Trame Quasi Cyclic Short Packet (QCSP) pour l'IoT avec des satellites LEO

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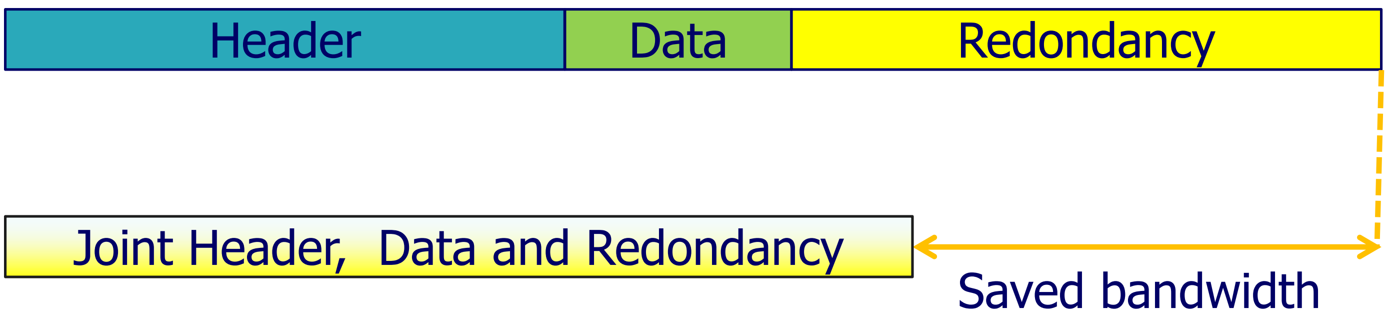
Massive IoT: paradigm shift

problem: Classical model of frame is inefficient for small payload,

=> Header, Data and Redundancy should be merged.



QCSP project: 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

Outline

- QCSP system model
- Receiver processing
- Project specification
- Multi-users detection
- Conclusion and perspectives

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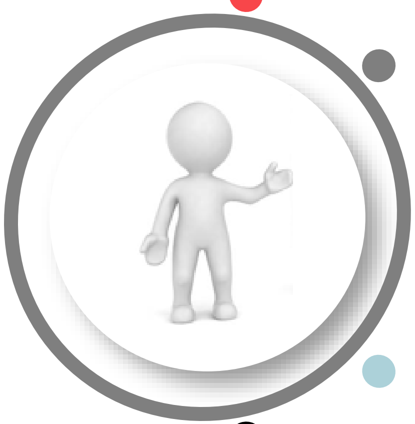

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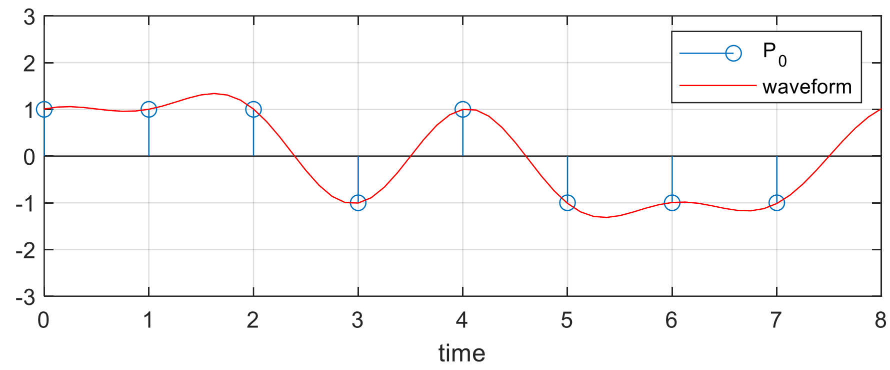
Cyclic Code Shift Keying modulation

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

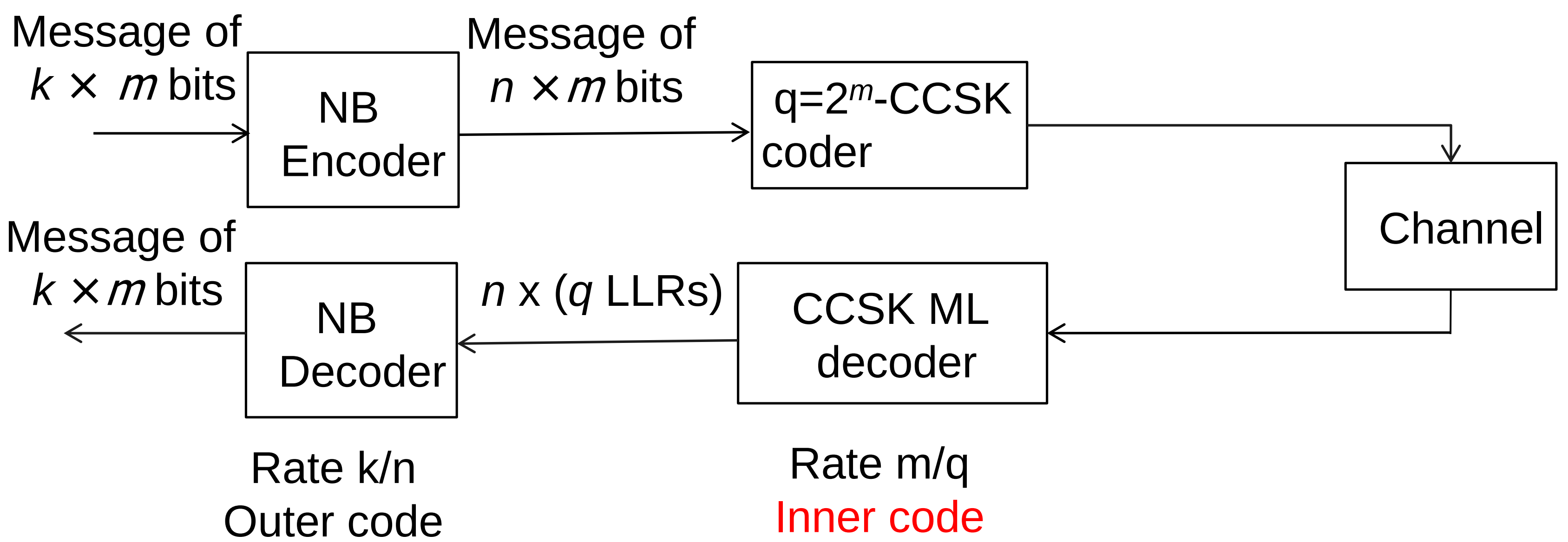
Make 3-uplet symbols: $(011)_2(001)_2(100)_2$

Take decimal value: 3 1 4

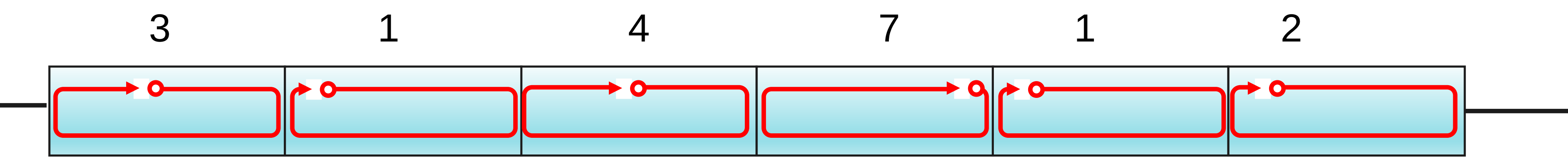
Associate CCSK symbol P_3 P_1 P_4

Send => 000111010111010010001110

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



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



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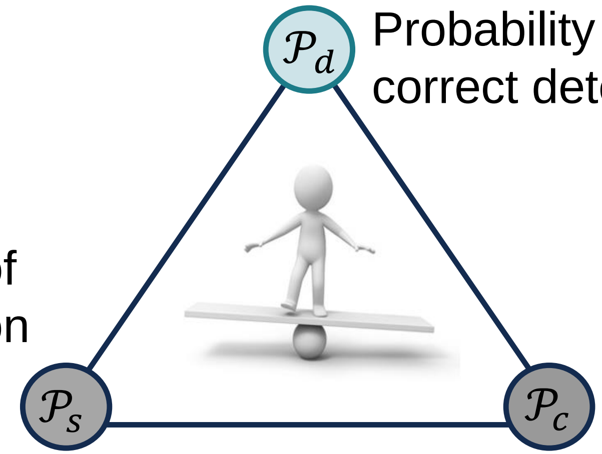
Objective

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

Probability of correct detection

Probability of correct synchronization



Probability of correct decoding

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

Synchronisation/correction principle…

Signal Processing factory

NB decoder engine

Messages
& Noise
& Time?
& Freq?

