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Machine Learning Methods for Communication Networks and Systems – 051911

Francesco Musumeci

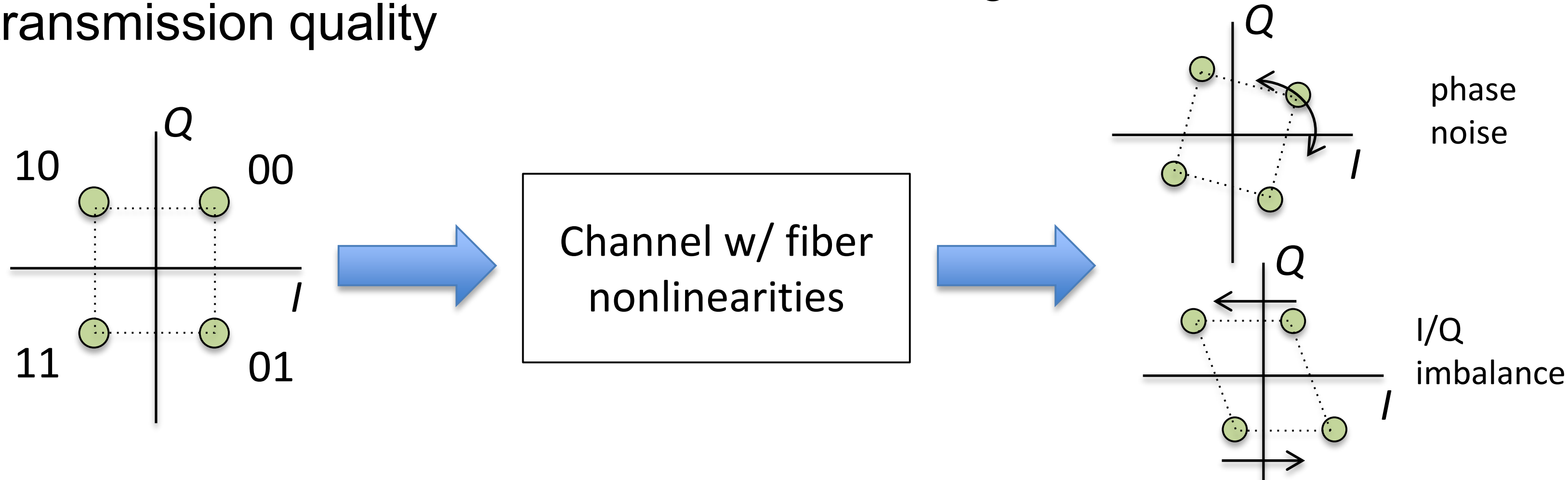
Dipartimento di Elettronica, Informazione e Bioingegneria (DEIB)

Politecnico di Milano, Milano, Italy

Part II – 6: Nonlinearities mitigation

Physical layer domain
Nonlinearities mitigation

- Traversing an optical fiber system, optical signal detection can be affected by fiber nonlinearities
  - Kerr effect, self-phase modulation (SPM), cross-phase modulation (XPM)…
  - This limits the transmission distance and degrades BER and transmission quality



- Traditional methods for nonlinearities mitigation require complex mathematical models and prior information on the traversed channel
- ML enables “safer” decision by learning from actual channel properties and allows increased transmission distance

