Soft decoding in optical systems: Turbo Product Codes vs. LDPC Codes

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speaker

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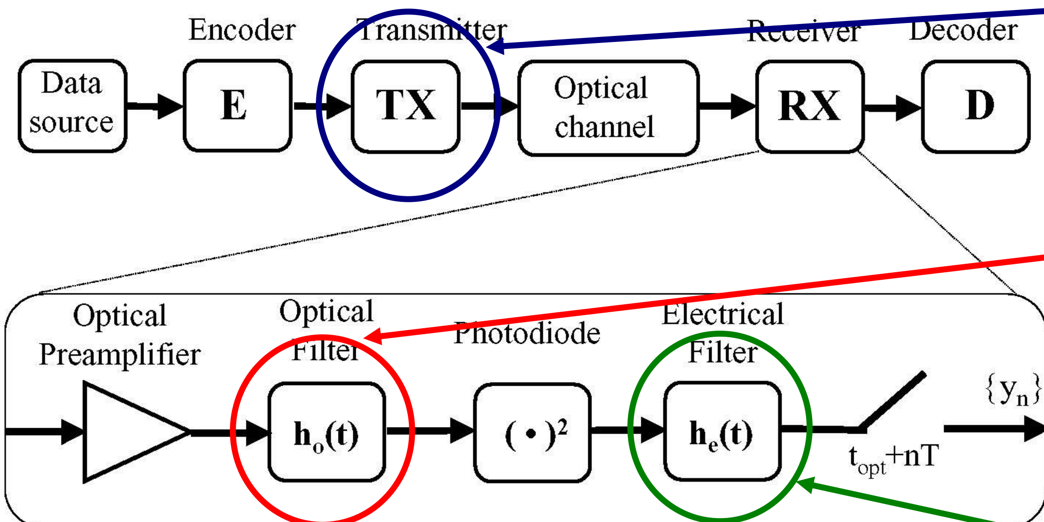
Introduction

- In this work, we compare the performance of two different classes of FEC codes in an optical communication system scenario that have been recently proposed to replace standard Reed-Solomon codes .
- Both codes make use a **soft iterative decoding** algorithm, which yields an increased coding gain of about 2 dB with respect to hard decoding.
- The simulation results also encompass the effect of **quantization** over a low number of bits on the log-likelihood ratio.

Optical system schematics

- Schematic representation of a digital optical communication system:



10 Gbit/s NRZ optical Pulses (raised-cosine, roll-off 0.8)

Raised-cosine optical filter (roll-off 0.25, bandwidth 20 GHz)

Five-pole Bessel Electrical filter (bandwidth 8 GHz)

Soft iterative decoding

- Soft iterative decoding is a powerful way of increasing the coding gain up to performance close to Shannon's theoretical limits.
- Two class of codes exploiting the advantages of soft iterative decoding are emerging in the field of optical communications:

TURBO PRODUCT (TP) CODES
Serially concatenated block codes with interleaver.

LOW-DENSITY PARITY-CHECK (LDPC) CODES
Binary, linear block codes with a highly sparse parity-check matrix.

