Weighted Coherent Detection of QCSP frames

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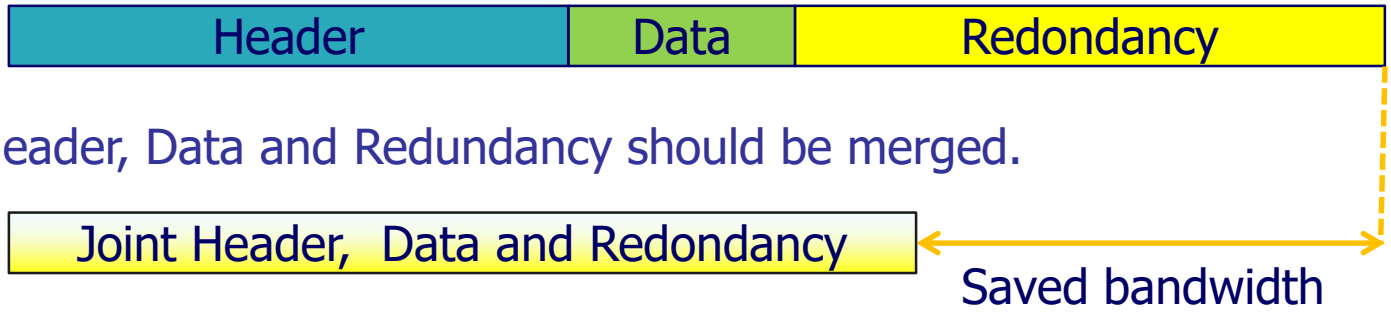
Massive IoT: paradigm shifts

10 users sending 1 Mbits vs 1 Millions user sending 10 bits ?

=> Only solution: suppress coordination… and accept collisions.

Classical frame (very) inefficient for small payload



=> Header, Data and Redundancy should be merged.

Big bet: new waveform for IoT for low cost sensors, unsupervised network

From space to earth

- **Cyclic-Code Shift Keying (CCSK)** used in Quasi-Zenith Satellite system (Japanese GPS enhancement system). 2003 **[1]**

- **Non-binary error correcting codes (NB-ECC)** used in BeiDou (Chinese GPS-like system) 2017 **[2]**.

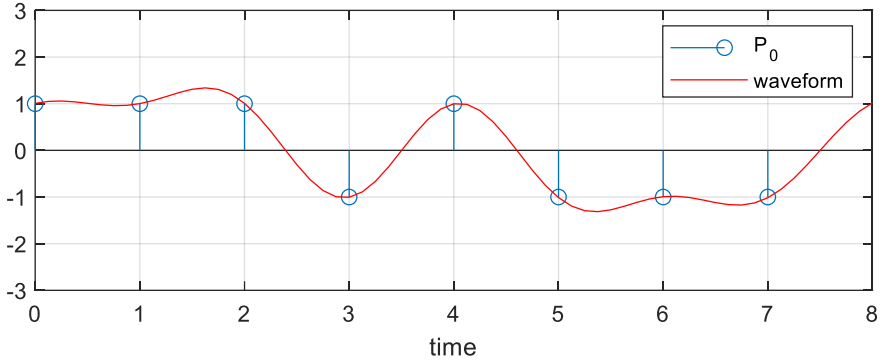
QCSP Approach: CCSK modulation and NB-code association

[1]: G. M. Dillard et al. “Cyclic code shift keying: a low probability of intercept communication technique”. In: *IEEE Transactions on Aerospace and Electronic Systems* 39.3 (**2003**), pp. 786–798.

[2]: China Satellite Navigation Office, *BeiDou Navigation Satellite System, Signal In Space,* *Interface Control Document, Open Service Signals, Dec.* **2017**
http://en.beidou.gov.cn/SYSTEMS/Officialdocument/201806/P020180608525871869457.pdf

Cyclic Code Shift Keying modulation

P_0 = 11101000 + BPSK modulation, roll-off factor 0.35, q = 8



- CCSK modulation:
  - P_0 = 11101000
  - P_1 = 01110100
  - P_2 = 00111010
  - P_3 = 00011101
  - P_4 = 10001110
  - P_5 = 01000111
  - P_6 = 10100011
  - P_7 = 11010001

Binary message : 011001100

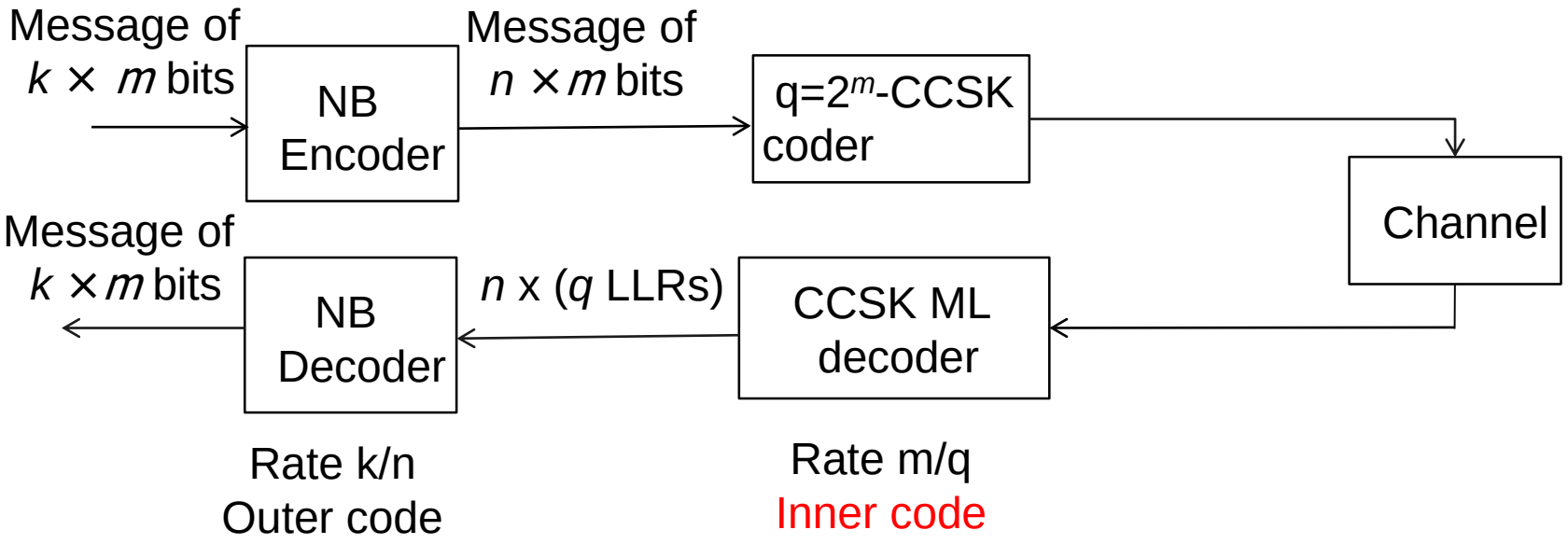
Make 3-uplet symbols: $(011)_2(001)_2(100)_2$