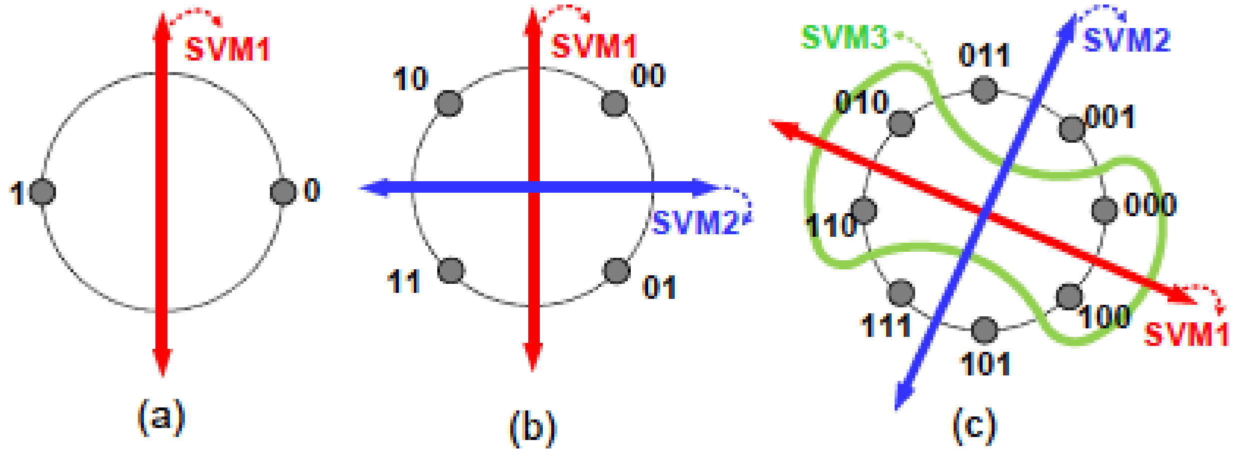
Nonlinearities mitigation
Source 1

- Wang *et al.*, "Nonlinear Decision Boundary Created by a Machine Learning-based Classifier to Mitigate Nonlinear Phase Noise", in *ECOC 2015*, Sep. 2015
- Paper objective: increase transmission distance and launch power dynamic range (LPDR) in optical fiber systems
  - input
    - Historical observation of signal transmission (I/Q samples)
  - output
    - Accurate decision boundaries for M-ary PSK modulation formats
  - ML algorithm: Support Vector Machines

Nonlinearities mitigation

Source 1

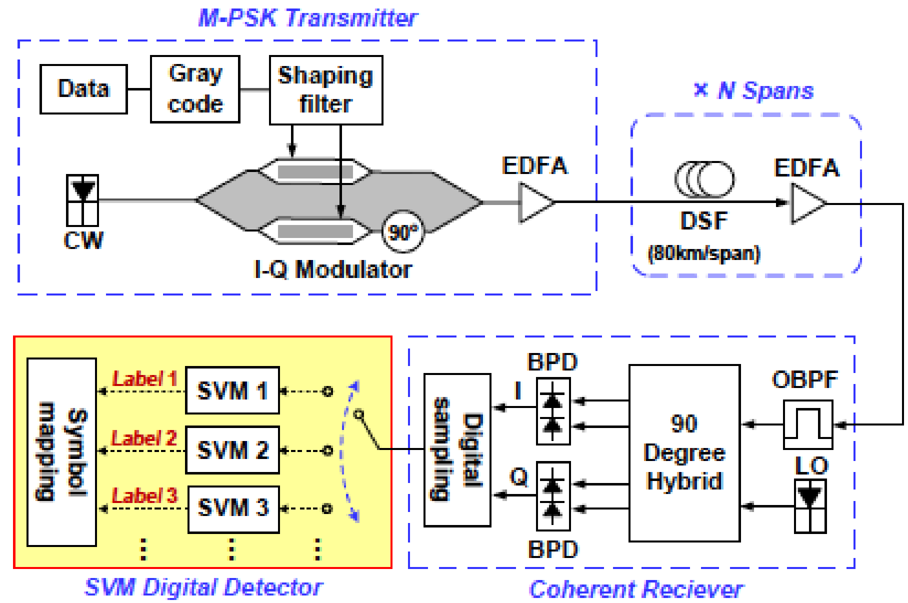
- SVM-based classifier
  - M-ary PSK is performad with $\log_2(M)$ independent SVMs (instead of M decision boundaries)
  - Each SVM "decides" one bit (SVM_i distinguishes i-th bit)
  - SVM enables ***nonlinear*** decision boundaries