Noise statistics

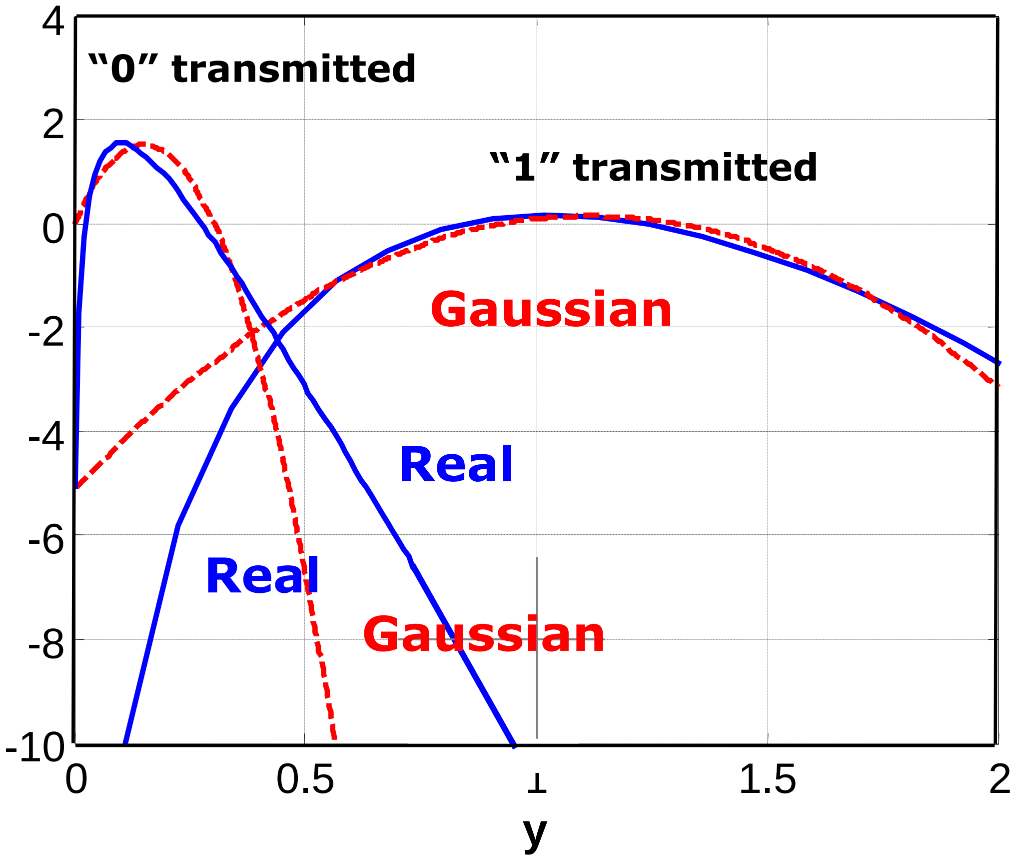
- The **soft information** from the communication channel to be used in the iterative decoding algorithm depends on the a-priori conditional probabilities, which in turn depend on channel **noise statistics** and receiver operations.

- If the communication channel can be properly modeled as an **additive white Gaussian noise (AWGN) channel**, the probability density function of the received signal is Gaussian and the **log-likelihood ratio** of the decision variable assumes a **very simple form**.

Noise statistics

- In long-haul amplified optical systems, the presence of a quadratic element (the photo-detector) at the RX, leads to a **strongly non-Gaussian noise statistics**:

Signal PDF after photodetection



Simulation technique

- In order to properly design an iterative decoding algorithm to be used in optical systems, the **exact expression of the a-priori conditional channel probabilities** has to be considered. In our simulations, we used the technique presented in [1] in order to properly evaluate such probabilities.

[1] G. Bosco, G. Montorsi, S. Benedetto, "Soft decoding in optical systems", *IEEE Trans. Commun.*, vol. 51, no. 8, pp. 1258-1265, Aug. 2003.

Simulations results

- We will focus on three different coding configurations:

TP CODE
BCH(128,113)^2

LDPC CODE 1
(3276,2556)

LDPC CODE 2
(16384,14840)

