Anomaly Detection in Optical Spectra via Joint Optimization

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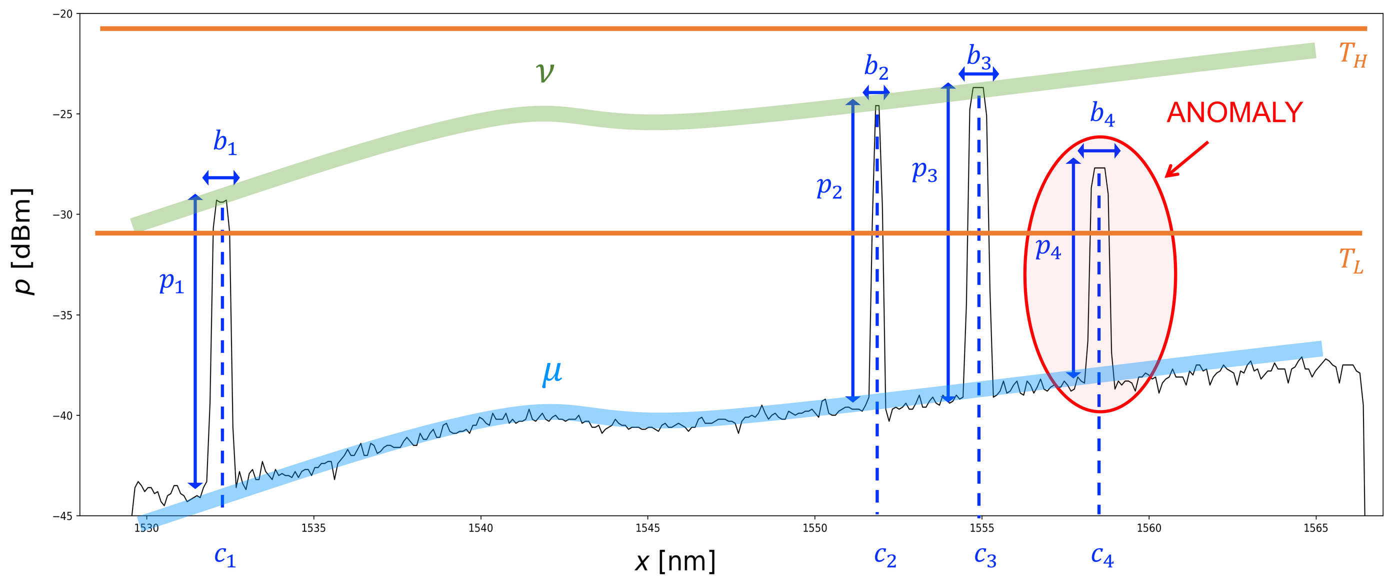
Introduction



- User information is enclosed into **spectra** and transmitted through fiber optics.
- A spectrum S contains a varying number of **channels** that follow an unknown trend ν.
- The **ASE** provides a base power level in regions with no channels. ASE samples follow a trend μ.
- The occurrence of faults cause **anomalies**
- Our **goal** is to automatically **detect the anomalies** in the spectrum, if any.

Key Intuitions

- Anomalies are channels that do not conform to the channel trend.
- Fit the channel trend via robust fitting, such as RanSaC.
- **Joint optimization** allows us to promote the similarity between channel and ASE trends.

Joint Optimization

Our method accounts for the similarity of the channel and ASE trends, ν and μ, by optimizing the following loss:

$$\overbrace{\underbrace{\sum_{p\in\mathcal{N}} \mathrm{err}(p,\mu)^2}_{\text{residuals between samples in } \mathcal{N} \text{ and } \mu} + \underbrace{\sum_{p\in\mathcal{C}} \mathrm{err}(p,\nu)^2}_{\text{residuals between samples in } \mathcal{C} \text{ and } \nu}}^{\text{data fidelity terms}} + \underbrace{\frac{\lambda}{k}}_{\text{balance the data fidelity and similarity terms}} \overbrace{\underbrace{\sum_{j=1}^{k} (n_j - m_j)^2}_{\text{coefficients } \nu \text{ and } \mu}}^{\text{similarity term}}$$