Take decimal value: 3 1 4

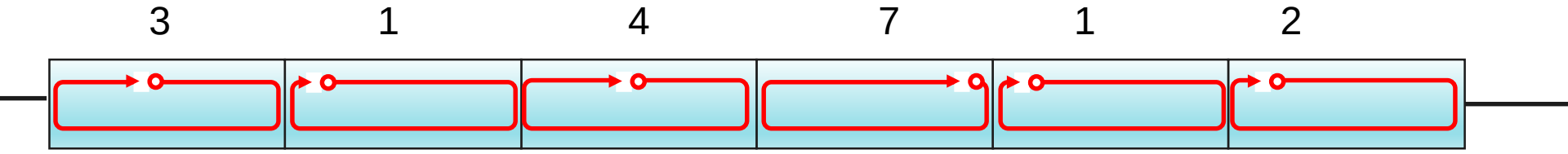
Associate CCSK symbol P_3 P_1 P_4

Send => 000111010111010010001110

QCSP frame structure ($q = 2^m$)

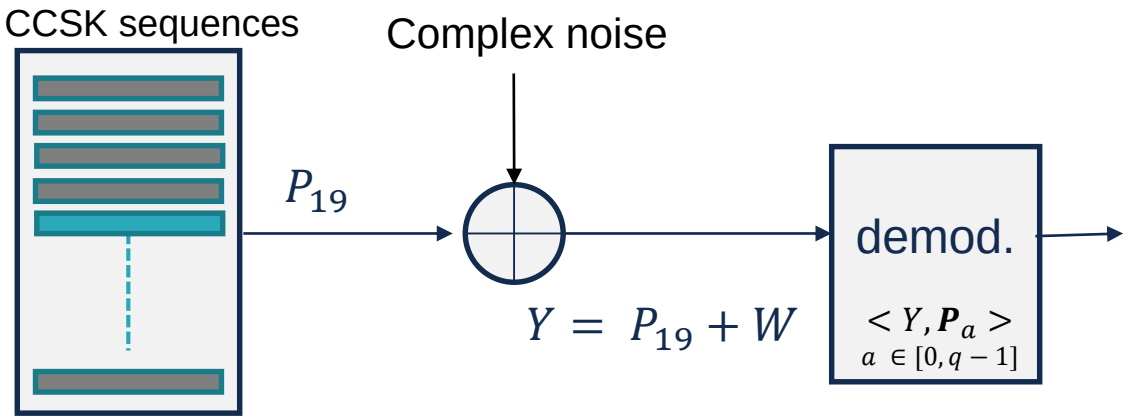


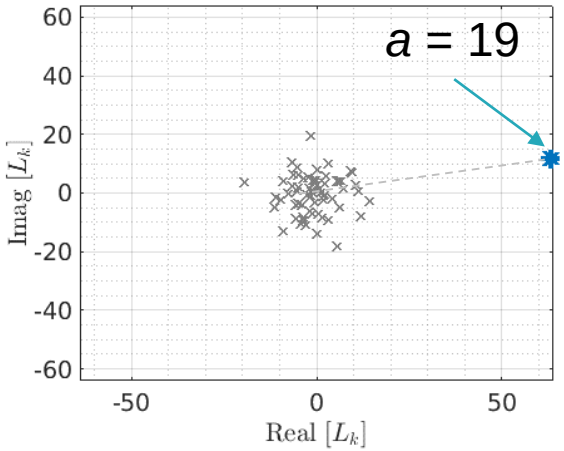
- The frame is composed of *N* segments of CCSK sequence (or symbol)



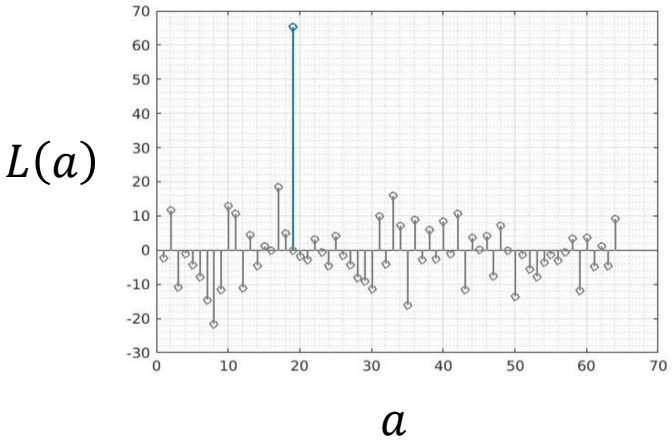
Demodulation of CCSK frame in complex noise

Correlation between each of the received symbols Y and the q CCSK sequences.





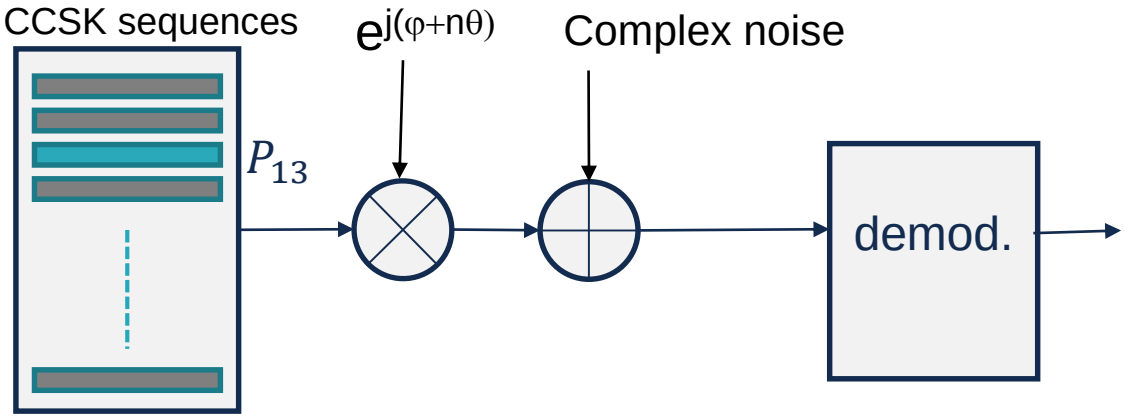
$$L(a) = \text{Real}\left(\sum_{k=0}^{q-1} Y(k) P_a(k)\right)$$

