Detecting, Identifying, and Localizing Soft Failures in Optical Networks

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Outline

1. Soft Failures
2. Related Work
3. Forward Error Correction
4. Our idea

Soft Failures

- Different from “hard” failures, where signal is completely disrupted
- Can harm signal quality, induce anomalies in the Bit Error Rate (BER), cause SLA and QoS violation, and, ultimately, result in service disruption
- Examples:
  - Laser Drift
  - Filter Shift
  - Tight Filter
  - Filter Misalignment
  - Reduced Amplification

[1] Shahin Shahkarami, Francesco Musumeci, Filippo Cugini, Massimo Tornatore, Machine-Learning-Based Soft-Failure Detection and Identification in Optical Networks, OFC, 2018
[2] Alba P. Vela, Marc Ruiz, Francesco Fresi, Nicola Sambo, Filippo Cugini, Gianluca Meloni,Luca Pot`ı, Luis Velasco, and Piero Castoldi, BER Degradation Detection and Failure Identification in Elastic Optical Networks, Journal of Lightwave Technology, 2017

Soft-Failure Examples

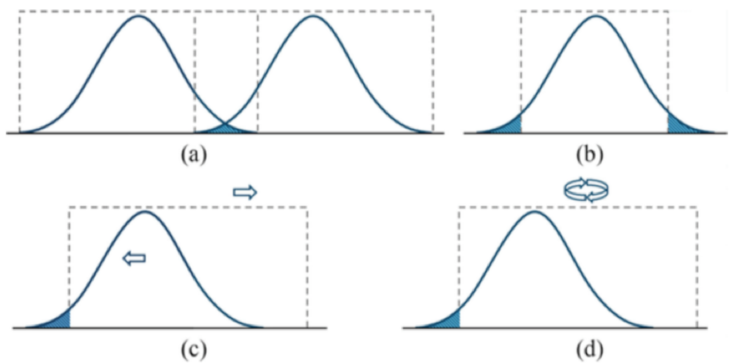

Fig. 1. Four failures affecting the signal of an optical connection: (a) signal overlap, (b) tight filtering, (c) gradual drift, and (d) cyclic drift.

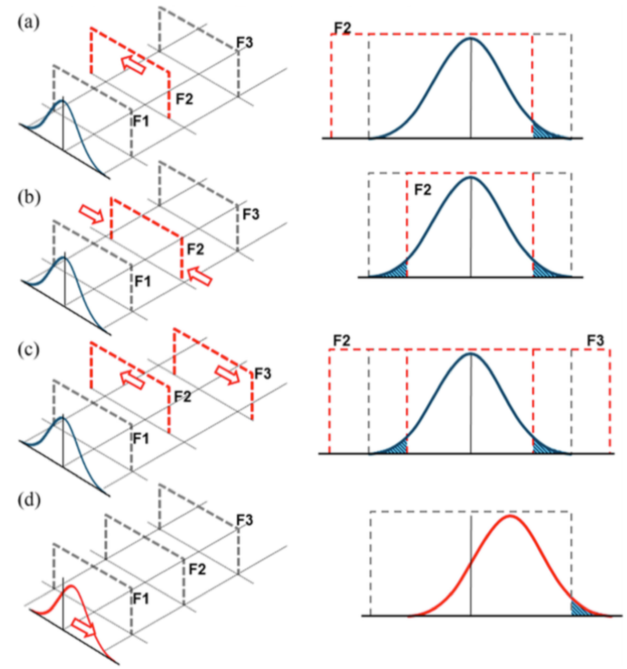

Fig. 2. Causes of tight filtering.

[1] Alba P. Vela, Marc Ruiz, Francesco Fresi, Nicola Sambo, Filippo Cugini, Gianluca Meloni,Luca Pot`ı, Luis Velasco, and Piero Castoldi, BER Degradation Detection and Failure Identification in Elastic Optical Networks, Journal of Lightwave Technology, 2017

Related Works

1. Alba P. Vela, Marc Ruiz, Francesco Fresi, Nicola Sambo, Filippo Cugini, Gianluca Meloni,Luca Pot`ı, Luis Velasco, and Piero Castoldi, BER Degradation Detection and Failure Identification in Elastic Optical Networks, Journal of Lightwave Technology, 2017
2. A. P. Vela, B. Shariati, M. Ruiz, F. Cugini, A. Castro, H. Lu, R. Proietti, J. Comellas,P. Castoldi, S. J. B. Yoo, and L. Velasco, Soft Failure Localization During Commissioning Testing and Lightpath Operation, J. OPT. COMMUN. NETW 2018
3. Shahin Shahkarami, Francesco Musumeci, Filippo Cugini, Massimo Tornatore, Machine-Learning-Based Soft-Failure Detection and Identification in Optical Networks, OFC, 2018

