Construction of very low rate NB-LDPC code for IoT.

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Very low rate communication

- Can we transmit small messages at very low power of emission (regulation of the ISM band) form a sensor to a base station?

- GPS antenna of 40 W, 20 000 km above the ground level, transmits data all over the word!
  - Secret: code rate of 1/20460 (repetition code).

⇒ We can probably do something to transmit few octets on medium range distance (20 kilometers for example) with few mJ.

Problem

- We want to construct very low rate code (up to 1/1500) better than the repetition code.
- We want to construct frames that have a structure that helps time and frequency synchronization when the signal level is far bellow the noise level.
- Proposed solution: joint Non Binary Code with CCSK modulation.

What is a NB–LDPC code?

It is a LDPC… except that parity check equations are done on a Galois Field GF(q) of cardinality q>2.

Let us remind what is a Galois Field.

Let P[X] be a irreducible polynomial of degree $\log_2(q)$.

The set of polynomial GF(q) = GF(2)[X] modulo P[X] has a Galois Field structure, i.e.:

addition: (GF(q),+)

multiplication (GF(q), x)

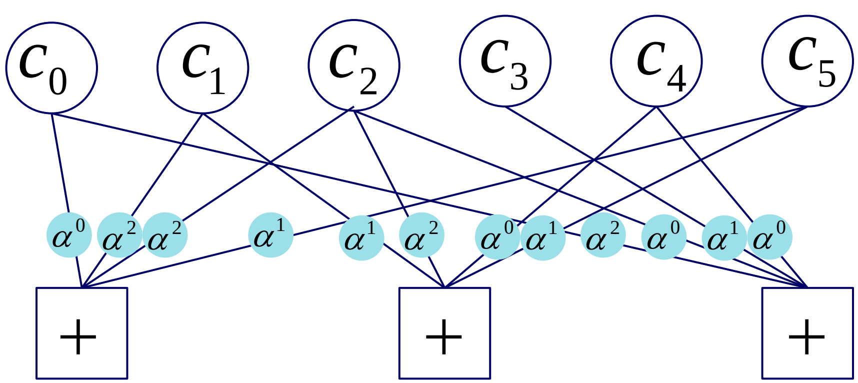
…and all associated nice properties

NB–LDPC

Parity check matrix:

$$H=\begin{pmatrix}\alpha^0 & \alpha^2 & 0 & \alpha^2 & 0 & \alpha^1\\ 0 & \alpha^1 & \alpha^2 & 0 & \alpha^0 & \alpha^1\\ \alpha^2 & 0 & \alpha^0 & \alpha^1 & \alpha^0 & 0\end{pmatrix}$$

$$\begin{cases}\alpha^0 c_0+\alpha^2 c_1+\alpha^2 c_3+\alpha^1 c_5=0\\ \alpha^1 c_1+\alpha^2 c_2+\alpha^0 c_4+\alpha^1 c_5=0\\ \alpha^2 c_0+\alpha^0 c_2+\alpha^1 c_3+\alpha^0 c_4=0\end{cases}$$



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NB–LDPC

A NB-LDPC of size (n,m) in GF(q) corresponds to a binary code of size ($n \times \log_2(q)$, $m \times \log_2(q)$)

Good decoding performance for $d_v = 2$ (variable degree)