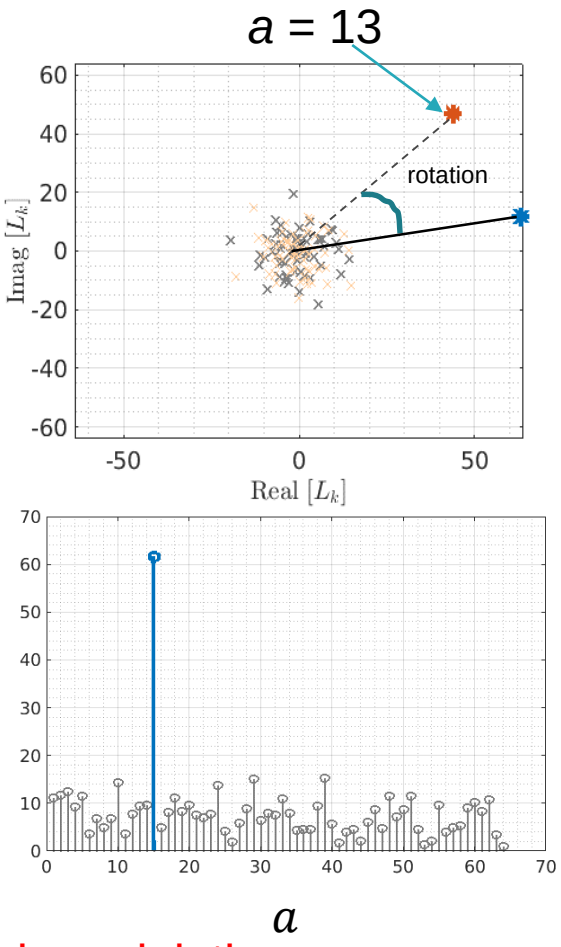


$$L(19) = \text{Real}\left(\sum_{k=0}^{q-1} (P_{19}(k) + w(k)) P_{19}(k)\right) = q + W$$

Demodulation with phase offset

Effect of Doppler of local oscillators mismatch



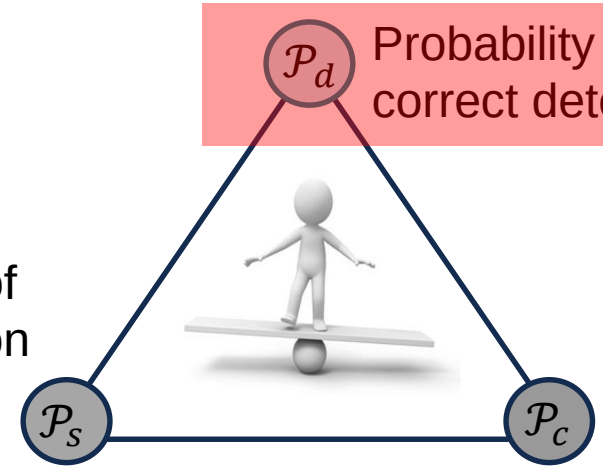


$$\hat{L}(a) = \left| \sum_{k=0}^{q-1} Y(k) P_a(k) \right|$$

Phase and/or frequency offset require non-coherent demodulation.

Objective

Developing blind detection and self-synchronization algorithms for achieving correct preamble-less short packet reception at very low SNRs.



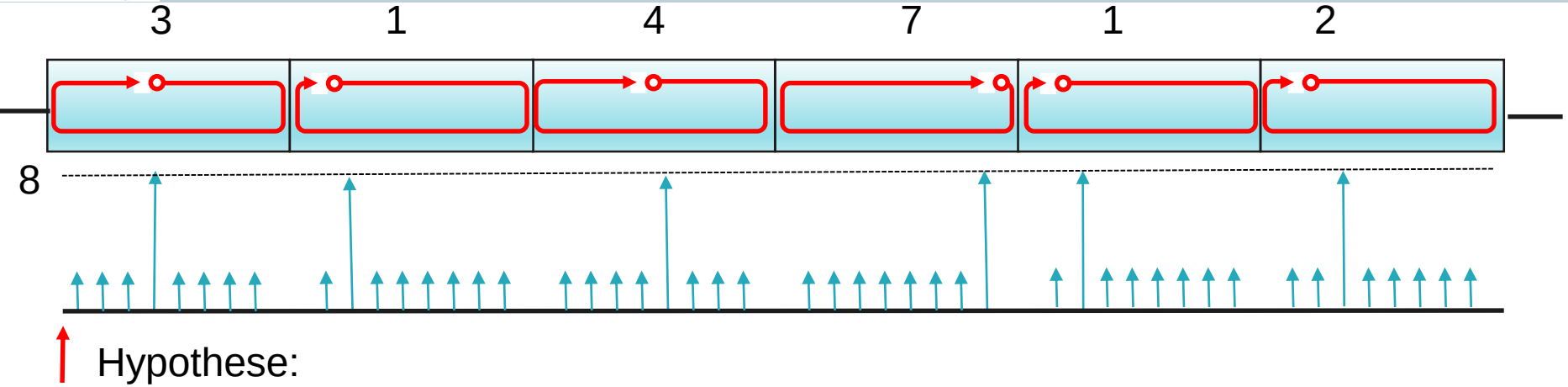
Joint overall probability:

$\mathcal{P} \approx \mathcal{P}_d \times \mathcal{P}_s \times \mathcal{P}_c$

➔ Aiming to maximize the overall probability is achieved by maximizing the weakest probability:

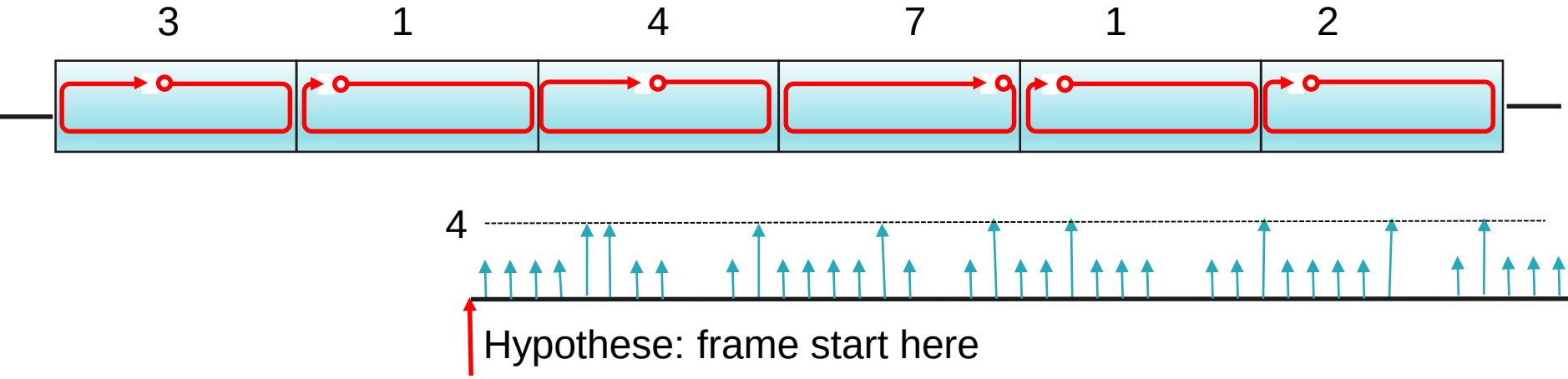
Max(min($\mathcal{P}_d, \mathcal{P}_s$, $\mathcal{P}_c$)).

