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Machine Learning Methods for Communication Networks and Systems

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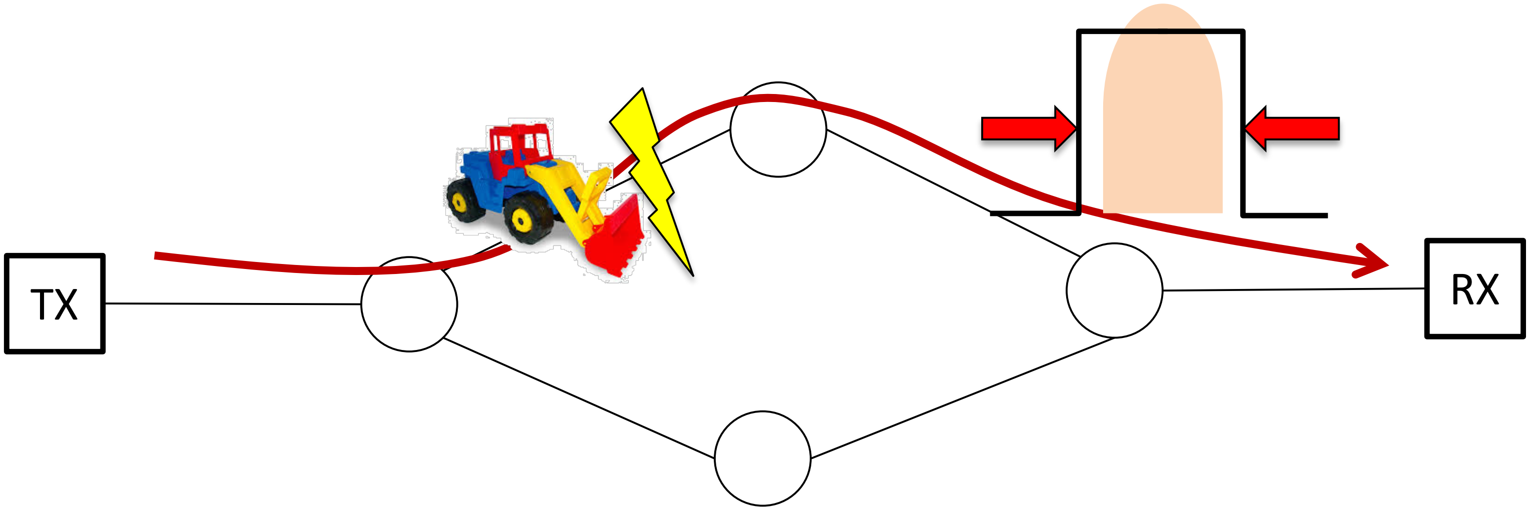
Part II – 8: Failure management

Two main failure types in optical networks

- Hard-failures
  - Sudden events, e.g., fiber cuts, power outages, etc.
  - Unpredictable, require «protection» (*reactive procedures*)
- Soft-failures:
  - Gradual transmission degradation due to equipment malfunctioning, filter shrinking/misalignment…
  - Trigger early network reconfiguration (*proactive* procedures)

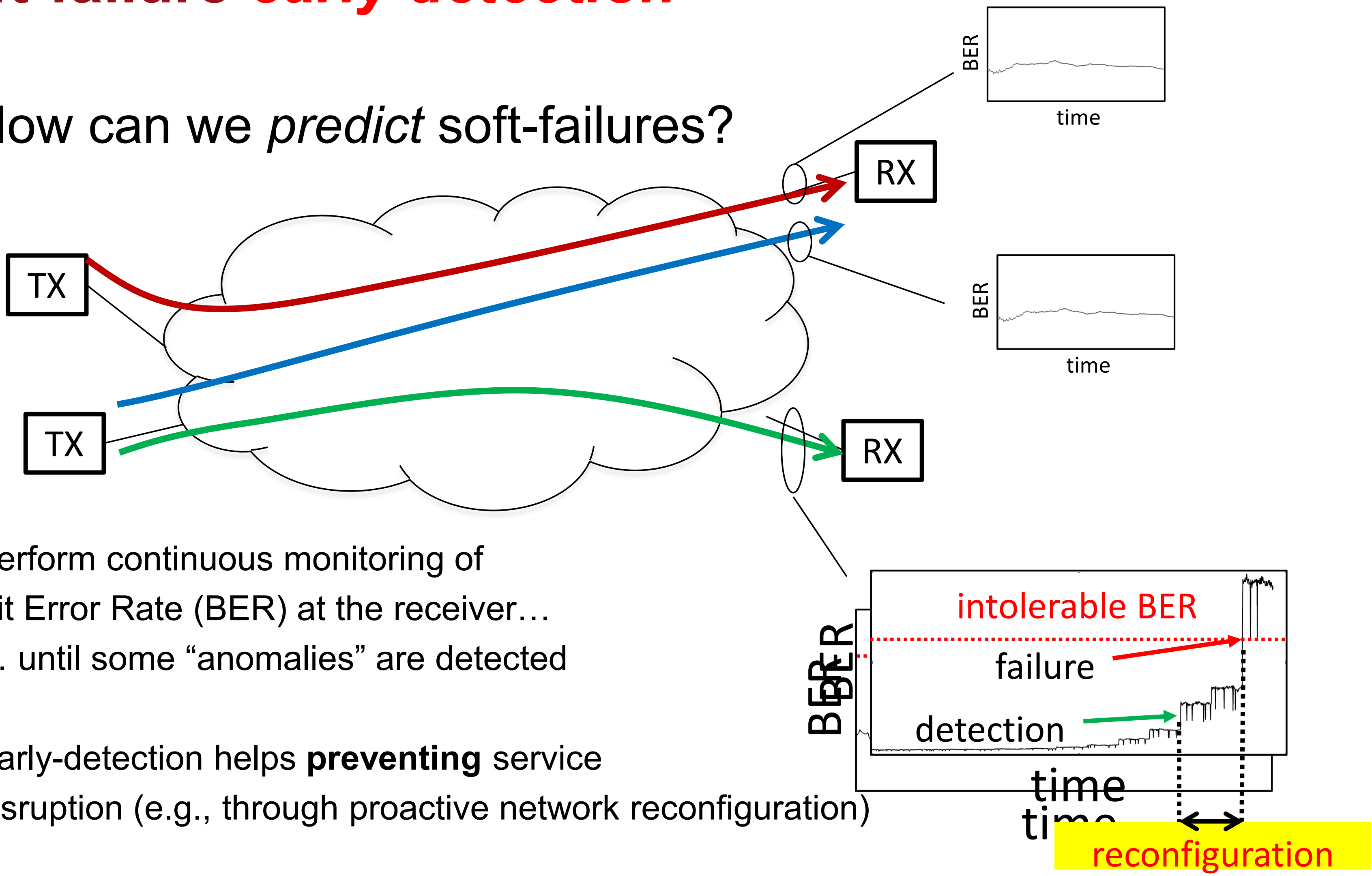


Handling soft-failures

1. **Early detection** (When?)
   - «Predict» that BER will go above a threshold
   - Allows early/quick activation of proactive procedures
2. **Identification** (Which element?)
   - e.g., filter misalignment, laser drift, fiber bending, amplifier malfunctioning ..
   - Reduced Mean Time To Repair (MTTR)
3. **Localization** of soft-failures (Where?)
   - e.g., which node/link along the path?
4. **Magnitude estimation** (How much?)
   - Triggers the proper reaction (e.g., device restart/reconfiguration, lightpath re-routuing, in-field reparation…)

Soft-failure *early detection*

- How can we *predict* soft-failures?

