Real-Time Power Control for Dynamic Optical Networks

Algorithms and Experimentation

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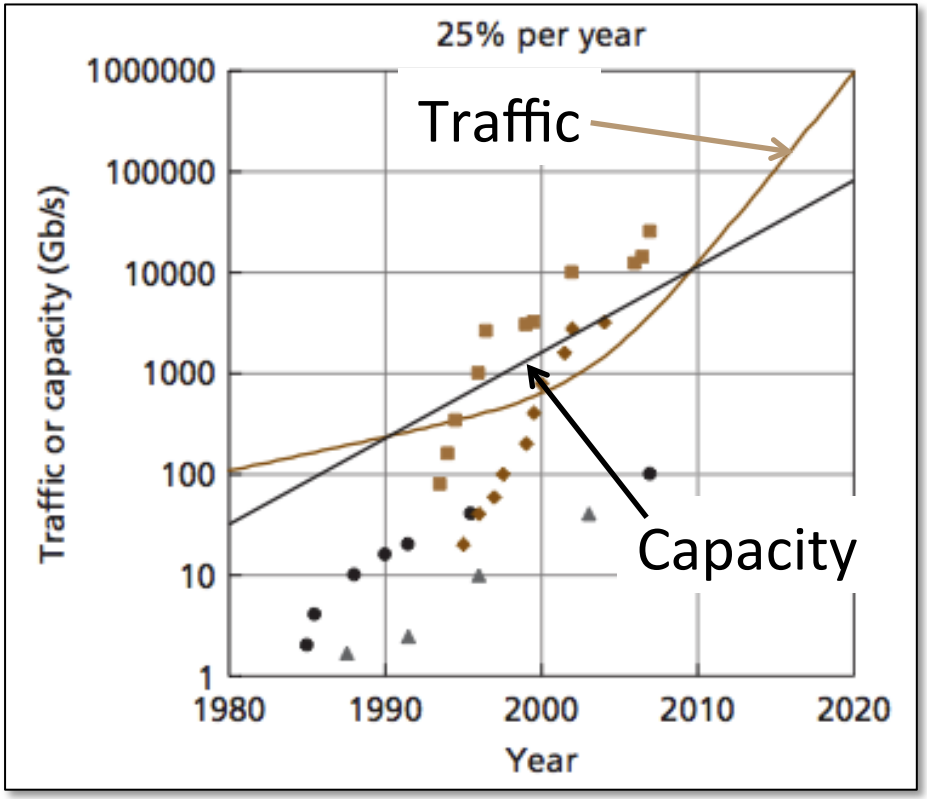
CENTER FOR INTEGRATED ACCESS NETWORKS

http://www.theverge.com/2012/11/17/3655442/restoring-verizon-service-manhattan-hurricane-sandy

Optical Transmissions

..0110101001 ..0110101001

- High capacity
- Low energy
- Error-free



Source: Tkach, 2010

Optical Transmissions

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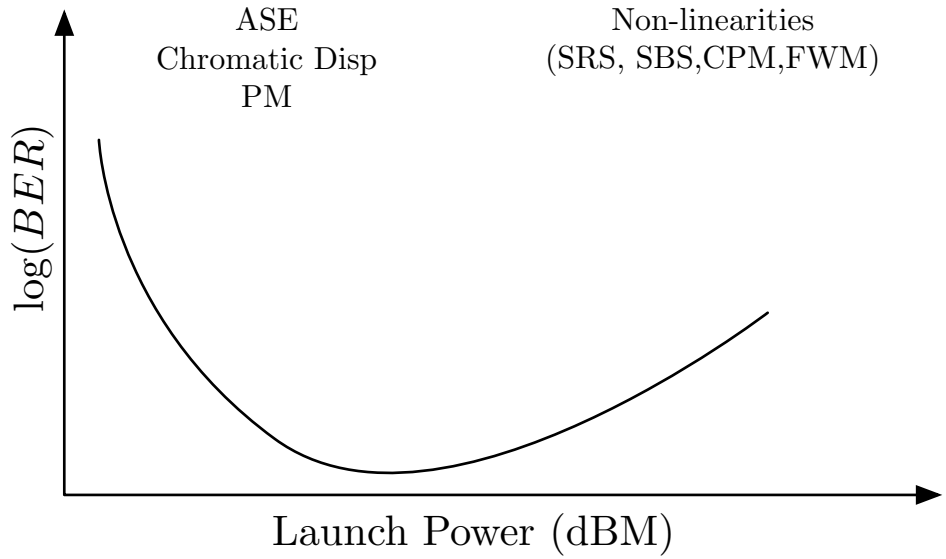
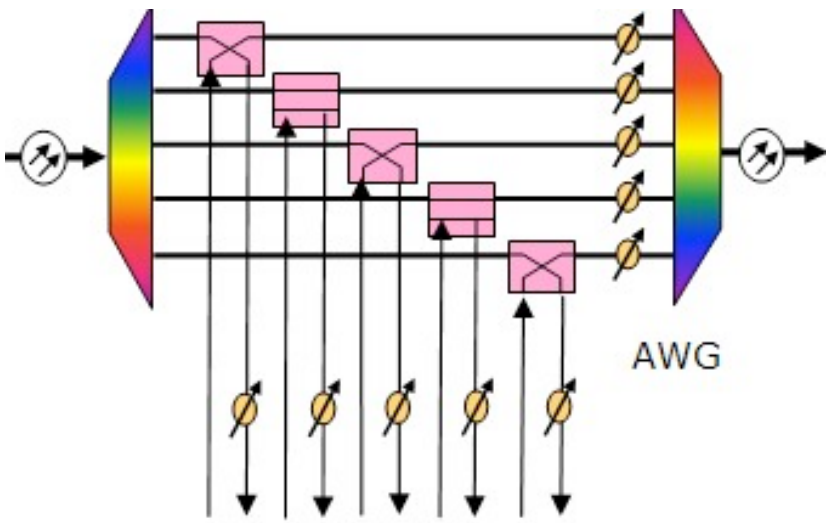
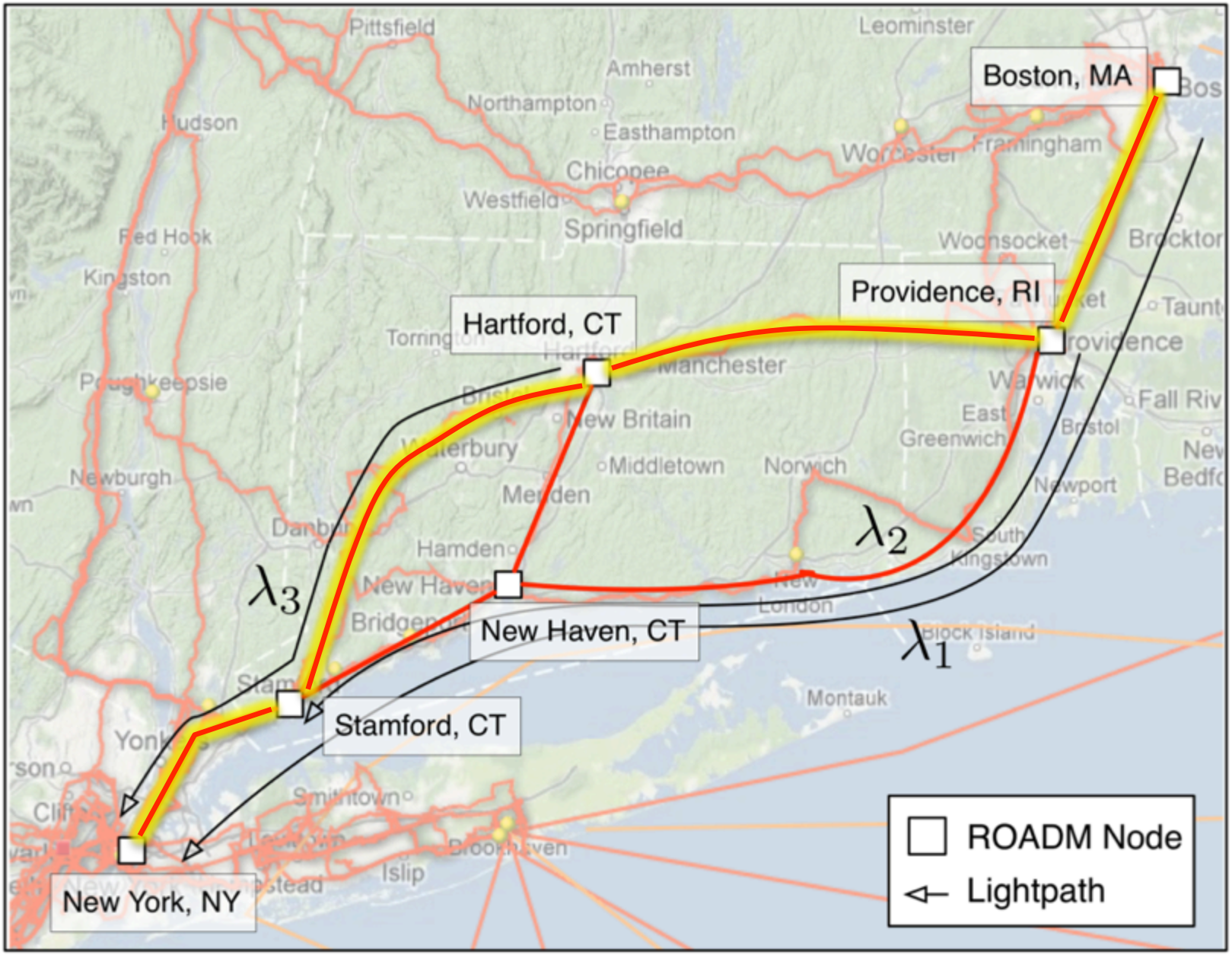


