

Optical Communication Systems and Networks

Maité Brandt-Pearce

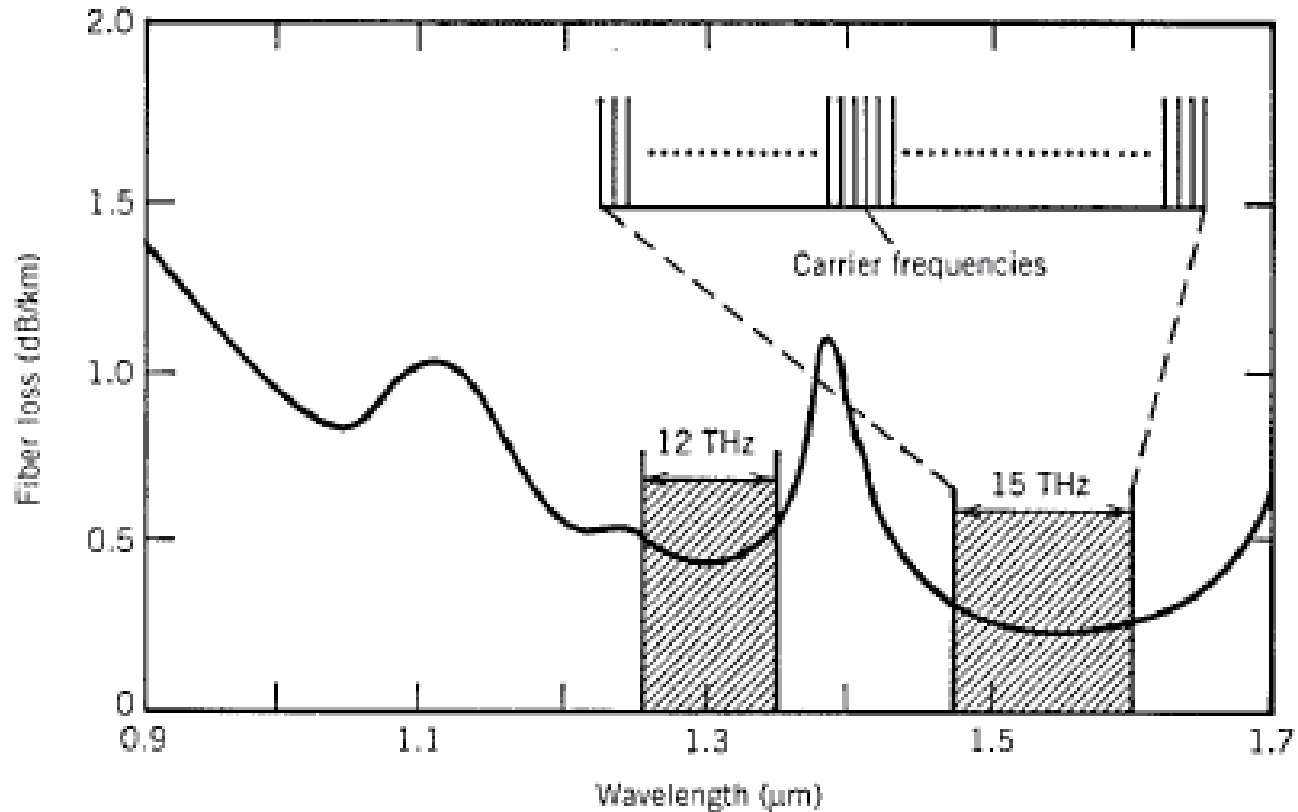
ECE 696

May 5, 2006

Motivation

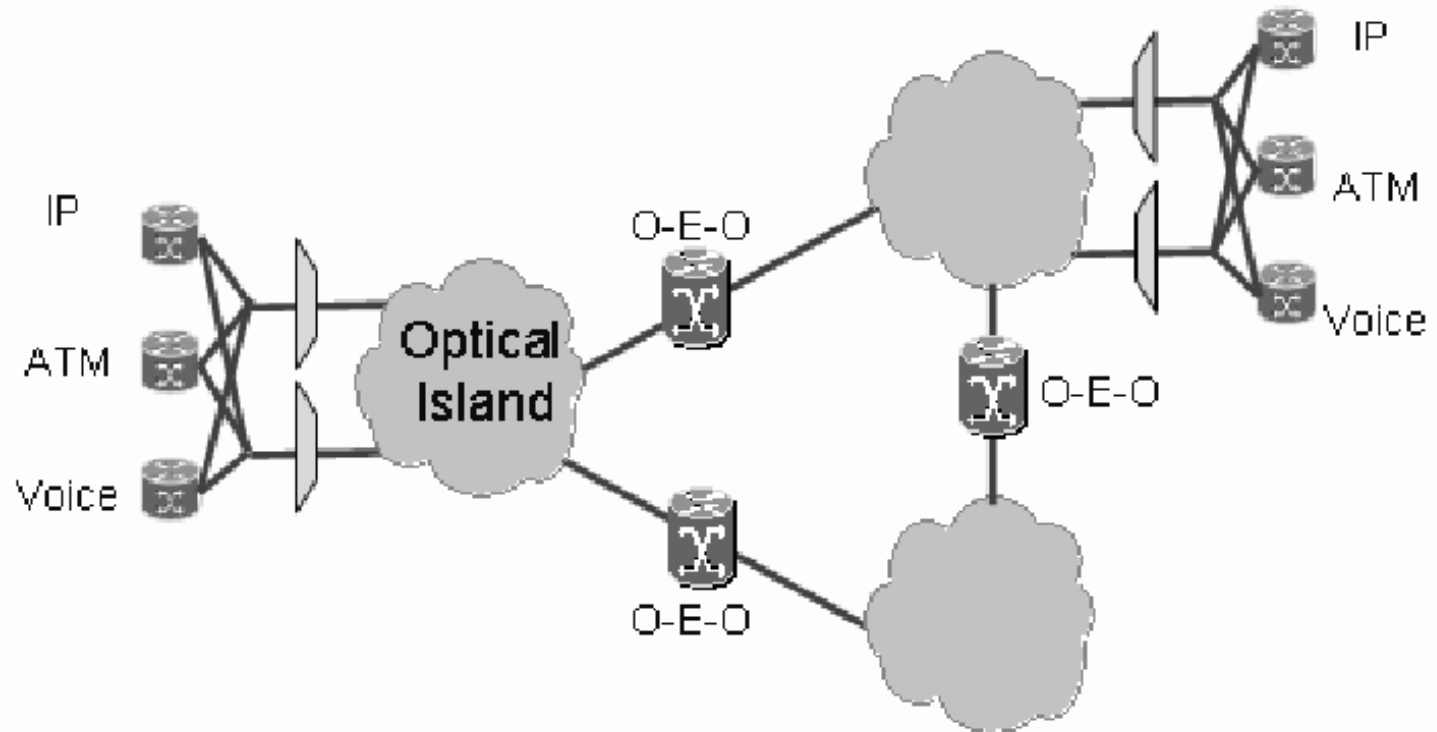
- Need:
 - More data throughput ...
 - over longer distances ...
 - connecting more network nodes.
- Problem encountered
 - Too much data (high data rates) ...
 - distances too long (fiber nonlinearity) ...
 - too many nodes (contention and crosstalk).

Loss-Spectrum of Fiber



From Fiber Optic Communication Systems, G. Agrawal, Wiley, 2002

Translucent Optical Network



Research Trends

- Bigger, longer, faster experiment: develop new techniques and new devices
- Signal processing tools applied to optical communications
- Exact performance calculation and simulation techniques
- Calculation of channel capacity
- Cross-layer design of optical networks

Novel Signal Processing Tools

- Adaptive filtering:
 - Combat PDM, dispersion, nonlinear effects
 - Multichannel processing to reduce interference and crosstalk
- MIMO (multiple input multiple output) techniques:
 - Exploit modes in multimode fiber
 - Multiple LDs and PDs in free space system to reduce scintillation
- Error control coding:
 - RS and turbo codes to reduce required $Q < 3$

Performance Computation and Simulation

- Measures used in practice are approximate: true statistics are difficult to describe
 - Several noise sources, not all Gaussian
 - Sums of filtered chi-squared if use optical amplifier
 - Many effects to consider: timing jitter, modal noise, etc
- Simulation of multichannel system and networks:
 - Too many details: all components affect signal
 - Too broadband: 10 THz bandwidth, cannot sample those rates
 - Too low BER: too many bits needed to estimate low BER

Channel Capacity

- Capacity limited by
 - binary signaling (to 1bit/s/Hz)
 - noncoherent detection
 - nonlinear interference
 - PMD fading and ISI
 - Typically use
 - Gaussian approximation
 - numerical computation
- no closed-form solution

