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Experimental Impact of Power Re-Optimization in a Mesh Network

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Abstract *We experimentally demonstrate the SNR degradation of existing services induced by loading new services in the network, and mitigate this degradation via 2 different power re-optimization strategies: static End-of-Life strategy and dynamic real-time strategy, yielding a 3.2 dB gain on the worst SNR. ©2022 The Author(s)*

Introduction

The Signal-to-Noise Ratios (SNRs) of services co-propagating through one or several link or Optical Multiplex Section (OMS) of an optical network are coupled by Kerr effect, Stimulated Raman Scattering (SRS), Wavelength Dependent Loss (WDL) and load-dependence of Erbium-Doped Fiber Amplifiers' (EDFA) gain spectrum, such that the SNRs of existing services change upon network layer changes including new services establishment or dropping. To avoid services' disruption in such cases, design margins are usually provided at network design time [1]. Reducing design margins can translate into either higher operation margins (making systems more robust to aging) or extra capacity.

A power re-optimization strategy consists of allocating power to each service, through actuation of per-channel attenuation of the Wavelength Selective Switch (WSS) at the beginning of each OMS [2-4]. A strategy that maintains the worst SNR at its optimum level decreases design margin and increases operation margins, which can then be consumed as stated above.

To maintain services running at their optimum SNR, the powers of all services, both existing and new, may be re-optimized upon any network layer change. This is considered as impractical by many operators, who prefer to use the so-called "set and forget" mode of operation, whereby the power of new services is indeed set using a pre-defined rule, but where the powers hence SNRs of existing services are left to drift.

The ambition of this paper is two-folds. First, we quantify the SNR degradation of existing services as new services are established. Second, we experimentally quantify and compare the SNR improvement of both existing and new services with 2 power re-optimization strategies, over a highly realistic mesh network testbed with 5 OMS (with span type and length heterogeneity) built with commercial equipment, where up to 292 services are established.

Power re-optimization strategies

The first power allocation strategy is Local-Optimum Global-Optimum (LOGO), which is a static End-of-Life (EoL) design strategy that uses "static" parameters available at design or commissioning. LOGO gives a flat power allocation based on the Gaussian Noise (GN) model by optimizing SNR of the worst channel at OMS level, assuming no SRS, flat amplifier gain, and flat fiber attenuation [5]. The LOGO launch power is set so that the total (over all channels) power ratio between linear and Kerr noises is 3 dB at the end of each OMS.

Contrarily, the second power re-optimization strategy is a "dynamic," real-time algorithm [6], dynamically accounting for the network wavelength-dependent physical layer state through monitoring feedback, and calculates the optimal power for each channel to attain the 3 dB aforementioned power ratio per channel at the end of each OMS.

Network scenario

We emulate the progressive loading of a mesh network and periodically optimize the power of each service. Service sources and destinations are randomly picked and first fit wavelength allocation is used, except for the last batch, which fills all OMS to full load. The process is, for each batch:

- Sequentially establish each new service and set its power to the static EoL design power; We do not re-optimize previous services from the same batch;
- Once all services of a batch are loaded, apply power allocation strategy on all (existing and new) services, either: a) "set and forget" (do nothing) or b) static power allocation strategy or c) dynamic power allocation strategy;
- Measure SNRs of all services;
- Repeat with next batch until full load.