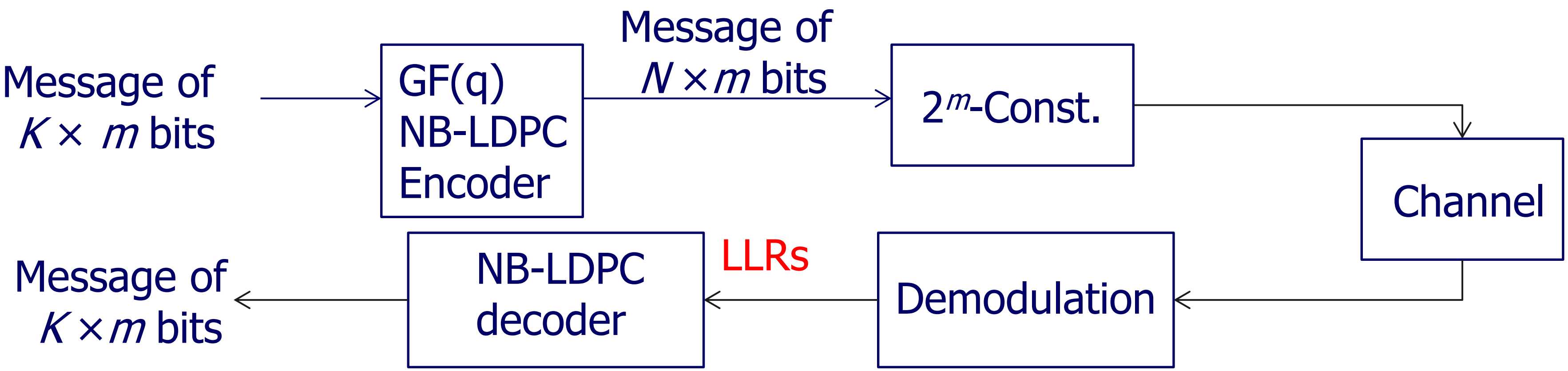
=> girth is high (higher than the binary counterpart)

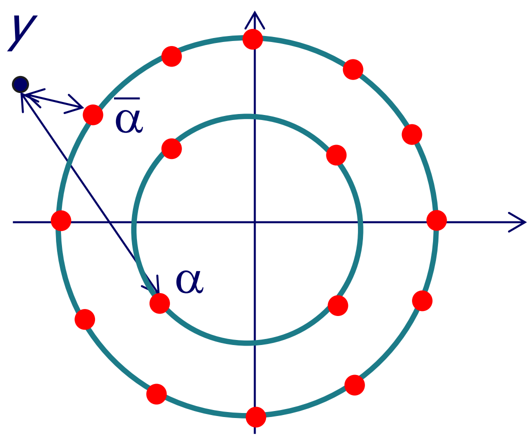
=> Belief Propagation is close to the MAP decoding algorithm

High spectral efficiency:

Coded modulation outperforms BICM modulation (information theory argument).