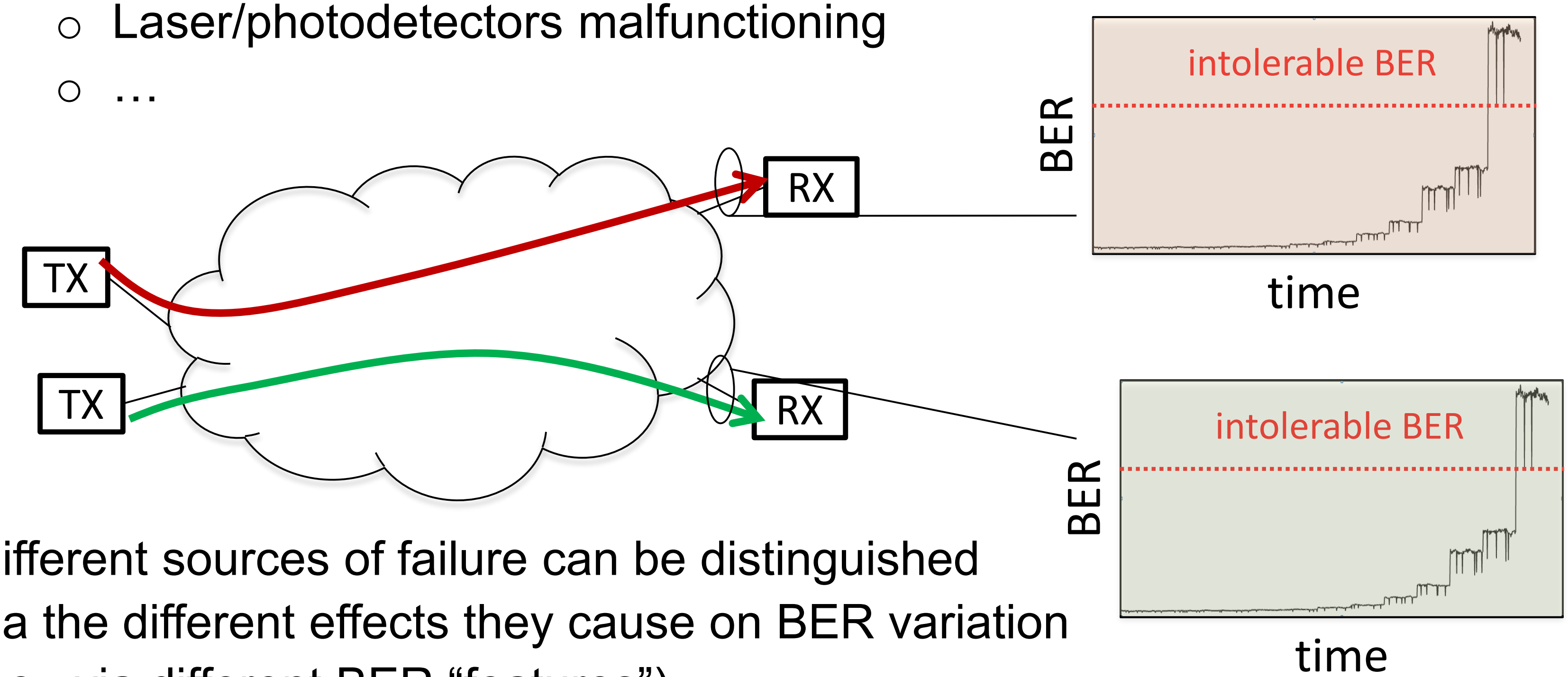


Perform continuous monitoring of
Bit Error Rate (BER) at the receiver…
… until some “anomalies” are detected

Early-detection helps **preventing** service
disruption (e.g., through proactive network reconfiguration)

Soft-failure *cause identification*

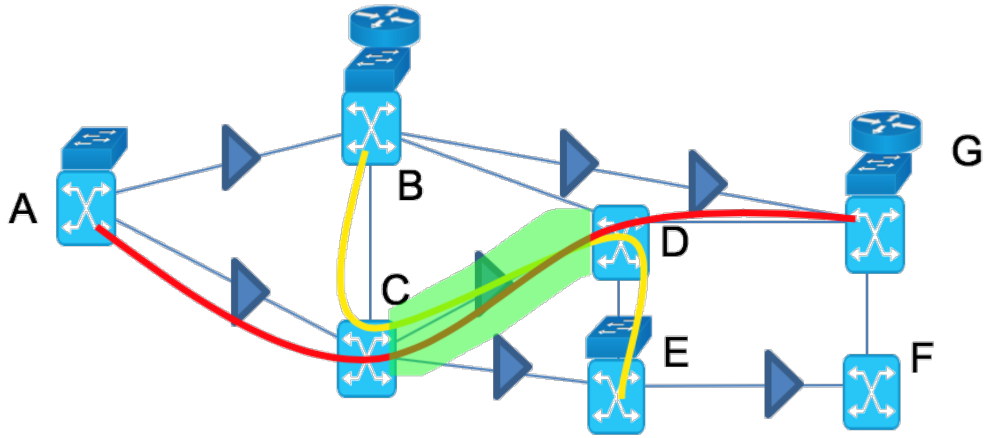
- How can we identify the *cause* of the failure?
  - Failures can be caused by different sources
    - Filters shrinking/misalignment
    - Excessive attenuation (e.g., due to amplifier malfunctioning)
    - Laser/photodetectors malfunctioning
    - …



Different sources of failure can be distinguished via the different effects they cause on BER variation (i.e., via different BER “features”)

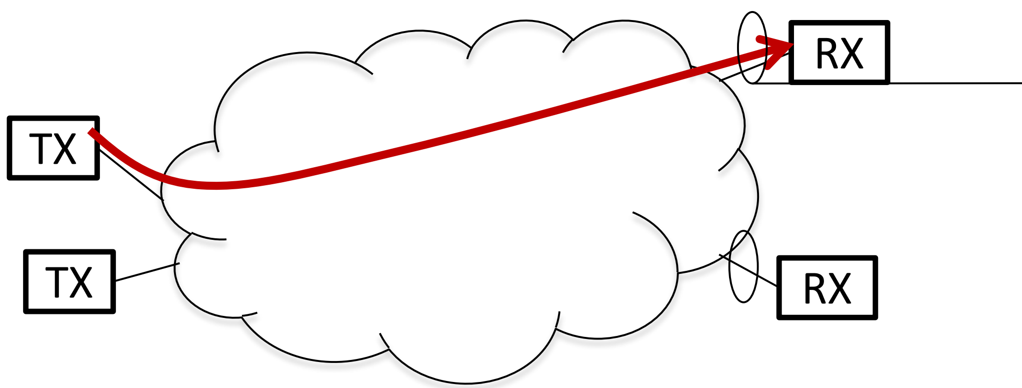
Soft-failure *localization*

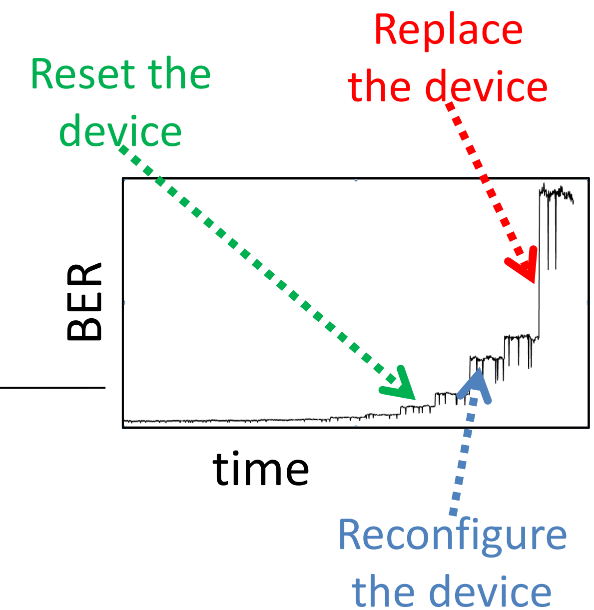
- How can we identify the location of the failure?
  - A single failure may affect multiple lightpaths
  - Leverage information on failure-cause on each lightpath in combination with routing information
  - No need for monitoring in the entire network (monitors can be deployed only at the receivers)