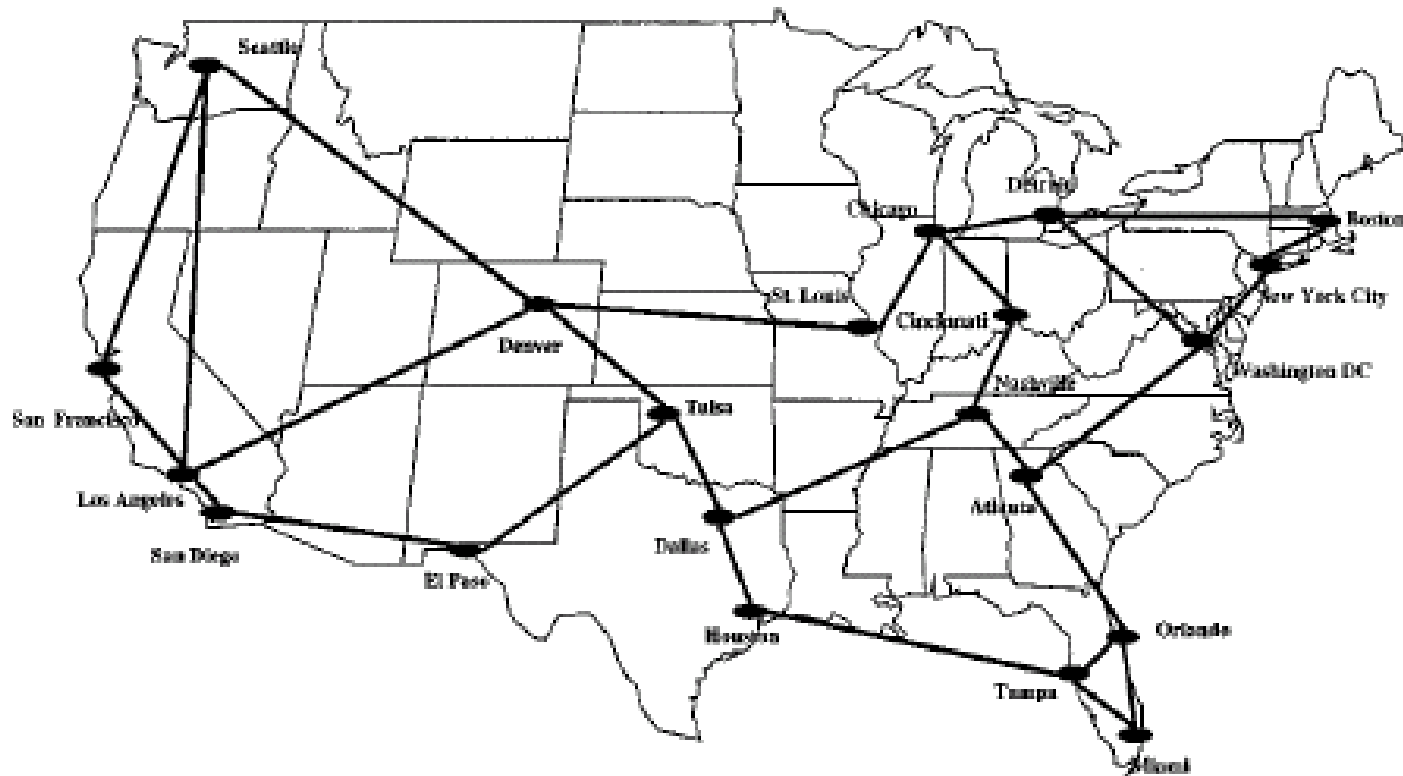
Cross-layer Network Design

- When networks pushed:
 - more channels and more degradation
- Then:
 - Physical layer no longer ‘perfect’
 - Network layer decisions affect performance through increased crosstalk
 - Physical limitations dictate limits on architecture, protocols, network management decisions

All-Optical Networks

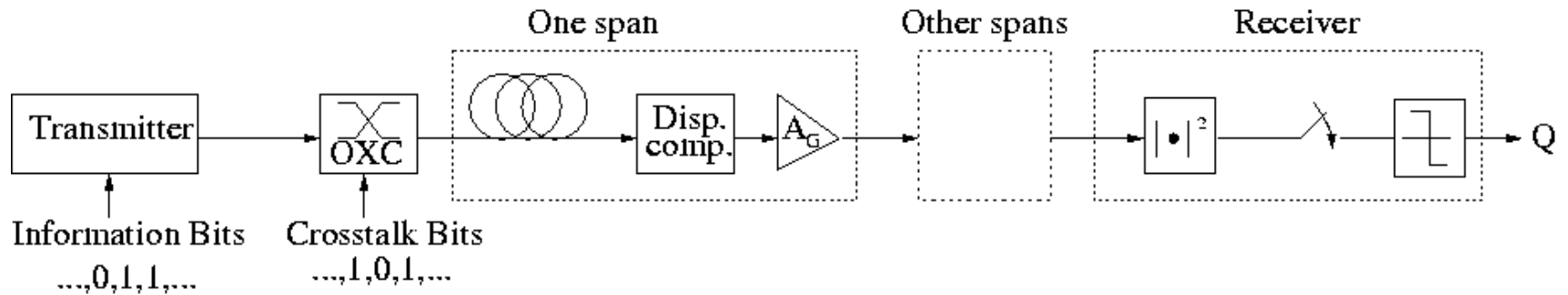
- Signal remains optical from source to destination: no O/E – E/O conversion
- Uses all-optical switches for routing
- Issues:
 - As signals pack in wavelength space, get crosstalk
 - As signals travel longer, problem worsens
- Two solutions proposed:
 - Cross-layer routing and wavelength assignment
 - Multichannel processing

