Techno-Economic Analysis of Carrier Sources in Slice-able Bandwidth Variable Transponders

M. Imran[(1)], A. D. Errico[(2)], A. Lord[(3)], L. Poti[(4)]

[(1)] Scuola Superiore Sant'Anna, Pisa, Italy, m.imran@sssup.it
[(2)] Ericsson, Pisa, Italy antonio.d.errico@ericsson.com
[(3)] BT Research Labs, Ipswich, UK, andrew.lord@bt.com
[(4)] CNIT Pisa, Italy, luca.poti@cnit.it

Abstract *Different carrier source implementation strategies in sliceable bandwidth variable transponders have been compared in terms of cost and power consumption. A reduction factor up to 4 has been obtained through novel centralized carrier source schemes.*

Introduction

The flexible optical networking envisions a network that is able to dynamically adjust its resources based on traffic and network conditions[1]. Flexible transceivers also referred as slice-able bandwidth variable transponders (SBVT) are expected to tune their parameters (modulation format, baud rate, etc.) to serve different capacity and reach requirements for single or multiple destinations using the same board. In terabit scale SBVTs spectrally efficient superchannels are formed by densely packing several low rate subchannels using advanced multicarrier transmission techniques like Nyquist WDM, coherent optical orthogonal frequency division multiplexing (CO-OFDM) and time frequency packing (TFP)[2]. Resultantly, higher number of optical carriers will be needed in flexible nodes equipped with multiple SBVTs. In addition to conventional lasers, multi-wavelength (MW) sources based on optical frequency combs have also been considered for optical carrier generation in SBVTs[2]. MW sources are an attractive solution because N-1 lasers can be saved and comb lines are intrinsically locked in frequency. The frequency locked carriers can improve the spectral efficiency (SE) by avoiding spectral guard bands between subchannels. The whole optical comb can be simultaneously tuned in wavelength and carrier spacing (CS) can also be varied. However, the achievable frequency spacing is limited (<50GHz) compared to lasers. Nevertheless, the comb based carrier sources must exhibit same optical characteristics, transmission performance, and cost and power consumption if they are to replace lasers. Several flexible comb generation techniques have been demonstrated recently for flexible transceivers[3]. Comparable optical and transmission performance have also been demonstrated. The impact of MW sources in SBVTs on network performance has also been reported[4]. However, techno-economic analysis to estimate impact on transponder cost and power consumption is still an open issue. Authors in[5] presented an estimate of affordable cost and power consumption for SBVTs and argued for the benefits of such sources.

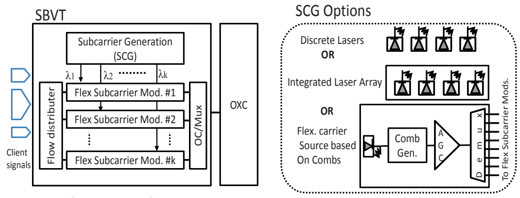

Fig. 1: SBVT reference architecture and SCG options

In this paper we present the cost and power analyses of comb based optical carrier sources with a practical perspective and estimate the expected cost and power reduction in next five to seven years. Based on analysis, we propose two cost effective and power efficient schemes for centralized flexible optical carrier source module (Flex-OCSM) providing different level of network flexibility. The results show that the cost and power reduction factor up to 4 can be achieved with the proposed schemes and hence overall SBVT cost and power consumption can be reduced.

Reference SBVT Architecture

The SBVT architecture[2] agreed by several operators and vendors taken as a reference for our study is shown in the Fig. 1. The SBVT consists of an array of flex subcarrier (FSC) modules, flow distributer and subcarrier generation (SCG) module. The client signals (OTN or Ethernet) are fragmented into different data streams after photonic layer adaptation. The flow distributer directs different OTN streams to the specific FSC module for carrier modulation. Each FSC module is a BVT equipped with phase modulator, polarization multiplexer and coherent detector.

