POLITECNICO DI TORINO

ACHIEVING FINE BIT-RATE GRANULARITY WITH HYBRID SUBCARRIER MODULATION

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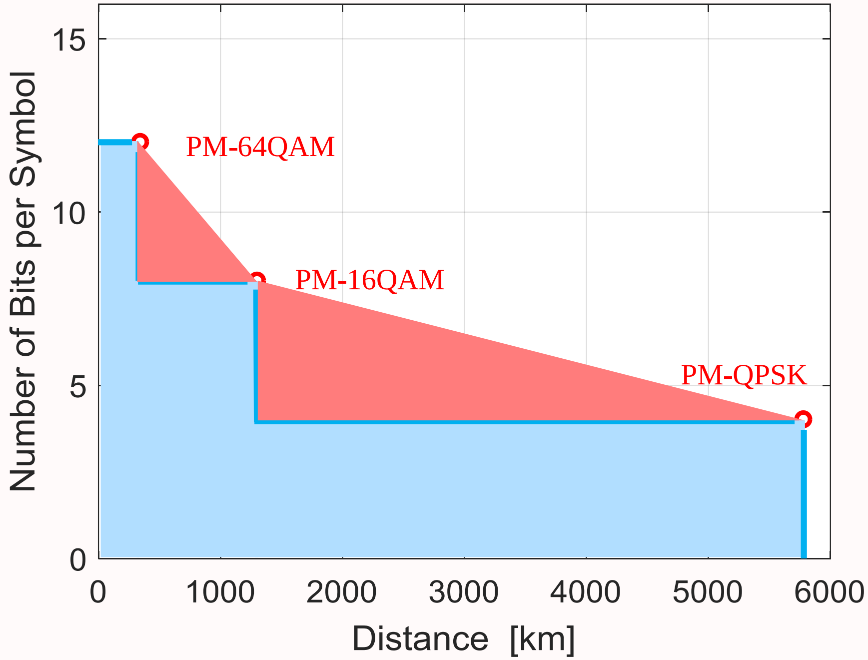
OUTLINE

- Motivations
- The proposed technique
  - Frequency Division Hybrid Modulation Formats (FDHMF)
- Simulations results
  - Comparing FDHMF and TDHMF
- Conclusions

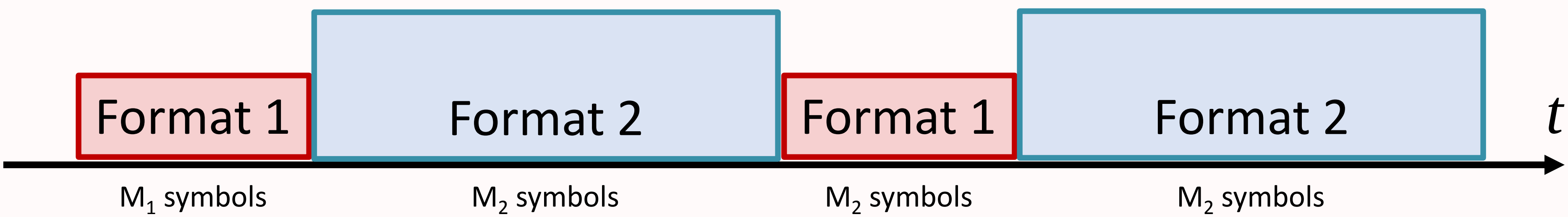
MOTIVATION: BIT-RATE GRANULARITY

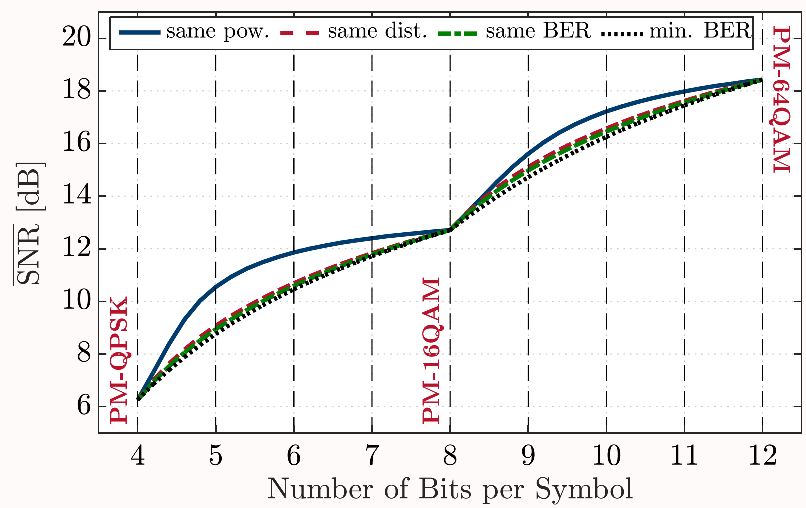
- Reach can be traded off with capacity
- Standard Polarization Multiplexed Square M-QAM modulation formats have a coarse bit-rate granularity
  - Steps of 4 bit/symbol



MOTIVATION: TDHMF

- A possible solution: Time-Domain Hybrid Modulation Format

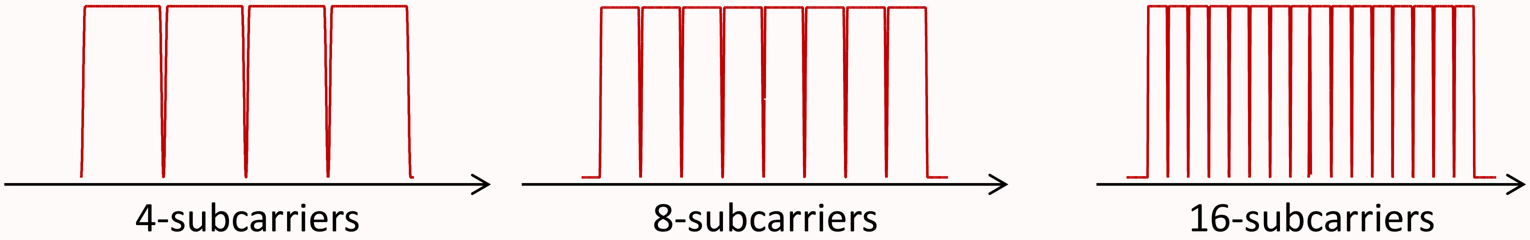


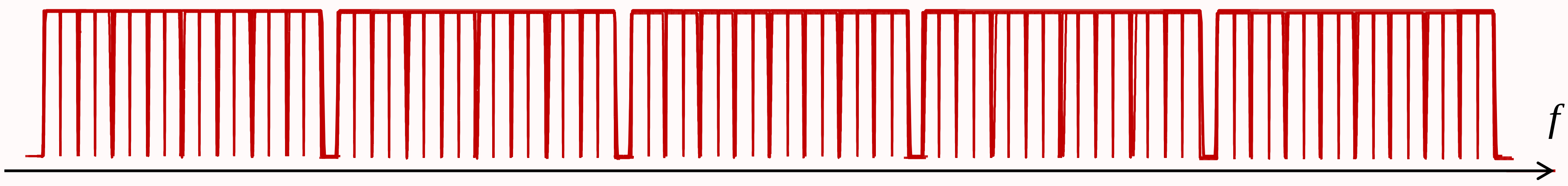


- Drawbacks: extra DSP complexity due to time-dependent modulation

MOTIVATION: SYMBOL RATE OPTIMIZATION

- Thanks to the EGN it has been shown that NLI can be minimized through Symbol Rate Optimization (SRO)
  - Recent experiments confirmed it
  - Optimal symbol rate are usually too small to be implemented as single wavelength → SubCarrier Multiplexing is a viable solution