Optical resources should be used more efficiently

Dynamic Optical Networks

- Optical devices are becoming dynamic
  - ROADMs, modulators, tunable lasers, and filters
- Modern networks are static
  - Overprovisioned, manual configured, fragile




Boston, MA
Providence, RI
Hartford, CT
New Haven, CT
Stamford, CT
New York, NY
λ_1
λ_2
λ_3
ROADM Node
Lightpath
Pittsfield
Leominster
Amherst
Northampton
Easthampton
Chicopee
Westfield
Springfield
Worcester
Framingham
Woonsocket
Hudson
Red Hook
Kingston
Poughkeepsie
Newburgh
Torrington
Manchester
New Britain
Waterbury
Middletown
Meriden
Norwich
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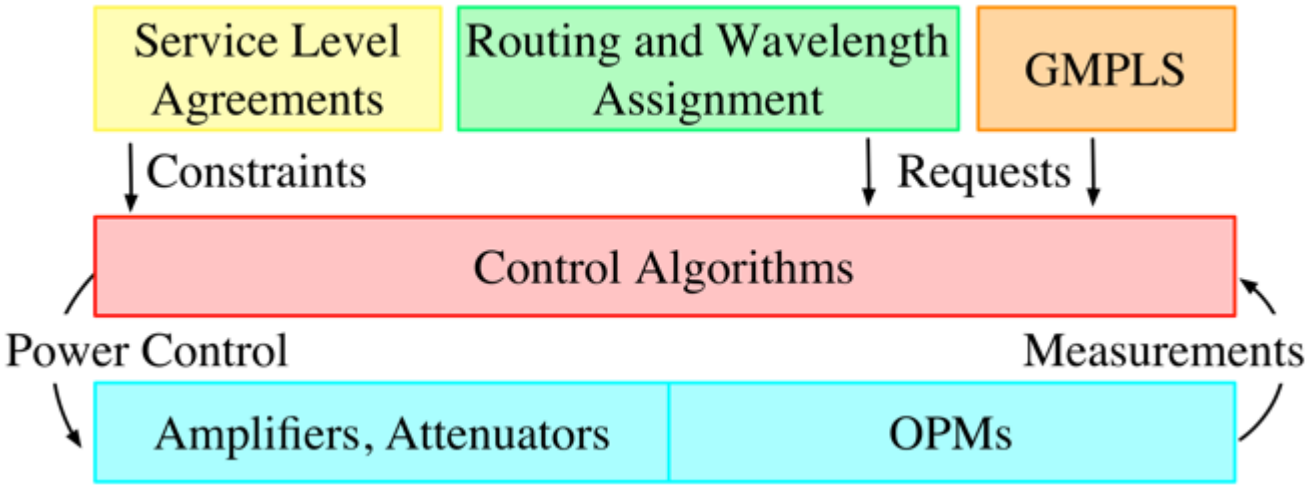
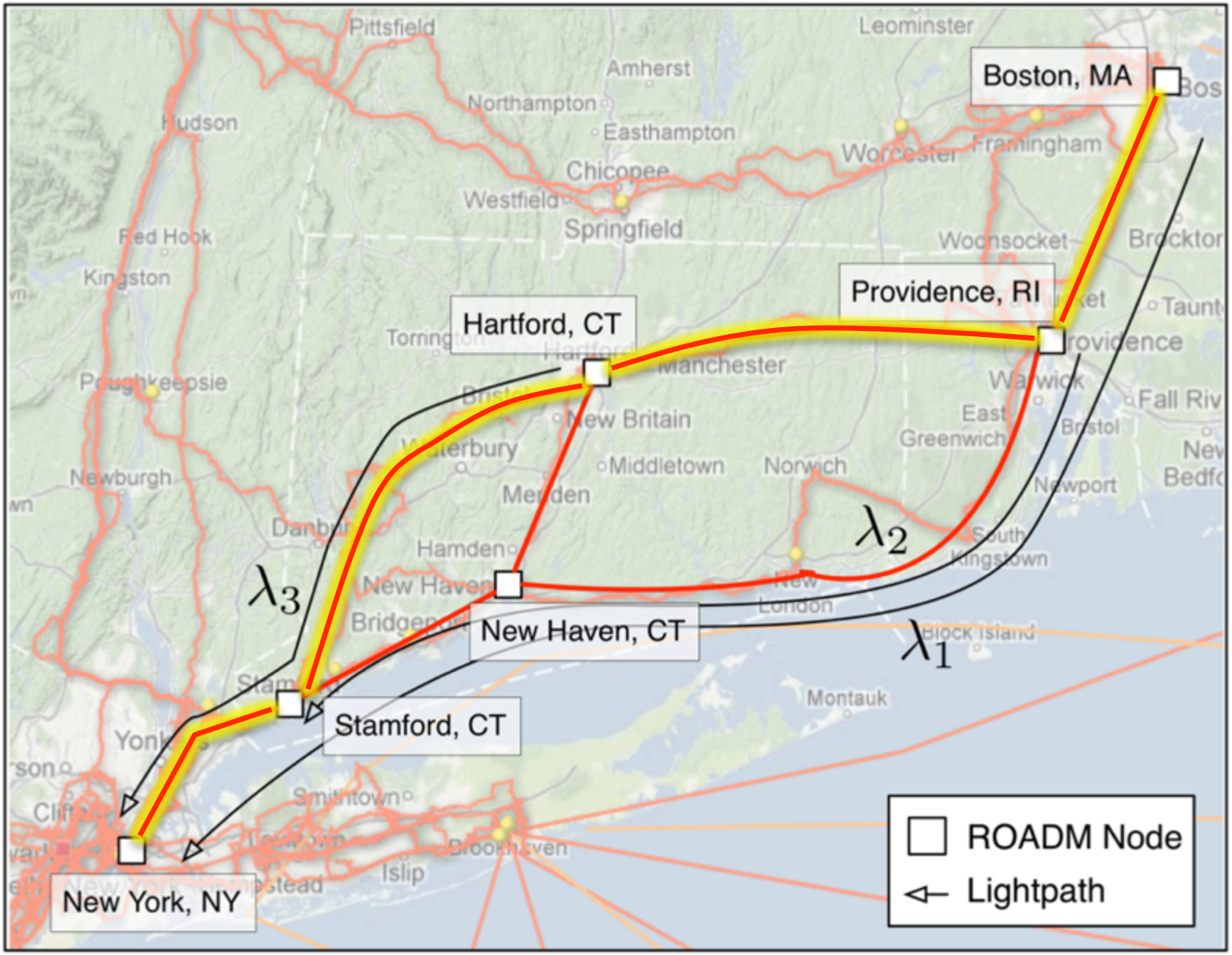
Montauk
Yonkers
Smithtown
Islip
Brookhaven
Hempstead

Dynamic Optical Networks

- Optical devices are becoming dynamic
  - ROADMs, modulators, tunable lasers and filters
- Modern networks are static
  - Manual configured, overprovisioned
- Optical Performance Monitors (OPMs) as enablers

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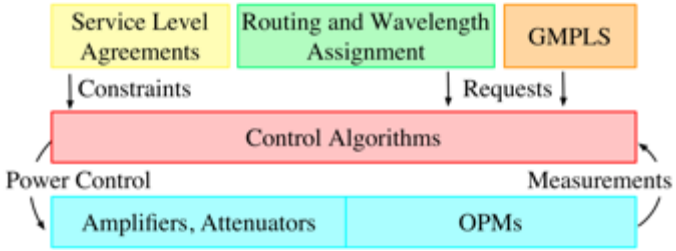
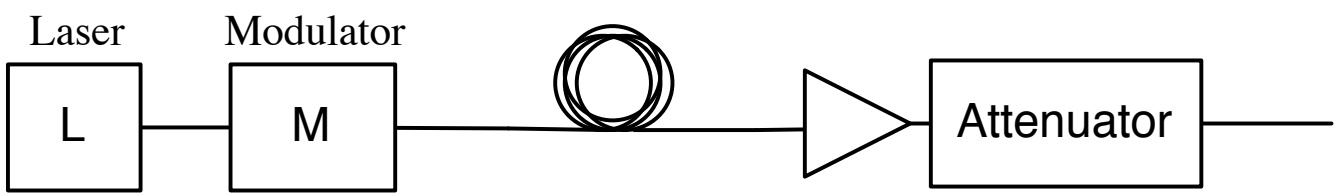
Our Contributions



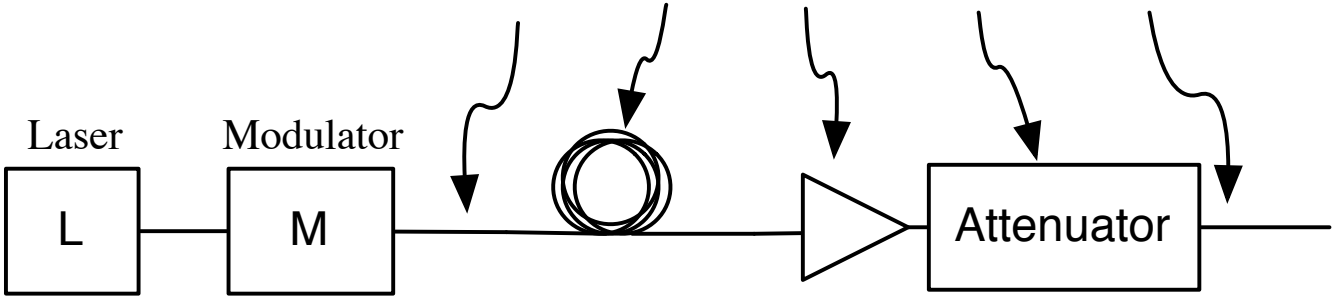
- We formulate power control problem for dynamic operation
- We develop a measurement-based algorithm
- We evaluate the performance of the algorithm using a realistic optical simulator and in an optical testbed

