Machine Learning Methods for Communication Networks and Systems – 051911

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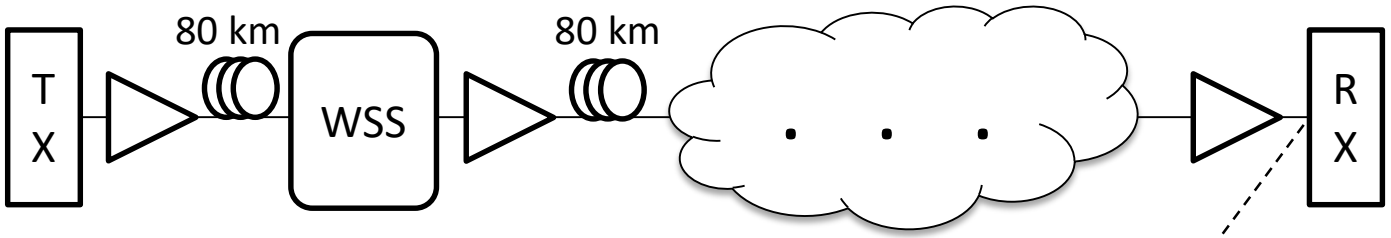
Part II – 3: Optical Performance Monitoring

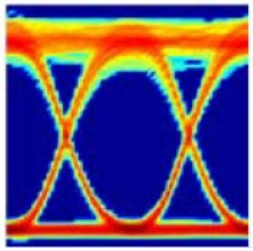
Physical layer domain

Optical performance monitoring

- **During** signal transmission, quality at the receiver (or even in intermediate spans) is constantly monitored to assess transmission performance
- The behaviour of several parameters is evaluated
  - OSNR, Polarization Mode Dispersion (PMD), Cromatic Dispersion (CD)
  - After a degradation in any of them, different actions can be triggered



- Traditional approaches:
  - involve several monitoring equipment
  - electrical post-processing is often needed
- ML:
  - enables real-time processing of monitored data
  - creates direct relationship between parameters and monitored data (e.g., eye diagram)



Optical Performance Monitoring

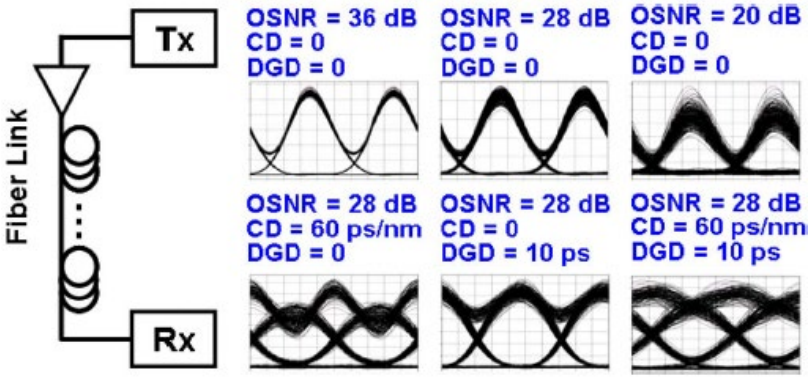
Source 1

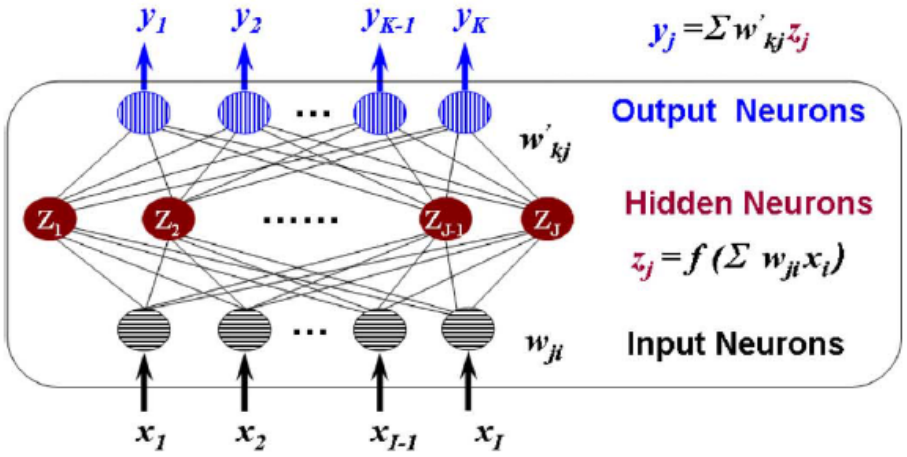
- Wu *et al.*, "Applications of Artificial Neural Networks in Optical Performance Monitoring", *Journal of Lightwave Technology*, vol. 27 n. 16, Aug. 2009
- Paper objective: perform signal quality monitoring to trigger possible reactions (equipment adjustment, repair damages, drive compensator/equalizer, reroute traffic…)
  - input
    - Several parameters retrieved from eye diagrams:
      - Q-factor
      - closure
      - RMS jitter
      - crossing amplitude
      - …
  - output
    - OSNR
    - CD (chromatic dispersion)
    - DGD (Differential Group Delay, a measure of polarization mode dispersion, PMD)
  - ML algorithm: Neural Network

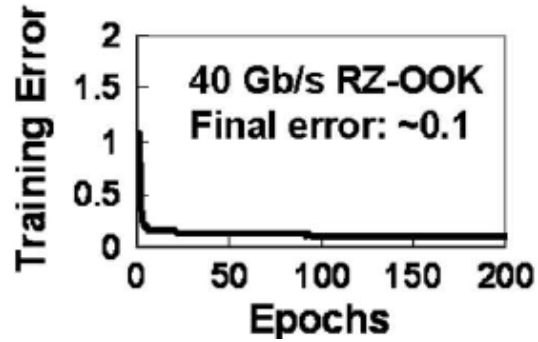
Optical Performance Monitoring

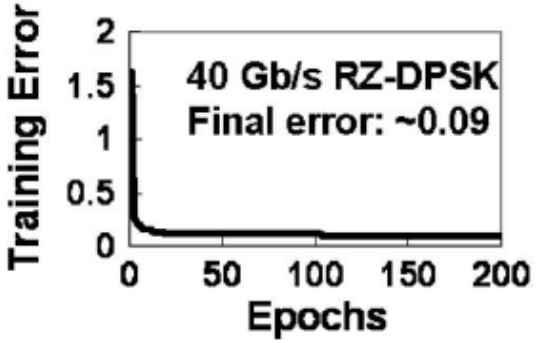
Source 1

- NN for CD/PMD/OSNR monitoring
  - Different alterations of OSNR/CD/DGD cause different effects in the eye diagram
  - NN with 12 hidden neurons
  - Sigmoidal activation function *f()*
  - Separate training for RZ-OOK and RZ-DPSK
  - Training set: 125 samples
  - Test set: 64 samples





