Digital Twins in Optical Networks: Insights and Applications

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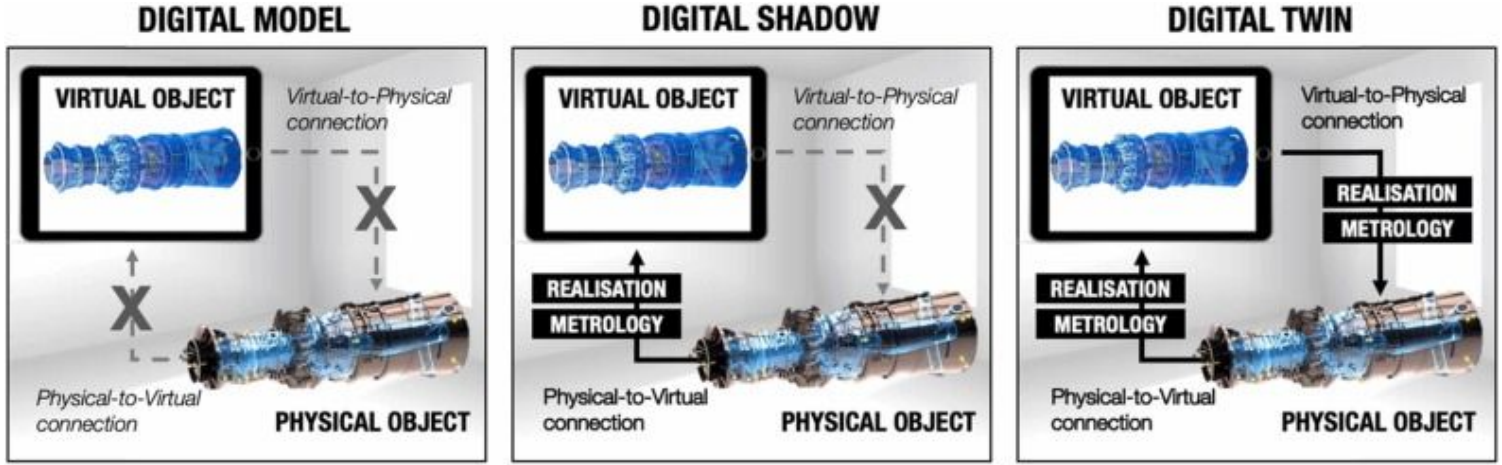
Outline

- What is a Network Digital Twin (NDT)?
- NDT in Optical Networks
- Issues and Challenges
- Case study: ML-based soft-failure localization using NDTs

What is a Network Digital Twin?

- But first, what is a digital twin? It is much more than a digital model or a simulator …



M. Bertoni, A. Bertoni, (2022), Designing solutions with the product-service systems digital twin: What is now and what is next?, Computers in Industry, Volume 138, https://doi.org/10.1016/j.compind.2022.103629.

W. Kritzinger, M. Karner, G. Traar, J. Henjes, W. Sihn, Digital Twin in manufacturing: A categorical literature review and classification,IFAC-PapersOnLine, Volume 51, Issue 11, 2018, Pages 1016-1022.

What is a Network Digital Twin?

- Network Digital Twin (ou Digital Twin Network)

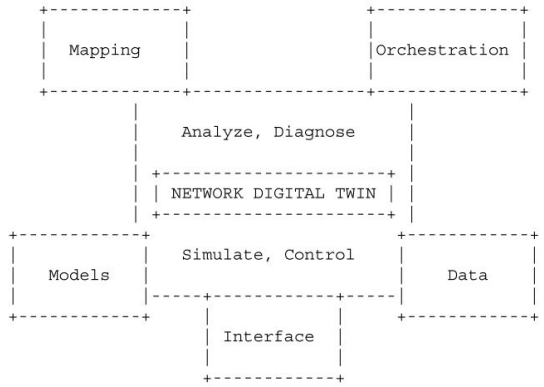
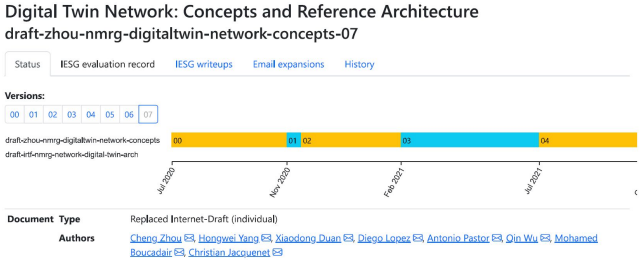