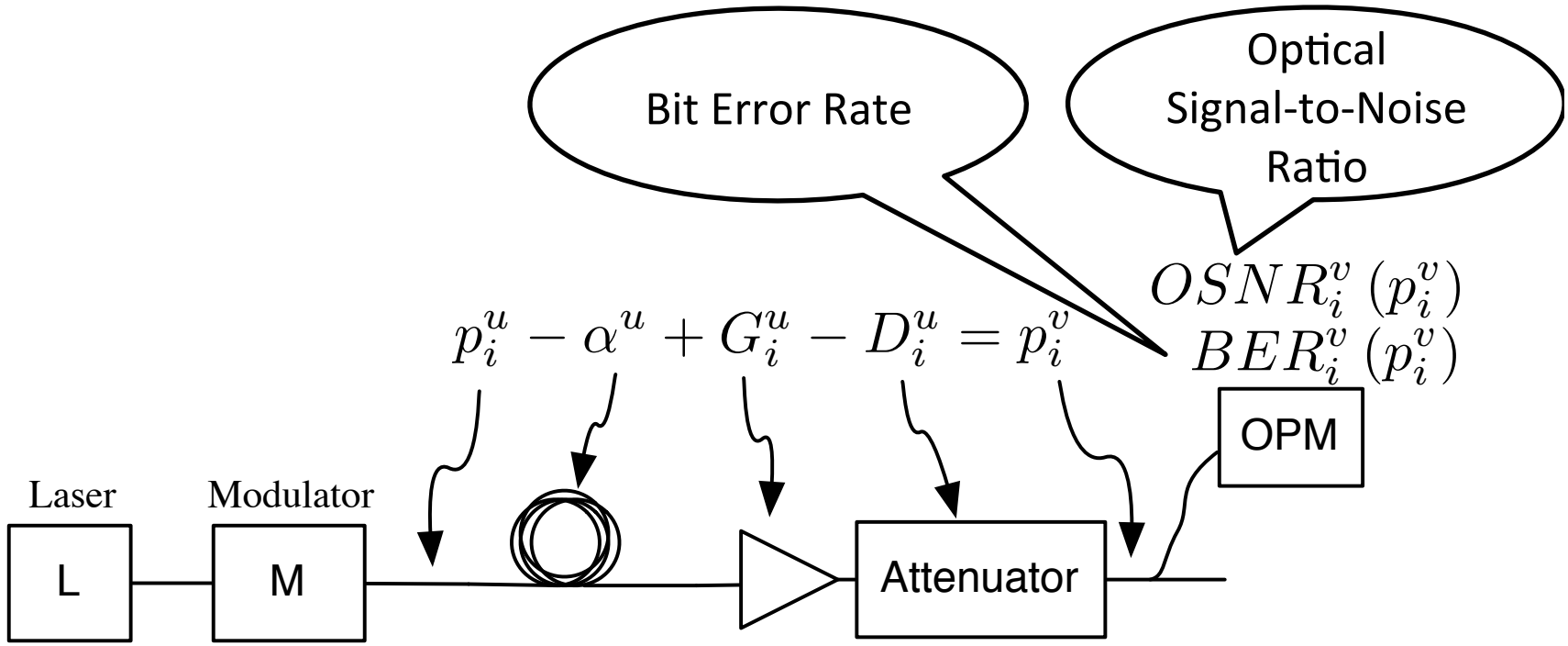
Optical Model



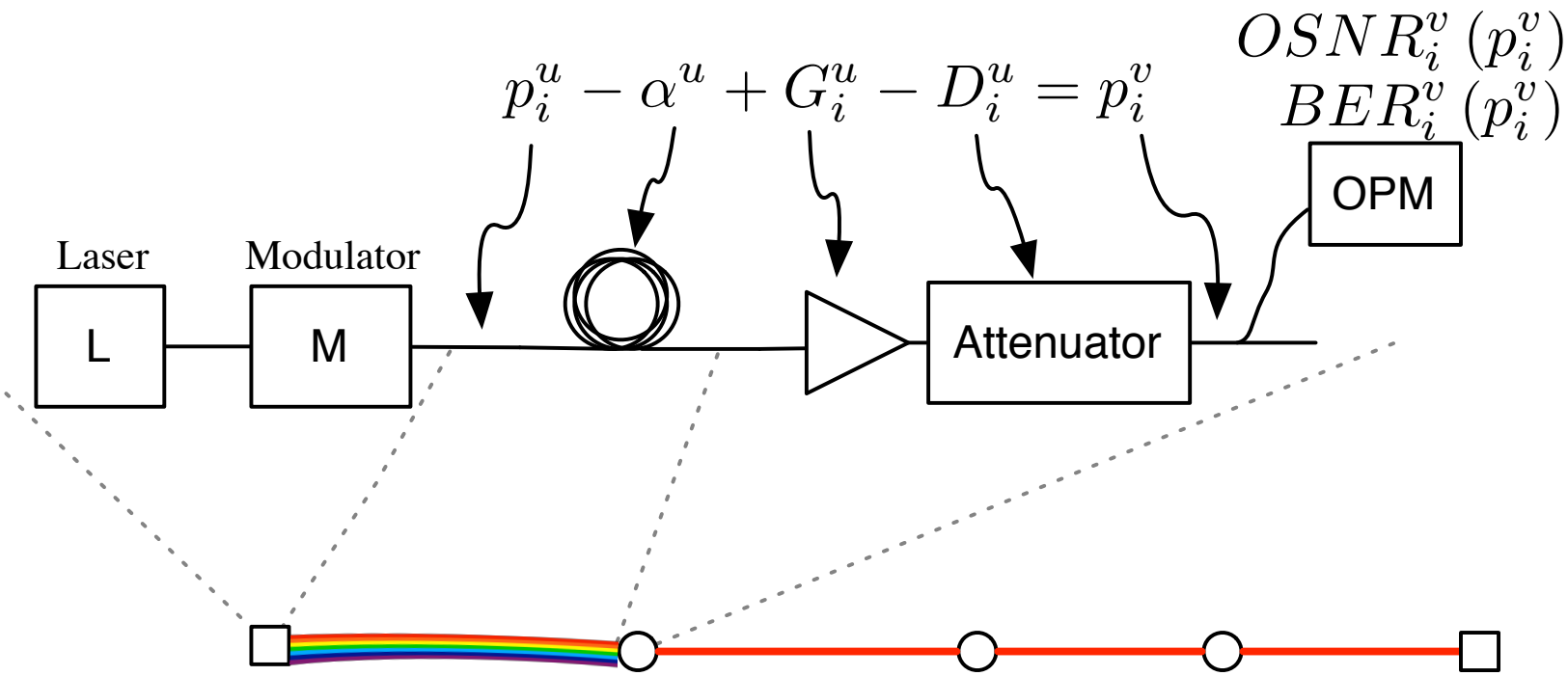
Optical Model

$$p_i^u - \alpha^u + G_i^u - D_i^u = p_i^v$$

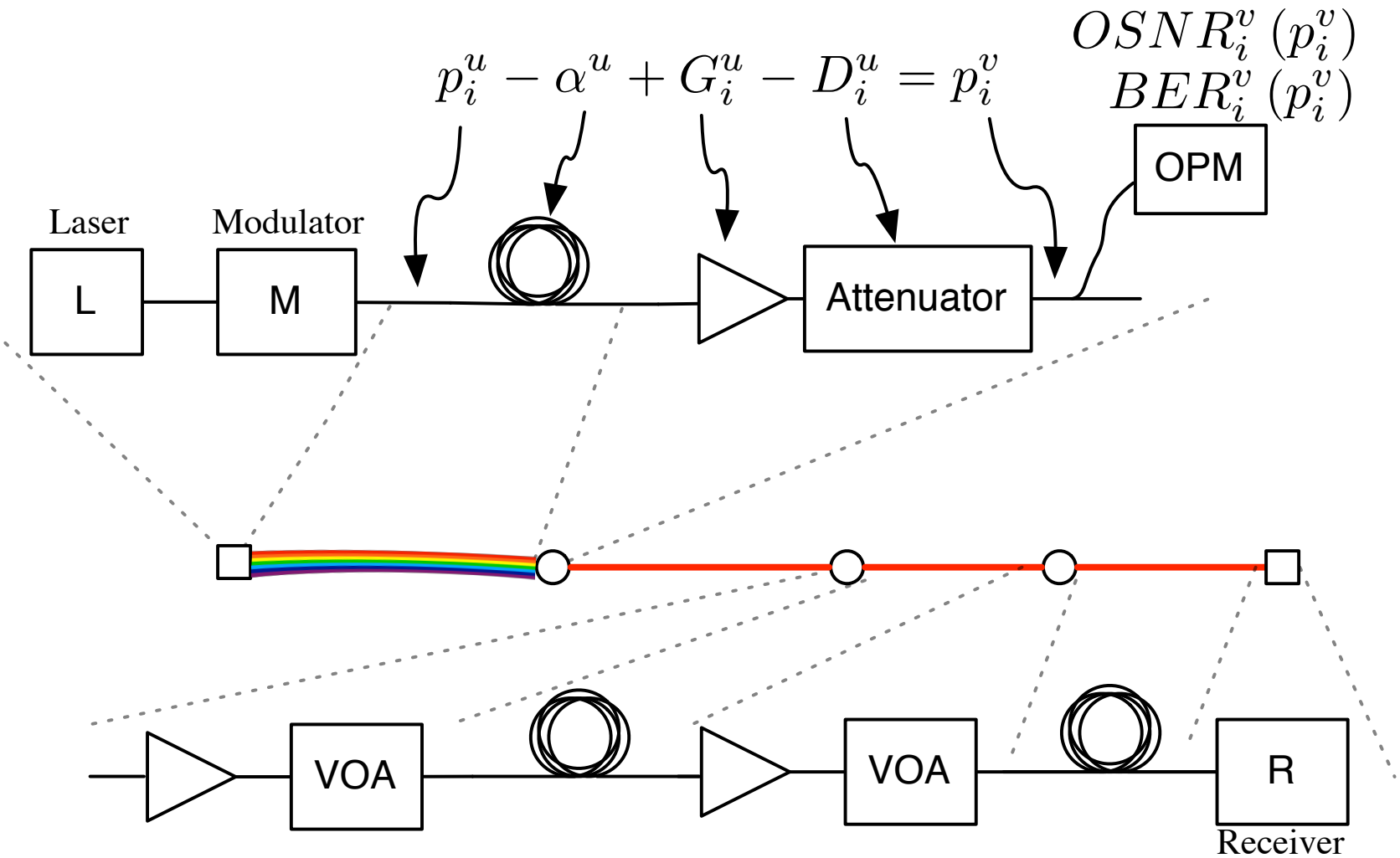



Bit Error Rate
Optical Signal-to-Noise Ratio
$OSNR_i^v(p_i^v)$
$BER_i^v(p_i^v)$
$p_i^u - \alpha^u + G_i^u - D_i^u = p_i^v$
OPM
Laser
Modulator
L
M
Attenuator

