Neural Network Based Wavelength Assignment in Optical Switching

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Aug. 21, 2017

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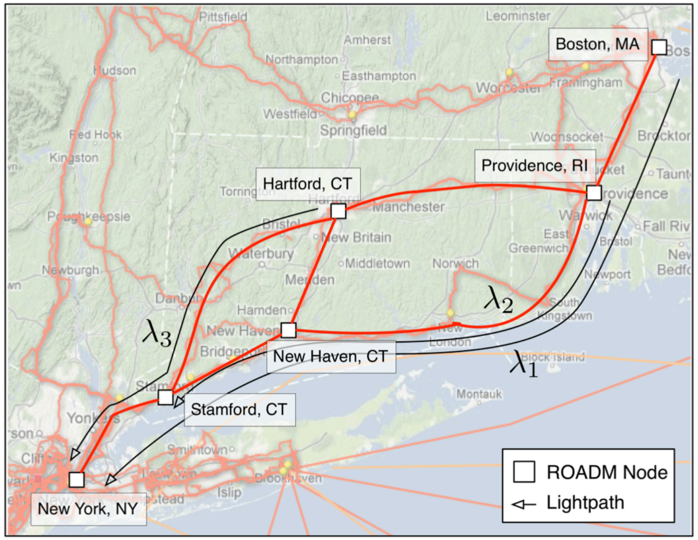
Optical Networks



- Modern networks are static, ‘set and forget’ approach
  - Overprovisioned, manual configuration
- Optical devices are capable of switching and dynamic operation
  - Wavelength selective switches, modulators, tunable lasers, and filters

Dynamic Optical Networks

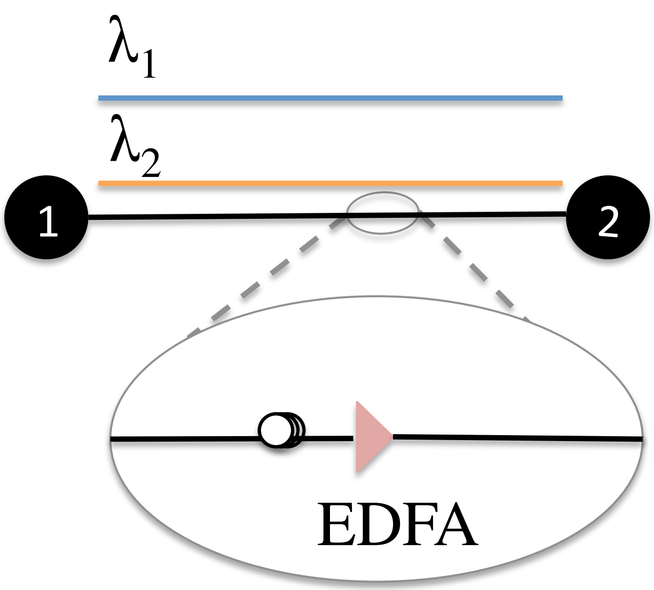
- Currently no real-time capacity management, wavelength reconfiguration and service provisioning in optical networks
  - Provision wavelength
  - Re-route/switch wavelength
- Service providers need to ensure reconfiguration will not affect service level agreement
  - Consider optical power dynamics: WDM channels are highly interactive
    - Disturbances grow in cascade, propagate through network
  - Current provisioning takes minutes to days per wavelength—cautious 'adiabatic' tuning to avoid disruptions
- Goal: Given active channel conditions, determine the placement of a new wavelength channel to minimize power excursions under real-time, rapid reconfiguration

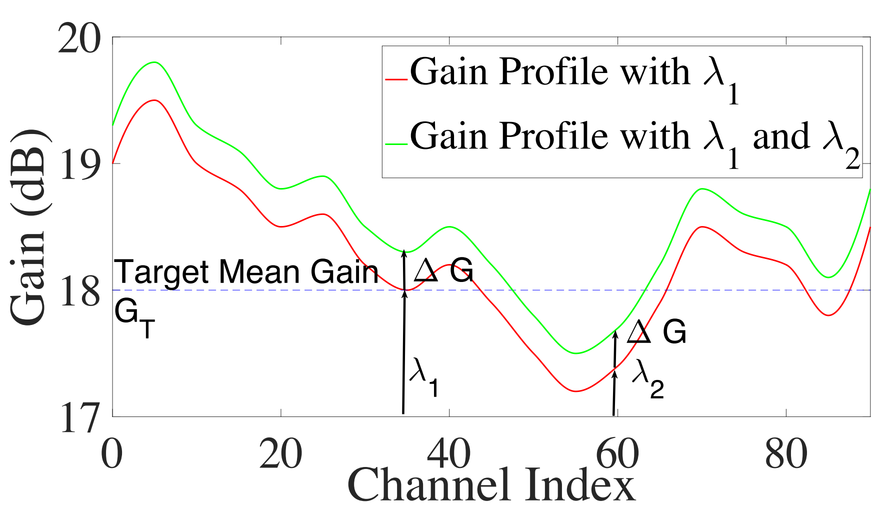
Optical Network Components

- Erbium-Doped Fiber Amplifier (EDFA): Optical **amplifier** to boost intensity of optical signal
- Reconfigurable Optical Add-Drop Multiplexer (ROADM): Allows for remotely switching traffic at wavelength layer
- Wavelength Selective Switch (WSS): Routes signals between optical fibers on a per-wavelength basis
- Variable Optic Attenuator (VOA) : Reduces power level of optical signal
- Optical Channel Monitor (OCM): Used to measure channel power

Power Excursions

- Erbium-Doped Fiber Amplifier (EDFAs)
  - Use Automatic Gain Control (AGC) to maintain constant target mean gain
  - Amplify input channel power to target gain
  - Results in deviations that perturb active channels causing **excursions**





