Machine Learning Techniques in Optical Networks

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Outline

- Why machine learning in optical networks?
- Machine learning techniques in optical networks
- Routing and wavelength assignment using machine learning

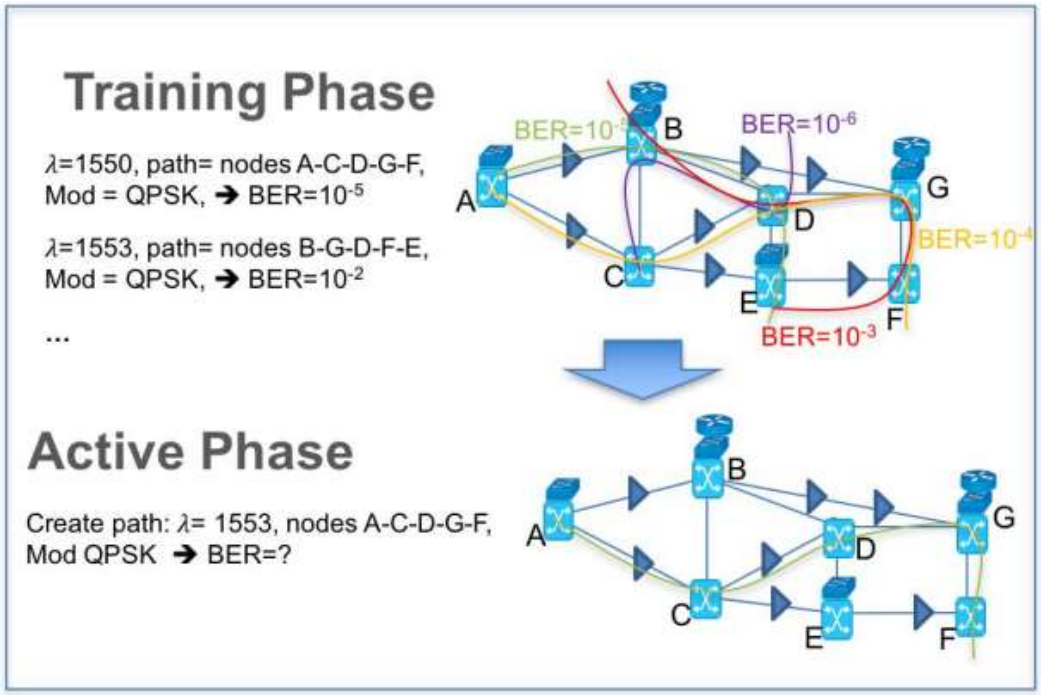
Machine Learning: Overview

- Machine learning (ML): by giving access to right data, machines can learn by themselves how to solve a specific problem [1]
- Optical network context: supervised learning, unsupervised learning, and reinforcement learning

[1] F. Musumeci *et al*., "An Overview on Application of Machine Learning Techniques in Optical Networks," *IEEE Communications Surveys & Tutorials*, vol. 21, no. 2, pp. 1383-1408, Second Quarter 2019.

Supervised Learning

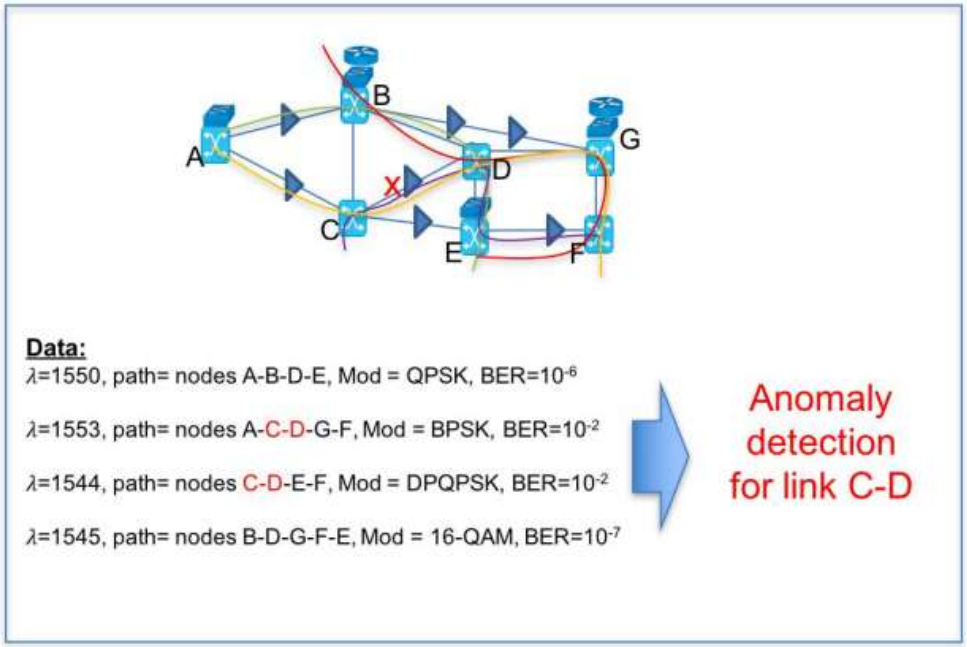
Machines predict output of unseen inputs based on experience learned from training data set