The transceivers are expected to be pluggable

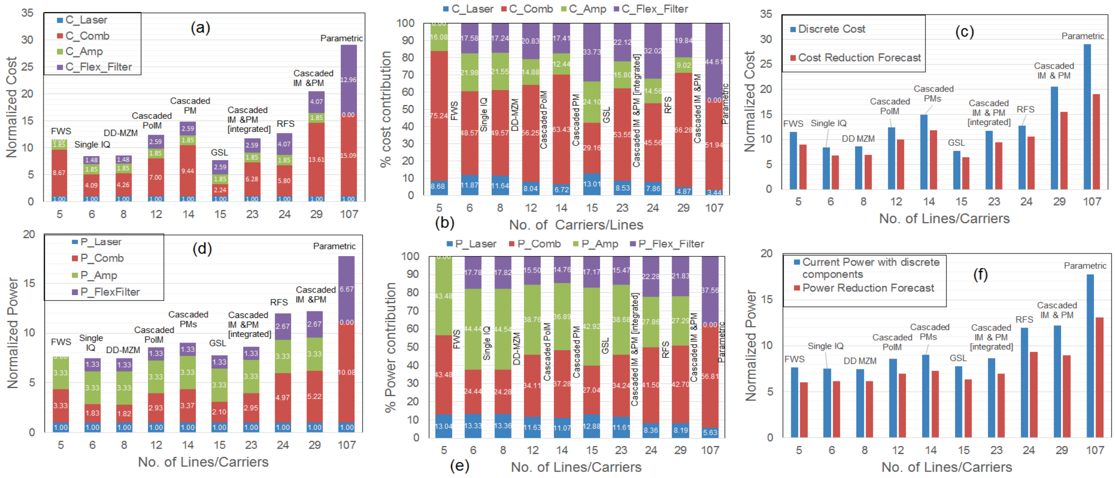

Fig. 2: (a,d) Normalized cost and power using discrete componets; (b,e) Percentage cost and power contributions of different functional blcoks ; (c,f) Cost and power reductoin forecast for different comb based SCGs.

modules. Due to power constraints of pluggable modules lasers are not included in transceiver case and are proposed to be integrated on the line card as a separate SCG module[6]. SCG module is responsible to provide *k* (typically ≤10) optical carriers for modulation in transmitter and local sources for coherent detection in receiver. Three possible SCG realizations are shown in the Fig. 1. It can be i) *k* discrete lasers ii) an integrated laser array e.g., III-V or iii) flexible MW source based on combs[2]. SCG can be connected to FSC module via planar lightwave circuits (PLC) or back plane (BP)[5]. Subchannels from different FSCs can be multiplexed to form a superchannel and fed to flex OXC. Comb based SCG (comb_SCG) also requires an additional amplification stage (e.g., EDFA) to bring the power per carrier at par with lasers and a flexible de-multiplexer/filter to get access on individual carrier for data modulation.

SCG: Cost and Power Analysis

The *N* discrete lasers (DL) are fully flexible but cost and power consumption (CPC) will increase linearly because equal number of thermal stabilizers (TS) and wavelength lockers (WL) are also required. The power consumption for *N*=10 can range from 20-40W depending on the optical launch power and required wavelength stability. Alternatively, the integration of *N* lasers on a single die with common TS, shared power and control unit can lead to 50% reduction in CPC, depending on the process yield and volume[5]. The third option of comb_SCG can save N-1 lasers but requires additional functional blocks (FB). To understand the impact on CPC we shortlisted few comb types after a detailed analysis of recently proposed schemes. The CPC of a DL has been taken as reference figure of merit throughout paper. The cost of comb_SCG is given by:

$$C\_Comb\_SCG = C\_Laser + C\_Comb + C\_Amp + C\_flexFilter$$

We have considered EDFA for amplification and LCoS based flexible filters for our analysis. Normalized cost and power for different schemes using discrete components are shown in the Fig. 2 (a,d). The number of lines has been calculated for 37.5GHz CS (except for gain switched (GSL) combs ~20GHz) based on demonstrated comb bandwidths for each type. We can see that the cost and power saving advantage is only significant for schemes providing more than 15-20 lines. It can also be observed from Fig. 2(b,e) that the distribution of cost and power for different FBs varies for each comb type. Each block's CPC will scale down differently based on technology, volume production, and cost erosion factor in the next 5 to 7 years. 25% reduction in cost and 30% decrease in power of integrable components (drivers, modulators, clock sources, etc.) of comb block are possible with the development of CMOS photonics together with introduction of advanced materials like silicon organic hybrid (SOH) structures[7]. Similarly 20-25% decrease in the cost and 25-30% decrease in power of seed lasers is considered based on cost erosion factor over time, volume and advancements in TSs and WLs. The CPC of EDFAs and specialty fibers (used in parametric combs) can decrease by 10% in same period with advancements in control mechanisms. 10% decrease for N≤20 and reduction in number of devices is assumed for flex_filters subject to availability of devices with N~33 (currently 1x9 and 1x20). The CPC will decrease proportionally with the number of devices. In conclusion, 16% (RFS) to 34% (parametric) decrease in cost (Fig. 2(c)) and 17 (DDMZM) to 26% (Cascaded IM and PM, Parametric) decrease in power (Fig. 2(f)) is estimated for different comb_SCG schemes.