Objective: Minimize ΔG

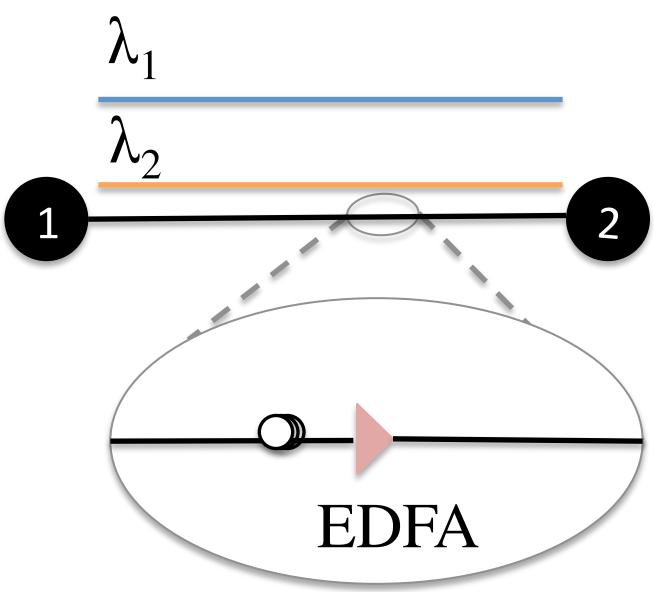
EDFA Gain Model

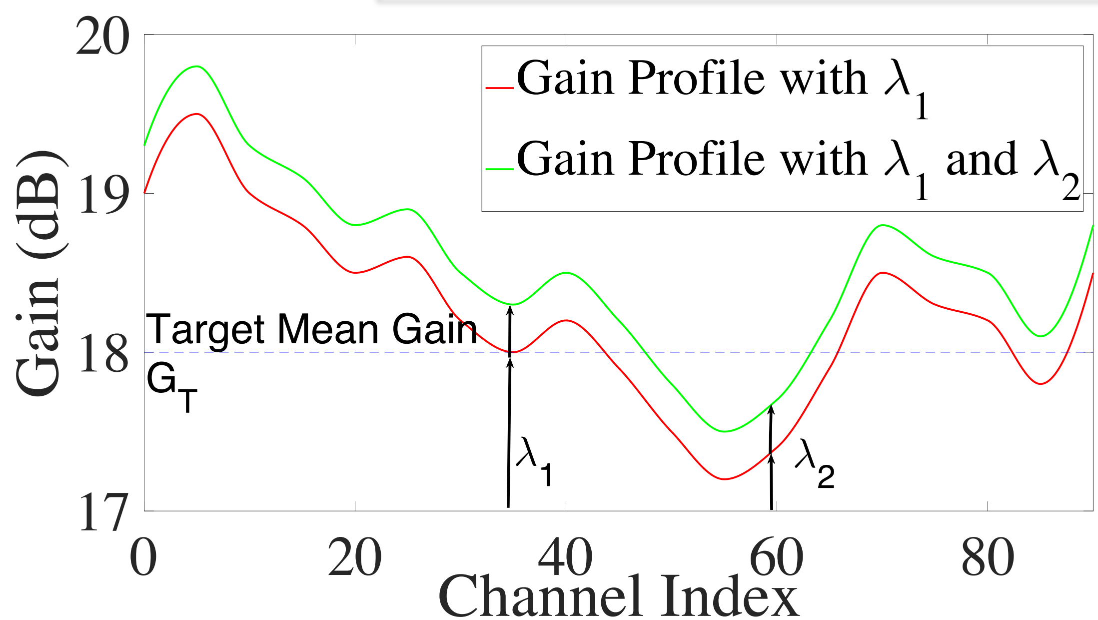
$$P_{\text{total}}^{\text{out}} = G_{\text{T}} P_{\text{total}}^{\text{in}}$$

$$P_{\text{total}}^{\text{out}} = \sum_{j=1}^{N} P_j^{\text{in}} G_j$$

$$\Delta G = \frac{N G_{\text{T}} + G_{\text{T}}}{N G_{\text{T}} + G_{N+1}}$$

G_{T}	: target mean gain
G_j	: channel gain
$P_{\text{total}}^{\text{in}}$	: total input power
$P_{\text{total}}^{\text{out}}$	: total output power
N	: number of active channels
ΔG	: power excursion



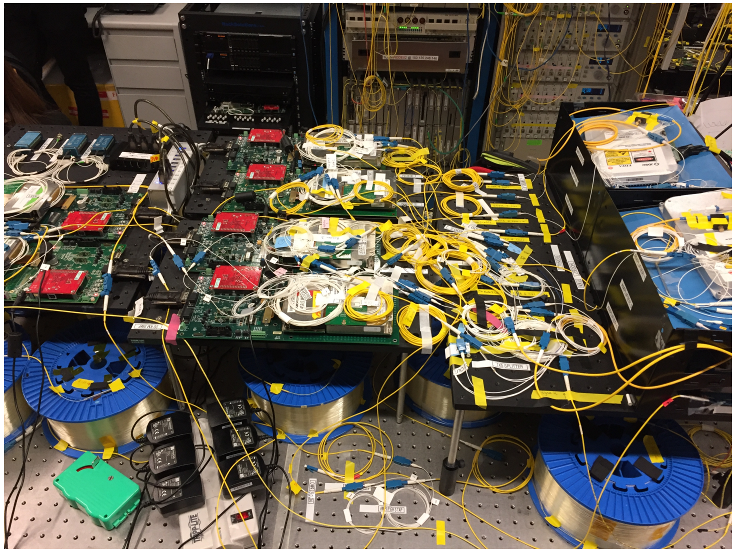


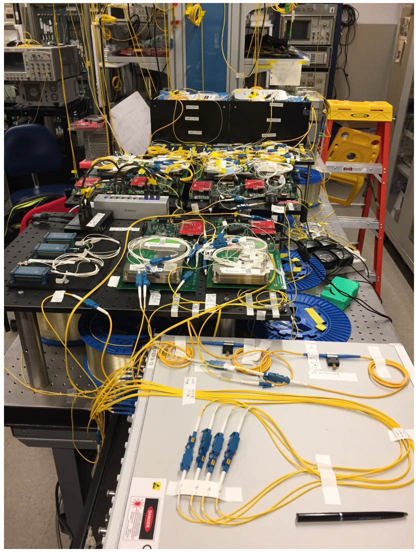
Previous Work

- Planning phase of dynamic optical network
  - [Angelou et al., 2012], [Doverspike et al., 2012], [Gringeri et al., 2013]
  - Dynamic optical design and architecture
  - No dynamic optical network algorithms for physical layer
- Analytical models
  - [Ishii et al., 2016], [Junio et al., 2012]
  - Non-real time (Junio), poor accuracy (Ishii)
- Machine learning for wavelength assignment
  - [Huang et al., 2017]
  - Only 24 channels, single hop system
  - Kernel Bayesian regression