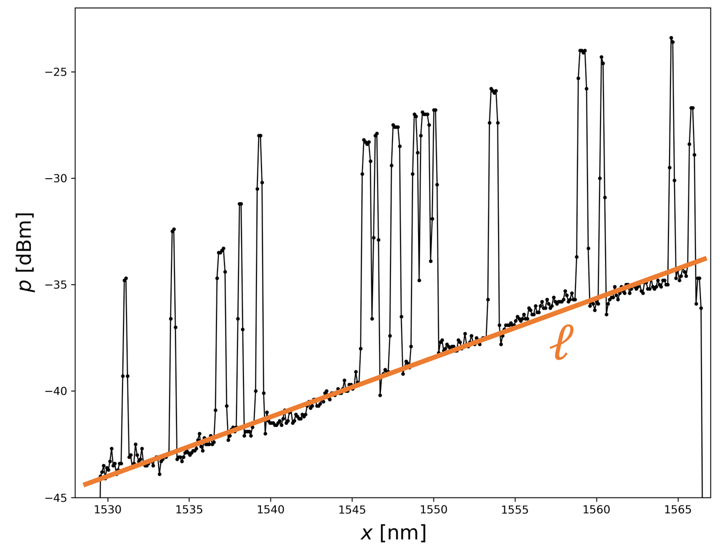
Proposed Method

Algorithm 1 Joint Optimization

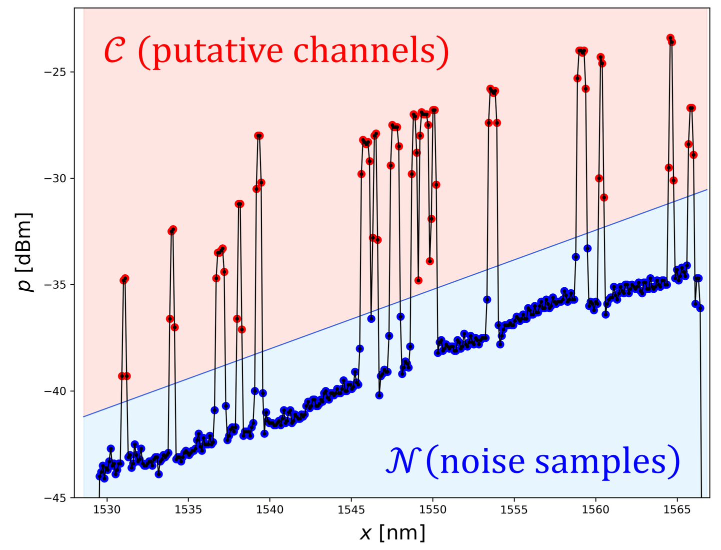
Input: Spectrum S, inlier threshold ε
Output: Central frequencies c_k of the K anomalies

Stage 1: Initialization.
Fit a linear trend $\ell \leftarrow$ LO-RanSaC$(x_i, S(x_i), \varepsilon)$
$h_r \leftarrow$ Construct the histogram of residuals.
$\mathcal{C}, \mathcal{N} \leftarrow \mathrm{Otsu}(h_r)$.
$\mathcal{C} \leftarrow \mathrm{FindPeaks}(\mathcal{C})$.
$\nu \leftarrow$ Fit polynomial to the samples in $\mathcal{C}$.
$\mu \leftarrow$ Fit polynomial to the samples in $\mathcal{N}$.
Stage 2: Joint optimization;
$\nu^*, \mu^* \leftarrow$ Jointly estimate trends as in Eq. (1).
Stage 3: Anomaly detection;
$c_k \leftarrow$ Recognize as anomalies $\{c_k \in \mathcal{C} \colon \mathrm{err}(p_k, \nu) > \varepsilon\}$.

