Load and Nonlinearity Aware Resource Allocation in Elastic Optical Networks

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Abstract: We propose a novel routing and spectrum allocation solution for elastic all-optical networks based on load-aware nonlinear impairment estimation that significantly improves service acceptance ratio and spectrum utilization compared to nonlinearity assignment based on fixed-margins.

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1. Introduction

There is a significant challenge faced by telecom infrastructure and service providers to support traffic requirements of large number of highly capable mobile devices accessing bandwidth intensive applications. In this context, elastic optical network technologies enable efficient utilization of network resources using programmable features on devices and components. In order to utilize the flexibility provided by elastic optical networks, we need complex control mechanisms that monitor/estimate network state and optimize resource allocation. Nonlinear impairments (NLI) such as SPM, XPM, FWM are important factors in assessment of the quality of transmission which is characterized by Optical Signal to Noise Ratio (OSNR) of optical signals. In fixed-grid WDM systems, NLI are generally assigned a fixed reference margin (*RM*) to calculate the link budget of the links/paths [1]. This approach does not consider the state of the link such as signal channel occupancy, modulation formats and power spectral density (PSD).

Assigning fixed reference margin to NLI can lead to underutilization of network spectrum resources in case of elastic optical networks, especially under dynamic services requirements. It is shown in [2] that in case of dynamic request scenarios, calculating NLI based on existing channel occupancy also results in high blocking ratio as future requests introduce more non-linear noise that affects existing requests and hence they are blocked.

Therefore, in this paper, we propose a novel hybrid NLI estimation technique using GN model [3] instead of fixed reference margin or channel occupancy nonlinearity analysis and then propose a novel resource allocation algorithm based on this model to improve network utilization. We further compare our approach with the reference margin approach using extensive simulation studies over NSFNET topology.

2. Hybrid Nonlinear Impairments Model

The impairment model that we have developed is based on following assumptions: (i) transparent dual-polarization optical system using coherent detection without inline compensation and with all optical CDC ROADM based switching; (ii) PMD and PDL are ignored while chromatic dispersion is compensated by DSP techniques at receivers; (iii) rectangle signal spectrum shape and no guard band between channels; (iv) NLI accumulates incoherently along spans; (v) equal transmission PSD among different channels; (vi) power loss is completely compensated by EDFA within a fiber span or at optical switching element; (vii) completely tunable, bandwidth variable and modulation format adaptable transceivers.

In this paper, we consider ASE and nonlinearity as dominant impairments during transmission that affect SNR at receiver. The SNR is calculated as $SNR = P_{ch}/(P_{ASE} + P_{NLI})$, where P_{ch} is channel launch power, P_{ASE} and P_{NLI} are the power of ASE noise and NLI within channel respectively. While ASE has a simple model, traditional NLI models are complex. In a WDM system, NLI are usually assigned fixed reference margin of 0.5 dB for each of SPM, XPM, FWM and SRS/SBS effects [1]. Similar to the fixed reference margin assignment, LOGON strategy in [4] calculates NLI in worst case, which also corresponds to around 2dB loss. In case of low channel occupancy, assigning fixed 2dB margin to NLI instead of their exact value leads to sub-optimal spectral utilization. However, in case of the greedy approach in [2], exact calculation of NLI based on existing channel conditions introduces inter-channel blocking. The cross-channel interference and multi-channel interference [3] introduced by future requests affects existing channels that leads to inter-channel blocking.

In order to solve these two problems, we propose a hybrid NLI estimation model which is a step-wise margin assignment depending on the channel occupancy of the link. We define five loading states of continuous channel occupancy within an optical link as 20%, 40%, 60%, 80% or 100% occupied. In our hybrid nonlinearity model, nonlinear noise is calculated in advance for above 5 loading states (*LS*) using the GN model [3].In this case, within same *LS*, NLI are over-estimated reasonably compared to actual NLI but our approach reduces the computational complexity of calculating NLI before provisioning each request. It also avoids inter-channel blocking after establishing the service while keeping the same *LS* of the link. This hybrid nonlinearity (*HN*) approach combines features of both conservative and greedy NLI models to improve spectral utilization. The proposed *HN* model is used in our Routing Modulation Spectrum Allocation (RMSA) solution below to maximize service acceptance ratio and spectrum utilization as discussed in the next section.

3. Loading Aware Resources Allocation Algorithm

As the *LS* of the link changes, NLI of the link changes and services provisioned based on previous *LS* may be affected. In order to preserve existing services and allow future requests while improving the spectrum utilization, we propose the Load and nonlinearity Aware Resources Allocation (*LARA*) algorithm as is shown in Fig. 1. *LARA* is able to find a proper path for the request. Based on ASE model and *HN* model, most suitable modulation format is assigned to the request for the path. *LARA* overcomes the inter-channel blocking problem by reconfiguring affected services. *LARA* is also able to mitigate verify-reconfigure loop by blocking the request that triggers reconfiguration of multiple existing services that may be affected. Since our solution considers only 5 states, it requires few numbers of reconfigurations which reduces control plane complexity.