Coherently
demodulated
messages

CCSK
redundancy

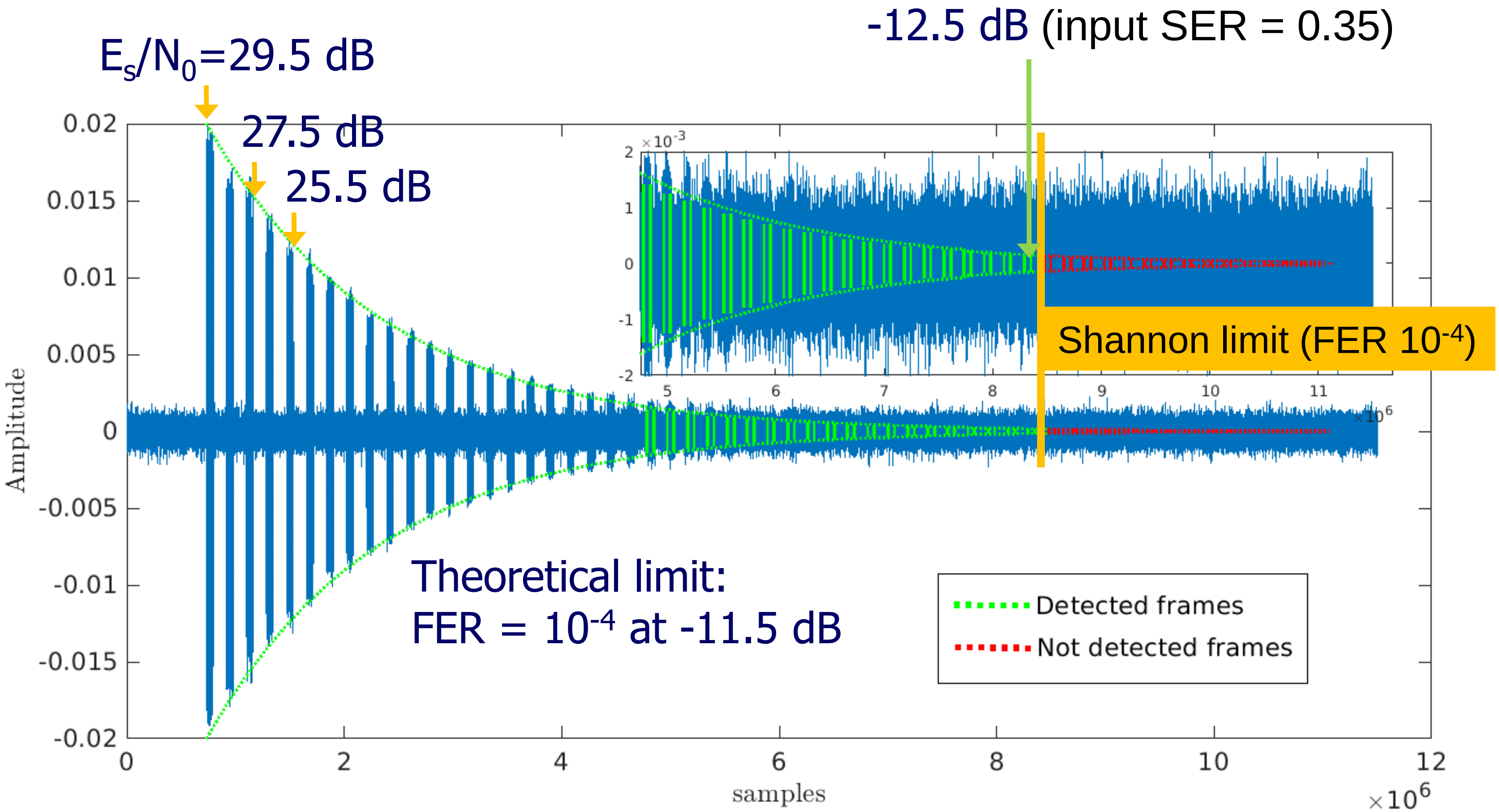
Over
Mod.

NB-LDPC
Redondancy

Use all available redundancy to estimate step by step unknown parameters

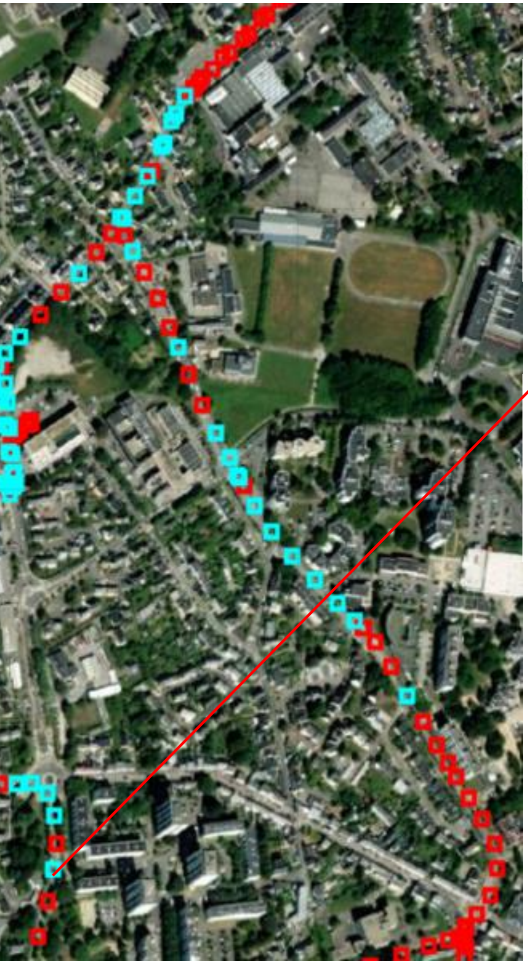
Decoded
messages

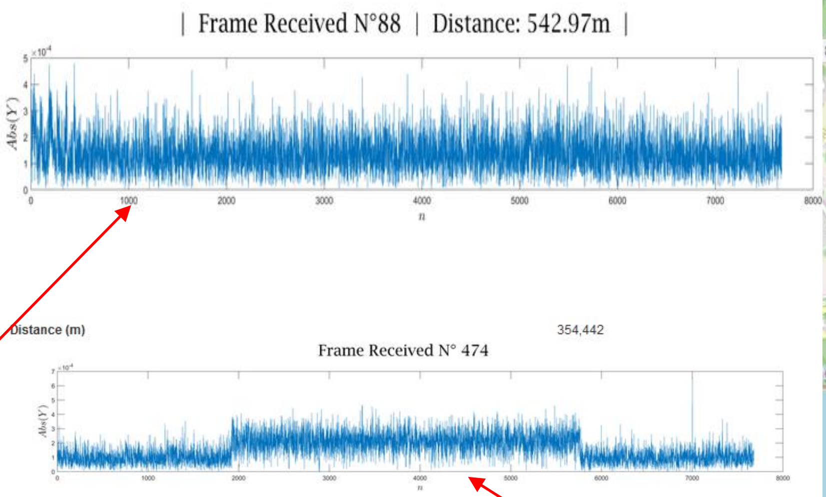
Practical results (offline GNU Radio)



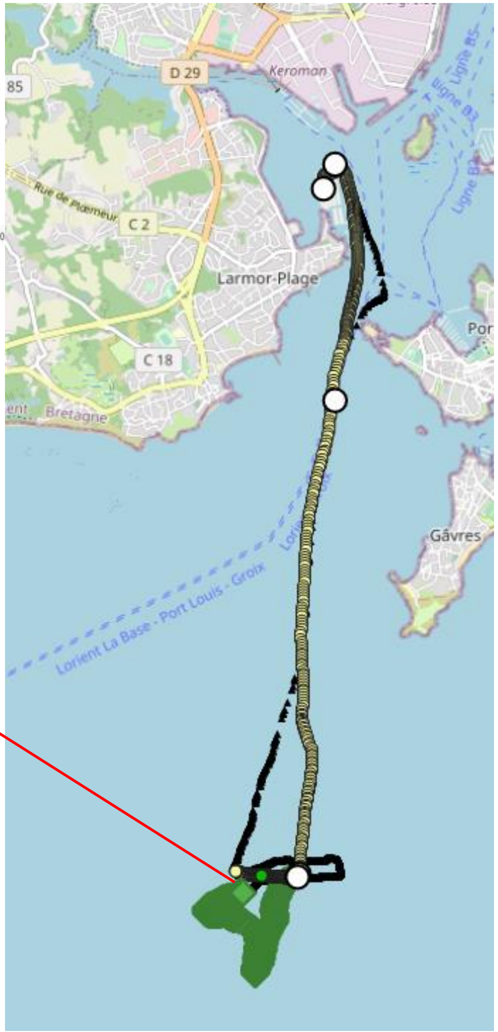
- Measures are consistent with the theory!

