# Digital Twin-Enabled Service Optimization Sequence of Actions for Power Equalization


Chenyu Sun
Paris Research Center, Optical Communication Technolog Lab
Huawei Technologies France
Boulogne-Billancourt, France
chenyu.sun1@huawei.com

Xin Yang
Department of Electronics, Information and Bioengineering
Politecnico di Milano
Milan, Italy
xin.yang@polimi.it

Gabriel Charlet
Paris Research Center, Optical Communication Technolog Lab
Huawei Technologies France
Boulogne-Billancourt, France
gabriel.charlet@huawei.com

Photios A. Stavrou
Communication Systems Department
EURECOM
Sophia Antipolis, France
fotios.stavrou@eurecom.fr

Yvan Pointurier
Paris Research Center, Optical Communication Technolog Lab
Huawei Technologies France
Boulogne-Billancourt, France
yvan.pointurier@huawei.com



***Abstract*—We experimentally demonstrate that service SNR can be degraded by several dB if links are not equalized in the correct sequence; this is prevented with our digital twin-enabled heuristic to optimize the sequence for equalization.**



***Keywords—optical network, optimization, digital twin***


## I. Introduction

Signal-to-noise ratio (SNR) is a significant criterion to assess the quality of transmission (QoT) of a communication system, and methods for optimizing SNR in an optical network by adjusting the channel power have been widely investigated [1-5]. When networks are operated for a long time, e.g. in "set and forget" mode or after some unforeseen event that changes the underlying physical layer (e.g., increasing span loss after repairing a fiber cut), power settings hence SNR may become suboptimal [3]. For this reason, it is important to periodically re-optimize (equalize) the network.

However, during power propagation, changing the configuration of a certain link, for instance tuning a service launch power by configuring the wavelength selective switch (WSS) or changing the total power with an Erbium-Doped Fiber Amplifier (EDFA), will affect the working state of the service(s) in the subsequent links, possibly resulting in temporary SNR degradation. For instance, compared to a current (non-equalized) state, two cascaded links may require higher and lower power respectively, and when the power of the first link is increased, the power of the next link will also be increased immediately, possibly driving the service to the nonlinear regime and degrading its SNR. Hence, how to configure a non-optimized network while ensuring that existing services do not degrade is a significant issue.

In this paper, we propose a digital twin (DT)-enabled algorithm to generate the sequence of actions on WSS of optical links or Optical Multiplex Section (OMS) to set per-service launch power at the booster (first link amplifier) to optimize the worst service in the optical network. Based on a realistic network state inspired by a real operator network, we carry experiment on our commercial products-based testbed. We experimentally demonstrate that while equalizing a service should improve its SNR by 1-2dB, a simple (baseline) sequential OMS equalization strategy causes a SNR drop around 3dB during the optimization, while the DT-enabled sequence of actions is experimentally shown to reach the expected 1dB gain without any SNR drop during equalization.

## II. Principles

### A. Optimization stretagy: ASENL equalization

Assuming flatness of amplifier gains and fiber attenuation, and neglecting Stimulated Raman Scattering (SRS), the Local-Optimum Global-Optimum (LOGO) [1] dictates that the SNR of the worst channel is maximized when the ratio between the amplifiers spontaneous emission (ASE) noise power $P_{ASE}$ and the nonlinear (NL) noise power $P_{NL}$ is $P_{ASE}/P_{NL}$=3dB [2]. Hereafter, we call this ASENL equalization.

For power equalization, DT is used to collect OMS parameters from physical layer so that the power of ASE and NL noise can be estimated.

Since the optimized booster launch power of the service in an optical network can be deduced by applying ASENL equalization, the target is to find the service-safe sequence of actions to reach the final state of service power at each booster.