Example of Continental-size Optical Network

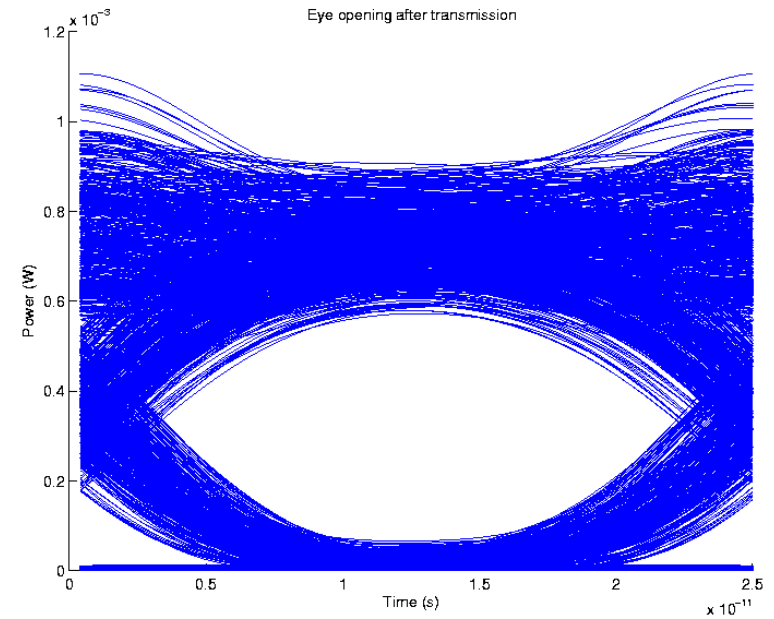
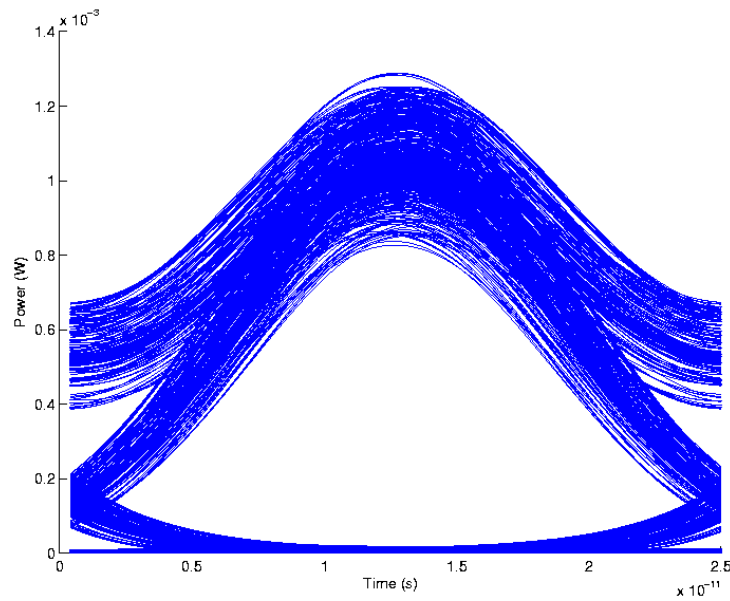