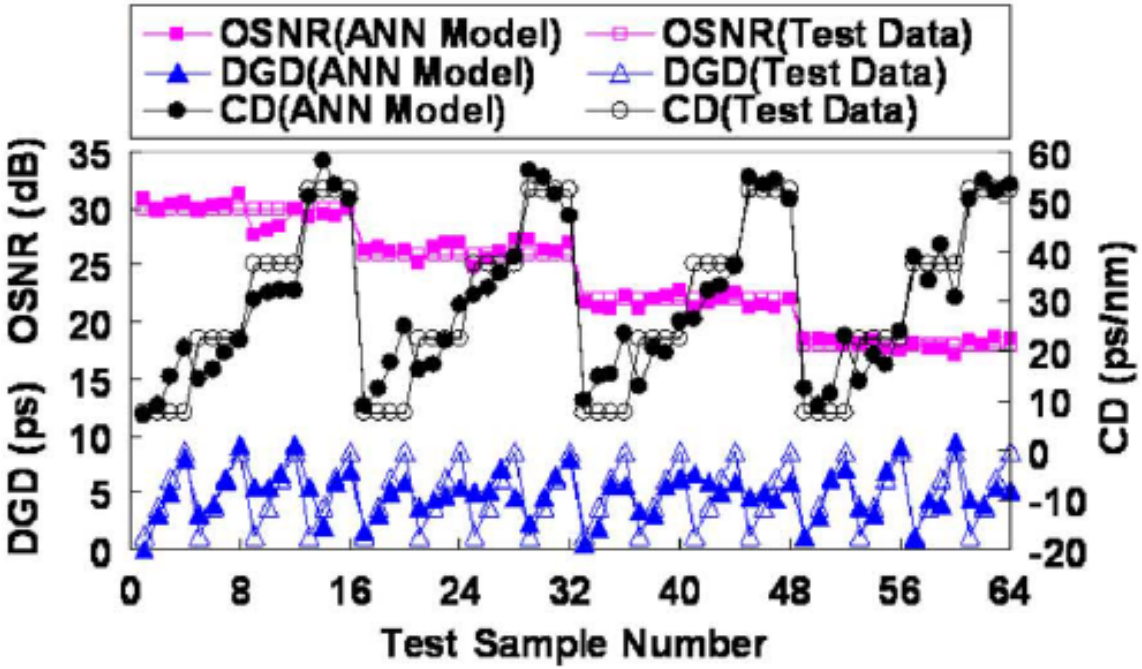




Optical Performance Monitoring

Source 1

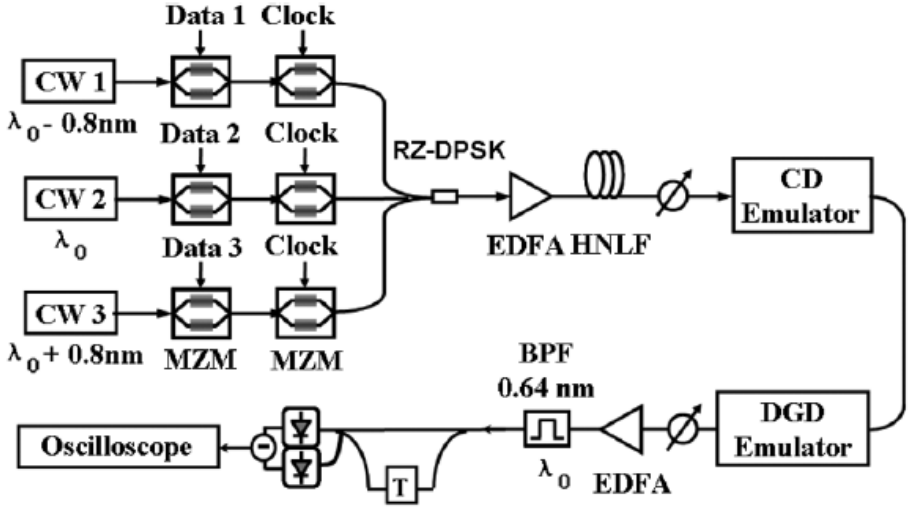
- NN for CD/PMD/OSNR monitoring (RZ-OOK)
  - 0.97 correlation coefficient
  - similar results for RZ-DPSK