### B. Sequence of actions

In any algorithm to generate a sequence of actions, we have:

- Service to be optimized: $\lambda_i$
- OMSes: $\{OMS_1, OMS_2, \dots OMS_N\}$
- Initial state: non-optimized booster launch power

$$P_{ini}(\lambda_i) = \{P_{ini}(\lambda_i, OMS_j)\},\ j = 1,2,\dots N$$

- Final state ($P_{ASE}/P_{NL}$=3dB): optimized launch power

$$P_{fin}(\lambda_i) = \{P_{fin}(\lambda_i, OMS_j)\},\ j = 1,2,\dots N$$

- Middle state:

$$P_{mid}(\lambda_i) = \{P_{mid}(\lambda_i, OMS_j)\},\ j = 1,2,\dots N$$

where

$$P_{mid}(\lambda_i, OMS_j) = \frac{P_{ini}(\lambda_i, OMS_j) + P_{fin}(\lambda_i, OMS_j)}{2}$$

TABLE I. OMS DESCRIPTION

| Item | OMS1 | OMS2 | OMS3 | OMS4 | OMS5 |
|---|---|---|---|---|---|
| Span number | 2 | 2 | 5 | 2 | 1 |
| Span details | 40+80 km LEAF | 80+20 km SMF | 5x80 km SMF | 80 km LEAF & 80 km TW | 20 km SMF |
| Total length | 120 km | 100 km | 400 km | 160 km | 20 km |
| Number of channels | 34 | 42 | 65 | 32 | 32 |

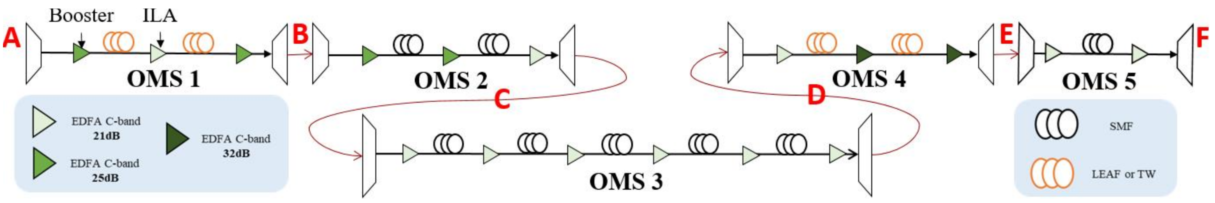



Fig. 1. Experimental setup. A 5-OMS network contains 3 different types of fiber: Single Mode Fiber (SMF), Large Effective Area Fiber (LEAF), True Wave (TW) fiber. The experiment is carried out on a 6 THz C-band network which has 75 GHz channel spacing and the real-time transponder is set to 200 Gb/s PDM-QPSK (68GBaud). In addition, the max gain of EDFA are 21 dB, 25 dB and 32 dB for different types. The first EDFA in an OMS called booster, and the EDFA after a fiber called in-line amplifier (ILA). The details of each OMS are listed in the Table I.

- Action $A_k$:

  set $OMS_j$ booster output power $P(\lambda_i, OMS_j) = P_{state}(\lambda_i, OMS_j)$,with $state$ in $\{ini,\ mid,\ fin\}$.

- Sequence of actions: $S_k = [A_1, A_2, \dots A_k]$.

Here we propose 2 algorithms to generate the sequence of actions: Algorithm 1 (Alg. 1) generates a baseline sequence of actions which sequentially equalize all the booster launch power, from first to last OMS of the service. Algorithm 2 (Alg. 2) generates the sequence of actions with the help of DT to ensure that the service SNR does not drop below initial value during the implementation of actions.

**Algorithm 1** Baseline sequence of actions

**Start** with $S_0 = []$
**for** $k = 1,\ 2,\ \dots N$ **do**
  $A_k: P(\lambda_i, OMS_k) = P_{fin}(\lambda_i, OMS_k)$
  $S_k = [S_{k-1},\ A_k]$
**end**
**output** $S_k$

The baseline sequence of actions (Alg. 1) minimizes the number of actions (=*N*), at the expense of not maintaining the ASE/NL balance during actions implementation. A heuristic algorithm (Alg. 2) uses a DT to predict the SNR variation after each action, and then searches a first sequence of actions to increase the SNR margin without failures until we can safely append the sequential sequence of actions (Alg. 1).