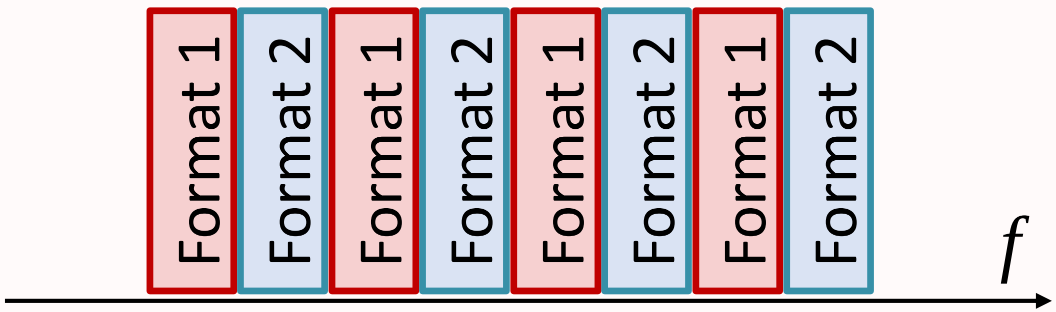


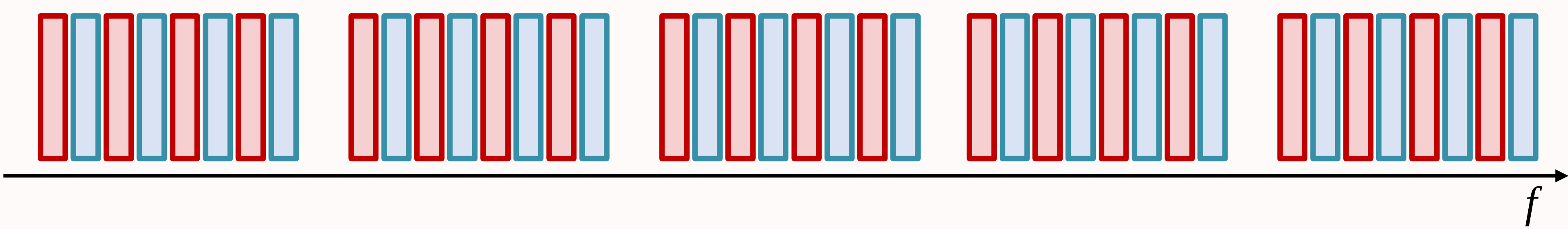


FREQUENCY DOMAIN HYBRID MODULATION FORMATS

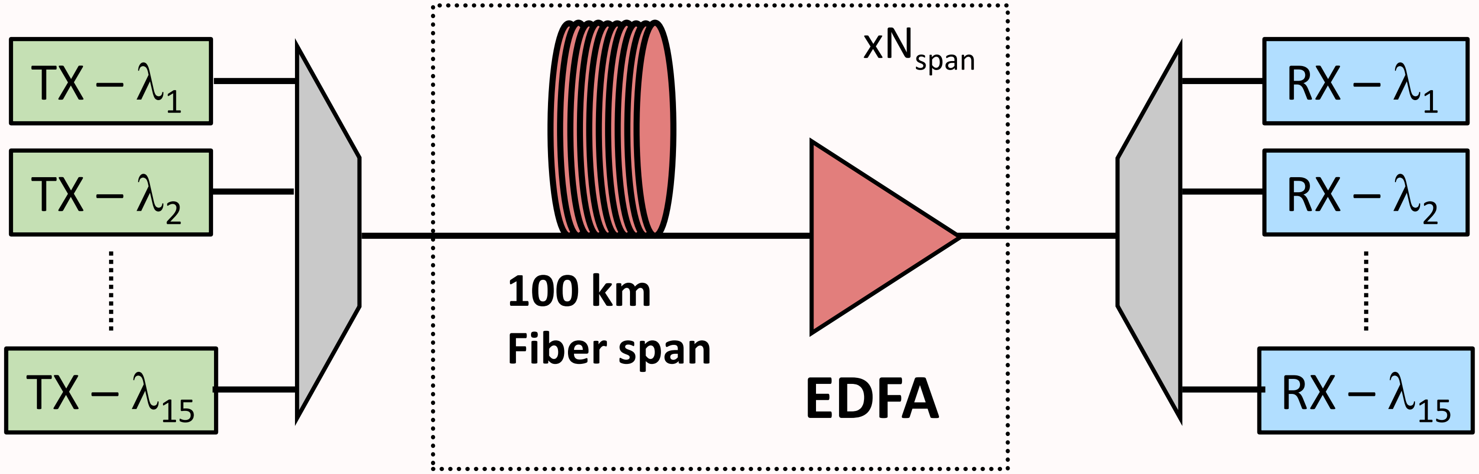
We propose to use frequency domain hybrid modulation formats (FDHMF)

It is a an hybrid subcarrier modulation





SIMULATION SETUP



TRANSMITTER

- R_S=32 Gbaud
- 15 channels
- Roll-off=0.05
- Δf=37.5 GHz

LINK

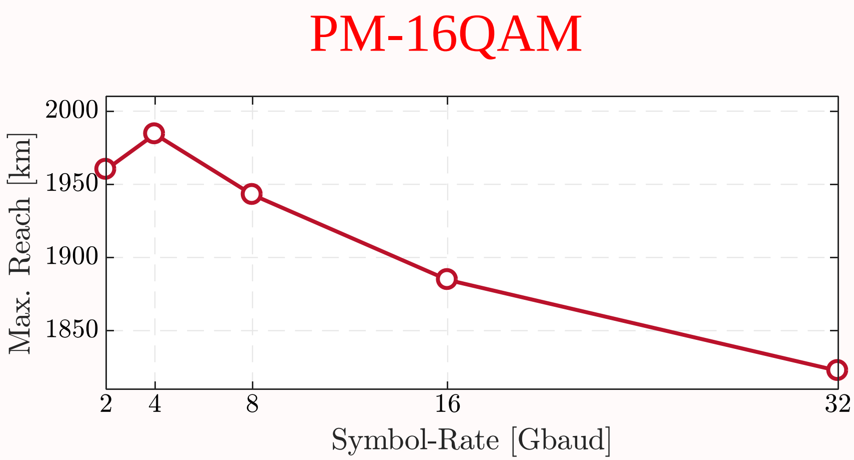
- Fiber: SMF
  - α=0.2 [dB/km]
  - γ=1.3 [1/W/km]
  - D=16.7 [ps/nm/km]
- EDFA
  - Gain recover fiber loss
  - F=5 dB

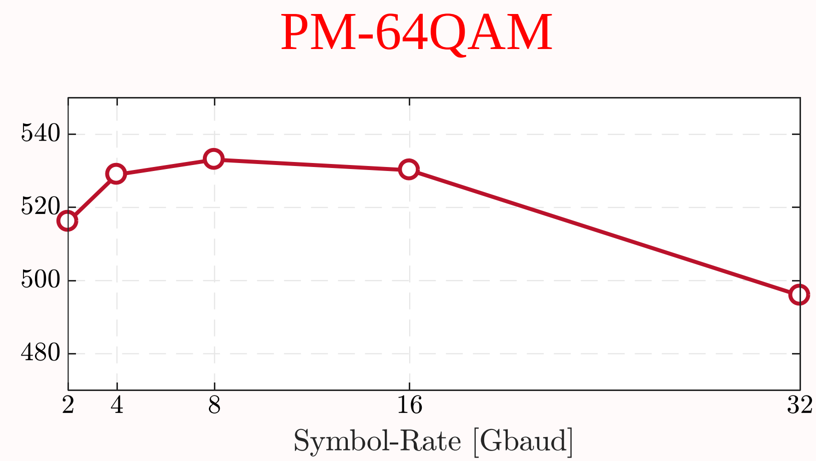
RECEIVER

- Coherent receiver
- ADC
  - 2 SpS (64 GSa/s)
- DSP:
  - DA-LMS with training sequence

OPTIMIZING SYMBOL RATE

- We consider FDHMF obtained mixing PM-16QAM and PM-64QAM, spanning from 8 to 12 Bits per Symbol (200G to 300G)