Soft-failure *magnitude estimation*

- What is the failure magnitude (i.e., severity)?
  - Different failures magnitude can affect the network differently
  - According to the severity, different actions can be triggered to solve the failure
    - device restart/reconfiguration
    - lightpath re-routuing
    - in-field reparation…)





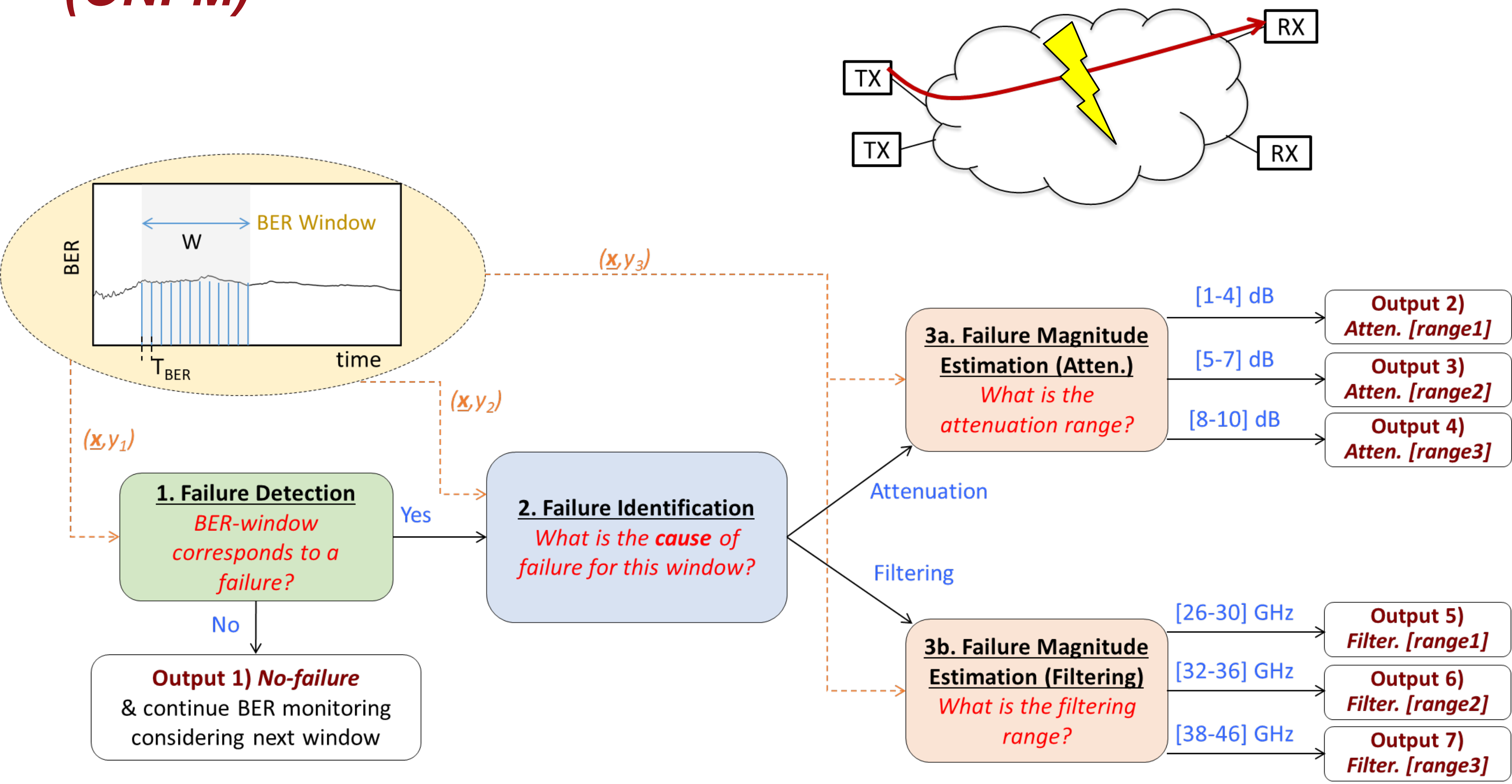
Failure management

Sources 1-2

1. F. Musumeci *et al.*, “A Tutorial on Machine Learning for Failure Management in Optical Networks”, *Journal of Lightwave Technology*, vol. 37, n. 16, Aug. 2019
2. S. Shahkarami *et al*, “Machine-Learning-Based Soft-Failure Detection and Identification in Optical Networks,” in OFC Conference 2018, pp. M3A–5

- Paper(s) objective: failure detection, cause identification and magnitude estimation in optical transmission system
  - input
    - monitored BER
  - output
    - failure detection, cause identification and magnitude estimation
  - ML algorithms:
    - ANN
    - SVM
    - RF

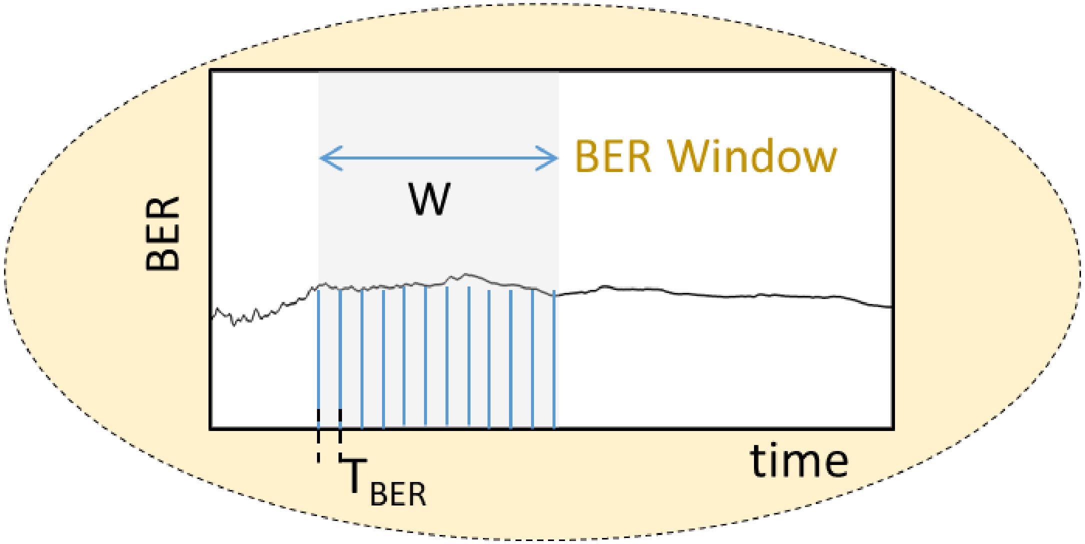
Our study: *Optical Network Failure Management (ONFM)*