Realtime experiment: mobile/maritime





THALOS
ADVANCED MARITIME SOLUTIONS



Interactive map: https://qcsp.univ-ubs.fr/events/

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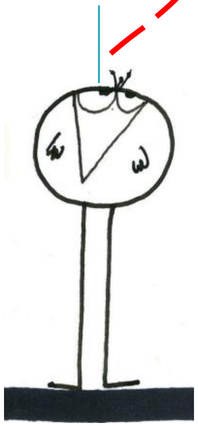
From earth back to space

- Ongoing project with CNES and KINEIS to study QCSP frames for low complexity sensors to LEO satellites.

- Technical specifications:
  - Payload: 200-400 bits.
  - 100 kHz of bandwidth.
  - Hundreds of packets/s
  - Emission power: 100 mW (20 dBm)
  - Received power (C/N_0): 20-50 dB-Hz
  - Packet error rate < 0.3

No-coordination Aloha protocol



From earth back to space (LEO sat.)…

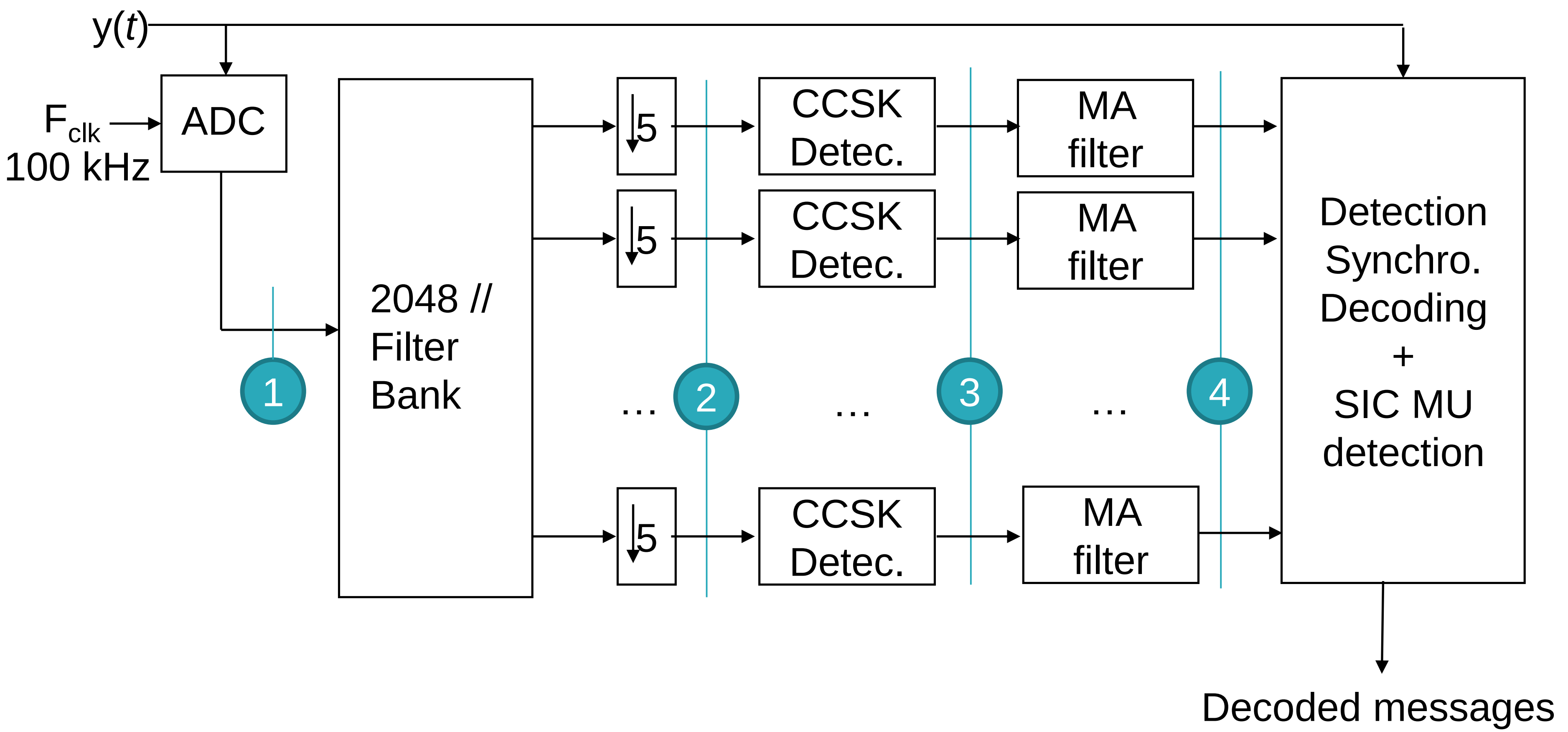
- Message affected by:
  - Doppler shift (+-10 kHz)
  - Doppler Chirp (0 – 100 Hz/s)
  - Attenuation A
  - Phase shift

At receiver,
T, F, ΔF, φ
all unknown

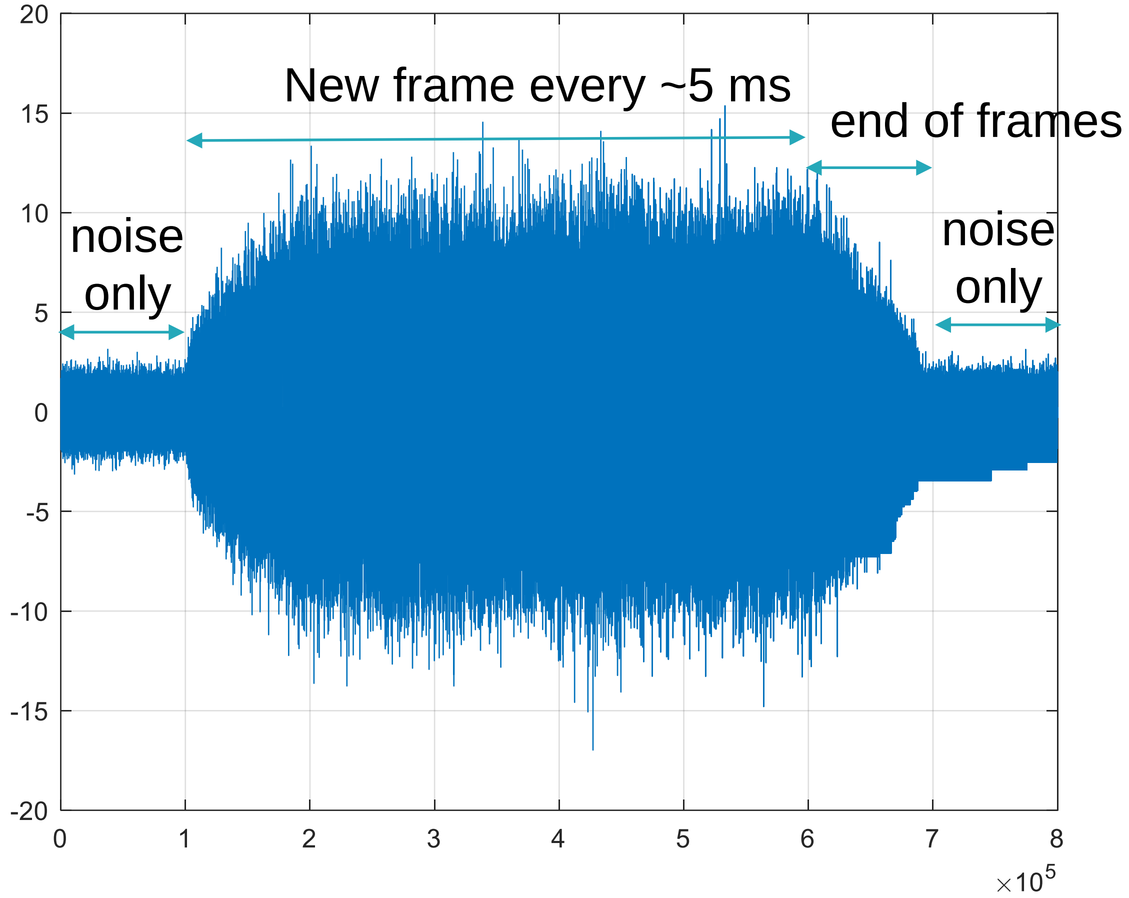
- All messages share the same structure.
  - Rate 1/3 NB-LDPC code over GF(64).
  - CCSK of size 64.
  - N = 99 symbols => 198 bits of payload.
  - CCSK at 6667 chip/s (~7 kHz of bandwidth)

