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Machine Learning Methods for Communication Networks and Systems – 051911

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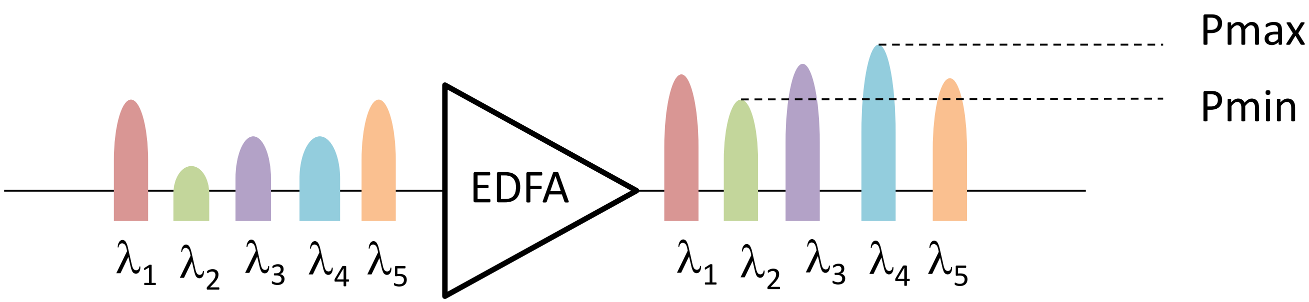
Part II – 4: Optical Power Control

Physical layer domain

Optical power control

- When adding/dropping channels into/from a WDM system, EDFA (Erbium Doped Fiber Amplifiers) gain should be adjusted to have a good balance between channels output power
- This effect is more critical in multiple-span systems



- Analytical models:
  - depend on the specific system (gain-control mechanism, EDFA gain tilt, nr of EDFAs…) and to its variations during lifetime
- ML allows to self-learn together all the parameters of any given system and adapt EDFA's features accordingly

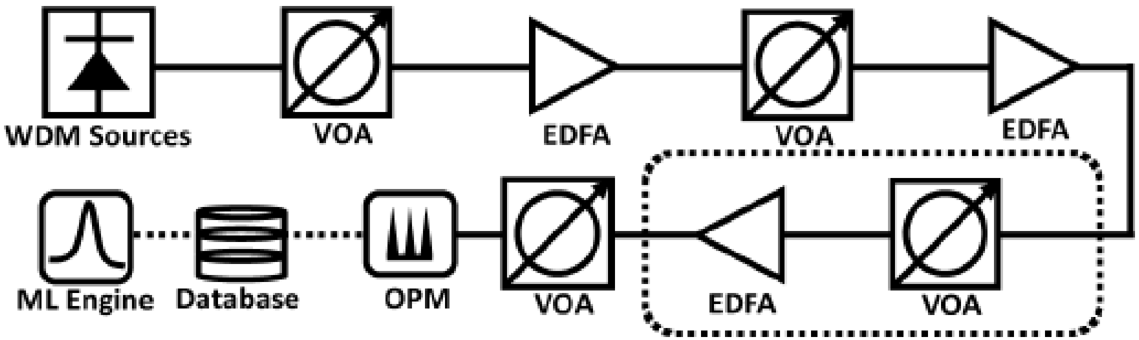
Optical Power Control

Source 1

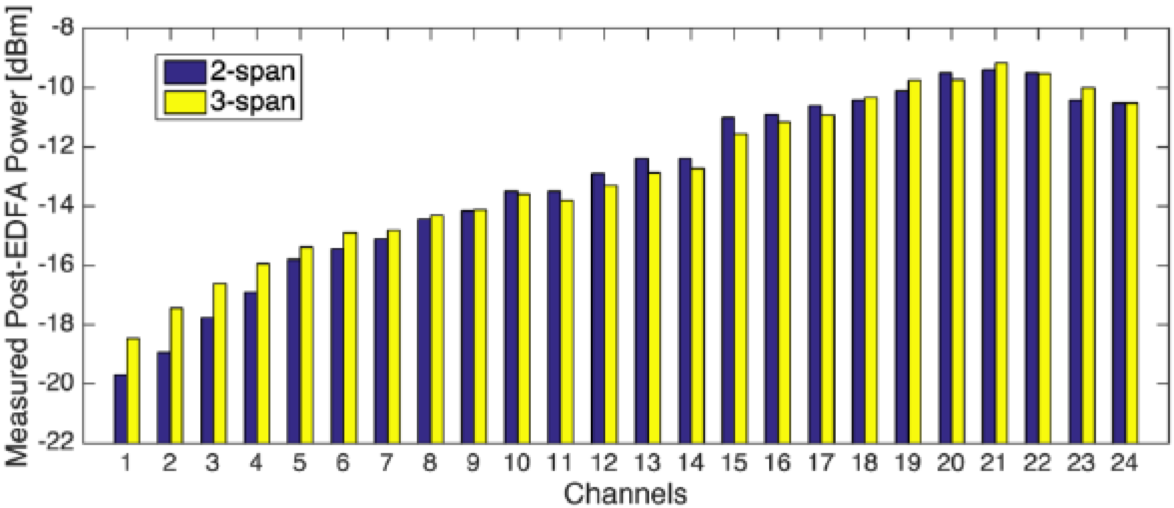
- Huang *et al.*, "Dynamic mitigation of EDFA power excursions with machine learning", *Optics Express*, vol. 25 n. 3, Feb. 2017
- Paper objective: mitigate EDFA power excursion in multiple-span WDM systems due to channel add/drop
  - input
    - Historical data on power excursion vs active (ON) channels
  - output
    - optimal wavelength assignment for the new channel
  - ML algorithms:
    - RR, Ridge Regression (linear regression with regularization)
    - KBR, Kernelized Bayesian Regression (≈ CBR)