LLR computation for $q = 2^m$ constellation

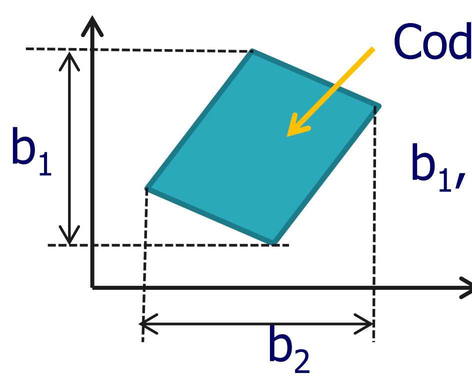




$$\mathrm{LLR}(\alpha) \approx \bar{d}(y,\alpha)^2 - d(y,\alpha)^2$$

16 LLR per symbol =>All channel information is extracted.

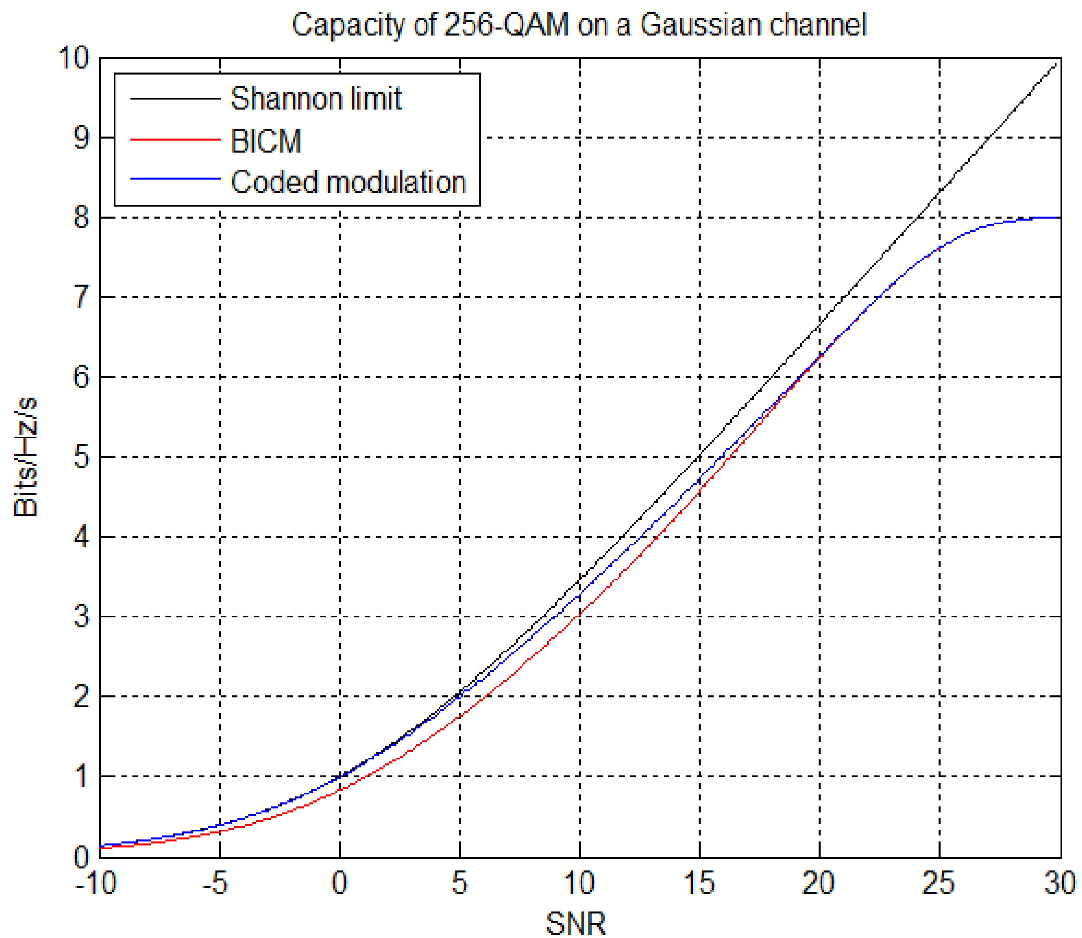
In binary =>only 4 LLR



Coded Modulation information

b_1, b_2 = BICM information

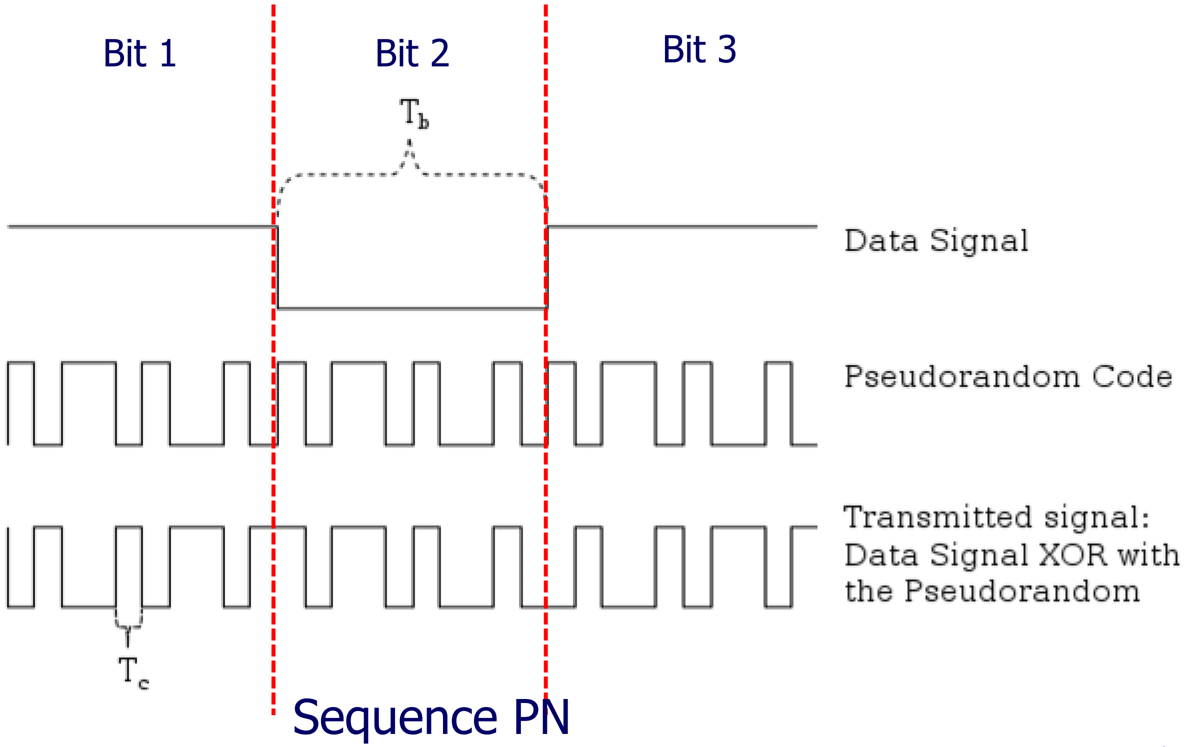
Mutual information in AWGN Channel



Can we use this adavantage for low spectral efficiency modulation?

CCSK signaling

➢ **Spread spectrum modulation** : the baseband signal bandwidth is intentionally spread over a larger bandwidth by injecting a higher frequency signal.



CCSK Modulation

- Cyclic Code-Shift Keying (CCSK) is an *q*-ary spread spectrum modulation where each $\log_2(q)$ binary symbol is mapped into a circularly shifted maximal-length Pseudo-Noise (PN) sequence.

GF(8)	CCSK: PN(k+ i % N)
000	01001011
001	10010110
010	00101101
011	01011010
100	10110100
101	01101001
110	11010010
111	10100101

- Demodulation:

$LLR(\alpha^i) \approx Distance(X, PN_i)$.