**Algorithm 2** DT-enabled sequence of actions

**Start** with $S_0 = []$, initial state performance $SNR_0$, $k$ =1
**while** True **do**
  **for** $j = 1,\ 2,\ \dots N$ **do**
    **for** $state$ in $\{ini,\ mid,\ fin\}$ **do**
      $A_{k,j,state}: P(\lambda_i, OMS_j) = P_{state}(\lambda_i, OMS_j)$
      DT estimates $SNR_{k,j,state}$
      **if** $SNR_{k,j,state} > SNR_k$ **then**
        $SNR_k = SNR_{k,j,state}$
        $A_k = A_{k,j,state}$
    **end**
  **end**
  $S_k = [S_{k-1},\ A_k]$
  $k = k + 1$
  **do Algorithm 1** to get $S_{algo1}$
  $S_{algo2} = [S_k,\ S_{algo1}]$
  DT estimates SNR after each action in $S_{algo2}$: $SNR_{S_{algo2}}$
  **if for** all $R$ in $SNR_{S_{algo2}}$, $R > SNR_0$ **then**
    **break**
**output** $S_{algo2}$

## III. Experimental Setup

Experiments are performed on an autonomous optical network testbed based on our software-defined networking (SDN) framework named AI-Light [6]. The DT has been used in the SDN to perform the QoT estimation by using the data collected from the physical layer.

The physical layer setup in our lab is shown in Fig. 1. We emulate what was observed on a 5-link section of a larger operator network; the emulated section carries 114 services. The details of each OMS in our setup and channel numbers are listed in Table I.

In the experiment, we configure the WSS channel attenuation to set the booster launch power to different state (initial, middle and final) for each action. After each action, we measure the SNR to assess the performance.

## IV. Results

We select 2 services ($\lambda_{34}$ and $\lambda_{62}$) with worst SNR, whose light paths are both OMS1-OMS2-OM3-OMS4-OMS5, to implement the optimization and get the final state. For instance, the initial and final states for service $\lambda_{34}$ is shown in Fig. 2(a).

### A. Simulations

To reach the final state, we first implement the baseline sequence of actions (Alg. 1), which simply set the power from OMS1 to OMS5 sequentially, and the first 2 steps are shown in Fig 2(b).

Alternatively, we perform Alg. 2 to get the DT-enabled sequence of actions so that we can carry out these actions in our testbed.

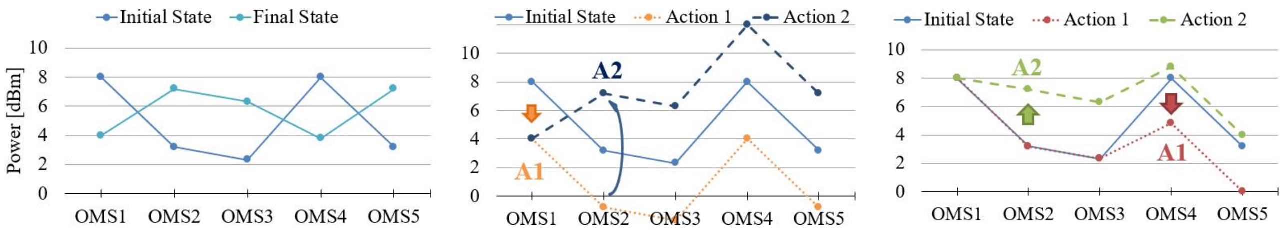
For the 1st selected service ($\lambda_{34}$), the DT-enabled Alg .2 gives a sequence of 2+5 actions, as shown in Fig. 2(c):

1. Set OMS4 booster launch power of $\lambda_{34}$ to final state;

2. Set OMS2 booster launch power of $\lambda_{34}$ to final state;

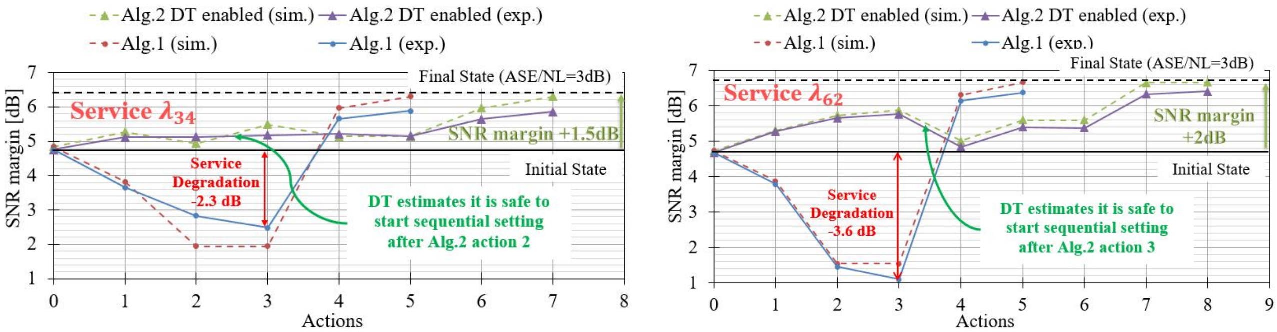
3-7. Sequentially set OMS1-5 booster launch power of $\lambda_{34}$ to final state.