Figure 1: Key Elements of Digital Twin Network



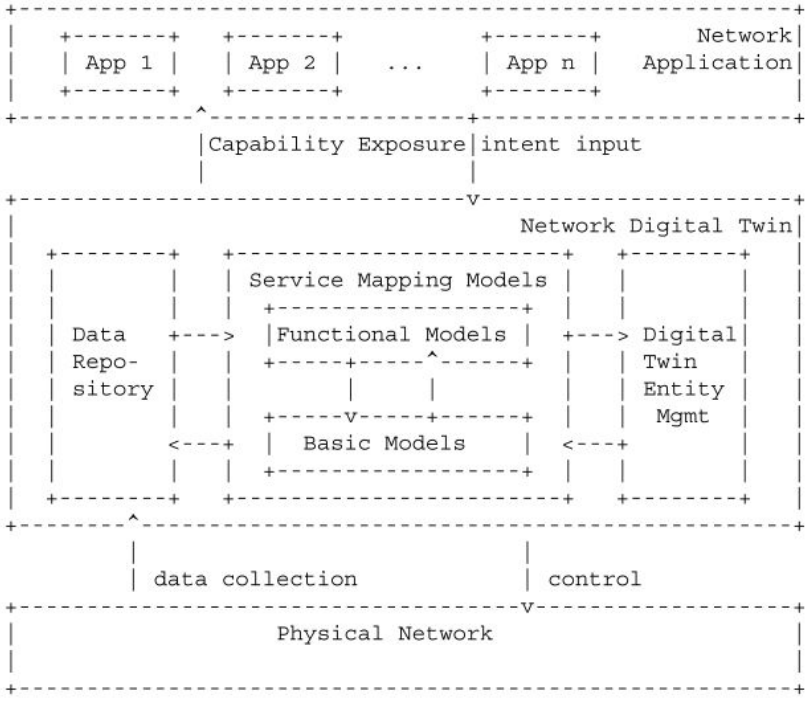


Figure 2: Reference Architecture of Digital Twin Network

Source: IRTF draft-zhou-nmrg-digitaltwin-network-concepts-00

What is a Network Digital Twin?

IEEE/IFIP Network Operations and Management Symposium
25-29 April 2022 // Budapest, Hungary
Network and Services Management in the Era of Cloudification, Softwarization and Artificial Intelligence

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WS4 - 1ST INTERNATIONAL WORKSHOP ON TECHNOLOGIES FOR NETWORK TWINS (TNT 2022)

All times listed are in Central European Summer Time (CEST)

TNT 2022 Program

Time - CEST	Duration	Session	Chair
09:00	45 min.	**Opening and Keynote** Keynote speaker: Adam Drobot, OpenTechWorks Title: Network Requirements for Digital Twins and Digital Twin Requirements for Networks	Laurent Ciavaglia
09:45	45 min.	**Invited talks**	Diego Lopez
	15 min.	Building a digital twin network leveraging model orchestration, Hongwei Yang – China Mobile *(remote)*	
	15 min.	An Industrial Network Digital Twin for enhanced cyber-security, Andrea Melis – Università di Bologna *(remote)*	
	15 min.	MTV: A Network Emulator for Digital Twins, Will Fantom – Lancaster University *(on site)*	
10:30	30 min.	*Coffee break*	
11:00	75 min.	**Technical session 1**	Roberto Minerva
	25 min.	Smart DC: An AI and Digital Twin-based Energy-Saving Solution for Data Centers, Ziting Zhang *(remote)*	
	25 min.	BSGEMINI: a Digital Twin Network for 5G and Beyond, Alberto Mozo Velasco *(remote)*	
	25 min.	Digital Twin for the Optical Network: Key Technologies and Enabled Automation Applications, Chris Janz *(on site)*	
12:30	60 min.	*Lunch break*	
13:30	75 min.	**Technical session 2**	Laurent Ciavaglia
	25 min.	Stopping the Data Flood: Post-Shannon Traffic Reduction in Digital-Twins Applications, Caspar von Lengerke *(on site)*	
	25 min.	Accelerating Deep Reinforcement Learning for Digital Twin Network Optimization with Evolutionary Strategies, Carlos Güemes Palau *(on site)*	
	25 min.	A Chaos Engineering Approach for Improving the Resiliency of IT Services Configurations, Filippo Poltronieri *(on site)*	
15:00	30 min.	*Coffee break*	
		Panel on Hot Topics in Network Digital Twins	

https://noms2022.ieee-noms.org/ws4-1st-international-workshop-technologies-network-twins-tnt-2022

1ST INTERNATIONAL WORKSHOP ON TECHNOLOGIES FOR NETWORK TWINS (TNT 2022)

What is a Network Digital Twin?