$$LLR(i) = \sum_{k=1}^{N} x(k) PN((k+i)\%N)$$

$$LLR = IFFF(FFT(X) * FFT(PN))$$

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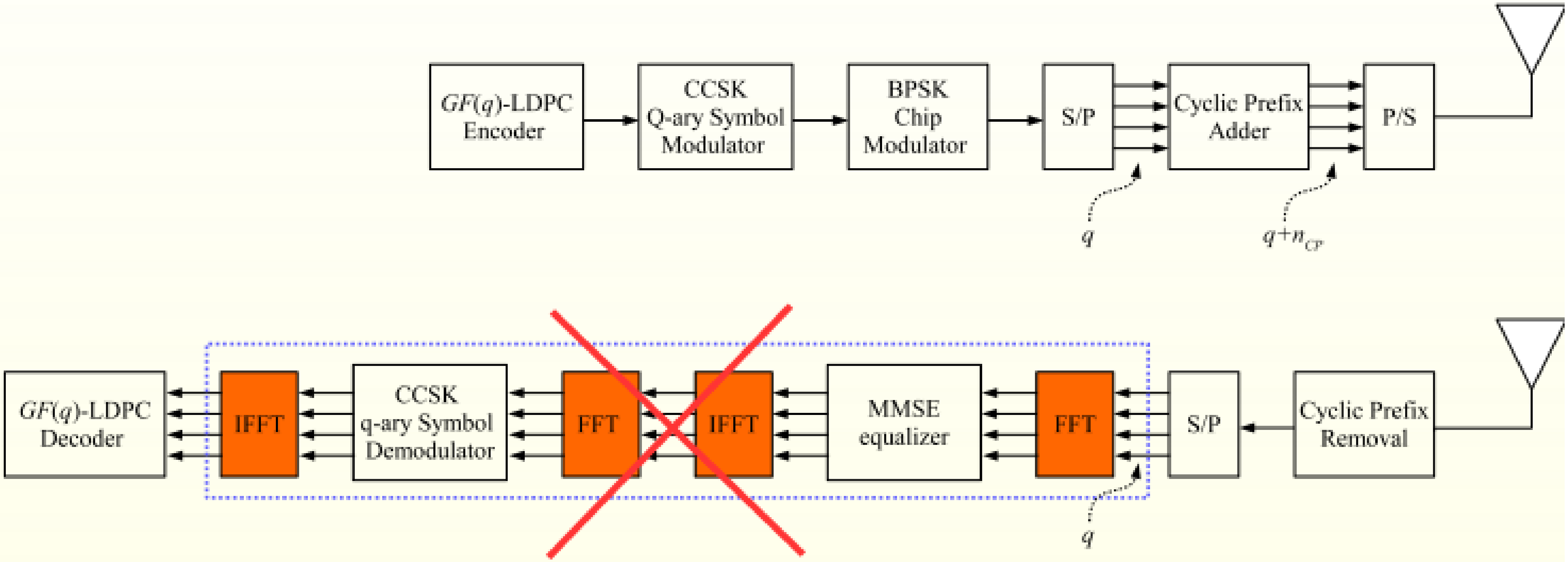
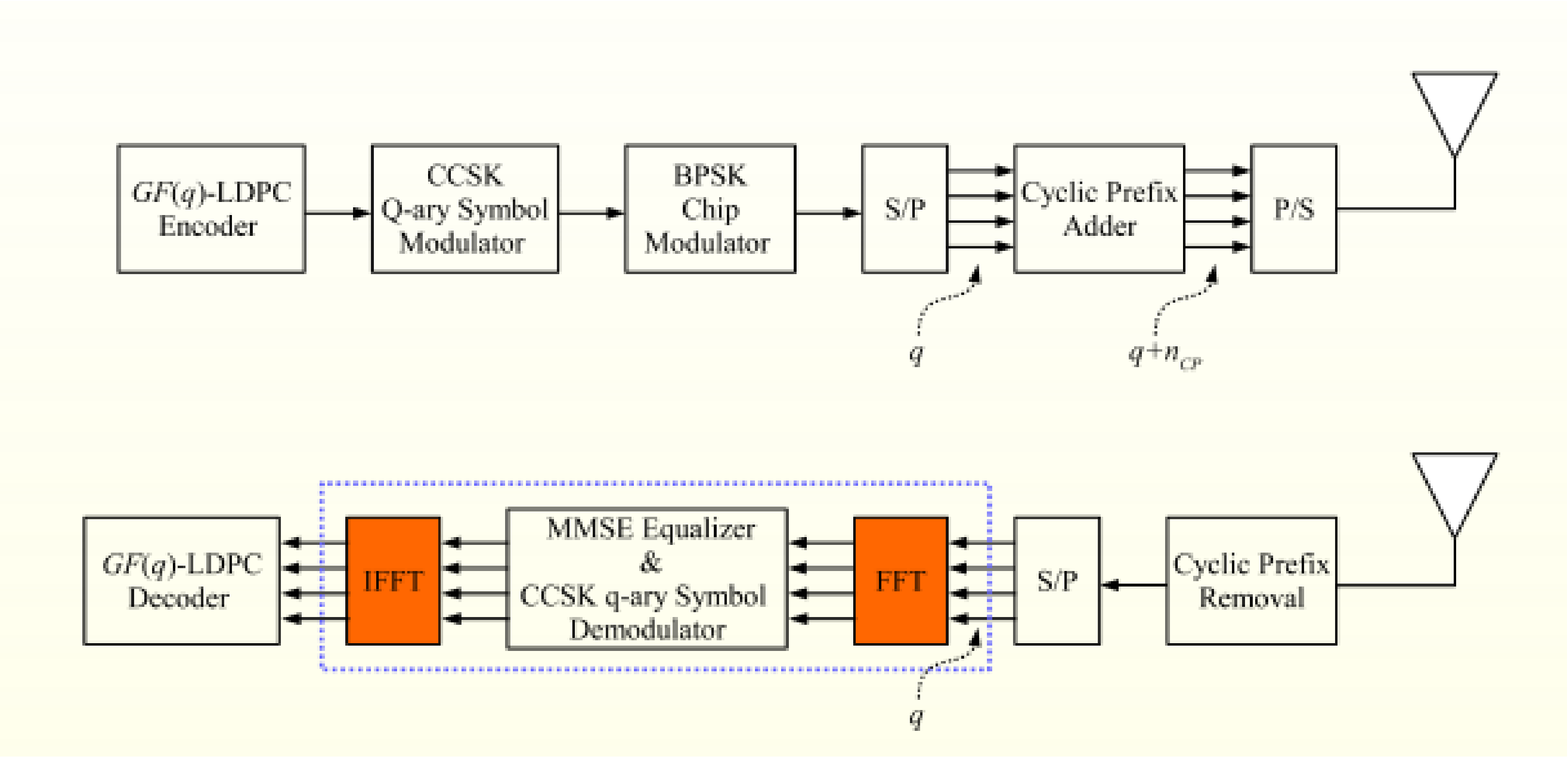
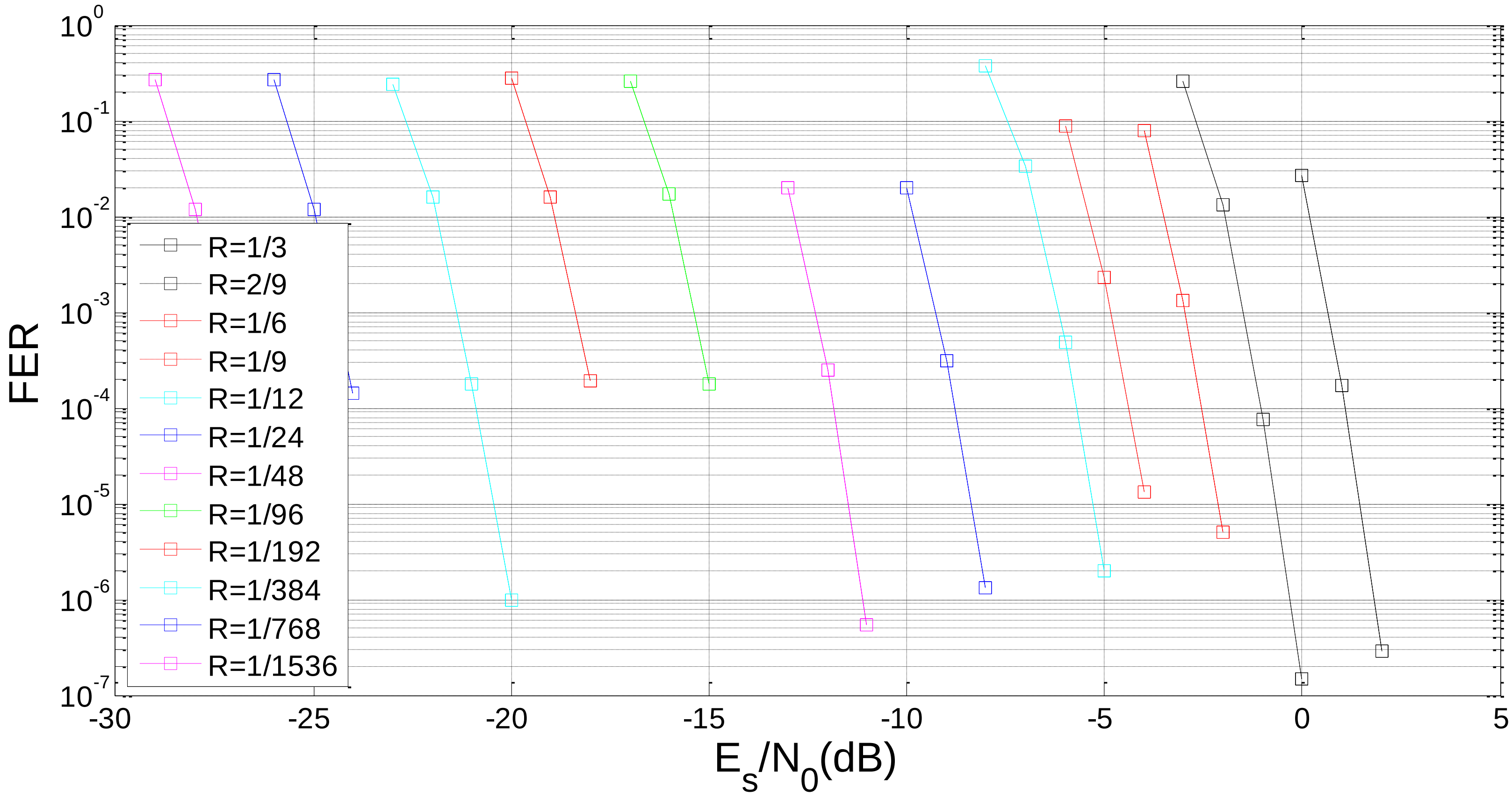
CCSK in multipath channel