Architecture of detection filter

- 15 samples per chip. Down-sampling factor of 5
  => 3 samples per chip at the output.



Let's take a look on the received signal



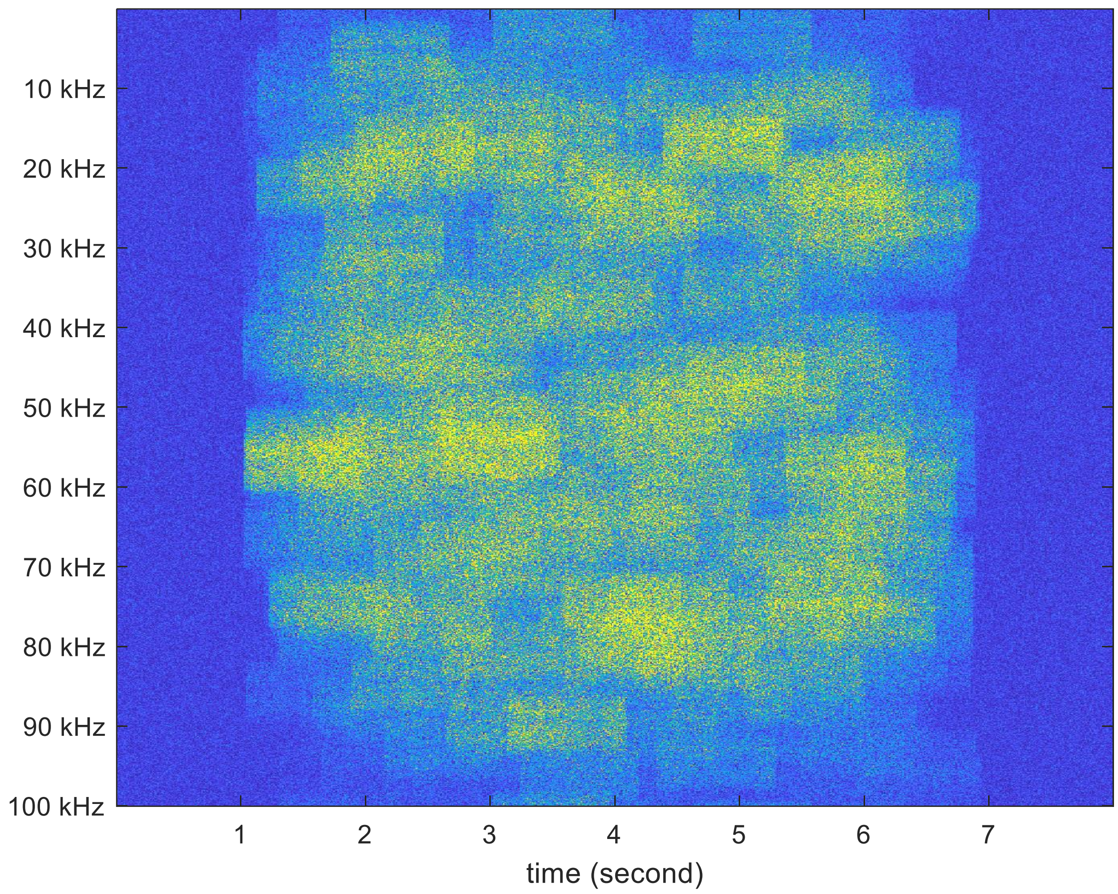
1

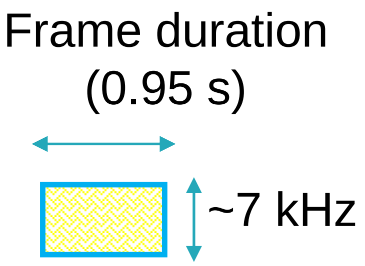
N_u = 200 users/second

Total of ~1000 messages…

Time/Frequency view of received signal

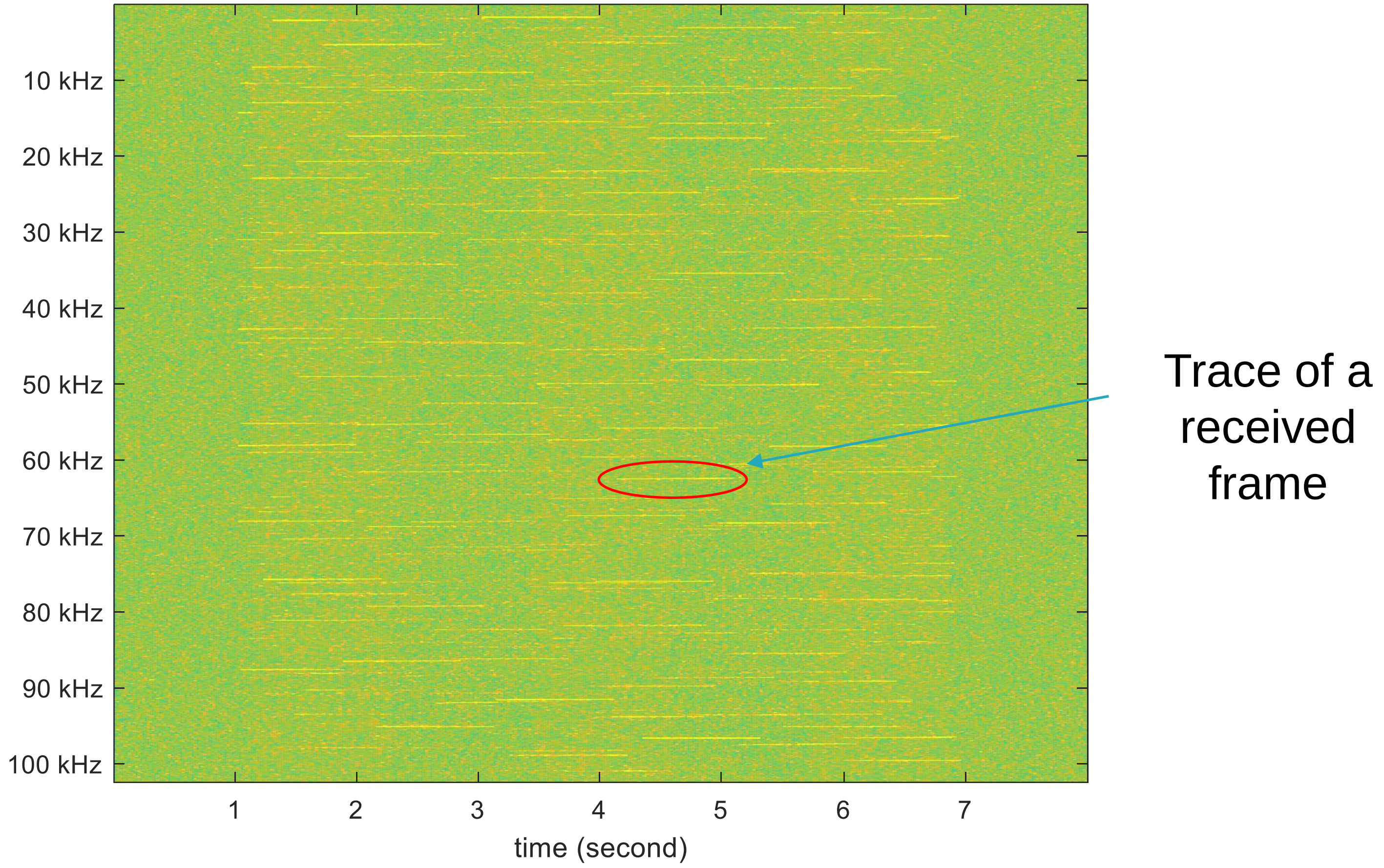
2





