Compressed BER monitoring in all-optical networks

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Agile All-Photonics Networks

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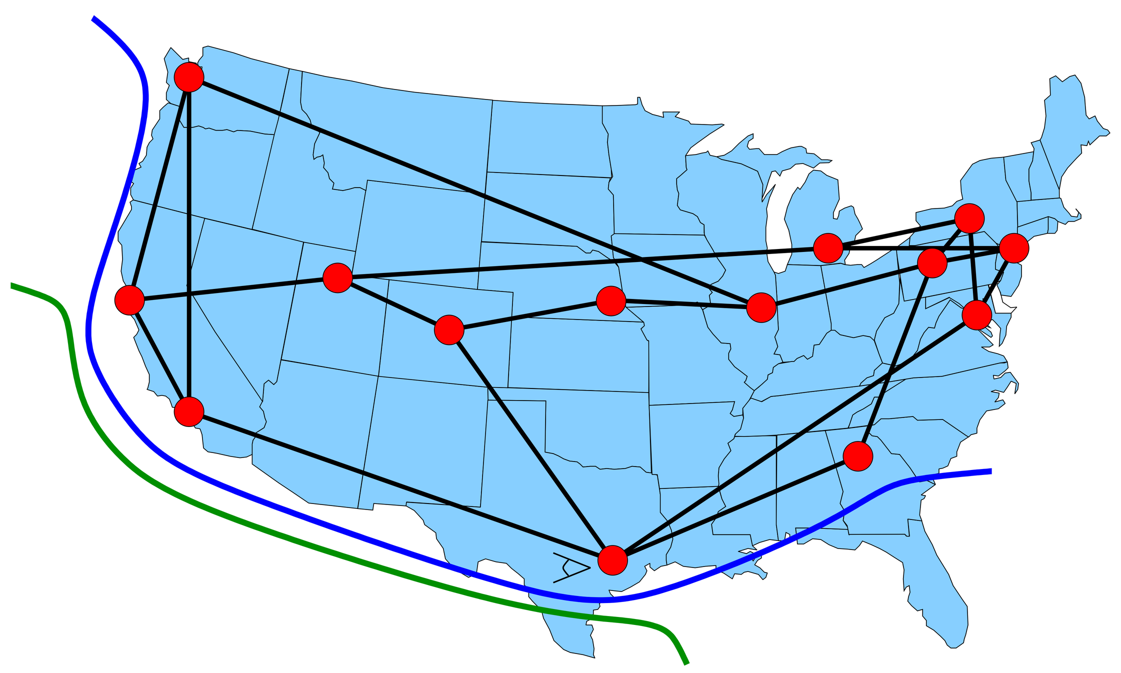
1. Introduction



All optical networks monitoring

- Optical networks with no optical-electrical-optical conversion
- Calls are routed over circuits
  - circuit = route + wavelength = lightpath
- Routing and Wavelength Assignment algorithms:
  - Wavelength continuity constraint
  - Quality of Service (QoS) constraint

Novel issues

- Physical impairments are not negligible
- New physical impairments: crosstalk (signal leaks)
- Long paths and no regeneration ⇒ impairments accumulates ⇒ QoS as measured by bit-error rate (BER) possibly unacceptable

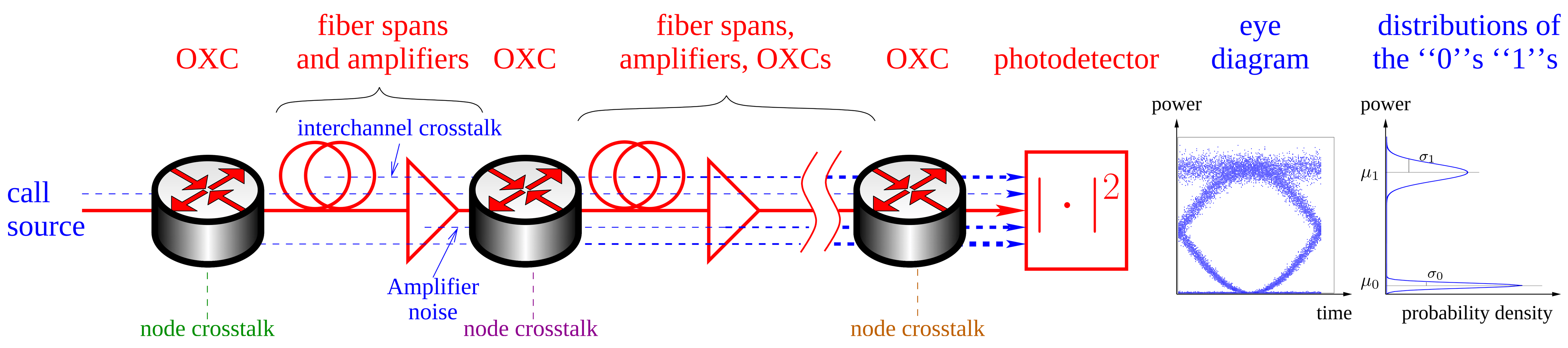
Problem

- Monitor QoS in all-optical networks
  - BER estimation is computationally expensive
  - Hardware monitors are expensive
- Given a budget (number of monitors), estimate the BER on most lightpaths at any time

