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PAPER M1I.2

POLITECNICO DI TORINO

LOW-COMPLEXITY NON-LINEAR PHASE NOISE MITIGATION USING A MODIFIED SOFT-DECODING STRATEGY

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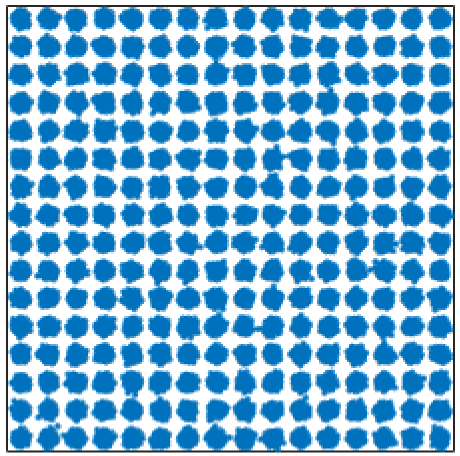
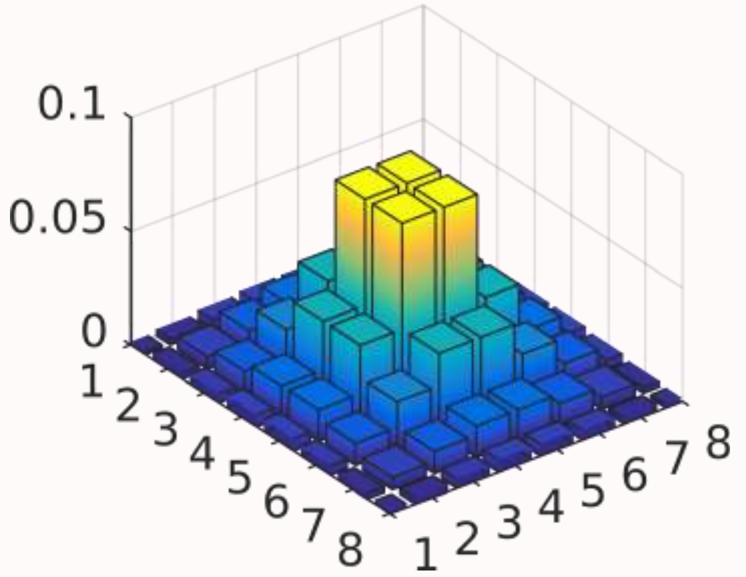
INTRODUCTION

- Future systems require **high spectral efficiency** and **data-rate flexibility**

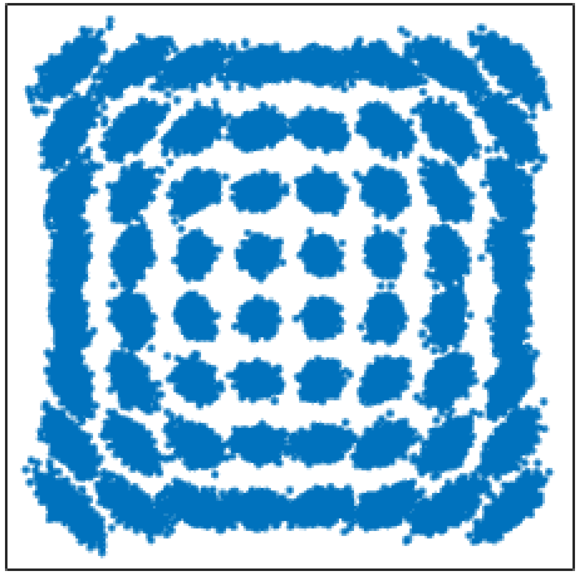
- Therefore, **large QAM constellations** often coupled with **constellation shaping** are employed





PHASE NOISE

- Large constellations suffer from **phase noise**
  1. Laser phase noise
  2. Non-linear phase noise (Kerr effect)
- Large constellations and shaping generate **more non-linear phase noise**



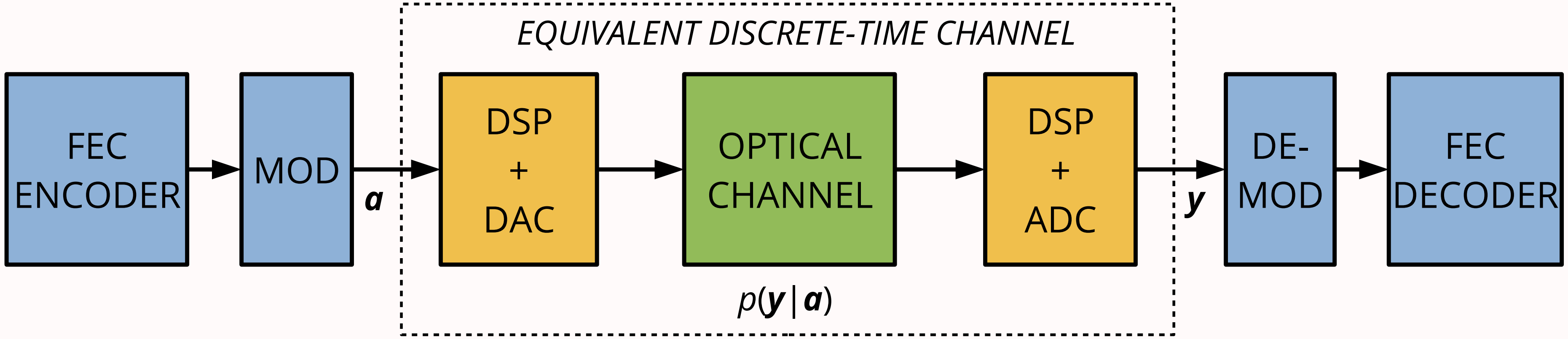
- **Phase recovery** compensates for **slow** phase noise