Optical Power Control
Source 1

- Testbed set-up with 24 WDM channels
  - 2 or 3 EDFA spans



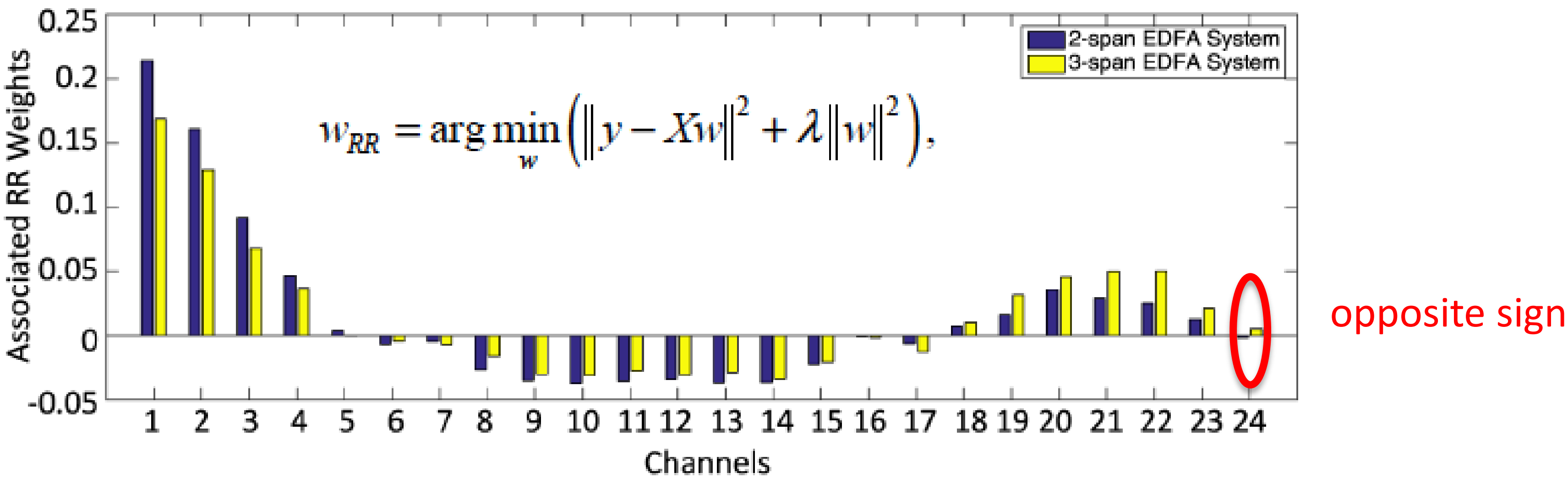
- Post-EDFA power levels
  - 24 channels ON with uniform launch power
    - ch1@192.1 THz
    - ch24@194.4 THz
    - 100 GHz spacing



Optical Power Control

Source 1

- ML algorithm #1 – Ridge Regression
  - Input (*X*): 24-bits array (i-th bit = 1 if i-th channel is ON)
  - Output (y): measured post-EDFA power discrepancy (captured via STDEV of channel power levels)
  - 600 training points (historical channel ON/OFF states and power STDEV values)
  - 270 test points
  - weights are calculated with regularization (optimized with cross-validation)



Optical Power Control

Source 1

- ML algorithm #2 – Kernelized Bayesian Regression
  - Kernel with radial basis function

$$K(x,x') = \alpha \exp\left(-\frac{1}{b}\|x-x'\|^2\right),$$

  - Kernel is used to weight the regression output
  - "α" and "b" are optimized via cross-validation
  - Prediction for a new scenario: take all the outputs in the KB and weight them using the kernel