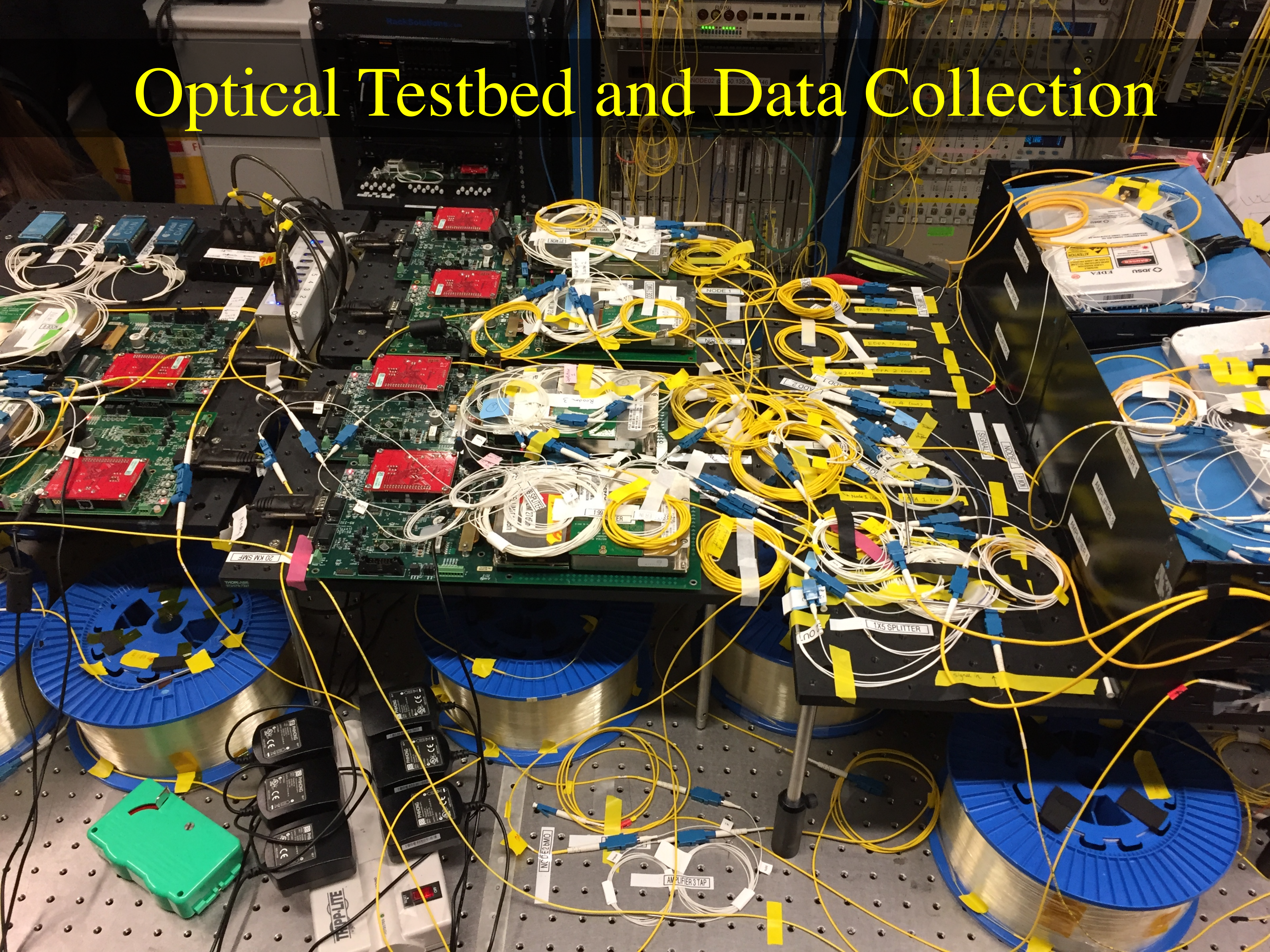
Our Contributions

- Design an optical testbed
- Collect real world data on optical network performance
- Develop a scalable neural network to predict power excursions at the physical layer
- Evaluate the performance using optical testbed measurements