R. Dar and P.J. Winzer, J. Lightwave Technol. **35**(4), 903-930 (2017)
D. Pilori *et al.*, J. Lightwave Technol. **36**(2), 501-509 (2018)
D.A.A. Mello *et al.*, J. Lightwave Technol. **36**(22), 5096-5105 (2018)

GOAL OF THIS WORK

- Show a **simple** and **low-complexity** decoder that takes into account the presence of **phase noise** that is:
  - Residual after CPE.
  - **Memoryless**
- **Apply** this method to an experimental scenario:
  - Probabilistically-shaped 64-QAM
  - Legacy low-dispersion optical fiber (NZDSF) that generates strong non-linear phase noise

CHANNEL MODEL

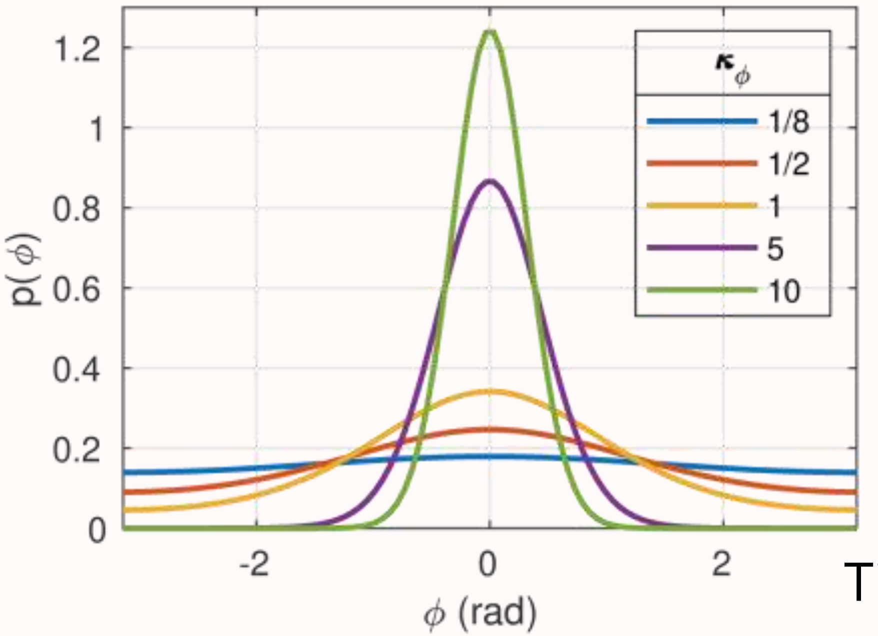


Transmitted QAM symbols

$$y_k = a_k e^{j\phi_k} + n_k$$

Phase noise (memoryless)

Additive white Gaussian noise



Tikhonov (or Von Mises) distribution

CHANNEL TRANSITION PROBABILITY

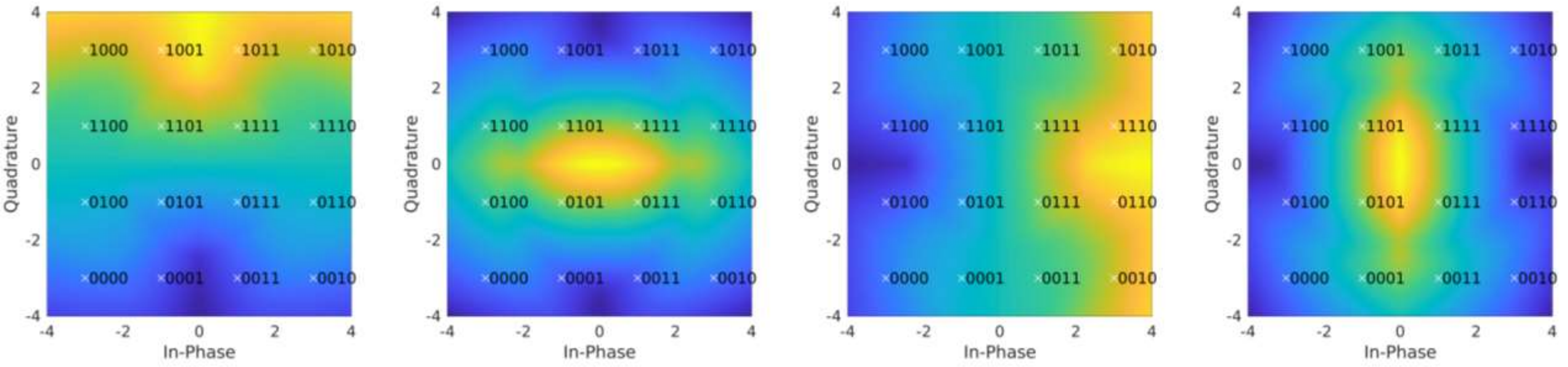
- This allows the derivation of an **analytical expression** of the channel probability:

$$p(y|a) \approx \sqrt{\frac{\kappa_\phi}{8\pi^3}} \frac{e^{-\kappa_\phi}}{\sigma_n^2} \exp\left(-\frac{|y|^2+|a|^2}{2\sigma_n^2} + \left|\frac{ya^*}{\sigma_n^2}+\kappa_\phi\right|\right)$$