F. Musumeci *et al.*, "A Tutorial on Machine Learning for Failure Management in Optical Networks", *Journal of Lightwave Technology*, vol. 37, n. 16, Aug. 2019

Window analysis

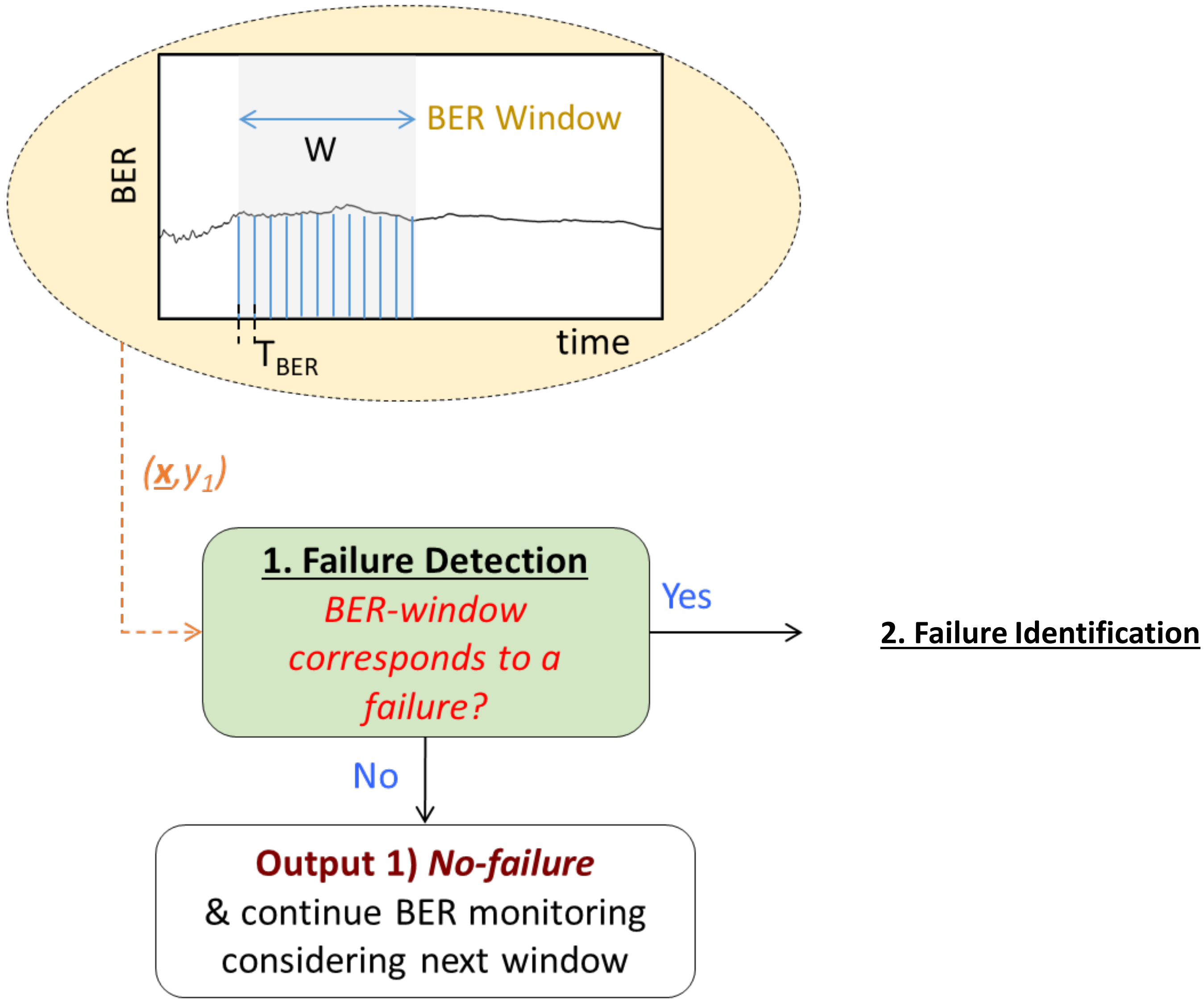
- BER window: two main optimization parameters
  - Window duration, W (variable)
  - BER sampling period, T_{BER} (=2 seconds in our study)
  - Training of the ML algorithms is done for different combinations of these two params



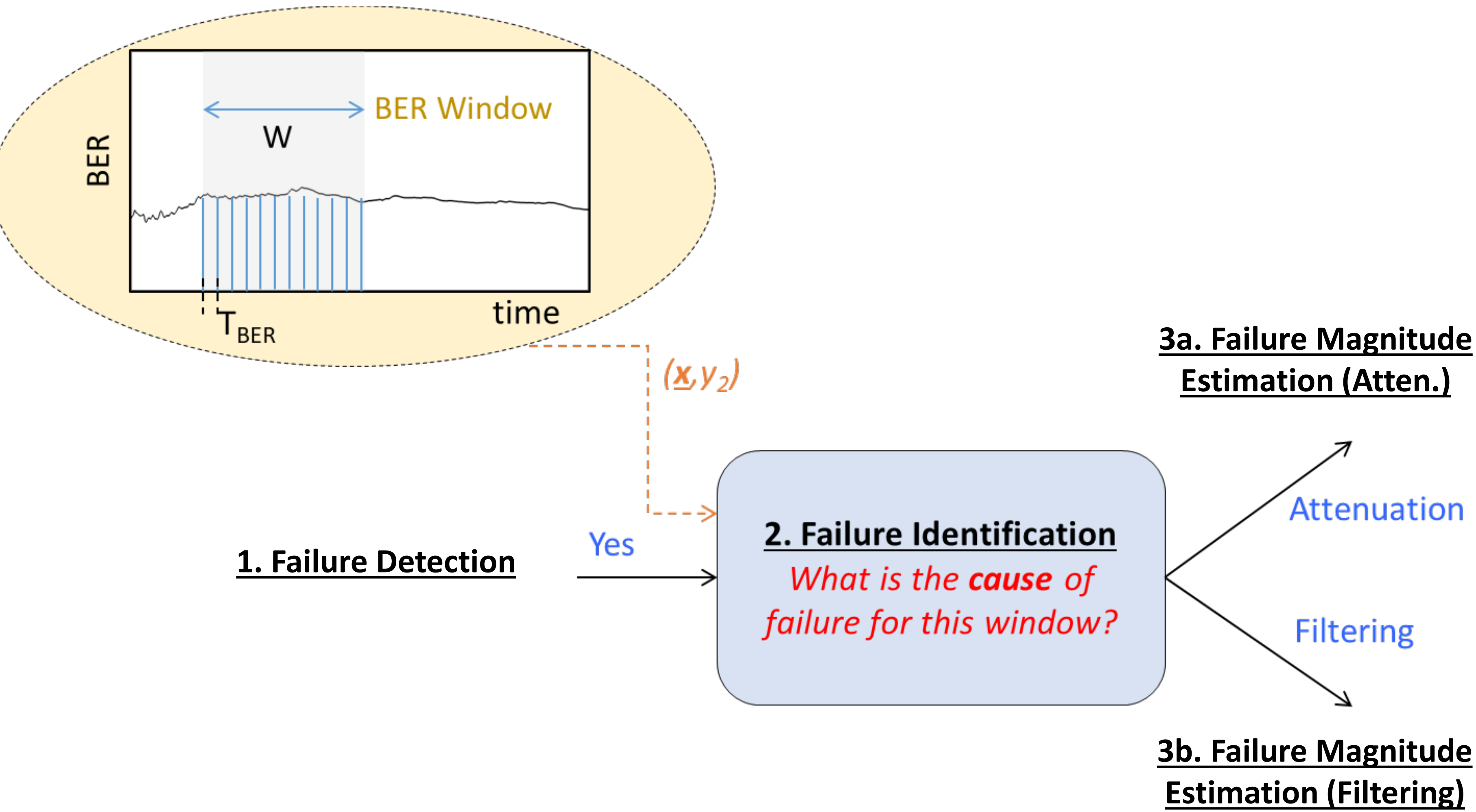
Features extracted:

- BER statistics:
  - mean
  - min/max
  - standard dev.
  - Peak-to-peak
- Window spectral components after FFT

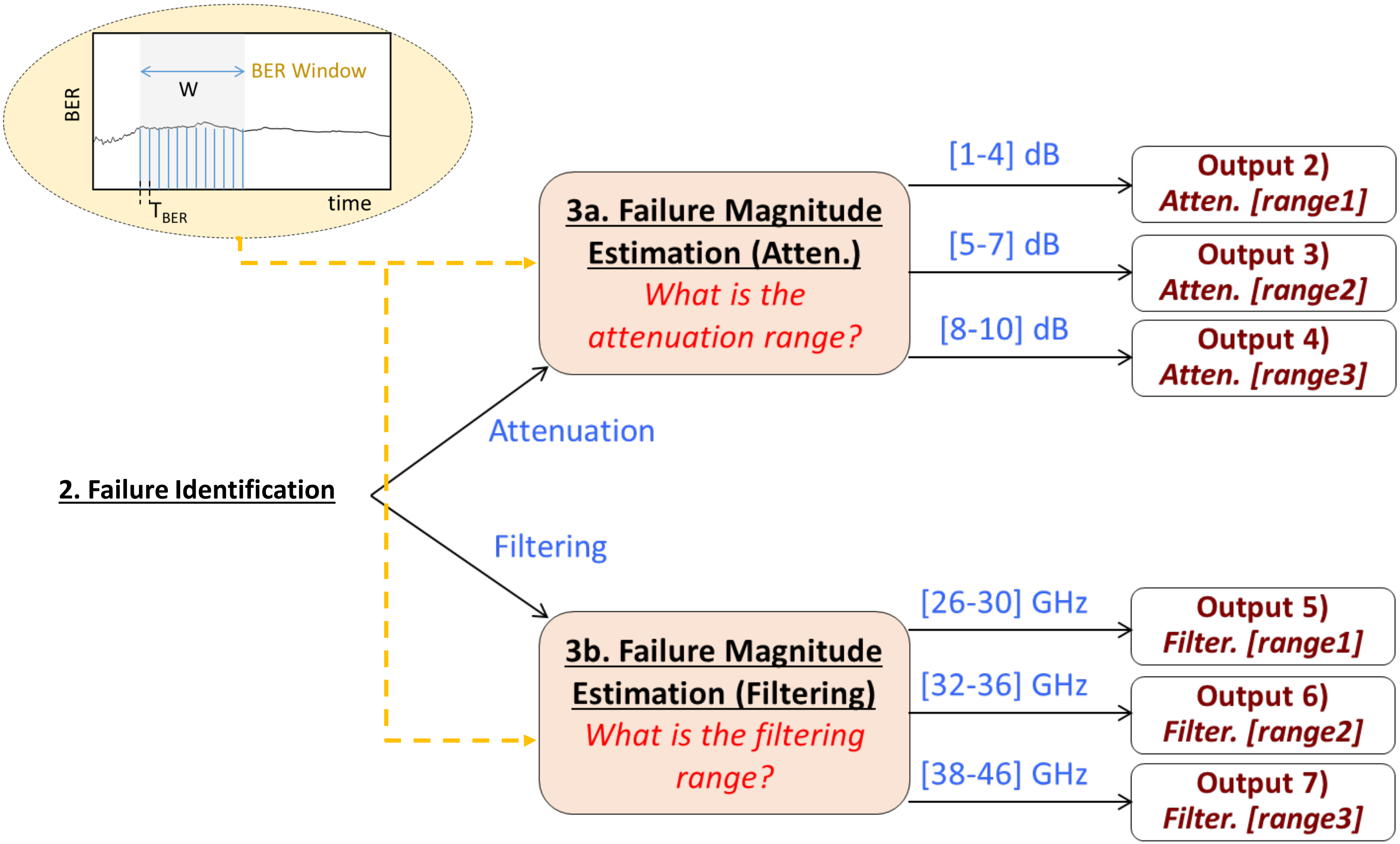
Failure detection



Failure identification

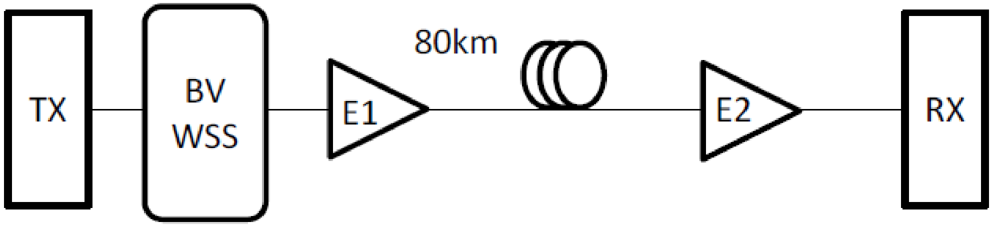


Failure magnitude estimation



Testbed setup (1)

- Testbed for real BER traces
  - Ericsson 80 km transmission system
    - 24 hours BER monitoring
    - 2 seconds sampling interval
  - PM-QPSK modulation @ 100Gb/s
  - 2 Erbium Doped Fiber Amplifiers (EDFA) followed by Variable Optical Attenuators (VOAs, not shown)
  - Bandwidth-Variable Wavelength Selective Switch (BV-WSS) is used to emulate 2 types of BER degradation:
    - **Filter misalignment (*Filtering*)**
    - Additional attenuation in intermediate span, due to EDFA gain-reduction **(*Attenuation*)**
  - Different failure magnitudes:
    - *Filtering*: 50-to-26 GHz at steps of 2 GHz
    - *Attenuation*: 0-to-10 dB additional attenuation at steps of 1 dB



