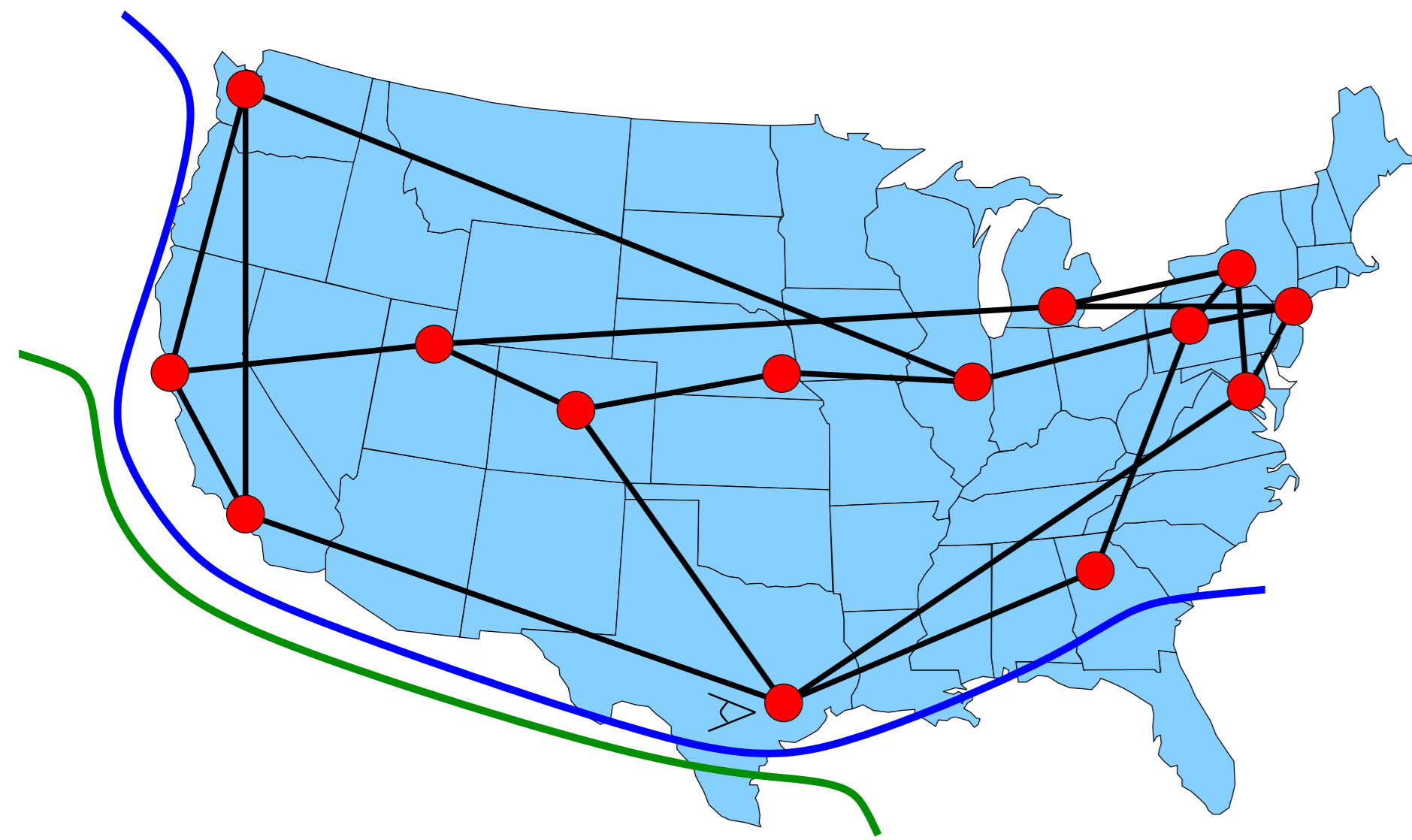


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1. Introduction



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 \Rightarrow impairments accumulates \Rightarrow QoS as measured by bit-error rate (BER) possibly unacceptable