- Digital Twins in Optical Networks

IEEE Comm. Magazine 2021

OFC 2022

Architecture to Deploy and Operate a Digital Twin Optical Network

R. Vilalta[1], R. Casellas[1], Ll. Gifre[1] R. Muñoz[1], R. Martínez[1], A. Pastor[2] , D. López[2], J.P. Fernández-Palacios[2]

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NDT in Optical Networks

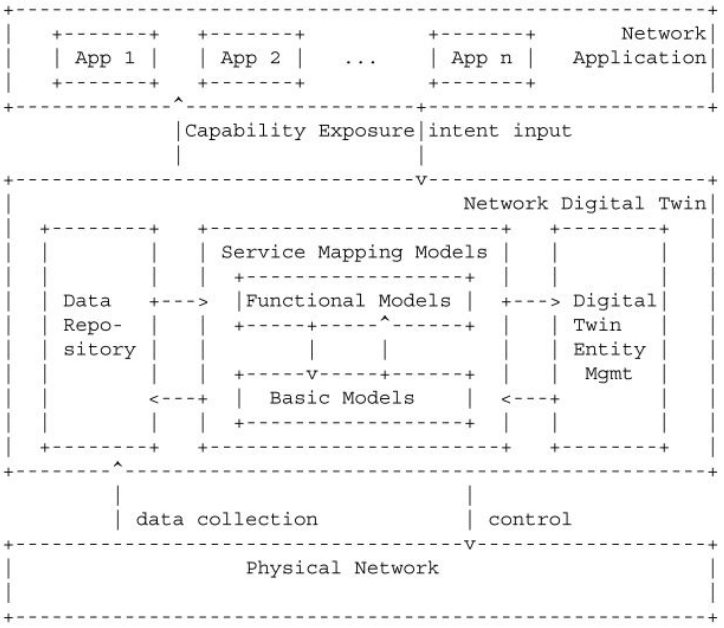
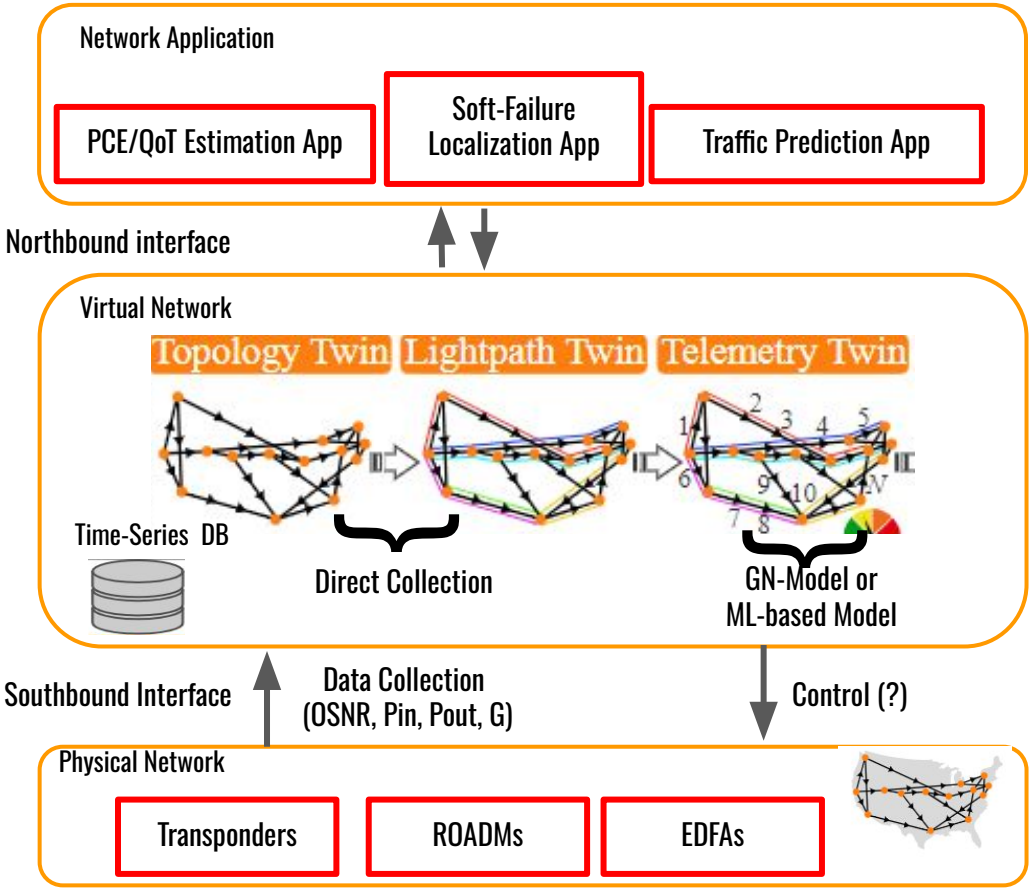
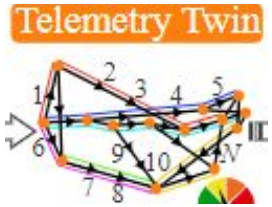