Optical Model

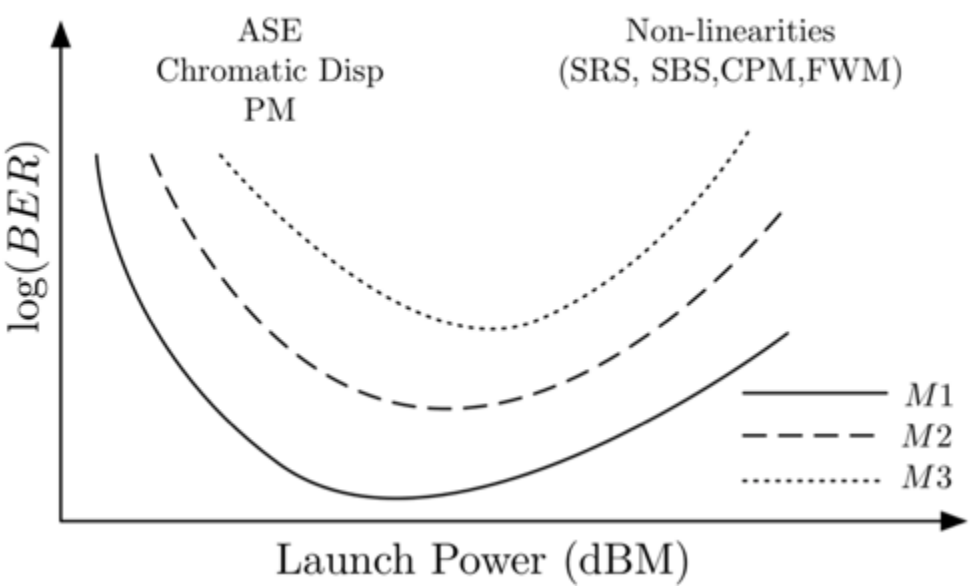


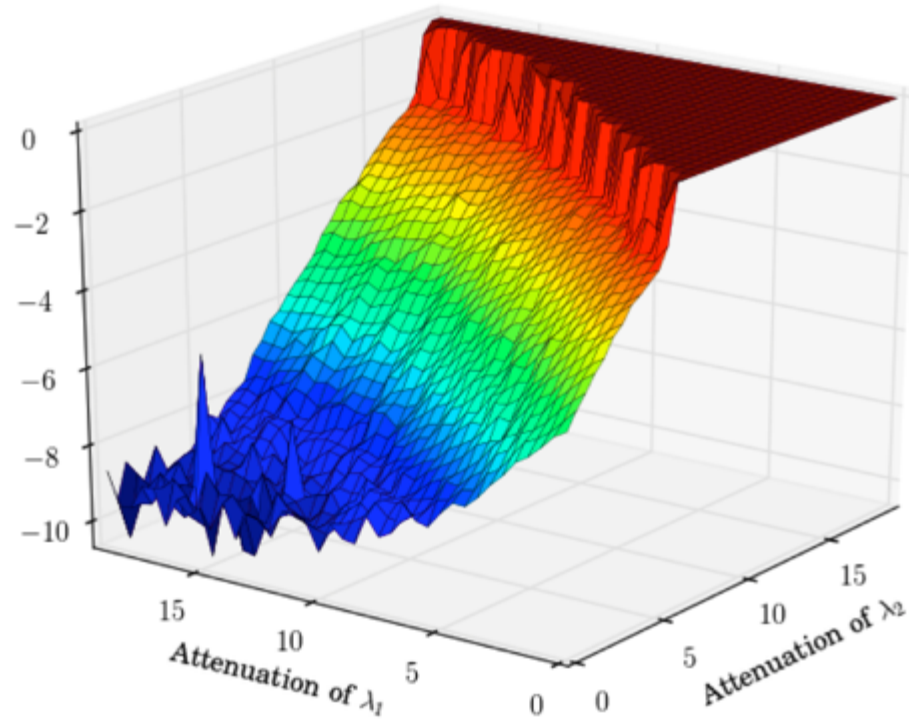
Optical Model



Performance Measurements

- Optical Performance Monitors (OPMs) provide OSNR, BER functions $\mathrm{OSNR}(p_i^v), \mathrm{BER}(p_i^v)$
- Convex functions

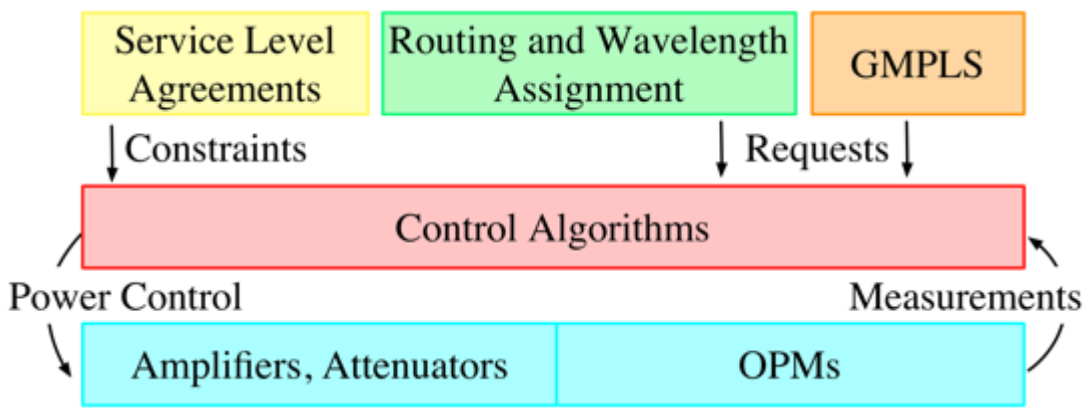




Problem Formulation

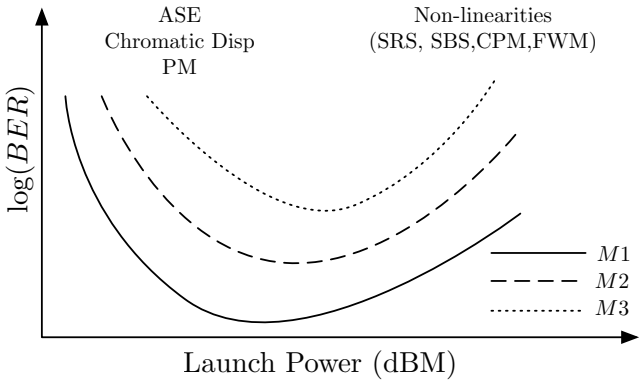
$$\underset{\mathbf{p},D}{\text{minimize}} \; h_{\text{MLO}}(\mathbf{p}, D) = \sum_{(u,\lambda_i)} (p_i^u - D_i^u)$$

$$\begin{aligned}
\text{subject to} \; & \text{BER}_i^u(\mathbf{p}) \leq \overline{\text{BER}_i^u}, \quad \forall (u, \lambda_i) \in \Lambda_{\text{BER}} \\
& \text{OSNR}_i^u(\mathbf{p}) \geq \overline{\text{OSNR}_i^u}, \quad \forall (u, \lambda_i) \in \Lambda_{\text{OSNR}} \\
& 0 \leq \mathbf{p} \leq \text{SAF},
\end{aligned}$$

