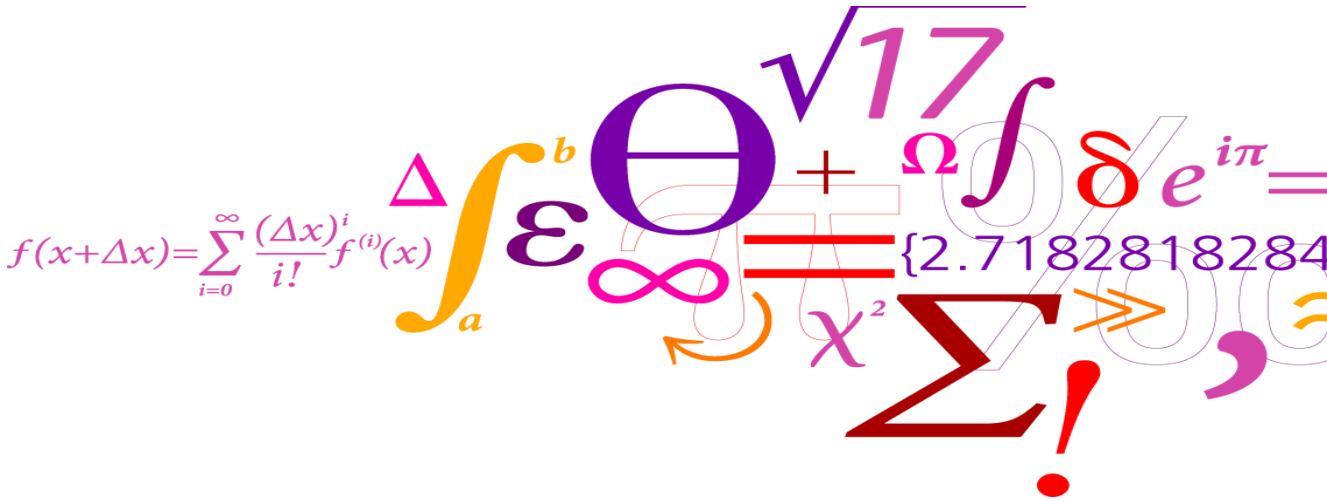
Neural Network based Hybrid Optical-Digital Equalization for Short-reach Transmission

Francesco Da Ros[1*], Stenio M. Ranzini[1], Hennning Bülow[2], and Darko Zibar[1]

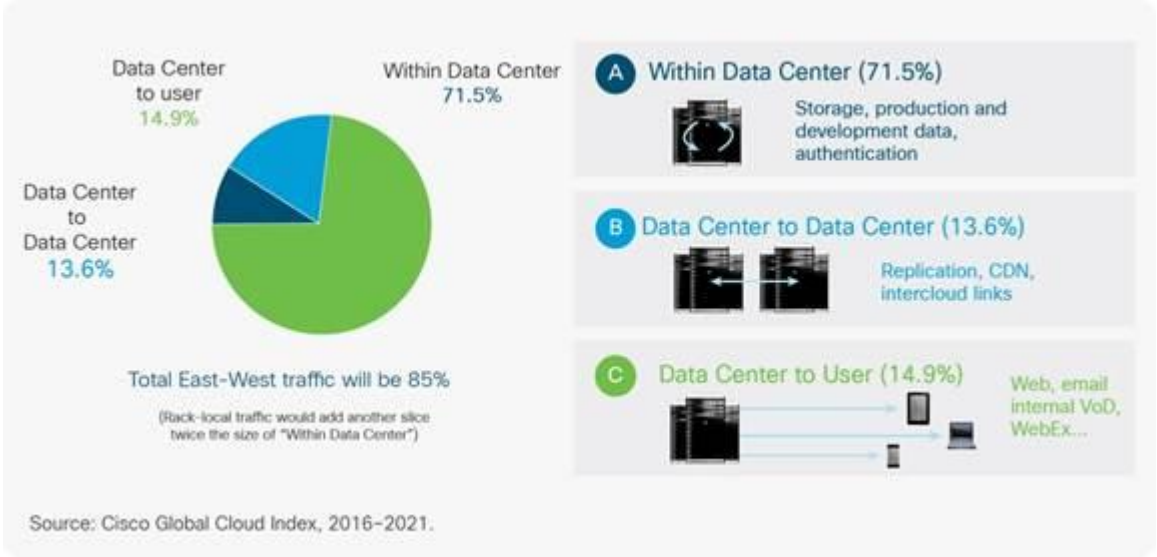
[1]Machine Learning in Photonic Systems, Technical University of Denmark
[2]Nokia Bell Labs, Stuttgart
*fdro@fotonik.dtu.dk



NOKIA Bell Labs

DTU Fotonik
Department of Photonics Engineering

Data rate / transmission reach demand



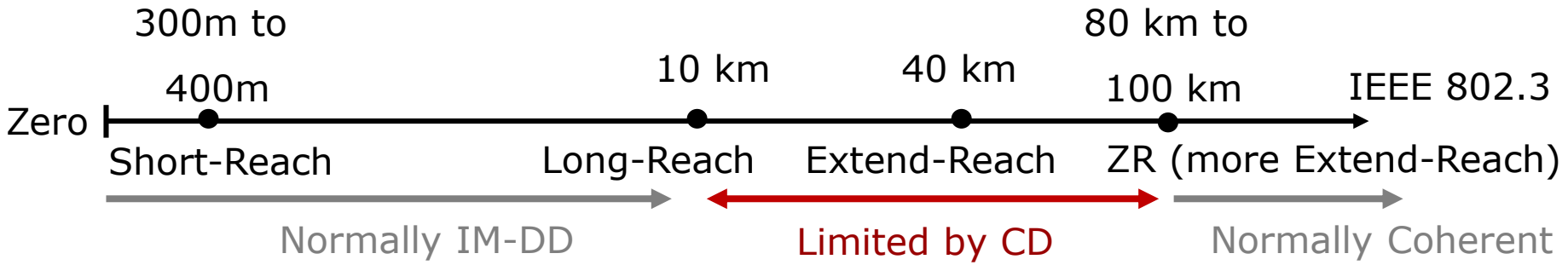
Data centers are one of the fastest growing segments of the optical communication system market

Data centers communications focuses on different requirements compared to medium/long haul systems:

- Direct-detection
- Low-latency
- Low complexity

⟷ Fiber chromatic dispersion induces inter-symbol interference (ISI) → **Limited transmission reach**