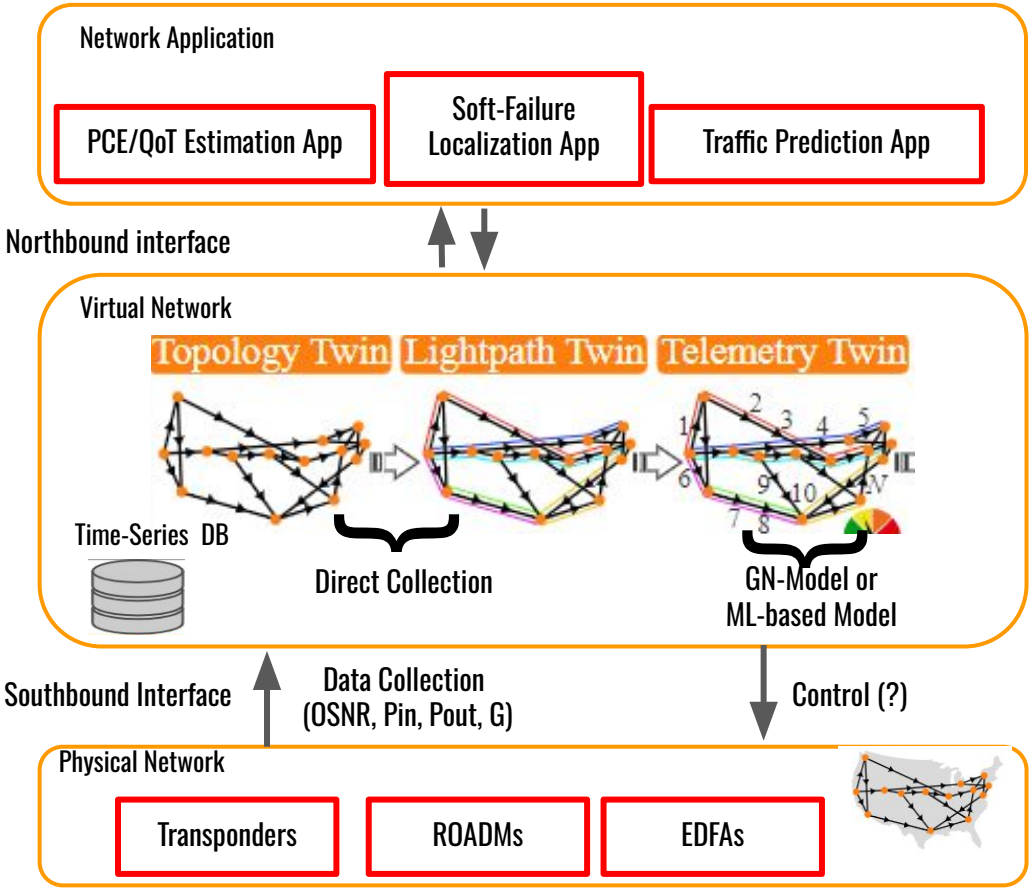
Figure 2: Reference Architecture of Digital Twin Network



NDT in Optical Networks



Parameter	Real Telemetry	Virtual Telemetry
EDFA_1_Pout	10 dBm	10.5 dBm
EDFA_1_Pin	-15 dBm	-14.7 dBm
TRX_2_OSNR	15 dB	17 dB
TRX_3_OSNR	13 dB	13 dB
TRX_5_OSNR	16 dB	14 dB



Issues and Challenges

- How to address inconsistencies between the virtual and the real network?