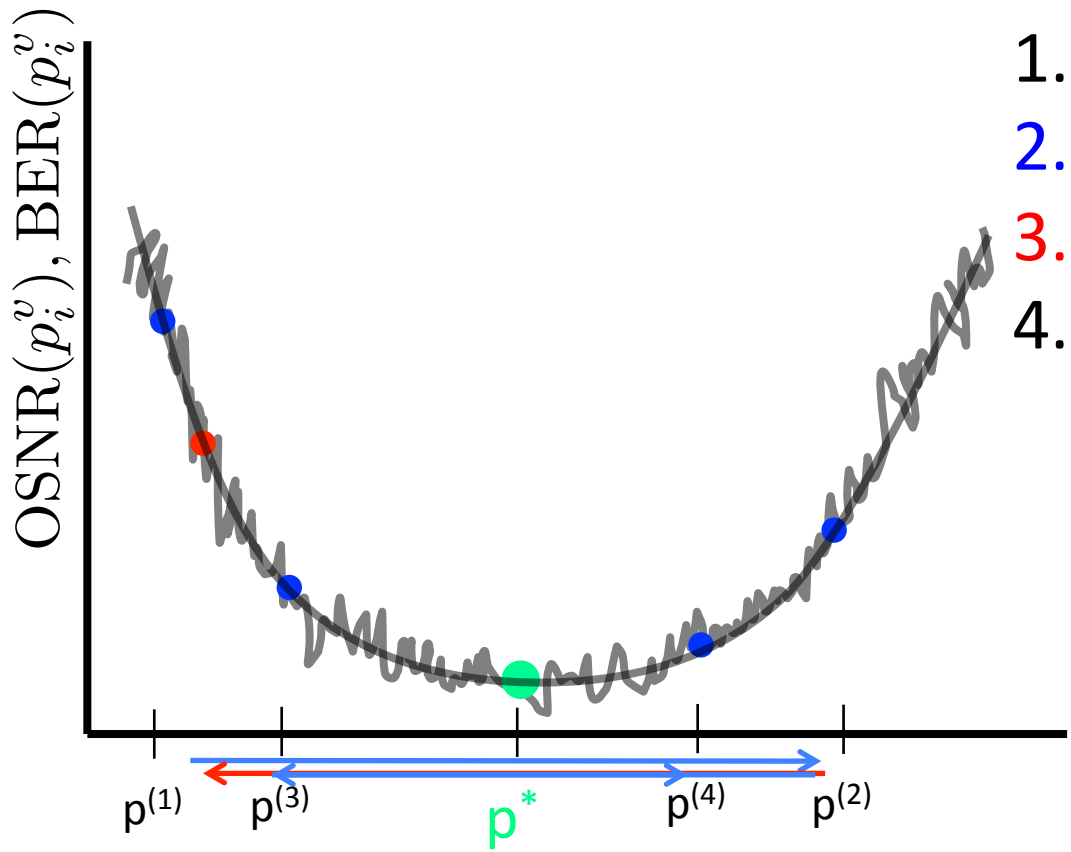


Algorithm (*SiMPLE*)

- Simultaneous Multi-Path Lambda Enhancement (*SiMPLE*)
- Convex solver
- Unique requirements
  - Runs on live optical network
  - SLA requirements are more important than optimality
  - Functions and derivatives are not known
  - Runs continuously
- Propose algorithm based on direct-search method



Algorithm (*SiMPLE*)



1. Pick a direction from D_k
2. Increase step size by θ^+
3. Decrease step size by θ^-
4. Repeat until step size reaches threshold

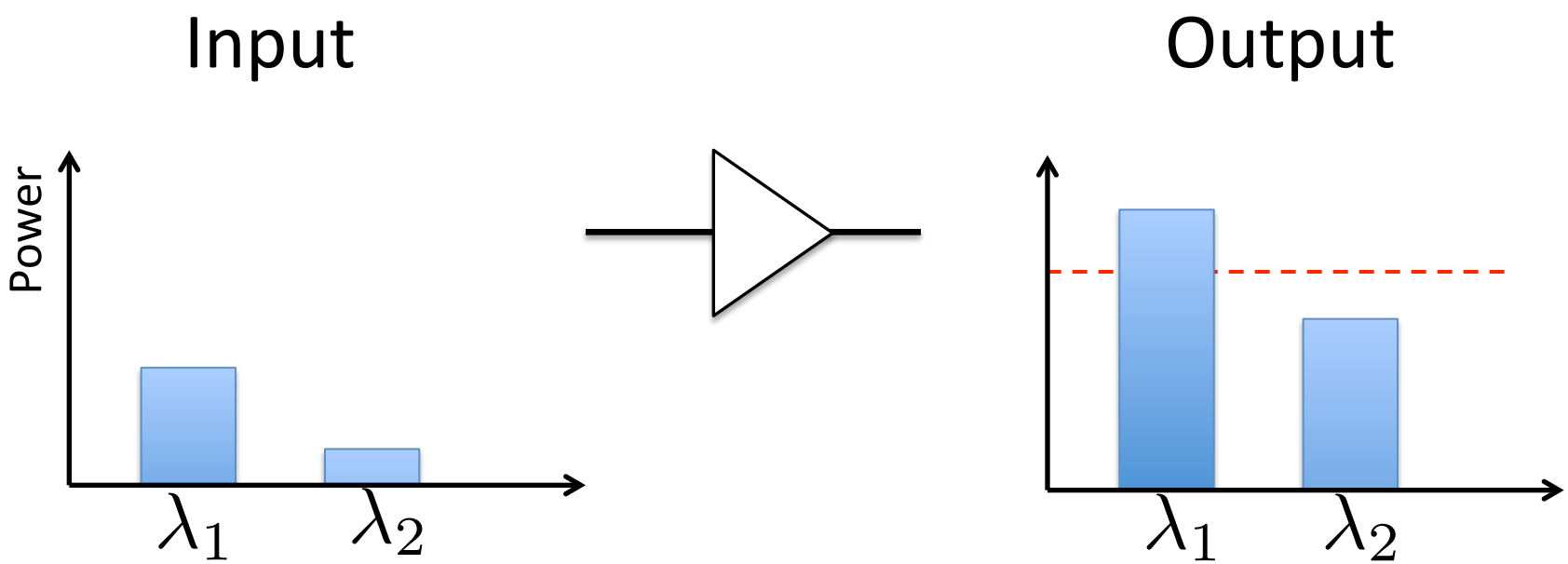
<u>Parameters</u>

(θ^-, θ^+)

<u>Direction heuristics</u>

D_k (H1-H3)

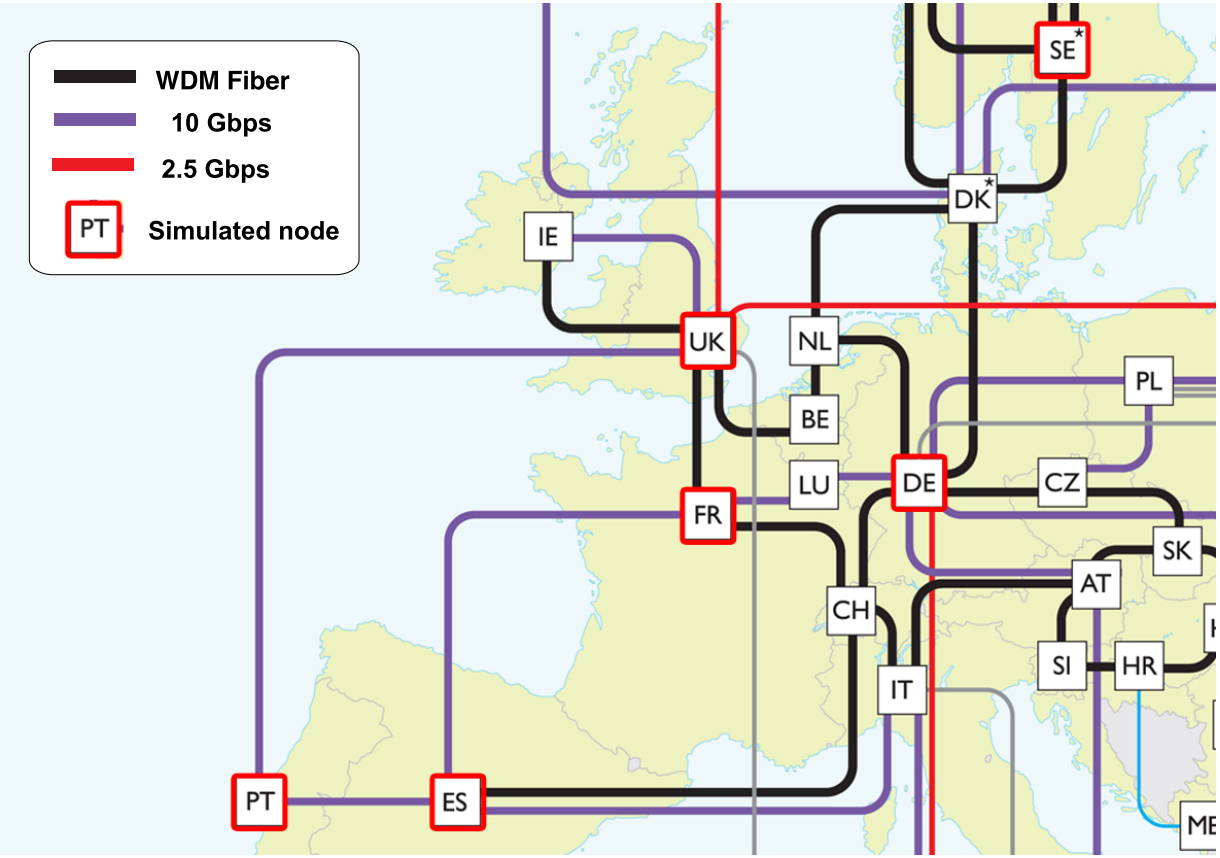
Gain Stealing Impairment



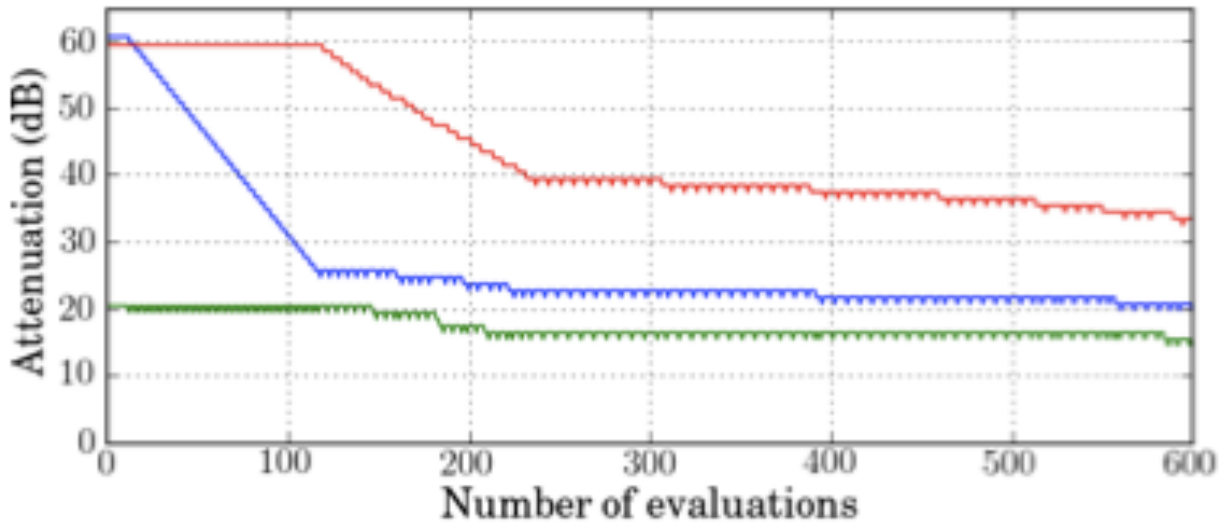
- Since the output power is constant, one wavelength steals the gain of the other