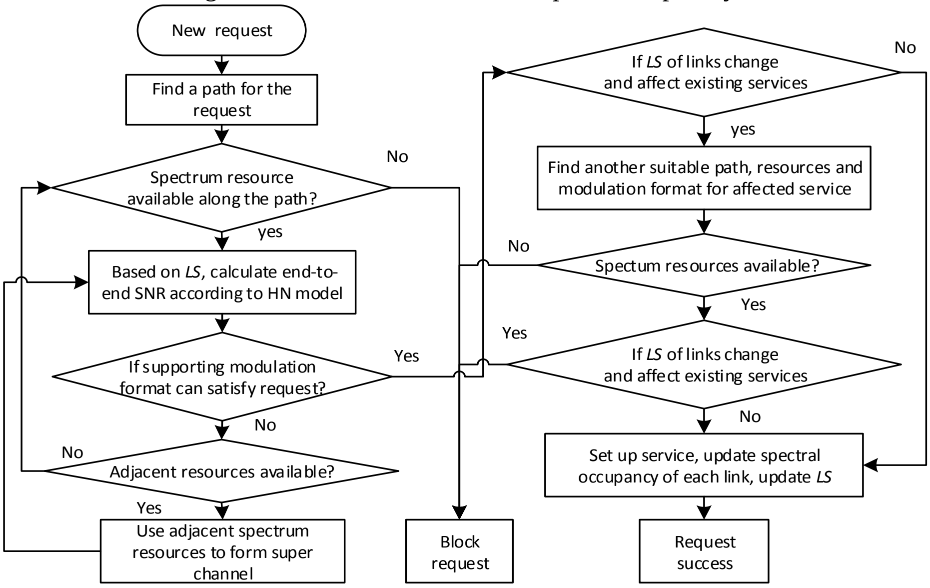

Fig. 1: *LARA* algorithm

4. Evaluation methodology and Results Discussion

In order to evaluate the performance of our *LARA* solution, we consider 5 THz of C-band (from 190.6 THz to 195.6 THz) optical spectrum which is assumed to be divided into 400 spectrum slots of 12.5 GHz granularity. Multiple continuous spectrum slots can be combined together to form a super-channel. The launch power spectrum density is optimized based on full channel occupancy and set to be 19 mw/THz [5]. We follow symbol SNR threshold for different modulation formats as mentioned in [6] to achieve 4×10^{-3} pre-FEC BER. All nodes are transparent CDC ROADMS with 7.25 dB insertion loss and all links in the network are assumed to be of identical span length of 80 km of SMF. The NSF topology with 14 nodes, 21 links is used for evaluation with same parameters as described in [6].

The traffic model consists of symmetric bi-directional requests with certain data rate (which includes FEC and corresponding overhead) between randomly selected pairs of source and destination. In this paper, we consider two types of traffic scenarios: 1) all 100Gbps requests, 2) equal numbers of 400Gbps, 100Gbps, 40Gbps and 10Gbps (mixed line-rate) requests to model different bandwidth granularities for different services. In each scenario, 5000 traffic requests are randomly generated and provisioned to saturate the network and our solutions are evaluated against 10000 different instances of each scenario to measure total blocking ratio and average number of requests using specific modulation format. We evaluate four solutions based on the combination of two non-linearity models: 1)fixed reference margin and 2)load-aware step-wise margin and two routing algorithms: 1) shortest-path routing algorithm and 2) congestion-aware routing algorithm [5] while using first-fit spectrum allocation.