[1] F. Musumeci *et al*., "An Overview on Application of Machine Learning Techniques in Optical Networks," *IEEE Communications Surveys & Tutorials*, vol. 21, no. 2, pp. 1383-1408, Second Quarter 2019.

Unsupervised Learning

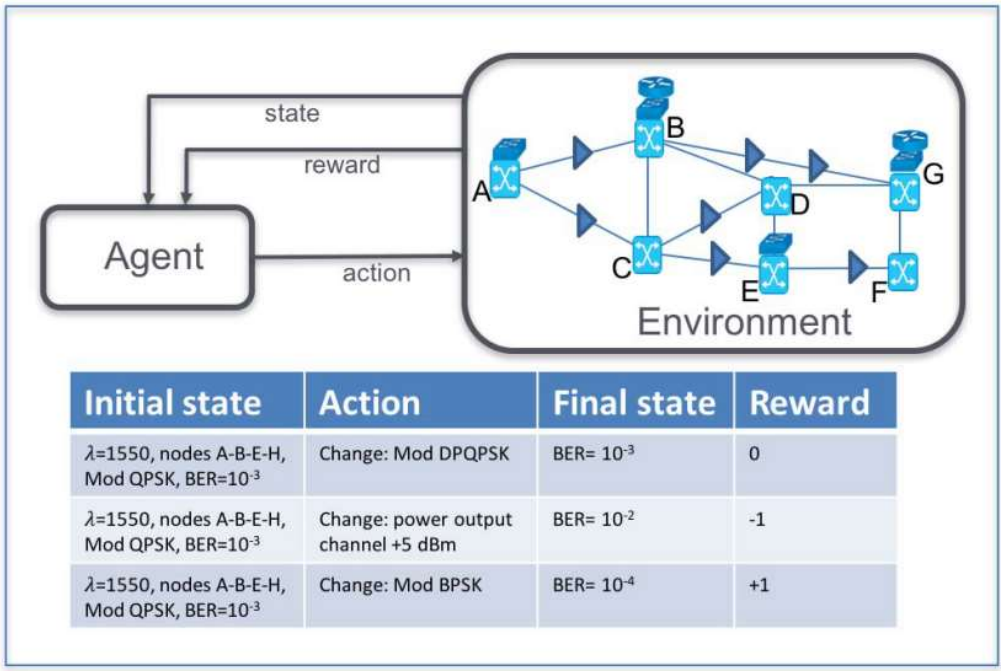
Finding structure hidden in collections of unlabeled data [2]



[1] F. Musumeci *et al*., "An Overview on Application of Machine Learning Techniques in Optical Networks," *IEEE Communications Surveys & Tutorials*, vol. 21, no. 2, pp. 1383-1408, Second Quarter 2019.
[2] R. S. Sutto and A. G. Barto, "Reinforcement Learning: An Introduction," *MIT Press*, 2018.

Reinforcement Learning

Learning to what to do in order to maximize reward [2]



Initial state	Action	Final state	Reward
λ=1550, nodes A-B-E-H, Mod QPSK, BER=10^{-3}	Change: Mod DPQPSK	BER= 10^{-3}	0
λ=1550, nodes A-B-E-H, Mod QPSK, BER=10^{-3}	Change: power output channel +5 dBm	BER= 10^{-2}	-1
λ=1550, nodes A-B-E-H, Mod QPSK, BER=10^{-3}	Change: Mod BPSK	BER= 10^{-4}	+1

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[2] R. S. Sutto and A. G. Barto, "Reinforcement Learning: An Introduction," *MIT Press*, 2018.