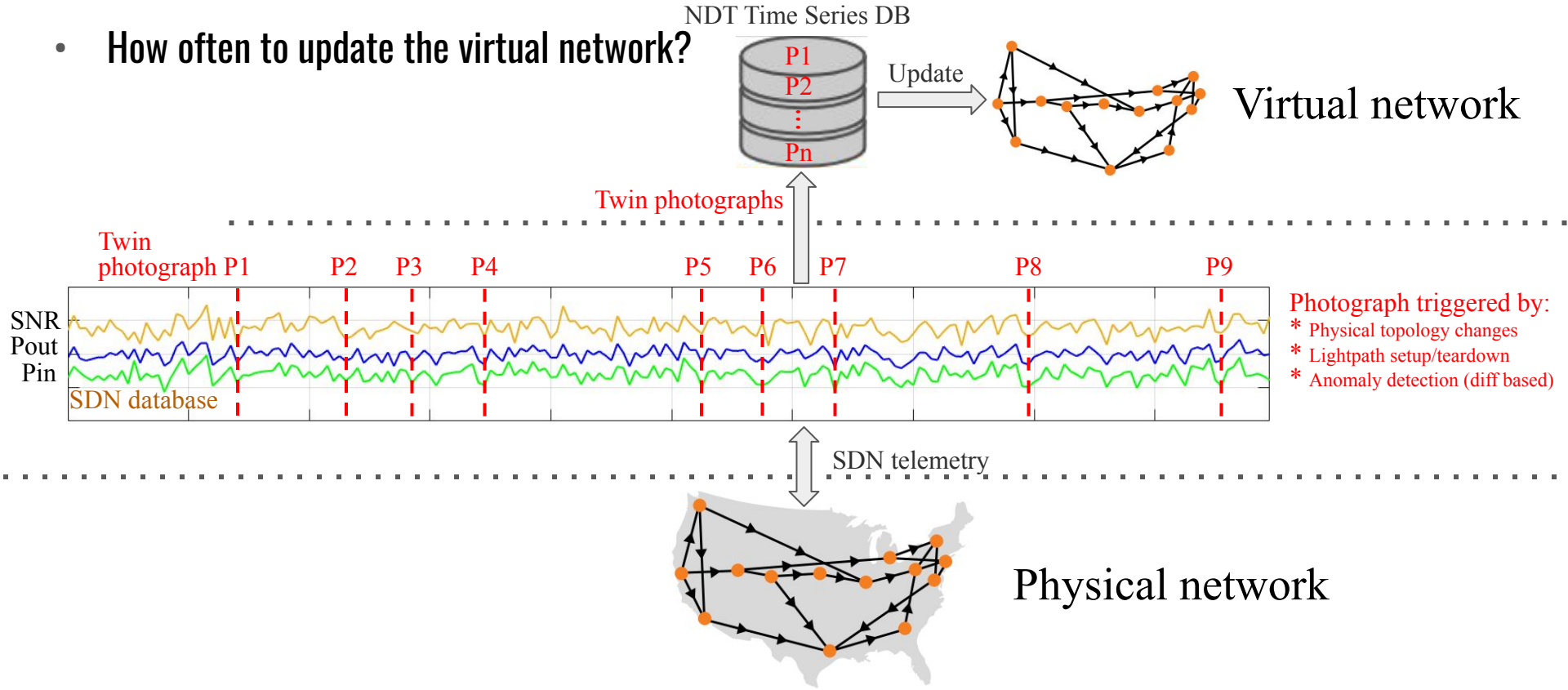
  - Some parameters can be read directly from the real network (e.g. fiber attenuation)
  - Other parameters must be estimated from the model: e.g. OSNR

- NDT models should be optimized to yield measured parameters
- GN-based models should yield considerable deviations (QoT estimation discussion!)
- ML-based models
- Numerically-optimized models (e.g. gradient descent algorithm)

14:50 – 14:15 Massimo Tornatore, Politecnico di Milano, ***Invited*** **(on-line)**
End-to-end Learning or Parameter Refinement? Lessons Learned when using Machine Learning in Optical Networks

Issues and Challenges

- How often to update the virtual network?



Issues and Challenges

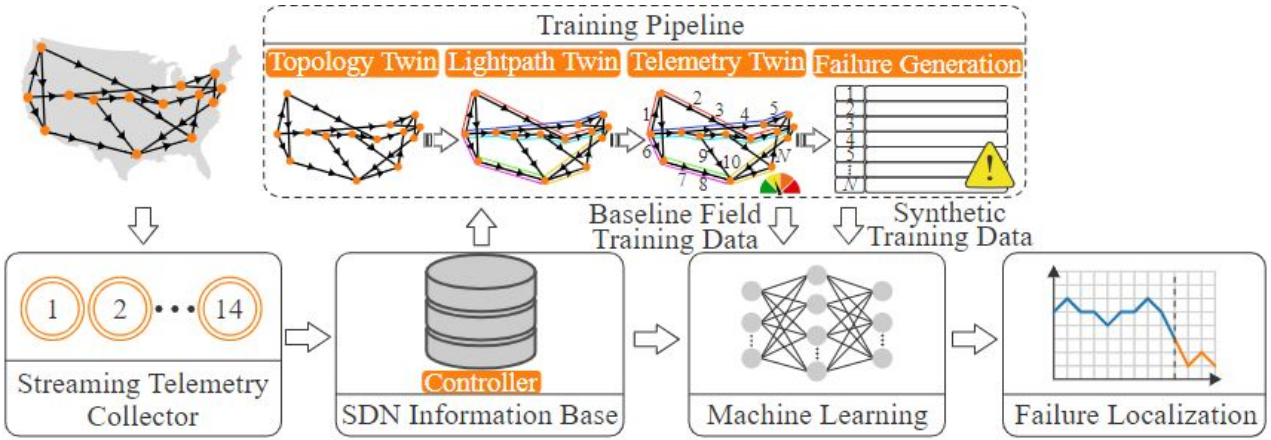
- Other issues (IETF)
  - Large-scale challenge (scalability, storage, data compression)
  - Interoperability
  - Data modelling
  - Real-time requirements
  - Security risks