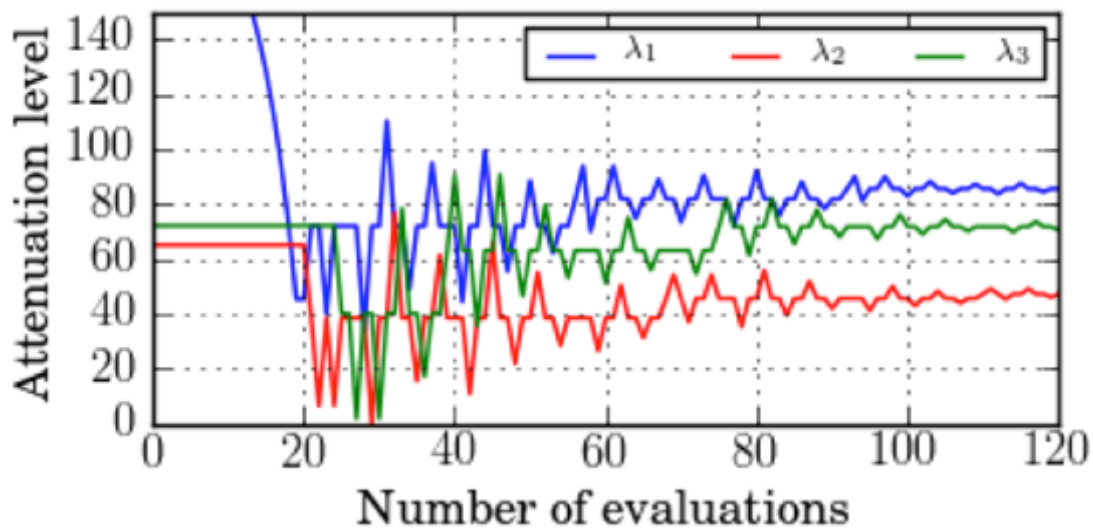
Simulation setup

- Network-level Optical Simulator
  - Géant topology



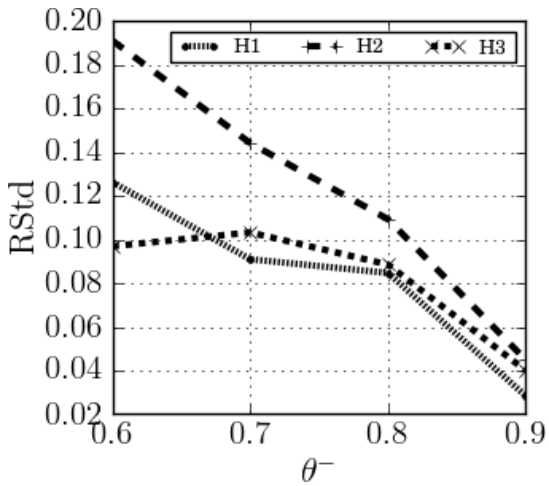
Sample Simulation Results

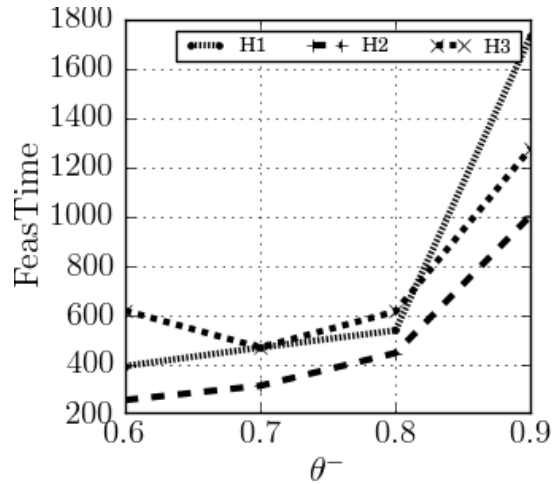




Effect of Parameters

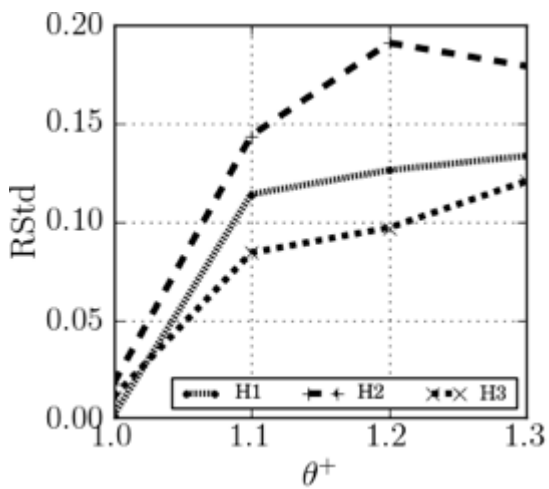
$\theta^+ = 1.2$

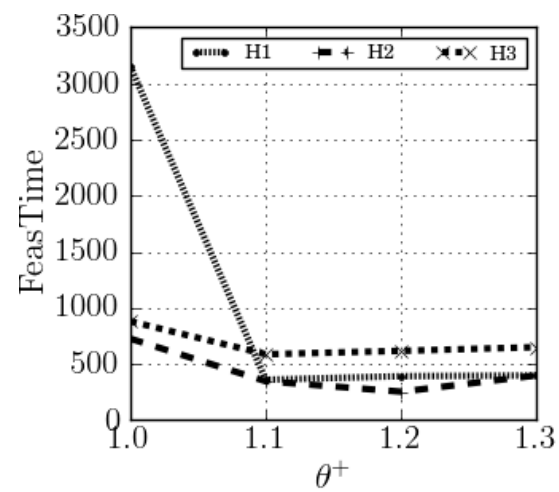




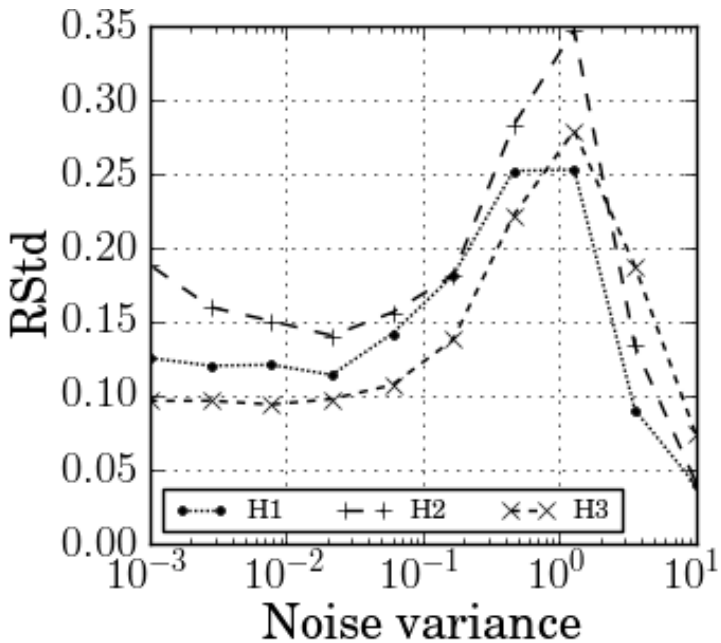
Trade-off between fluctuation and convergence speed