Detection in a glance



Hypothese:
frame start here

When synchronised: sum max correlation = Nq = 6x8 = 48



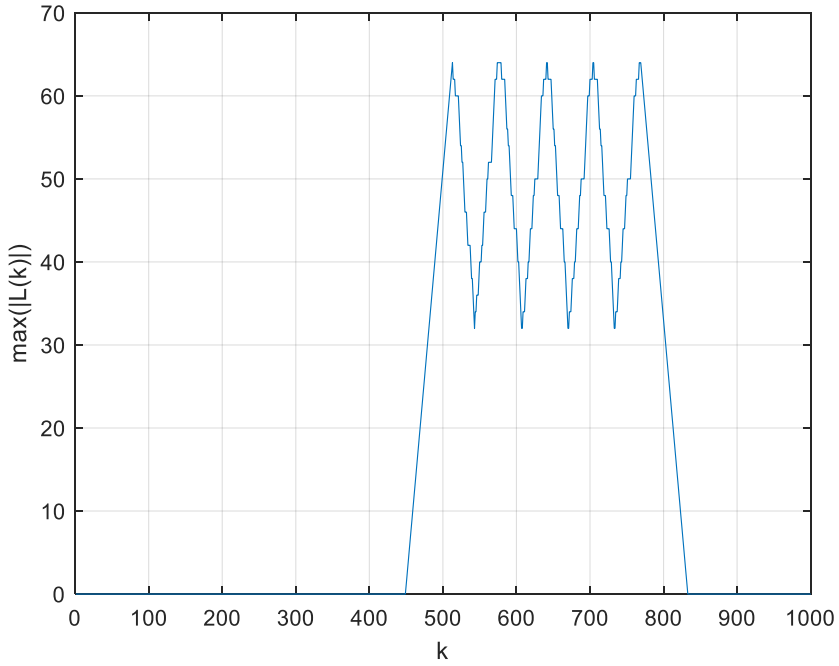
When not synchronised: sum max correlation = 4 + 4 + 4 + 4 + 4 = 20

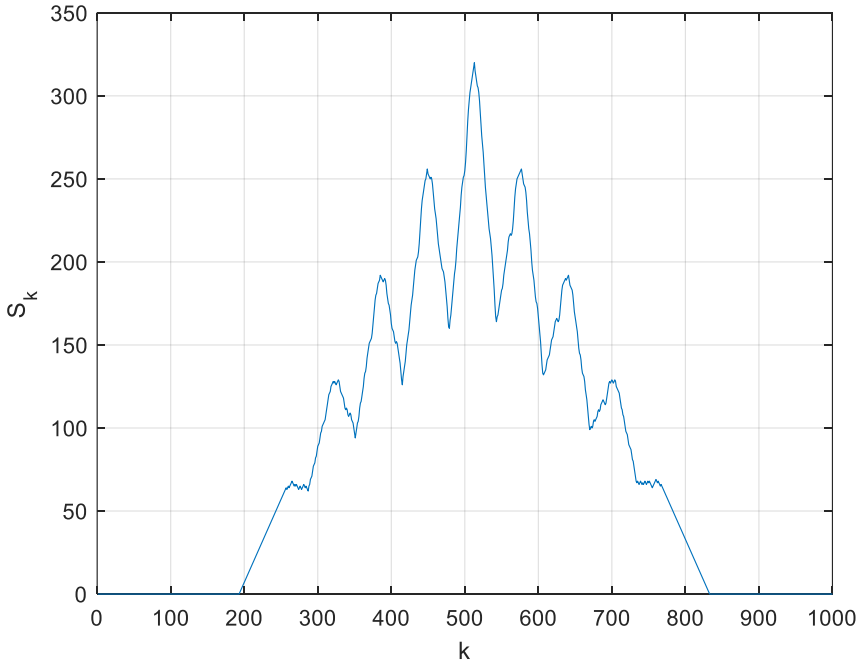
Detection legacy method: Non coherent sum of decoded symbols.