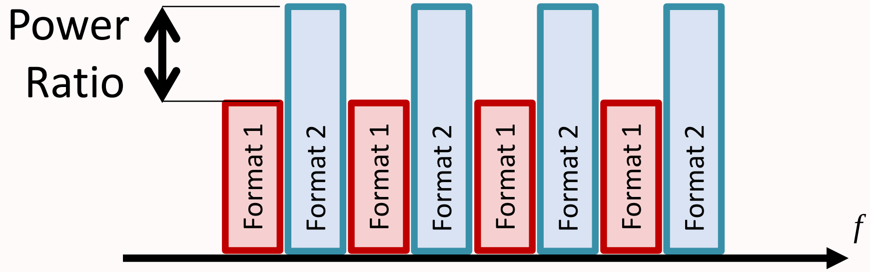


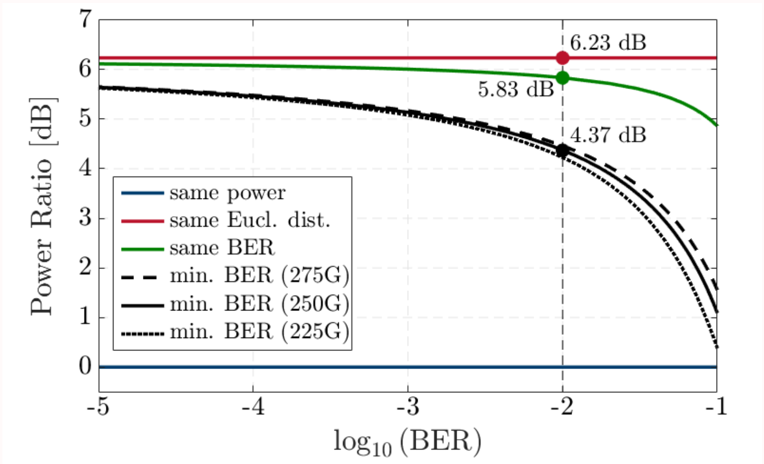


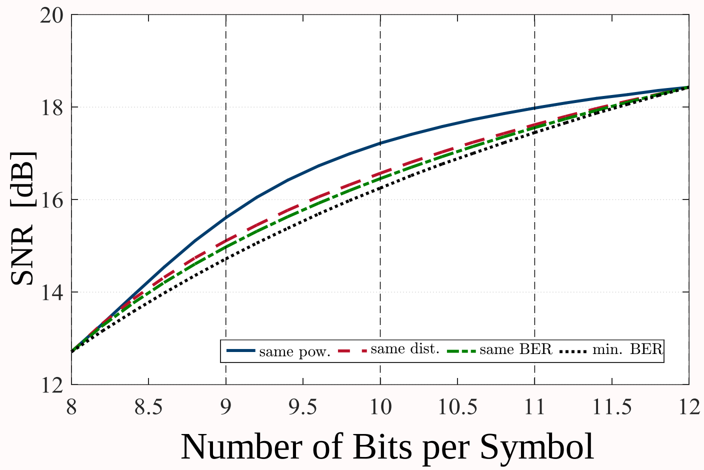
- Optimal symbol-rates are:
  - 4 GBaud for PM-16QAM
  - 8 GBaud for PM-64QAM
- We define a FDHMF configuration composed of 8 subcarriers, enabling a net bit-rate granularity of up to 12.5 Gb/s

OPERATION MODE

- FDHMF transceivers can be operated in difference modes
  - Power ratio between formats depends on them





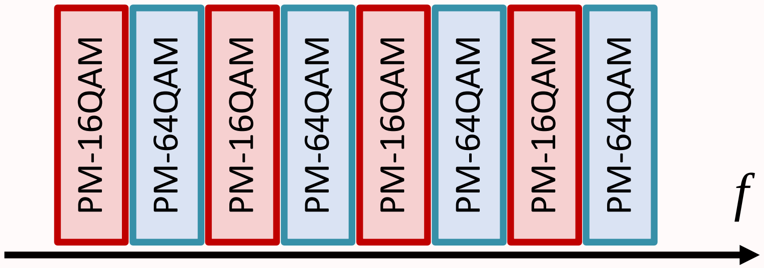


- We used the "same BER" approach
  - Power ratio is set to 5.83 dB between PM-16QAM and PM-64QAM

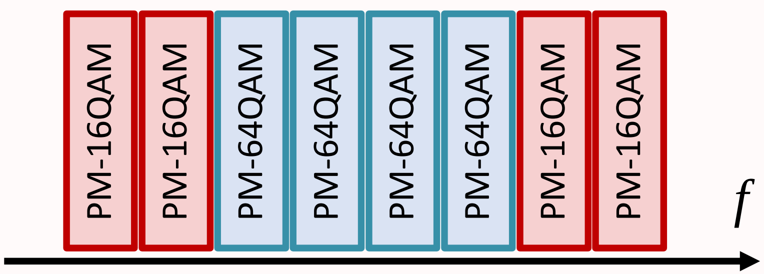
F. P. Guiomar, R. Li, C. R. S. Fludger, A. Carena, and V. Curri, "Hybrid Modulation Formats Enabling Elastic Fixed-Grid Optical Networks," J. Opt. Commun. Netw. **8**, A92-A100 (2016)

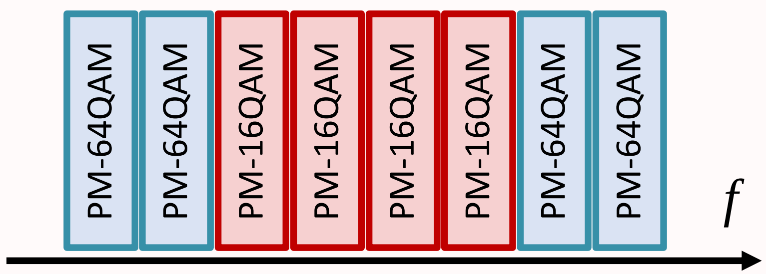
FDHMF CONFIGURATIONS

- We considered three configurations
  1. frequency interleaving of the low- and high-cardinality formats



  2. allocating the low-cardinality format to the edge subcarriers and the high-cardinality format to the center subcarriers
  3. applying the reverse of 2

