Receiver Architecture with Filter for Power-Efficient Drop&Waste Networks

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Abstract: Power budget analysis of filterless Drop and Waste networks is first reported. A receiver architecture encompassing a low-cost tunable integrated filter is then proposed and evaluated, showing significant improvements in power margin and optical reach.

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1. Introduction

The Drop and Waste (D&W) architecture has been proposed to target a significant cost reduction in optical networks [1, 2]. A D&W pilot network has been already implemented by Croatian Telecom, considering a horseshoe topology (Fig. 1) [3]. In D&W, the key idea is the use of 100G coherent transponders in routers and only splitters/couplers and amplifiers in the transport network. That is, no expensive ROADMs and Wavelength Selective Switches (WSS) are envisioned in D&W solutions. Indeed, thanks to the coherent technology, each transmitted signal can be properly selected at the receiver. In D&W, as a major drawback, a waste of spectrum resources is experienced since each signal occupies the entire horseshoe network [2]. However, significant CAPEX and OPEX savings are envisioned due to the use of inexpensive hardware and thanks to the simple control and maintenance operations.

In this paper, we first consider the issues related to the excess supply of optical power to the receivers in D&W networks. So far, this aspect has not being adequately discussed in the literature even if it may represent a major obstacle in the implementation of D&W solutions. Then, we propose to encompass a low-cost tunable filtering technology within receiver architecture. This way, the amount of power at the receiver transponder is drastically reduced, thus successfully enabling the implementation of ROADM-free D&W networks. Moreover, thanks to the improved power margin, a optical reach increase of 40% is successfully obtained.

2. Performance of Filterless D&W networks

The considered D&W network consists of an horseshoe topology with N nodes (N=5 in Fig. 1). Each node (Fig. 2) consists of two amplifiers, two 1x2 asymmetric line splitters/couplers for the drop/add section, and two 1x8 splitters/couplers to reach up to T=8 transponder per node [3]. The transponder supports polarization multiplexed quadrature phase shift keying (PM-QPSK) 100G transmission. According to typical off-the-shelf 100G transponder performance [4], a line rate of around 125Gb/s (including 25% of overhead) is utilized. Pre-FEC Bit Error Rate (BER) threshold is $1\text{x}10^{-2}$. The receiver sensitivity is S=-14 dBm, but it can be considered as S_{pen}=-20dBm if 0.5dB of OSNR penalty can be tolerated [4]. The transponder is designed to operate with a per-channel maximum optical received power of 0dBm. Moreover, an overall maximum value of P_T=+5dBm, not introducing significant nonlinearities in the photodiode optical response is here assumed as in [5]. Since in the case of a filterless D&W network all DWDM channels enter the receiver, a careful design of power budget has to be performed. K=96 50GHz-spaced optical channels are here considered [4]. Assuming to fix the overall received optical power entering the receiver P_{RX} to the maximum acceptable value P_T (i.e., +5dBm), each single channel should be received with a power value no higher than p_{rx}=-14.8dBm (acceptable with some OSNR penalty). According to such value, the launch power per channel is no higher than p_{tx}=-1dBm. Clearly, lower transmitted power would further approach the receiver sensitivity S_{pen}. On the other hand, higher transmitted power would exceed the P_T threshold. With such a low power per channel and considering a 80km-long span between each adjacent D&W node, a maximum number of N=8 nodes can be traversed with acceptable BER performance (the transmission model presented in [6] is here considered). This corresponds to an overall optical reach along the horseshoe limited to up to 640km (see Fig. 5(b)), in-line with results reported in [3].

For this reason, we propose to include an optical filter into the receiver architecture. Such filter should provide very relaxed performance (e.g., a passband of 100GHz with no specific needs of rectangular shaping) since it only has to