N = 5, q = 64, no noise

$$\max(|\boldsymbol{L_k}|)$$

$$S_{\mathrm{k}}(\mathrm{Y}) = \sum_{n=0}^{4} \max(|\boldsymbol{L_{k+64n}}|)$$





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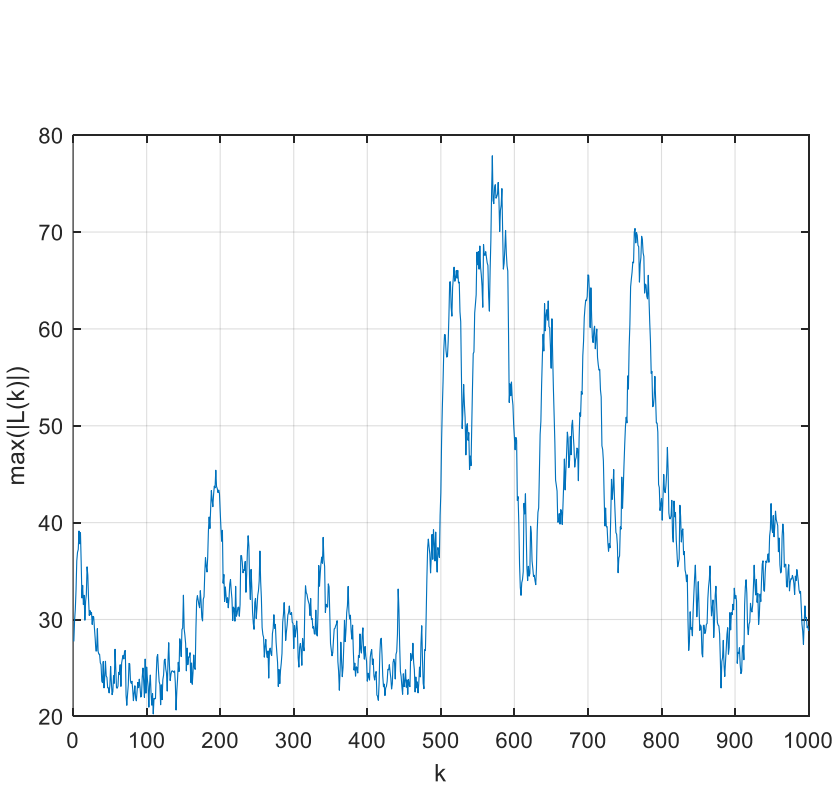
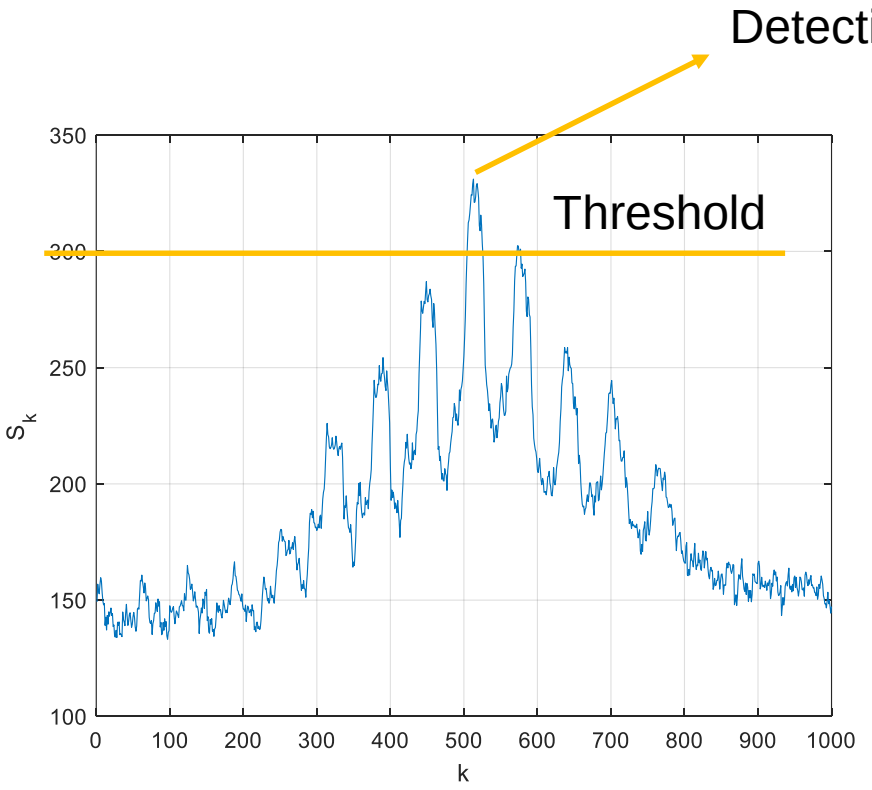
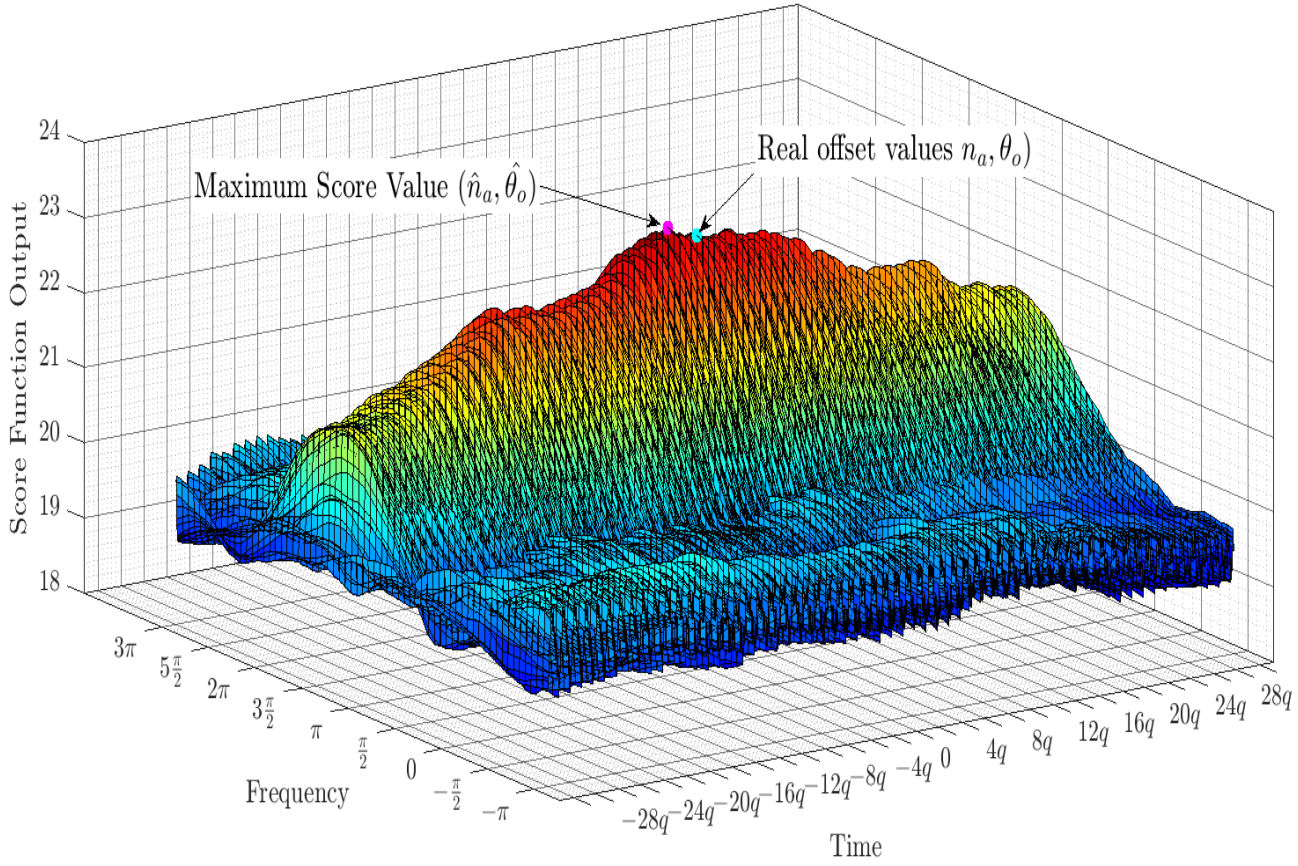