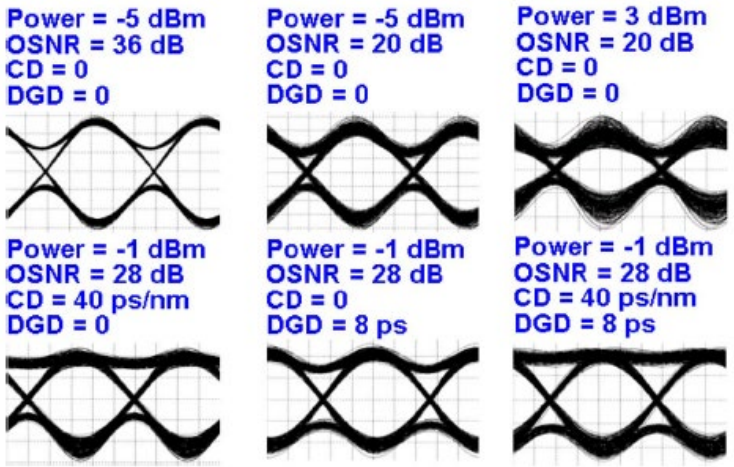


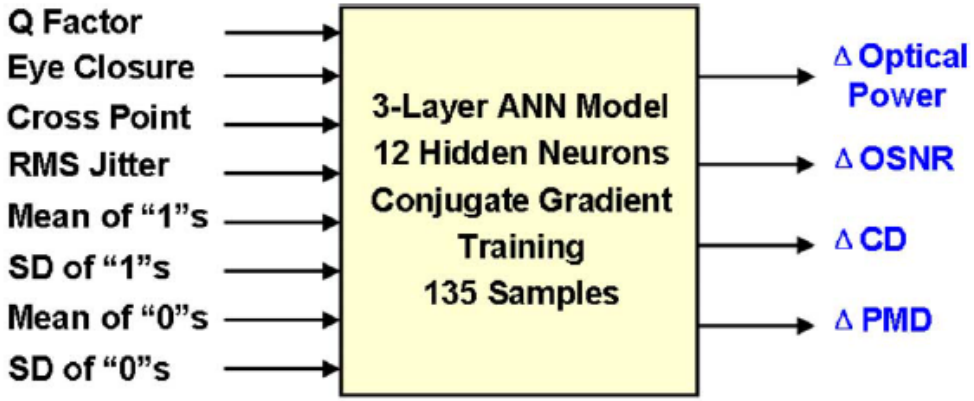
Optical Performance Monitoring

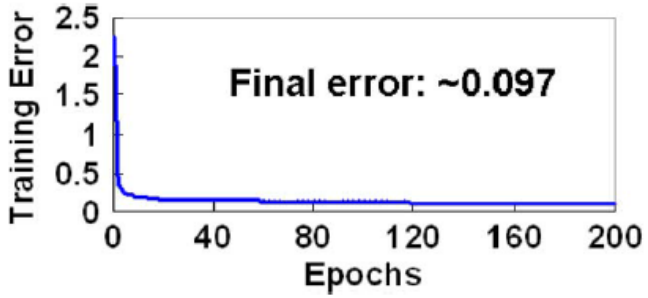
Source 1

- NN for CD/PMD/OSNR/accumulated nonlinearity





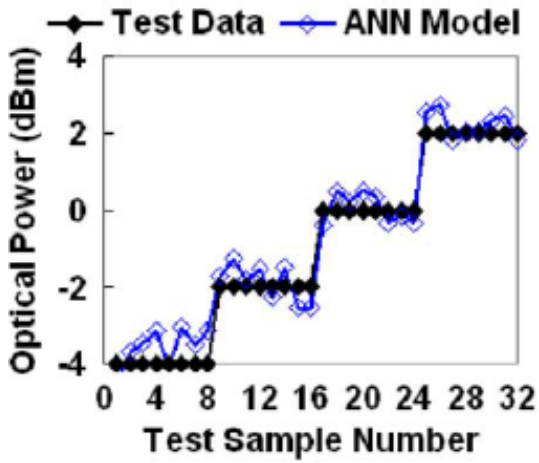


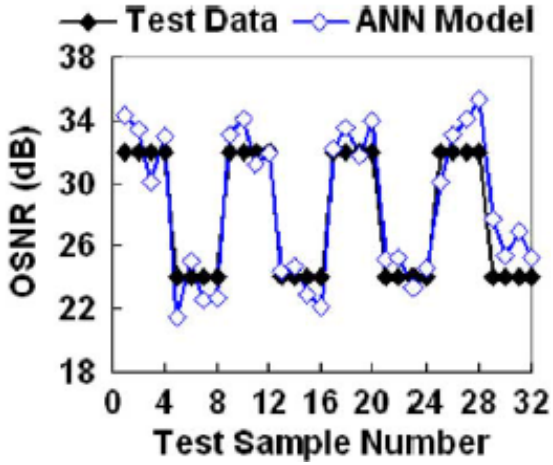


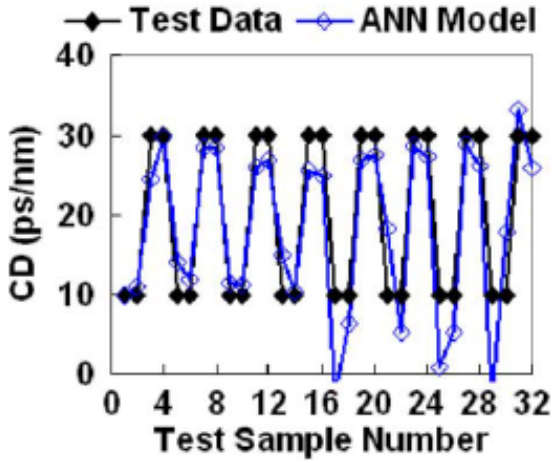
Optical Performance Monitoring

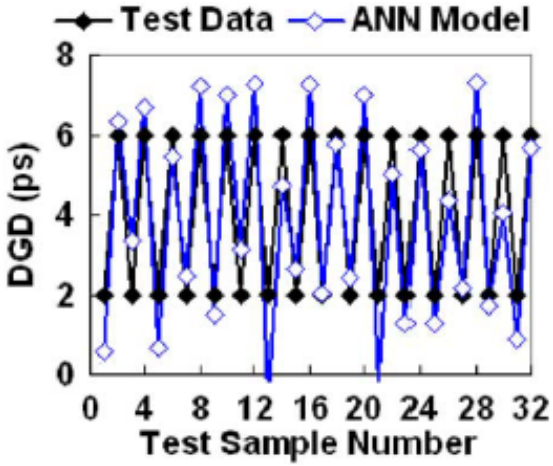
Source 1

- NN for CD/PMD/OSNR/accumulated nonlinearity









Optical Performance Monitoring

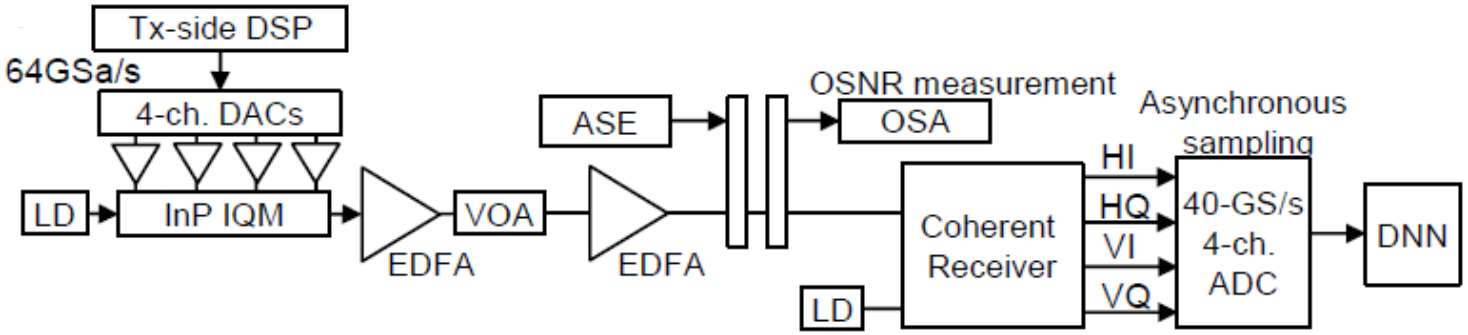
Source 2

- Tanimura *et al.*, "OSNR Monitoring by Deep Neural Networks Trained with Asynchronously Sampled Data", in *OECC 2016*, Oct. 2016