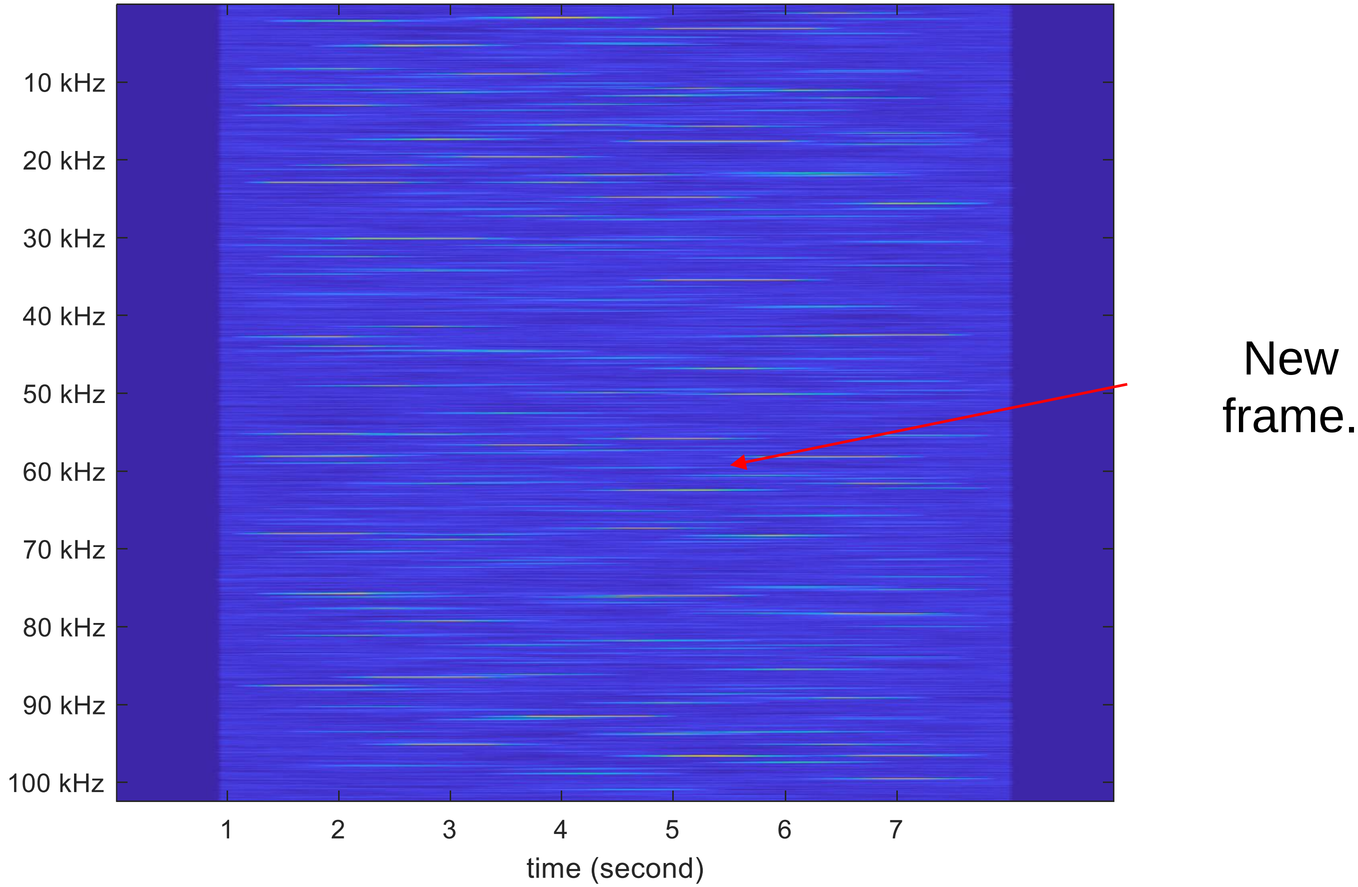
Time/Frequency After CCSK despreading

3



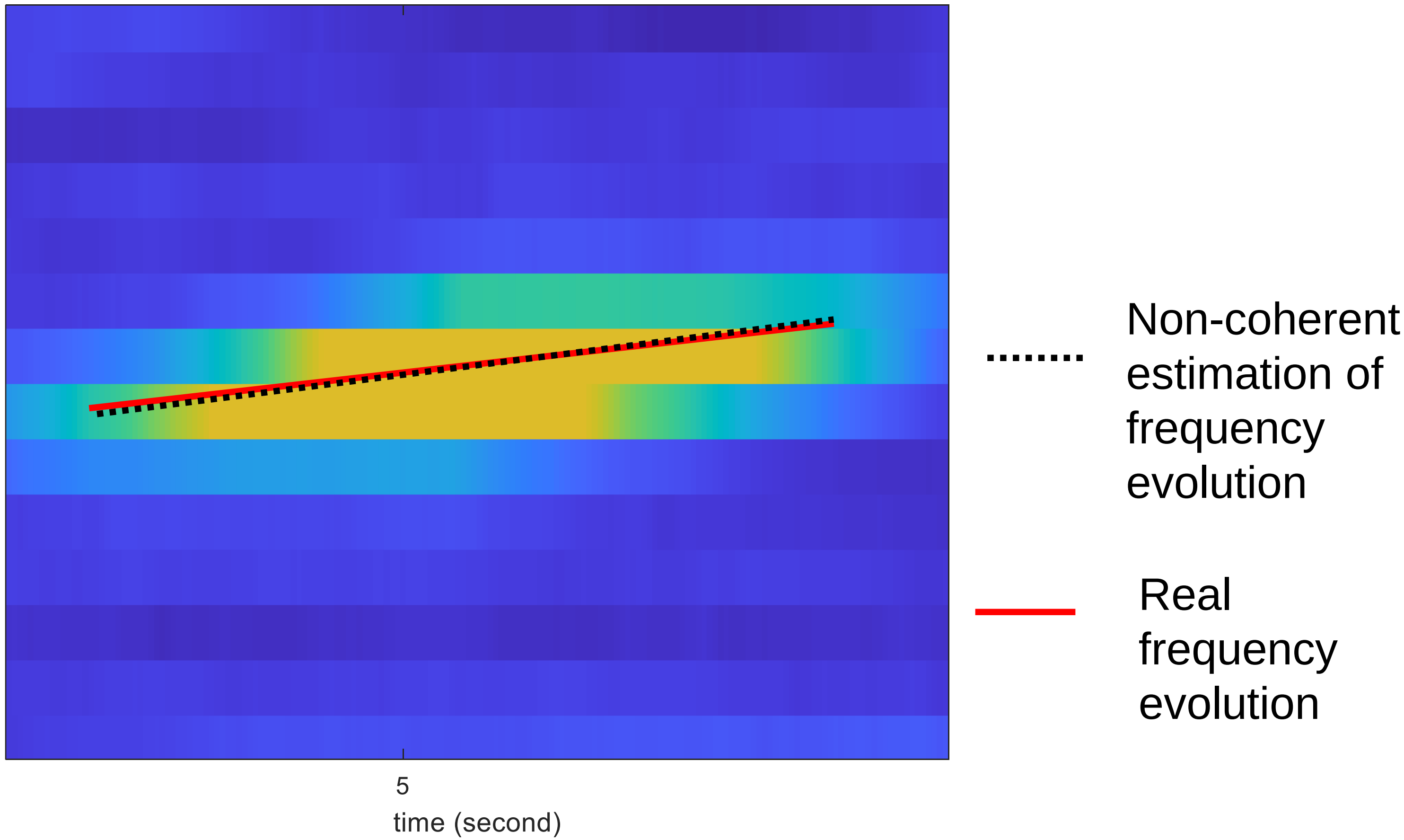
Time/Frequency view after despreading/frame accumulation

4



Note: representation of the output of the detection filter

Zoom on the output of the detection score filter



Possibility to estimate F and ΔF in the non coherent domain

=> It triggers the processus of coherent demodulation.