Centralized Optical Carrier Source Modules

In the reference SBVT architecture SCG is

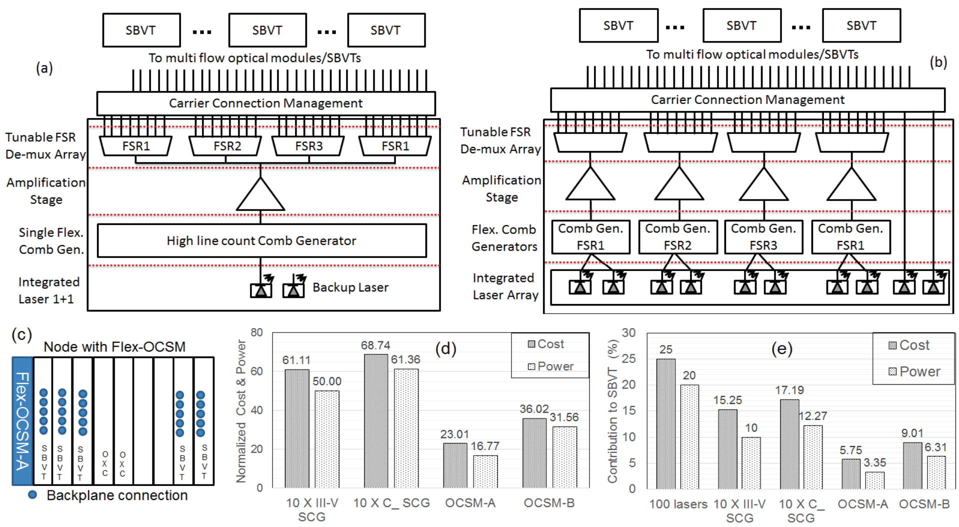

Figure 13. Flex- OCSM module schemes (a) Flex-OCSM-A single high line count comb source (b) Flex-OCSM-B shared modular with full flexibility (c) Node with Flex-OCSM (d) Normalized cost and power forecast (e) % contribution to SBVT.

dedicated to each SBVT and unused carriers cannot be shared with other SBVTs in the same node. We propose two schemes for centralized flexible optical carrier source modules (Flex-OCSM-A and B). The optical carriers can be connected to any SBVT board in the node through BP connections (Fig. 3(c)). The CS constraint is resolved. Flex-OCSM-A in Fig. 3(a) uses a single high line count parametric comb source, variable CS is achieved through flex_filters array. However, the re-assignment of same wavelength in different direction is limited by number of flex_filters and central wavelength tuning is not possible. Flex-OCSM-B in Fig. 3(b) is a modular architecture, resources are shared by different seed lasers reducing the number of devices compared to dedicated SCGs hence CPC. The comb generation blocks can be set on different CS and carriers requiring same spacing can share the same set of comb generator, amplifiers and flex_filters. The superchannels can be simultaneously tuned in wavelength by tuning seed laser. The findings in[4] suggest SE advantages of MW sources and slice-ability benefits of lasers can be combined by using two types of SBVT boards. Flex-OCSM-B is equipped with 15-20% lasers to support slice-ability thus eliminating the need for two types of SBVT boards. A comparison of normalized cost and power forecast for different SCG implementations assuming a flex node with 10x1Tb/s SBVTs requiring 100 carriers is depicted in the Fig. 3(d). For conventional dedicated SCG architecture, III-V laser array SCG are cost and power efficient than comb_SCG. However, proposed flex-OCSMs provide significant cost and power saving compared to dedicated SCGs. OCSM-A has 62% and 66% cost, and 66% and 72% power saving compared to dedicated III-V and comb_SCG respectively but the flexibility is limited. OCSM-B has 41% and 47% cost, and 36% and 48% power saving compared to dedicated III-V & comb_SCG respectively while providing same level of flexibility. 25% of total SBVT cost and 20% of total SBVT power consumption is attributed to DLs[5]. Using these figures in our analysis the normalized cost of 10x1Tb/s SBVTs is 400 and normalized power is 500 (i.e., 2000W). The estimated percentage contribution of each SCG scheme to 10x1Tb/s SBVT cost and power is shown in the Fig. 3(e).

Conclusions

The choice of SCG depends on desired level of flexibility. For SBVTs having dedicated SCGs, III-V laser arrays will be cost and power efficient compared to discrete lasers and comb based SCGs. However, proposed centralized schemes based on combs for flex nodes can reduce SCG cost and power by a factor of 4 hence reducing overall contribution to SBVT cost from 15% to 5 % and power from 10% to 3% compared to III-V dedicated SCG.

References

[1] M. Jinno et al., IEEE Commun. Mag., (2009)

[2] N. Sambo *et al.*, "Next generation sliceable bandwidth variable transponders," in *IEEE Com.Mag*, vol. 53,2015.

[3] V. Torres-Company et al, Optical frequency comb technology for ultra-broadband radio-frequency photonics, *Laser & Photonics Reviews*, (2013)

[4] M. Dallaglio et al.,"Routing, Spectrum, and Transponder Assignment in Elastic Optical Networks," in *JLT*(2015).

[5] A. D'Errico et al., "Next Generation Terabit Transponder," in OFC (2016), paper W4B.4.

[6] C.R. Doerr, “Silicon photonic integration in telecommunications,” Frontiers in Physics, vol. 3, (2015).

[7] C. Weimann et al "SOH frequency comb sources for terabit/s data transmission," Opt. Express 22, (2014).