Short-reach scenarios



Optical compensation

High loss

High latency

Not anymore

Coherent systems

Power hungry

Expensive

High latency

Not yet

Digital equalization

Quite complex

Potentially power hungry

Maybe

Hybrid compensation

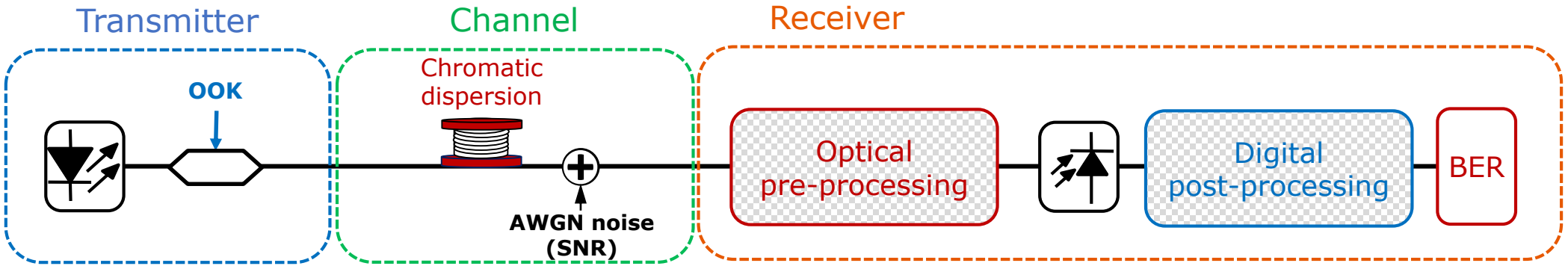
Share complexity between domains

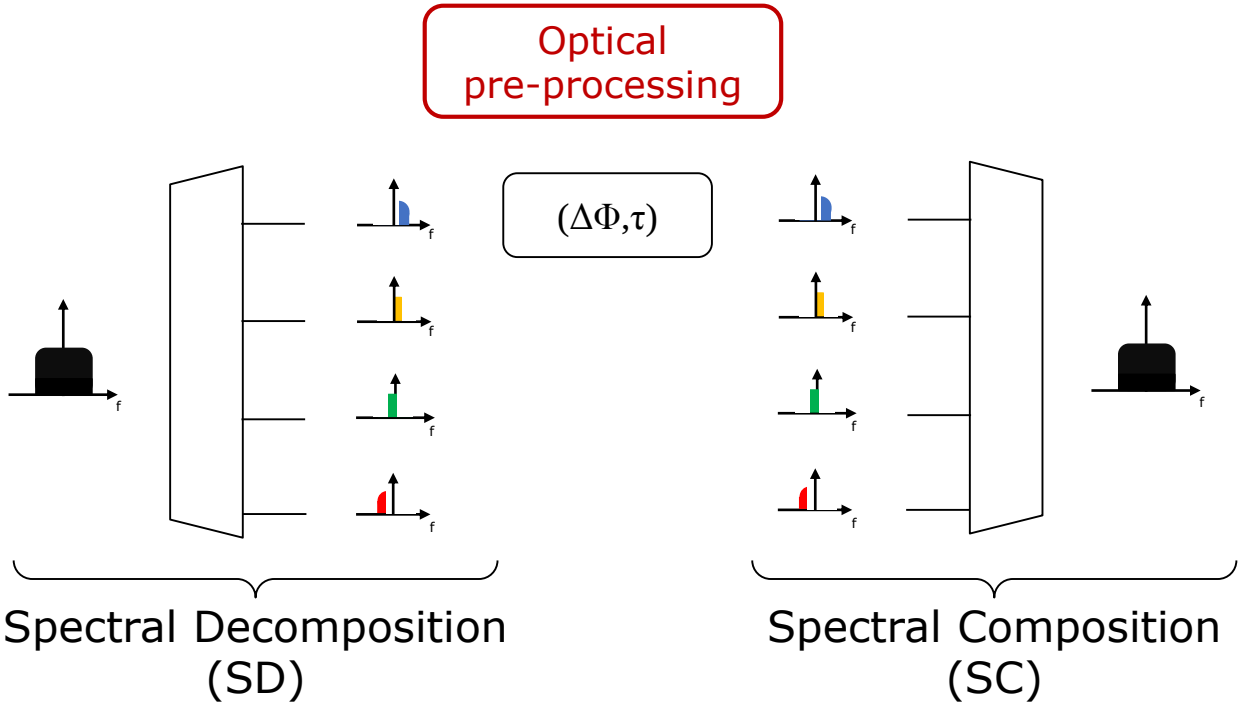
Maybe

Outline

- Motivation
- **System under test**
- Neural-network based post-processing
  - Feed-forward neural networks
  - Reservoir computing
- Spectral-slicing optical pre-processing
- Hybrid optoelectronic equalization
  - Spectral slicing and feed-forward neural networks
  - Spectral slicing and reservoir computing
- Conclusions