Impact of the frequency offset

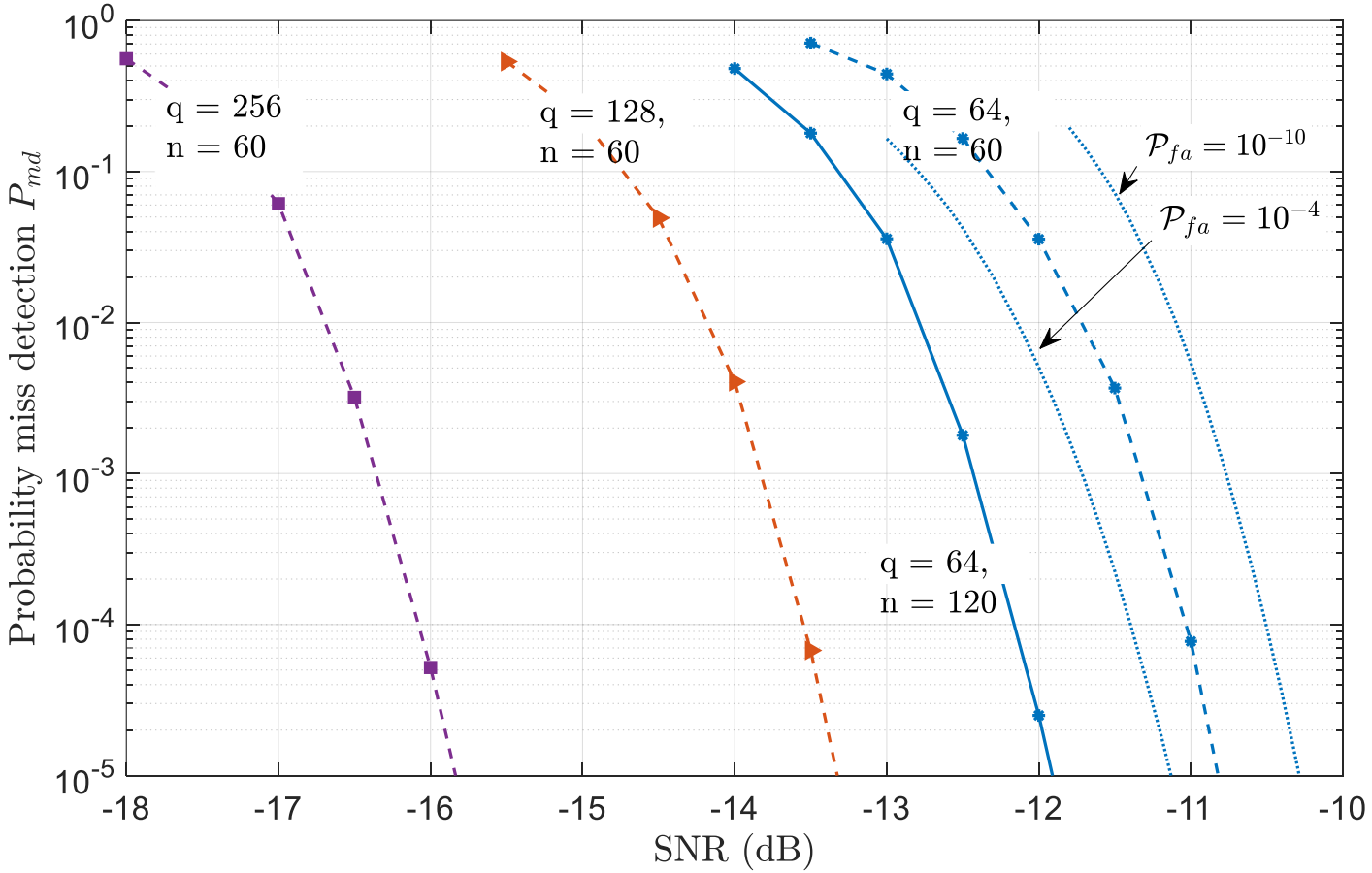
Score values in 3D grid where $\mathrm{N} = 60,\ q = 64$ and a frequency offset.



Detection if score > Threshold (trade-off miss-detection vs false alarm

Theoritical result

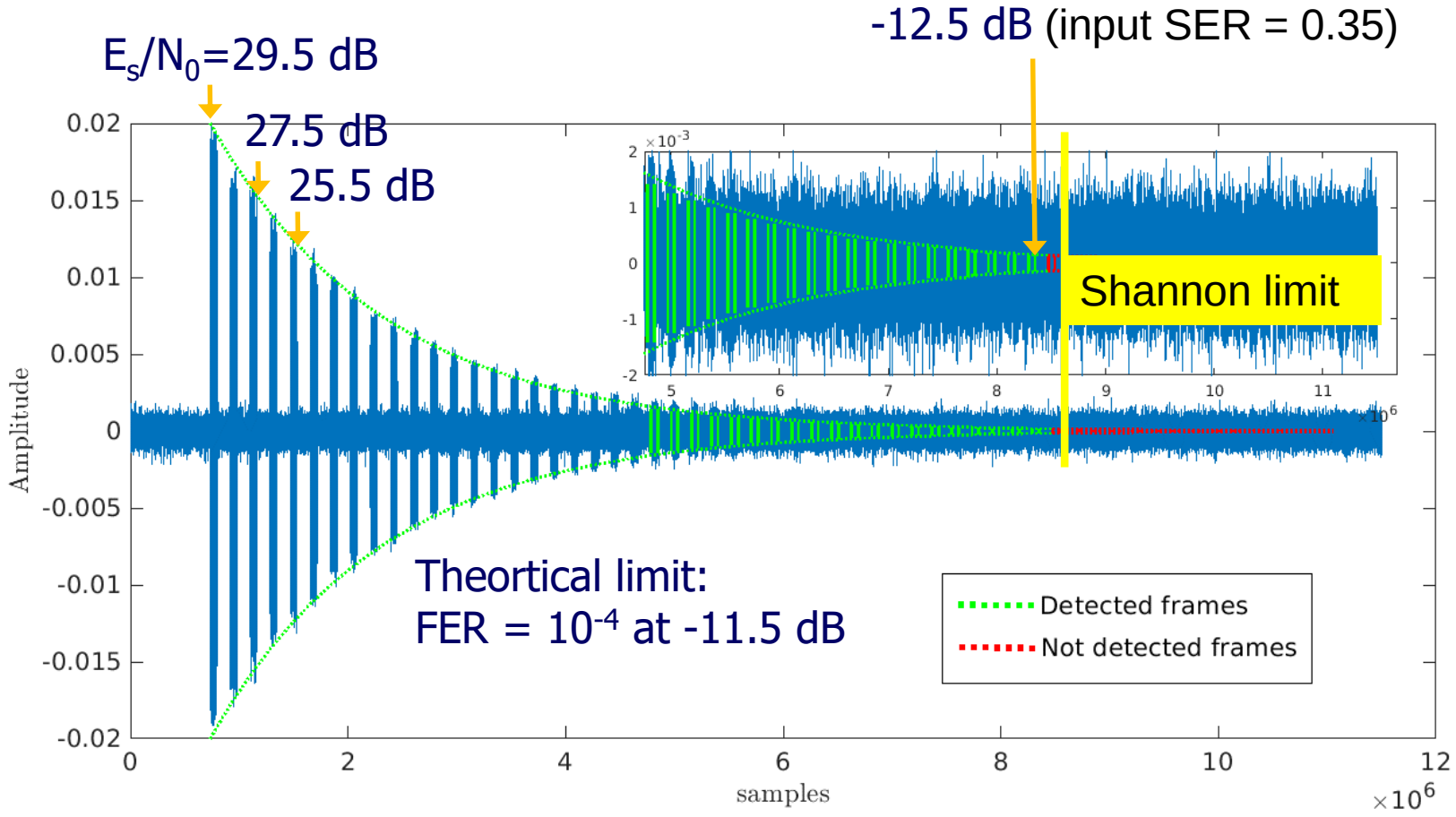
Theoretical performance [1]: $P_{md} = (P_{fa}, q, n)$, confirmed by Monte-Carlo simulation.