Machine Learning in Optical Networks

- Motivation and feasibility:
  - Increased complexity (many parameters): e.g., coherent technology, EON, nonlinearity
  - Widely available data: e.g., traffic traces, signal quality indicator
- Cross-layer approach: physical layer and network layer

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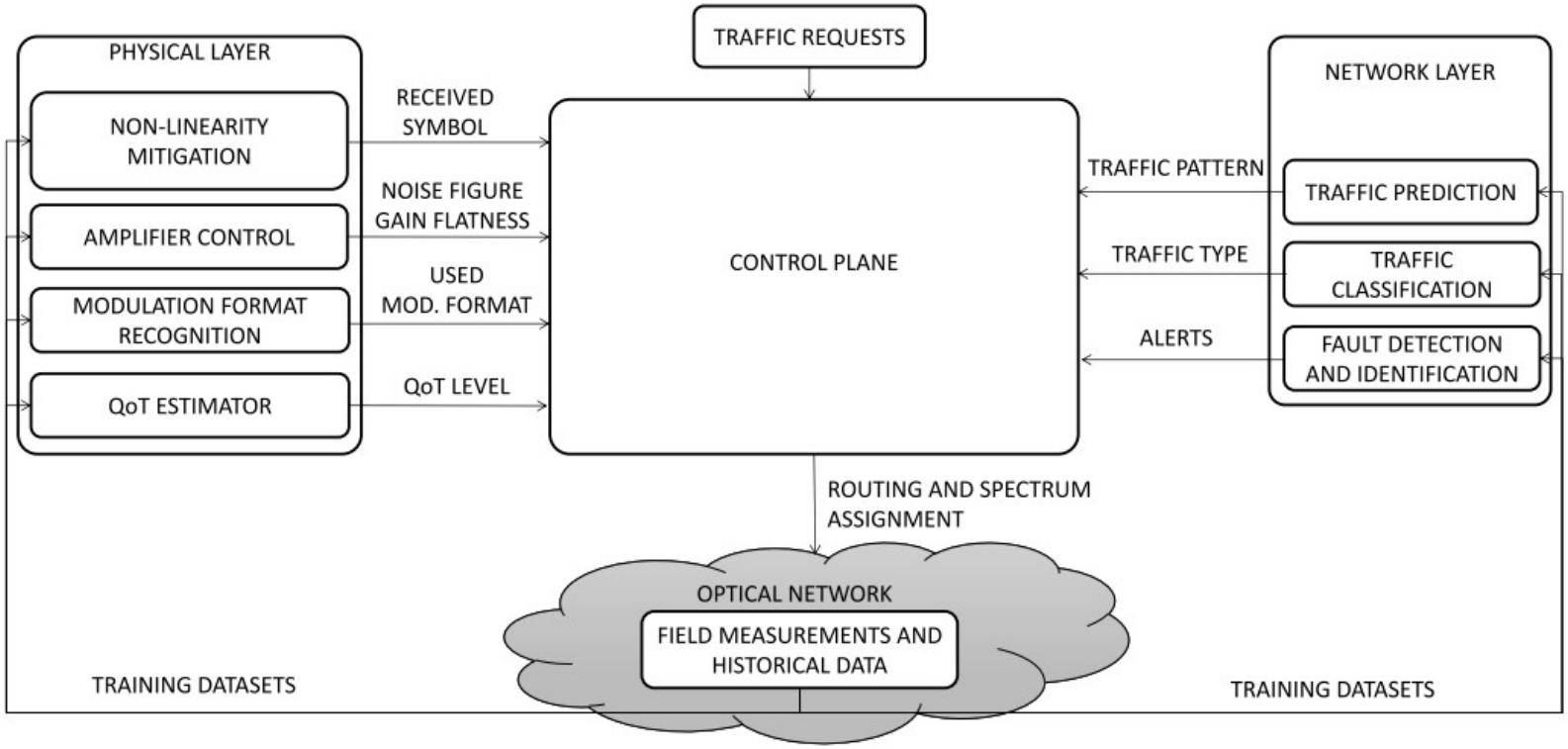
Framework of ML in Optical Networks