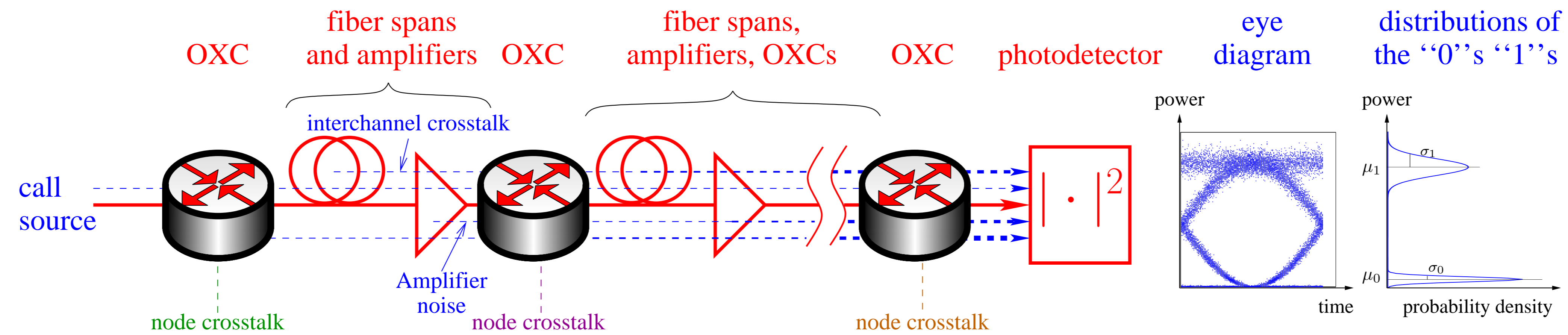
Problem

- 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:

$$BER = \frac{1}{2} \operatorname{erfc} \left(\frac{\mu_1 - \mu_0}{\underbrace{\sigma_0 + \sigma_1}_Q} / \sqrt{2} \right)$$

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

3. Estimation technique

Nonlinear estimation

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

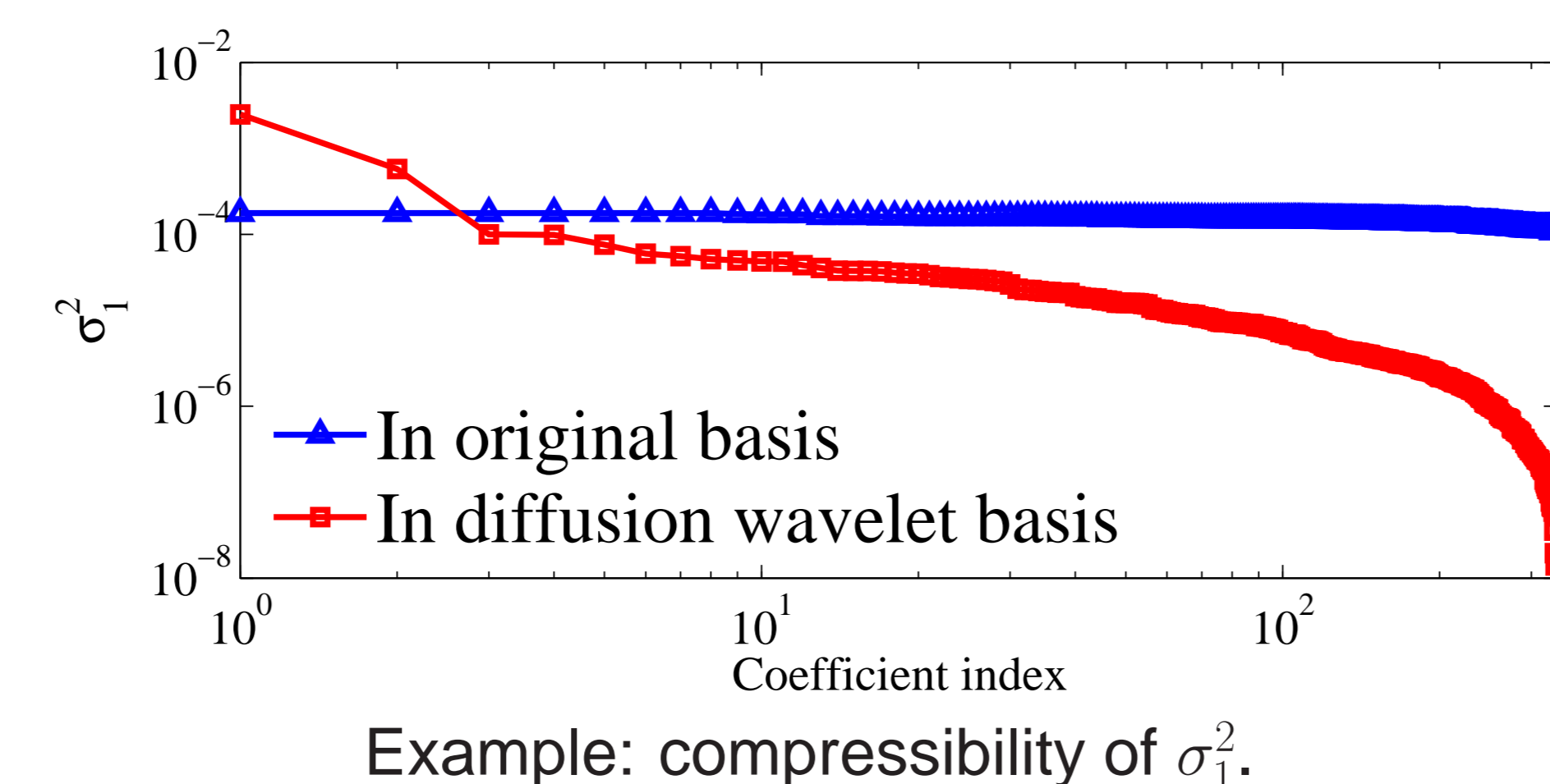
$$y_{est} = \arg \min_{\tilde{y}} \|\tilde{y}\|_{\ell_0} \text{ subject to } A\tilde{y} = y_{obs}$$
- Can recover a **sparse** signal y given **a few samples** $y_{obs} = Ay$ are observed (A = observation matrix)
- NP-hard problem
- Conditions on A are very restrictive
- ℓ_0 -minimization \Leftrightarrow ℓ_1 -minimization (Candès/Tao)
- ℓ_1 -minimization can be done with a **linear program**
- Here: estimate in turn $\mu_0, \mu_1, \sigma_0, \sigma_1$, 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