Optical Power Control
Source 1

- Results – Impact of training set size on MSE and model complexity

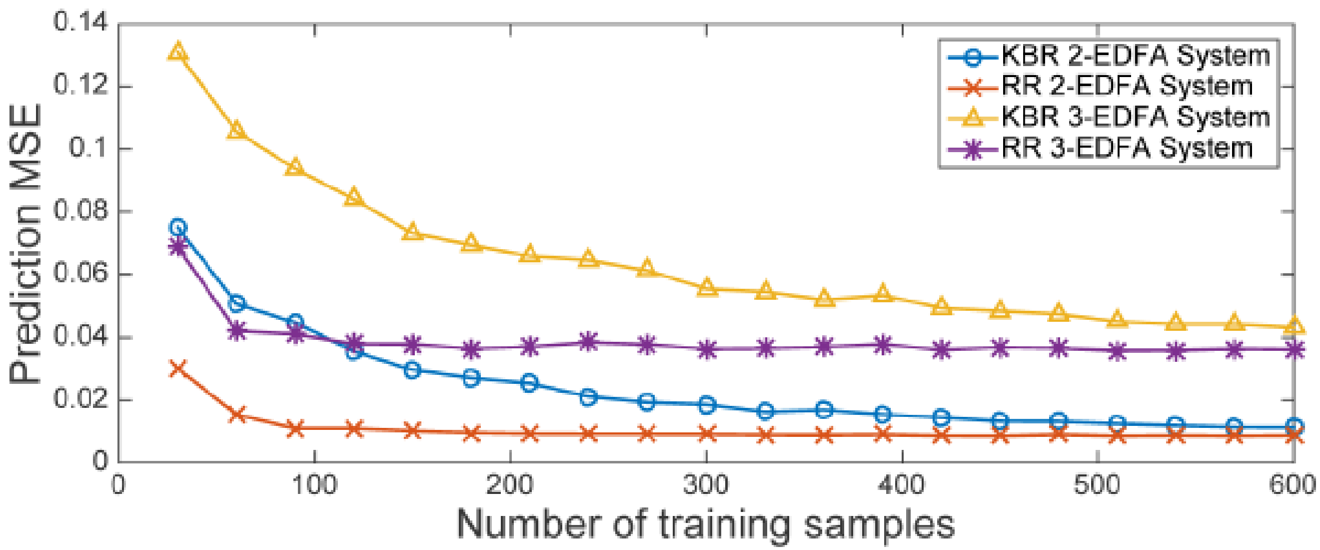


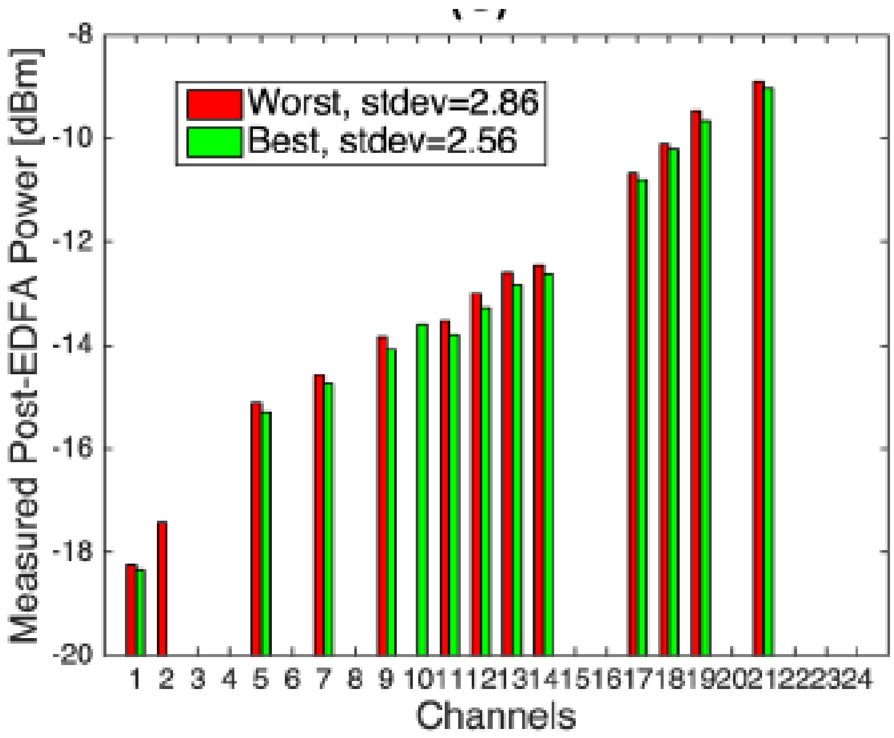
Table 1. Time consumption of training and prediction for RR and KBR.

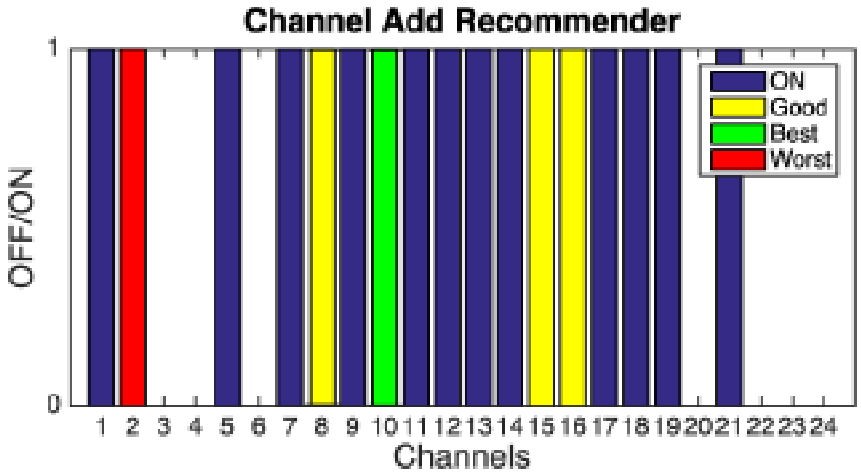
Model	RR	KBR
Time to train with 600 data points [ms]	82.2	2300
Time to predict for a single scenario [ms]	0.068	467