CCSK in multipath channel

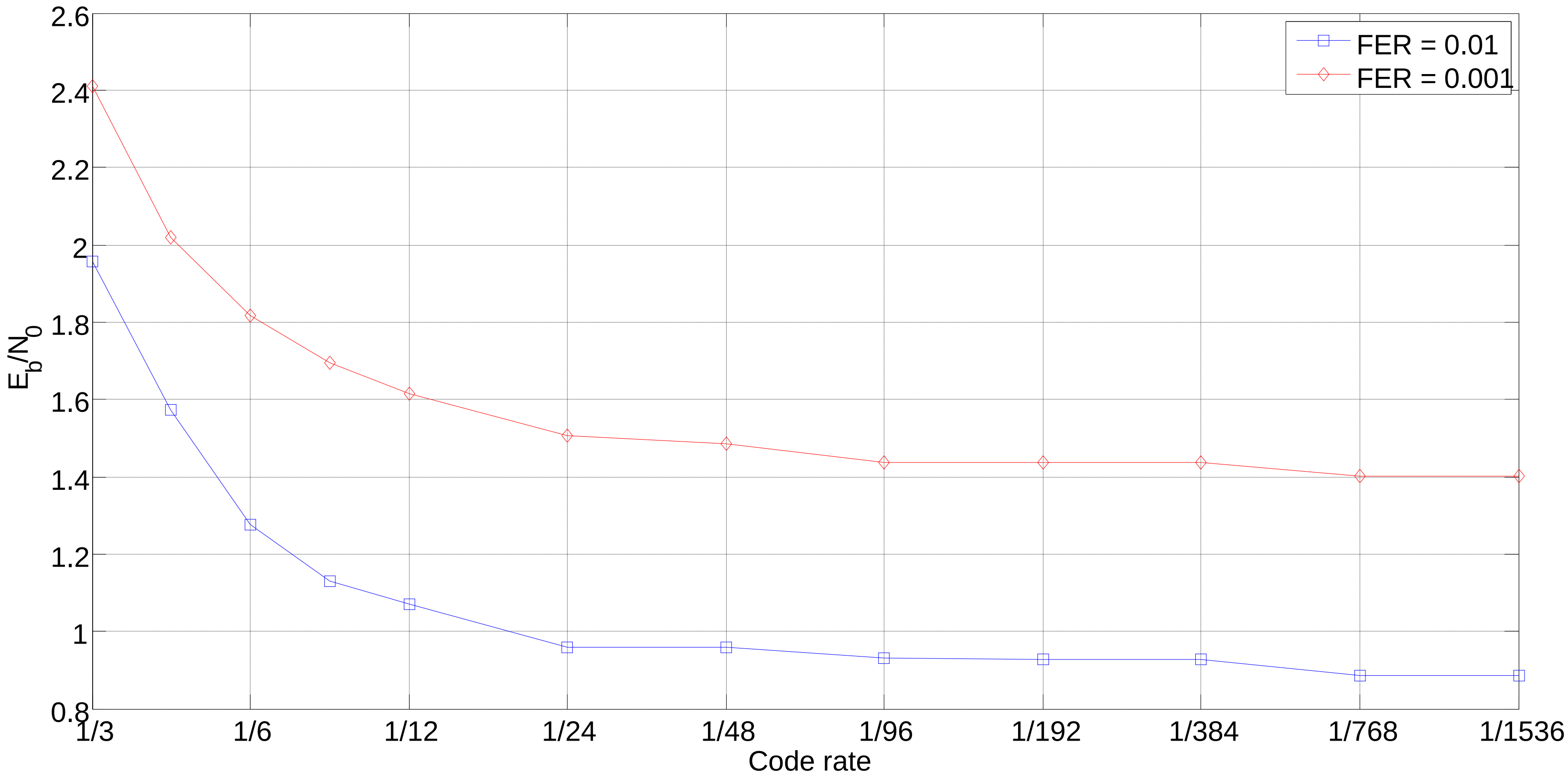


Performance for very low code rate



K = 112 bits, BPSK modulation, AWGN channel, 6 bits of quantization, 10 decoding iterations, sub-optimal decoding algorithm.