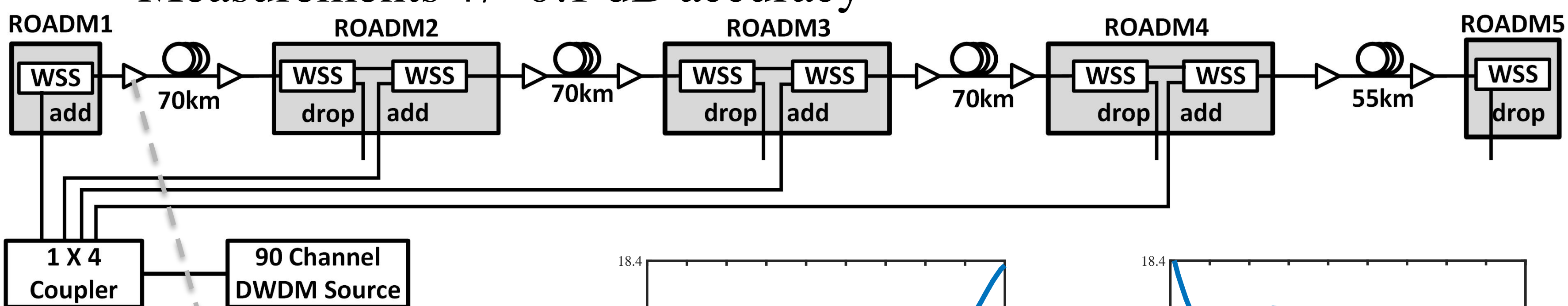


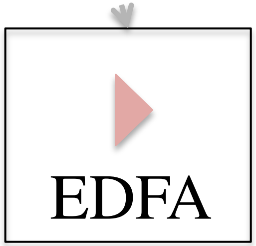
Optical Testbed and Data Collection

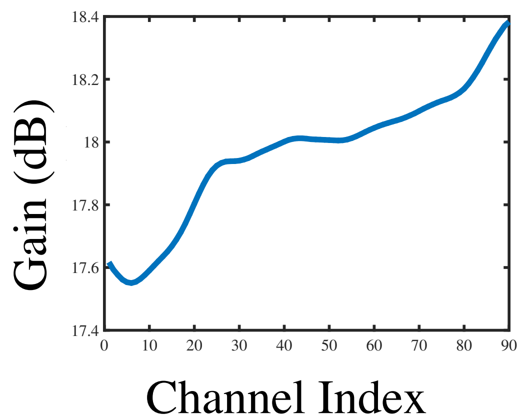


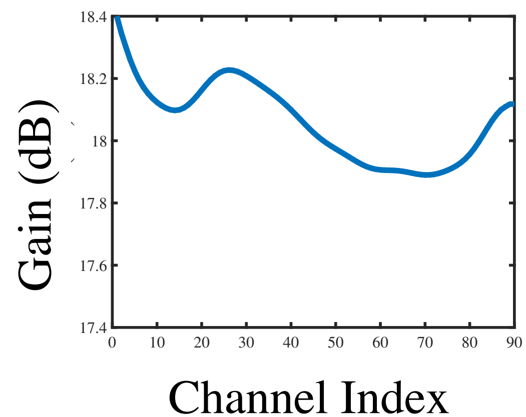
Optical Testbed

- 5-ROADM experiment setup
  - Nodes separated by 4 standard Single Mode Fiber (SMF) spans
  - Each span has 2 EDFAs
  - 90 channel DWDM source
  - Measurements +/- 0.1 dB accuracy

