ITSNT 2018
15/11/2018

Joint Design of GNSS Signal and Message Structure for Galileo 2nd Generation

Lorenzo Ortega Espluga, *TéSA*
Charly Poulliat, Marie-Laure Boucheret, *Toulouse INP*
Marion Aubault, *CNES*
Hanaa Al Bitar, *Thales Alenia Space*

Motivation

- Context: Galileo 2nd Generation (G2G)
- Goal:
  - Improve the acquisition phase
    - Improve the receiver sensitivity
    - Reduce the TTFF*
- Opportunity:
  - Design a new signal to improve the acquisition phase
- Wayforward:
  - Design of a new modulation
  - Design of a new family of PRN* code
  - Co-design of the message structure and the channel coding scheme

PRN* = Pseudo Random Noise
TTFF* = Time To First Fix

Content

- Introduction & background
- Design a new modulation for fast acquisition:
  - BCS
- Design new PRN codes for fast acquisition:
  - Random codes
- Co-design of the message structure and channel coding:
  - Maximum distance separable codes(MDS)
  - Full diversity Codes
- Conclusion
- Future Lines

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New signal to improve the TTFF and the receiver sensitivity

- What does improving the TTFF involve?

- What does improving the receiver sensitivity involve?

New signal to improve the TTFF and the receiver sensitivity

- What does improving the TTFF involve?

$$TTFF = T_{warm-up} + T_{acq} + T_{track} + T_{CED} + T_{PVT}$$

- What does improving the receiver sensitivity involve?
    - Acquisition
    - Tracking
    - Data Demodulation ...