System under test





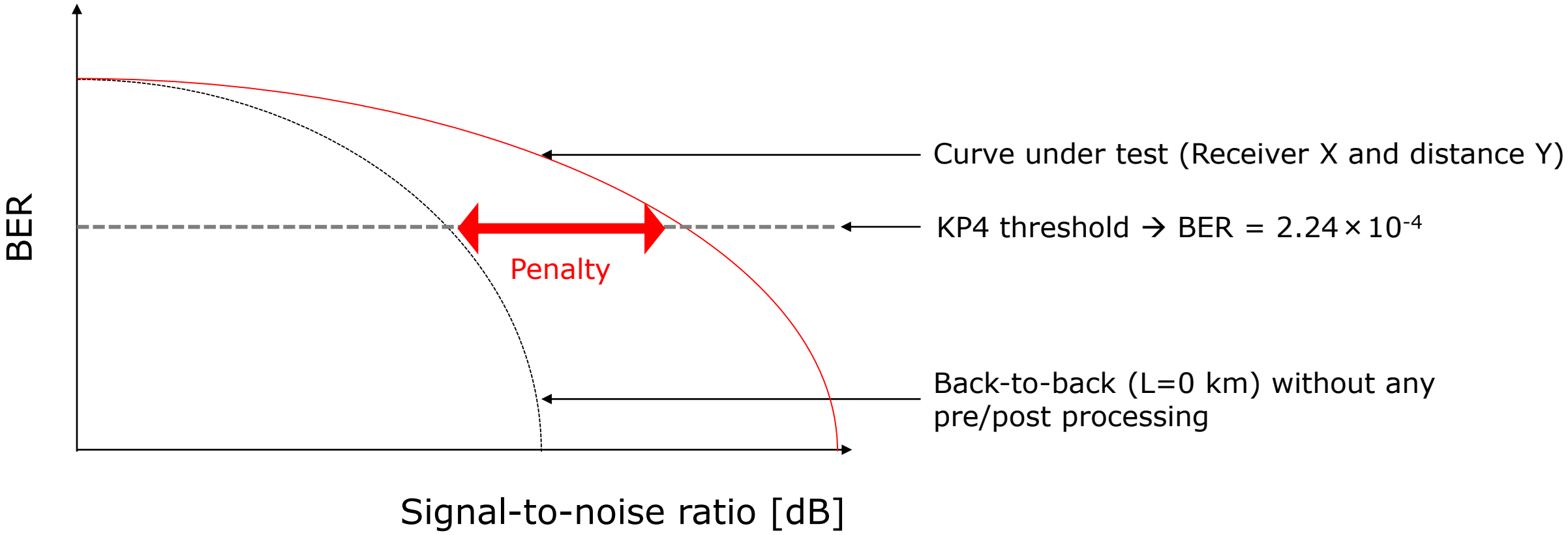
Digital post-processing

Maximum likelihood sequence estimation

Feed-forward NN

Reservoir computing

Penalty definition



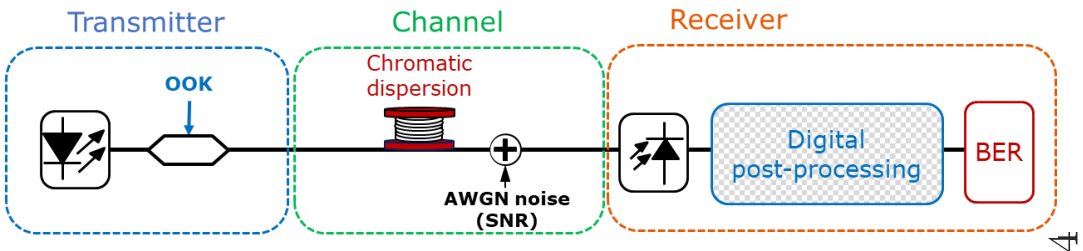
All the schemes will be benchmarked against the SNR penalty compared to the 0-km without any processing

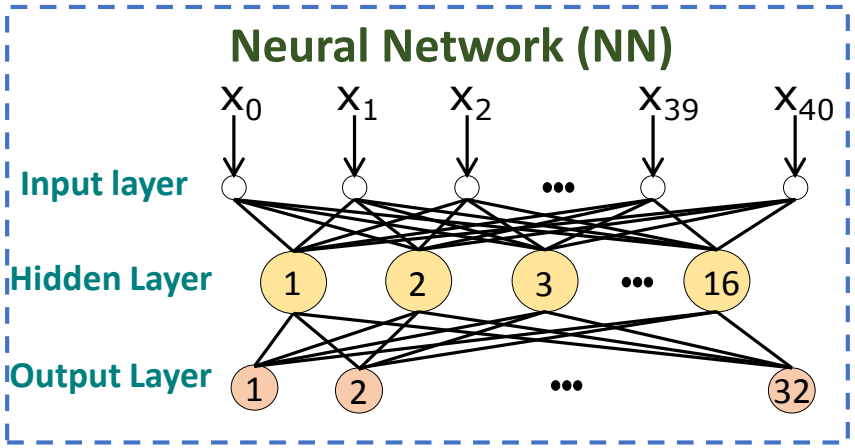
Outline

- Motivation
- System under test
- **Neural-network based post-processing**
  - Feed-forward neural networks
  - Reservoir computing
- Spectral-slicing optical pre-processing
- Hybrid optoelectronic equalization
  - Spectral slicing and feed-forward neural networks
  - Spectral slicing and reservoir computing
- Conclusions