- Paper objective: perform OSNR monitoring
  - input
    - sampled signal values
  - output
    - OSNR
  - ML algorithm: Neural Network
    - 1/3/5 hidden layers

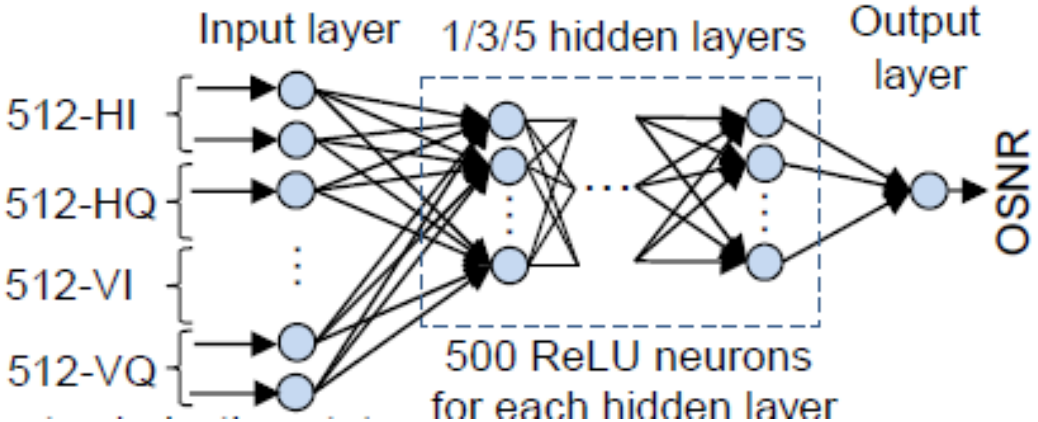
Optical Performance Monitoring

Source 2

- OSNR monitoring



- 2048 (=512x4 values) input neurons
- 1/3/5 hidden layers
  - 500 neurons per layer
  - ReLU activation function
- Batch gradient descent
- 4k/40k/400k training points
- 10k test points



Optical Performance Monitoring

Source 2

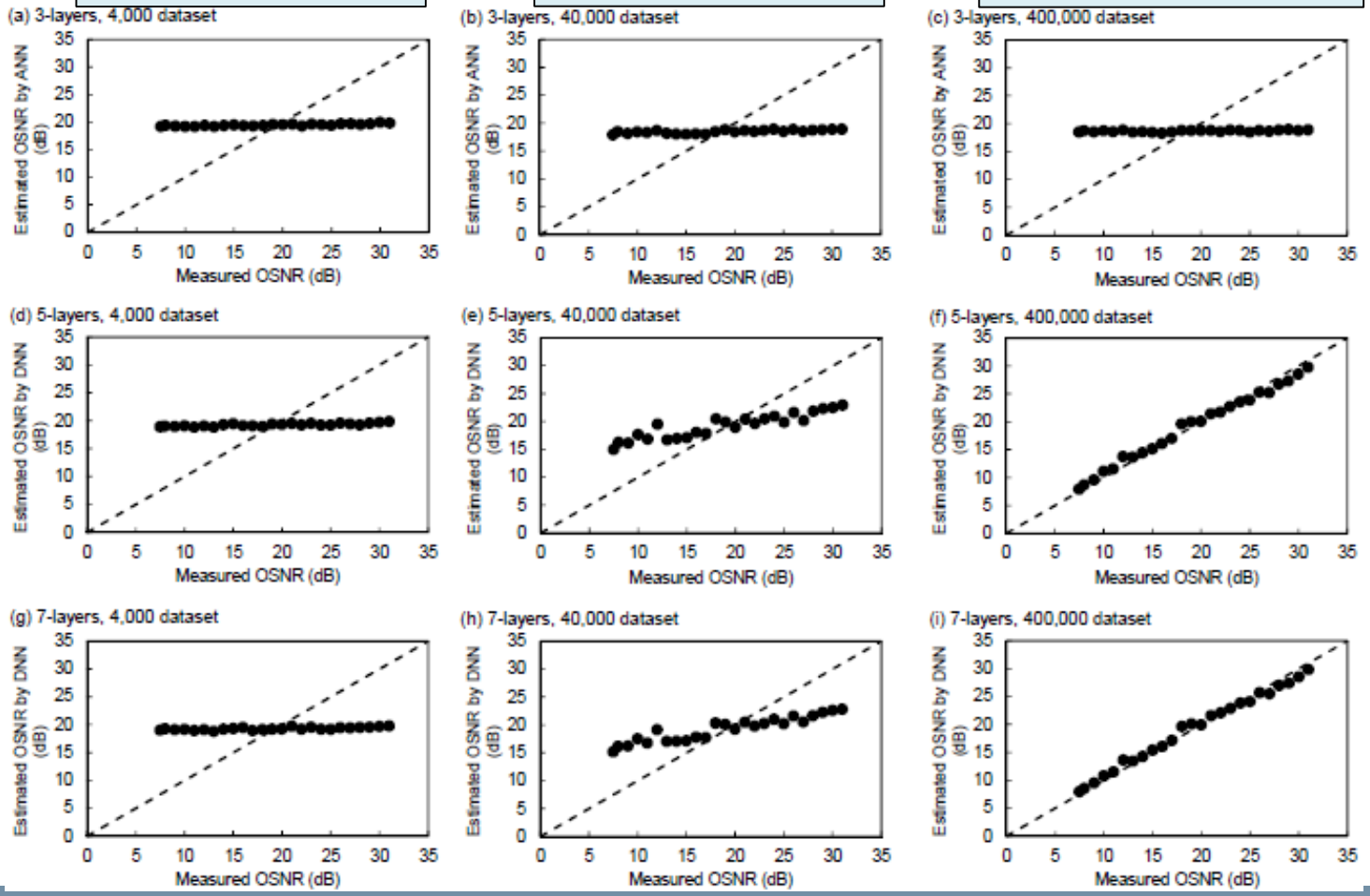
- Estimated vs measured OSNR: impact of train. set size and # hidden layers