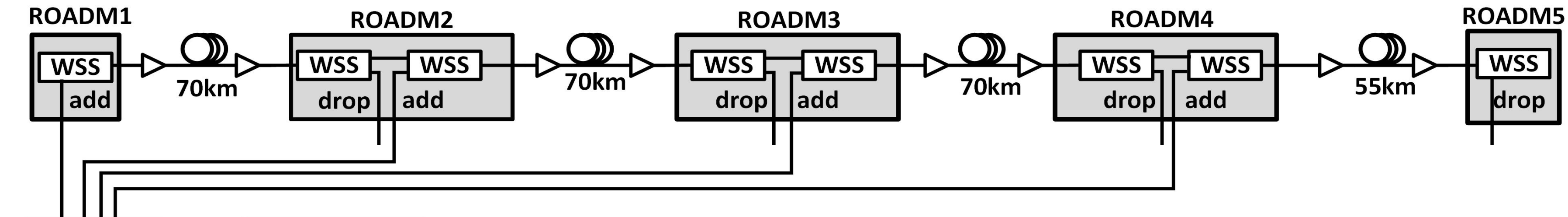


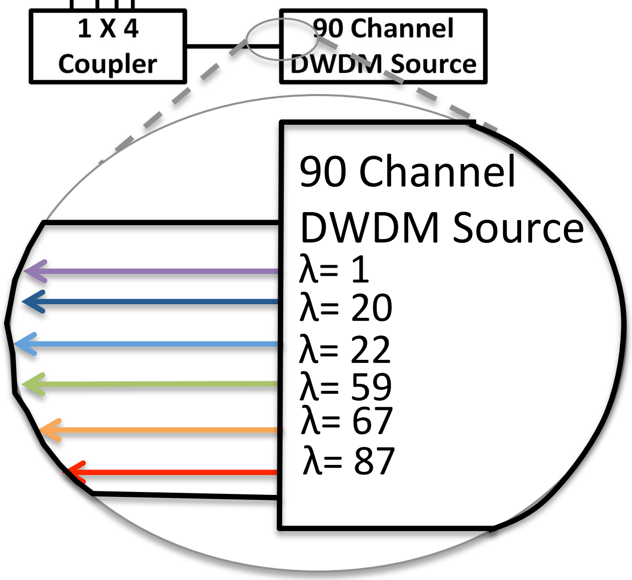


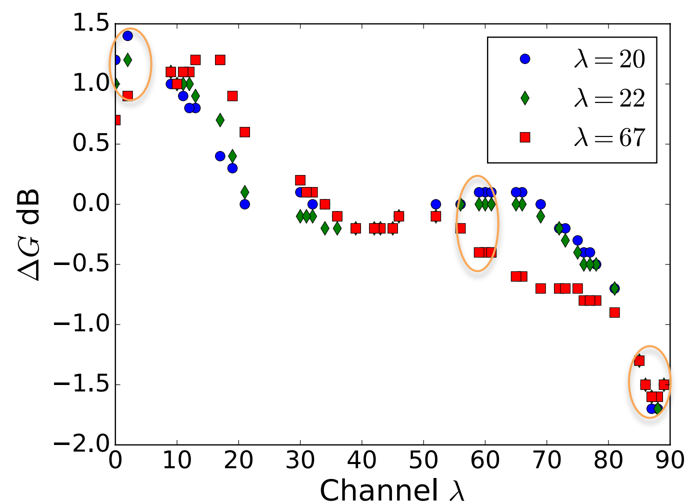




Optical Testbed – Measurements Collection







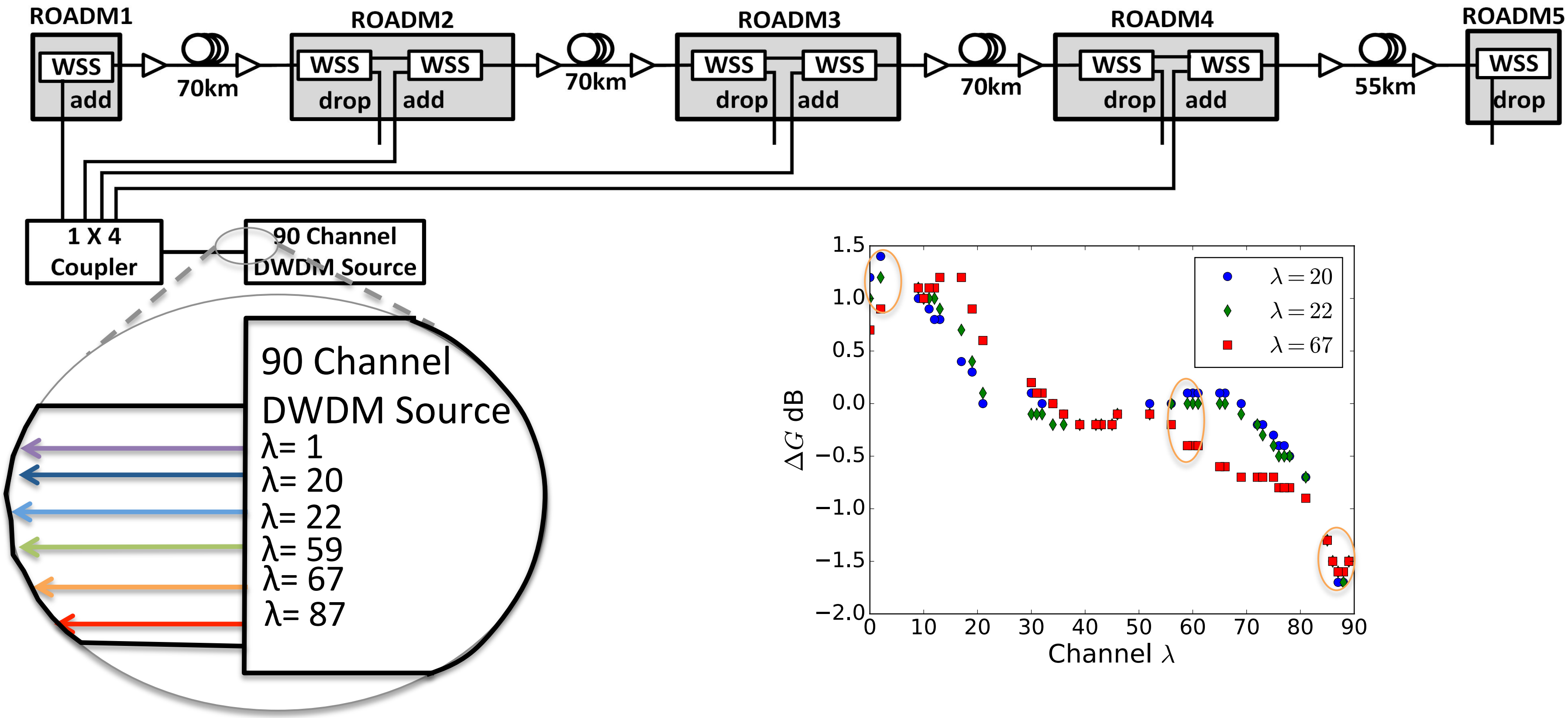
2,100 measurement cases

- 3-5 active channels
- 40 new channels added/removed one at a time
- 40 samples/case

84,000 samples

- Training: 1,680 cases (67,200 samples)
- Validation: 210 cases (8,400 samples)
- Test: 210 cases (8,400 samples)
- Data collection: ~4 seconds/sample

Optical Testbed – Measurements Collection



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Feed forward Neural Network

- Predict the maximum power excursion among all active channels

$$y^k = \max_{j \in \text{ActiveChannel}} \Delta G_j^k, \;\; k \in \text{Available Channel}$$

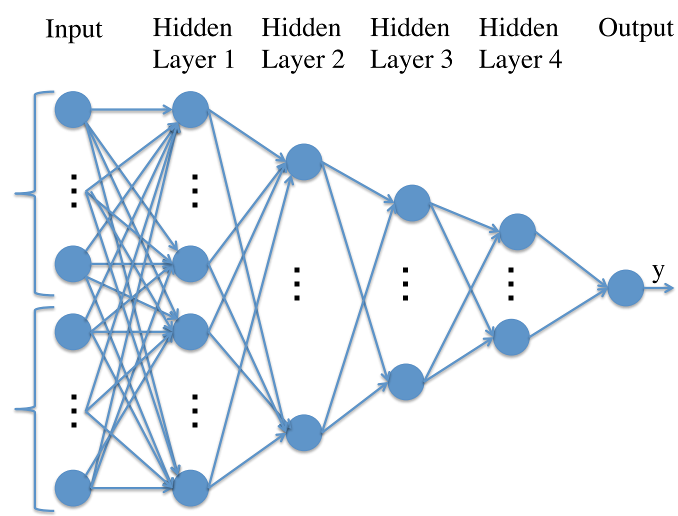
- Goal: Given initial channel conditions predict which new channel will minimize the effect of power excursion

$$\text{New Channel} = k^* = \arg \min_{k \in \text{AvailableChannels}} \hat{y}^k$$

$$\begin{aligned}\vec{x} &= [\vec{x}_{\text{Active}}, \vec{x}_{\text{Available}}] \\ &= [\underbrace{x_1, \cdots, x_{90}}_{\text{ActiveChannels}}, 0, \cdots, \underbrace{1}_{(90+k*)-\text{th}}, \cdots, 0] \in \{0,1\}^{180}\end{aligned}$$

$$x_i = \begin{cases} 1, & \text{if } i \in \text{ActiveChannel}, \; \forall i \in \{1, \cdots, 90\} \\ 0, & \text{Otherwise} \end{cases}$$

$$x_{i+90} = \begin{cases} 1, & \text{if } i = k^\star \\ 0, & \text{Otherwise} \end{cases}$$



Feed forward Neural Network

- Test neural network parameters
  - Activation functions
  - Number of layers
  - Number of neurons per layer
- Optimal Performance
  - 4 Hidden Layers: 180, 120, 30, 15 neurons
  - Tanh activation for hidden layers
  - Linear activation for the output layer

$$x_i = \begin{cases} 1, & \text{if } i \in \text{ActiveChannel}, \ \forall i \in \{1, \cdots, 90\} \\ 0, & \text{Otherwise} \end{cases}$$