Approach

- Select BER monitor locations
- Exploit spatial and temporal correlation between lightpaths to design a diffusion operator
- Work in a diffusion wavelet basis where metrics to be estimated are compressible
- Use a nonlinear estimator, powerful when data is compressible

2. Lightpath model



Lightpath BER

- Lightpaths are subject to physical impairments:
  - Traditional impairments: Intersymbol Interference (ISI), amplifier noise, interchannel crosstalk
  - New physical impairment: node crosstalk = signal leaks within the nodes
- Need to know BER at call arrival time, for all calls
- BER of a lightpath:

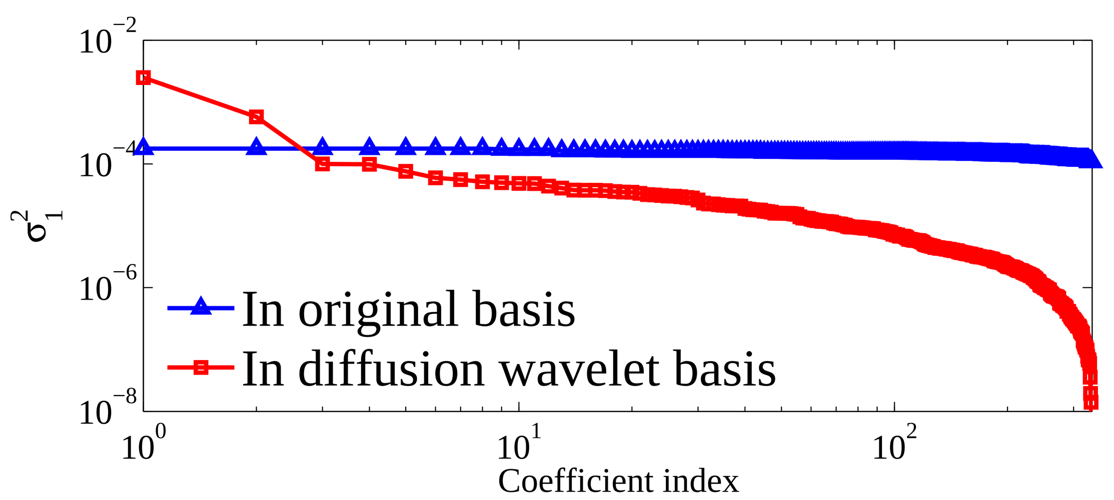
$$BER = \frac{1}{2}\mathrm{erfc}\Big(\underbrace{\frac{\mu_1-\mu_0}{\sigma_0+\sigma_1}}_{Q}/\sqrt{2}\Big)$$

- Variance σ_1^2 accounts for all impairments, modeled as noises

3. Estimation technique

Data compression

- Use diffusion wavelet framework
  - Extension of the wavelet theory to graphs
  - Inputs: graph, diffusion operator
  - Output: basis in which data coefficients decay fast
- We provide a diffusion operator:
  - Describe a physical process at the local scale
  - Similar to heat diffusion in continuous matter
  - Here: describe how “close” 2 nodes/lightpaths are
  - Spatial correlation: lightpaths are “close” when they share many links
  - Temporal correlation: a lightpaths is “close” to the same lightpath, at the next/previous time instant



Example: compressibility of σ_1^2.

Nonlinear estimation

- Consider a compressible (= fast decay) signal y:

$$y_{est} = \arg\min_{\tilde{y}} ||\tilde{y}||_{\ell_0} \text{ subject to } A\tilde{y} = y_{obs}$$