=> On going work…

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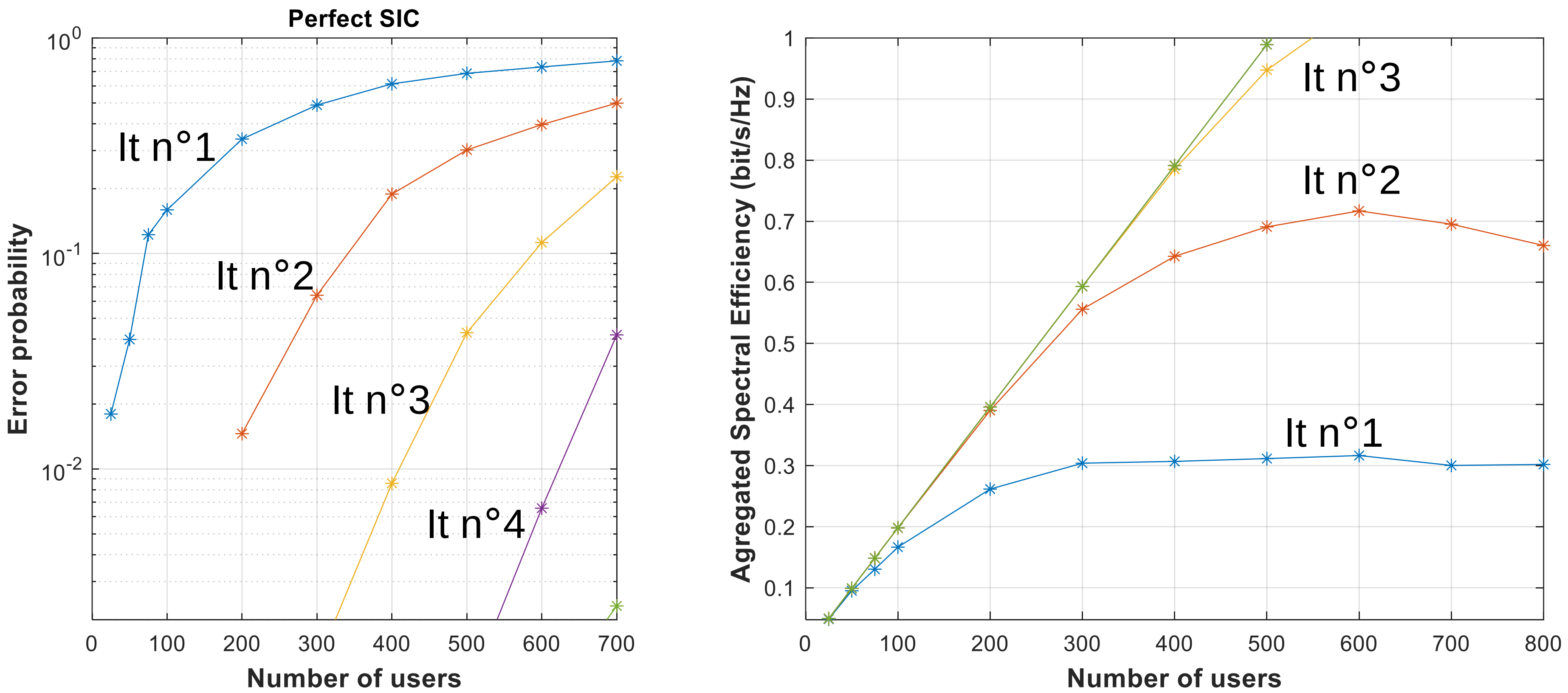
Multi-users Successive Interference Cancellation

- Work on progress…

- Principle: once a frame decoded, the associated signal is estimated and subtracted from the received signal to help the decoding of weaker received frames.
- Genius demodulators (G-Dem): receiver knowns all modulation parameters of all received frames (time, phase, frequency, chirp) => allows perfect coherent demodulation.
- Genius SIC (G-SIC): receivers is able to perfectly subtract each decoded frame.

G-Dem and G-SIC performance



Estimated SIC

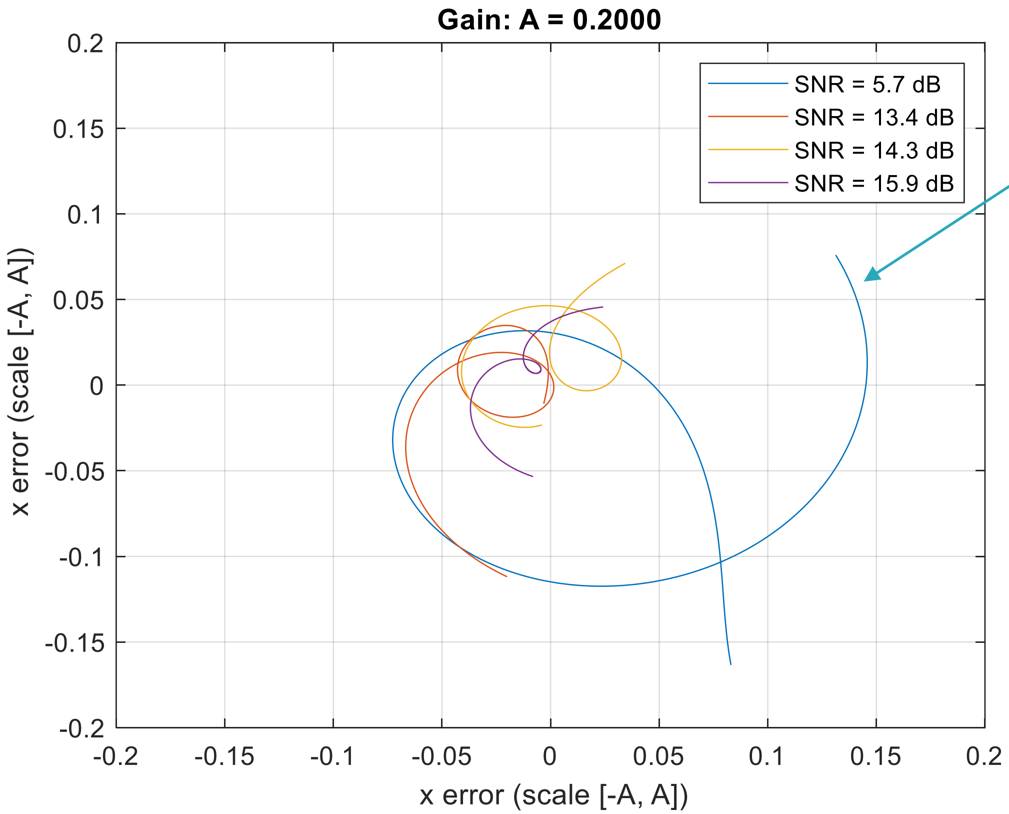
- G-SIC: receivers is able to perfectly subtract each decoded frame.

- Estimated SIC (or Real SIC): Once a frame decoded, its parameters are estimated (Maximum Likelihood estimation), the associated frame is then (imperfectly) reconstructed and subtracted from the incoming signal

  => Residual error that degrades SIC performance.