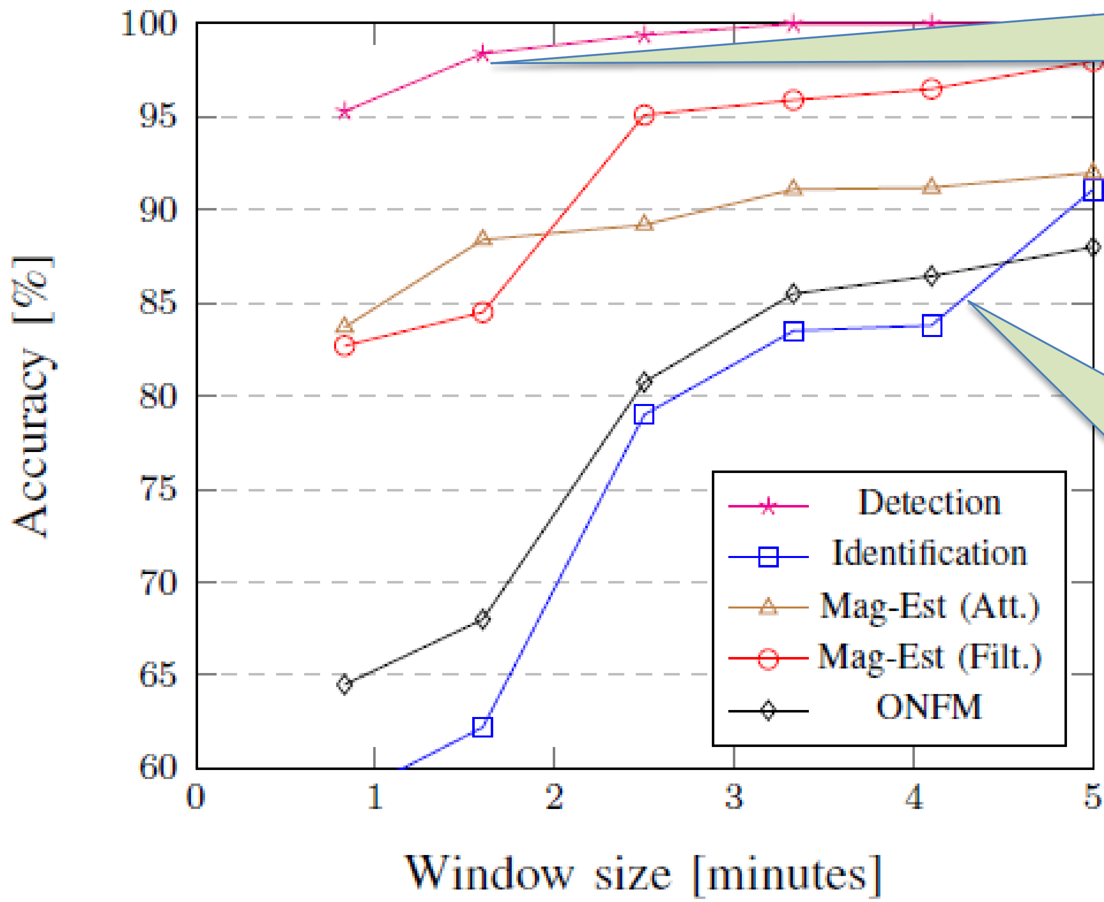
F. Musumeci *et al.*, "A Tutorial on Machine Learning for Failure Management in Optical Networks", *Journal of Lightwave Technology*, vol. 37, n. 16, Aug. 2019

Results

Takeway1: Accuracy always increases with window duration

Takeway2: Detection (finding anomalies) is accurate also for in short-time windows

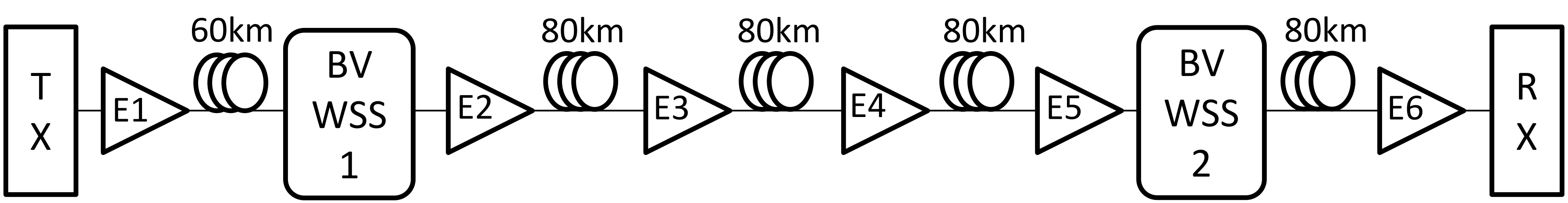
Takeway3: Complex tasks (e.g., failure-cause identification) requires more BER info (longer windows) to have sufficient accuracy



F. Musumeci *et al.*, "A Tutorial on Machine Learning for Failure Management in Optical Networks", *Journal of Lightwave Technology*, vol. 37, n. 16, Aug. 2019

Testbed setup (2)

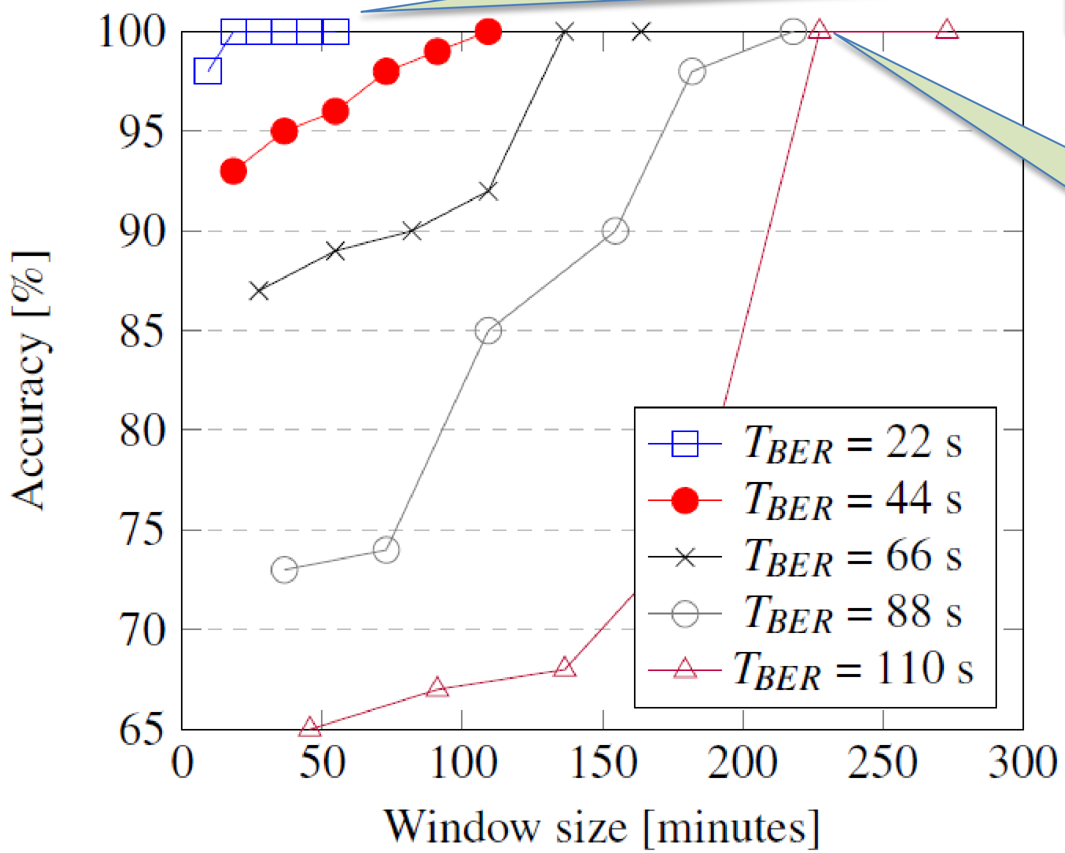
- Testbed for real BER traces
  - Ericsson 380 km transmission system
    - 24 hours BER monitoring
    - 3 seconds sampling interval
  - PM-QPSK modulation @ 100Gb/s
  - 6 Erbium Doped Fiber Amplifiers (EDFA) followed by Variable Optical Attenuators (VOAs)
  - Bandwidth-Variable Wavelength Selective Switch (BV-WSS) is used to emulate 2 types of BER degradation:
    - **Filter misalignment**
    - Additional attenuation in intermediate span (e.g., due to **EDFA gain-reduction**)



