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Suspect Fault Screening Assisted Graph Aggregation Network for Intra-/Inter-Node Failure Localization in ROADM-based Optical Networks

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Abstract *We propose a suspect fault screening assisted graph aggregation network for intra-/inter-node failure localization in ROADM-based optical networks, which is validated in both simulated topology and testbed. Results show that it achieves satisfactory accuracy under different percentage of OPMs and the number of service requests. ©2022 The Author(s)*

Introduction

In optical networks, failure localization is crucial to stable operation and service restoration[1]. Several approaches were presented to achieve accurate failure localization, including rule-based reasoning with routing and alarms[2-3], and the analysis of alarms and monitoring data through machine learning[4-7]. These above works were mainly investigating the failure localization of nodes and inter-nodes, where the failures of inter-node include fibers and EDFA. However, due to the increase of traffic and demand for flexibility, the reconfigurable optical add/drop multiplexer (ROADM) node is evolving towards multi-degree architecture, e.g., 32-degree[8-10]. Thus, its internal composition will contain multiple devices, such as wavelength selective switch (WSS) and splitter, which makes the failures of intra-node become more complex. In this context, failure localization of intra-node can effectively reduce the pressure on operators to further find specific devices. Moreover, it also ensures that partial degrees within ROADM node are available when service re-routing. Therefore, failure localization of intra-/inter-node is essential for multi-degree ROADM-based optical networks.

To locate failure of intra-/inter-node, it is an effective method to deploy a mass of optical performance monitors (OPMs) into intra-/inter-node for monitoring network status. However, operators expect to deploy fewer OPMs for reducing CAPEX, which may result in ambiguity of failure locations. Moreover, because of traffic exchange between different degrees and nodes, it reinforces the complex dependency between monitoring data. Thus, it is difficult to analyse these interacting data. The above issues make failure localization of intra-/inter-node become an imperative challenge.

In this paper, we propose a Suspect Fault Screening assisted Graph aggRegation Network (SFS-GRN) to locate failure of intra-/inter-node in ROADM-based optical networks. SFS is used to reduce ambiguity of failure locations through screening out potential fault devices from all devices. GRN is responsible for analysing these interacting data and determining the most likely failure location between potential fault devices. We evaluate our scheme in both emulated network and testbed network carrying live traffic. Experimental results show that different failure types are localized with satisfactory accuracies under different percentage of OPM deployment and the number of service requests.

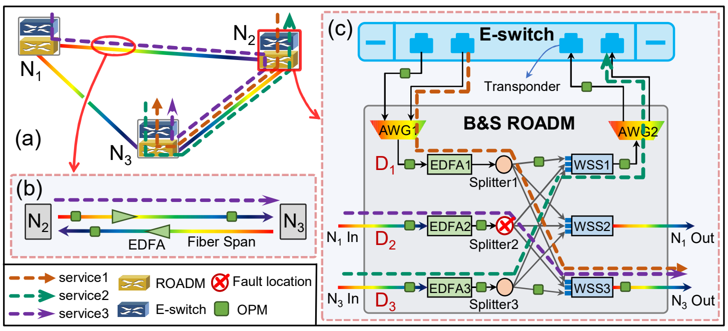


Fig. 1: (a) ROADM-based optical network; (b) Bidirectional lightpath between two nodes; (c) 3-degree B&S ROADM and E-switch.

Tab. 1: Failure devices of intra-/inter-node and corresponding influences.

Failure Devices	Failure Influences
EDFA	Insufficient amplification (0%~50% of normal)
Fiber	Extra attenuation (150%~200% of normal)
Splitter	
WSS	
AWG	
Transponder	Insufficient launch power (0%~50% of normal)

Network Architecture and Intra-/Inter-Node Failure Model

Fig. 1(a) shows a ROADM-based optical network carrying multiple service requests. For each link, the bidirectional lightpaths are provided for traffic transmission, and each of them includes two fiber spans and one EDFA shown in Fig. 1(b). For each node, it consists of an electrical switch (E-switch) and a broadcast-and-selected (B&S) ROADM shown in Fig. 1(c). E-switch is equipped with several transponders for sending and receiving traffic. The ROADM is composed of arrayed waveguide grating (AWG), EDFA, splitter and WSS. It achieves flexible switching between different degrees (e.g., D_1~D_3 in Fig. 1(c)) and nodes (e.g., N_1~N_3 in Fig. 1(a)). Meanwhile, we consider two ways to deploy OPMs, in which random and uniform ways mean that their locations are randomly or uniformly selected in proportion from all available positions.