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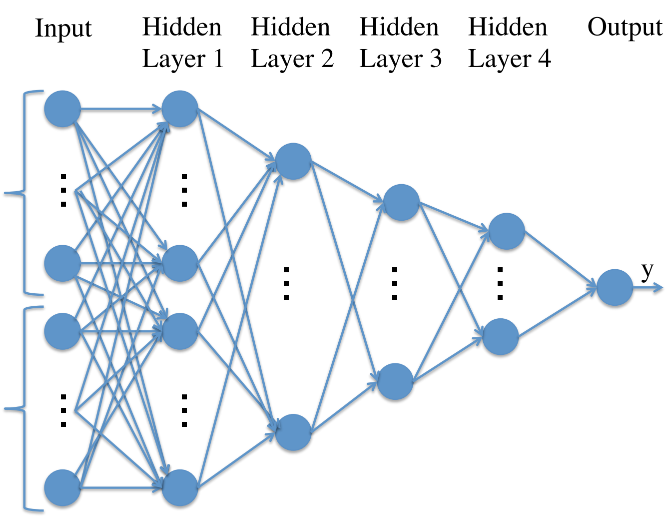


Outline

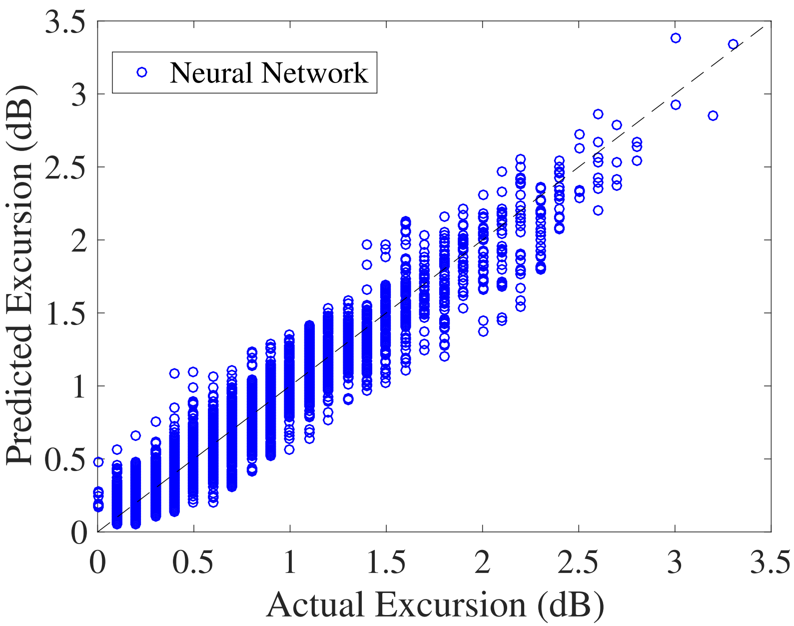
- Design an optical testbed
- Collect real world data on optical network performance
- Develop a scalable neural network to predict power excursions at the physical layer
- Evaluate the performance using optical testbed measurements
  - Prediction
  - Recommendation
  - Classification

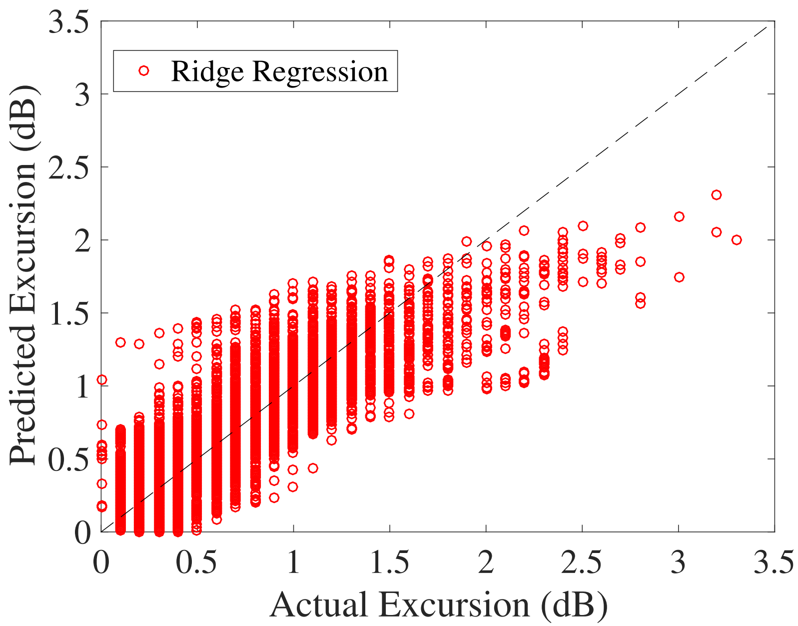
Prediction Results

- Training: 67,200 samples
- Test Points: n = 8,400 samples
- Excursion:

$$y_l = \max_{j \in \text{ActiveChannel}} \Delta G_j^k, \;\; k \in \text{Available Channel}, \; \forall l \in \{1, ...n\}$$

- For Neural Network (NN) comparison Ridge Regression (RR) is trained and parameters tuned on the same data set