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ML-Based RWA in WDM Optical Networks

- Routing and Wavelength Assignment (RWA):
  - Design an optical network for a traffic matrix
  - Re-optimize due to dynamic traffic changes

ML-Based RWA in WDM Optical Networks

- Solution for RWA problems:
  - Integer Linear Programming (ILP)
  - Mixed-Integer Programming (MIP)
  - Relaxation
  - Heuristic
  - Machine learning

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ML-Based RWA in WDM Optical Networks

$$
\begin{aligned}
d_{12} &\rightarrow (e_{12}, \lambda_1) \\
d_{13} &\rightarrow (e_{13}, \lambda_1) \\
&\vdots \\
d_{24} &\rightarrow (e_{23}, e_{34}, \lambda_2) \\
&\vdots \\
d_{54} &\rightarrow (e_{52}, e_{23}, e_{34}, \lambda_3)
\end{aligned}
$$

These relations can be formulated as a supervised learning problem

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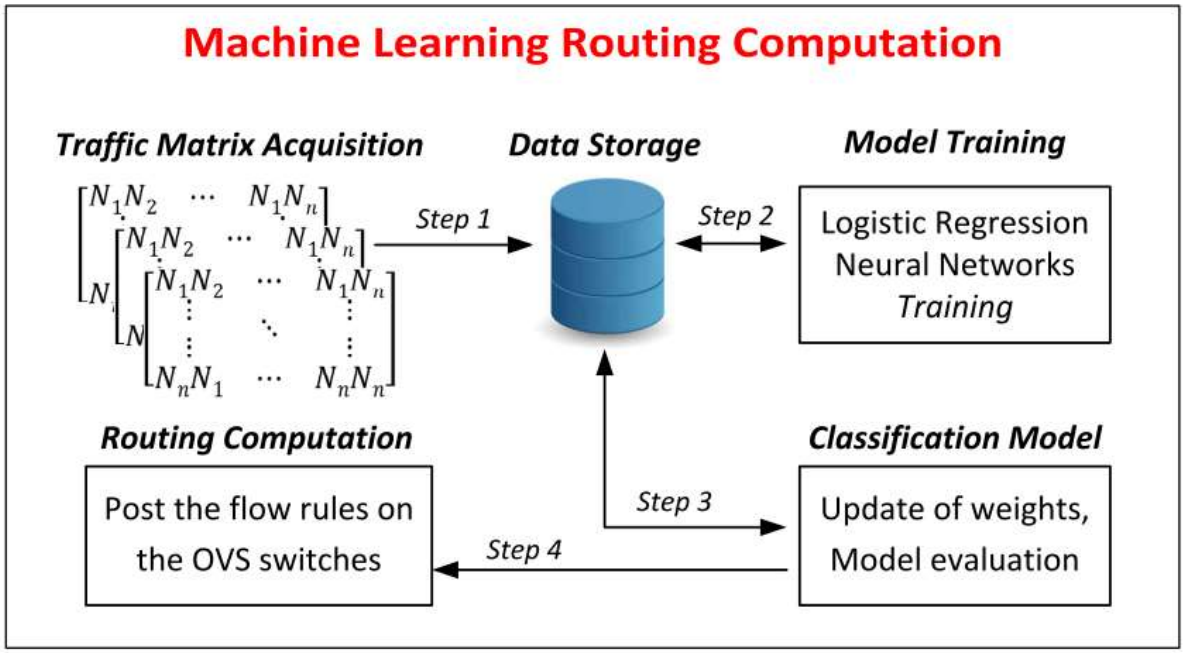
[3] I. Martín *et al*., "Machine Learning-Based Routing and Wavelength Assignment in Software-Defined Optical Networks," *IEEE Transactions on Network and Service Management*, vol. 16, no. 3, pp. 871-883, Sept. 2019.

ML-Based RWA in WDM Optical Networks



- Sub-optimal solution with 93% reduced computation time

[3] I. Martín *et al*., "Machine Learning-Based Routing and Wavelength Assignment in Software-Defined Optical Networks," *IEEE Transactions on Network and Service Management*, vol. 16, no. 3, pp. 871-883, Sept. 2019.