Alba P. Vela et al., BER Degradation Detection and Failure Identification in Elastic Optical Networks, JLT, 2017

- Monitoring the Pre-FEC bit sequence, they study how to detect: *signal overlaps, tight filtering, gradual/cyclical drifts*
- Solution consists of
  - One finite state machine that detects suspicious Pre-FEC BER fluctuations and reports them to a central controller
  - Central controller keeps time-series and identifies possible causes for problematic fluctuations using "machine learning techniques"
- Test results show good detection and identification capabilities

A. P. Vela et al., Soft Failure Localization During Commissioning Testing and Lightpath Operation, JOCN, 2018

- Propose a network-wide infrastructure composed of optical test channels (and related ingress, and egress measurement devices at each node of the path) and Optical Spectrum Analyzers in each node (one per degree of the node)
- With such infrastructure, use two machine learning based algorithms to analyze optical measurements (OSNR, bandwidth, etc.) and Pre-FEC BER to identify and localize failures
- Results show good performance

Shahin Shahkarami, Massimo Tornatore et al., Machine-Learning-Based Soft-Failure Detection and Identification in Optical Networks, OFC, 2018

- Propose a machine learning framework for Pre-FEC BER anomaly detection
- Such framework can identify if anomaly was due to narrow filtering or reduced amplification
- Sensitivity results on different framework parameters is presented
- Good performance

Forward Error Correction - FEC

- Method widely used (standardized in ITU-T G.975.1) to detect and correct errors that occur during transmission
- In optical networks, most popular ones are *Block-Turbo Codes* (BTC) and ***Low-Density Parity-Check*** **(LDPC)**
- Example: Reed-Solomon code, in short an RS(N,K) code over a Galois Field GF(2q), is a non-binary code that consists of *N q*-bit symbols, where $N \leq 2q-1$

➢RS(255,239) code over GF(28) can correct up to eight symbol errors (or a single burst error of up to 57 bits) with 6.7%

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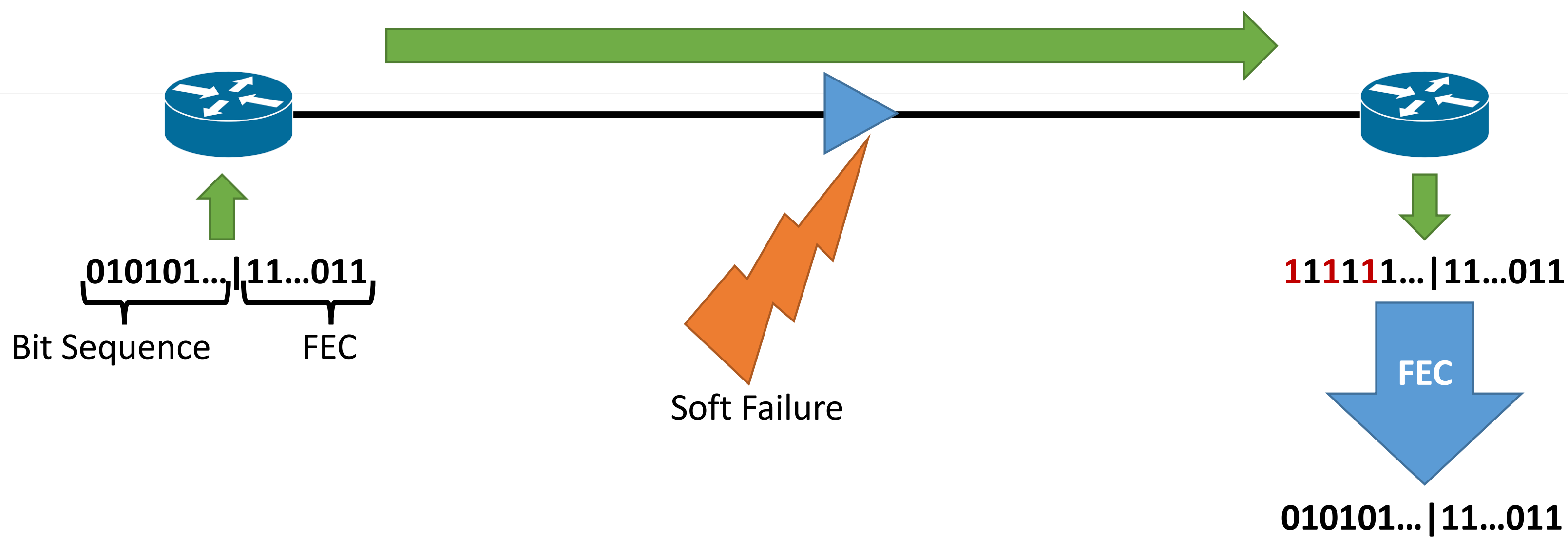
Forward Error Correction - Example