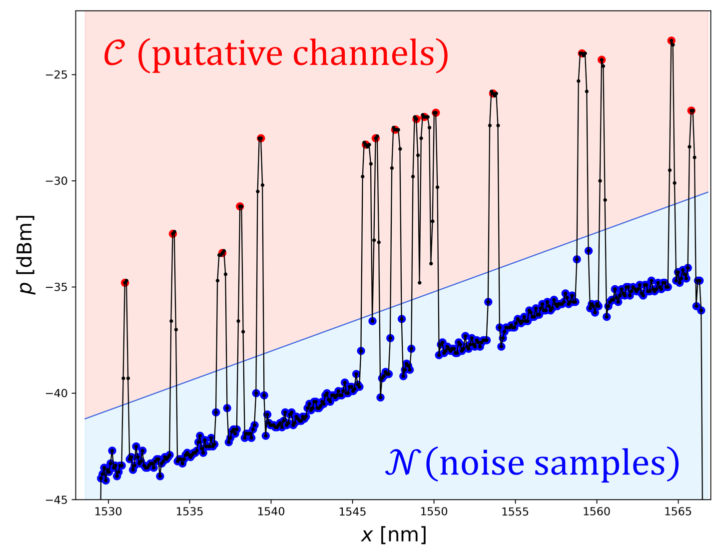
Running example



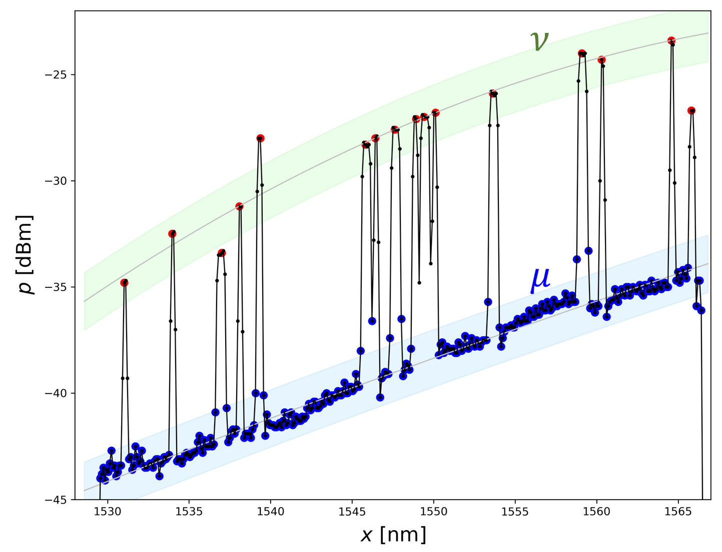
(a) Fit linear trend ℓ



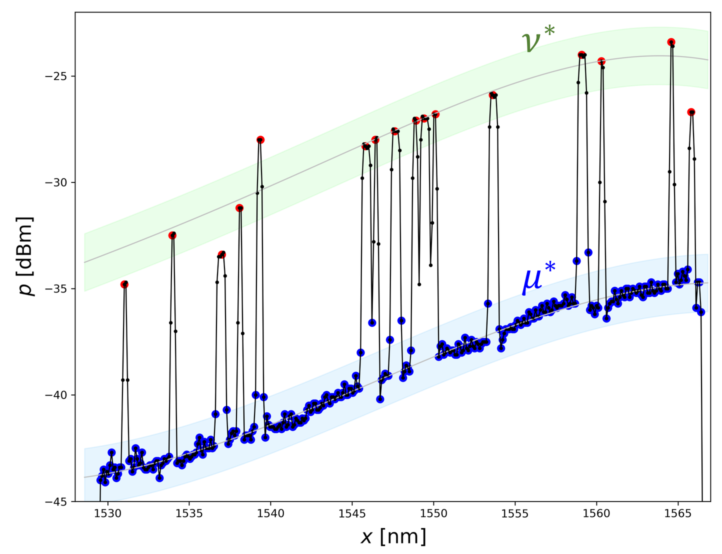
(b) Denote $\mathcal{C}$ and $\mathcal{N}$