In ROADM-based optical networks, several devices at intra-/inter-node may fail and result in service disruption. As shown in Tab.1, we take all failures into three categories: 1) amplification failures include all EDFA, and they will provide insufficient amplification to signals; 2) attenuation failures contain fiber, splitter, WSS and AWG, where they bring extra attenuation into network; 3) launch failures include all transponders, and they can't ensure sufficient launch power. In addition, multiple devices usually don't fail simultaneously. Thus, we only consider single failure localization.

Suspect Fault Screening Assisted Graph Aggregation Network (SFS-GRN)

SFS-GRN is a collaborative way for intra-/inter-node failure localization. The whole scheme consists of two modules shown in Fig. 2.

Module1: Screening of suspect fault devices by SFS. Firstly, we establish a bipartite graph between all services and device set D based on routing and wavelength assignment (RWA) results, in which each link denotes a service passing through a corresponding device. Then, total services are divided into abnormal set A and normal set N according to whether they have alarms. These links are further transformed into two matrices, i.e., $M^1_{(D,A)}$ and $M^2_{(D,N)}$, where the subscript is the size of matrix. Moreover, several operations are designed to distinguish between all devices that are normal or suspect fault devices. This design is mainly based on two principles: 1) failure is not a device that normal services pass through; 2) failure is one of devices through which all abnormal services pass. These operations can be expressed as follows:

$$R^1_{(D,1)} = M^1_{:,1} \;\&\&\; M^1_{:,j} \;(\forall\, 1 < j \leq \mathrm{A}) \qquad (1)$$

$$R^2_{(D,1)} = M^2_{:,1} \;||\; M^2_{:,j} \;(\forall\, 1 < j \leq \mathrm{N}) \qquad (2)$$

$$R_{(D,1)} = R^1_i \;\&\&\; (\neg R^2_i) \;\; (\forall\, 1 < i \leq \mathrm{D}) \qquad (3)$$

where &&, || and ¬ denote local "AND", "OR" and "NOT" operators respectively. The final output R is a D-dimensional vector, in which "1" and "0" indicate whether each device is suspect fault or normality respectively.

Module2: Locating of failure device by GRN. After screening by SFS, failure location will be limited to a small space, but it is usually unable to directly find a specific failure location. Therefore, the GRN is used to explore monitoring data from OPMs and further locate failure device. Firstly, these monitoring results of each ROADM node and its adjacent links are split into multiple vectors, e.g., F_1~F_3 of network layer in Fig. 2, where the number of vectors depends on the degree of this ROADM. Then, these vectors are aggregated by bidirectional recurrent neural network (RNN)[11], and the output results are concatenated as node-features into feature graph. Meanwhile, graph neural network (GNN) is responsible for exploiting these graph-features in network-wide[12], and the analysed results are flattened into artificial neural network (ANN) for locating failure between suspect fault devices.

