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ANOMALY DETECTION IN OPTICAL SPECTRA VIA JOINT OPTIMIZATION

Antonino Maria Rizzo[1], Luca Magri[1], Pietro Invernizzi[2], Enrico Sozio[2], Stefano Piciaccia[2], Alberto Tanzi[2], Stefano Binetti[2], Cesare Alippi[1,3], Giacomo Boracchi[1]

[1]Politecnico di Milano, [2]Cisco Photonics, [3]Università della Svizzera Italiana

ABSTRACT

Despite the remarkable progress of fiber optics in communication, little attention has been devoted to the automatic detection of anomalies in optical spectra, i.e., poorly transmitted channels. This task is typically addressed by ad-hoc heuristics that fall short in spectra presenting heavy distortions caused by optical amplifiers during transmission. We propose a method based on a joint optimization procedure for estimating the major trends that characterize the spectrum, enabling the detection of anomalies even in the presence of few channels and heavy distortions. Our experiments have shown that the proposed method can successfully localize anomalies achieving more than 98% accuracy, outperforming all competitors.

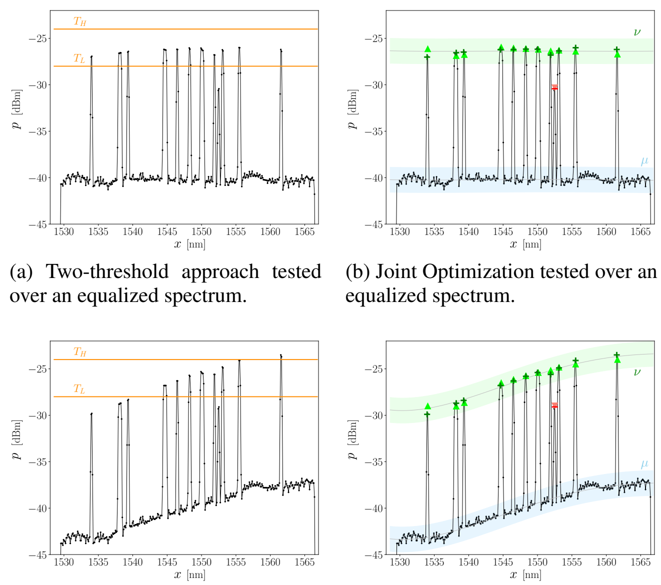
***Index Terms*—** Anomaly Detection, Optical Spectra, Joint Optimization.

1. INTRODUCTION

Fiber optics are essential to transmit data over long distances. User information is transmitted through channels that form an optical signal called *spectrum*. An example of such a signal is shown in Fig. 1a, where channels appear as well-equalized peaks, meaning that they have the same power level. At the bottom of the spectrum, the Amplified Spontaneous Emission (ASE), introduced by the amplifiers, provides a base power level in regions with no channels.

A significant problem that occurs in the composition of spectra is the presence of *anomalies*, which are mostly caused by faults in the fiber and typically result in non-equalized peaks (marked in Fig. 1b by the red triangle with the tip down). To guarantee proper data transmission, it is essential to design automatic procedures to detect anomalies to trigger corrective actions. Otherwise, systems mounted along fiber links that autonomously operate to improve the transmission quality (e.g., optical amplifiers) might undertake wrong actions leading to potentially dangerous cascade-effects.

Although anomaly detection is an active research field [1, 2], this problem has not been extensively investigated in the context of optical spectra. In practice, the common solution adopted in industrial applications consists of setting two thresholds on channel power, T_L and T_H (orange lines in Fig. 1a), to recognize as anomalies all the peaks that fall outside these two. However, this solution fails in the general case and is only effective on well-equalized spectra, which rarely happens in practice. As a matter of fact, when transmitted over long distances, amplifiers introduce fluctuations and tilts that distort the spectrum such that both channels and ASE follow a trend, denoted as ν and μ in Fig. 1d. When these trends are non-horizontal, the two-thresholds approach fails, as illustrated in Fig. 1c, where the spectrum is tilted, and the trend is no longer straight as in Fig. 1a. Since this anomaly has a higher power level than the leftmost channel, it is not possible to adjust the two thresholds to detect the anomaly without invalidating at least one channel.



(a) Two-threshold approach tested over an equalized spectrum.

(b) Joint Optimization tested over an equalized spectrum.

(c) Two-threshold approach tested over a distorted spectrum.

(d) Joint Optimization tested over a distorted spectrum.

Fig. 1: In (a) all the channels appear as peaks in the spectrum having the same power level (equalized), whereas in (c) the spectrum becomes distorted and the channels are no more equalized. While in (a) the thresholds T_H and T_L (colored orange) can successfully separate channels from anomalies, in (c) the use of thresholds becomes ineffective. Figures (b) and (d) depict the channel and ASE trends, ν and μ, estimated by our proposed method.

Anomalies could be in principle detected by considering the spectrum as a time series and using a supervised detection network to identify channels and anomalies. This strategy adapts visual recognition models, such as the Faster R-CNN [3] and YOLO [4], to 1D signals. Among the most recent works, this has been successfully applied to the detection of anomalies in ECG tracings [5], earthquakes in seismic waves [6], optical events in OTDR traces [7], and speech objects in a fixed-length audio signal [8]. Unfortunately, while localizing channels and anomalies is straightforward, classifying between them is difficult since anomalies are rare and have the same shape as channels, the only difference is that their power levels deviate from the channel trend.

In this work, we consider the general scenario where spectra are tilted and might follow a trend as in Fig. 1. We define anomalies as peaks that do not follow the channel trend. Therefore, instead of directly localizing channels and anomalies, our goal is to estimate the channel trend and detect anomalies as peaks departing from it.