4k training points | **40k** training points | **400k** training points

3-layers DNN

5-layers DNN

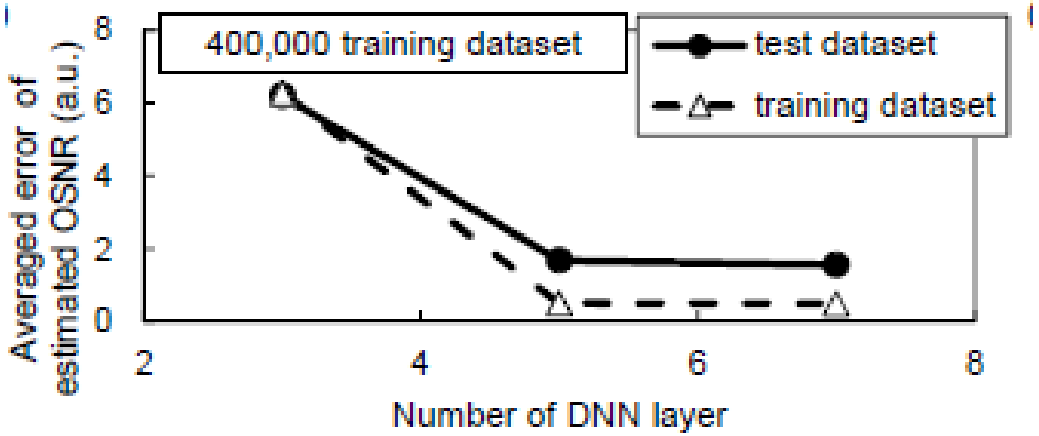
7-layers DNN

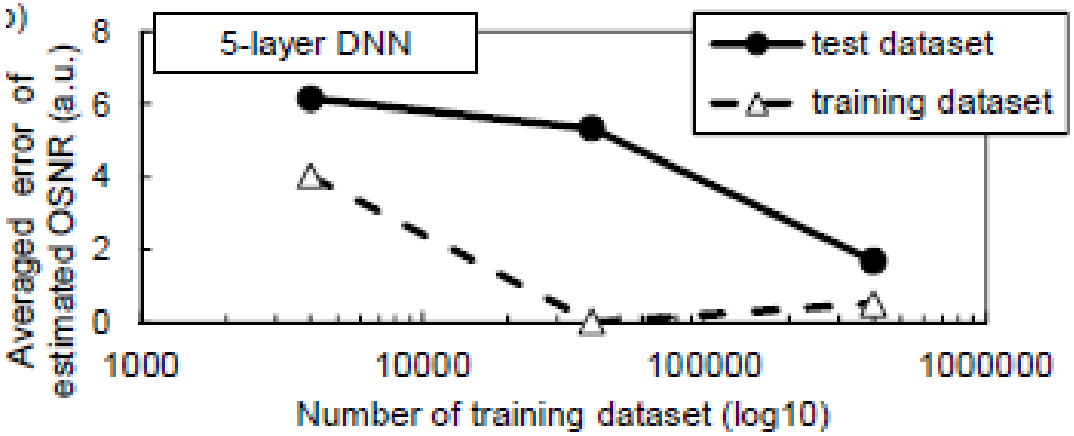


Optical Performance Monitoring

Source 2

- Training vs test error: impact of train. set size and # hidden layers





Optical Performance Monitoring

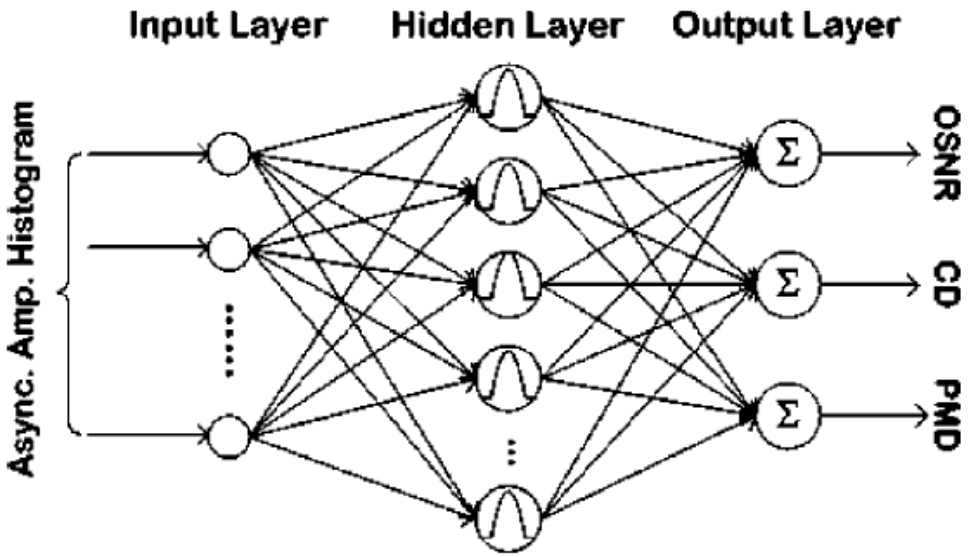
Source 3

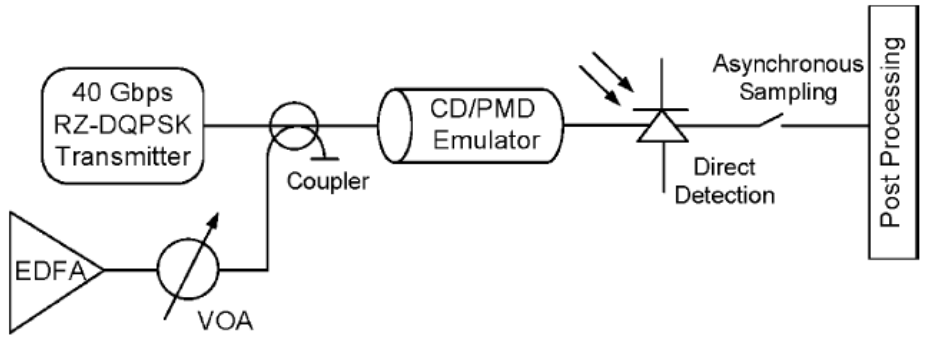
- Shen *et al.*, "Optical Performance Monitoring Using Artificial Neural Network Trained With Asynchronous Amplitude Histograms", *Photonic Technology Letters*, vol. 22, n. 22, Nov. 2010
- Paper objective: perform OPM for channel impairments
  - input
    - Asynchronous amplitude histograms (optical signal power)
  - output
    - OSNR
    - CD
    - PMD
  - ML algorithm: Neural Network

Optical Performance Monitoring

Source 3

- NN charachteristics:
  - Input (200 neurons)
    - 100: amplitude levels
    - 100: nr of occurrencies for each level
  - 1 hidden layer
  - Radial activation function in hidden nodes
  - Linear weighted function at the outputs
  - Separate NN training for different systems
    - RZ-DQPSK
    - NRZ-16QAM
  - 2706 histograms for training/testing
    - obtained changing OSNR, CD and PMD
    - 700 histograms randomly chosen to form test set