- This expression can be then used to perform **soft decoding**
  - Log-likelihood ratios can be analytically computed (no histograms)
  - GMI can be experimentally evaluated with Monte-Carlo integration

F. Kayhan and G. Montorsi, IEEE Trans. Wireless Commun. **13**(5), 2874-2883 (2014)

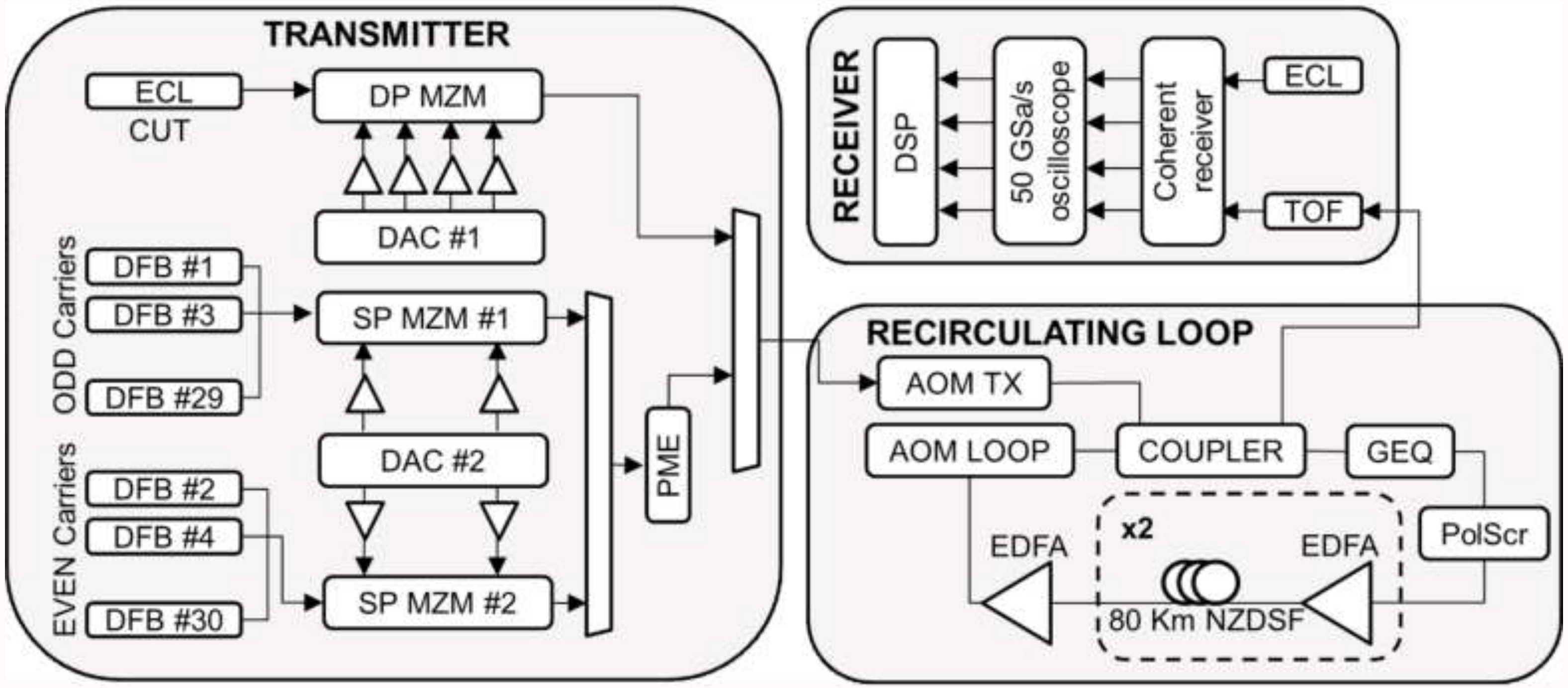
LLR COMPUTATION EXAMPLE

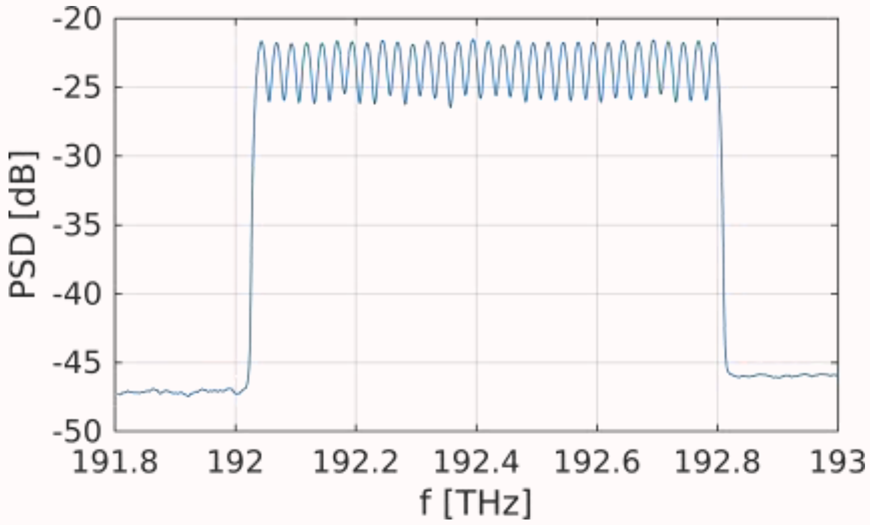


Bit-wise log-likelihood ratios (LLRs) heat map for:

- 16-QAM
- SNR = 13 dB
- $\sigma_{PN} = 10°$

EXPERIMENTAL SETUP

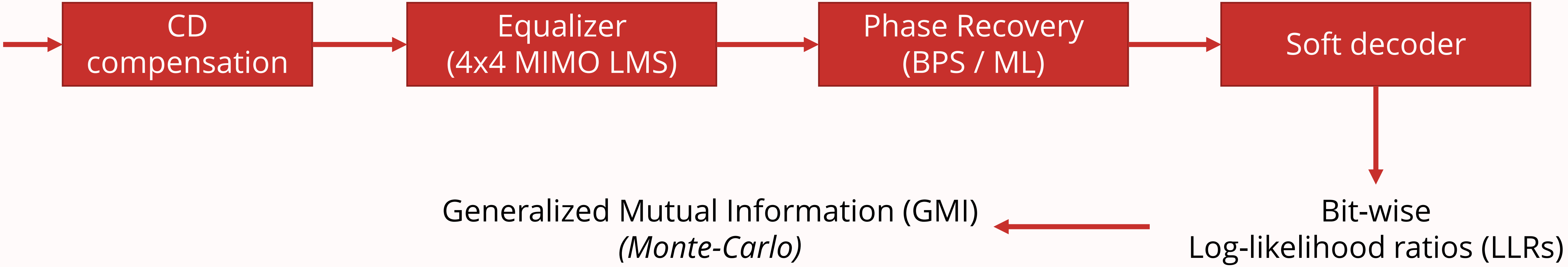




R_s=16 GBd, Δf=25 GHz

Parameter	Value
EDFA noise figure	5.2 dB
Chromatic dispersion	2.65 ps/(nm km)
Non-linearity coeff.	2 1/(W km)
Attenuation	0.23 dB/km

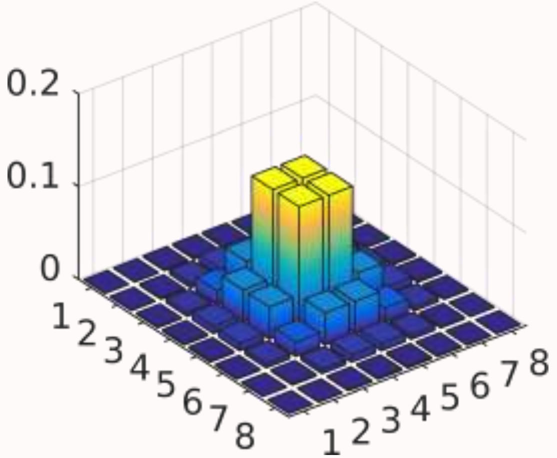
RECEIVER DSP



- Pure AWGN channel
- AWGN channel with memoryless phase noise (PN-aware)

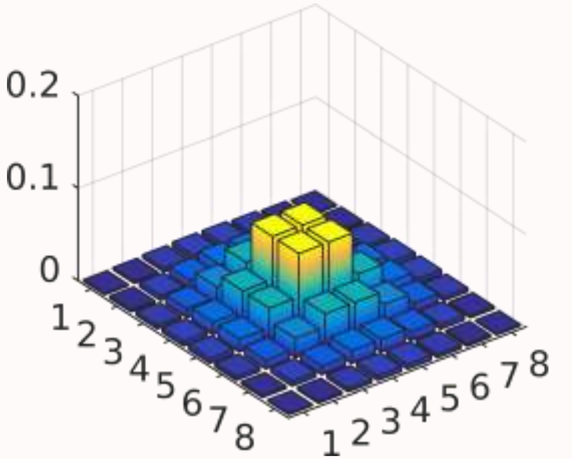
$$l_i = \log \frac{\sum_{a_1 \in \chi_i^1} p(y|a_1) P(a_1)}{\sum_{a_0 \in \chi_i^0} p(y|a_0) P(a_0)}$$