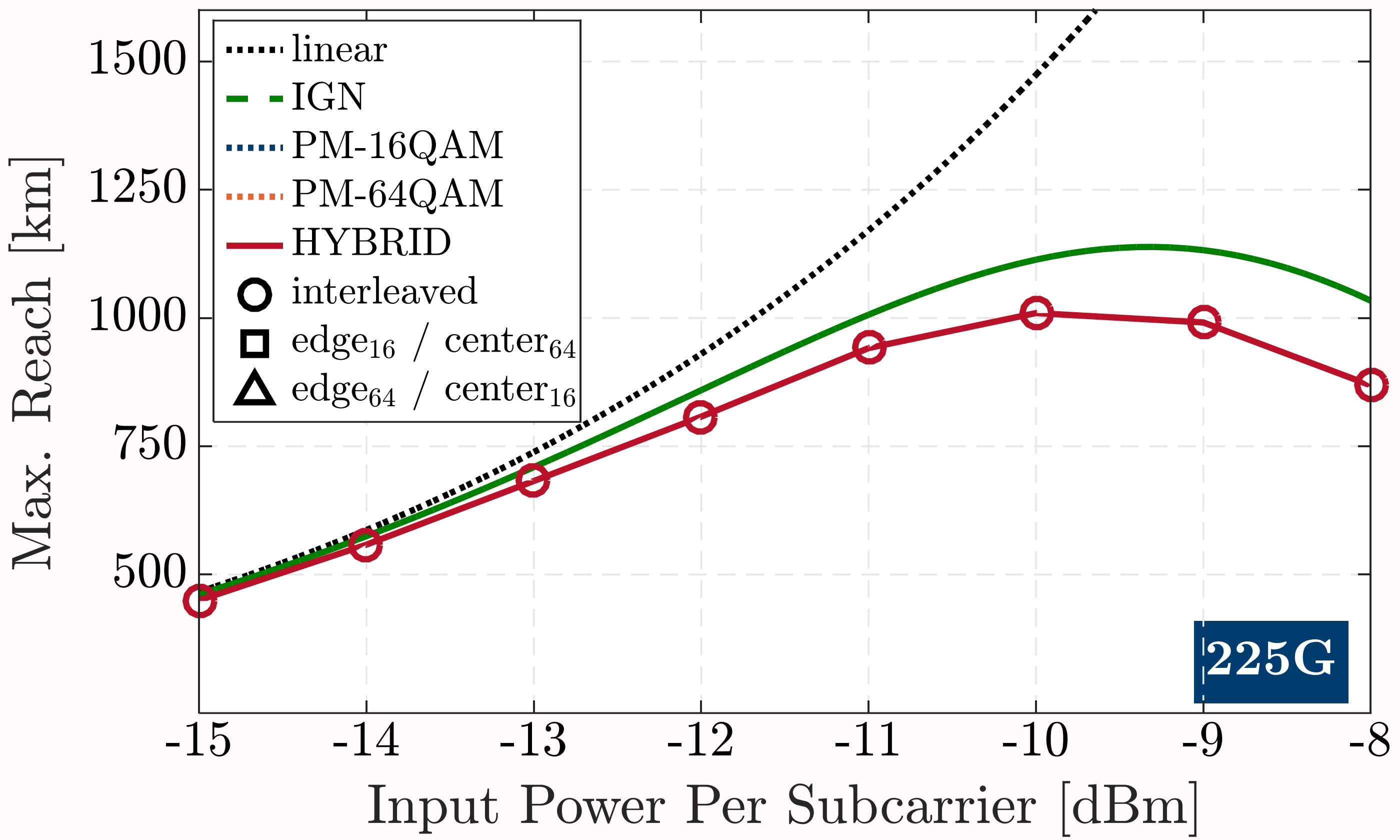


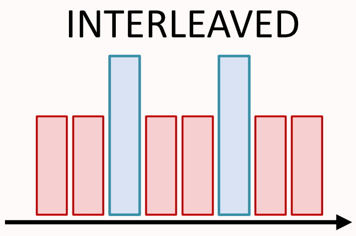


FDHMF MAXIMUM REACH

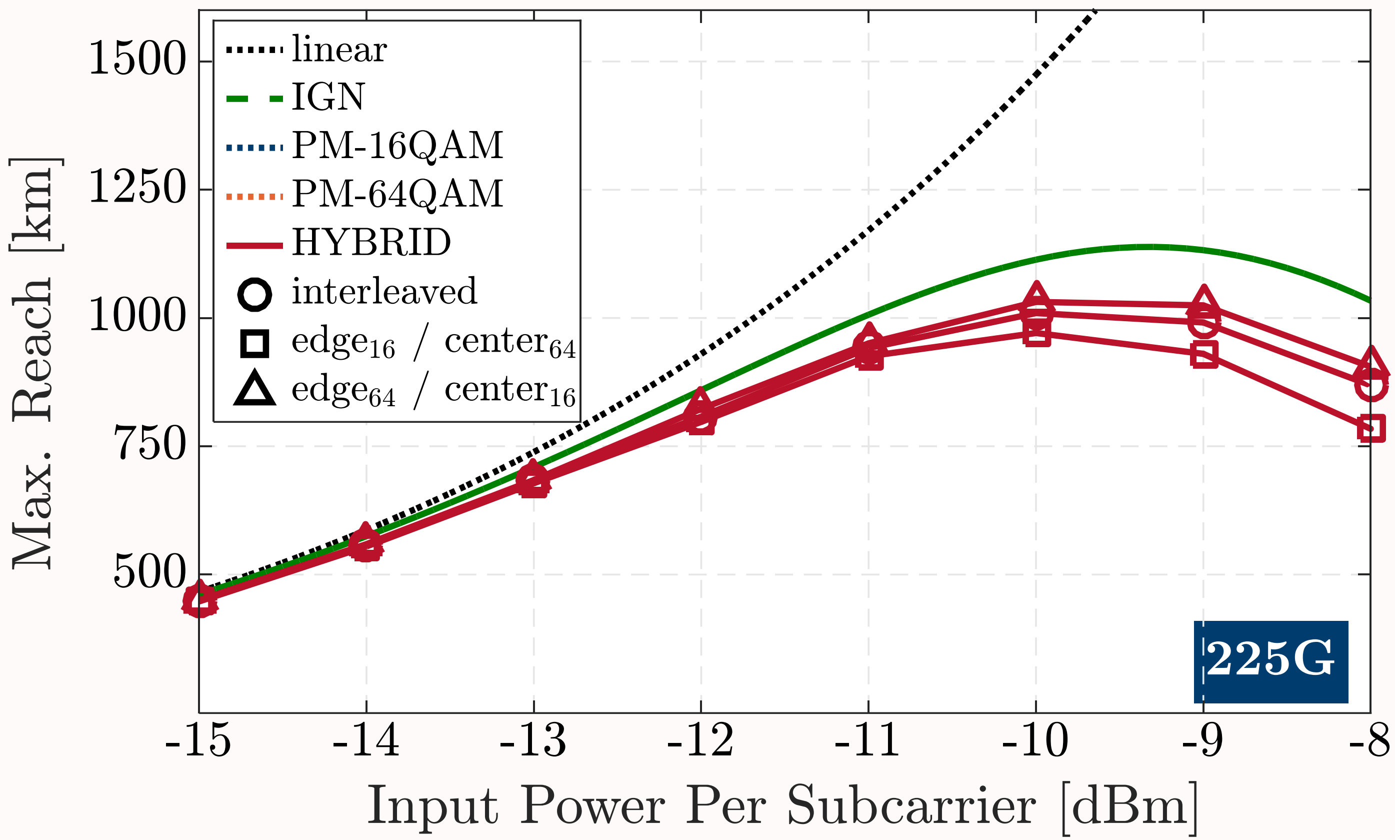
- We restrict our simulation analysis to a 25 Gb/s granularity
  - 225G: 6SC x PM-16QAM + 2SC x PM-64QAM
  - 250G: 4SC x PM-16QAM + 4SC x PM-64QAM
  - 275G: 2SC x PM-16QAM + 6SC x PM-64QAM
- The maximum reach is calculated taking into account the average BER among all subcarriers
- In order to assess the performance of each modulation format, we also plot the average BER of each set of subcarriers associated with PM-16QAM and PM-64QAM modulation formats

