Time-Division Hybrid Modulation Formats: Tx Operation Strategies and Countermeasures to Nonlinear Propagation

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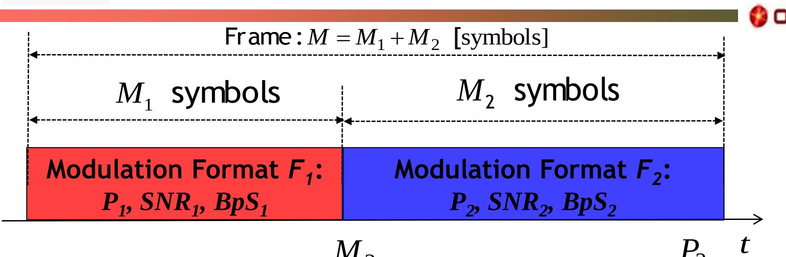
Motivation and outline

- **Symbol-rate and wavelength grid given: continuity of reach vs. spectral efficiency**
- **Use of reduced-complexity "squared" constellations** → **TDHMF**
- **Flexible network optimization**

- Transmitted frame and operation-setting parameters
- Strategies to define the Tx operation and b2b performance
- Nonlinear propagation of NyWDM channels on SSMF and NZDSF
  - Effects of frame length
  - Benefits of predistortion
  - The polarization interleaving technique
- Comments and conclusions

Tx frame and operation-setting parameters



Format ratio: $FR = 100\frac{M_2}{M}$ **Power ratio:** $PR = \frac{P_2}{P_1}$

OSNR in R_s

$$SNR = \left(1-\tfrac{FR}{100}\right)\cdot SNR_1 + \tfrac{FR}{100}\cdot SNR_2$$

Average power

$$P_{Tx} = \left(1-\tfrac{FR}{100}\right)\cdot P_1 + \tfrac{FR}{100}\cdot P_2$$

Overall bit-per-symbol

$$BpS = \left(1-\tfrac{FR}{100}\right)\cdot BpS_1 + \tfrac{FR}{100}\cdot BpS_2$$

M is irrelevant for b2b performance

Overall BER

$$BER = \frac{1}{\left(1-\frac{FR}{100}\right)\cdot BpS_1 + \frac{FR}{100}\cdot BpS_2}\cdot\left\{\left(1-\tfrac{FR}{100}\right)\cdot BpS_1\cdot\Phi_1\left[\frac{SNR}{\left(1-\frac{FR}{100}\right)+\frac{FR}{100}\cdot PR}\right]+\tfrac{FR}{100}\cdot BpS_2\cdot\Phi_2\left[PR\frac{SNR}{\left(1-\frac{FR}{100}\right)+\frac{FR}{100}\cdot PR}\right]\right.$$

Strategies for Tx working point

Given F_1, F_2 and FR, PR is the parameter to set according to one of the following strategies:

a) *Min BER: PR is obtained minimizing SNR in BER equation ➔ PR varies with the target BER*

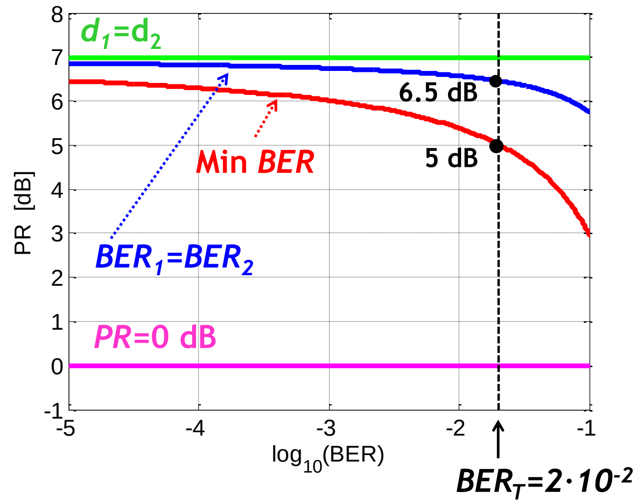
b) ***BER_1=BER_2:*** both F_1 and F_2 are forced to operate at the same *BER* ➔ *PR* is consequently defined

c) ***d_1=d_2:*** the minimum Euclidean distance d_i (i=1,2) is kept equal for both F_1 and F_2 ➔ *PR* is a constant depending on constellations

d) *PR*=0 dB: it keeps constant power during transmission (P_1=P_2=P_{Tx}) ➔ the highest-cardinality modulation format operates at the FEC cliff, the other is working error free