CONSTELLATIONS UNDER TEST

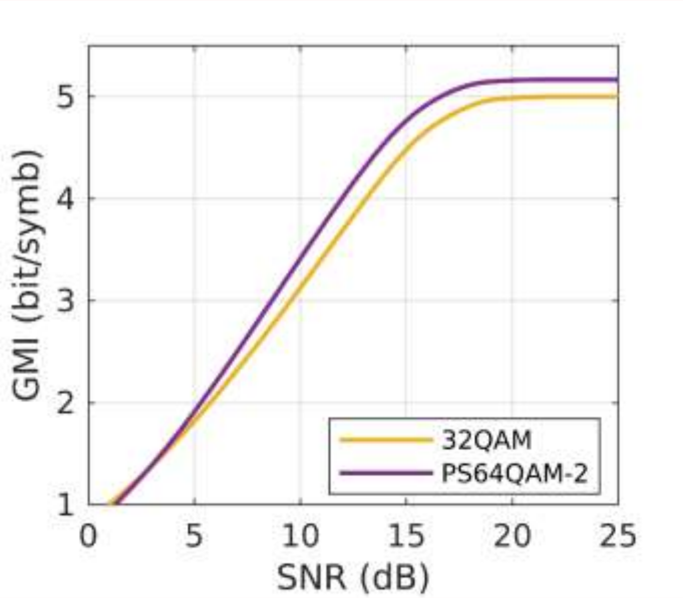


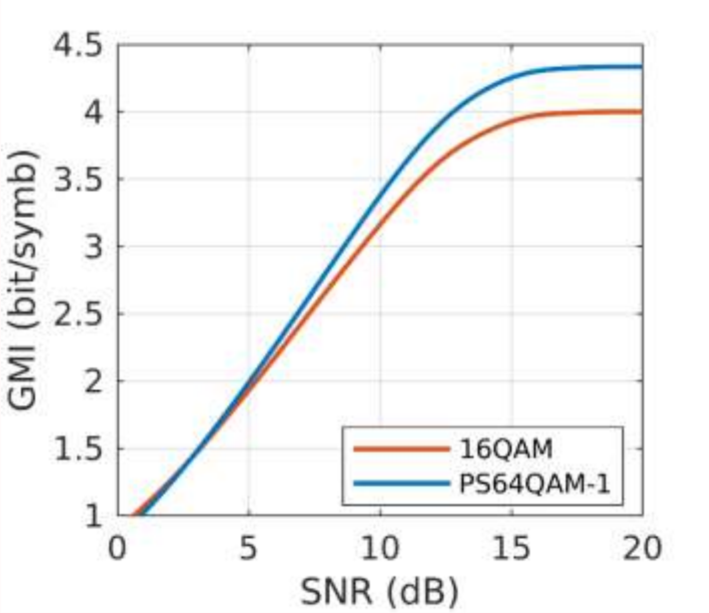
PS64QAM-1

- Two different PS-64-QAM constellations were tested
- Same **net data rate** after 20% FEC as:
  - Uniform 16-QAM
  - Uniform 32-QAM
- Normalized GMI (NGMI) threshold: **0.90**