Experimental testbed

We experimentally implement in our lab the mesh

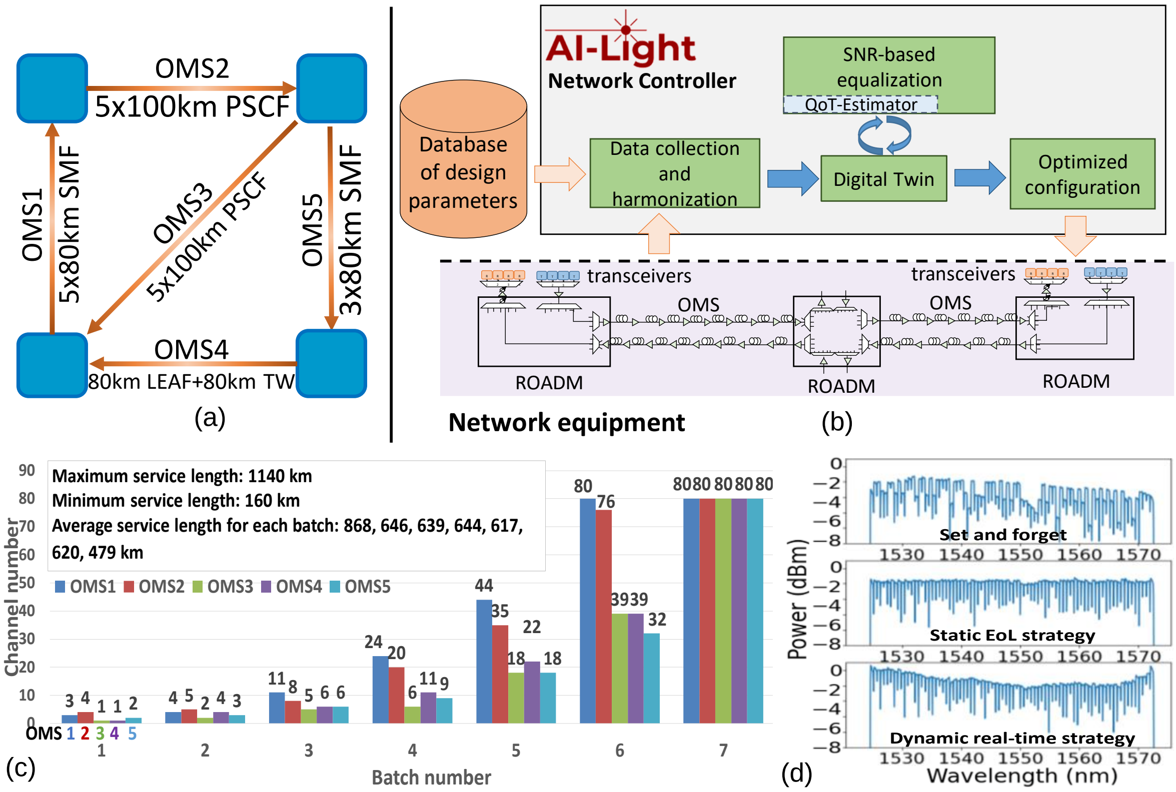

Fig. 1: (a) Topology of the experimental mesh network; (b) AI-Light SDN framework; (c) Number of services transported by each OMS after loading each batch; (d) Full-load normalized power spectrum for each power re-optimization strategy.

network depicted in Fig. 1(a). As traffic demand increases exponentially we accordingly sequentially load 7 batches of new services with sizes: 5, 5, 10, 20, 40, 80, 132 (5, 10, 20, 40, 80, 160, 292 services after each loading). After loading each batch, the number of channels on each OMS and the service length information are shown in Fig. 1(c) SNRs are measured with a single real-time commercial transponder via pre-FEC BER (PDM-QPSK, 200 Gb/s, 75 GHz spacing) with up to 80 channels per OMS in the extended 6 THz C band and loading is otherwise emulated through ASE loading, the only part of the experiment that does not rely on commercial equipment. Unless otherwise stated, we use only information available in real networks. Also, to save time, we measured the SNR of half of the services. Without loss of generality, we report SNR margins (measured SNR-SNR at FEC limit).

Service management, monitoring, data collection, GN-model based SNR estimation, and power optimization is done with our Autonomous Driving Network “AI-Light” Software Defined Networking (SDN) platform [7] (Fig. 1(b)).

The static EoL design power per span is computed using static parameters from design (e.g., fiber type and length) or monitored at commissioning (e.g., span loss). Note that (per-span) EoL design launch power is also used to configure amplifiers in the network; amplifier settings are never changed during network life.

The dynamic real-time power per channel is computed using design parameters, but also dynamic parameters monitored in real-time, either directly (e.g., output power spectrum of the first and last amplifiers only at each OMS, EDFA total input and output powers) or indirectly through estimation (e.g., gain profiles, power profiles of the in-line amplifiers [8,9]).

Fig. 1(d) shows the full load output power spectrum from Optical Spectrum Analyzer (OSA) at the first EDFA of OMS1 with “set and forget” mode, static design power re-optimization, and dynamic real-time power re-optimization, highlighting the sharp differences across the strategies.

Results

Fig. 2(a) shows the impact of loading new services on existing (previously established) services. Existing services’ SNRs are degraded by up to 1.2 dB as each new batch of services are added, which warrants power optimization not only of new services, but also of existing services, upon new service establishment. Fig. 2(b) shows the SNR degradation of the first-loaded service (Service 1, going through OMS 1,2,5) when loading different numbers of services in the network. We can observe that the SNR of Service 1 drops fast after loading batches 1 and 2 (10 services), and decreases by up to 3.4 dB after loading all 292 services. To study the SNR

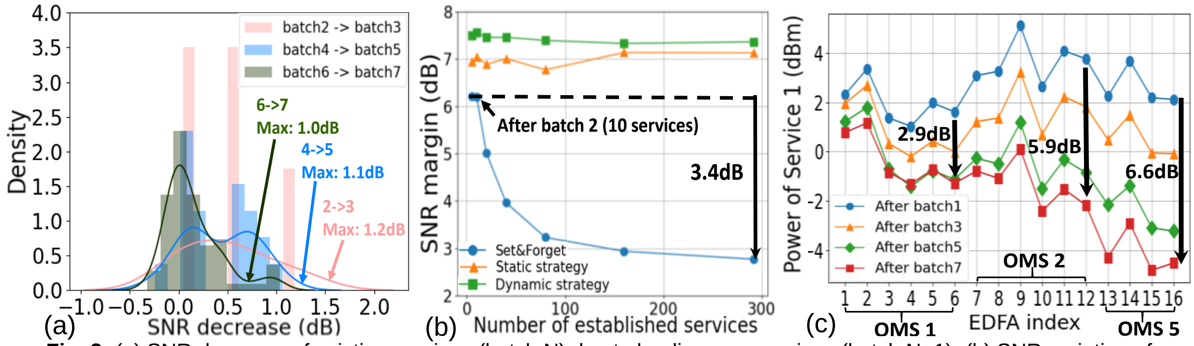

Fig. 2: (a) SNR decrease of existing services (batch N) due to loading new services (batch N+1); (b) SNR variation of Service 1 with different number of established services; (c) Power of Service 1 after each traversed EDFA.