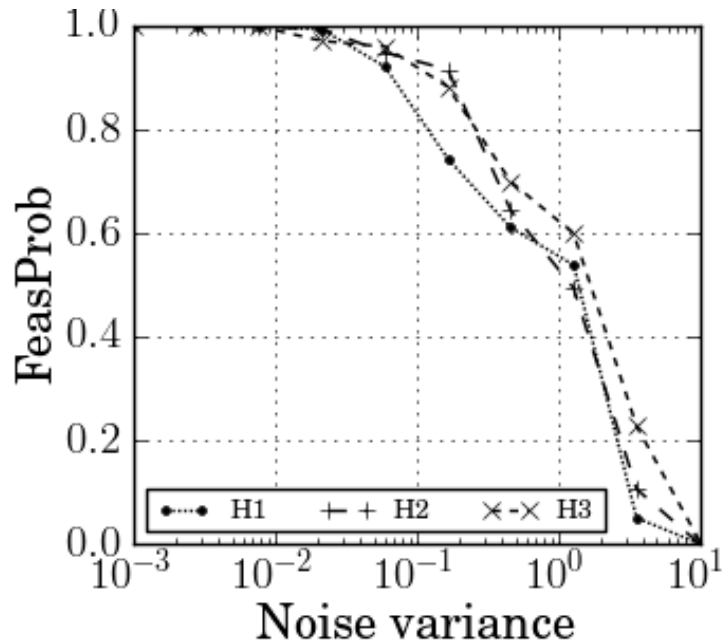
$\theta^- = 0.6$





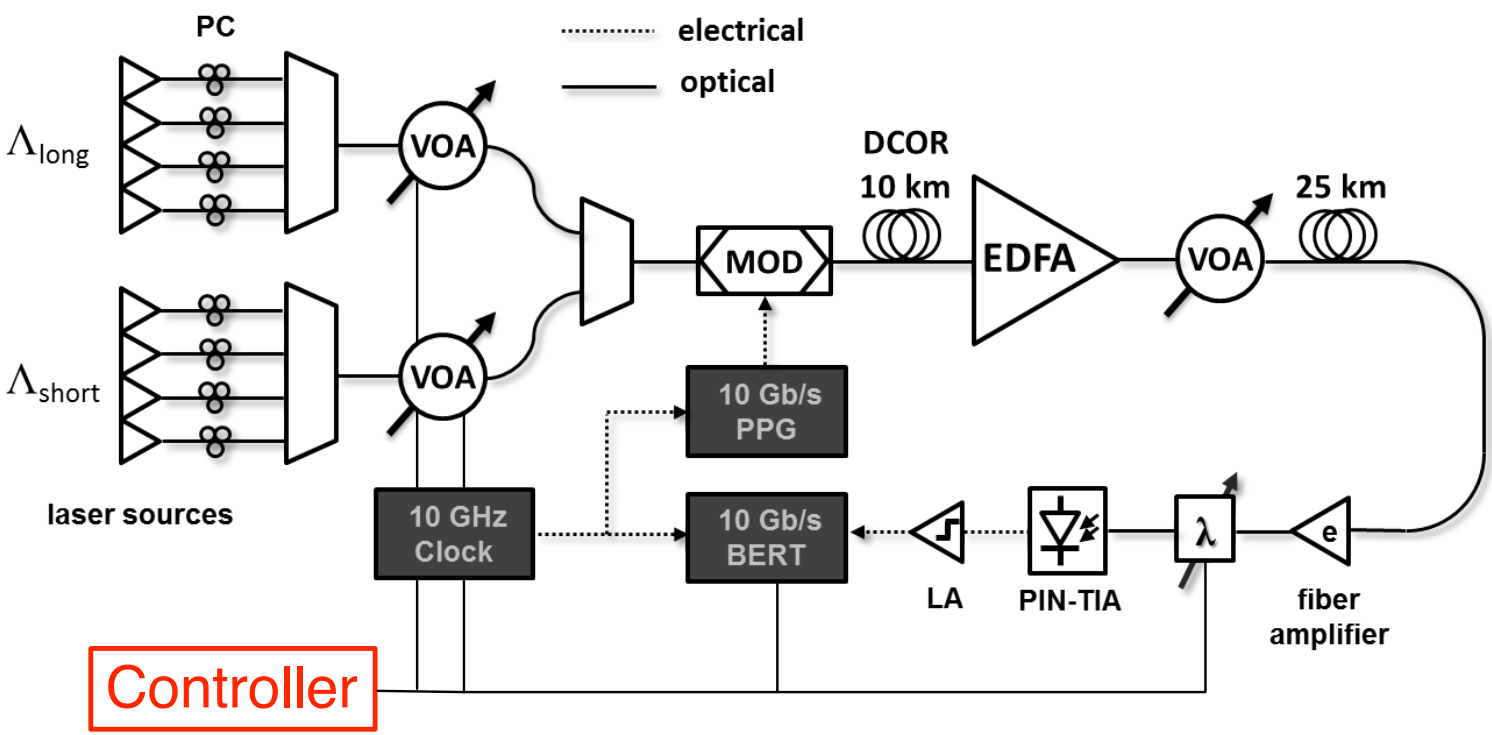
Effect of Noise



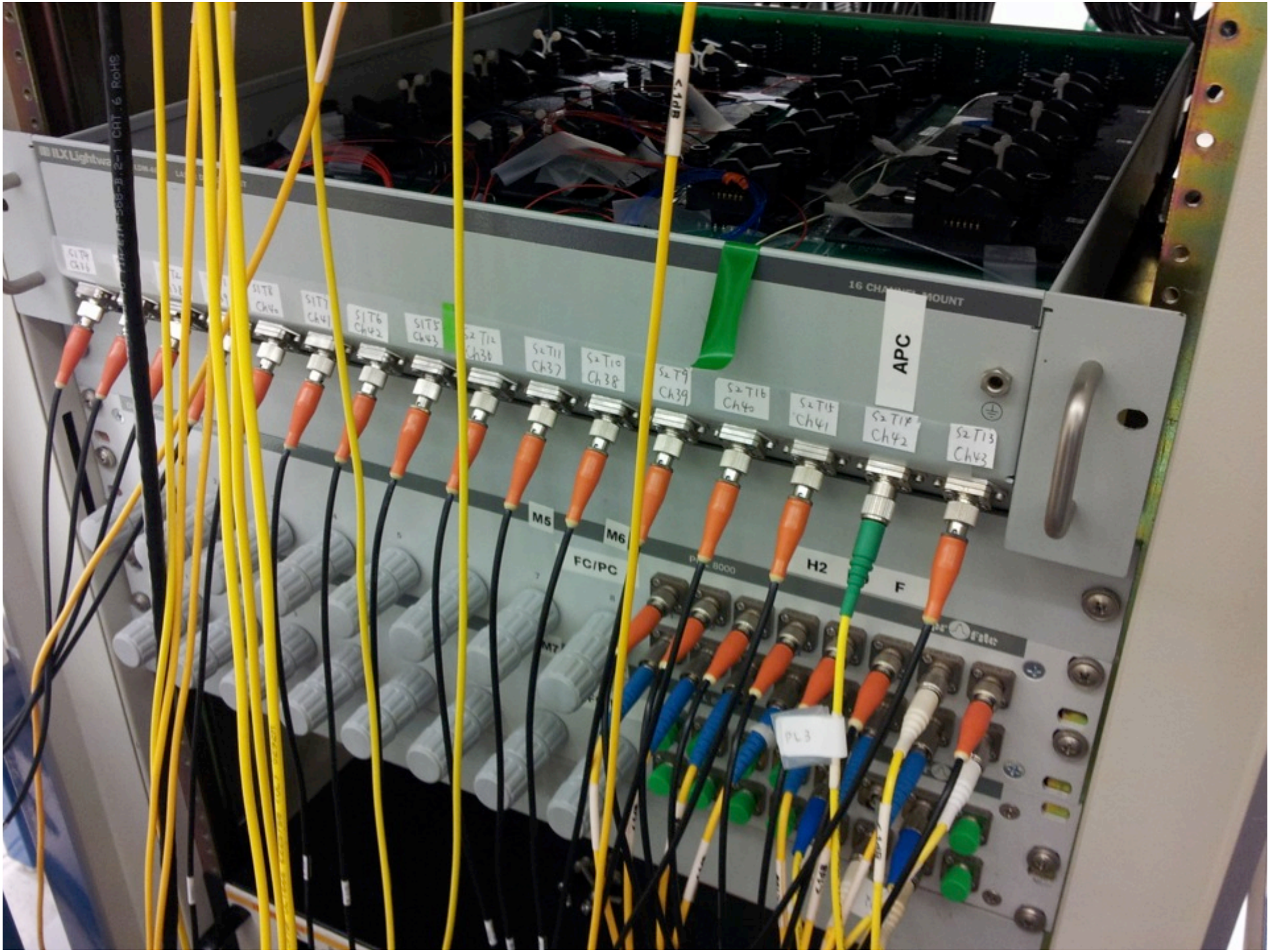


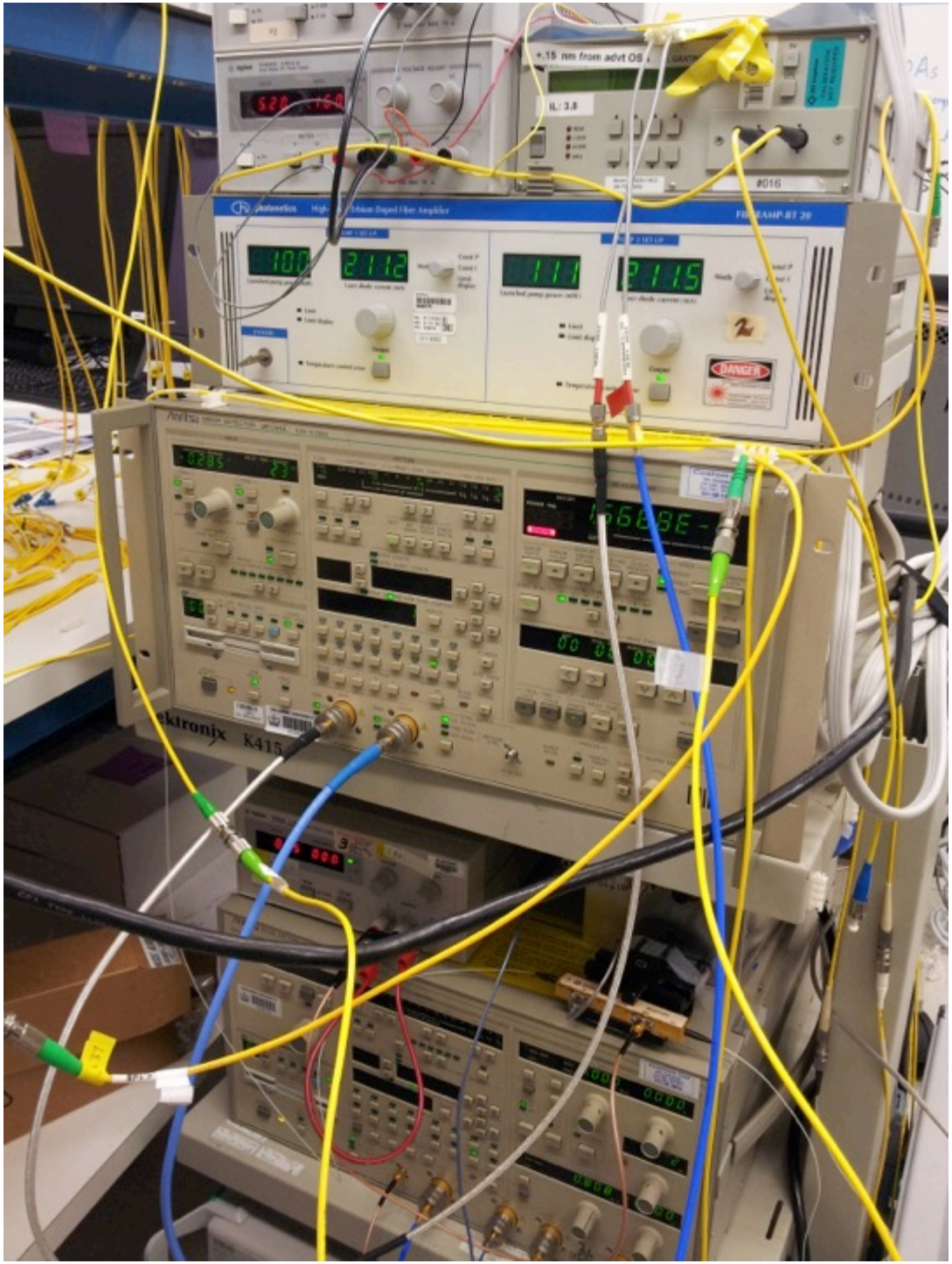
- Increasing noise value creates fluctuations
- Prevents convergence
  - Mitigated by the continuous operation