From Fiber Optic Communication Systems, G. Agrawal, Wiley, 2002

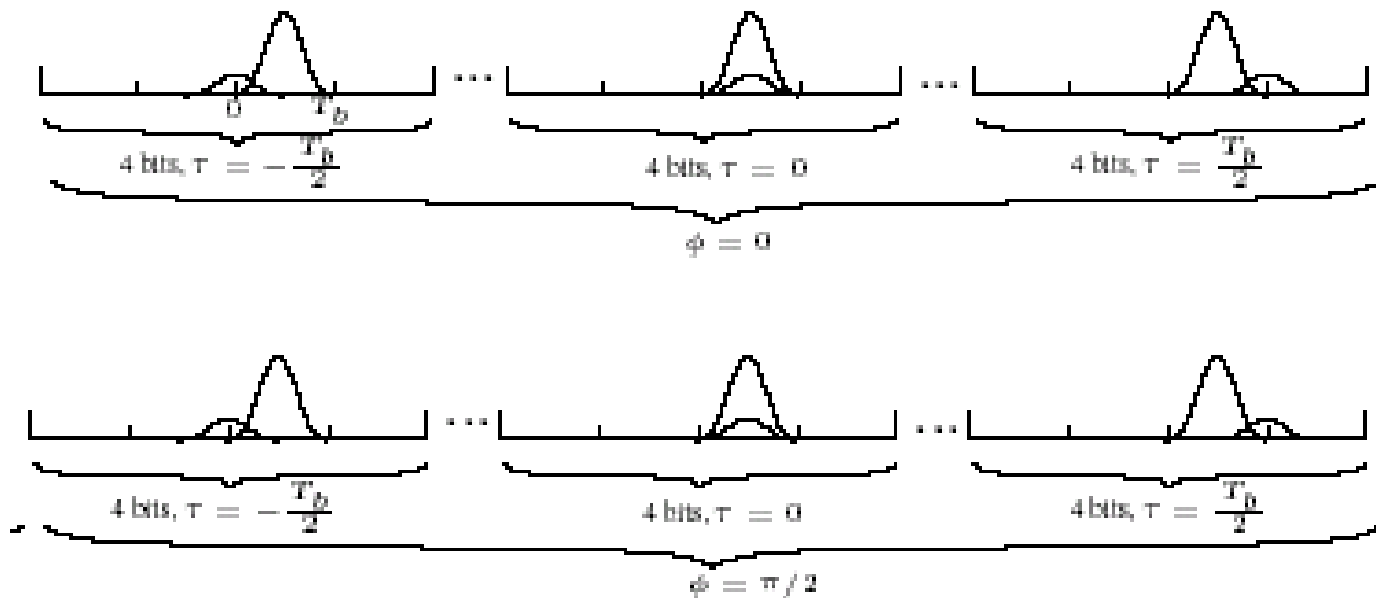
Point-to-point Fiber Model



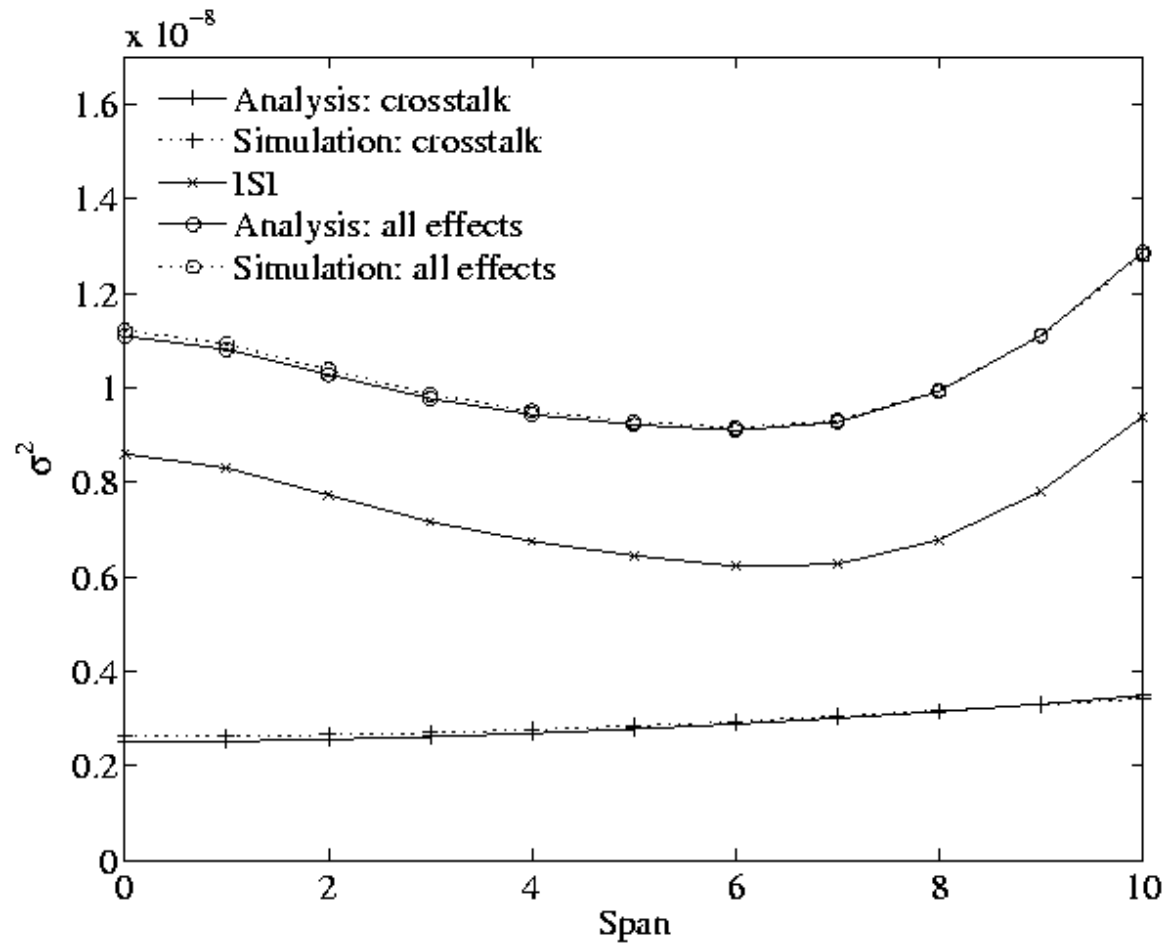