New signal to improve the TTFF and the receiver sensitivity

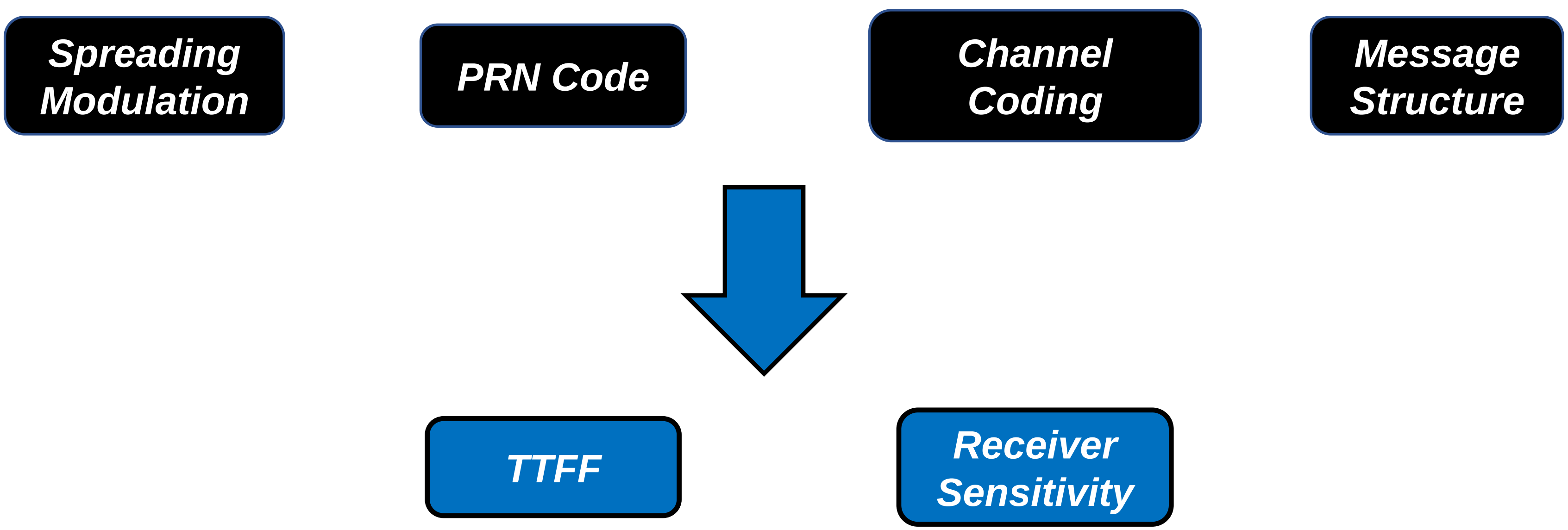
Spreading Modulation

PRN Code

Channel Coding

Message Structure

New signal to improve the TTFF and the receiver sensitivity



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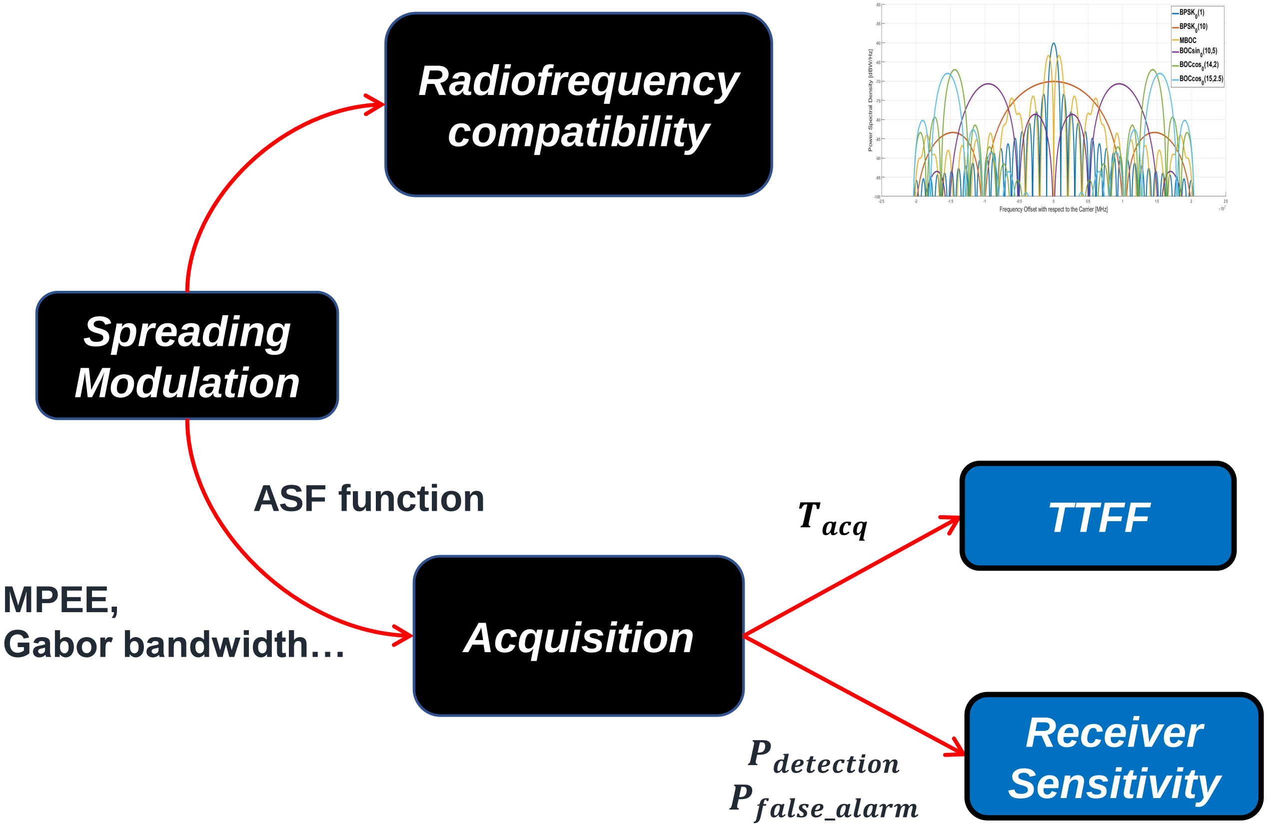
Design new modulation