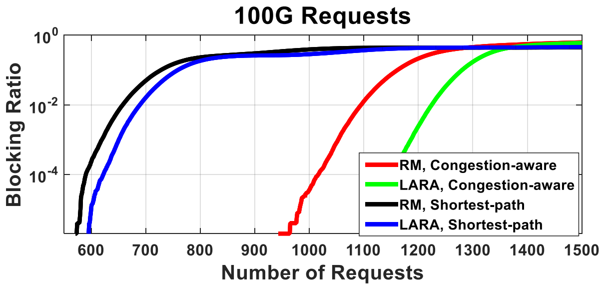

Fig. 2: (a) Services blocking ratio under 100G requests

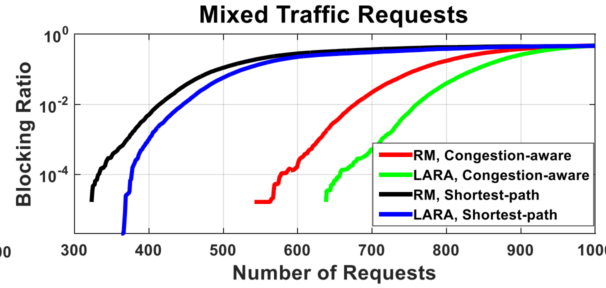

Fig. 2(b) Services blocking ratio under mixed traffic requests

Figure 2 shows the average blocking ratio of *LARA* solution and *RM* solution for number of requests. It indicates *LARA* is able to achieve higher service acceptance ratio than *RM* method. In case of congestion-aware routing strategy, *LARA* accepts approximately 130 more 100G requests than *RM* solution at 1% blocking ratio as shown in Fig. 2(a). Similarly, as shown in Fig. 2(b) *LARA* accepts approximately 100 more requests in case of mixed-traffic demands. The comparison between different solutions from Fig. 2 clearly shows that *LARA* solution with congestion-aware routing is optimal for both fixed line-rate and mixed line-rate demands.

In Figure 3, we showcase average number of requests provisioned at different modulation formats for *LARA* and *RM* case at 1% blocking ratio. It can be seen that *LARA* assigns high modulation formats for more number of requests compared to *RM* method under all scenarios thus achieving greater spectral efficiency. In case of 100G requests, our solutions do not assign 8QAM to any requests as 8QAM is not a suitable modulation format for 100 Gbps requests compared to QPSK as it consumes same spectrum slots as QPSK but QPSK can reach longer distances and is more tolerant to NLI.

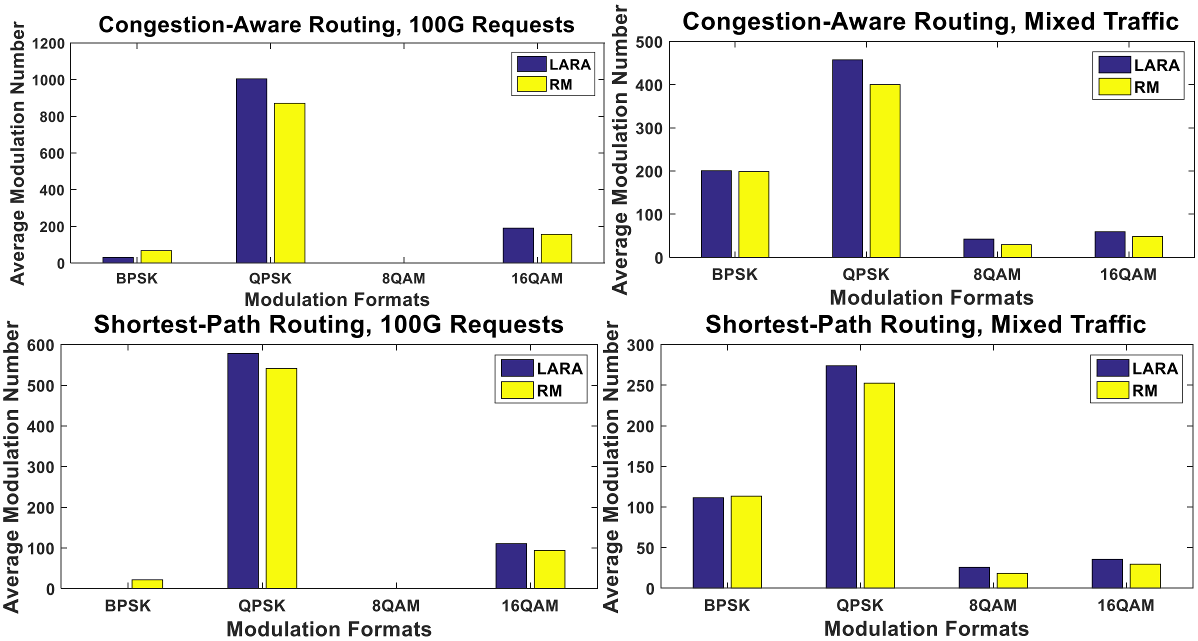

Fig. 3: Modulation formats number under 1% blocking probability

At 1% blocking ratio, *LARA* only requires average 27.6 and 7.5 number of reconfigurations for congestion-aware routing and shortest-path routing respectively. Similarly, 15.6 and 5.7 reconfigurations are needed in case of mixed traffic demands.

4. Conclusion

In this paper, we proposed a hybrid nonlinearity estimation model based on the channel occupancy which decides loading state of the optical link. We also proposed a Load and nonlinearity Aware Resource Allocation algorithm that can provision significantly more service requests than traditional *RM* method while also achieving higher spectral efficiency. The proposed *LARA* solution reduces computational complexity of NLI estimation and also simplifies optical service provisioning with minimal number of re-planning. The *LARA* solution is evaluated through extensive simulation studies under different traffic models and routing algorithms and the results verify the benefits of the solution.

Acknowledgments

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5. References

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