Input and Output Eye Diagrams



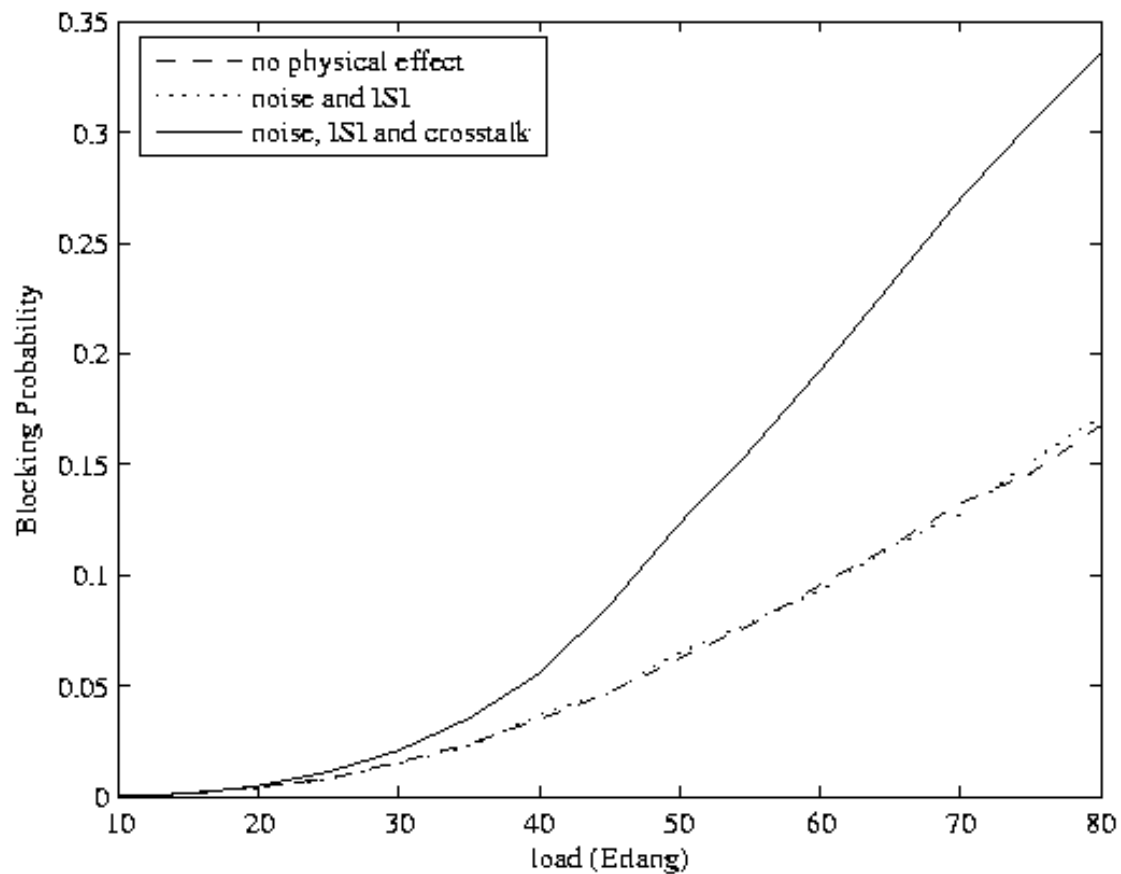
Crosstalk-Signal Interaction



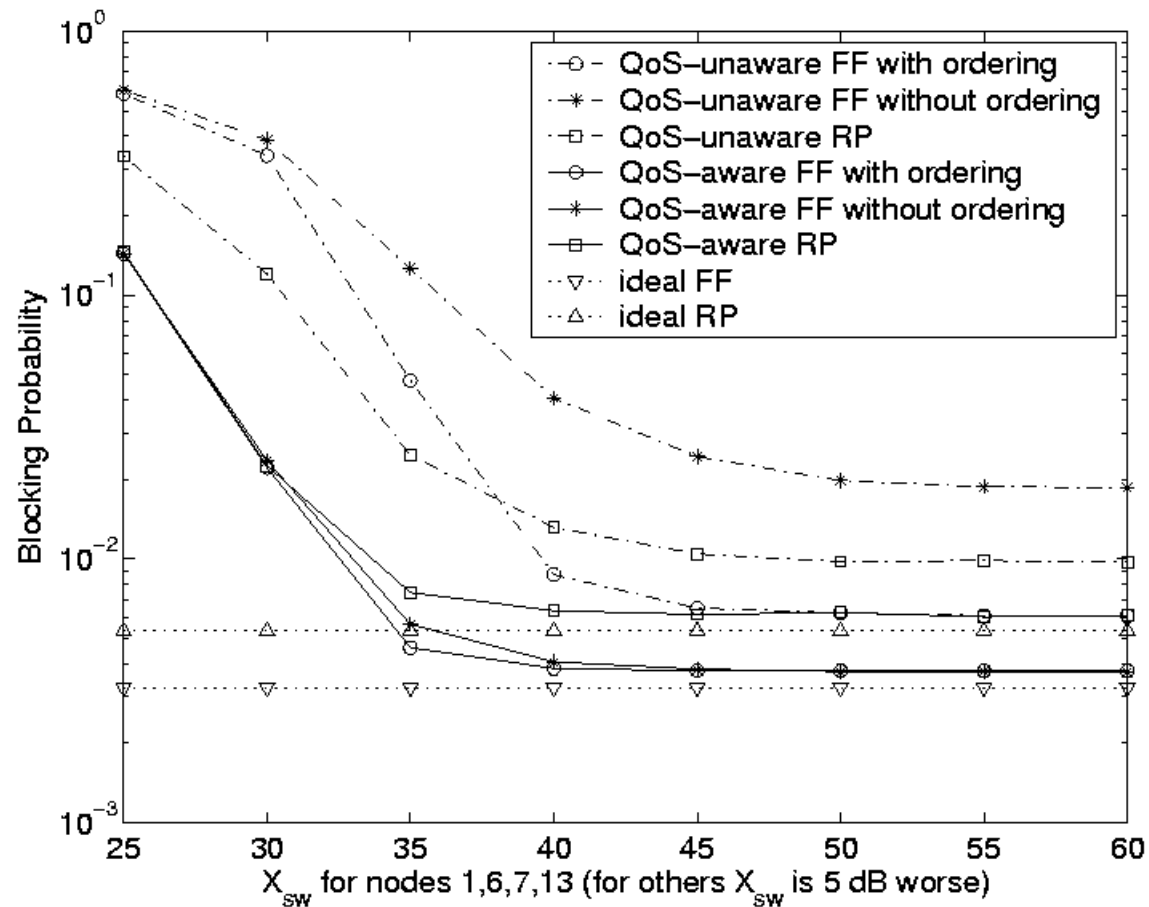
Small Perturbation Model of Crosstalk in Nonlinear Fiber