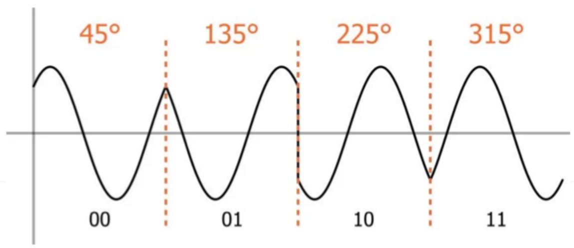


Information (possibly) Provided by FEC - 1

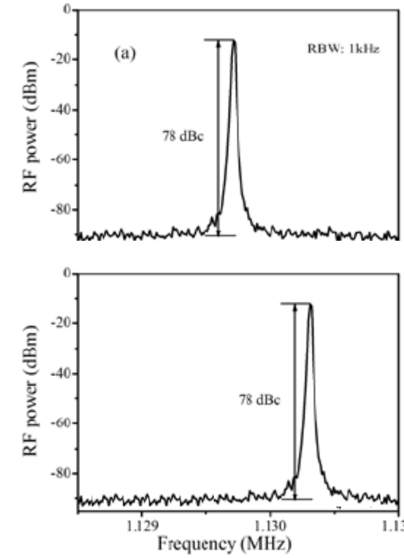
This difference might not be true for all modulations…

00011011…|11…011

QPSK Modulation

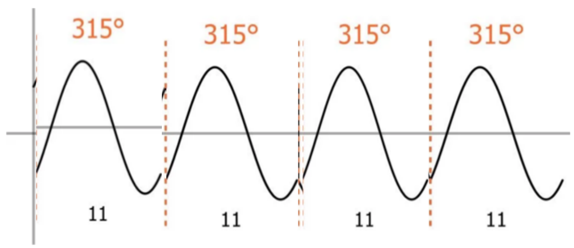


Frequency Components



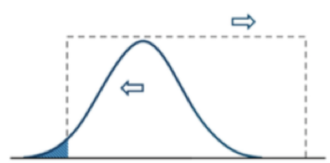
11111111…|11…011

QPSK Modulation



Frequency Components

Indicative of a laser drift?



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Information (possibly) Provided by FEC - 2

1111111100000011111010101011110101010111010101010101010001110101101010101101101…|11…011

Why bursty errors?

1111111011111110001101010101000101010101101010101010101111000101010101010101101101…|11…011

Why homogeneous errors?

1111111011111110001101010101000101010101101010101010101111000101010101010101101101…|11…011

Why few very long errors?

Is there a jitter-like observation to be made about what bits suffer from errors?
(i.e., how homogenously they are spaced)

Why related works only use Pre-FEC?

- "(…) pre-FEC Bit Error Rate over the pre-defined limit would imply a non-error-free post-FEC transmission and, as a result, communication would be disrupted. Therefore, a prompt detection of optical connections with excessive pre-FEC BER can greatly reduce SLA violations."
- "(…) pre-FEC BER, Optical Signal to Noise Ratio (OSNR), Q-factor, and also electrical SNR can be monitored by already available commercial transponders."

Our Idea

- Given: Pre-FEC and Post-FEC data, possibly usual optical layer measurements (OSNR, center frequency, etc. – whatever is available to most current coherent transponders), optical paths, lambda, elements in the path
- Output: A diagnostics of whether there is some soft-failure in the path, and, if so, the identification of what failure that is (possibly, the localization of the failure also)
- Method: Yet to investigate (ML and other techniques)