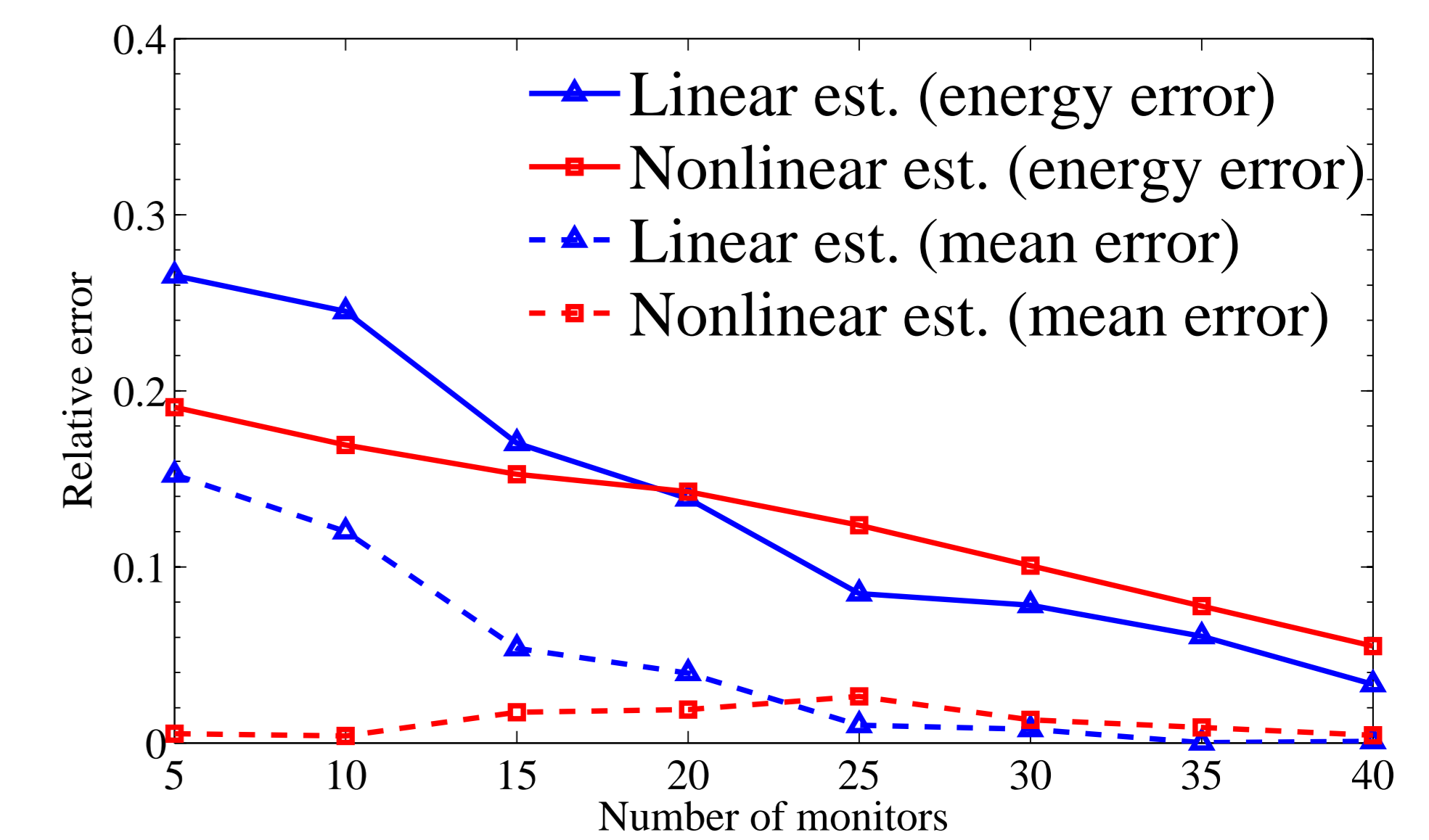
Data compression

- 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

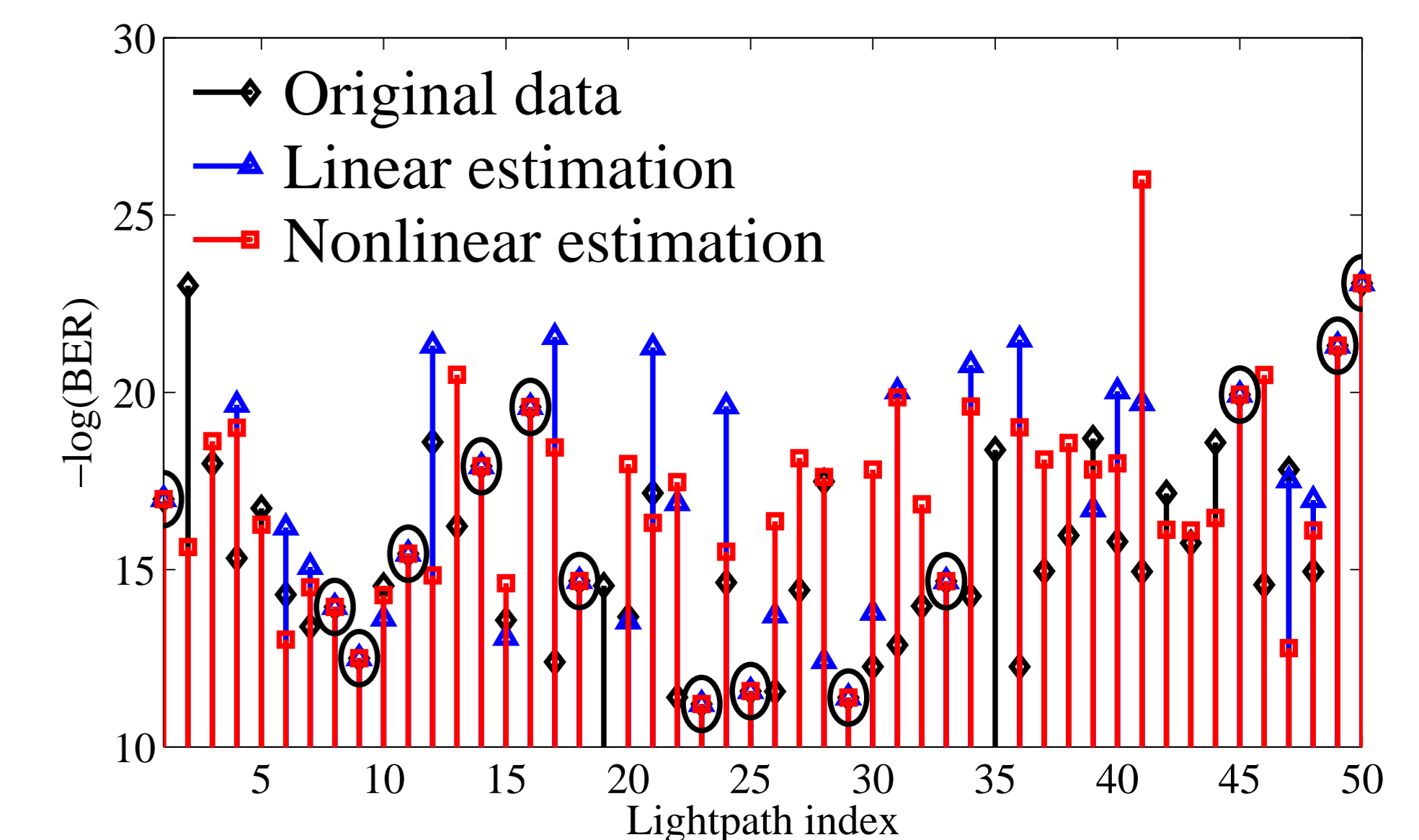


4. Results

- 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 $\log(\text{BER})$
 - 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