$P_{fa} = 10^{-6}$

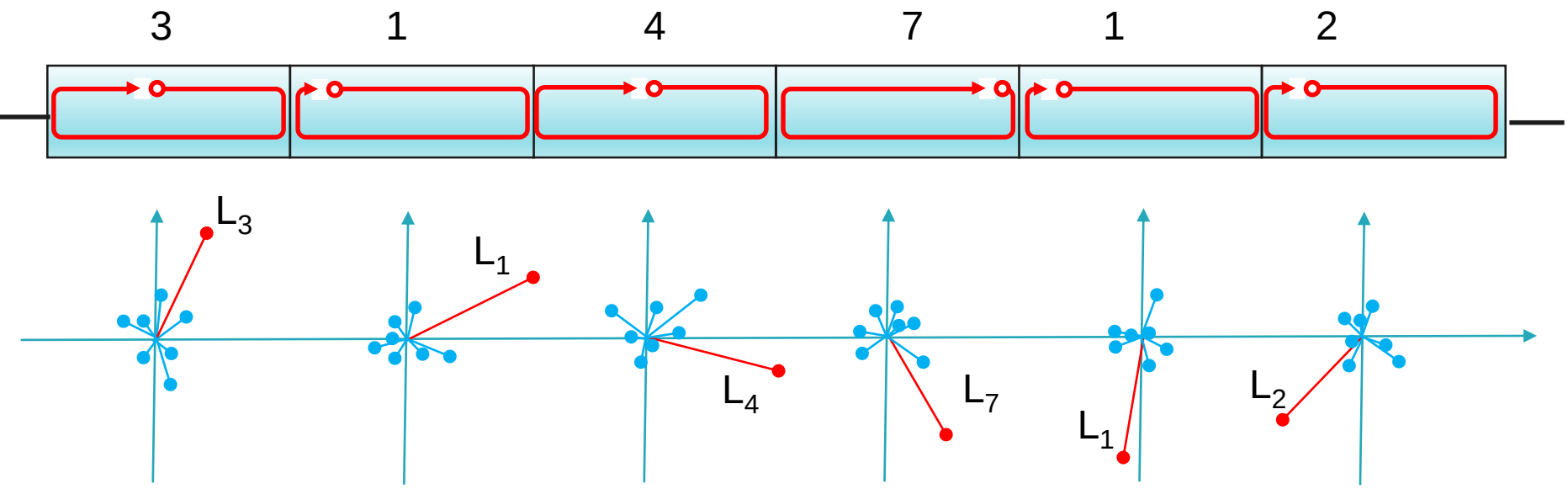
[1] K. Saied, A. Al Ghouwayel, E. Boutillon, «Short Frame Transmission at Very Low SNR by Associating CCSK Modulation with NB-Code », IEEE Transactions on Wireless Communications, 2022.

Practical results (Software radio)



+ Experimentation mobile and maritime channels

Idea: use coherent summation



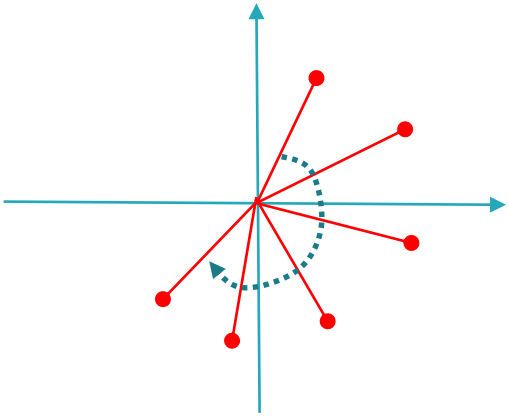
Max corellation rotated though the symbols

=> coherent summation through <u>different hypothesis</u> of rotation speed

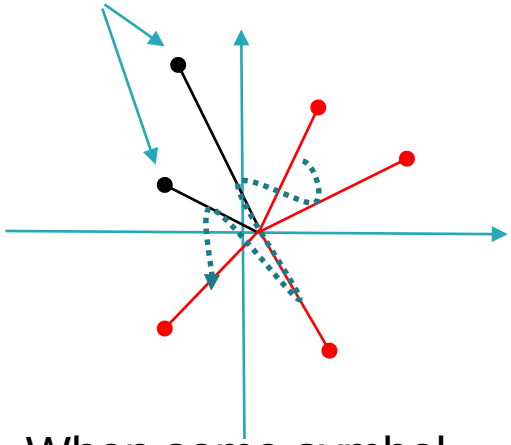
=> In signal processing it is called « Fast-Fourier Transform »

Problem due to symbol errors

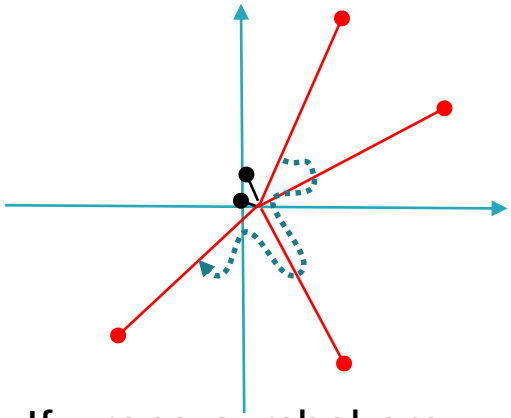
Symbol errors



When all symbol decisions correct, the rotation pattern appears clearly and can be used for efficient detection.