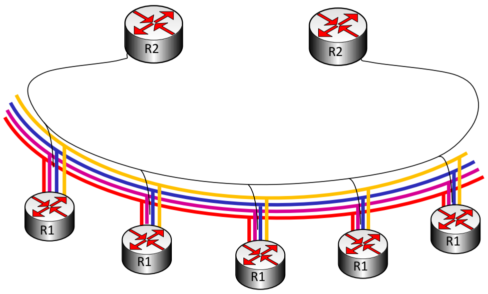


Fig. 1. Drop and Waste (D&W) horseshoe network

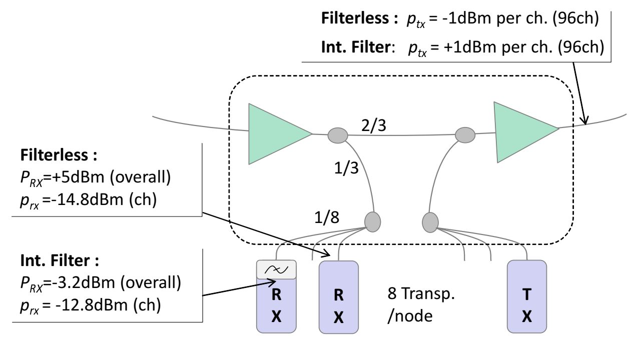


Fig. 2. Drop and Waste (D&W) node architecture

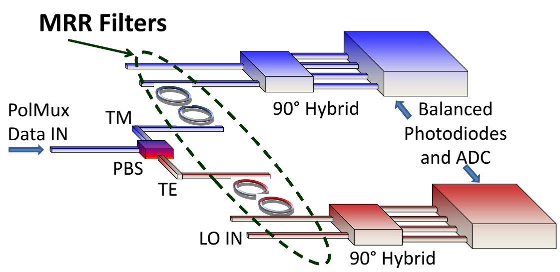


Fig. 3. Receiver architecture including MRR-based filter

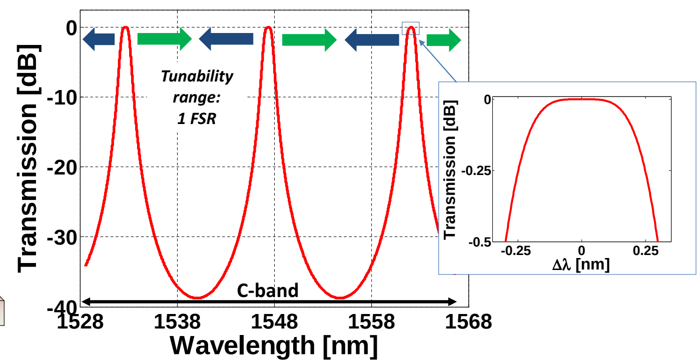
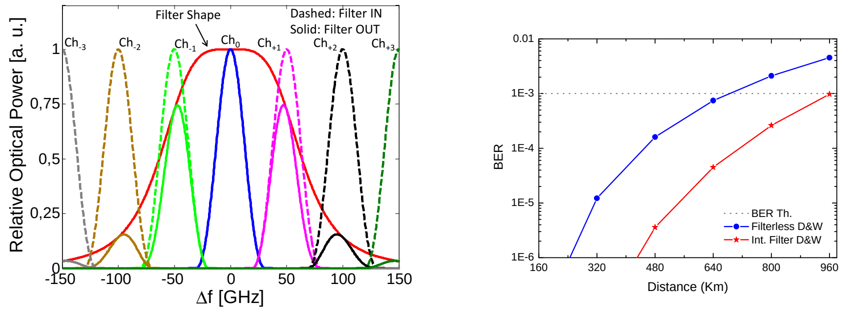


Fig. 4. Full-Span filter transmission vs wavelength

reduce power entering into the receiver. We can assume the filter as integrated into the receiver [**?**], thus it should not have a relevant impact on the costs. Note that switching still remains filterless.

3. Receiver architecture encompassing filtering solutions

In this section we propose to encompass a tunable filtering technology within the receiver architecture. A possible implementation based on a low-cost microring-based filter is considered [7,8], due to its potential to be monolithically integrated with polarization beam splitters and germanium photodiodes to realize a cost-effective polarization-diversity multi-channel receiver. The design of a low-order flat-top filter, with wide passband width for minimized tuning accuracy requirements, is here reported (Fig. 3). The basic building blocks of the photonic integrated circuit include a polarization beam splitter, a pair of two serially-coupled microring resonator add/drop filters (MRR-ADF) that can be thermally-tuned by current injection through metallic heaters placed above the MRRs, and 90 optical hybrids for LO coupling followed by balanced photodiodes. All these components can be suitable realized in silicon photonics technology and monolithically integrated on a single chip [7, 8].The serially-coupled MRR-ADF implements at its drop output a second-order maximally-flat Buttherworth filter design with a 0.5dB passband width of 75GHz. This value has been chosen as a convenient trade-off between attenuation of the overall power impinging at photodiodes and tuning accuracy, which strongly relaxes the complexity of the heater control systems. Due to the periodic nature of the filter, the filter frequency response repeats itself with a period (the free-spectral range, FSR) set by the ring dimension (a radius value of 6μm [9], ensuring negligible radiation loss with standard silicon-on-insulator (SOI) lithographic technology, has been here considered). Assuming full-etch silicon strip waveguides, for which the guided-mode group index n_g is 4.3, a FSR of about 15nm is attained. The corresponding simulated filter drop transmission $T(f)$ over a frequency span of $\sim$38.5nm, relative to the full C-band, is shown in Fig. 4. As depicted, up to three passband peaks fall within the full channels spectrum. This worst-case scenario has been considered in the performance analysis.



(a) Relative optical power entering the receiver within each pass-band peak

(b) BER performance vs. distance

Fig. 5. Performance analysis.

4. Performance evaluation

Simulations have been carried out to evaluate transmission performance of the considered filter technology. Details of the filter transmission spectrum over 300GHz frequency range are shown in Fig. 5(a), together with the power-spectral density (PSD) of five adjacent 31.241 Gbaud QPSK signals shaped with a squared root raised cosine filter.

The number of equivalent channels (*ECN*) that enter the photodiode results to be ECN=8.55, while in the traditional filterless case is ECN=96. Then, the *ECN* value is utilized to assess the transmission performance of D&W networks when the proposed integrated filter technology is employed at the receiver. In the same network scenario detailed above, given the introduced filter, no critical constraints have to be considered in terms of the overall received optical power. Indeed, assuming each channel is now lunched in the horseshoe spans with the typical optical power p_{tx}=1dBm, it is then received with a power value of p_{rx}=-12.8dBm, above the receiver sensitivity S (i.e., with no OSNR penalty). Moreover, in this case, the overall received power entering the transponder is only P_{RX}=-3.2dBm, largely below the critical conditions (i.e., P_T).

In this scenario, and considering as well 80km-long span between adjacent D&W nodes, a maximum number of N=12 nodes can be successfully traversed with acceptable BER performance. This corresponds to an overall optical reach along the horseshoe of up to 960km (Fig. 5(b)).

5. Conclusions

A receiver architecture encompassing a low-cost tunable integrated filter is proposed to successfully implement Drop and Waste (D&W) ROADM-free networks. The filter successfully limits the optical power entering the transponder: up to only 9 channels enter the receiver, instead of 96 as for the filterless. This way, the power margin is significantly improved and the overall optical reach is increased of around 40

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