Example of estimation errors

C/N0 = 24.3 dB-Hz

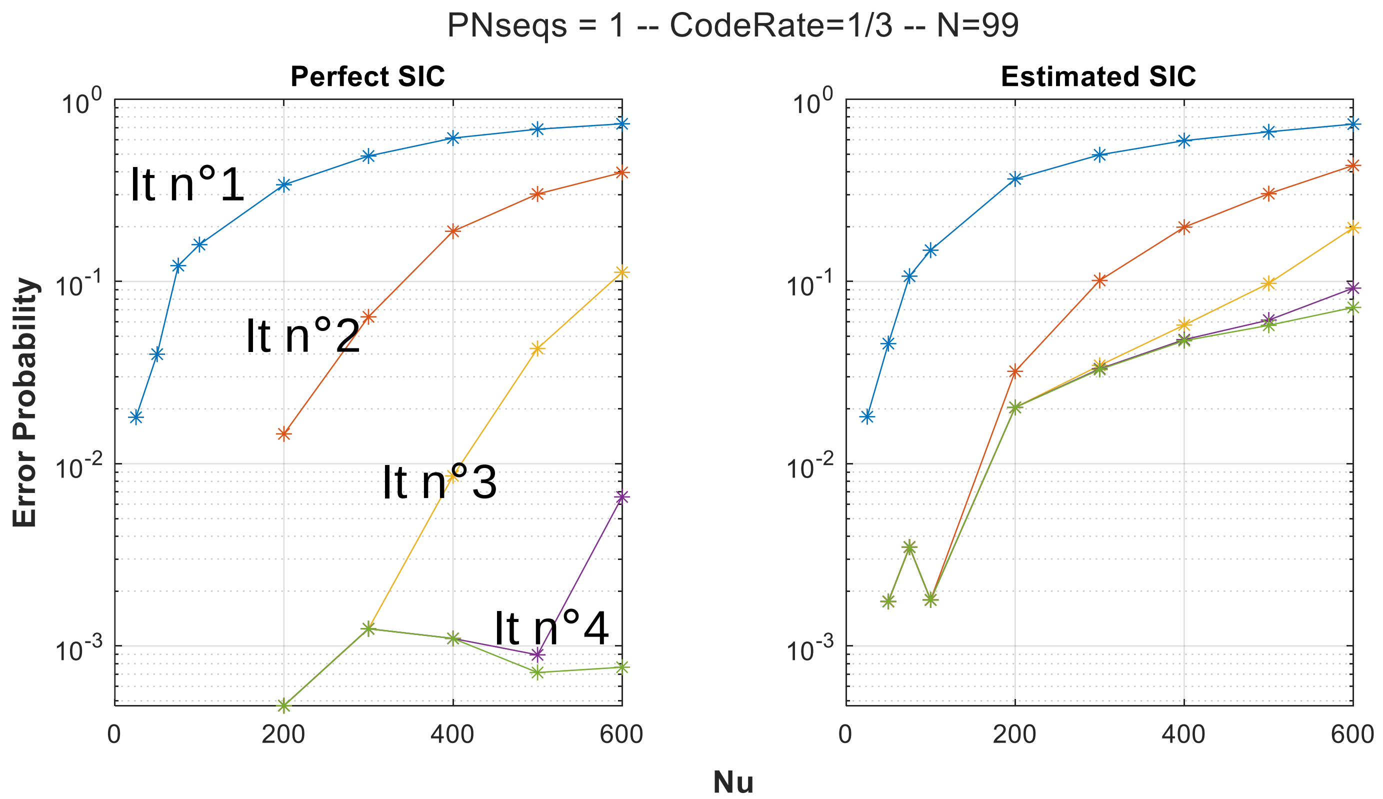


Example of reconstruction error trajectory.

$$e(n) = x(n) - \hat{x}(n)$$

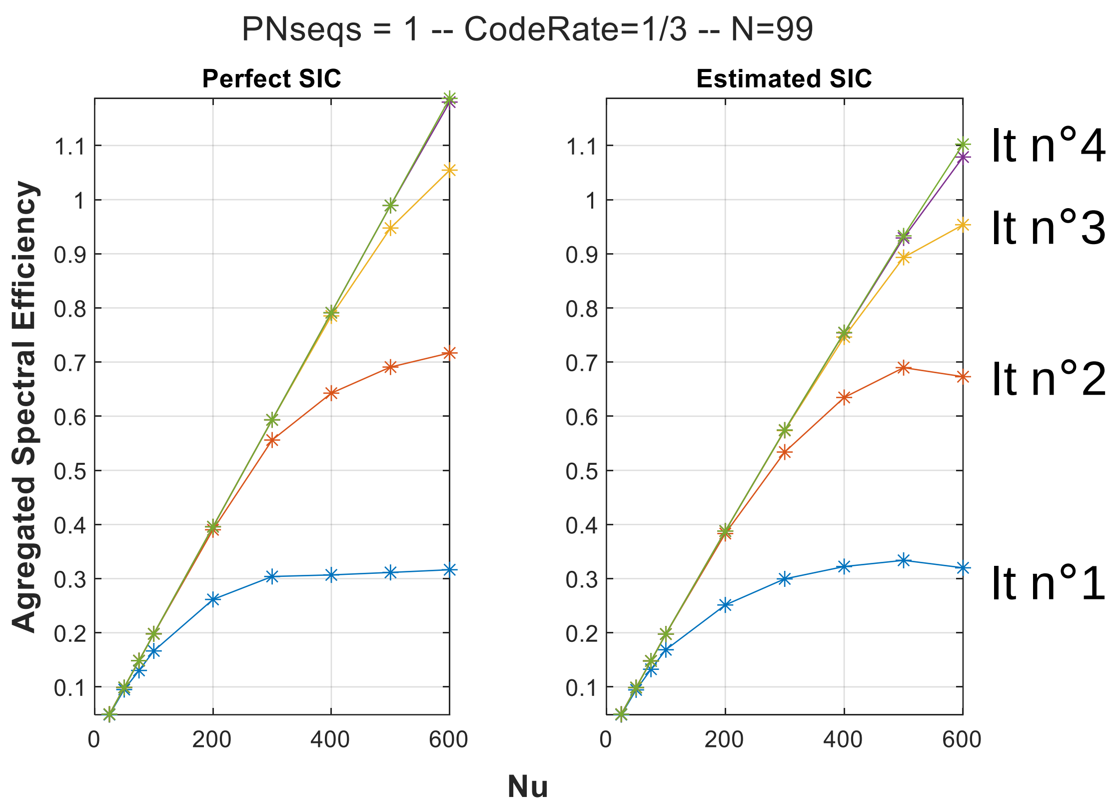
$$\text{SNR} = 10\log_{10}\left(\frac{x^2}{e^2}\right)$$

G-Demo-Estimated SIC decoder: Probability of error



Nu = number of frames/s

G-DEM, Estimated SIC decoder: agregated capacity (Bit/s/Hz)