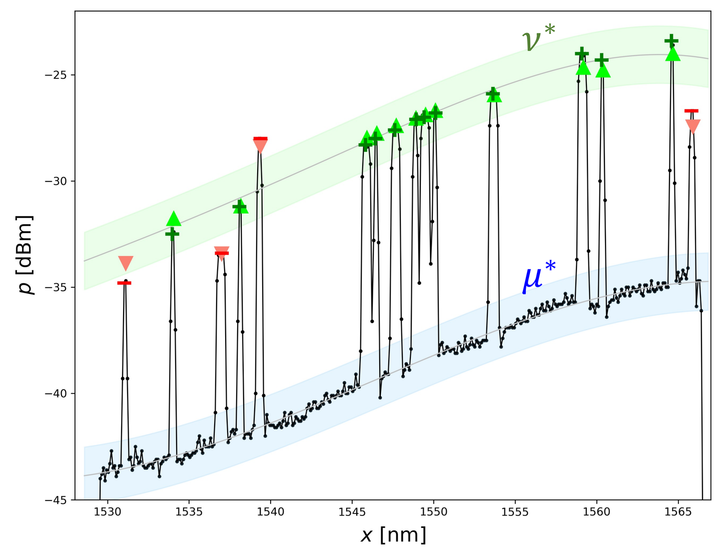
(c) Find peaks



(d) Fit initial guess



(e) Joint Optimization



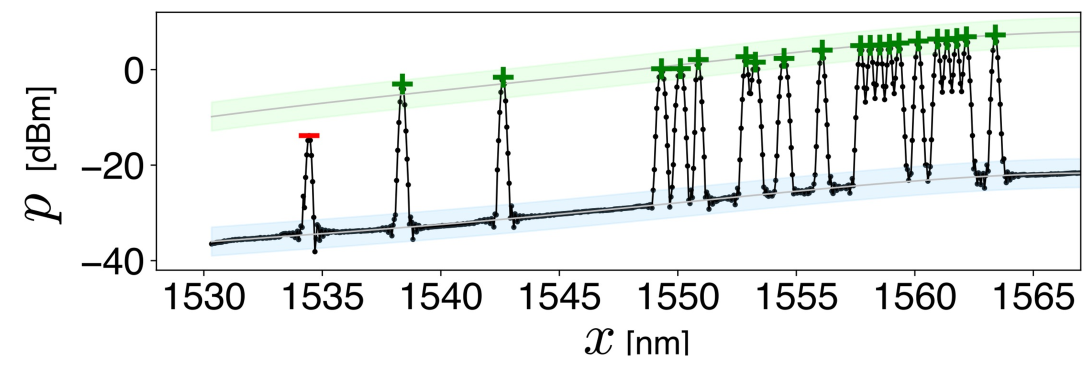
(f) Anomaly Detection

Experiments

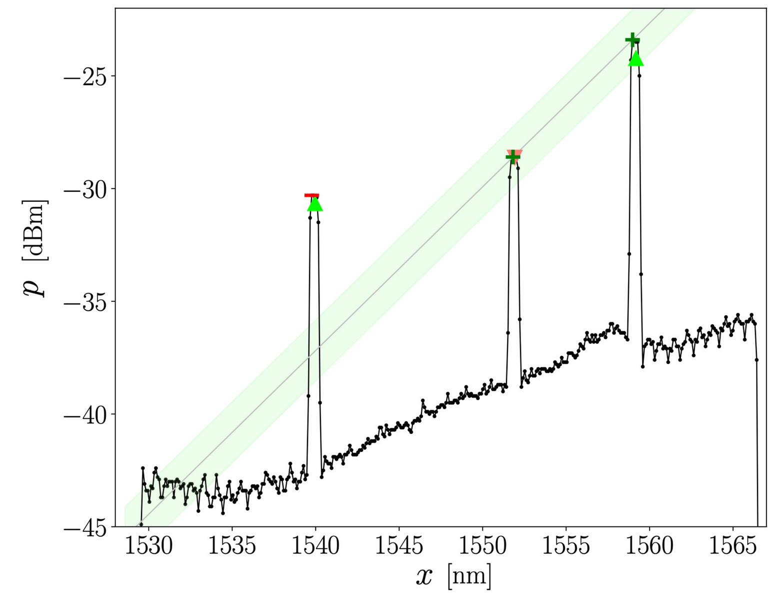
Our joint optimization procedure enhances channel trend estimation, enabling the accurate detection of anomalies.

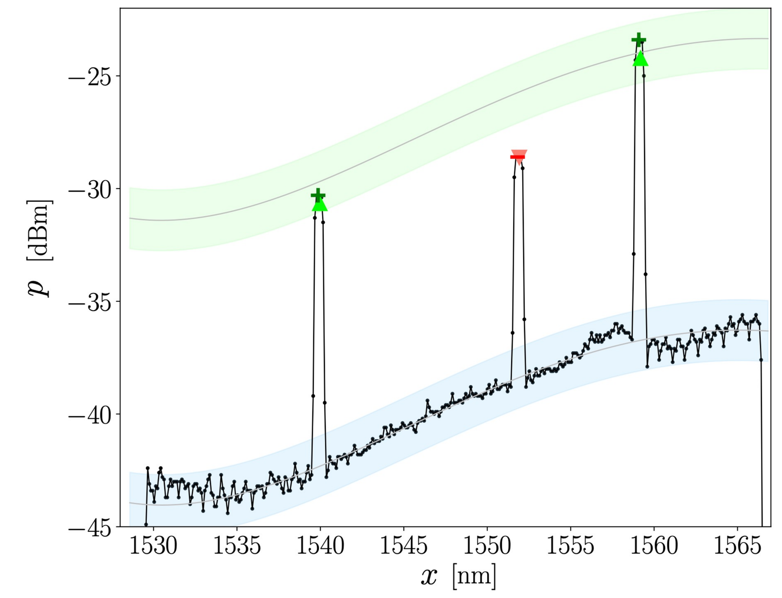
Qualitative Experiments

Real Spectrum



Synthetic Spectra





Quantitative Experiments

	Accuracy		Precision		Recall		F_1 Score	
	Mean	Var.	Mean	Var.	Mean	Var.	Mean	Var.
Two-thresholds	0.662	0.054	0.329	0.119	0.697	0.141	0.391	0.112
Robust Fitting	0.951	0.010	0.800	0.117	0.810	0.110	0.789	0.106
Faster R-CNN	0.857	0.006	0.000	0.000	0.000	0.000	0.000	0.000
Joint Optimization	**0.989**	0.002	**0.968**	0.028	**0.937**	0.036	**0.948**	0.030

Conclusions

- Our method overcomes currently employed solutions and provides us an estimate of the channel and ASE trends.
- The **joint optimization** procedure that allows us to fit the channel trend and extracting useful information encoded in the ASE.

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