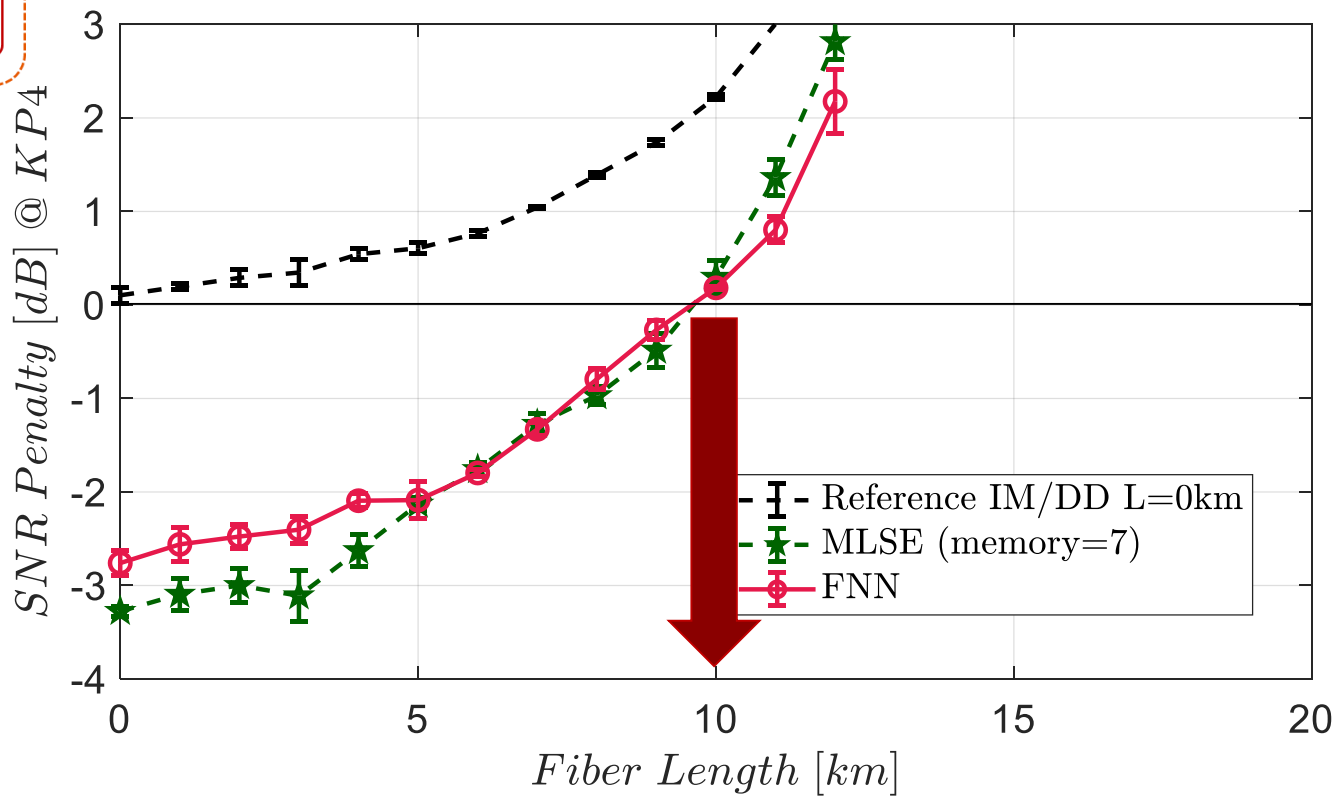
Digital-only equalization

Feed forward NN





Sliding-window with 5-symbols/window

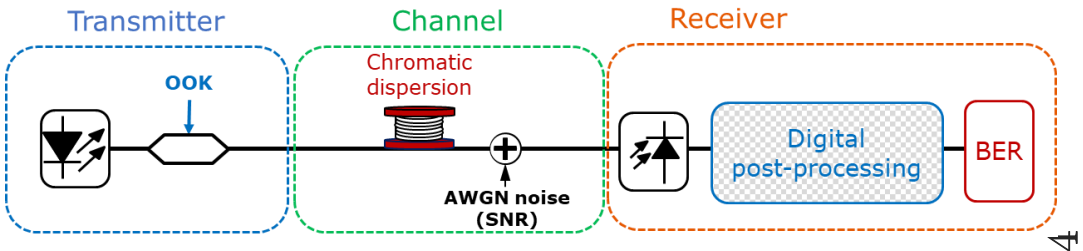


Significant performance improvement but with high-complexity training which needs to be repeated for each length.

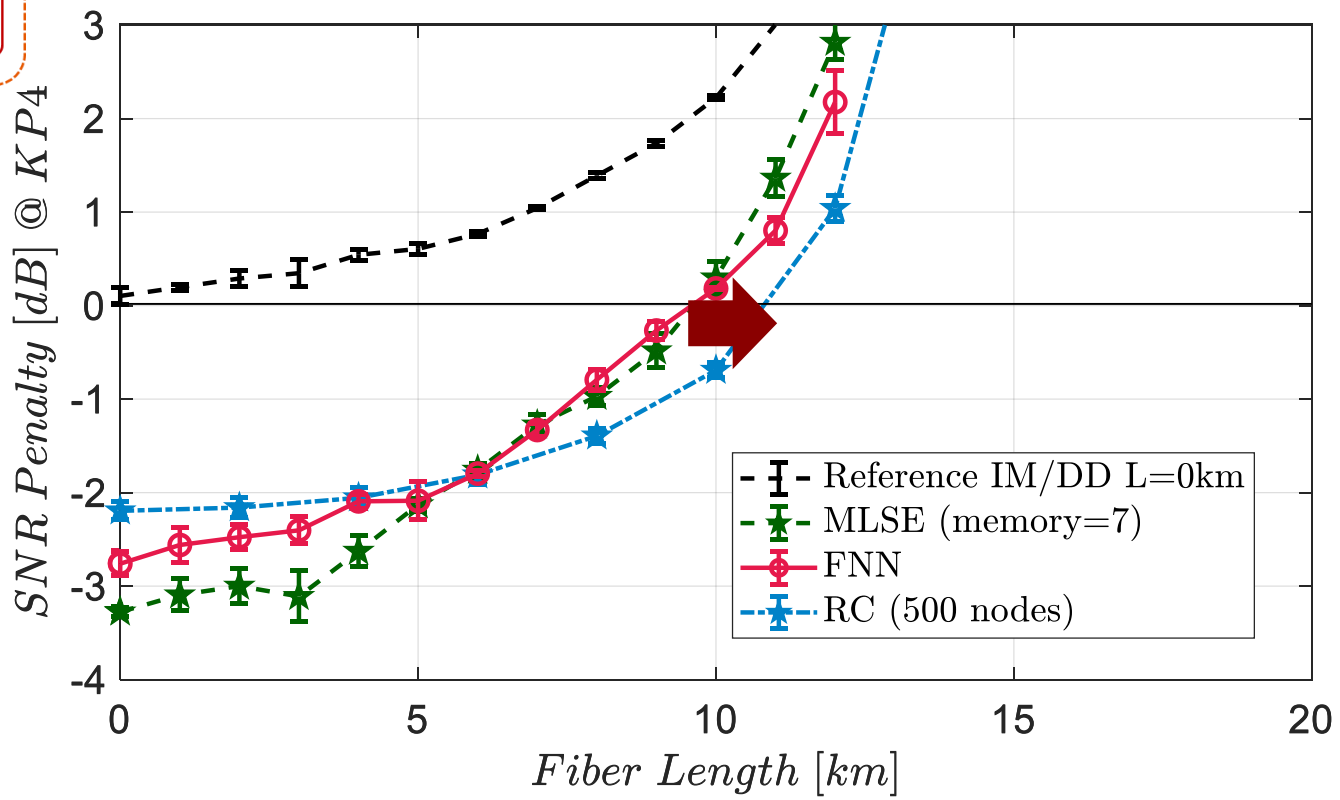
S.M. Ranzini, et al., Appl. Science 2019

Digital-only equalization

Reservoir computing



- Reservoir of 500 nodes with a 99% sparsity.
- Interconnections with uniform weights [0,1]
- Linear regression for output layer training.
- Impact of different reservoir properties (size/memory/nonlinear dynamics) tested



Small improvement but significantly faster training (lower complexity).