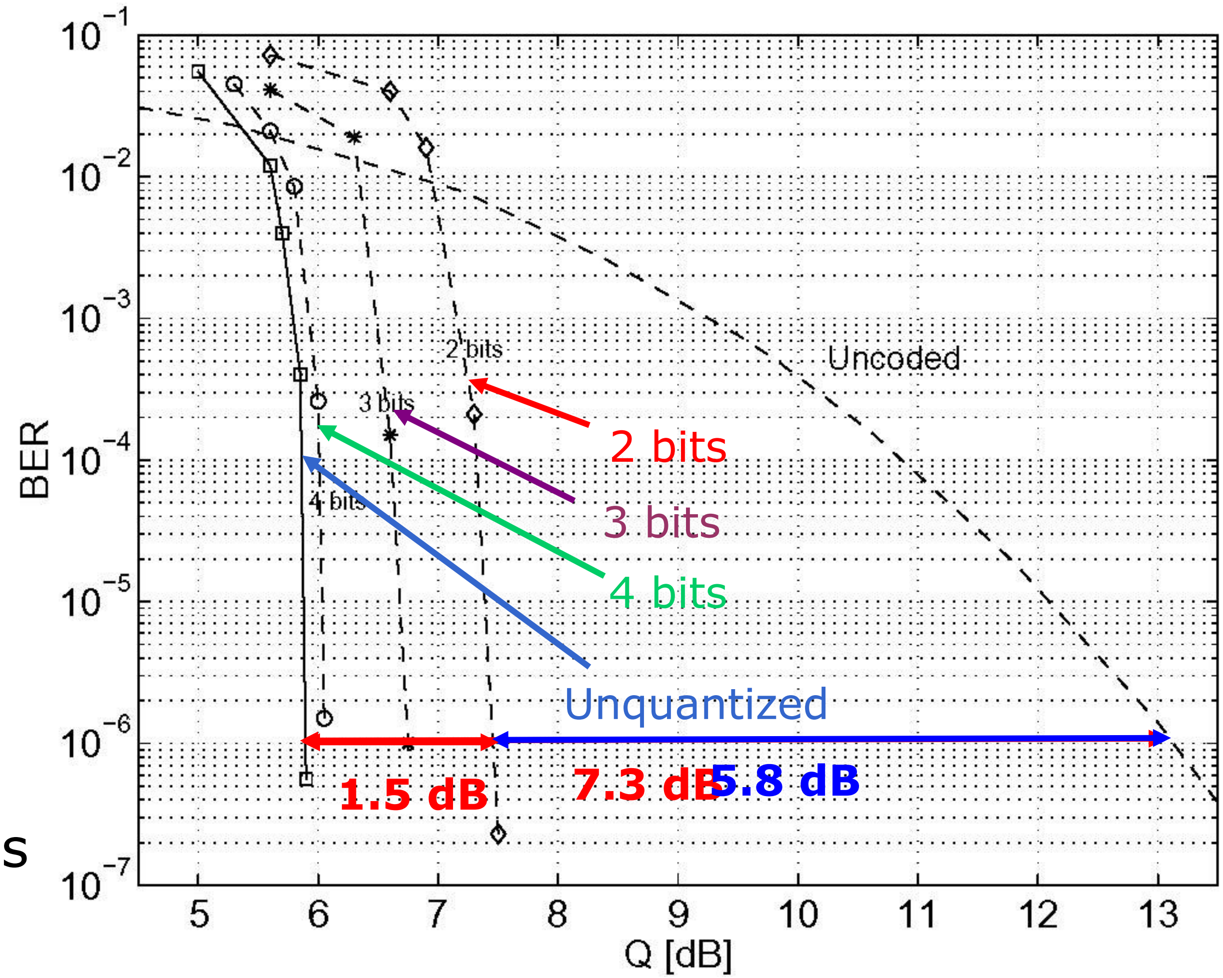
28 % redundancy

16 % redundancy

(more suitable for the use in a highly bandwidth efficient optical communication system)