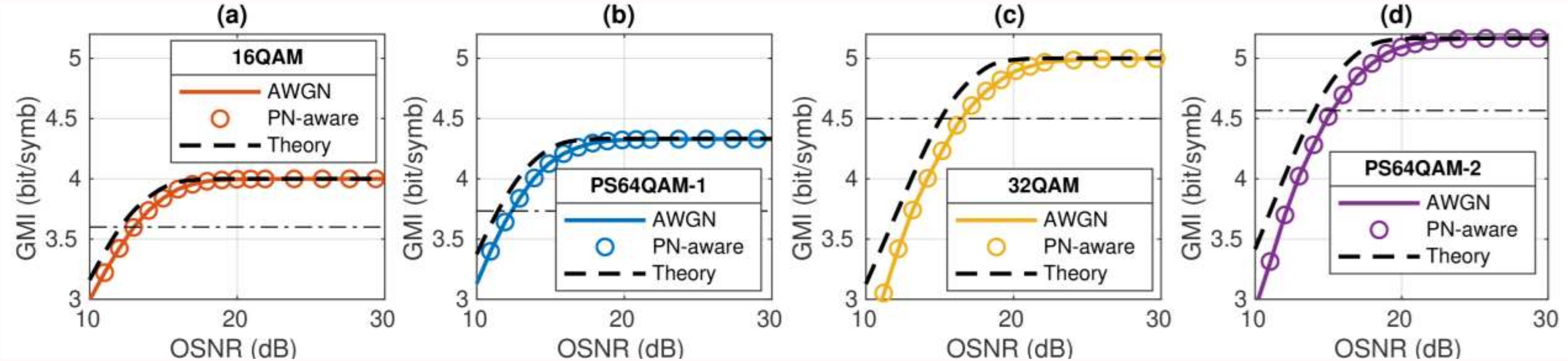


PS64QAM-2





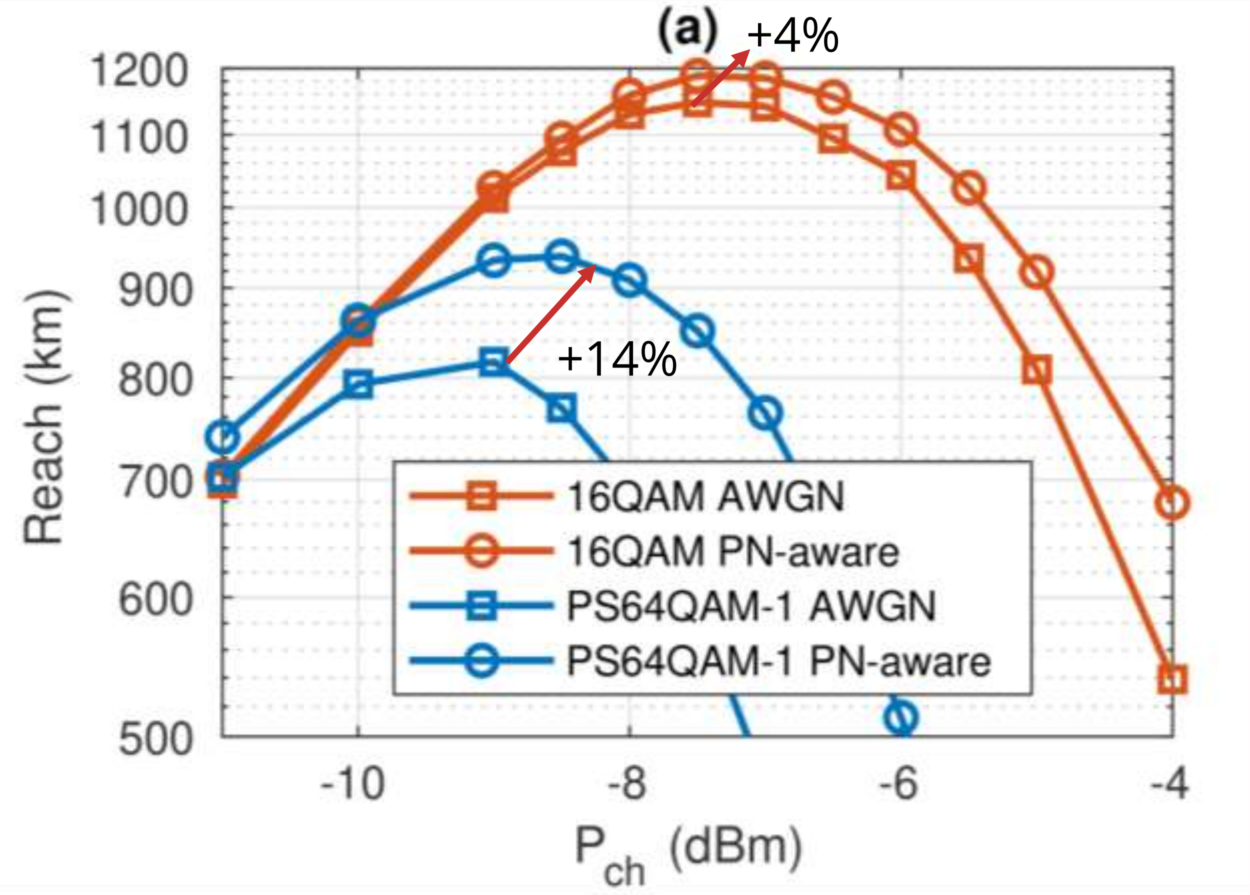
BACK-TO-BACK RESULTS



Thresholds correspond to an NGMI=0.9

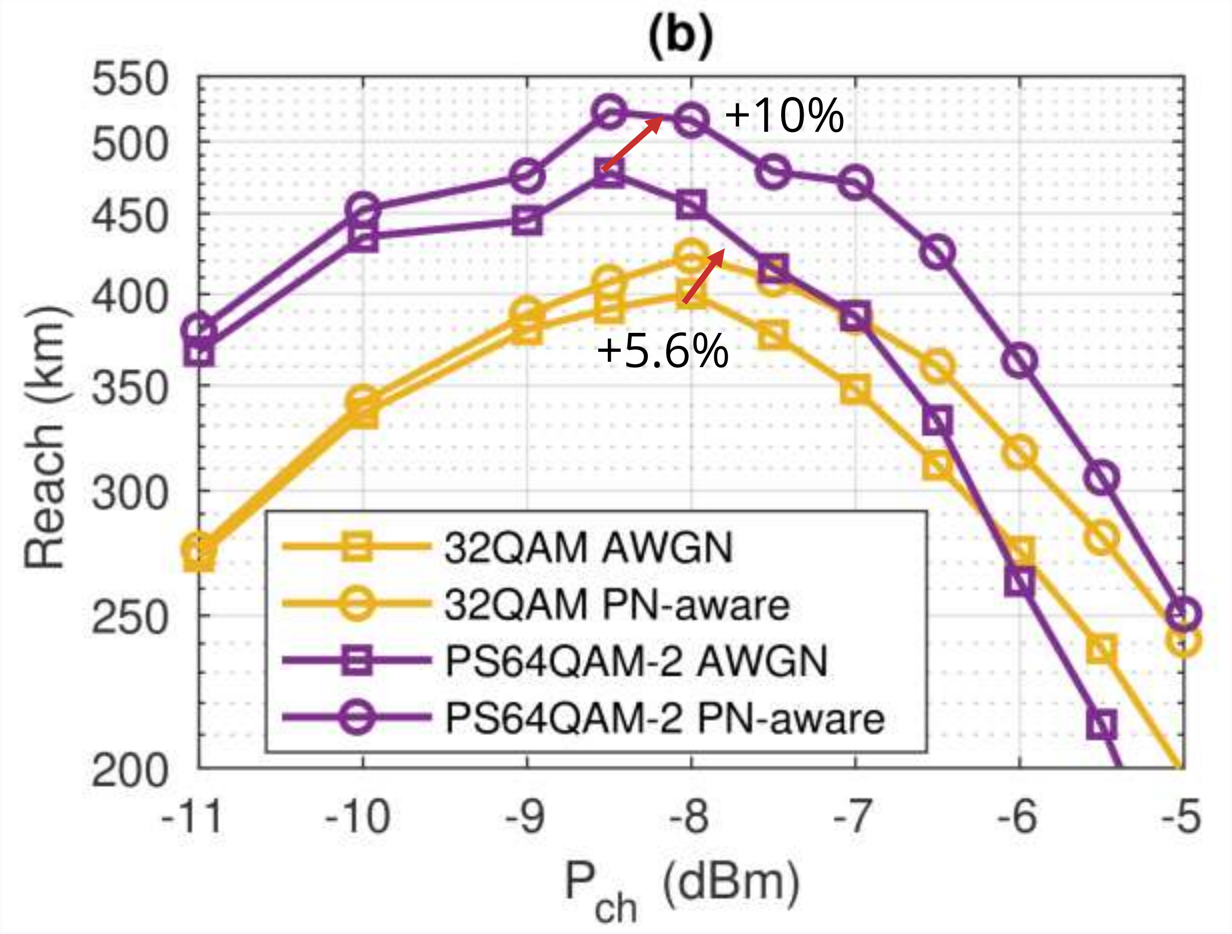
- Without non-linear phase noise, PN-aware decoding does not improve, nor worsens, performance