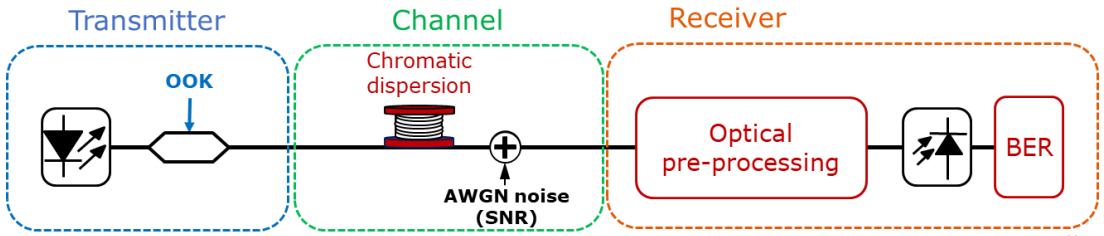
F. Da Ros, JSTQE, submitted 2019

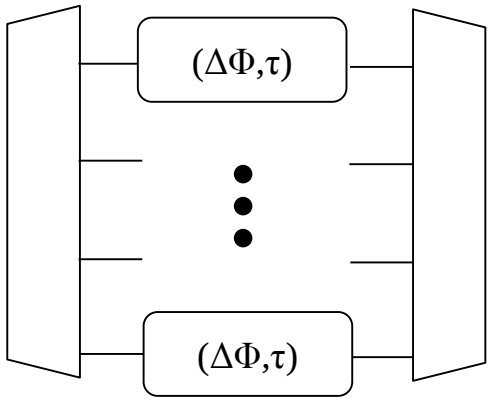
Outline

- Motivation
- System under test
- Neural-network based post-processing
  - Feed-forward neural networks
  - Reservoir computing
- **Spectral-slicing optical pre-processing**
- Hybrid optoelectronic equalization
  - Spectral slicing and feed-forward neural networks
  - Spectral slicing and reservoir computing
- Conclusions

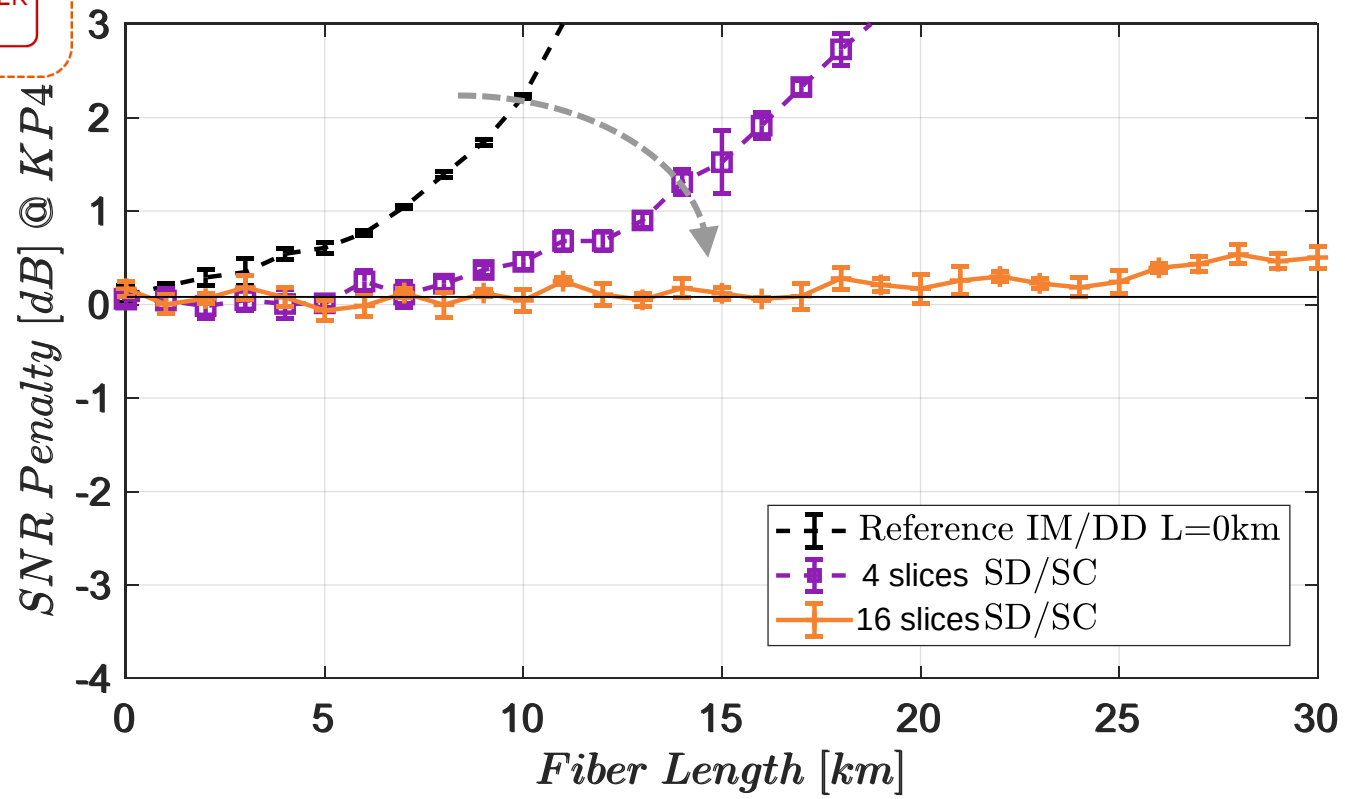
Optical-only equalization

Spectral slicing & recombining





Slice-wise dispersion compensation



Higher dispersion tolerance but no improvement, missing equalization.

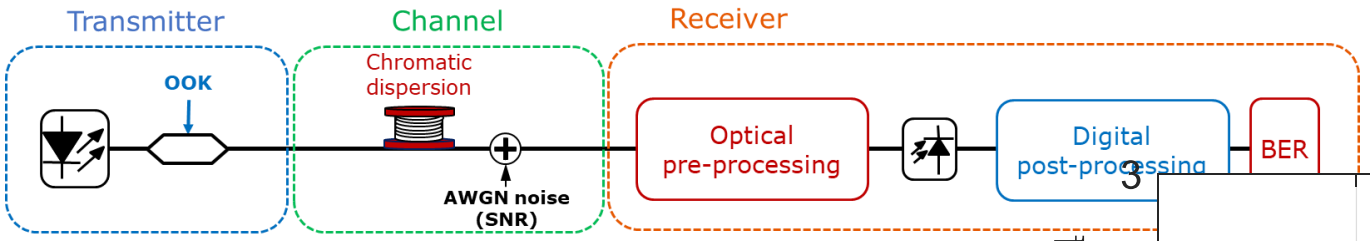
S.M. Ranzini, et al., Appl. Science 2019