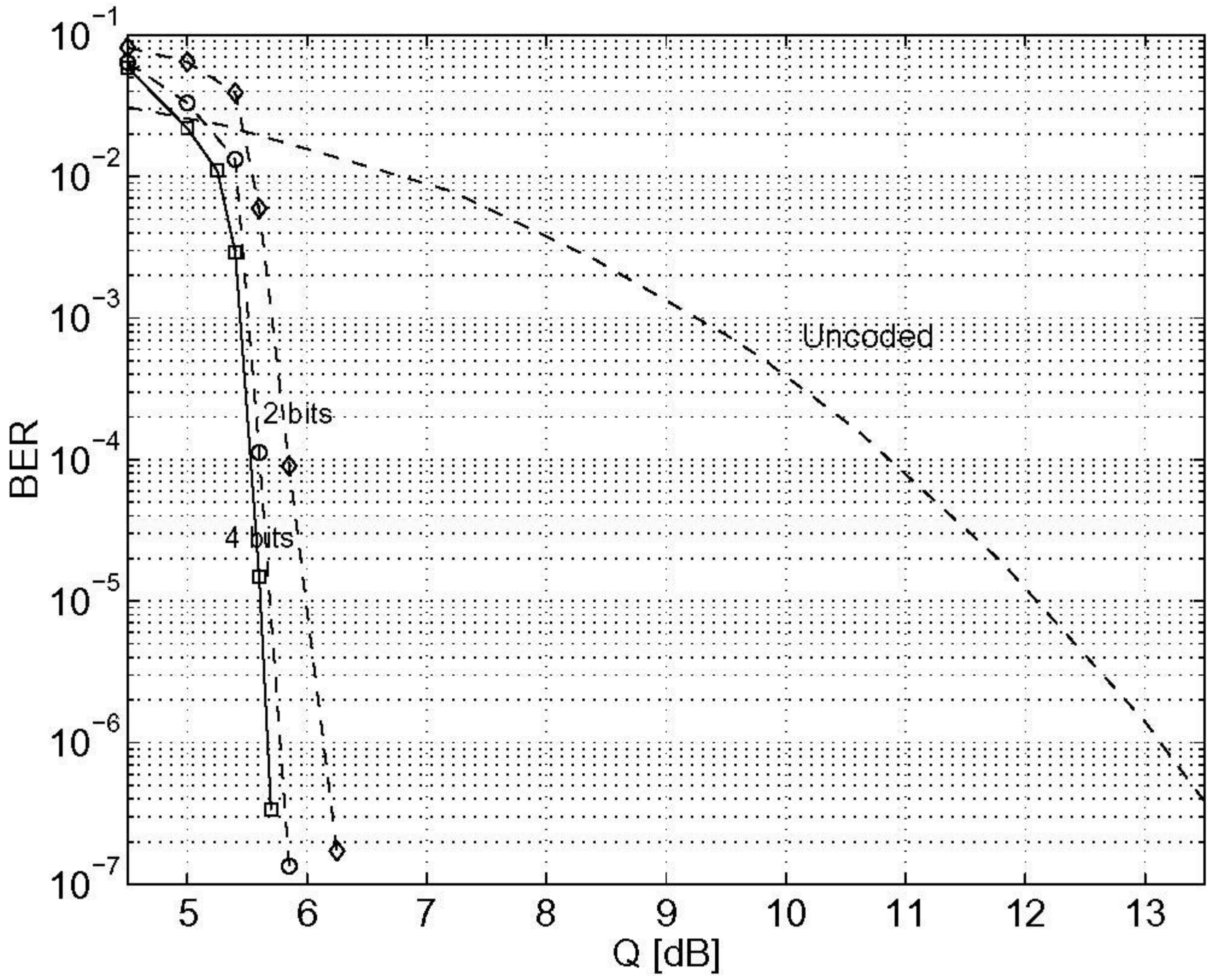
Product code BCH(128,113)²

- 7.3 dB coding gain at 10^{-6}, vs. 4.6 dB of concatenated RS(255,223)+ RS(255,239)
- Four bits of quantization yield almost ideal performance
- Using only two bits corresponds to a 1.5 dB penalty.



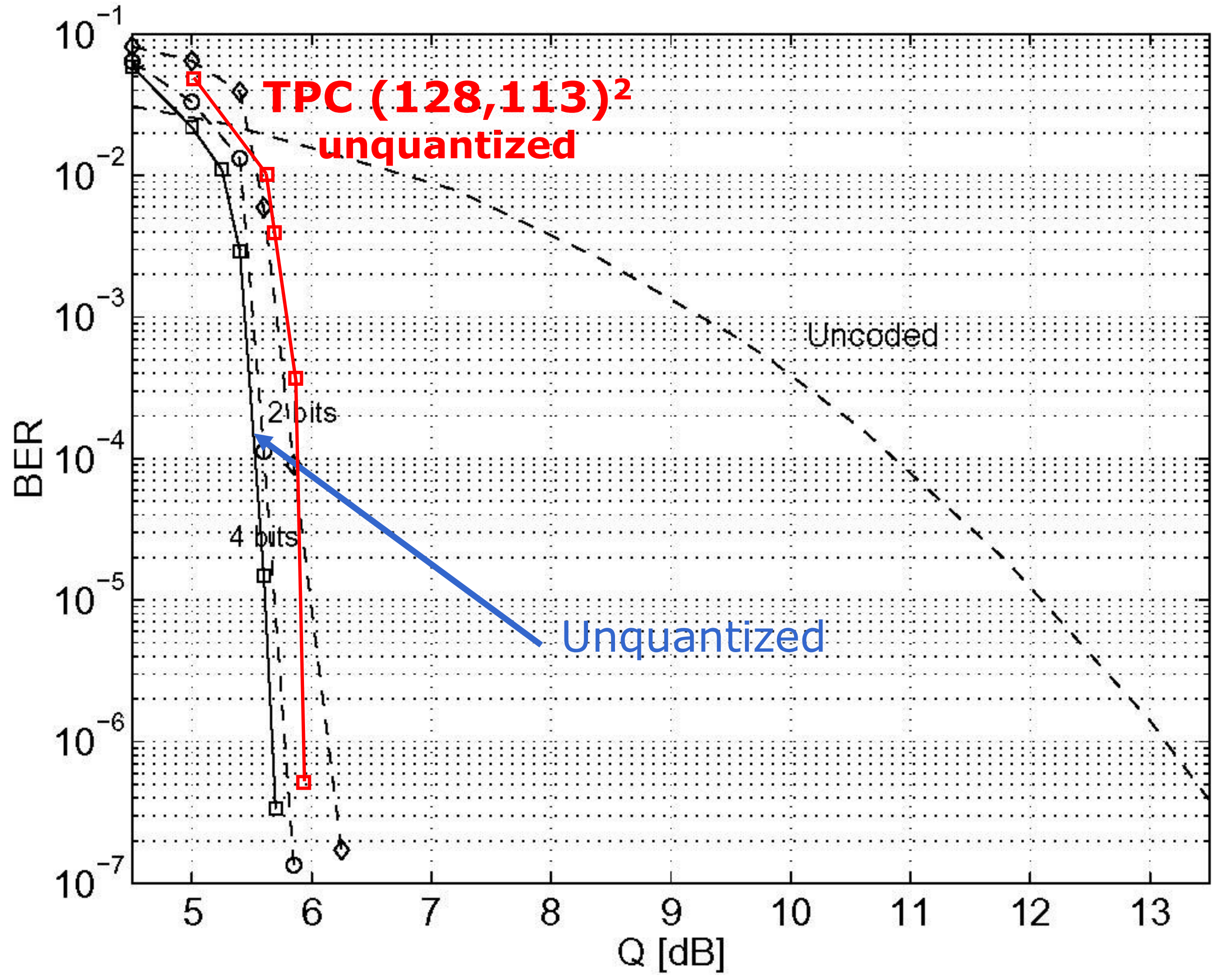
LDPC code (3276,2556)