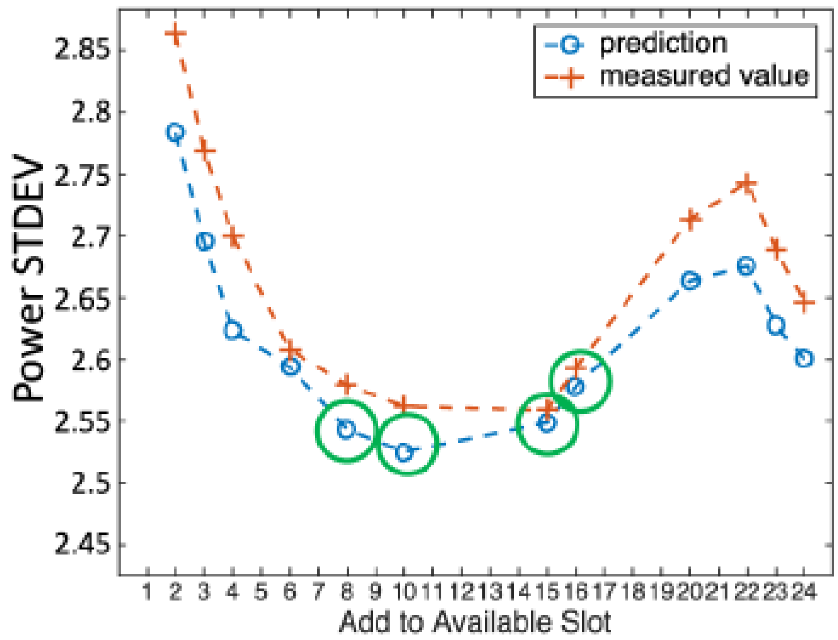
Optical Power Control

Source 1

- Results – Single channel ADD



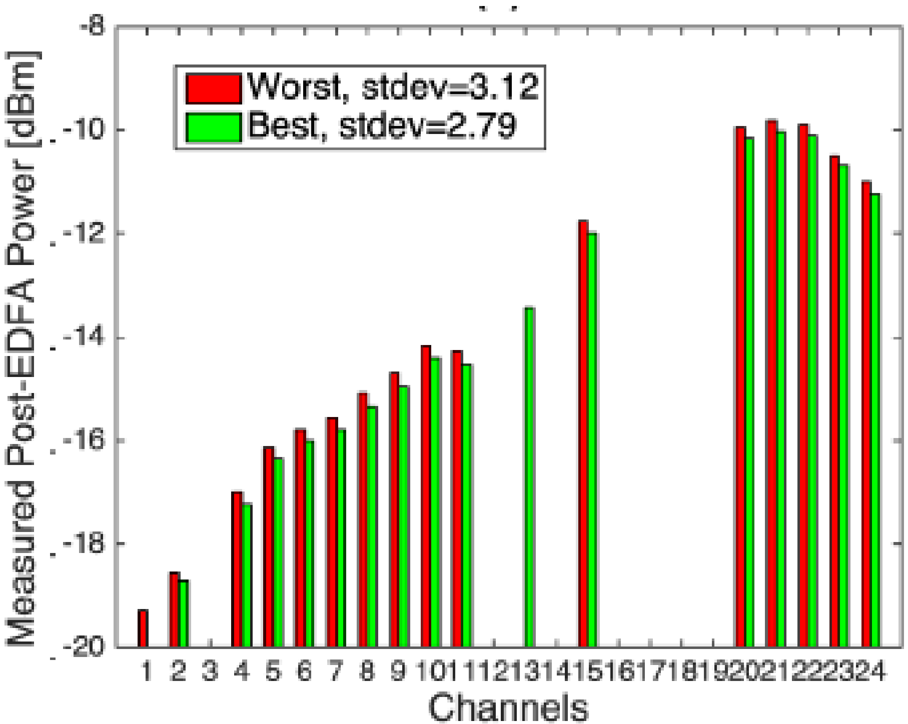


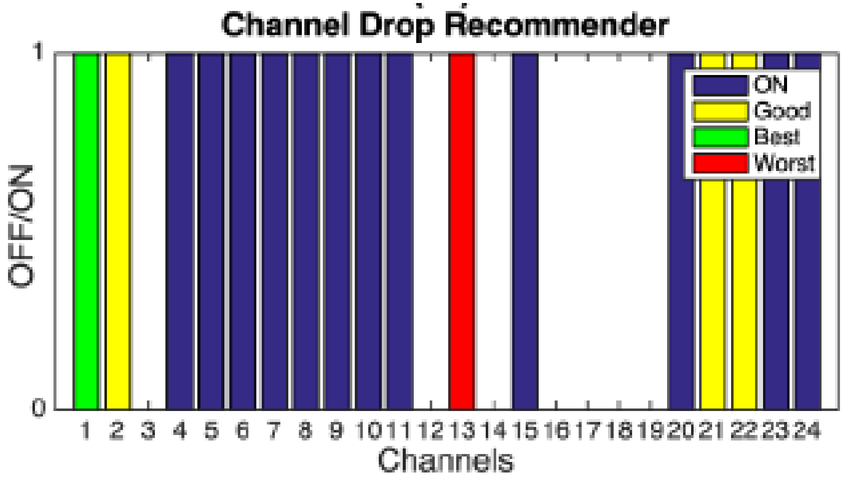