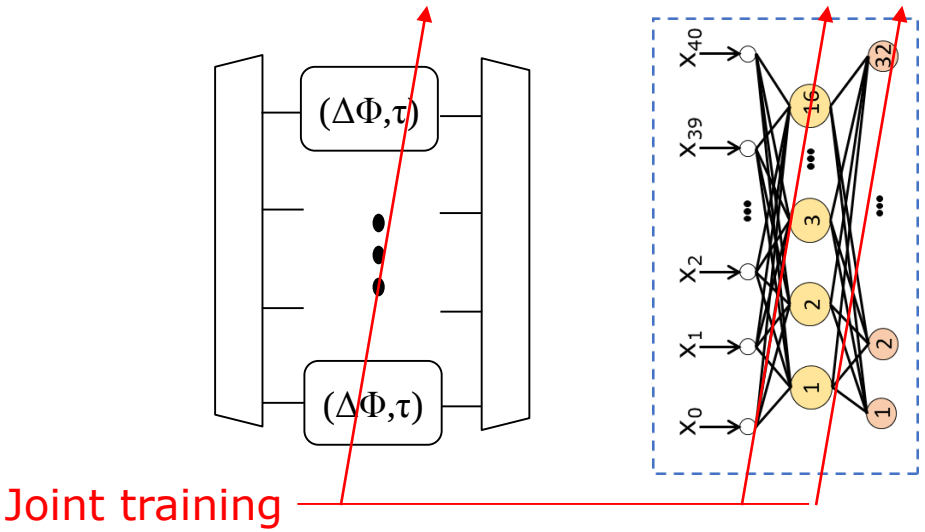
Outline

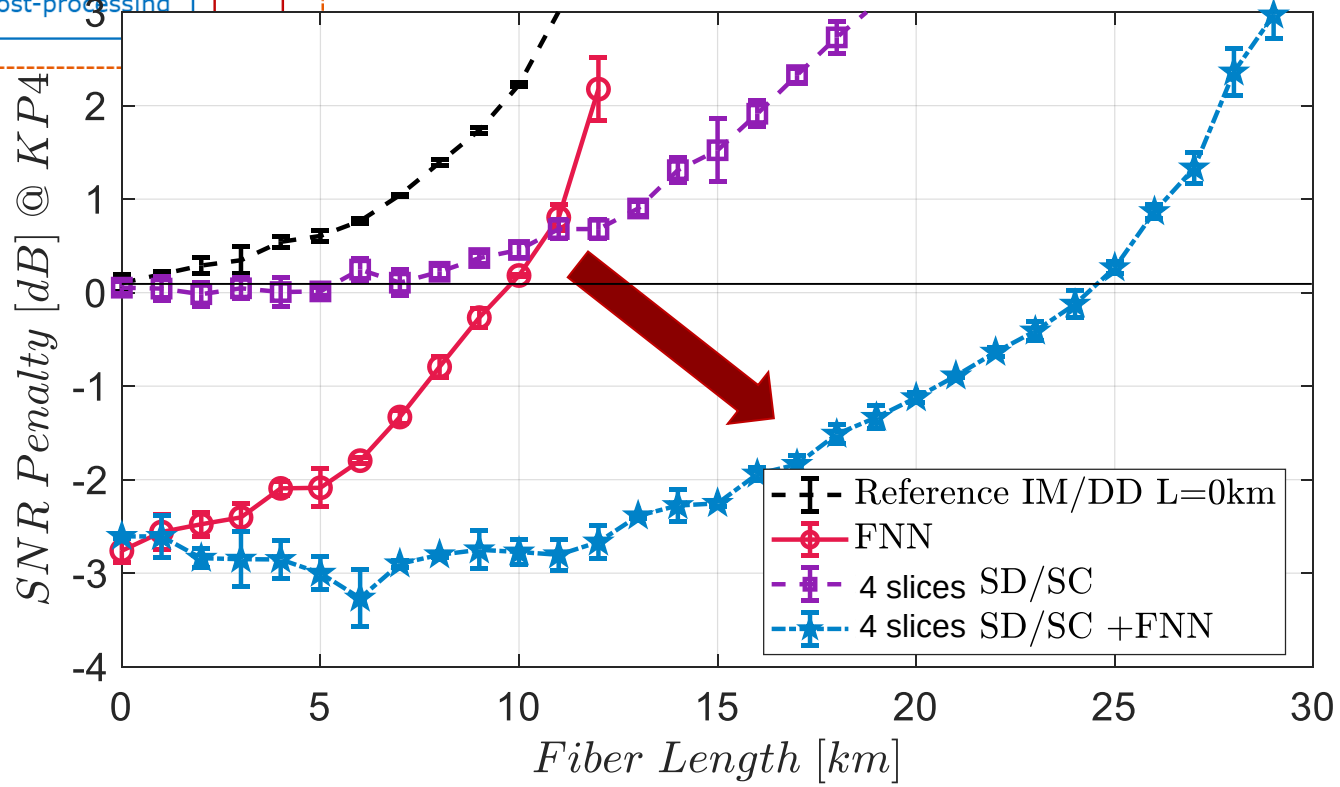
- Motivation
- System under test
- Neural-network based post-processing
  - Feed-forward neural networks
  - Reservoir computing
- Spectral-slicing optical pre-processing
- **Hybrid optoelectronic equalization**
  - Spectral slicing and feed-forward neural networks
  - Spectral slicing and reservoir computing
- Conclusions

Hybrid equalization

Spectral slicing, spectral recombining & FNN





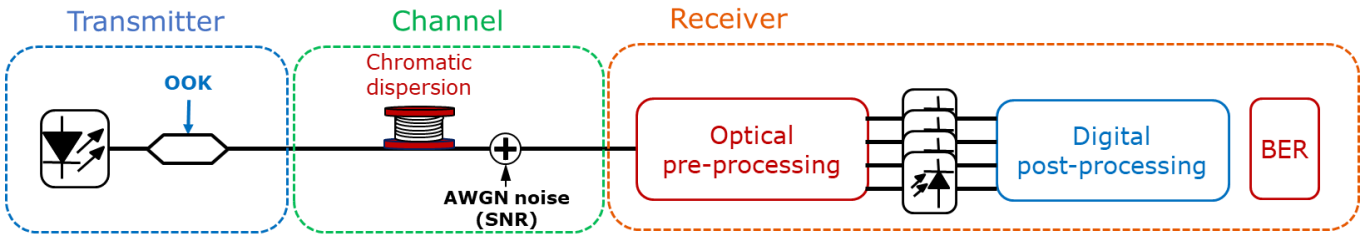


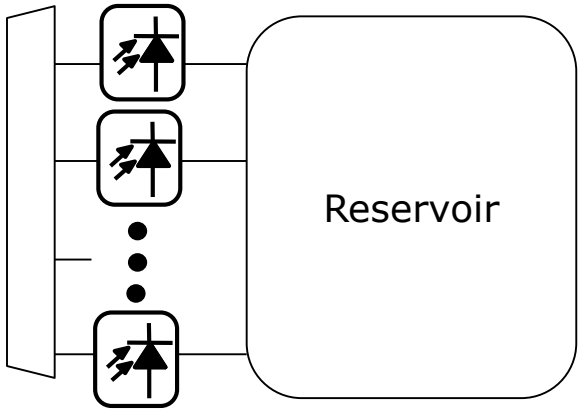
Combining processing in the optical domain and digital domain brings substantial improvements