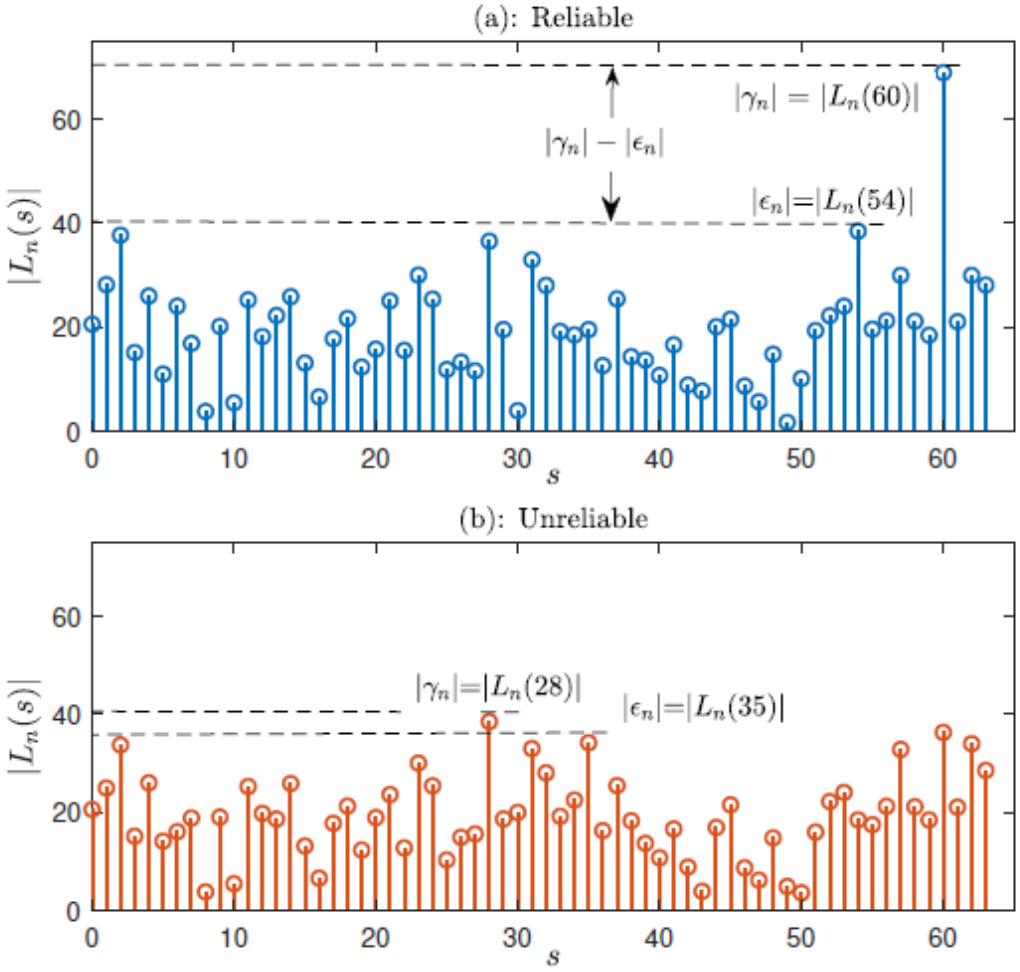
When some symbol decisions are wrong, the rotation pattern is completly « jammed »



If wrong symbol are attenuated and good one amplified, distorted (but still usefull) rotation pattern appears.

Problem: defined weighting factor α_n for the n^{th} symbols

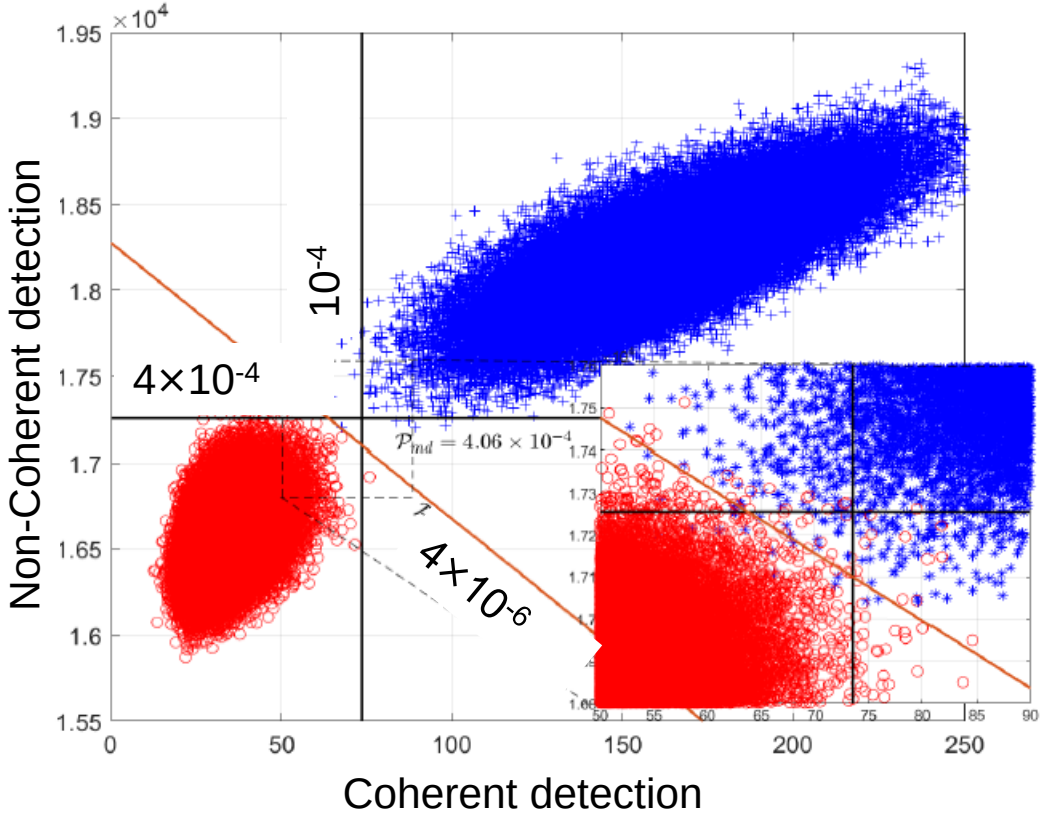
Weighting factor of decision



$$\alpha_n = \frac{|\gamma_n| - |\epsilon_n|}{\|\boldsymbol{y}_n\|}$$

Joint coherent/non-coherent detection

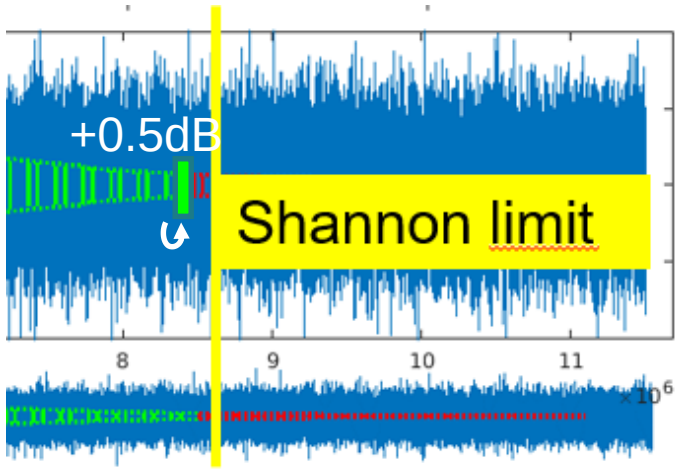
Porb miss detection indicated on the lines.
Prob false alarm constant at 10^{-6}



Probability of miss detection: $4x10^{-4}$ (NC) => 10^{-4} (C) => $4x10^{-6}$ (NC+C)

Conclusion

- About QCSP frames:
  - Close to theoretical limit in Gaussian channel
  - Proved efficient in several channels
  - Real-time software receiver.



- Take away on the paper
  - Joint coherent/non-coherent detection gives 0.5 dB of detection improvement.

Current/future experimentations

THALOS
ADVANCED MARITIME SOLUTIONS


qcsp.univ-ubs.fr/
Thank you !