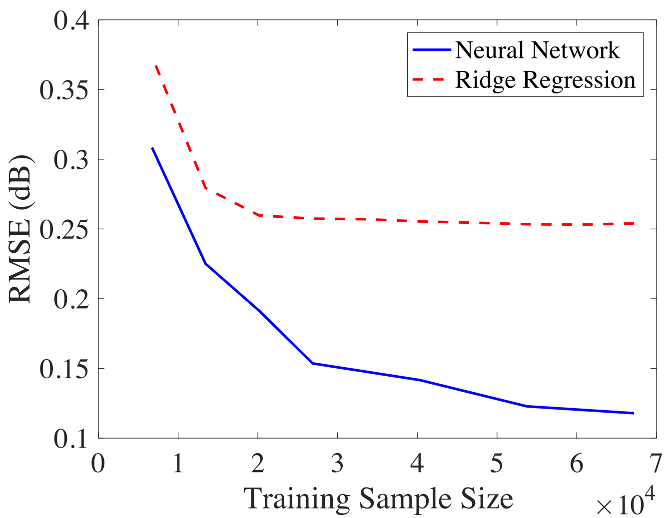


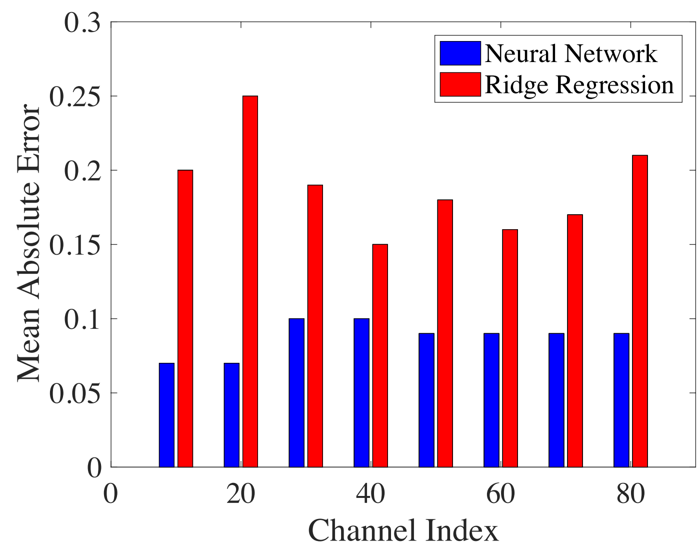
Prediction Performance Evaluation

- Training: 67,200 samples
- Test Points: n = 8,400 samples
- Excursion:

$$y_l = \max_{j \in \text{ActiveChannel}} \Delta G_j^k, \; k \in \text{Available Channel}, \forall l \in \{1, \ldots n\}$$

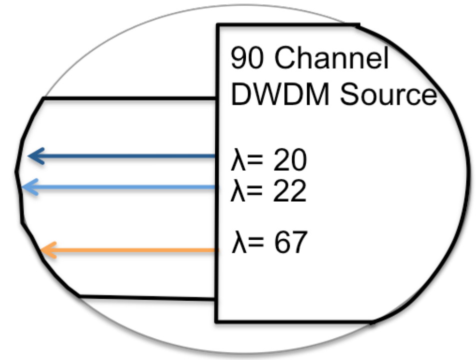
- Test data Root Mean Square Error (RMSE): $$RMSE_{Test} = \sqrt{\frac{1}{n}\sum_{l=1}^{n}(y_l - \hat{y}_l)^2}$$
- Test data Mean Absolute Error (MAE): $$MAE_{Test} = \frac{1}{n}\sum_{l=1}^{n}|y_l - \hat{y}_l|$$