- Maximum number of iterations: 25
- The product between the code length and the number of iterations (directly related to complexity) is the same as the one of the TP code.



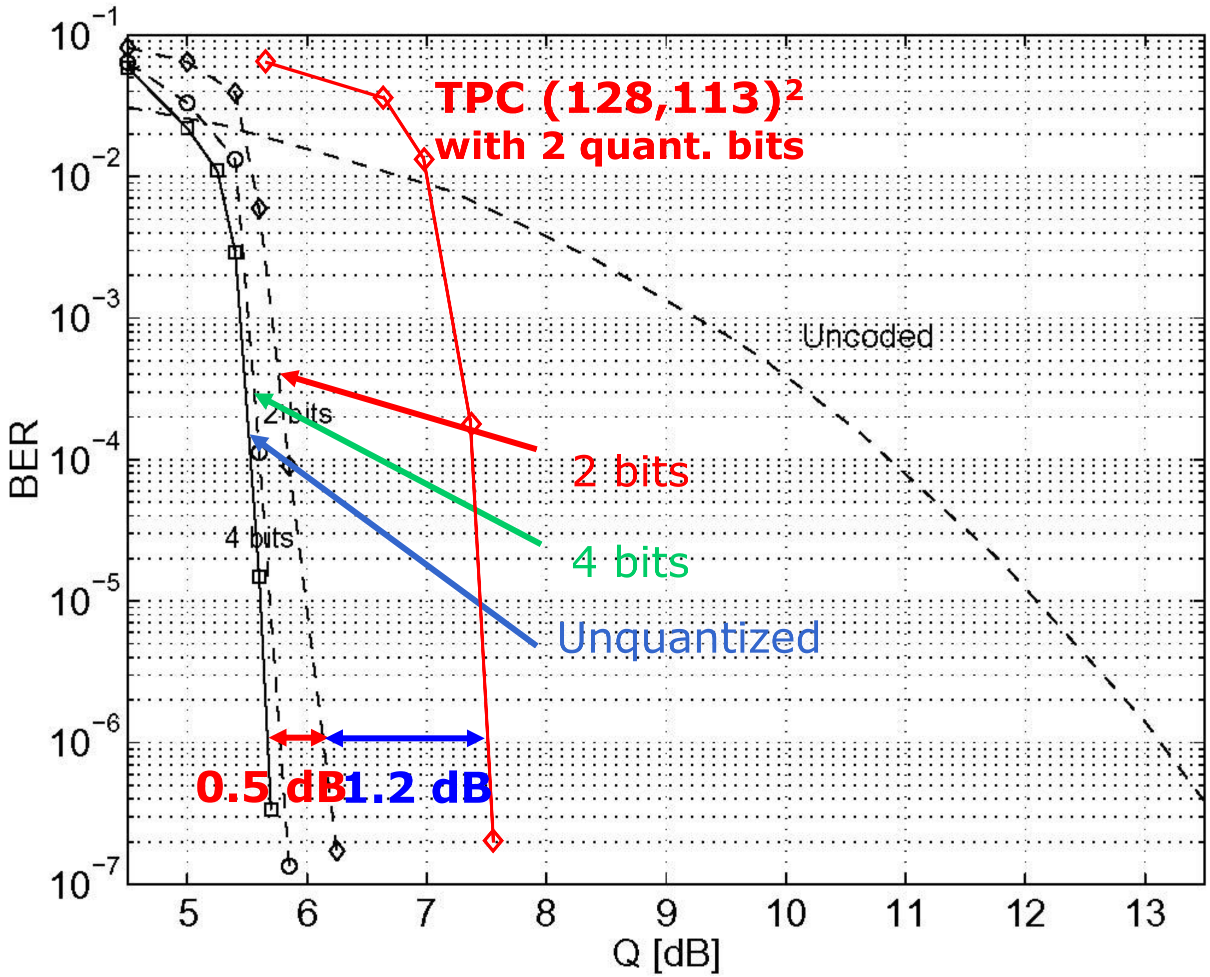
LDPC code (3276,2556)

- LDPC code (3276,2556) has slightly better performance than the previously analyzed turbo product code.
- Maximum number of iterations: 25
- The product between the code length and the number of iterations (directly related to complexity) is the same as the one of the TP code.