PROPAGATION RESULTS: 16-QAM



- Phase noise severely impairs PS64QAM-1
  - *Negative* reach gain!
- Strong gain of **PN-aware** decoding

PROPAGATION RESULTS: 32-QAM



- Slightly smaller gain than 16-QAM

CONCLUSIONS

- Using **large constellations**, with shaping, over legacy fibers (NZDSF) generate a strong non-linear **phase noise**.
- The phase recovery eliminates the **slow** phase noise component, leaving a **residual *memoryless*** phase noise.
- An optimized soft decoding strategy can **improve** the performance in the presence of such noise

ACKNOWLEDGMENTS

Acknowledgements:

- This work is carried out in the PhotoNext initiative at Politecnico di Torino http://www.photonext.polito.it/

- The work was partially sponsored by Cisco Photonics Italy S.r.l.

THANK YOU

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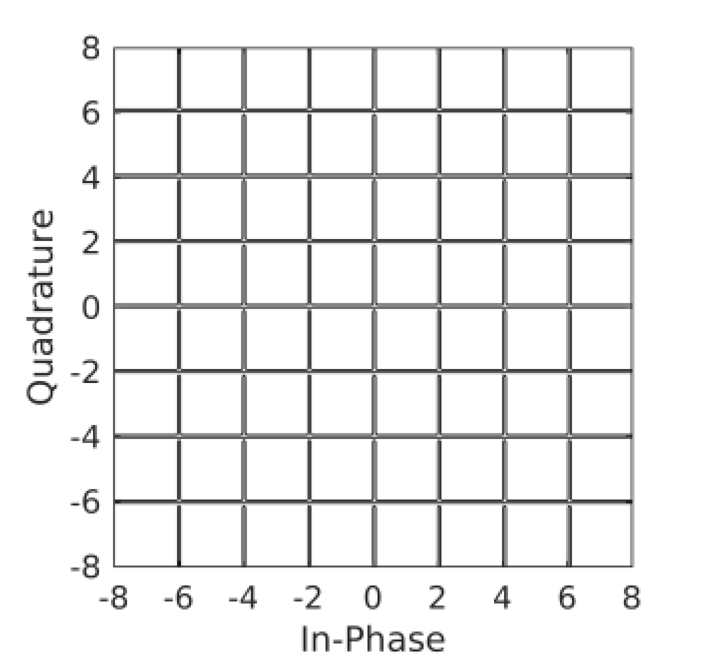
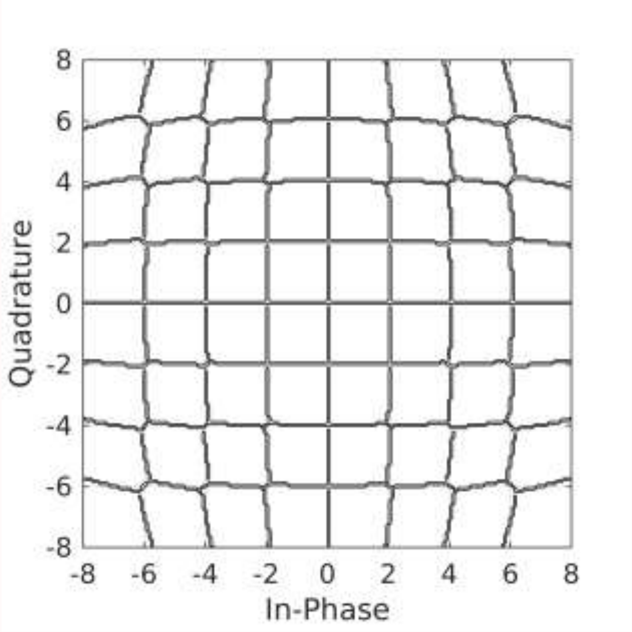
SLIDES AVAILABLE FOR DOWNLOAD AT: HTTPS://WWW.OPTCOM.POLITO.IT/TALKS