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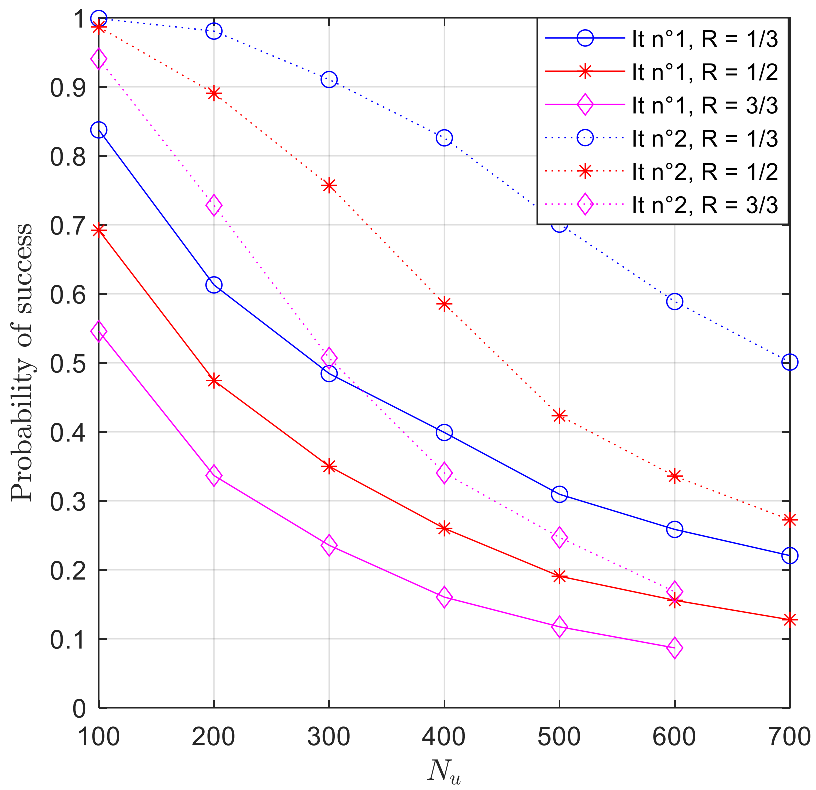
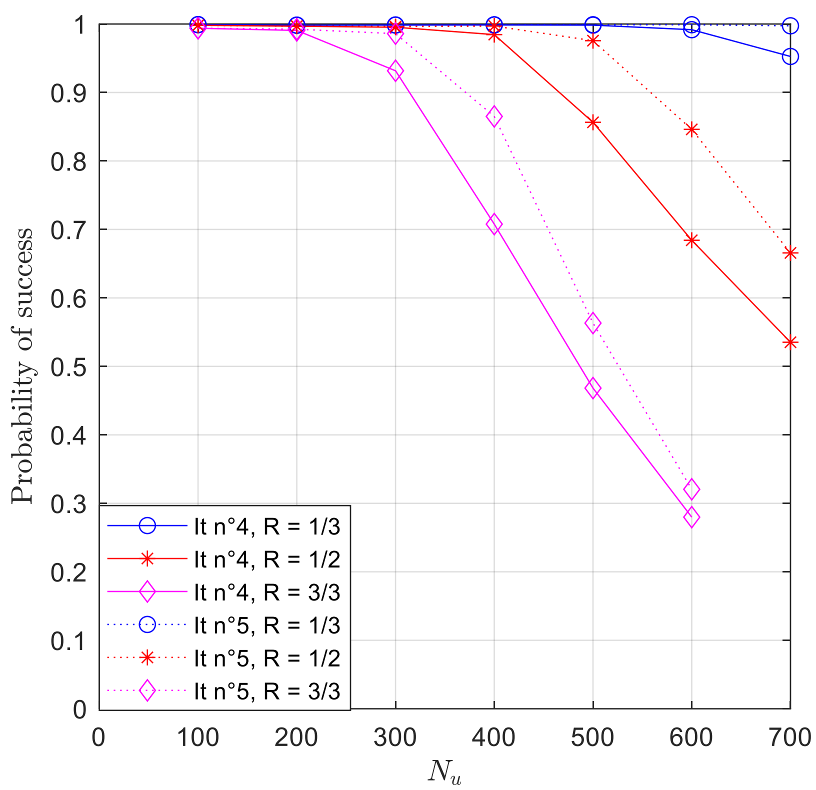
Conclusion

- Take away on QCSP frames:
  - Very low complexity at emitter side
  - Close to theoretical limit in Gaussian channel
  - Tested in real conditions.
- QCSP for IoT -> LEO satellite
  - Promising technique
  - Hundred of non-coordinate users at the same time.
  - …still ongoing work.


qcsp.univ-ubs.fr/
Thank you !

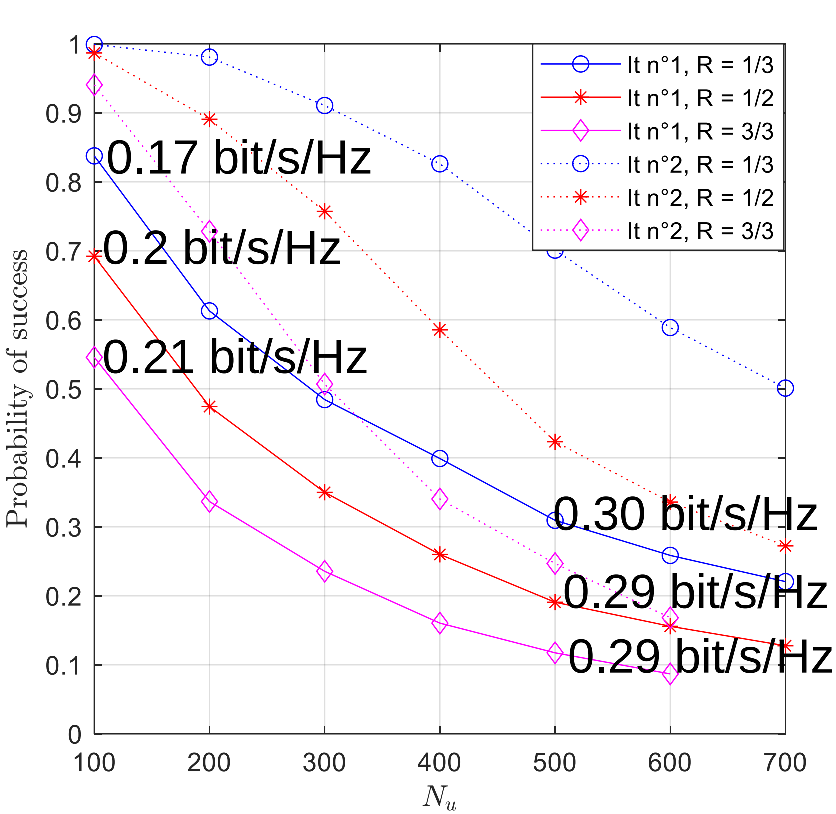
Performance of G-Dem and G-SIC (GF(64))

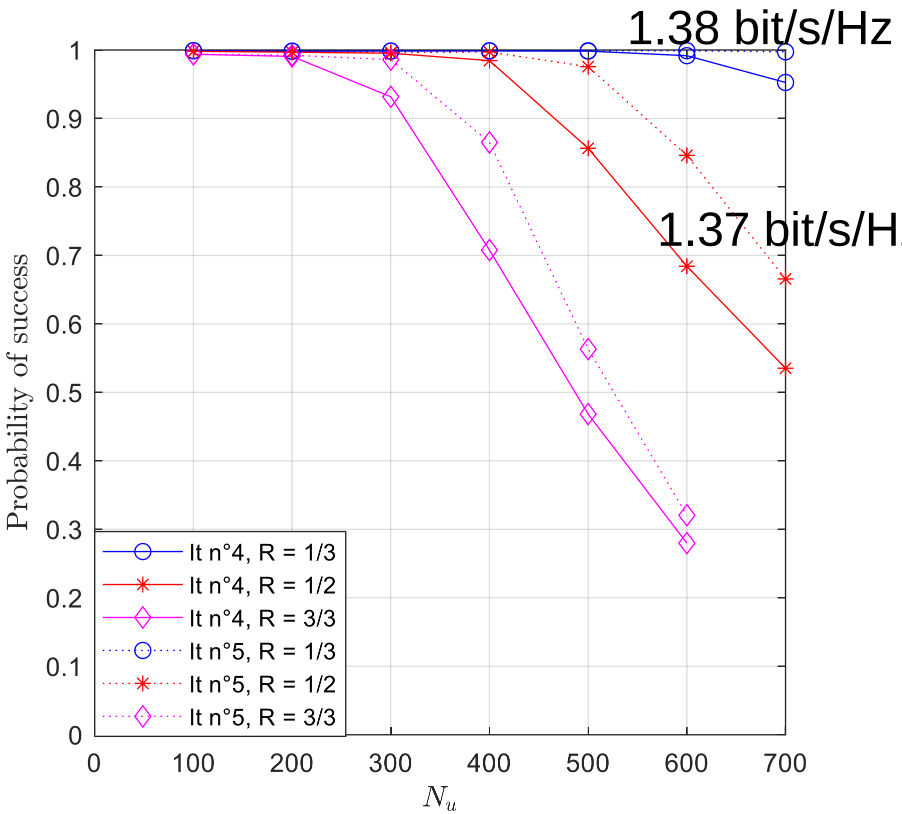




- Code rate 1/3 (K = 33, N = 99) => 198 bits of payload
- Code rate 1/2: (K = 48, N = 96) => 288 bits of payload
- Code rate 2/3: (K = 66, N = 99) => 396 bits of payload

Genie-aided SIC





- Code rate 1/3 (K = 33, N = 99) => $N_u \times 198 \times P/10^5$ bit/s/Hz
- Code rate 1/2: (K = 48, N = 96) => $N_u \times 288 \times P/10^5$ bit/s/Hz
- Code rate 2/3: (K = 66, N = 99) => $N_u \times 396 \times P/10^5$ bit/s/Hz