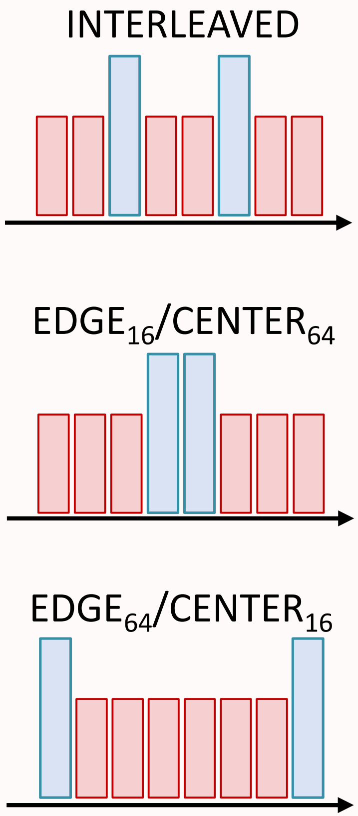
FDHMF MAXIMUM REACH: 225G





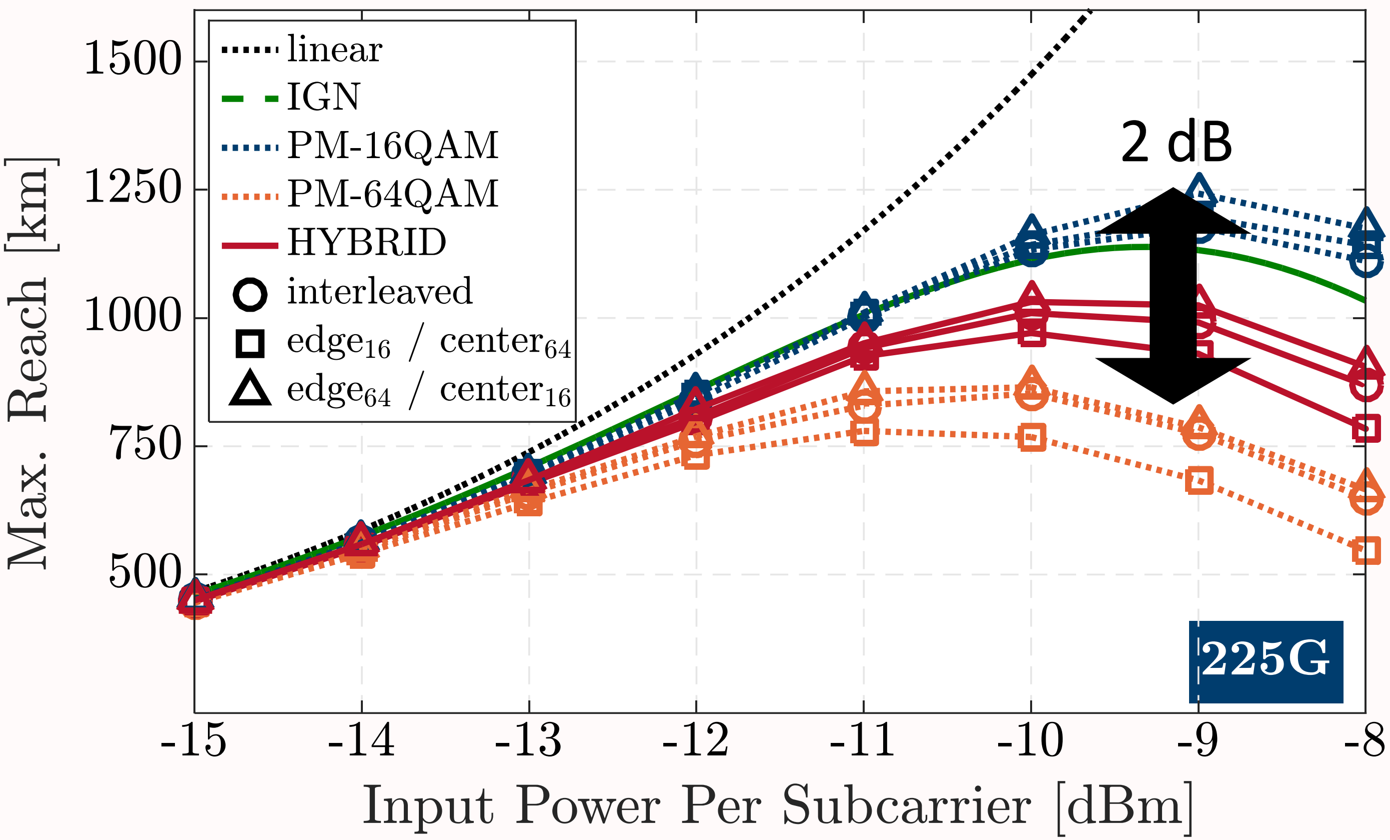
FDHMF MAXIMUM REACH: 225G

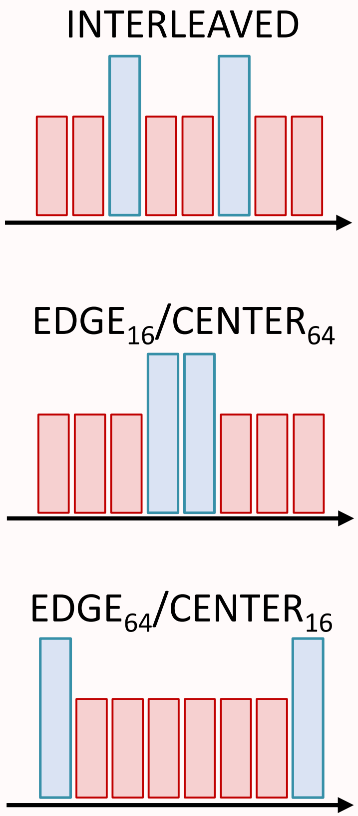




FDHMF MAXIMUM REACH: 225G

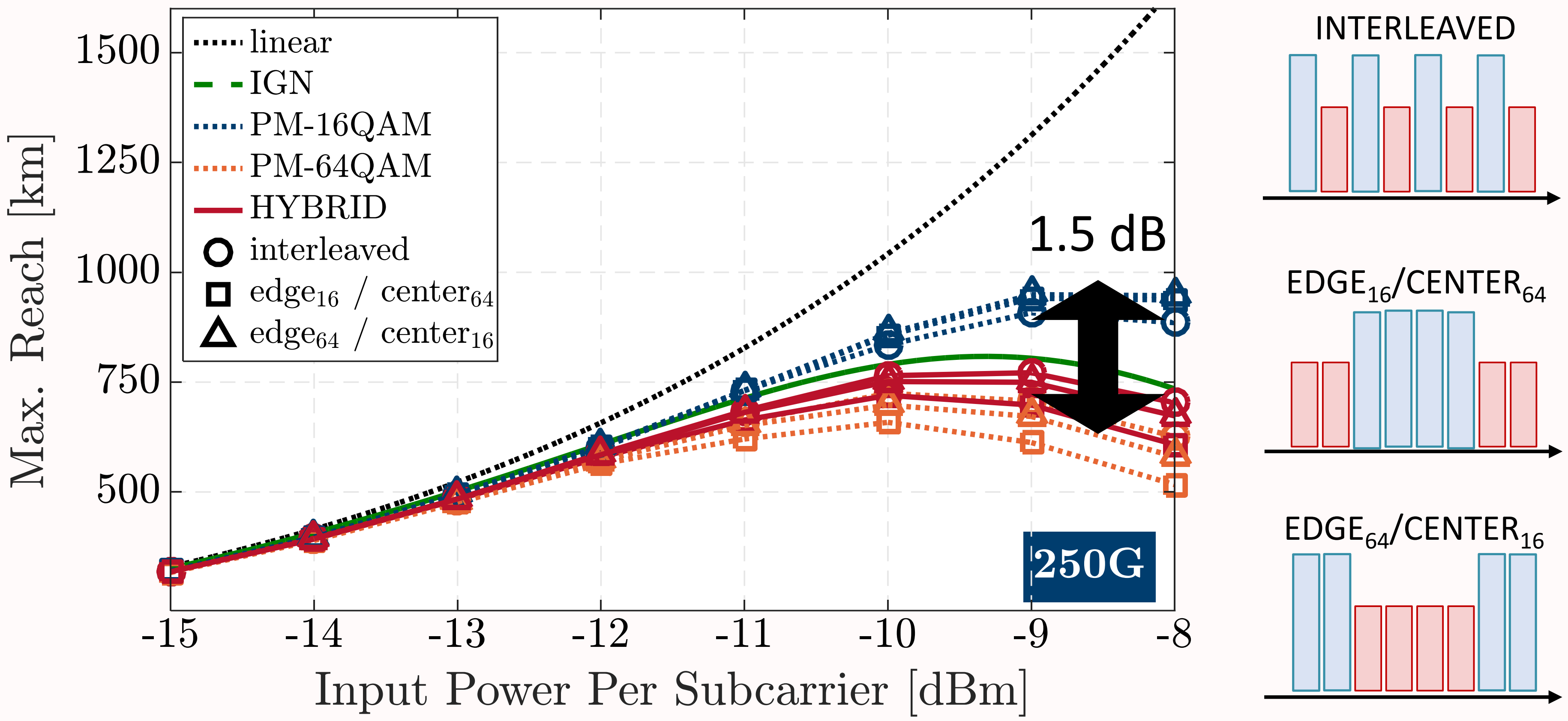
P_{64QAM}/P_{AVG} = 3.5 dB