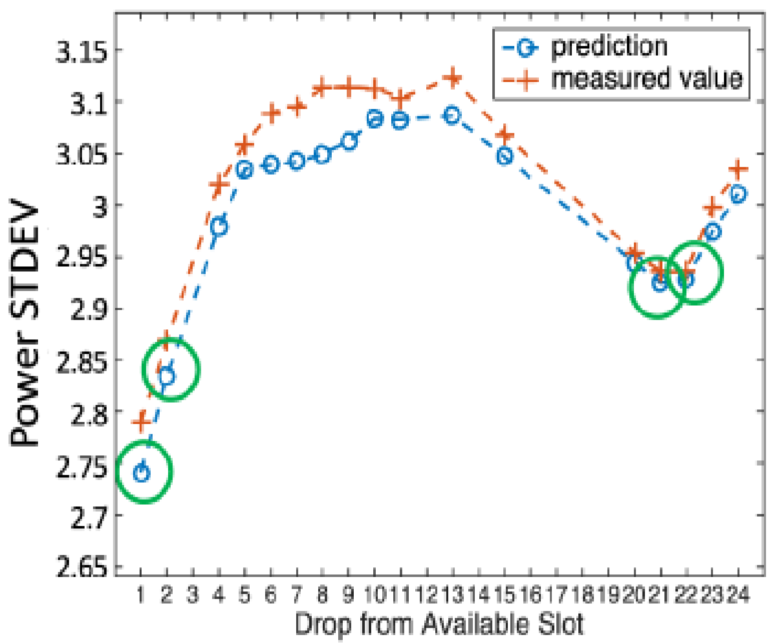
Optical Power Control

Source 1

- Results – Single channel DROP



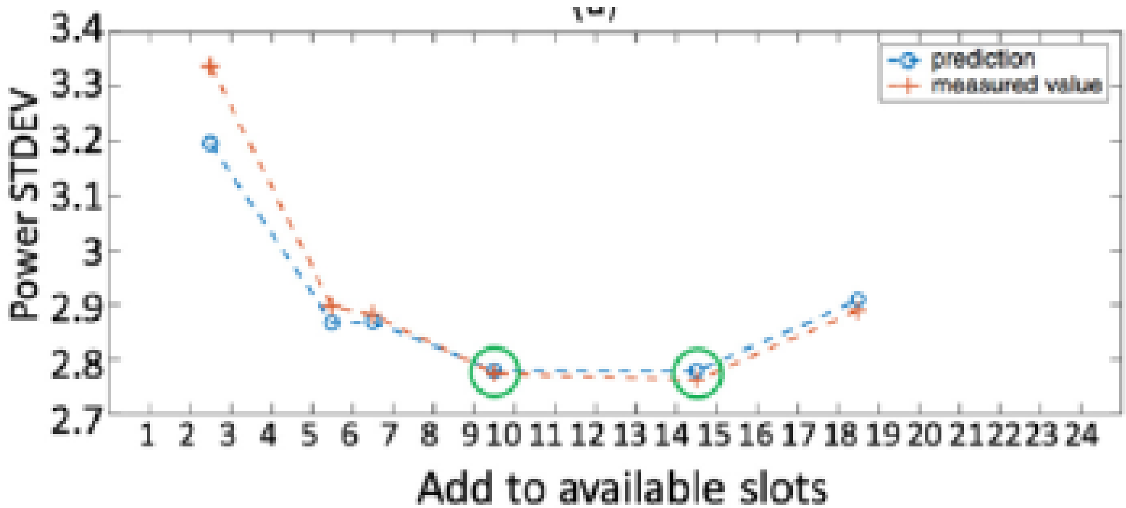


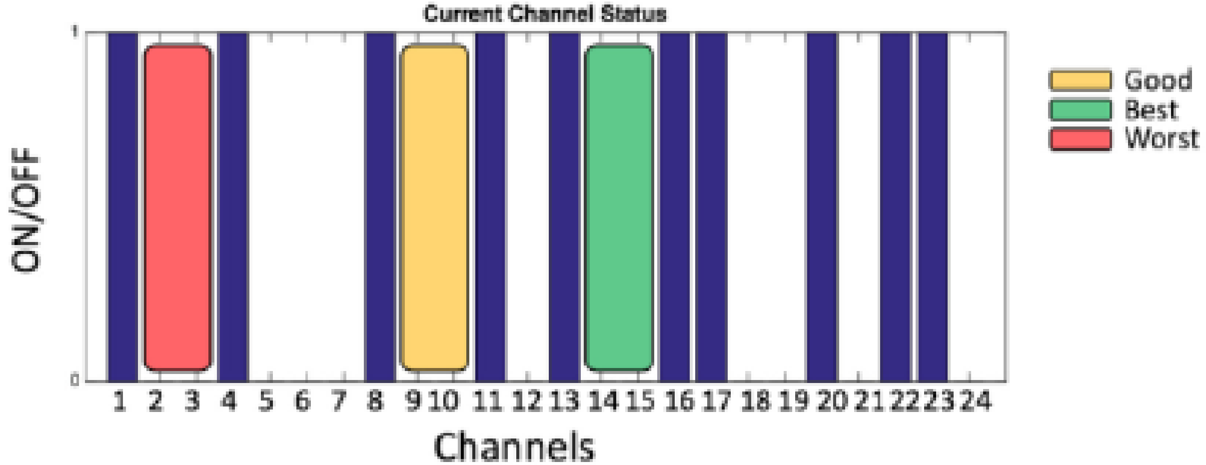


Optical Power Control