Blocking Probability – Effect of Crosstalk



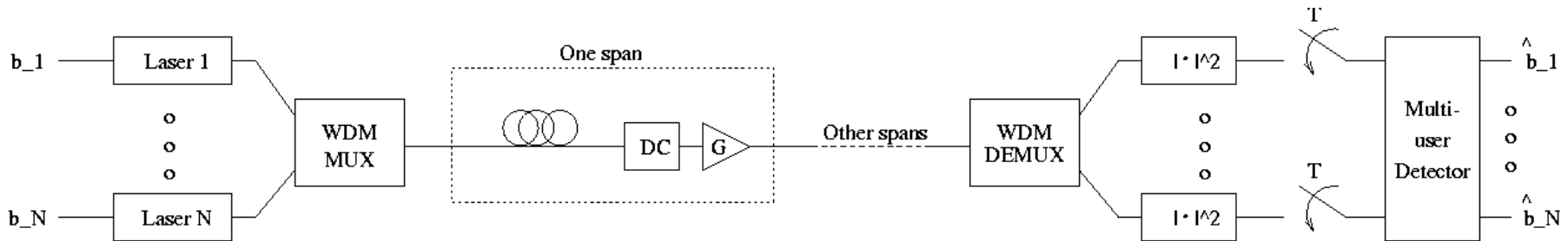
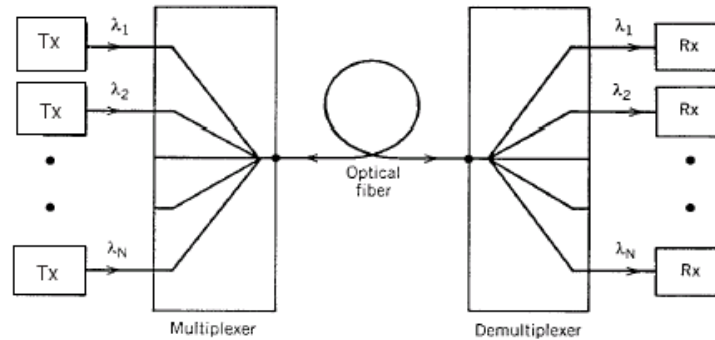
RWA to Minimize Crosstalk



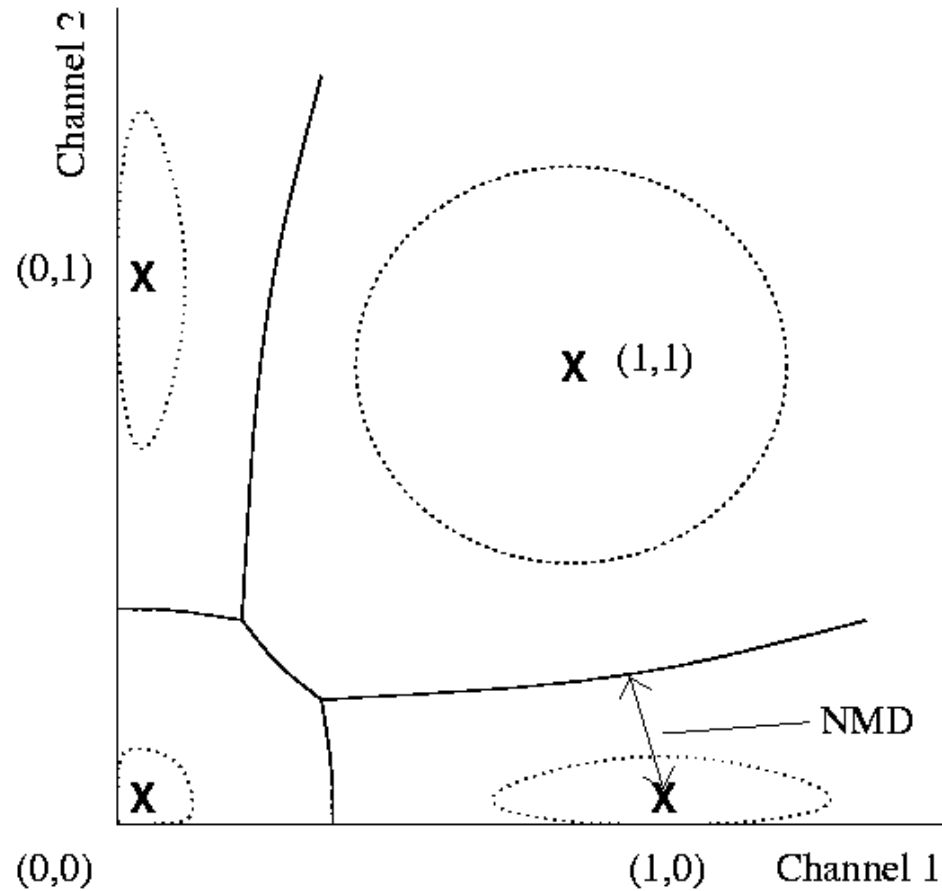
All-Optical Networks

- Signal remains optical from source to destination: no O/E – E/O conversion
- Uses all-optical switches for routing
- Issues:
 - As signals pack in wavelength space, get crosstalk
 - As signals travel longer, problem worsens
- Two solutions proposed:
 - Cross-layer routing and wavelength assignment
 - Multichannel processing