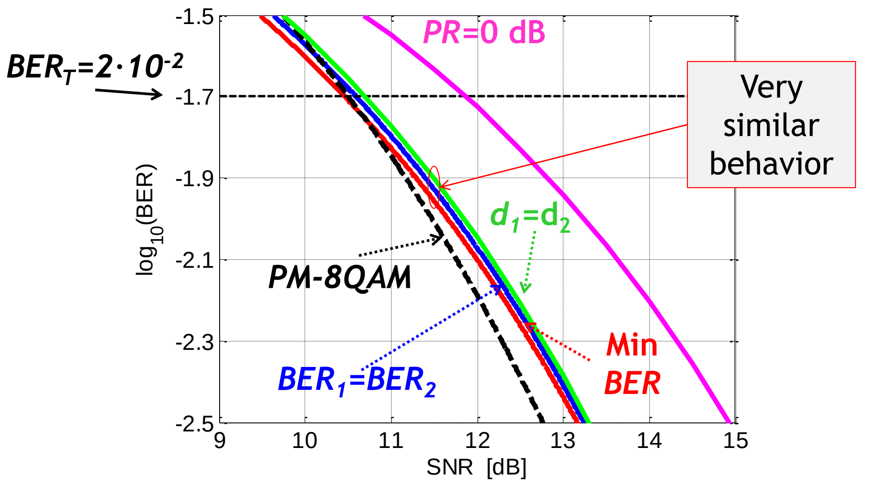
PR vs. *BER* for different strategies

F1: PM-QPSK, F2: PM-16QAM, BpS=6 → FR=50%



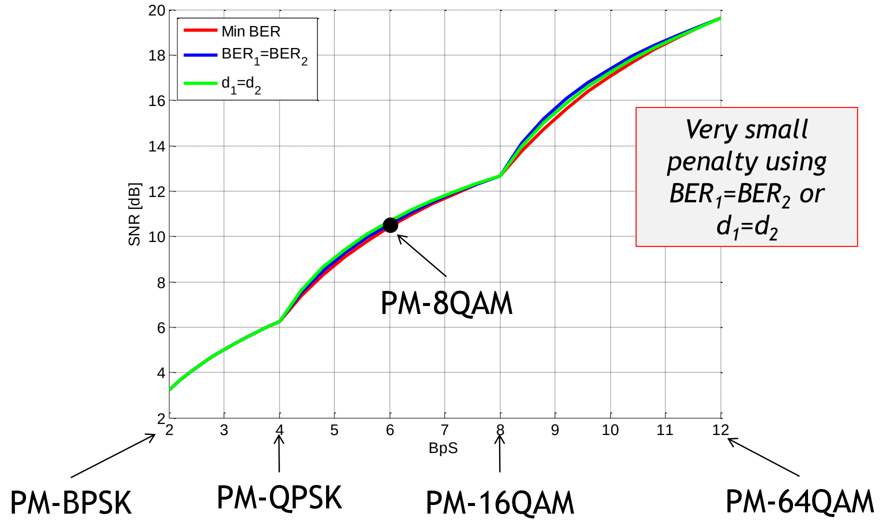
BER vs. *SNR* for different strategies

F1: PM-QPSK, F2: PM-16QAM, BpS=6 → FR=50%



SNR@$BER_T=2\cdot10^{-2}$ vs. BpS

Combining the first “squared” constellations…



… and the fiber propagation?

- F1: PM-QPSK, F2: PM-16QAM with “Min BER” Tx
- BpS=6 ➔ *FR*=50%
- R_s=32 Gbaud
- 9-channel NyWDM comb @ Δf=33.6 GHz=1.05·R_s
- $BER_T=2\cdot10^{-2}$
- Multispan link with L_s=100 km, EDFA with NF=5 dB
- Two typical fiber types:
  - SSMF

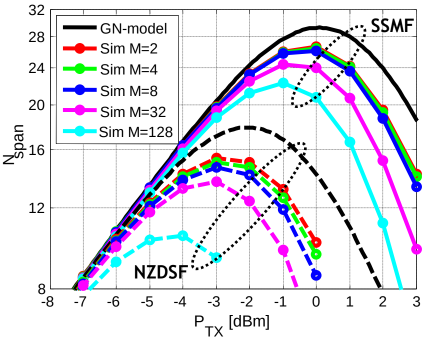
    α_{dB} = 0.22 dB/km, D=16.7 ps/nm/km, γ = 1.3 1/W/km
  - NZDSF