BACKUP SLIDES

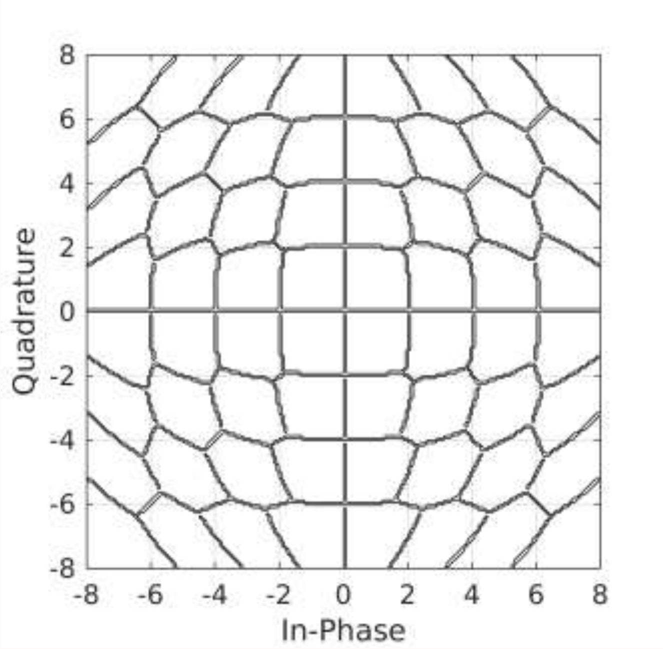
GRAPHICAL EXAMPLE: HARD DECISION REGIONS



AWGN only
(no phase noise)



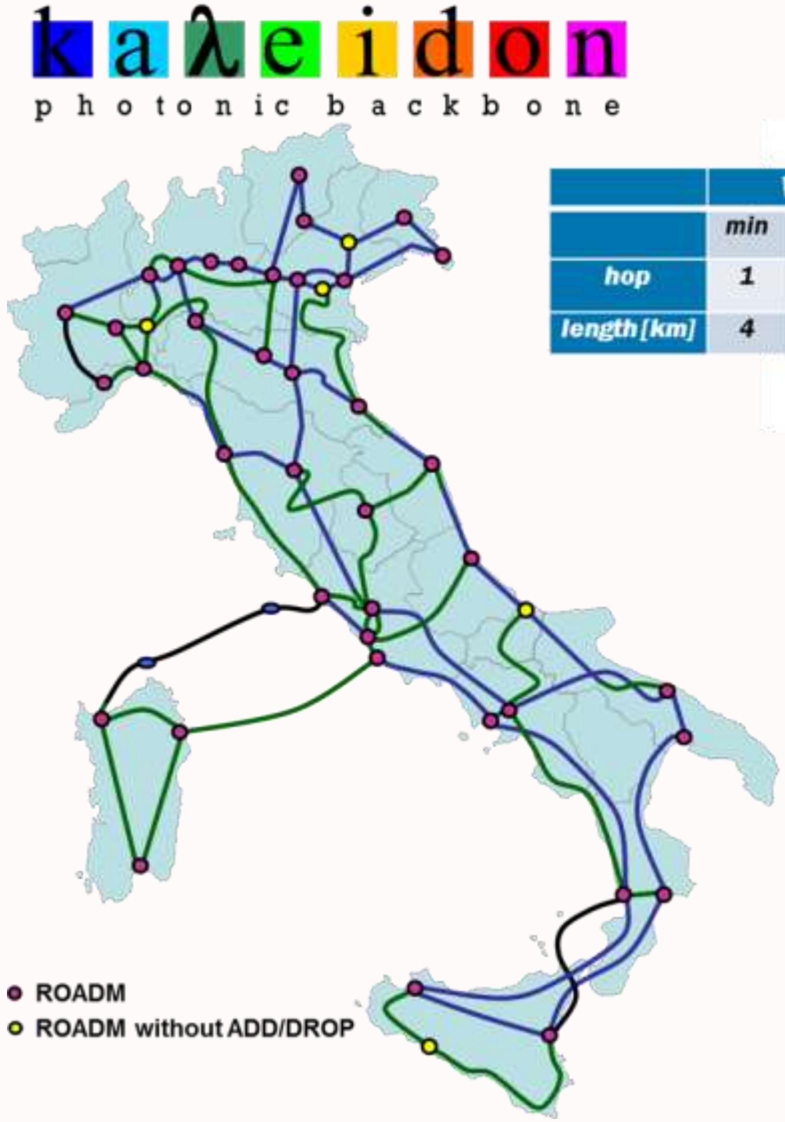
$\sigma_{pn} = 2°$, SNR = 16 dB



$\sigma_{pn} = 5°$, SNR = 16 dB

- PN-aware expression can be also applied to **hard decision**

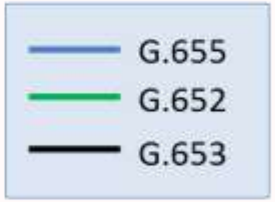
EXAMPLE OF NATIONAL NETWORK



	Working path			Protection path		
	min	average	max	min	average	max
hop	1	4.72	11	1	6.46	15
length [km]	4	758	2164	36	1046	2606

Nodal degree	Numbers of nodes
2	10
3	12
4	18
5	4

Fiber type



Telecom Italia network (2013)

From: EU project “Idealist” D.1.1 technical report