Source 1

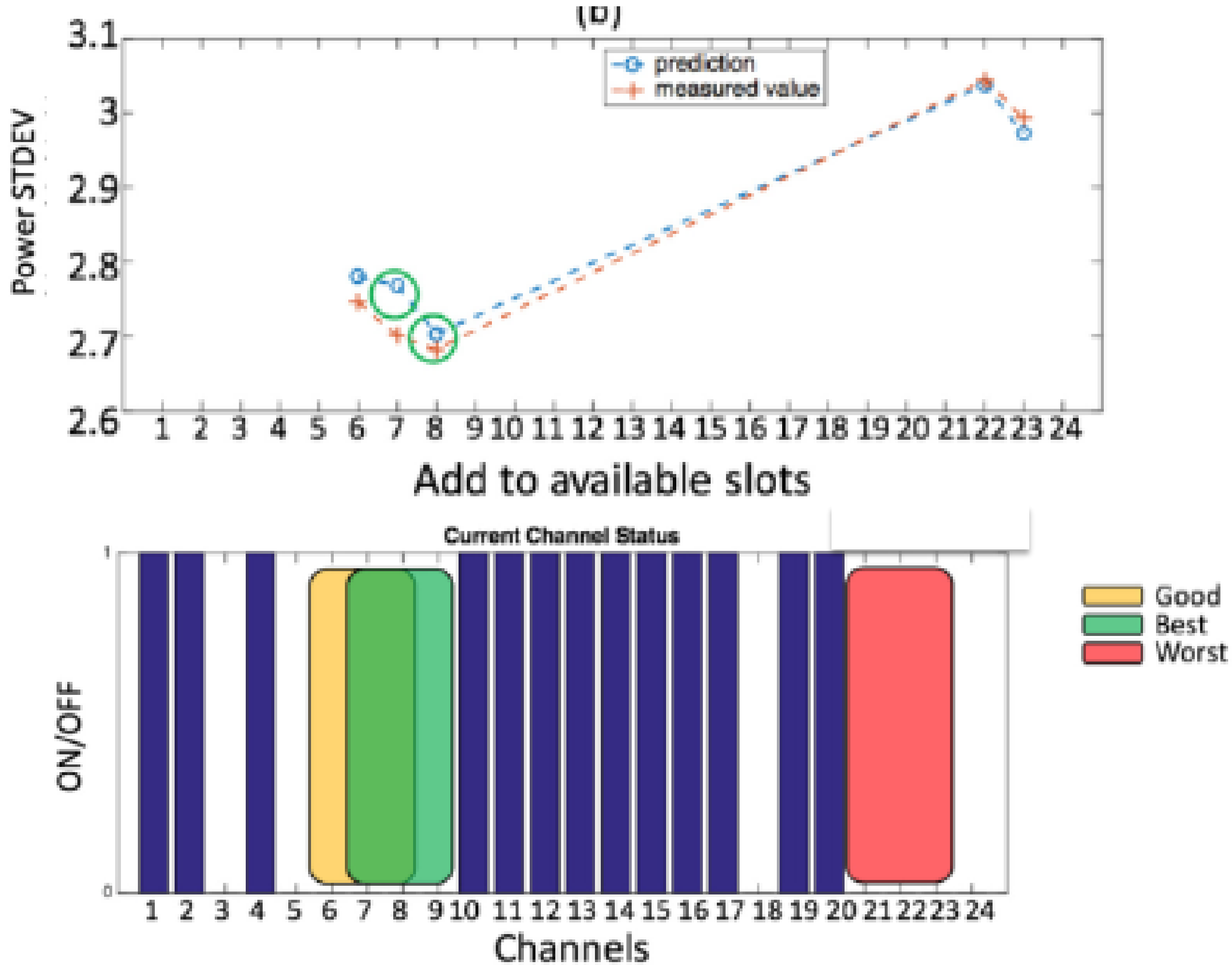
- Results – Superchannel ADD (2 contiguous channels)





Optical Power Control
Source 1

- Results – Superchannel ADD (3 contiguous channels)