    α_{dB} = 0.22 dB/km, D = 3.8 ps/nm/km, γ = 1.5 1/W/km

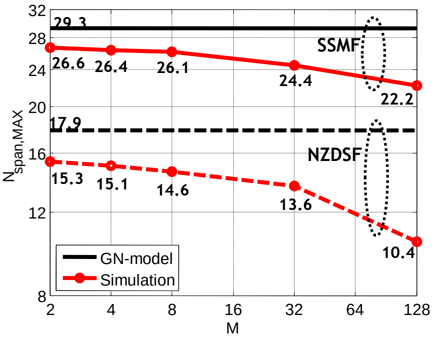
Maximum reach vs. GN-model

OPTCOM

FR=50%, F1: PM-QPSK, F2: PM-16QAM, $BER_T=2\cdot10^{-2}$



Power per channel



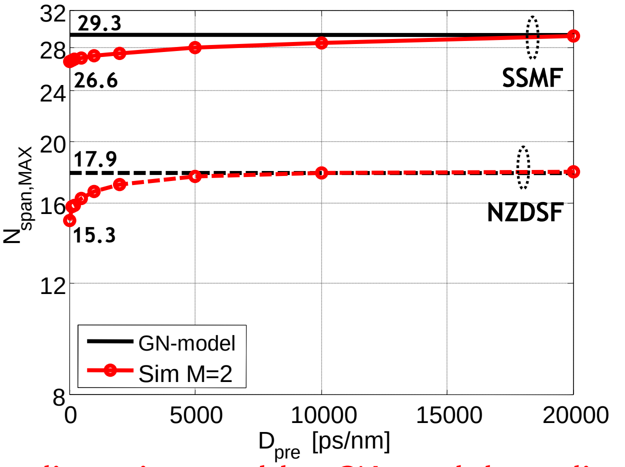
Frame length

The frame length does matter!

Predistortion: Max Reach vs. D_{pre}

OPTCOM

FR=50%, F1: PM-QPSK, F2: PM-16QAM, $BER_T=2\cdot10^{-2}$

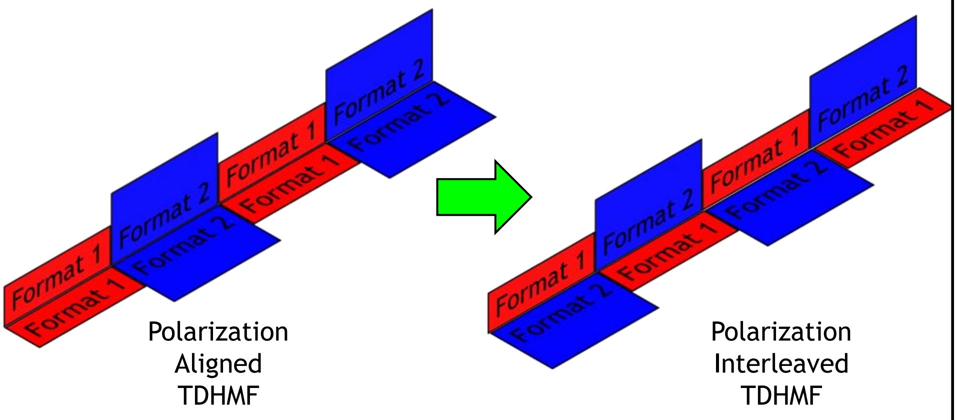


Proper predistortion enables GN-model-predicted reach

Polarization Interleaving (PI)

OPTCOM

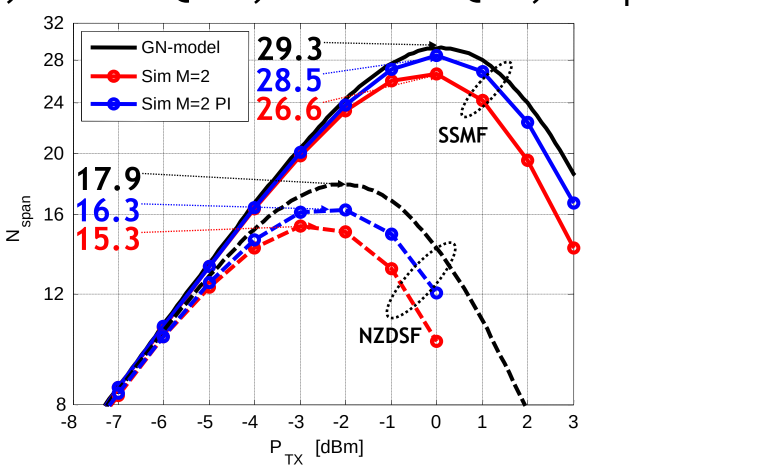
In order to keep constant power…



PI: Max Reach vs Power per channel

OPTCOM

FR=50%, F1: PM-QPSK, F2: PM-16QAM, $BER_T=2\cdot10^{-2}$



PI helps and reduces the required predistortion

Comments and conclusions

- Strategies for Tx setup giving b2b performance
- Combining "squared" constellation → continuity in spectral efficiency w/o substantial b2b penalties with respect to specific modulation formats
- Nonlinear propagation: the shorter the frame length, the better
- Predistortion enables to obtain GN-model predictions
- Polarization interleaving helps and substantially reduces the required predistortion

Acknowledgemets

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