaces. We assume that operators would like to migrate their infrastructure to use SBVTs, if 30% savings are possible as demonstrated with the target cost estimations for SBVTs done in this work.

This article is a first work to demonstrate the viability of this solution from a techno-economic point of view. Once transponder layer is evaluated, architecture interfacing client network elements will be evaluated.

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