Experimental Setup

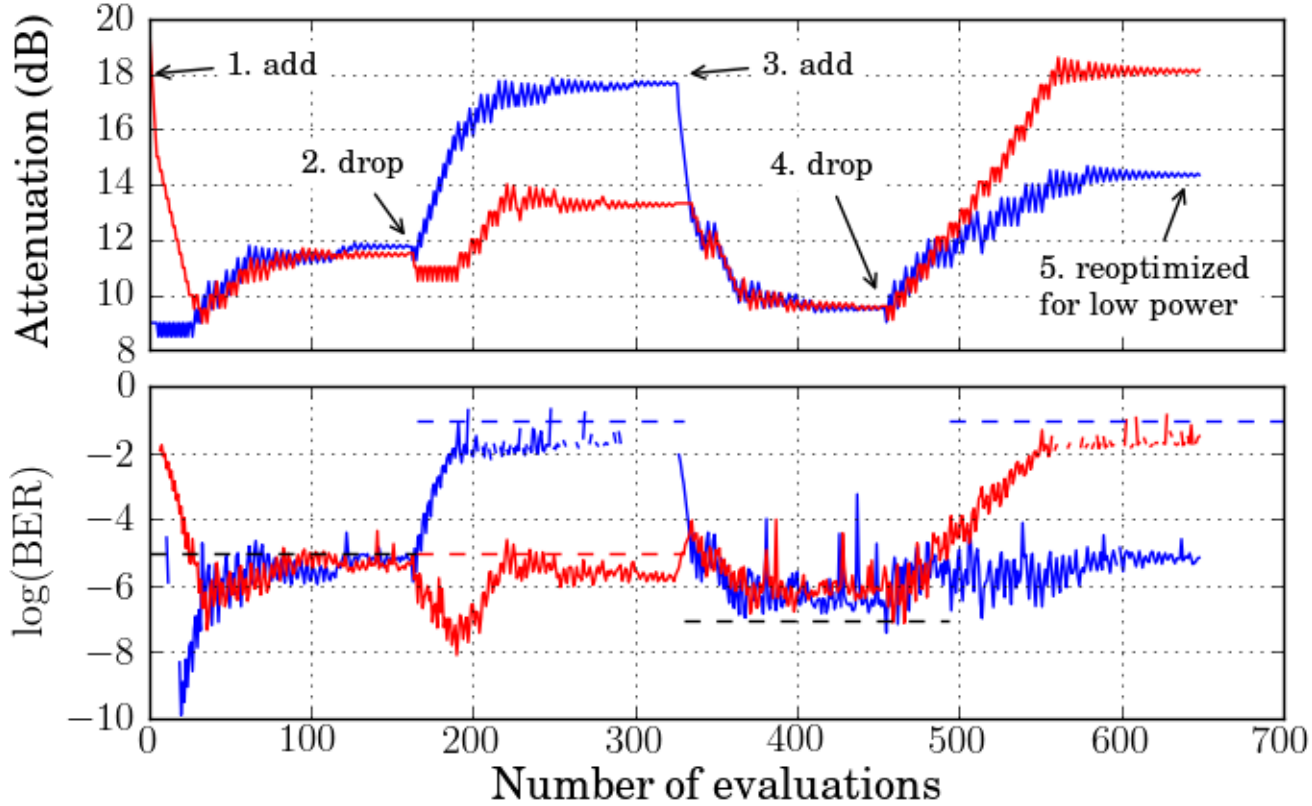


- 1-hop experiment
  - 25km fiber
  - 8 wavelengths that can be controlled in two groups
- Uses off-the-shelf telecom equipment
- Central controller manages power levels


APC
M5
M6
FC/PC
H2
F
S2T11 Ch37
S2T10 Ch38
S2T9 Ch39
S2T16 Ch40
S2T15 Ch41
S2T13 Ch43


DANGER
Tektronix K415

Experimental Results



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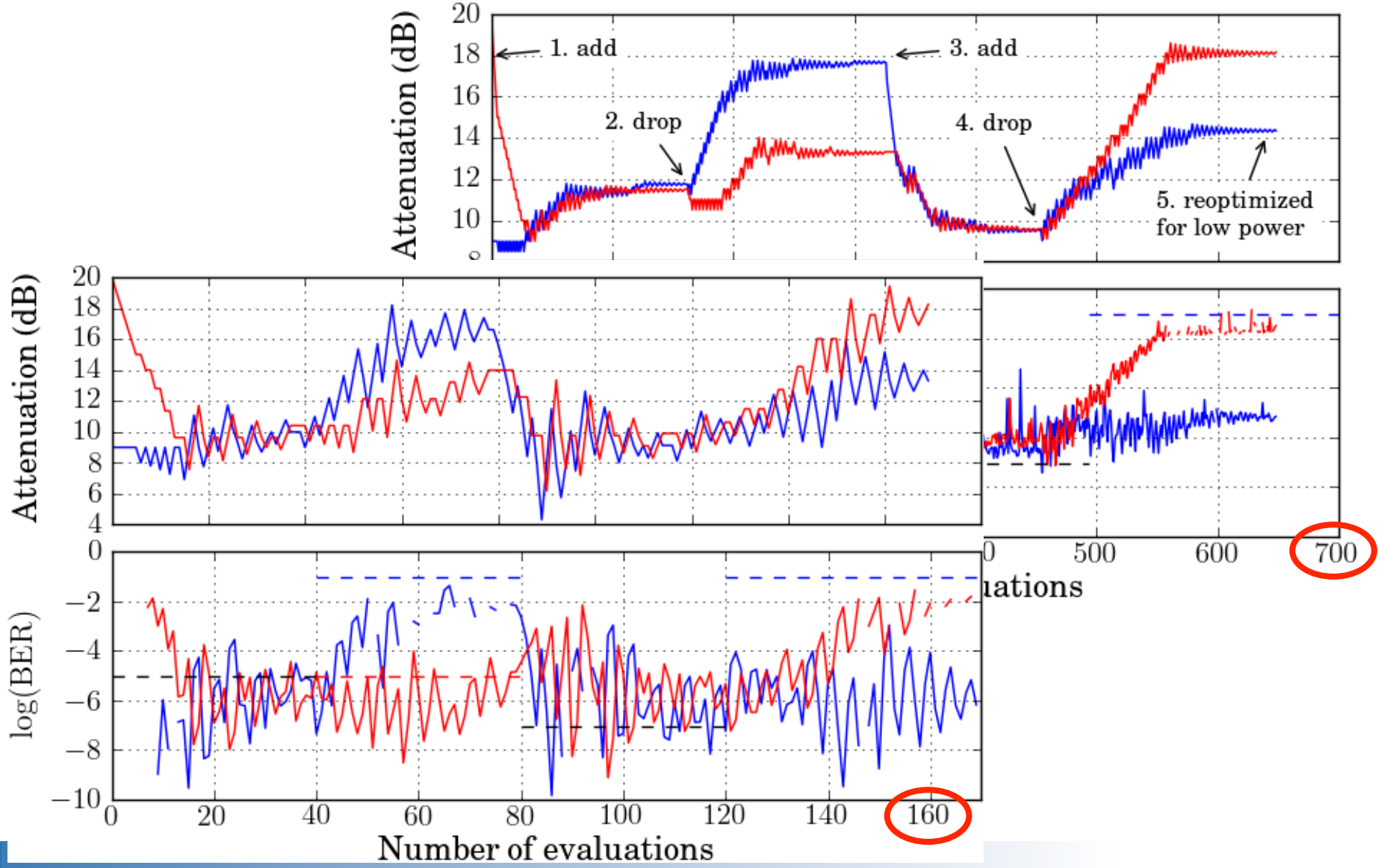
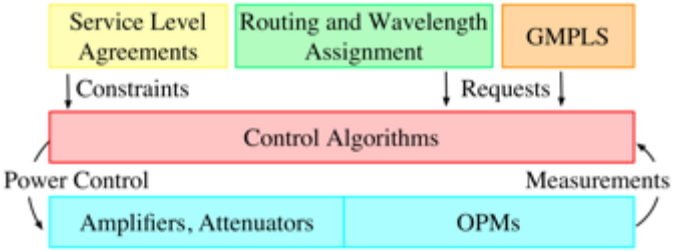


Our Contributions



- We formulate control problem for dynamic operation
- We develop a measurement-based power control algorithm
- We evaluate the performance of the algorithm using a realistic optical simulator and in an optical testbed
- First-step towards SDN for optics

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