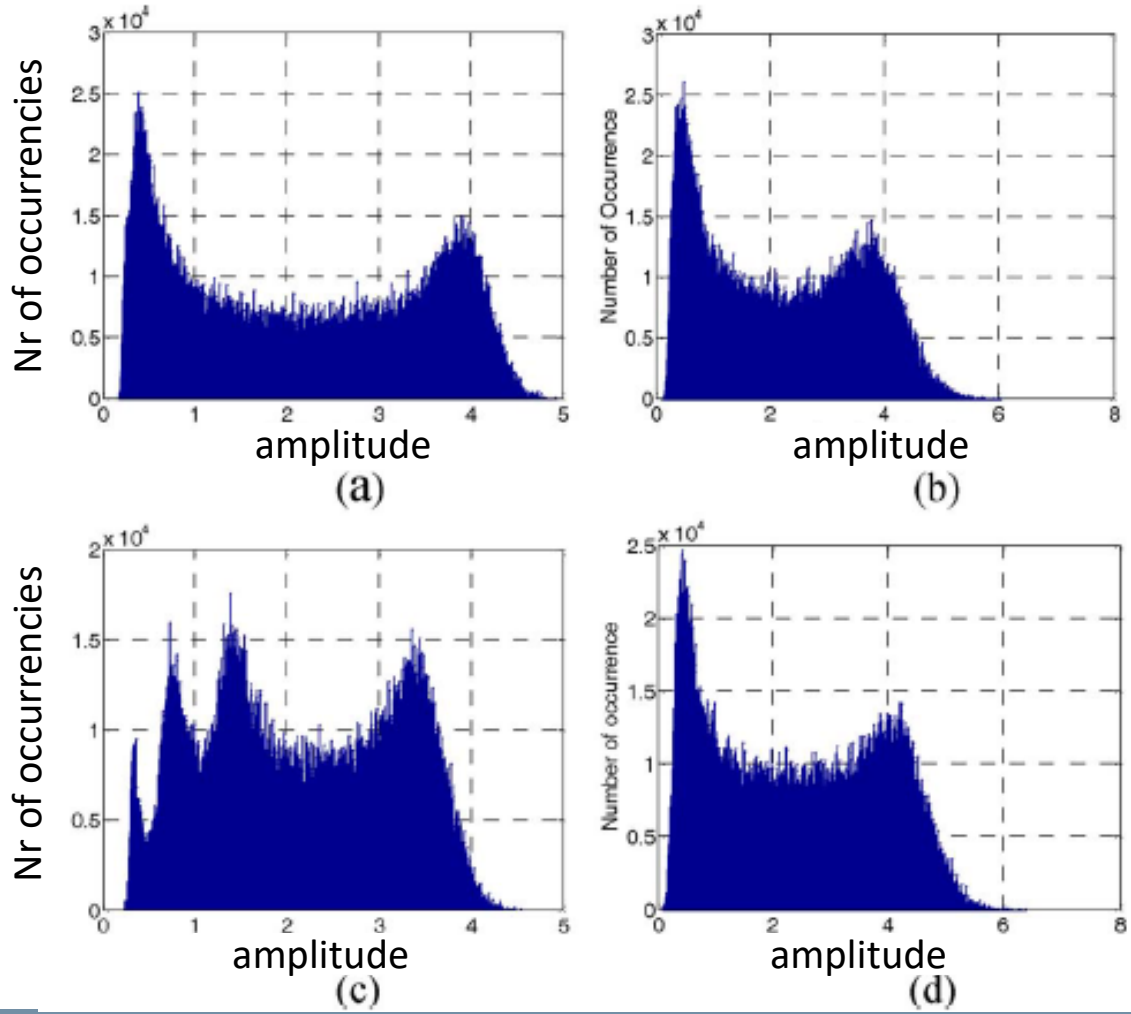




Optical Performance Monitoring

Source 3

- Amplitude histograms - RZ-DQPSK



(a) OSNR = 30 dB; CD = 0 ps/nm; DGD = 0 ps

(b) OSNR = 24 dB; CD = 0 ps/nm; DGD = 0 ps

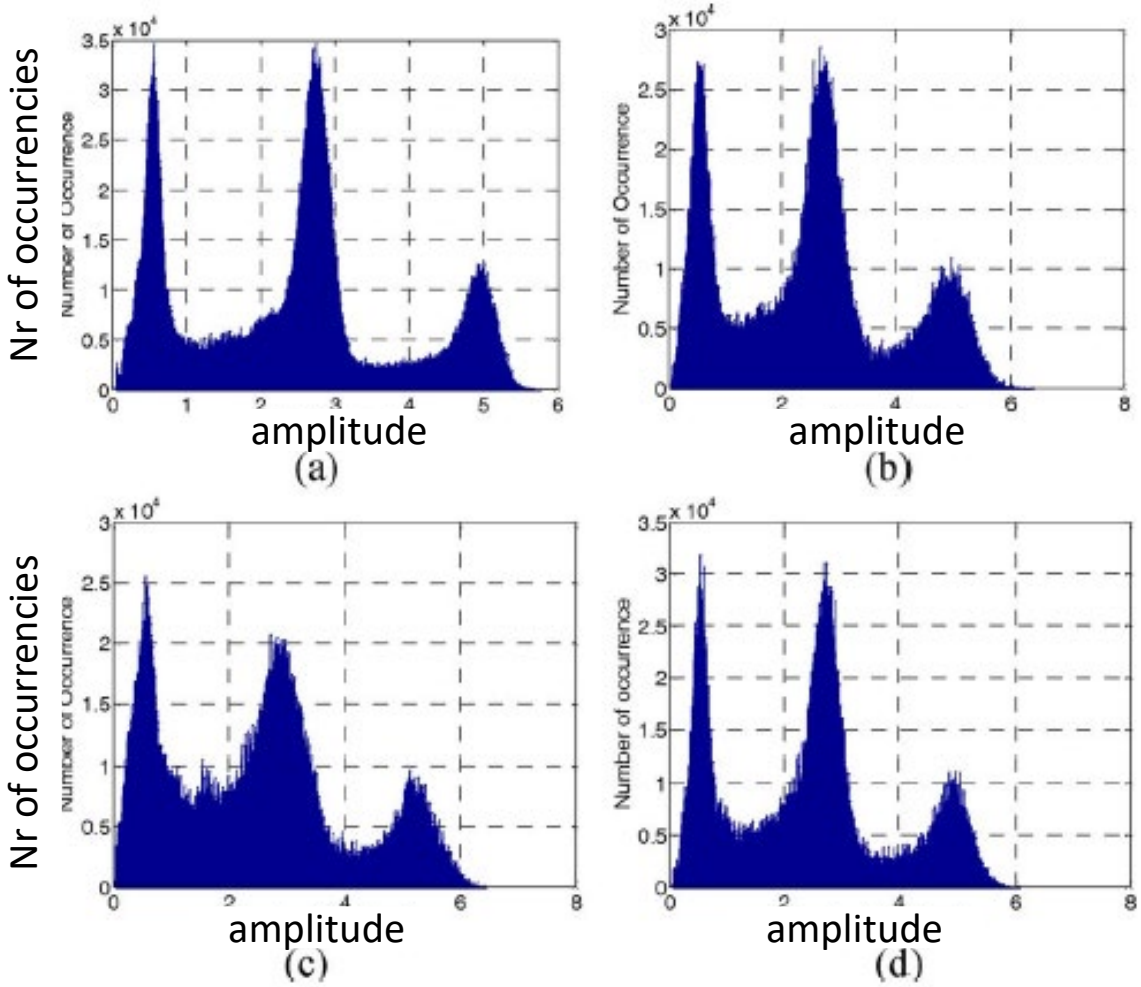
(c) OSNR = 30 dB; CD = 100 ps/nm; DGD = 0 ps