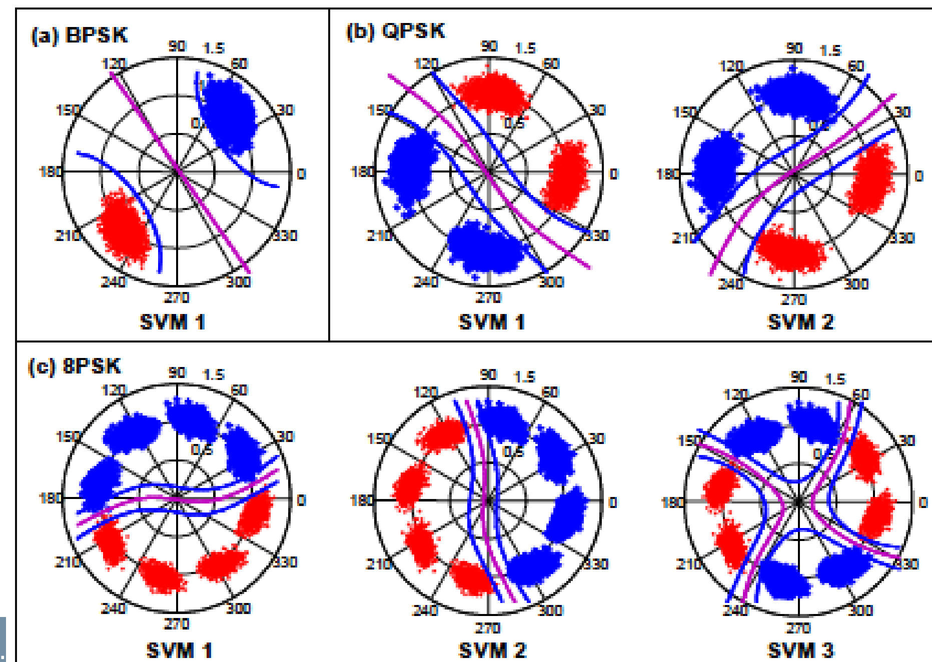


Nonlinearities mitigation

Source 1

- When nonlinearities are present, phase shifts are tightly dependend on the specific channel
  - Need to mitigate it!
- Test bed with Nx80km spans (up to N=50→4000km)
  - N=50 (BPSK)
  - N=35 (QPSK)
  - N=20 (8PSK)
- Dataset w/ 1000 training examples
- Each SVM is trained separately
  - decision boundaries w/ higher margins and robust w.r.t. phase distortions

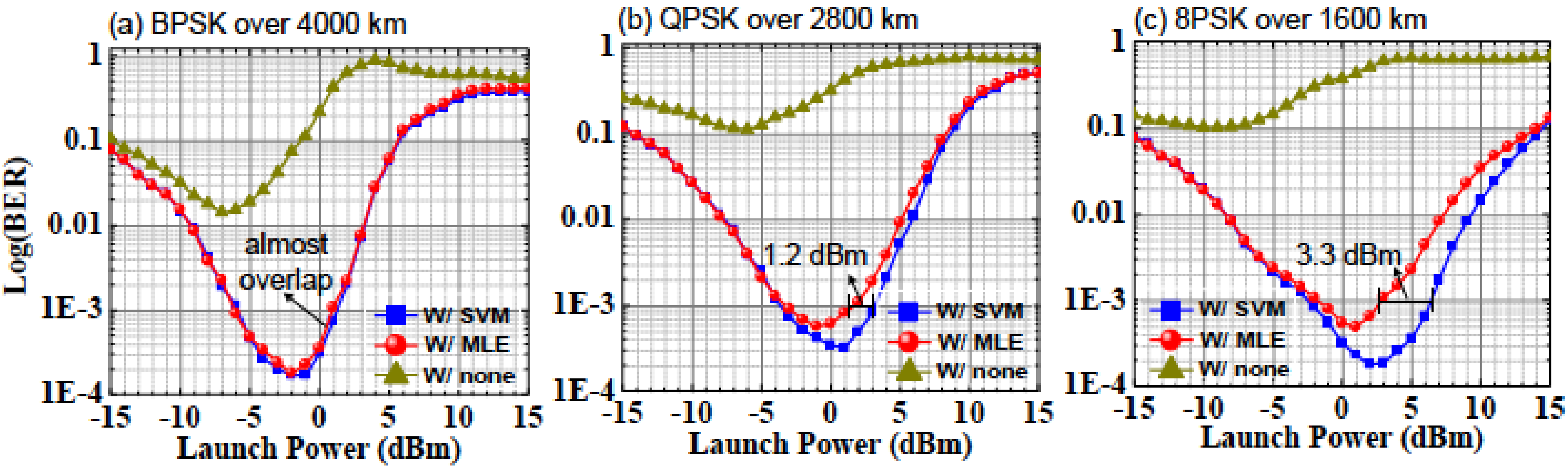




Nonlinearities mitigation

Source 1

- Results: comparison w/ other nonlinearities mitigation strategies
  - For a given BER (e.g., 10^{-3}) launch power dynamic (LPDR) is improved w/ SVM classification for all modulation formats