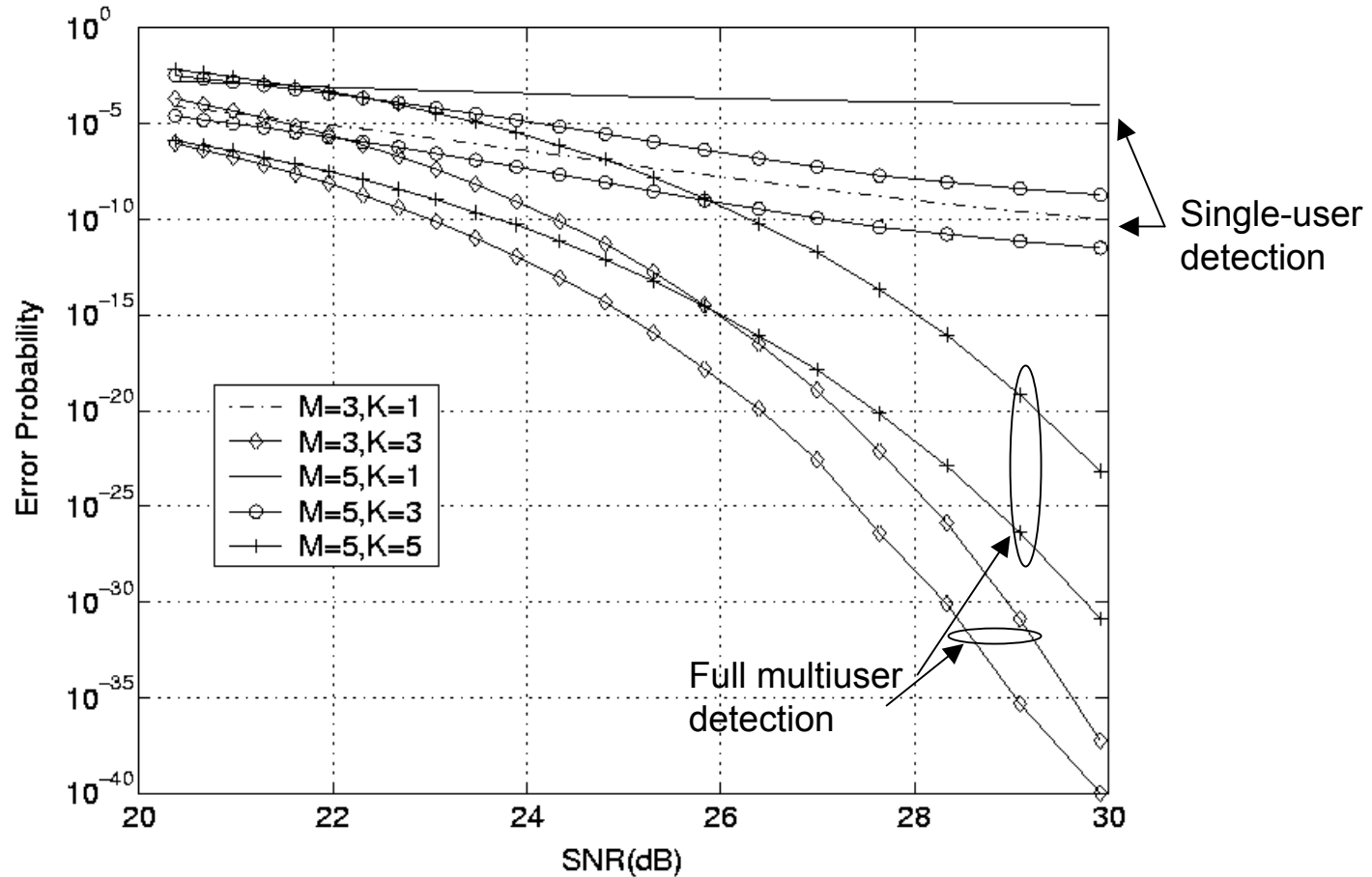
Single-channel vs. Multichannel Processing



2-Channel Signal Constellation



Multuser Detection for Long-haul Fiber WDM Systems



Conclusions and Ongoing Work

- More data, longer distances, more nodes:
 - Proper design and processing can really help
 - Solutions are cross-layer
- Next step:
 - Network capacity for optical systems: what are the fundamental limits?
 - Holistic system design: how close can we really get to those limits?

Acknowledgements

- Research Collaborator:
 - Suresh Subramaniam (GWU)
- Past and current students:
 - Bo Xu
 - Yvan Pointurier
 - Jun He
- Funding:
 - National Science Foundation