For the 2nd selected service ($\lambda_{62}$), the DT-enabled Alg. 2 gives a sequence of 3+5 actions:




(a) Initial state and final state (b) Sequential first 2 actions (Alg. 1) (c) DT-enabled first 2 actions (Alg. 2)

Fig. 3. Service $\lambda_{34}$ power variation after different actions.




(a) SNR margin of service $\lambda_{34}$ (b) SNR margin of service $\lambda_{62}$

Fig. 4. SNR margin variation after performming different actions.

1. Set OMS4 booster launch power of $\lambda_{62}$ to final state;

2. Set OMS2 booster launch power of $\lambda_{62}$ to middle state;

3. Set OMS5 booster launch power of $\lambda_{62}$ to final state;

4-8. Sequentially set OMS1-5 booster launch power of $\lambda_{62}$ to final state.

The DT also estimates the SNR margin after each action as shown in Fig. 3, which reveals that Alg. 1 would result in SNR margin drop during the actions, while Alg. 2 ensures the SNR margin never drops below the initial value.

### *B. Experiments*

During the implementation of actions from Alg. 1, SNR margin drop by 2.3dB is observed in Fig. 3(a) (service $\lambda_{34}$), while a 3.6dB drop is observed in Fig. 3(b) (service $\lambda_{62}$). Consistent with the simulation results, the DT-enabled Alg. 2 avoids such a degradation of service's quality. As shown in Fig. 3, the SNR margin never below the initial value although it might decrease after an action, e.g. Action 4 in Fig. 3 (b).

In addition, we also observe that the SNR margin remains flat during first 5 actions of Alg. 2 in Fig. 3(a), this is due to the negotiation between the ASE/NL balancing of different OMS during the power re-configuration and power propagation. For instance, Action 1 achieves the ASE/NL balance for OMS4 and SNR margin improves, then action 2 achieves the ASE/NL balance for OMS 2 so that the OMS4 ASE/NL balance is broken, etc.

## V. Conclusion

In this work, we proposed a heuristic DT-enabled algorithm which provides the ability to avoid the service degradation during an optimization task. We presented an 2dB SNR gain with ASENL equalization and cancel the 3.6dB SNR descending during carrying out the actions of optimization.

## References


[1] P. Poggiolini, G. Bosco, A. Carena, V. Curri, Y. Jiang and F. Forghieri, "The GN-Model of Fiber Non-Linear Propagation and its Applications", J. Lightw. Technol., vol. 32, no. 4, Feb. 2014.

[2] V. V. Garbhapu, A. Ferrari, I. F. de Jauregui Ruiz, D. Le Gac, G. Charlet and Y. Pointurier, "Network-Wide SNR-based Channel Power Optimization," 2021 European Conference on Optical Communication (ECOC), Bordeaux, France, 2021, pp. 1-4.

[3] X. Yang, A. Ferrari, D. Le Gac, G. Charlet, M. Tornatore, and Y. Pointurier, "Experimental impact of power re-optimization in a mesh network," J. Opt. Commun. Netw. 15, C20-C28 2023.

[4] Y. Fan, Y. Li, Z. Liu, W. Wang, Y. Zhao, J. Zhang et al., "Channel power equalization based on joint optimization of EDFA and ROADM configuration in open optical network," Opt. Express 31, 23229-23244, 2023

[5] R. T. Jones, K. R. H. Bottrill, N. Taengnoi, P. Petropoulos, and M. P. Yankov, "Spectral power profile optimization of a field-deployed wavelength-division multiplexing network enabled by remote EDFA modeling," J. Opt. Commun. Netw. 15, C192-C202, 2023

[6] A. Ferrari, V. V. Garbhapu, D. Le Gac, I. F. de Jauregui Ruiz, G. Charlet, and Y. Pointurier, "Demonstration of AI-Light: an Automation Framework to Optimize the Channel Powers Leveraging a Digital Twin," in Optical Fiber Communication Conference (OFC) 2022