S. Shahkarami et al, "Machine-Learning-Based Soft-Failure Detection and Identification in Optical Networks," in OFC Conference 2018, pp. M3A–5

Numerical results: *Detection*
Accuracy vs window features

- Binary SVM



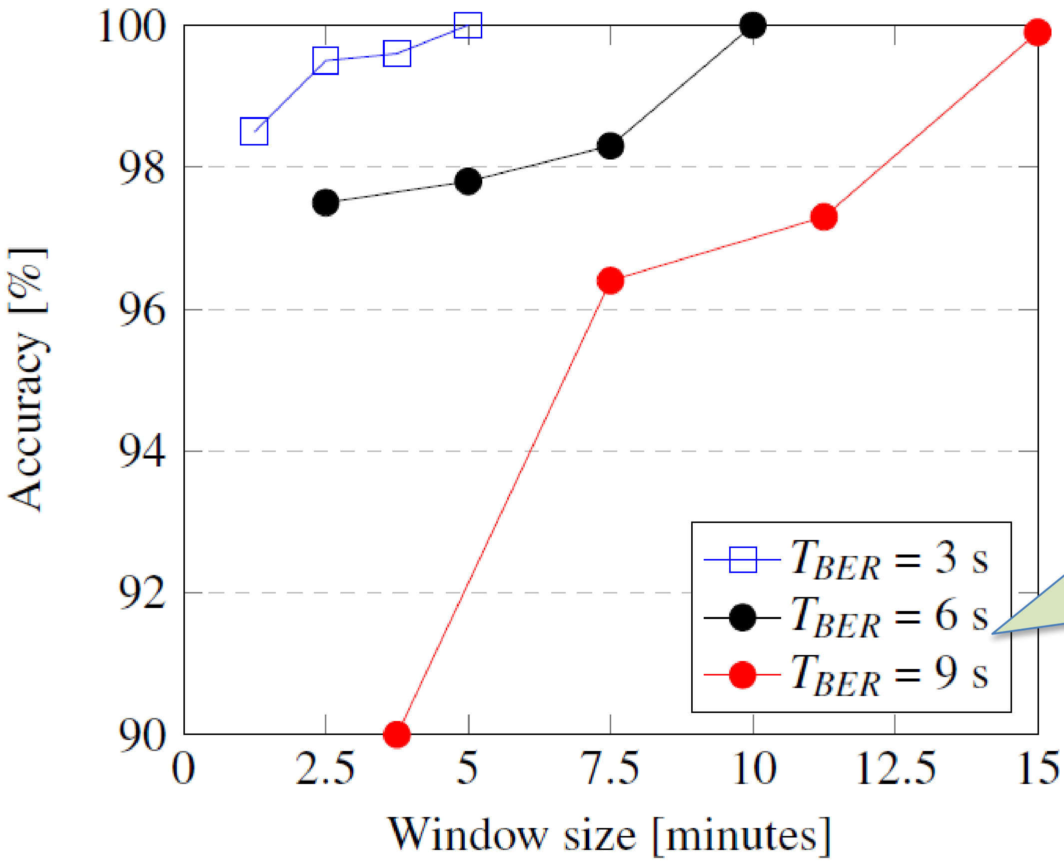
Take-away 1: Higher performance with low sampling time
→ Fast monitoring equipment is required

Take-away 2: For increasing sampling time, longer "Windows" are needed for high accuracy

S. Shahkarami et al, "Machine-Learning-Based Soft-Failure Detection and Identification in Optical Networks," in OFC Conference 2018, pp. M3A–5

Numerical results: *Identification*
Accuracy vs window features

- Neural Network



Take-away 3: To perform failure-cause identification, much smaller sampling period is needed wrt failure detection

S. Shahkarami et al, "Machine-Learning-Based Soft-Failure Detection and Identification in Optical Networks," in OFC Conference 2018, pp. M3A–5

Transfer Learning: Motivation

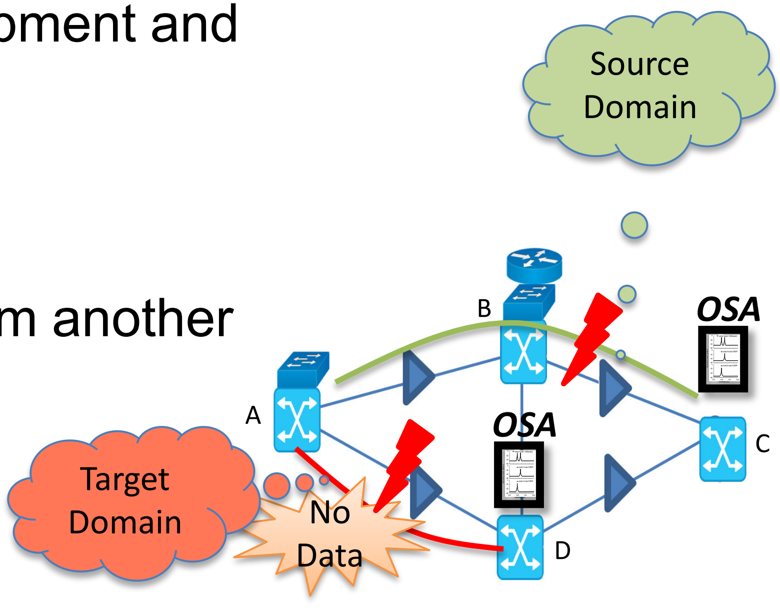
☹ ML requires training phase and its knowledge does not generalize to *any* condition

- Data collection issues
  - lack of monitoring equipment (OSA, etc...) at every network node
  - costly acquisition of large datasets
  - **training should be re-done on every link**
- Strategy 1: install new monitoring equipment and generate failures

COSTLY! Generating soft-failures requires lot of effort!!!

- Strategy 2: acquire OSNR samples from another lightpath. However…
  - …different data distributions

TRANSFER LEARNING
Re-use data from a source domain in a target domain

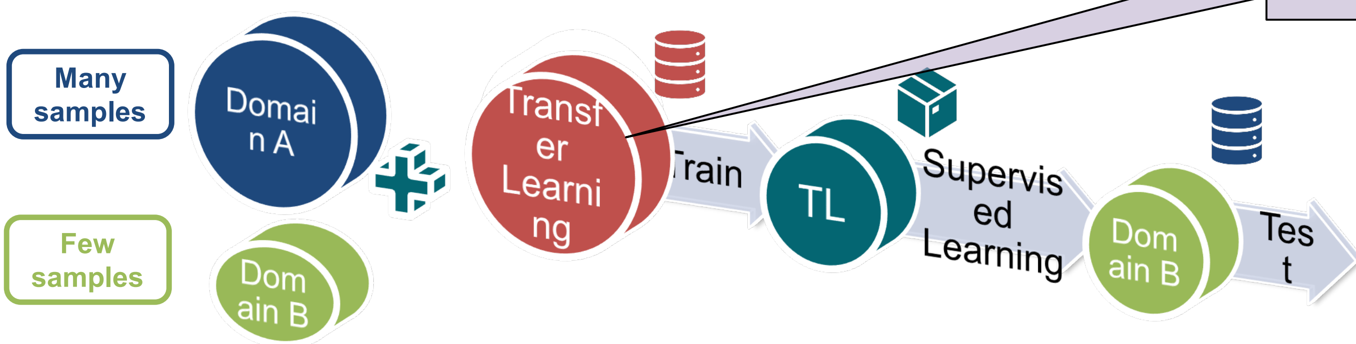


Transfer Learning (TL): Principles

Option 1: [Pure TL] no samples from B (target domain) available
→ **TRAIN** with samples of **A (source domain)** and **TEST** with samples of **B (target domain)**