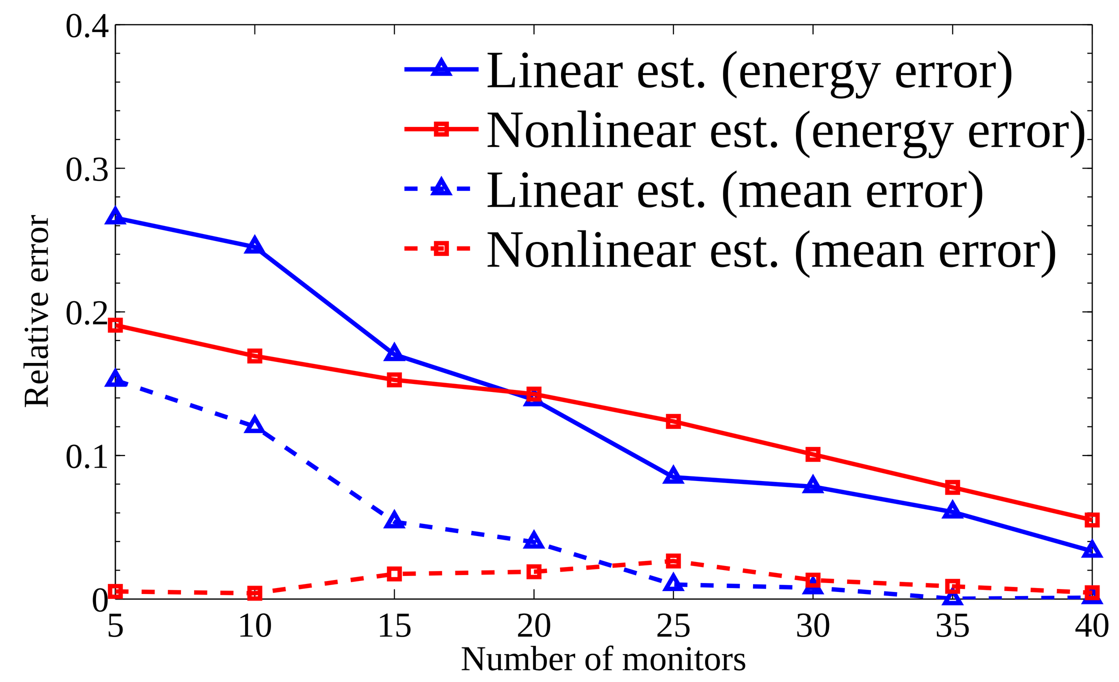
- Can recover a sparse signal y given a few samples $y_{obs} = Ay$ are observed (A = observation matrix)
- NP-hard problem
- Conditions on A are very restrictive
- ℓ_0-minimization ⇔ ℓ_1-minimization (Candès/Tao)
- ℓ_1-minimization can be done with a linear program
- Here: estimate in turn μ_0, μ_1, σ_0, σ_1, for all lightpaths, on blocks of timesteps
- Perform estimation in the diffusion wavelet basis

BER monitor placement

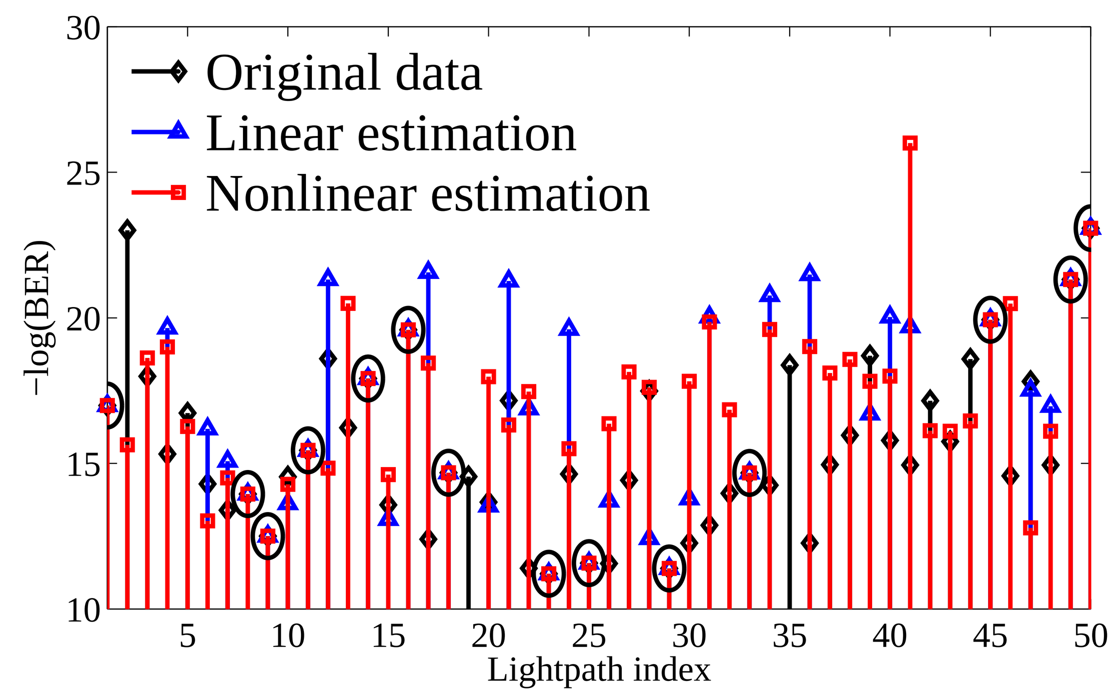
- Assume fixed budget
- The number of observed lightpaths varies with time
- Use a heuristic based on subset selection
  - Adapted to linear estimators
  - Works well for nonlinear estimation

4. Results

- Simulate all-optical network operation
- 350 calls, regional-sized network (NSF topology scaled 10 times down)
- Compare our nonlinear estimation framework with known linear estimation techniques
- Measure relative error for $\log(\mathrm{BER})$ mean: $|\langle y - y_{est}\rangle|/\langle y\rangle$; energy: $\|y-y_{est}\|_{\ell_2}/\|y\|_{\ell_2}$
- Nonlinear estimator is unbiased and returns estimates in cases where linear estimator fails
- Nonlinear estimator best with few BER monitors



Comparison of nonlinear estimation framework and standard linear estimator



BER of sample lightpaths, before and after estimation
Observed lightpaths are circled

5. Conclusions/Future work

- Able to estimate BERs when few BER monitors are deployed
- Improve monitor placement heuristic
- Improve technique for high number of BER monitors