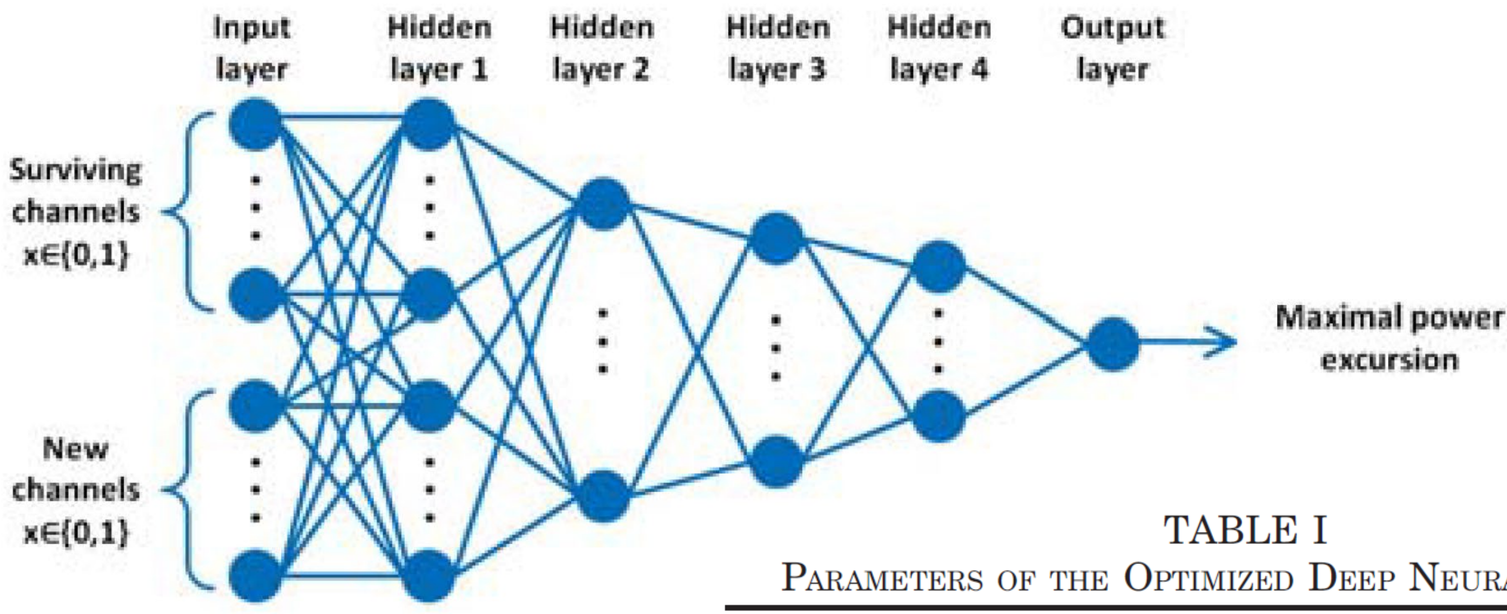


Optical Power Control

Source 2

- Mo *et al.*, "Deep-Neural-Network-Based Wavelength Selection and Switching in ROADM Systems", *Journal of Optical Communications and Networking*, vol. 10, n. 10, Oct. 2018
- Paper objective: reducing power excursion in WDM system
  - Input
    - Existing and candidate add channels (wavelengths)
  - Output
    - Maximum power excursion
  - ML algorithm: Deep NN, compared against Ridge regression and Random Forest

Optical Power Control
Source 2



- 1680 training pts (combinations of lightpaths)
- 210+210 val+test pts
- 40 power-excursion measurements for each point

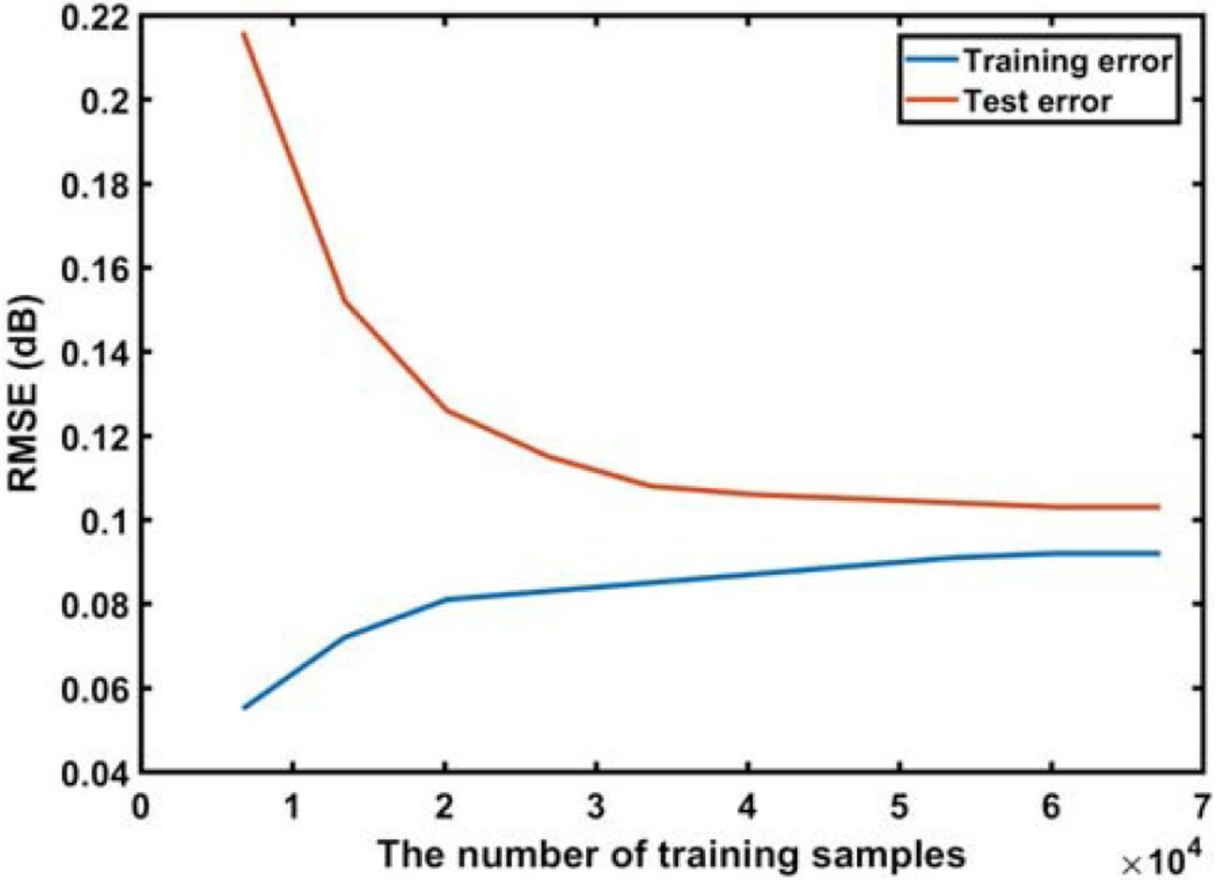
TABLE I
PARAMETERS OF THE OPTIMIZED DEEP NEURAL NETWORK