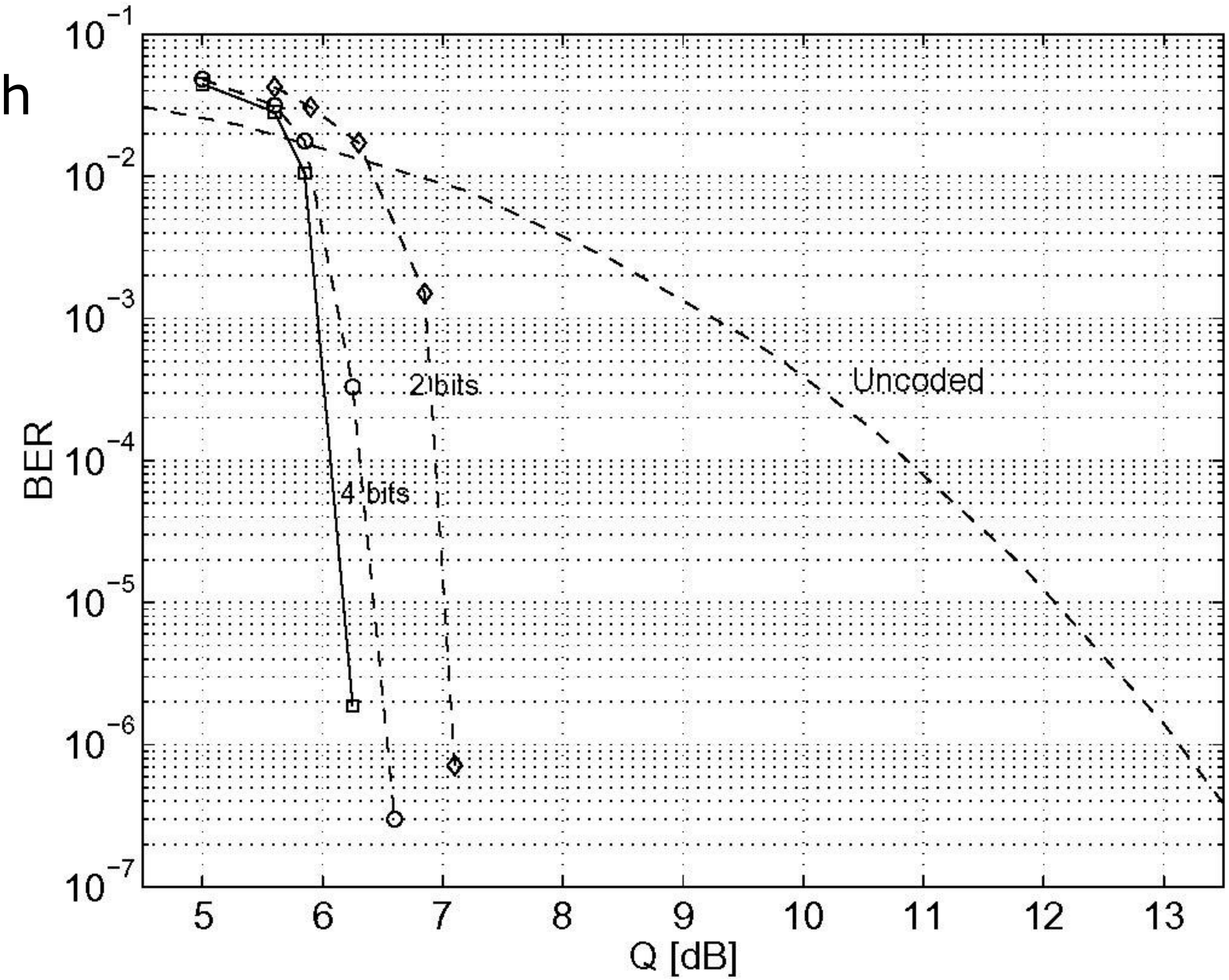
LDPC code (3276,2556)

