Machine Learning Algorithms for Optical Fiber Telecoms

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Bangor University, Wales, UK (PhD)
- Optical transmission for >40-Gb/s local and access networks

Athens Information Technology centre, Athens, Greece
- Passive optical networks (PONs)

Telecom Paris-Tech, France (collaboration with France Telecom-Orange Labs)
- Coherent optical communications for >100-Gb/s multi-channels

Aston University, UK
- Digital signal processing (DSP)-based fibre nonlinearity compensation

University of Sydney, Sydney, Australia
- Machine learning DSP for optical commun. and photonic-chip applications

Dublin City University (DCU), Ireland (visiting researcher at Xilinx-Ireland)
- Real-time machine learning DSP for optical communications
Machine learning for optical communications

Machine Learning
- DET, KDE, GMM
- PCA, ICA
- IS, MCMC
- HMM (EKF, UKF, PF)
- ANN (MLP, HNN, RBM, CNN, RNN)
- SVM (kernel: polynomial, RBF, sigmoid)
- Deep learning (DBN, etc.)

Optical Communications
- Linearity: CD, PMD
- Nonlinearity: SPM, XPM, XPolM, FWM
- Nonlinear equalization
- Polarization recovery
- Carrier phase recovery
- Nonlinear capacity analysis
- Coded-modulation design
Photonics: machine learning under the spotlight
Typical optical communication system
DSP importance in optical communications

Introduce a known digital signal for measuring waveform distortion due to CD.

Rapidly measures waveform distortion from the known digital signal, and cancels waveform distortion.
Constellation diagrams for modulation

1) Information is in amplitude
2) Information is in phase

We have constructed 4 vectors → One vector position in the complex plane codes 2 bits
DSP receiver processing:

- Synchronization
- Optical carrier frequency offset compensation
- Linear Equalization & Machine Learning
- Data Recovery
Clustering-based machine learning

K-means

Fuzzy-logic c-means
Algorithm: k-means, Distance Metric: Euclidean Distance

Phase Modulator OCDMA setup

K-means: Step 1
Phase Modulator OCDMA setup

K-means: Step 2

expression in condition 1

expression in condition 2

$k_1$

$k_2$

$k_3$
Phase Modulator OCDMA setup

expression in condition 1

expression in condition 2

$K$-means: Step 3
K-means: Step 4

Expression in condition 1 vs. expression in condition 2

- $k_1$
- $k_2$
- $k_3$
K-means: Step 5

Phase Modulator OCDMA setup

expression in condition 1

expression in condition 2
Fuzzy-logic c-means

Single-dimensional data

MD: Membership Degree

Hard clustering

Fuzzy clustering
Received constellation diagrams for 16-QAM

No equalization

Linear equalization - hard decision boundaries

Machine learning - soft decision/nonlinear boundaries
**CASE-1**

**Step 1:** large group of 4 clusters

**Step 2:** 4 groups of 4 clusters

**CASE-2**

**Single-step:** 1 group of 4 clusters & 6 groups of 2 clusters
Shapes of constellation diagrams
DSP transmitter

Digital-to-Analogue Conversion

Optical modulation

Optical channel

Photo-Detection

Analogue-to-Digital Conversion

DSP receiver with machine learning

MATLAB Electrical Transmitter

MATLAB Electrical Receiver

Transceiver setup
Nonlinear distortion

High power intensity → Refractive index change → Frequency chirp → Spectrum broadening → Waveform distortion due to chromatic dispersion

Optical fiber
ANN: Artificial Neural Network

- $\varphi_{k,i}(x) = \text{nonlinear transformations of subcarrier } k$
- $N = \text{level of constellation mapping}$
- $w = \text{weights}$
- $e = \text{error}$
- $s = \text{signal}$
- $\text{MMSE} = \text{minimum-mean square-error}$

$$
e(k) = s(k) - \hat{s}(k)$$

$$\hat{s}(k) = \sum_{i=1}^{N} w_{k,i} \varphi_{k,i}(s(k))$$
Why machine learning is good for us?

- Machine Learning tackles stochastic noises in optical networks without knowledge of the fibre link parameters (versatile learning).
- It has benefit over wireless systems because optical link has stable parameters.

Complexity comparison (Number of operations)

Comparison with benchmark technologies

Nonlinear compensation techniques:
- Digital back propagation (DBP)
- Optical phase conjugation (OPC)
- Phase conjugated twin wave (PC-TW)

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<th>PC-TW</th>
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✓ Advantage  😞 Limited benefit  😞 Challenge
Crucial points

Real-time signal processing on FPGA

areas where errors are most likely
3D deep learning?
Thank you for your attention !!!