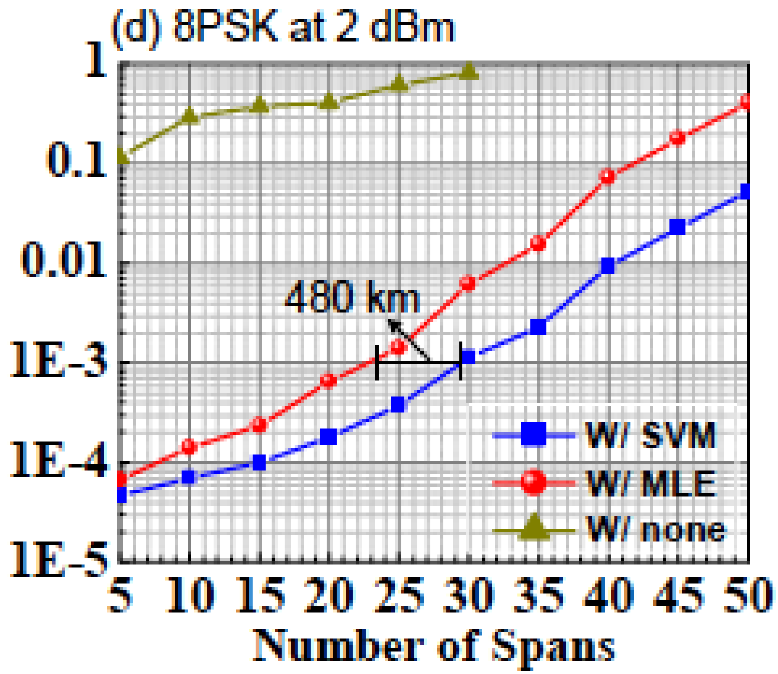


LPDR=Launch Power Dynamic Range

Nonlinearities mitigation

Source 1

- Results: sensitivity on transmission distance (8PSK)
  - Launch power = 2dBm as it gave the best performance for 8PSK SVM (see prev. slide)
  - SVM provides >480km improvement in transmission distance w.r.t. other approaches



Nonlinearities mitigation

Source 2

- Wang *et al.*, "Nonlinearity Mitigation Using a Machine Learning Detector Based on k-Nearest Neighbors", *Photonics Technology Letters*, vol. 28 n. 19, Oct. 2016
- Paper objective: increase transmission distance and launch power dynamic range (LPDR) in optical fiber systems
  - input
    - Historical observation of signal transmission (I/Q samples)
  - output
    - Accurate decision boundaries for 16QAM transmission
  - ML algorithm: KNN, distance-weighted KNN (DW-KNN)

Nonlinearities mitigation

Source 2

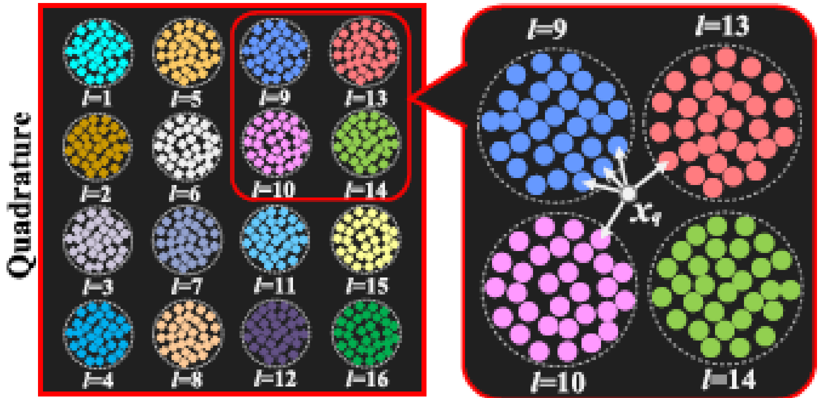
- KNN is used to determine QAM symbol and does not require training
- in some cases "simple" KNN is not sufficient (see fig. c)
  - DW-KNN: closer neighbors are more "important"

$$d(\mathbf{x}_q, \mathbf{x}_i) \equiv \sqrt{(I(\mathbf{x}_q) - I(\mathbf{x}_i))^2 + (Q(\mathbf{x}_q) - Q(\mathbf{x}_i))^2},\quad f_{KNN}(\mathbf{x}_q) = \arg\max_{l \in \mathrm{L}} \sum_{i \in N_k(\mathbf{x}_q)} \delta(l,\ l_i),$$

$\delta(l, l_i) = 1$ if $l = l_i$, and $\delta(l, l_i) = 0$ if $l \neq l_i$

$$f_{\omega KNN}(\mathbf{x}_q) = \operatorname{argmax}_{l \in \mathrm{L}} \sum_{i \in N_k(\mathbf{x}_q)} \omega_i \delta(l,\ l_i),$$