- Morover, it is more robust to quantization
- Using only two quantization bits, the loss at 10^{-6} is less than 0.5 dB.
- This corresponds to a gain of 1.2 dB over the Turbo Product Code BCH$(128,113)^2$



LDPC code (16384,14080)

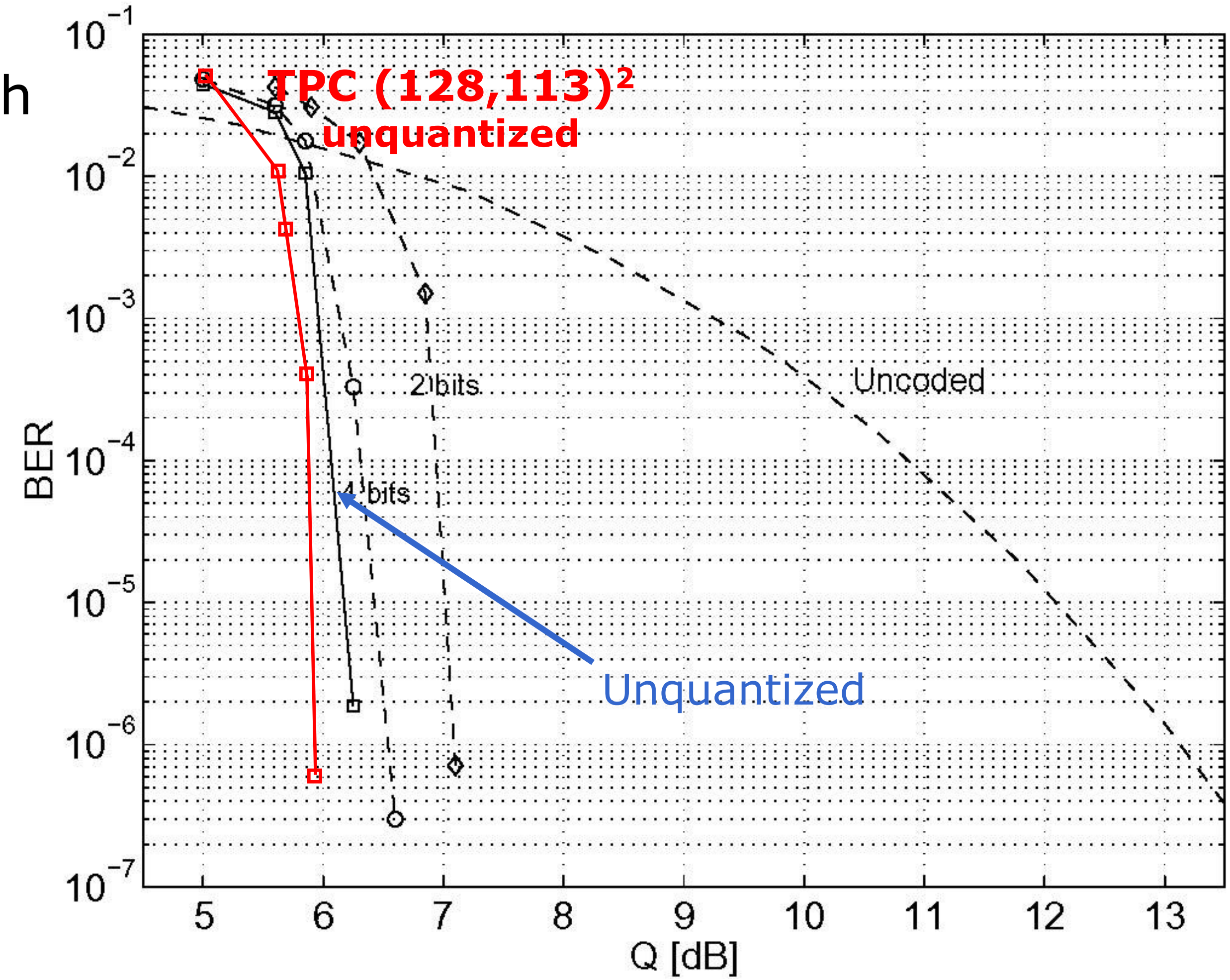
- This code has been chosen with a significantly higher rate than the other codes, in order to increase the bandwidth efficiency of the system.