Case Study: ML-based Soft-Failure Localization

4514 JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 40, NO. 14, JULY 15, 2022

Demonstration of ML-Assisted Soft-Failure Localization Based on Network Digital Twins

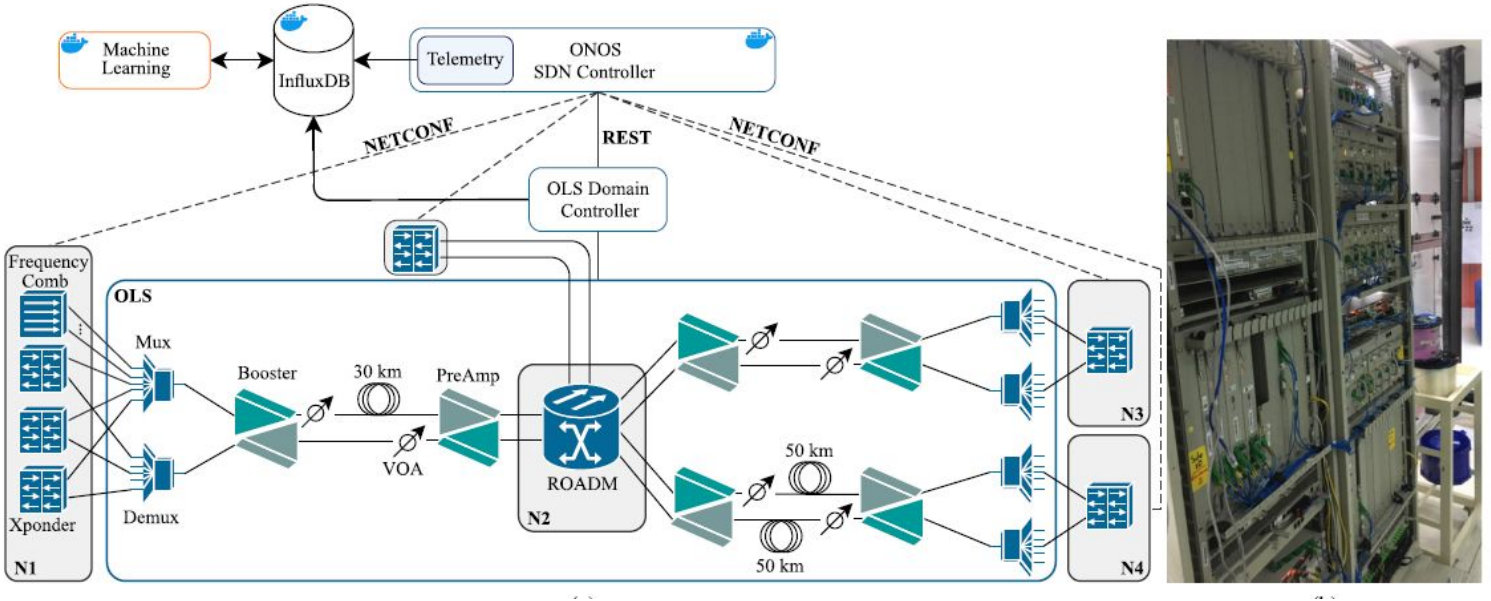
Kayol S. Mayer, Rossano P. Pinto, Jonathan A. Soares, Dalton S. Arantes, Christian E. Rothenberg, Vinicius Cavalcante, Leonardo L. Santos, Filipe D. Moraes, and Darli A. A. Mello



- Lesson learned: for soft-failure localization, baseline training is the secret for proper algorihtm performance!