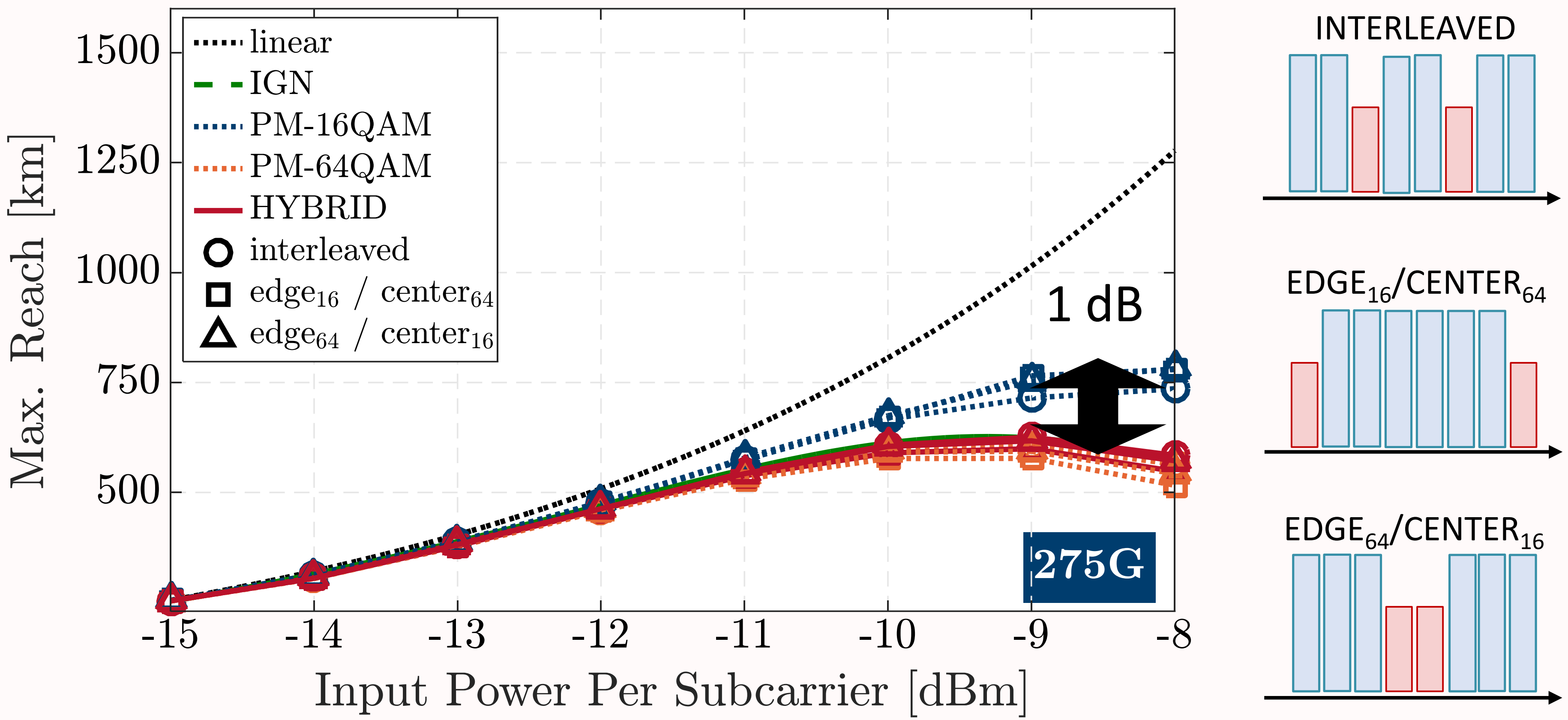
FDHMF MAXIMUM REACH: 250G

P_{64QAM}/P_{AVG} = 2.0 dB



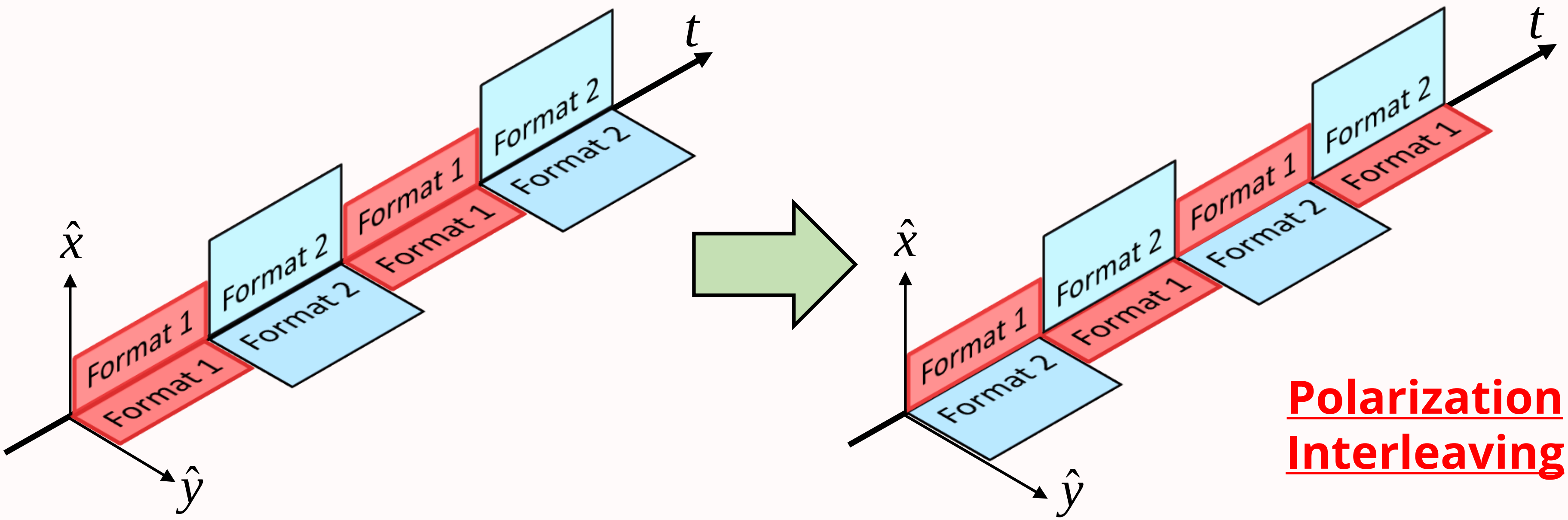
FDHMF MAXIMUM REACH: 275G

P_{64QAM}/P_{AVG} = 0.9 dB



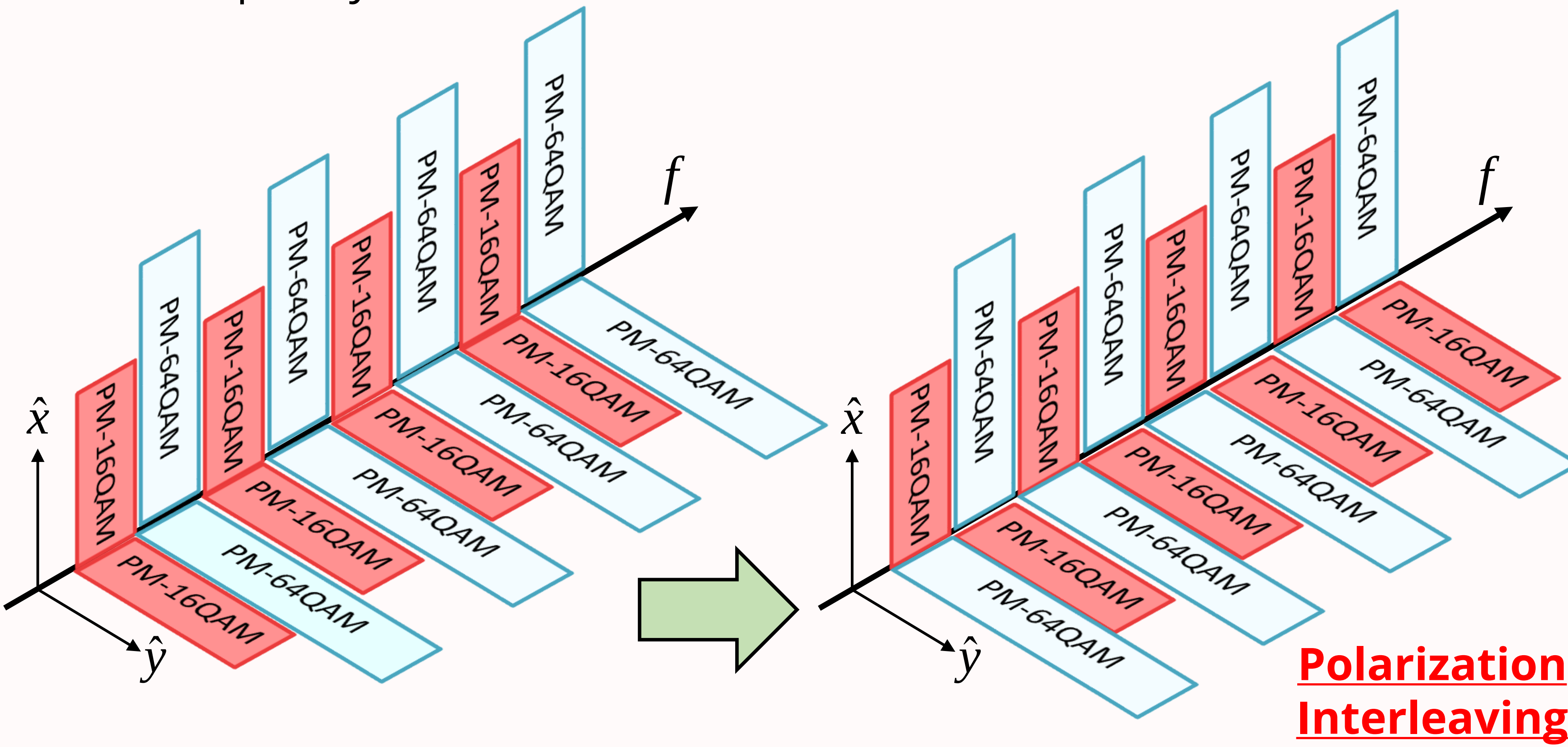
POLARIZATION INTERLEAVING

- For TDHMF, in order to keep power level constant