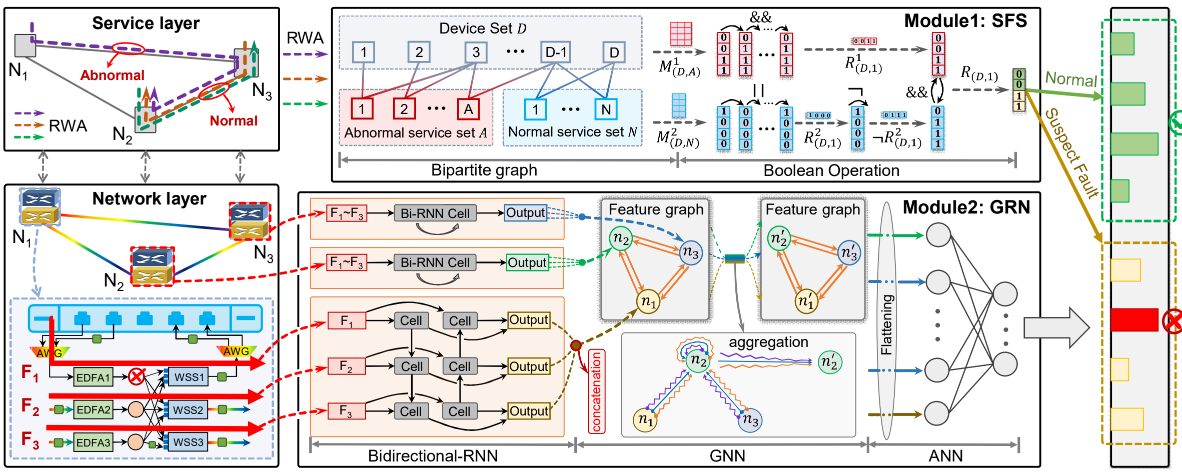
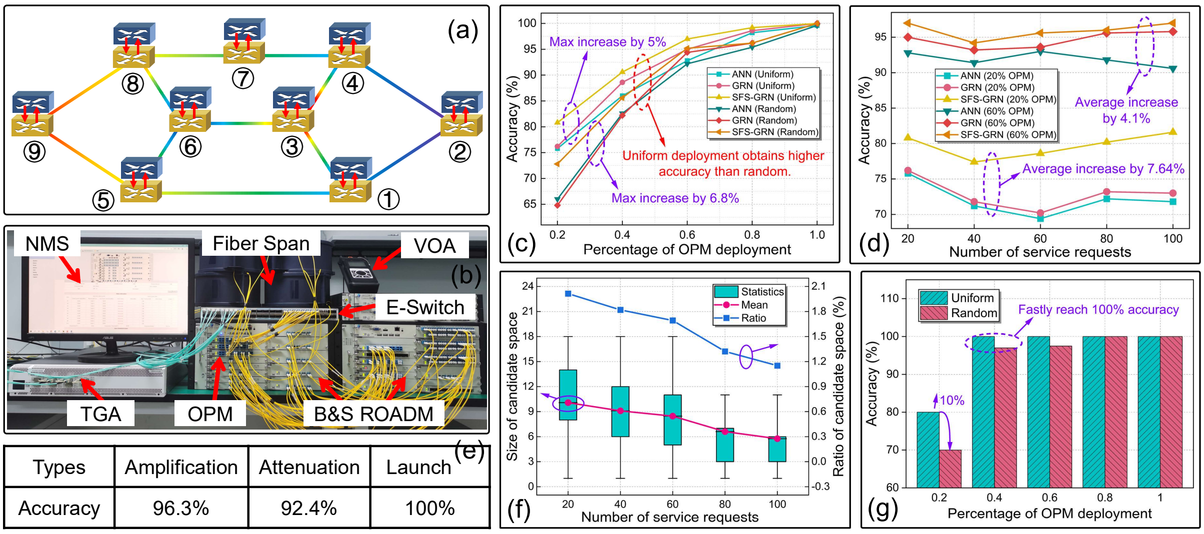


Fig. 2: Intra-/inter-node failure localization scheme based on SFS-GRN.



Types	Amplification	Attenuation	Launch
Accuracy	96.3%	92.4%	100%

Fig. 3: (a) Simulated network; (b) ROADM-based testbed; (c) Percentage of OPM deployment vs. accuracy; (d) No. of service requests vs. accuracy; (e) Accuracy of different failure types; (f) No. of service requests vs. No. of suspect fault devices; (g) Percentage of OPM deployment vs. accuracy in testbed network.