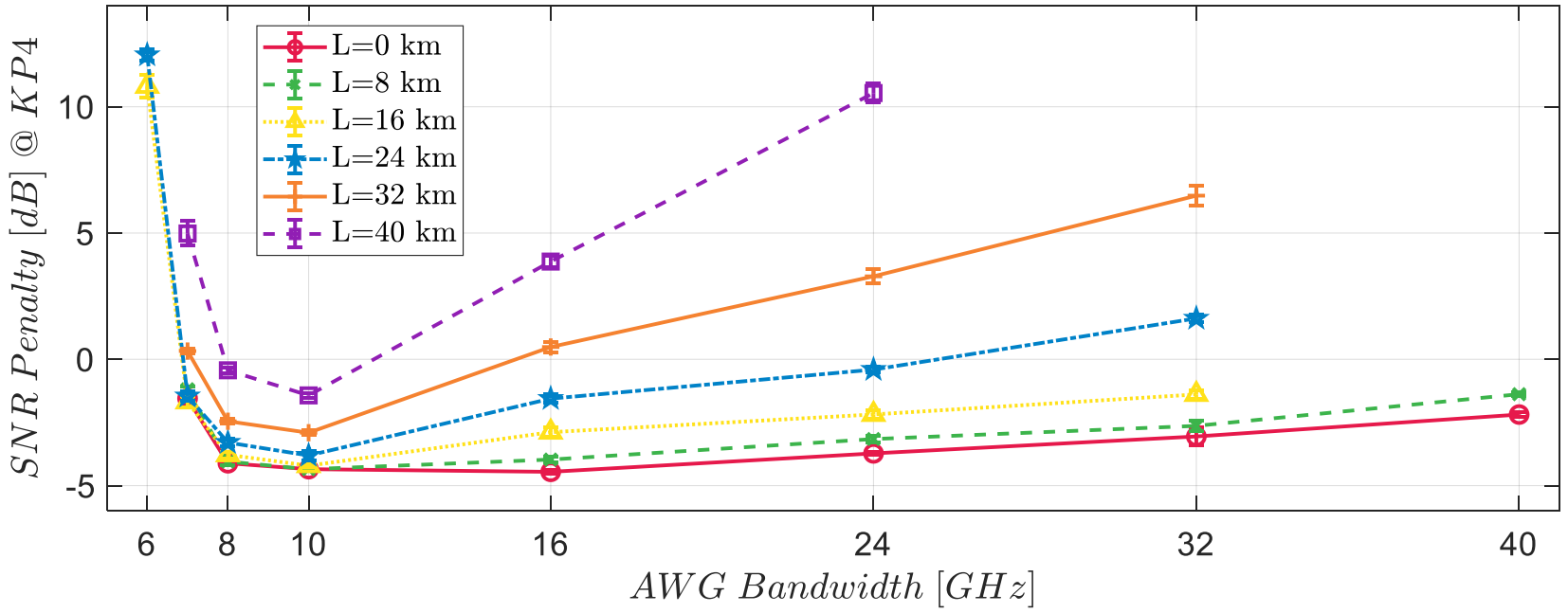
S.M. Ranzini, et al., Appl. Science 2019

Hybrid equalization

Spectral slicing, multiple PDs & RC





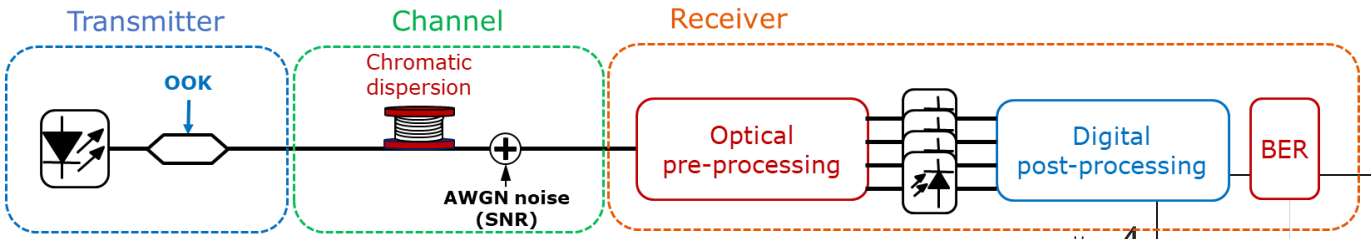


Optimum number of spectral slices: trade-off between the need for memory in the reservoir and the injection of noisy inputs