symbol by symbol, polarization interleaving has been proposed
  - It helped improve system performance

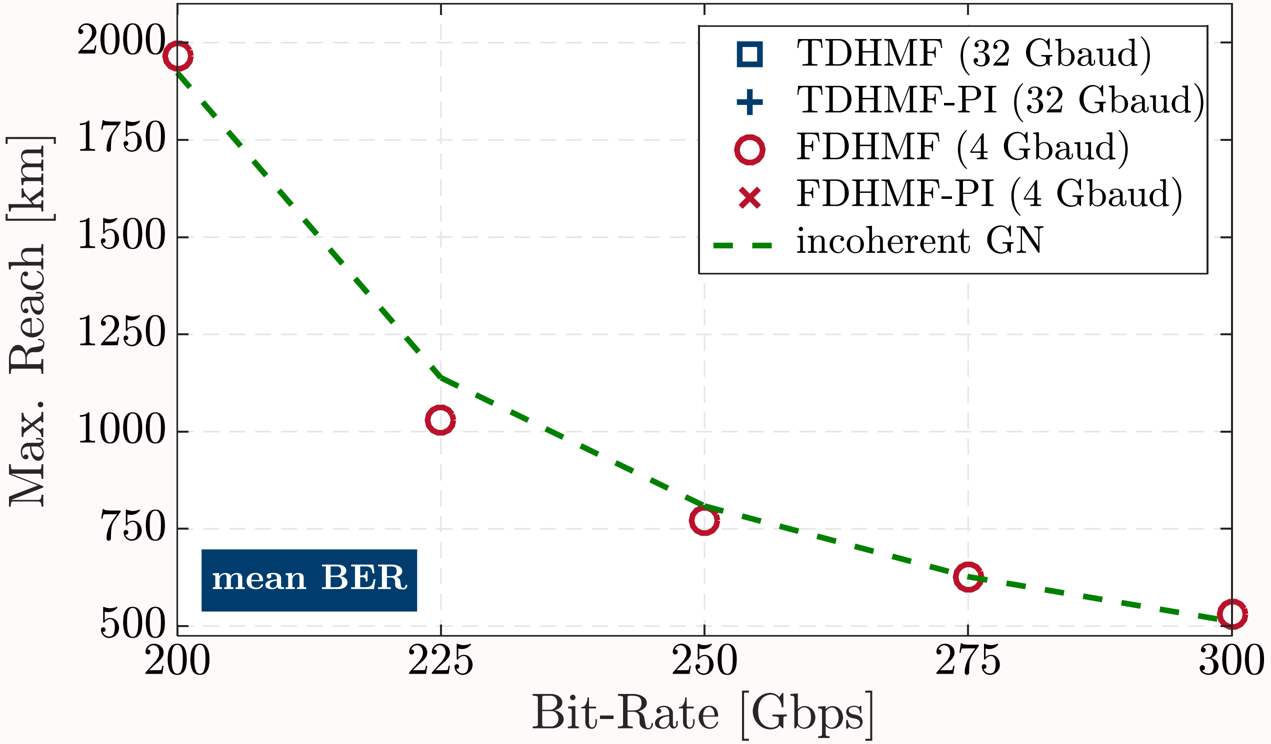


POLARIZATION INTERLEAVING

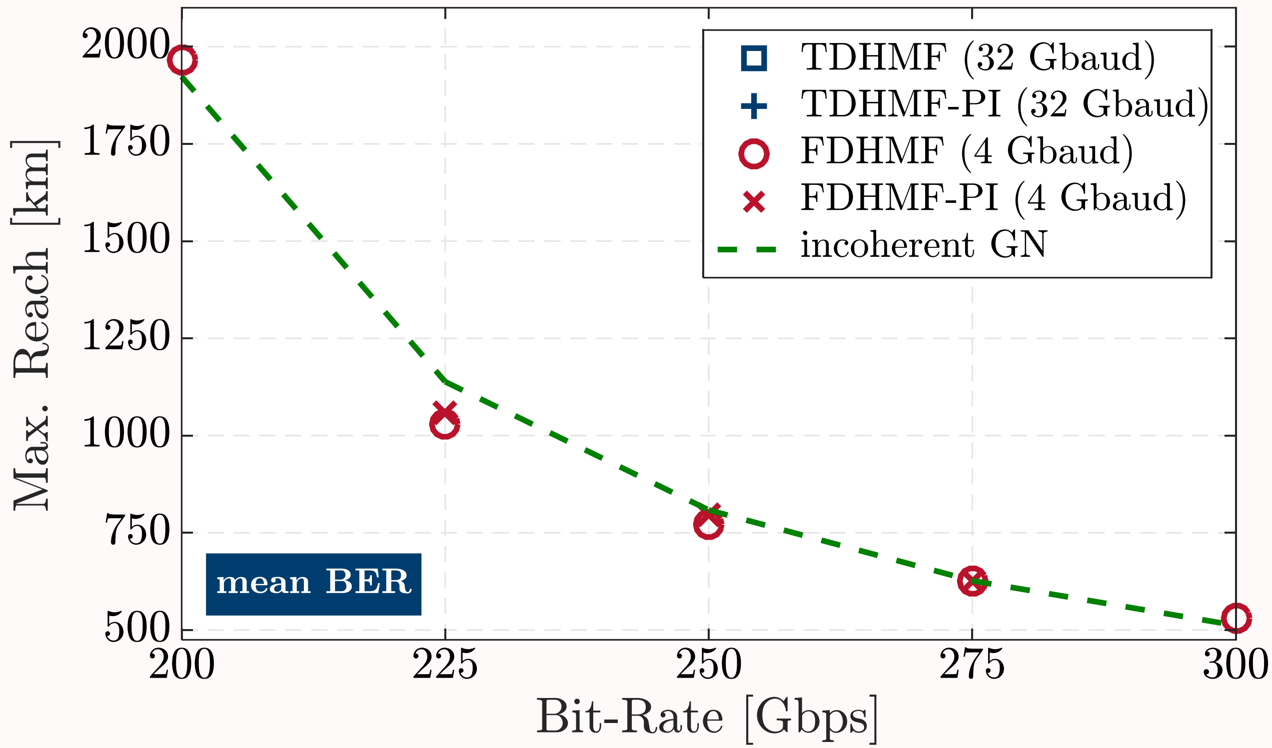
- We similarly applied it also to FDHMF to equalize power in the frequency domain