LDPC code (16384,14080)

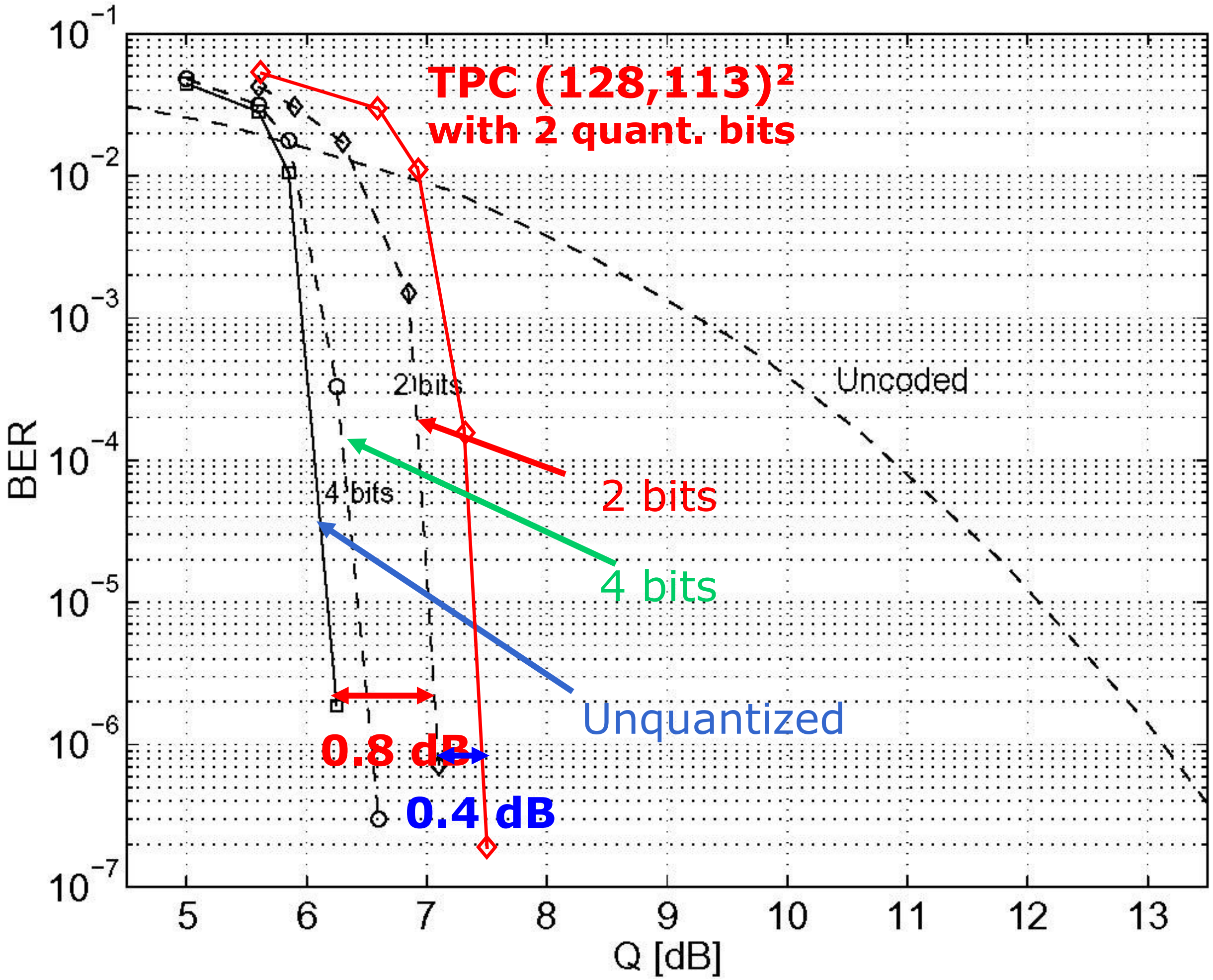
- This code has been chosen with a significantly higher rate than the other codes, in order to increase the bandwidth efficiency of the system.

  LDPC code, which has the same codeword length as the BCH(128,113)^2, yields similar performance as the product code, but with a sensibly higher code rate.



LDPC code (16384,14080)

- Like the other LDPC code, it is more robust to quantization than TP code.
- Using only two quantization bits, the loss at 10^{-6} is less than 1 dB.
- Using two quantization bit, it has a gain of 0.4 dB respect to the TP code, which has the same length but lower rate.



Conclusion

- In this work, we have compared the performance of two different classes of FEC codes in an optical communication system scenario.
- Simulation results refer to practical turbo-product and LDPC codes that have been proposed to replace the Reed-Solomon codes in optical communication systems, and encompass the effect of quantization on the log-likelihood ratio.
- The results show that LDPC codes give in general better results than turbo product codes.
- One of the main advantages of LDPC codes over TP codes for the application in optical systems is their intrinsic higher robustness to quantization.