Experimental Setup and Results

We evaluate our scheme on simulated and real testbed networks respectively. Fig. 3(a) shows the simulated topology, which consists of nine nodes and twelve bidirectional links. For each node, the launch power of transponder is -1 dBm, while EDFA with gain of 15 dB is used to amplify signal power. The attenuation of each WSS, splitter and AWG are set as 6 dB, 2 dB and 6 dB respectively. For each link, the fiber span ranges from 20 to 60 km with 0.2 dB/km attenuation, while the gain of EDFA is set as 20 dB to withstand fiber attenuation. Three wavelengths with total capacity of 3×10 Gbps are used to carry traffic. These above parameters mainly depend on our testbed and existing works[13]. Meanwhile, we generate 20 ~ 100 services with random source-destination pairs and bandwidth demands collected from nine real geo-distributed areas[14]. Auxiliary graph (AG) model[15-17] performs RWA for each service request. Moreover, we also develop a real network (see Fig. 1(a)), and field trial is shown in Fig. 3(b). It is a ROADM-based testbed presented in our previous work [14]. The traffic generator and analyser (TGA) is connected to E-switch for injecting live traffic, while variable optical attenuator (VOA) is used to simulate failures. These real data are collected by OPMs and reported to network management system (NMS) for validating our scheme. Besides, GRN of two layers with 20×30 neurons are applied, while ANN of three layers is taken as benchmark.

Fig. 3(c) shows failure localization accuracy under different percentage of OPM deployment, in which the number of services is set as 40. It can be observed that SFS-GRN achieves higher accuracy followed by GRN and ANN. In addition, uniform deployment obtains higher accuracy than random. This is because random may cause OPMs to be centrally placed on a few nodes and links, which is not beneficial to feature exploration. Fig. 3(d) shows localization accuracy with the number of service requests under uniform OPM placement, where SFS-GRN improves accuracy of 7.64% and 4.1% on average when OPM ratio is 20% and 60% respectively. It also shows that our scheme has no strong correlation with the number of services. Meanwhile, we present location accuracy of different failure types under uniform and 60% OPM, and results are shown in Fig. 3(e), where our scheme obtains satisfactory results regardless of failure types. Fig. 3(f) shows the distribution of suspect fault space after SFS screening, in which SFS removes more than 98% of devices. This is beneficial to further detection and repair of operators. Moreover, SFS-GRN is validated in real testbed network, and the experimental results are shown in Fig. 3(g). Uniform OPM deployment obtains more superior results than random. The above results indicate that our scheme achieves similar performance in both simulated and real network scenarios.

Conclusions

To further reduce the pressure of operation and keep partial transmission ability of ROADM node under failure, we proposed an SFS-GRN scheme to locate failure of intra-/inter-node in ROADM-based optical networks. It obtained satisfactory accuracy in both simulated and real testbed scenarios. This approach has the potential to achieve accurate failure localization for multi-degree ROADM-based optical networks.

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References

[1] F. Musumeci, C. Rottondi, G. Corani, S. Shahkarami, F. Cugini and M. Tornatore, "A Tutorial on Machine Learning for Failure Management in Optical Networks," *Journal of Lightwave Technology*, vol. 37, no. 16, pp. 4125-4139, 15 Aug.15, 2019. DOI: 10.1109/JLT.2019.2922586

[2] C. Delezoide, P. Ramantanis, L. Gifre, F. Boitier and P. Layec, "Field Trial of Failure Localization in a Backbone Optical Network," *2021 European Conference on Optical Communication (ECOC)*, Bordeaux, France, 2021, pp. 1-4. DOI: 10.1109/ECOC52684.2021.9606152

[3] S. Barzegar, E. Virgillito, M. Ruiz, A. Ferrari, A. Napoli, V. Curri, L. Velasco, "Soft-Failure Localization and Device Working Parameters Estimation in Disaggregated Scenarios," *2020 Optical Fiber Communications Conference and Exhibition (OFC)*, San Diego, CA, USA, 2020, pp. 1-3. DOI: 10.1364/OFC.2020.Th1F.2

[4] Z. Li, Y. Zhao, Y. Li, S. Rahman, F. Wang, X. Xin and J. Zhang, "Fault Localization based on Knowledge Graph in Software-Defined Optical Networks," *Journal of Lightwave Technology*, vol. 39, no. 13, pp. 4236-4246, July1, 2021. DOI: 10.1109/JLT.2021.3071868

[5] K. S. Mayer, J. A. Soares, R. P. Pinto, C. E. Rothenberg, D. S. Arantes and D. A. A. Mello, "Machine-learning-based soft-failure localization with partial software-defined networking telemetry," *Journal of Optical Communications and Networking*, vol. 13, no. 10, pp. E122-E131, October 2021. DOI: 10.1364/JOCN.424654