COMPARING WITH TDHMF

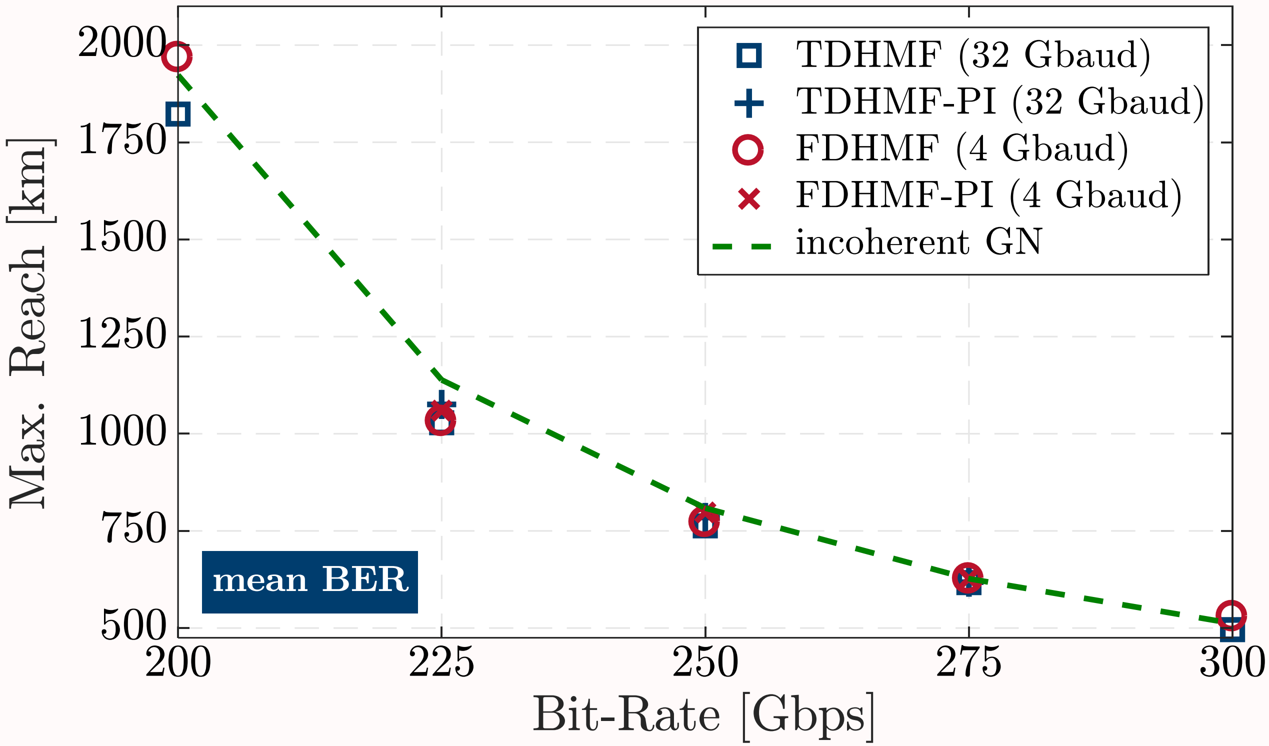


COMPARING WITH TDHMF



- The impact of PI on the average BER performance is negligible

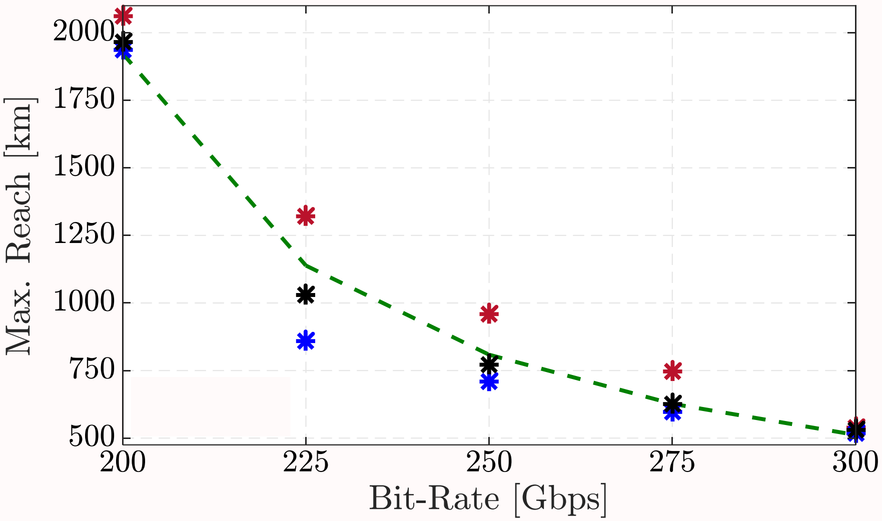
COMPARING WITH TDHMF



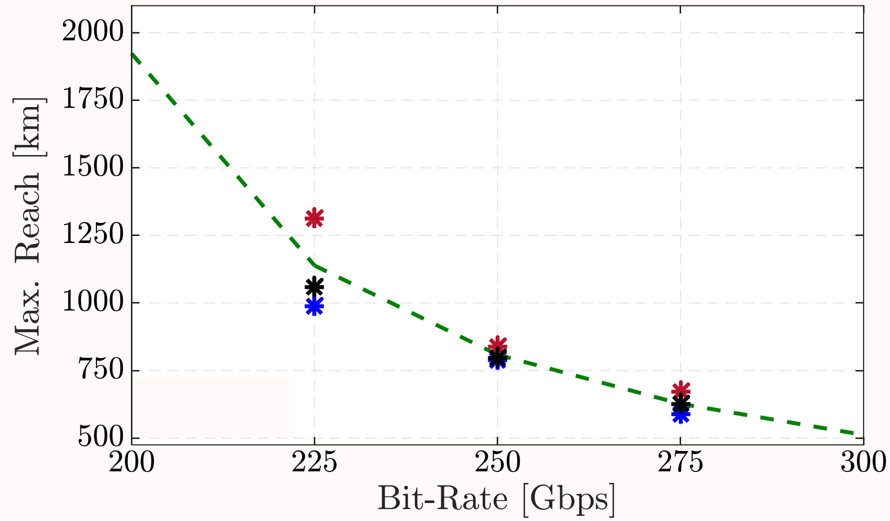
- The impact of PI on the average BER performance is negligible
- FDHMF reaches performances similar to TDHMF

PI EFFECT

Without PI



With PI



* red: best SC   * blue: worst SC   * black: mean SC

- Although the impact on the average BER performance is negligible, PI is shown to significantly reduce the gap between the best and worst performing subcarriers

CONCLUSIONS

- We proposed a new format to achieve fine bit-rate granularity: FDHMF
- FDHMF performs similarly to the previously introduced TDHMF solution
- FDHMF being time invariant has significant advantages for the DSP implementation
- Polarization Interleaving has been shown to be an effective technique to mitigate BER differences between subcarrier after non-linear propagation

THANK YOU!

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