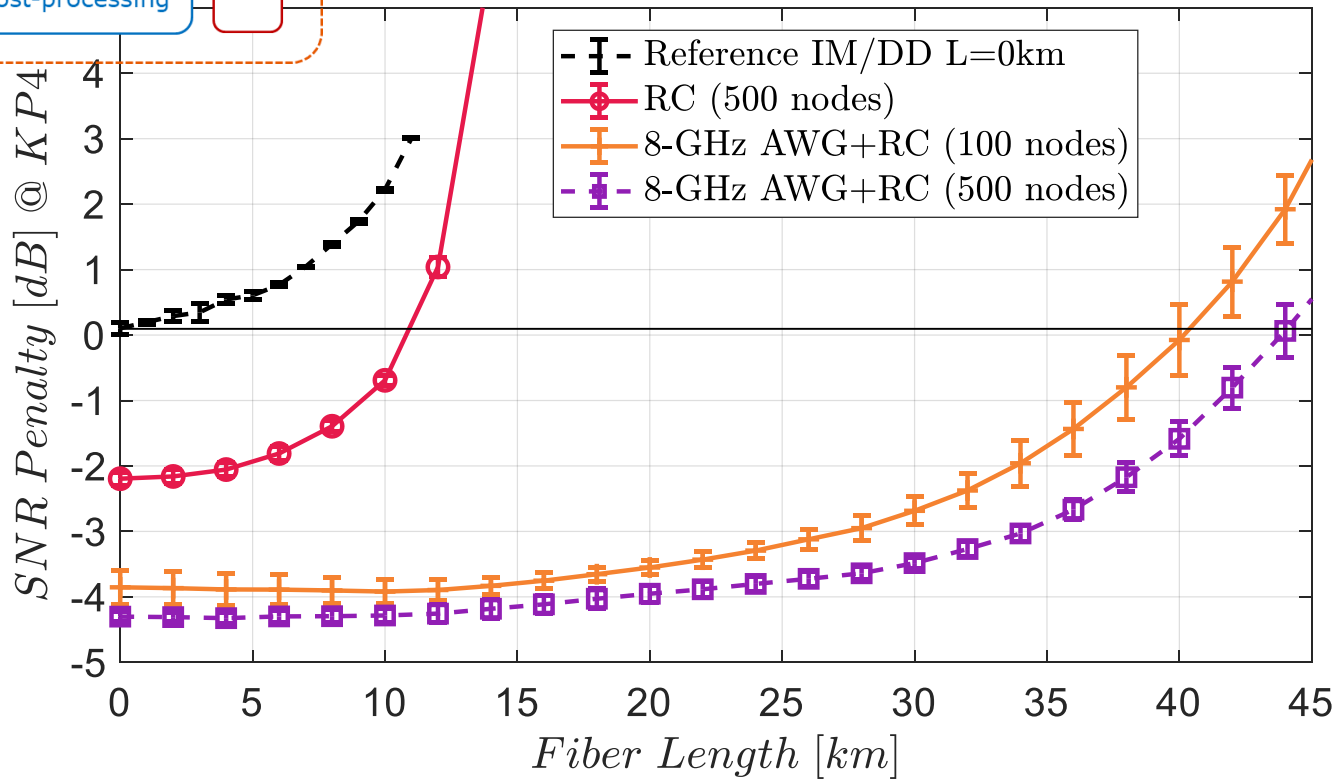
F. Da Ros, JSTQE, submitted 2019

Hybrid equalization

Spectral slicing, multiple PD receiver & RC



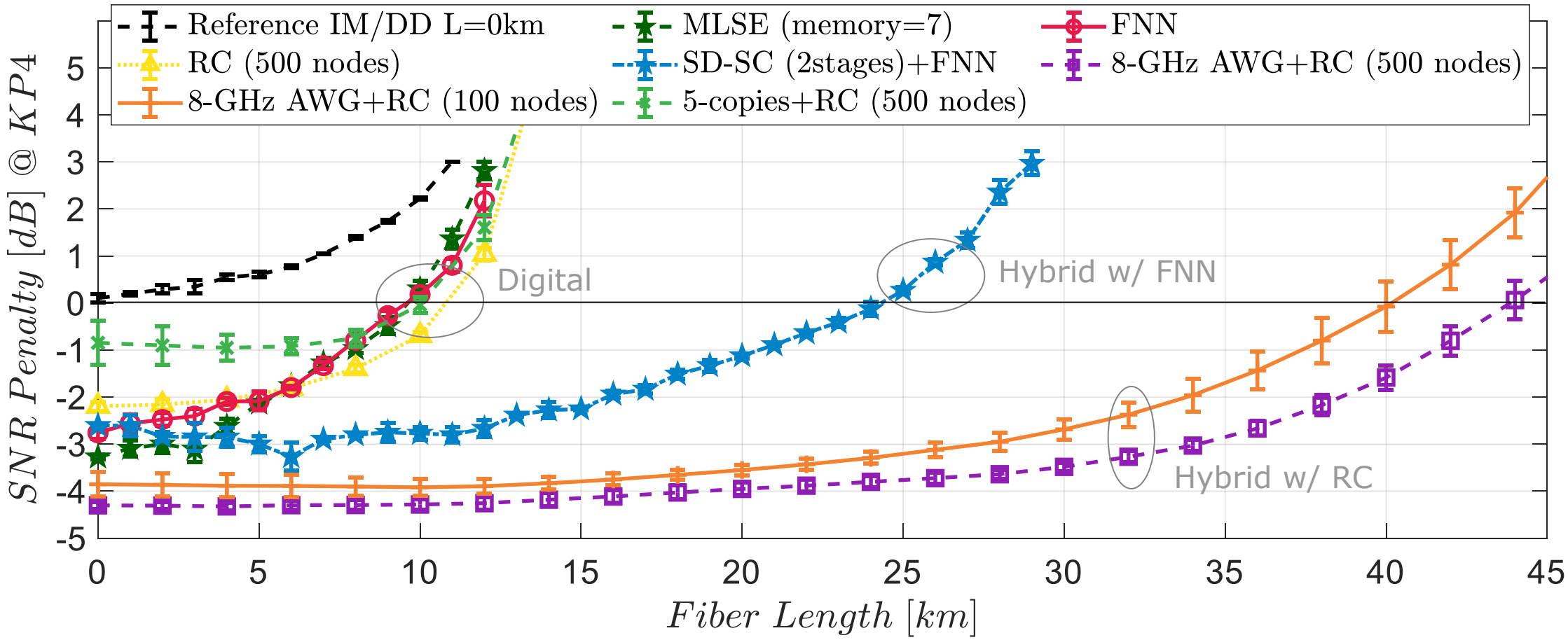
- <Interconnections> = 5
- Interconnections with uniform weights [0,1]
- Linear regression for output layer training.
- Impact of different reservoir properties (size/memory/nonlinear dynamics) tested



The spectrally sliced inputs is better matched to the memory of the reservoir, improving the compensation

F. Da Ros, JSTQE, submitted 2019

Overall comparison



Reservoir computing with appropriate signal pre-processing/pre-conditioning yields very significant improvement.

F. Da Ros, JSTQE, submitted 2019

Conclusions

- We have compared optical, digital and hybrid techniques for equalization of short-reach IM/DD transmission
- Standard digital-only techniques allow limited gain with relatively high training complexity
- Digital RC enables similar performance to standard techniques but with the advantage of a significantly faster training step
- Optical pre-processing/pre-conditioning of the signal can further improve the performance with a significant extension in reach, also for relatively small reservoirs.

Thank you for your attention.

Acknowledgements
European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 766115.
European 252 Research Council through the ERC-CoG FRECOM project grant agreement No 771878.