degradation caused by the load-dependence of EDFA gain profile, we track the channel output power variation along each EDFA that Service 1 crosses as different number of services are loaded, see Fig. 2(c): The channel output power decreases by up to 6.6 dB as all 292 services are loaded, corresponding to the 3.4 dB SNR drop in Fig. 2(b). The power decrease is also roughly proportional to the number of crossed EDFAs due to the accumulation of gain variation induced by each EDFA (2.9/5.9/6.6 dB power decrease at the last EDFA of OMS 1/2/5). This can be also observed in Fig. 1(d) where the power spectrum of “set and forget” has different levels (the lower powers correspond to longer services).

Fig. 3(a) shows the SNR margin after optimization (static or dynamic strategy) vs. “set and forget”. The SNR margin of the service with the worst SNR improves by up to 4.6 dB. The dynamic strategy improves SNR margins more than the static strategy due to better adjustment to actual, monitored network configuration compared with static strategy, which assumes no wavelength dependence during transmission.

Fig. 3(b) shows the PDF of SNR margins of all services at full load. The network margin (margin of worst service *after* power re-optimization minus margin of worst service *before* re-optimization) improves by 3.2 dB (A→B in Fig. 3(a)) with the dynamic strategy and 2.6 dB (A→C in Fig. 3(a)) with the static strategy. Fig. 3(c) shows the PDF of SNR gain by applying static (top) or dynamic (bottom) strategy after loading each batch, compared with “set and forget” mode, for each service length (number of traversed OMS). After applying dynamic strategy, SNR decreases for a small number of services due to the total output power limitation for certain EDFAs as many services are loaded, such that some services move from optimum SNR to the slightly linear regime. For single-OMS services, which are back-to-back limited, SNR cannot be improved and in fact decreases by up to 0.8 dB due to the power limitation, however their margins remain high. On the contrary, SNRs for longer services are improved after power re-optimization: the average improvement is 0.5 dB, resp. 1.5 dB for lengths of 2, resp. 3 OMS and the maximum improvement is 2.1 dB, resp. 4.6 dB. Notably, the SNRs of the longest services (3 OMS; smallest SNR margins) are always improved with dynamic (but not with static) power re-optimization, see min SNR values in Fig. 3(c).

Conclusions

In this paper, we experimentally quantify the impact of establishing new services on existing services on a 5-OMS testbed using commercial equipment only. SNRs of existing services are decreased by up to 3.4 dB after loading close to 300 services. Periodic per-service, per-OMS power re-optimization improves network SNR margin by up to 3.2 dB, making the network significantly more robust.

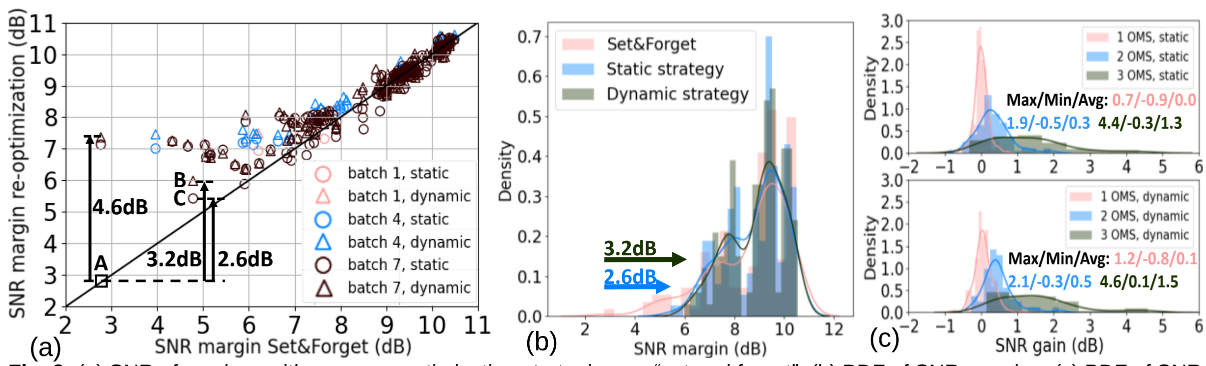

Fig. 3: (a) SNR of services with power re-optimization strategies vs. “set and forget”; (b) PDF of SNR margins; (c) PDF of SNR gain per length (1, 2, 3 OMS) and per power re-optimization strategy.

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