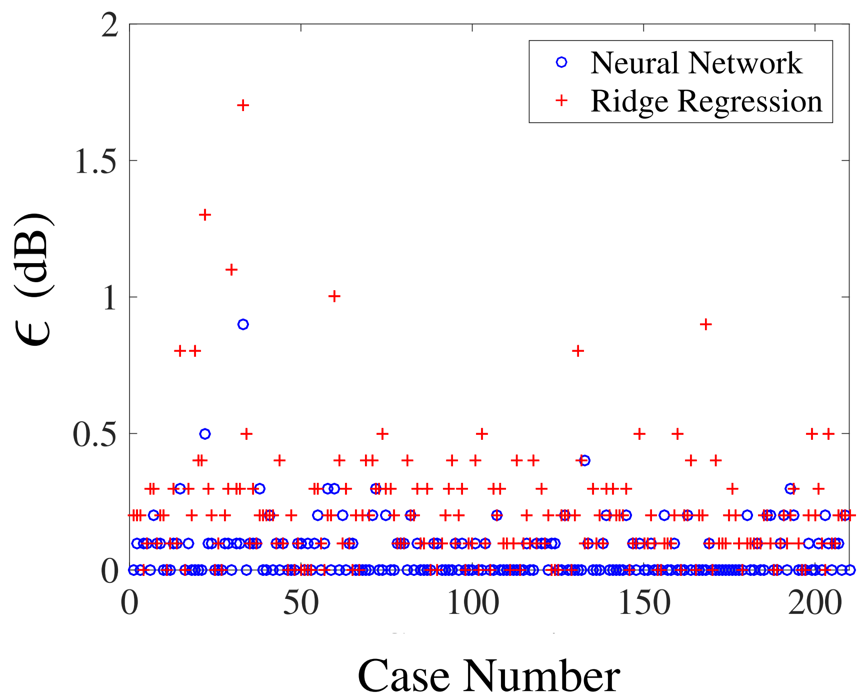


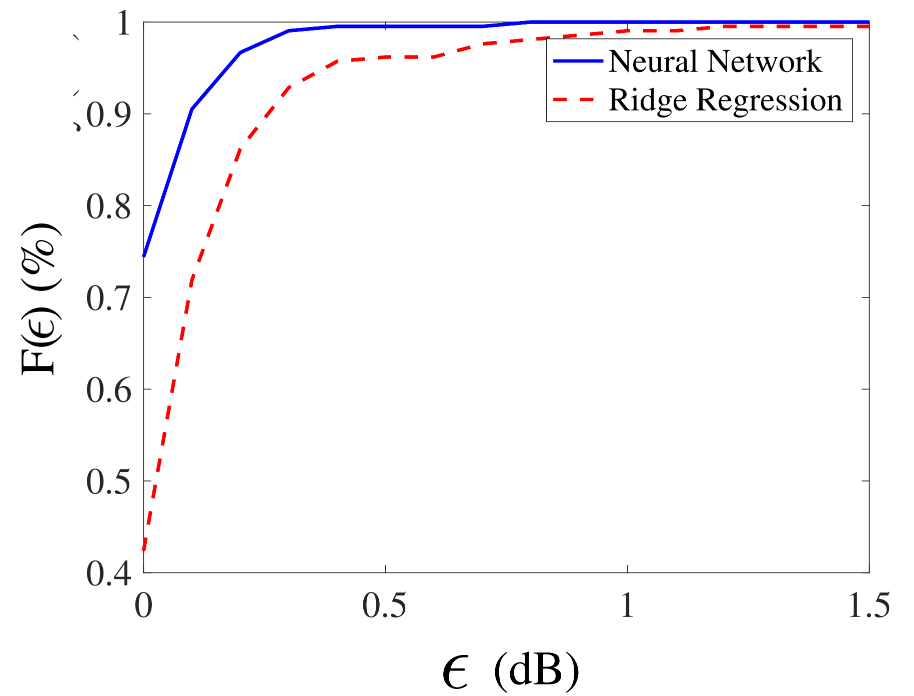
ϵ-Recommendation Accuracy

- Training: 67,200 samples
- Test Cases: 210
- Test Points: n = 8,400 samples



$$\text{Recommendation Error} = \epsilon = |y^{\hat{k}^*} - y^{k^*}|$$





Classification Accuracy

- Classification: predict if excursion below threshold

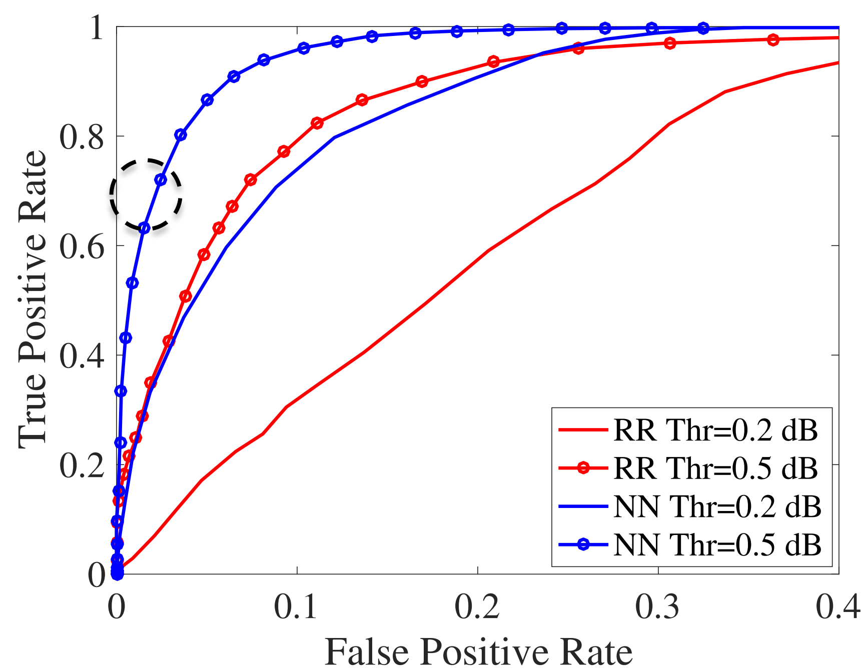
  1 : Below Threshold

  0 : Above Threshold

- Set threshold of excursion to 0.5 dB

$$\text{True Positive Rate (TPR) or Recall} = \frac{TruePositive}{TruePositive + FalseNegative}$$

$$\text{False Positive Rate (FPR)} = \frac{FalsePositive}{FalsePositive + TrueNegative}$$

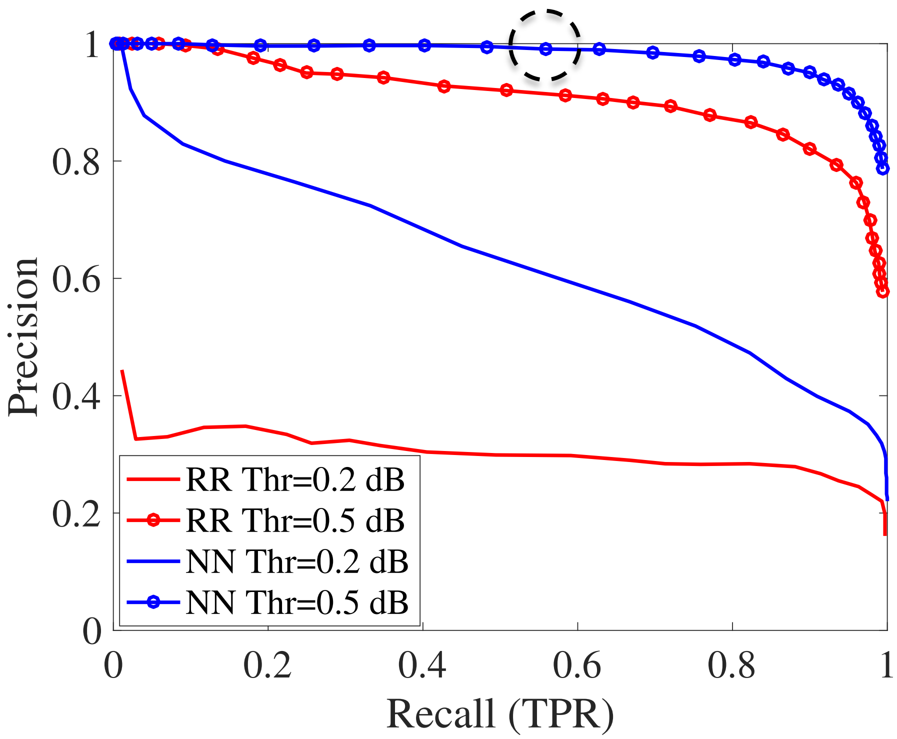


Classification: Precision at Recall Rate (PSRR)

- Priority for reliable optical system operation:
  1. Minimize false positives: Violates SLA
  2. Minimize false negatives: Wastes open bandwidth

$$\text{True Positive Rate (TPR) or Recall} = \frac{TruePositive}{TruePositive + FalseNegative}$$

$$\text{Precision (PPV)} = \frac{TruePositive}{TruePositive + FalsePositive}$$



Summary

- Fabricated a 90-channel multi-hop ROADM optical testbed for data collection
- Developed a neural network to predict optical power excursions
- Demonstrated very good performance
  - Prediction: Average prediction error on each channel **below 0.1 dB**
  - Recommendation: Pick best channel (out of 40), **over 70%** of the time
  - Classification: Predict maximum excursion to be less than 0.5 dB threshold with a precision of **over 99%** while obtaining a true positive rate greater than 55%
- Future Work:
  - Machine learning solution for ring and mesh networks
  - Implementation in Optical Software Defined Networks (OSDN)

Thank you!

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