Option 2: [Domain Adaptation (DA)] <u>a few</u> samples from B are available
→ **TRAIN** with (many) samples of **A** and (few) of **B**, and **TEST** with samples of **B**

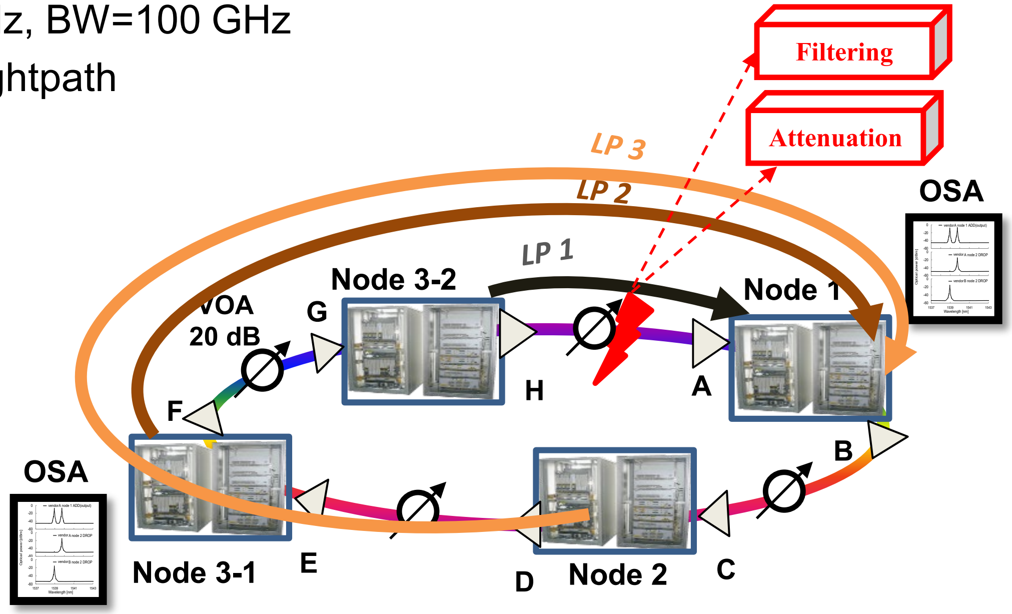
Our algorithm DA+CORAL*



**Baochen Sun, Jiashi Feng, and Kate Saenko. "Return of Frustratingly Easy Domain Adaptation". In Prof. Of AAAI'16:: (Nov. 2015).*

Testbed Setup

- Opt. Net. testbed @NICT Sendai w/ 4 ROADMs
  - Data collected for 3 lightpaths at the receiver sites (pre-amp)
  - Center-wavelength @194.8 THz, BW=100 GHz
  - 6 hours of measurement per lightpath
  - Sampling time: T_{OSNR} = 1 s
  - 10 Gbps, OOK modulation



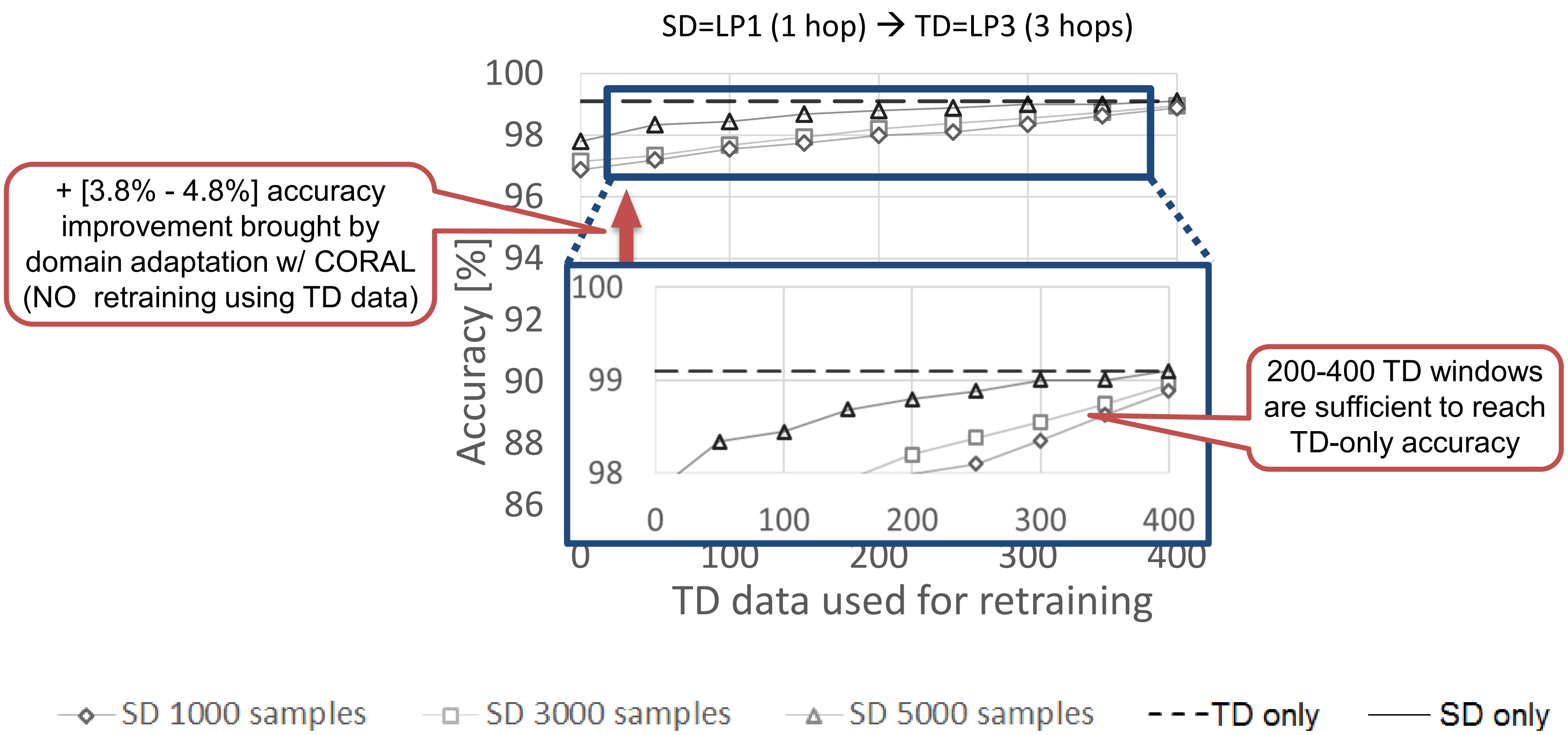
Baseline scenarios

1. **Target Domain Only (TD Only)**
   – trains the classifier using all labeled data points in the target domain (|TD|=5000 windows)
   – represents an "upper bound" on identification accuracy

2. **Source Domain (SD Only)**
   – trains the classifier only on source domain data (|SD|=5000 windows), then test on the TD data
   – equivalent to Pure Transfer Learning

TL-assisted failure-cause identification: results

Window size = 20sec



F. Musumeci *et al.*, "Transfer Learning across Different Lightpaths for Failure-Cause Identification in Optical Networks", *ECOC 2020*