$$\omega_i \equiv 1/d(x_q,\ x_i)^2.$$

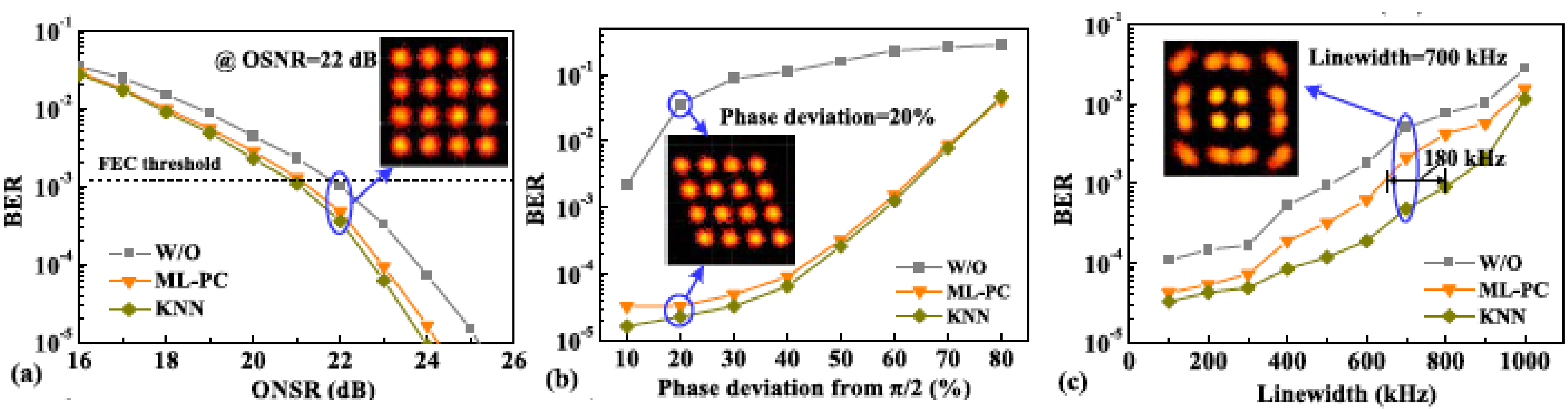


(a) Inphase (b) KNN (k=5)

Nonlinearities mitigation

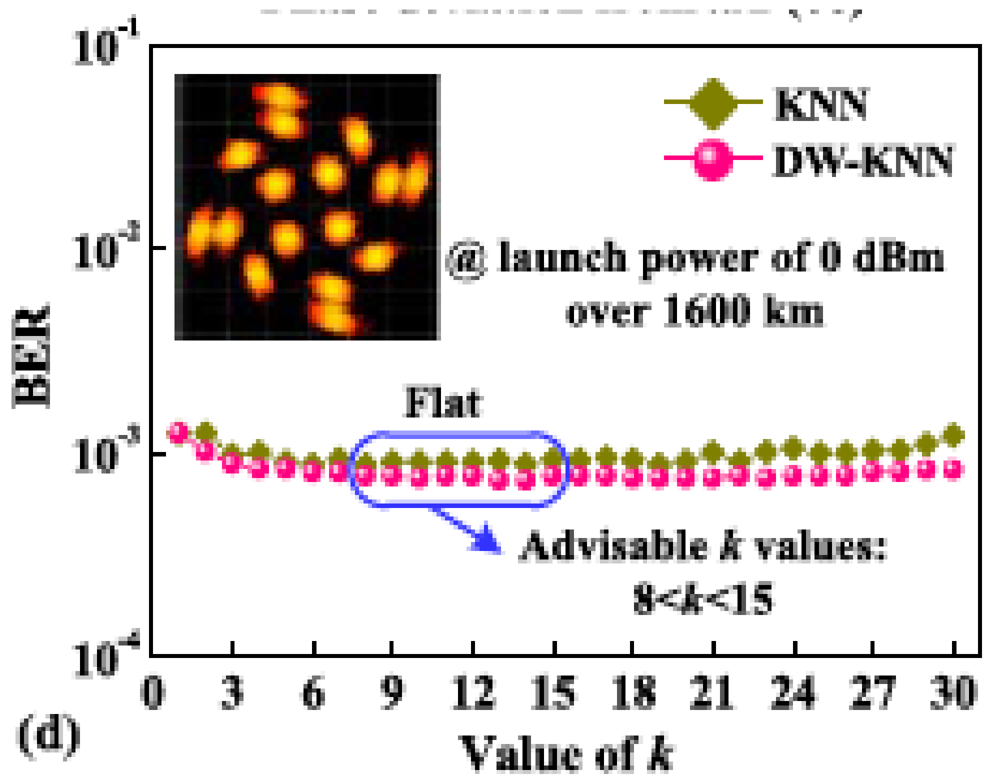
Source 2

- Results: KNN vs Max-Likelihood Post-Compensation (ML-PC)
  - (a): additive ASE (Gaussian) noise only
  - (b): I/Q imbalance
  - (c): I/Q imbalance+laser phase noise



Nonlinearities mitigation
Source 2

- Results: KNN vs DW-KNN with varying k



Nonlinearities mitigation
Source 2

- Results: KNN vs DW-KNN vs ML-PC
- DW-KNN provides:
  - increased launch power tolerance
  - increased transmission distance