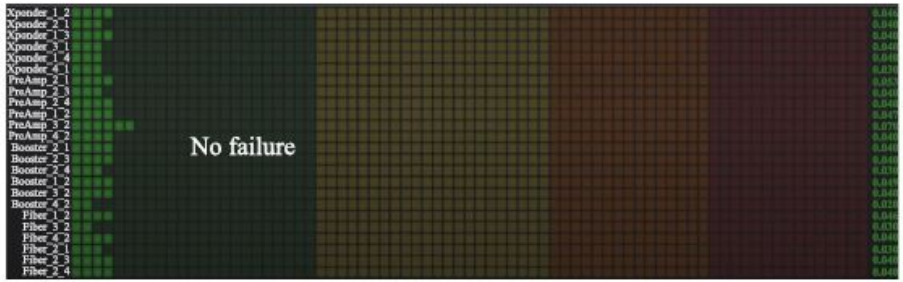
Case Study: ML-based Soft-Failure Localization

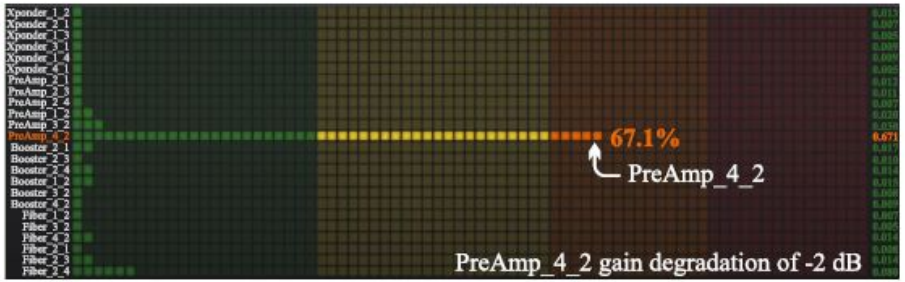
- Experimental setup

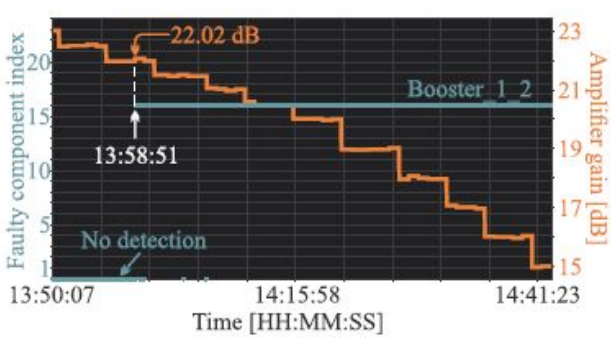


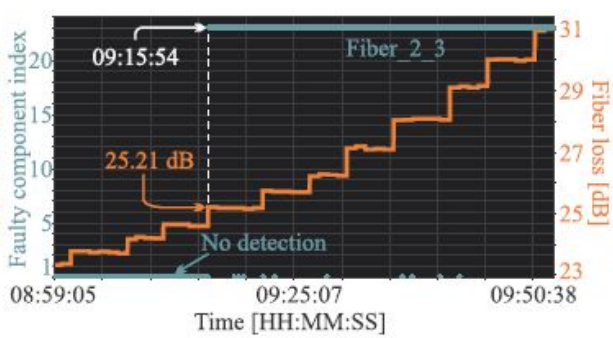
Case Study: ML-based Soft-Failure Localization

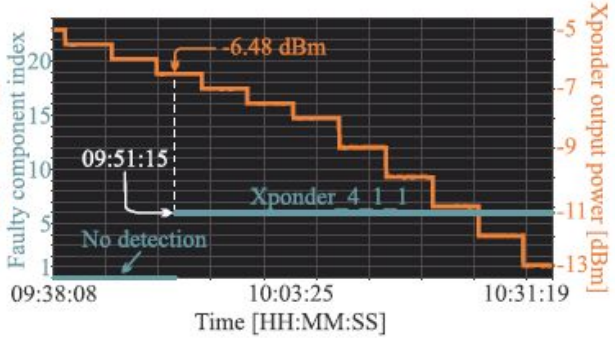
- Experimental soft-failure localization