E_b/N_0 required for a given FER



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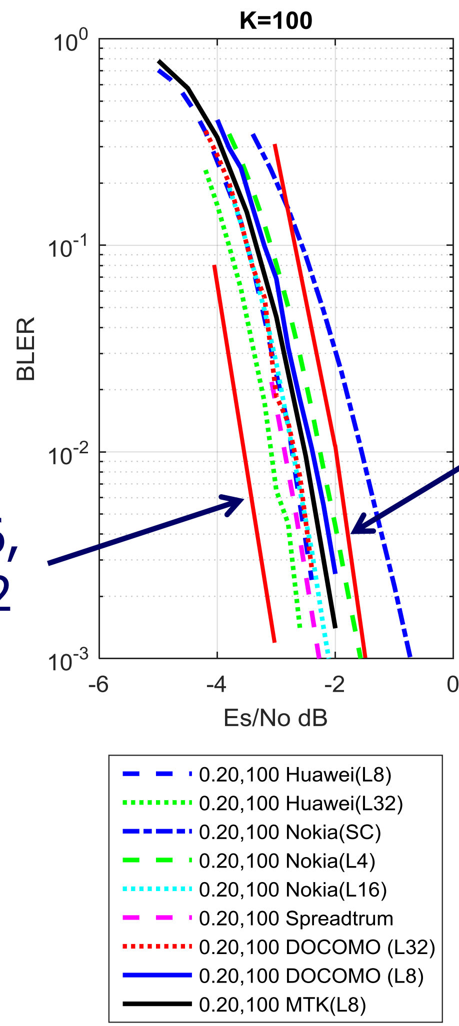
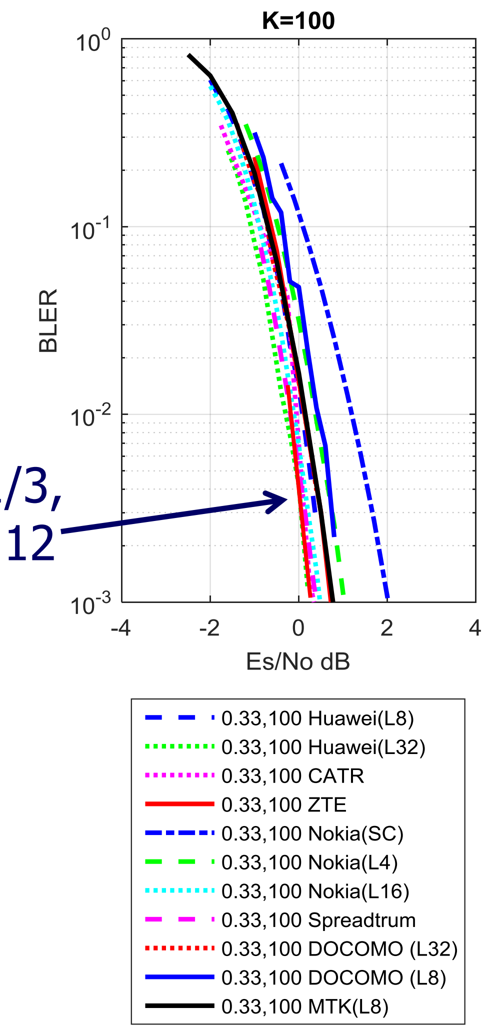
Comparison with Polar-code

Curves taken from 3GPP, R1-1610931, 10/2016



R = 1/6,
K = 112

R = 4/9,
K = 112



R = 1/3,
K = 112

Conclusion

- NB-LDPC + CCSK allows better gain than $10\log_{10}(2)$ = 3.01 dB in E_s/N_0 when the code rate is divided by 2.
- NB-LDPC + CCSK has a structure that helps time and frequency synchronization (not detailed in the presentation).
- Very simple message generation: only XOR operations at the emitter side (but complex receiver).
- Probably room for further code improvement.