Parameter	Value
Neurons in hidden layers	(180,120,30,15)
Activation function	(tanh, tanh, ReLU, ReLU)
L2 regularization	0.001
Dropout rate	0.1
Initial learning rate	0.005
Number of epochs	217

Optical Power Control

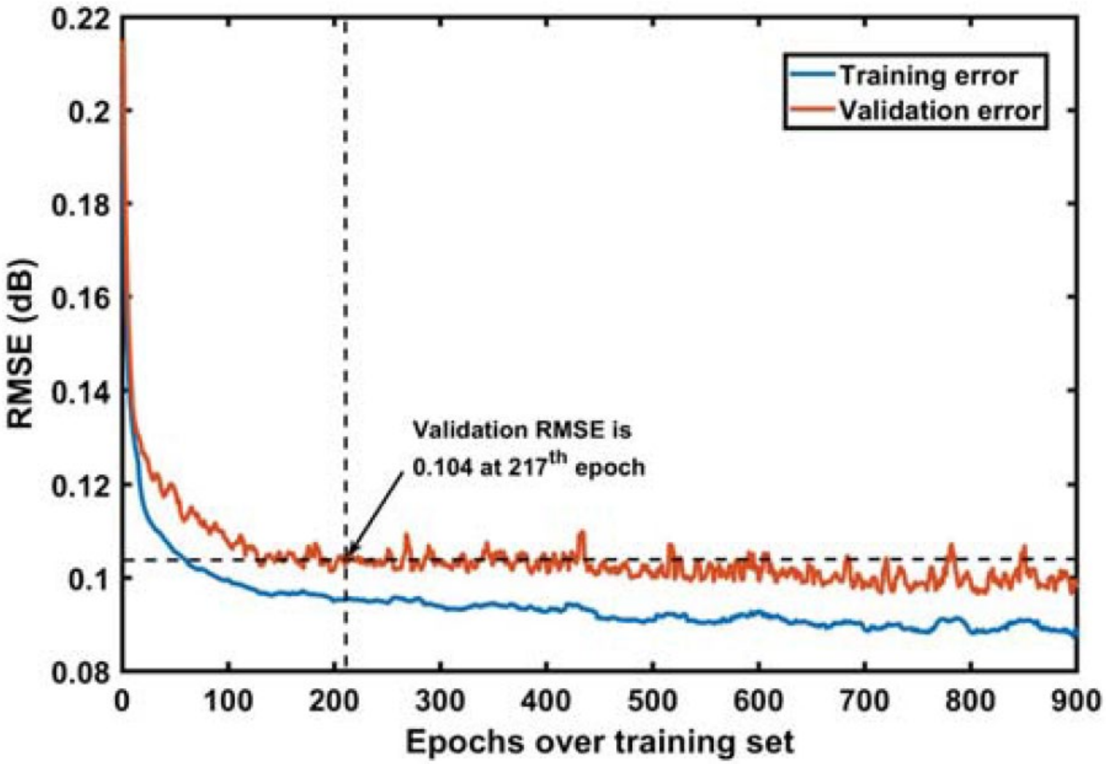
Source 2

- Impact of training set size



Optical Power Control
Source 2

- Learning curves
  - **Early stopping**: stop training after 3 consecutive epochs with no improvement in the validation RMSE



Optical Power Control
Source 2

- Results (RMSE)

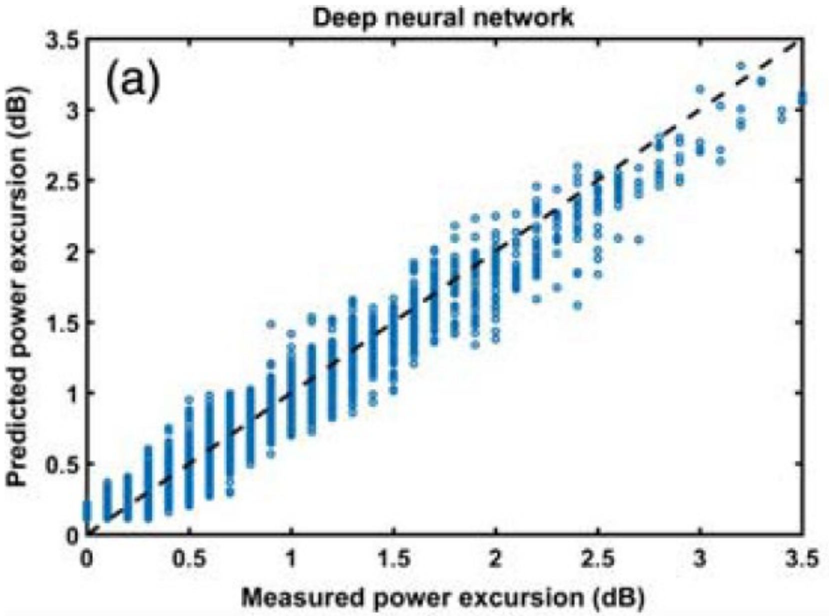


TABLE II
TEST RMSE AND MAXIMAL PREDICTION ERROR

Machine Learning Model	RMSE (dB)	Maximal Error (dB)
Deep neural network	0.104	0.8
Ridge regression	0.273	2.3
Random forest	0.281	2.7