Case Study: ML-based Soft-Failure Localization

- Soft-failure localization results

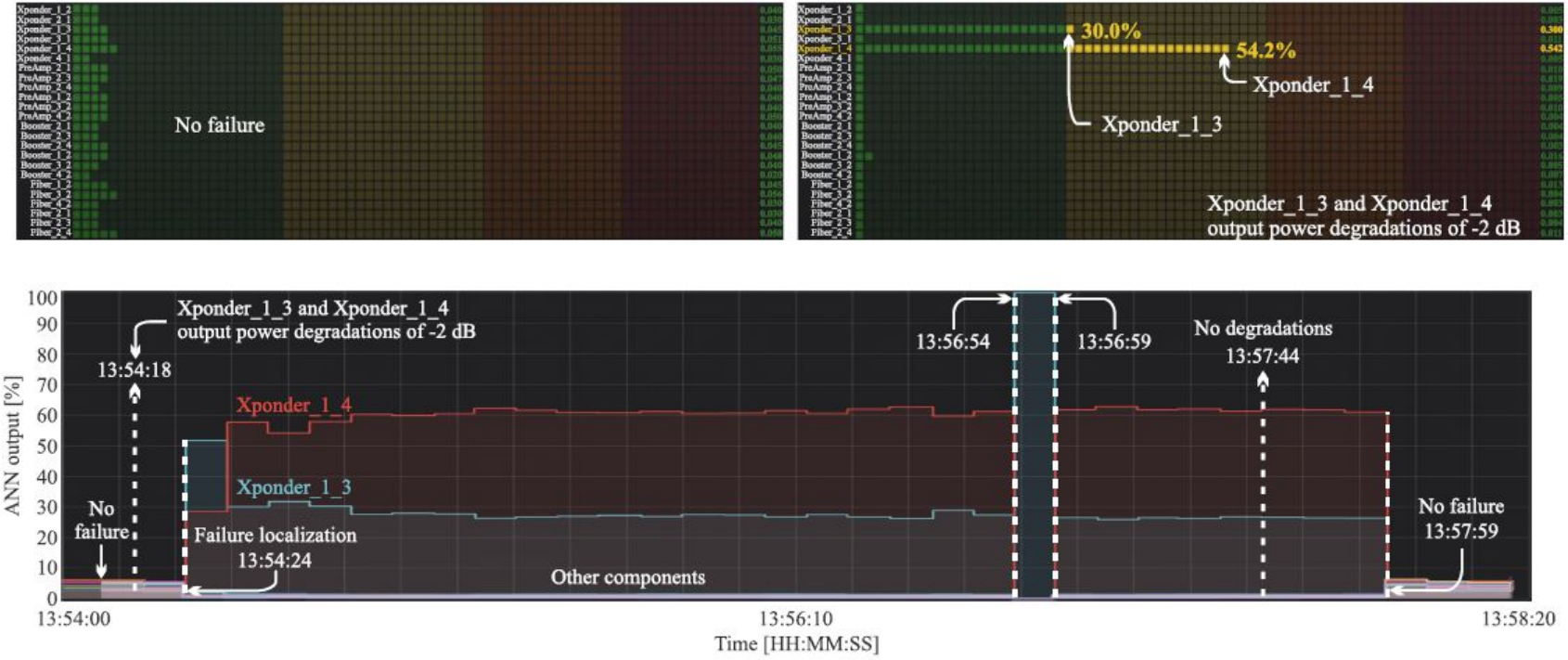
TABLE I
SINGLE-FAILURE LOCALIZATION RESULTS

Component	D_{FL} [dB]	T_{FL} [s]	Component	D_{FL} [dB]	T_{FL} [s]	Component	D_{FL} [dB]	T_{FL} [s]
Booster_1_2	0.98	185	PreAmp_2_3	1.92	80	Fiber_2_4	2.00	4
Booster_2_1	1.95	65	PreAmp_3_2	1.55	17	Fiber_4_2	1.42	5
Booster_2_3	2.13	65	PreAmp_2_4	1.46	107	Xponder_1_2	1.46	8
Booster_3_2	1.72	4	PreAmp_4_2	1.51	272	Xponder_2_1	1.48	5
Booster_2_4	2.54	4	Fiber_1_2	3.73	5	Xponder_1_3	1.97	4
Booster_4_2	1.49	15	Fiber_2_1	1.57	127	Xponder_3_1	1.51	54
PreAmp_1_2	1.49	4	Fiber_2_3	1.89	5	Xponder_1_4	1.48	6
PreAmp_2_1	2.90	5	Fiber_3_2	2.51	4	Xponder_4_1	1.50	122

D_{FL} and T_{FL} are the degradation and time to failure localization, respectively.

Case Study: ML-based Soft-Failure Localization

- Double failure localization



Conclusions

- DTs are gaining several fields of knowledge, and they should also become widespread in optical transmission systems
- NDTs should be of paramount importance for QoT estimation and soft-failure localization
- There are open challenges involving the NDT update behaviour and the consistency between the virtual and the physical network (related with QoT estimation!). Classic numerical optimization and ML-based techniques may be used
- We demonstrated an ML-based soft-failure estimation method based on synthetic failures generated in the virtual network

This work was supported by Padtec

Thanks!

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