[6] J. Jia, D. Wang, C. Zhang, H. Yang, L. Guan, X. Chen, M. Zhang, "Transformer-based Alarm Context-Vectorization Representation for Reliable Alarm Root Cause Identification in Optical Networks," *2021 European Conference on Optical Communication (ECOC)*, Bordeaux, France, 2021, pp. 1-4. DOI: 10.1109/ECOC52684.2021.9606141

[7] C. Zhang, D. Wang, J. Jia, L. Wang, S. Liu, L. Guan, M. Zhang, "Attention Mechanism-Driven Potential Fault Cause Identification in Optical Networks," *2021 Optical Fiber Communications Conference and Exhibition (OFC)*, San Francisco, CA, USA, 2021, pp. 1-3. DOI: 10.1364/OFC.2021.W1F.1

[8] D. C. Morão, L. G. Cancela and J. L. Rebola, "Exploring future large-scale ROADM architectures," *2021 Telecoms Conference (ConfTELE)*, Leiria, Portugal, 2021, pp. 1-6. DOI: 10.1109/ConfTELE50222.2021.9435539

[9] D. G. Sequeira, L. G. Cancela and J. L. Rebola, "Impact of physical layer impairments on multi-degree CDC ROADM-based optical networks," *2018 International Conference on Optical Network Design and Modeling (ONDM)*, Dublin, Ireland, 2018, pp. 94-99. DOI: 10.23919/ONDM.2018.8396113

[10] C. Zhang, J. Li, H. Wang, A. Guo and C. Janz, "Evaluation of Dynamic Optical Service Restoration on a Large-Scale ROADM Mesh Network," in *IEEE Communications Magazine*, vol. 57, no. 4, pp. 138-143, April 2019. DOI: 10.1109/MCOM.2019.1800307

[11] Y. Song, D. Wang, M. Zhang and Q. Cui, "A Fiber-Optic Channel Modeled Through BiLSTM Technique," *18th International Conference on Optical Communications and Networks (ICOCN)*, Huangshan, China, 2019, pp. 1-3. DOI: 10.1109/ICOCN.2019.8933906

[12] P. Velickovic, G. Cucurull, A. Casanova, A. Romero, P. Lio and Y. Bengio, "Graph Attention Networks", *2018 International Conference on Learning Representations (ICLR)*, Vancouver, Canada, 2018. https://arxiv.org/pdf/1710.10903.pdf

[13] K. S. Mayer, J. A. Soares, R. P. Pinto, C. E. Rothenberg, D. S. Arantes and D. A. A. Mello, "Soft Failure Localization Using Machine Learning with SDN-based Network-wide Telemetry," *2020 European Conference on Optical Communications (ECOC)*, Brussels, Belgium, 2020, pp. 1-4. DOI: 10.1109/ECOC48923.2020.9333313

[14] Z. Chen, J. Zhang, B. Zhang, R. Wang, H. Ma and Y. Ji, "ADMIRE: Demonstration of Collaborative Data-Driven and Model-Driven Intelligent Routing Engine for IP/Optical Cross-Layer Optimization in X-Haul Networks," *2022 Optical Fiber Communications Conference and Exhibition (OFC)*, San Diego, CA, USA, 2022, pp. 1-3. DOI: 10.1364/OFC.2022.M3F.4

[15] H. Zhu, H. Zang, K. Zhu and B. Mukherjee, "A novel generic graph model for traffic grooming in heterogeneous WDM mesh networks," in *IEEE/ACM Transactions on Networking*, vol. 11, no. 2, pp. 285-299, April 2003. DOI: 10.1109/TNET.2003.810310

[16] H. Yu, T. Taleb, J. Zhang and H. Wang, "Deterministic Latency Bounded Network Slice Deployment in IP-Over-WDM Based Metro-Aggregation Networks," in *IEEE Transactions on Network Science and Engineering*, vol. 9, no. 2, pp. 596-607, 1 March-April 2022, DOI: 10.1109/TNSE.2021.3127718

[17] H. Yu, T. Taleb and J. Zhang, "Deterministic Latency/Jitter-aware Service Function Chaining over Beyond 5G Edge Fabric," in *IEEE Transactions on Network and Service Management*, DOI: 10.1109/TNSM.2022.3151431