(d) OSNR = 30 dB; CD = 0 ps/nm; DGD = 10 ps

Optical Performance Monitoring

Source 3

- Amplitude histograms - NRZ-16QAM



(a) OSNR = 30 dB; CD = 0 ps/nm; DGD = 0 ps

(b) OSNR = 25 dB; CD = 0 ps/nm; DGD = 0 ps

(c) OSNR = 30 dB; CD = 250 ps/nm; DGD = 0 ps

(d) OSNR = 30 dB; CD = 0 ps/nm; DGD = 10 ps

Optical Performance Monitoring

Source 3

- Results
  - RZ-DQPSK

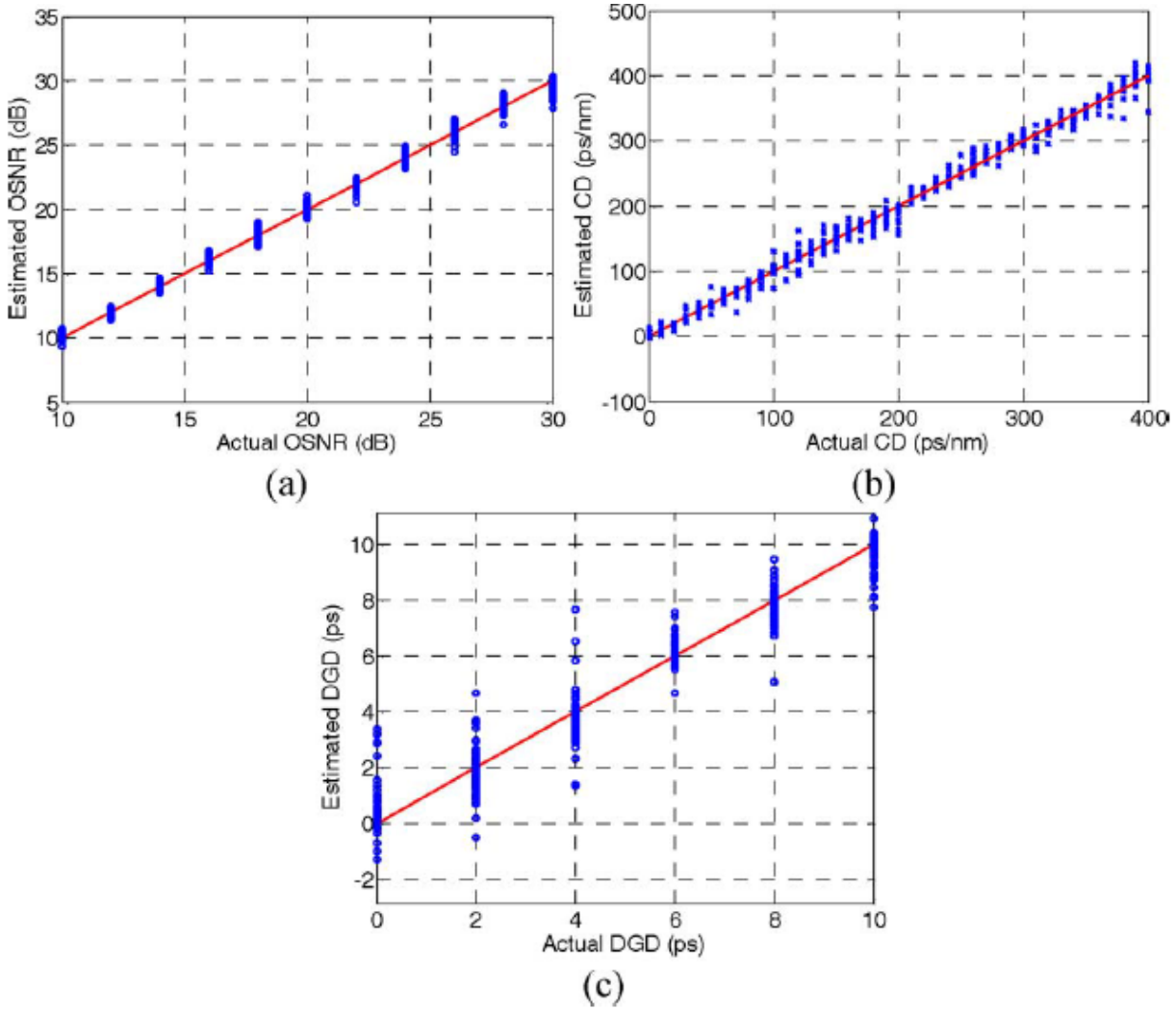


Fig. 4. (a) OSNR, (b) CD, and (c) DGD monitoring results for a 40-Gb/s RZ-DQPSK system using ANN with AAH as inputs.

Optical Performance Monitoring

Source 3

- Results
  - NRZ-16QAM

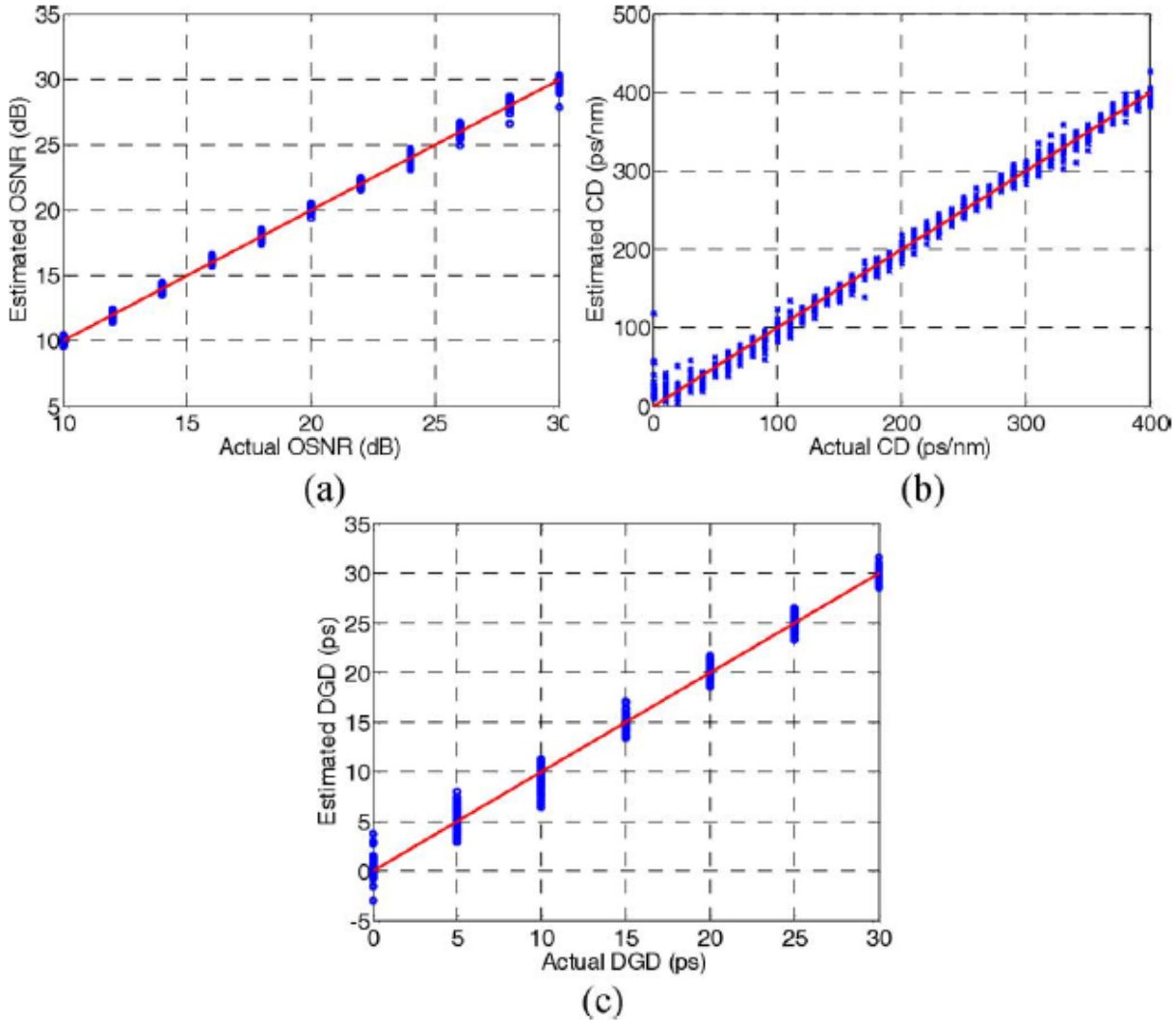


Fig. 6. (a) OSNR, (b) CD, and (c) PMD monitoring results for a 40-Gb/s NRZ-16-QAM system using ANN with AAH as inputs.