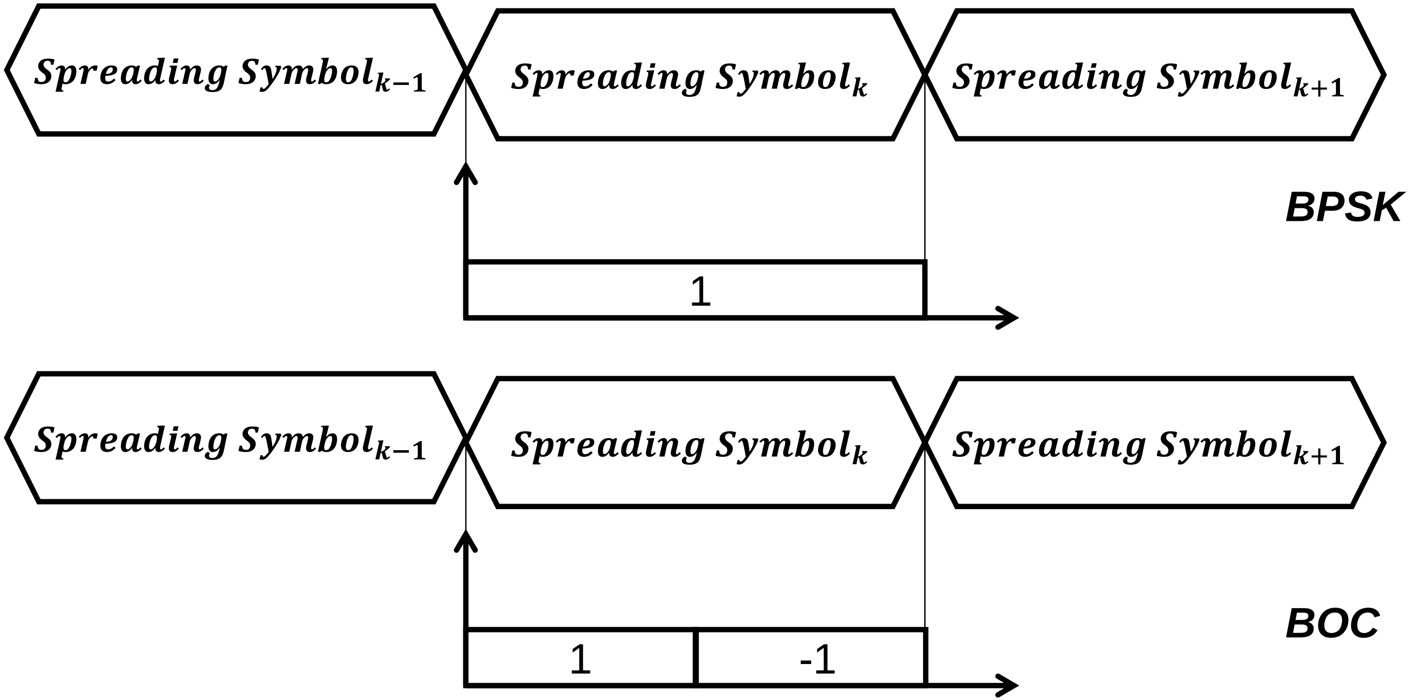
Design new modulation

- Spreading Modulation Criteria for Design

Figure of Merit	Criteria
Radio Frequency Compatibility	SSC
Correlation Properties	ACF
Resistance Against Multipath	MPEE
Ranging Performance	Gabor bandwidth
Anti-Jamming Capability	Demodulation & anti-jamming of narrowband Code tracking & anti-jamming of narrowband Demodulation & anti-jamming of matched spectrum Code tracking & anti-jamming of matched spectrum

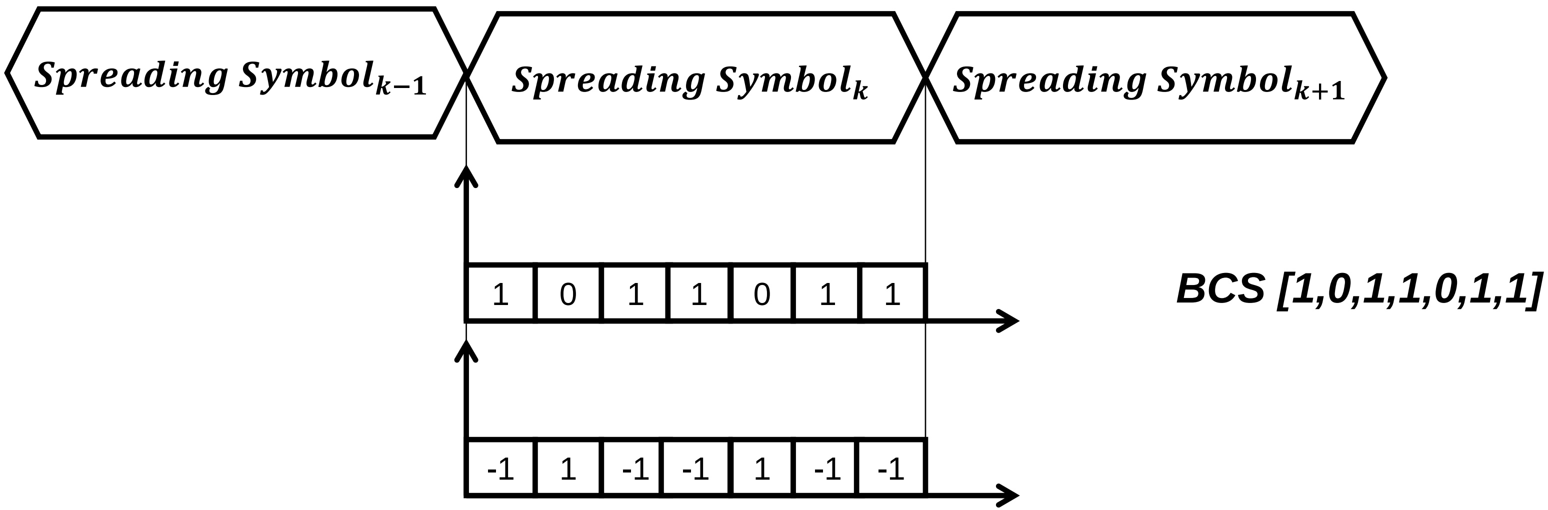
Design new modulation

- Standard spreading modulations:



Design new modulation

- Binary Coded Symbol (BCS)
  - Spreading modulation candidate

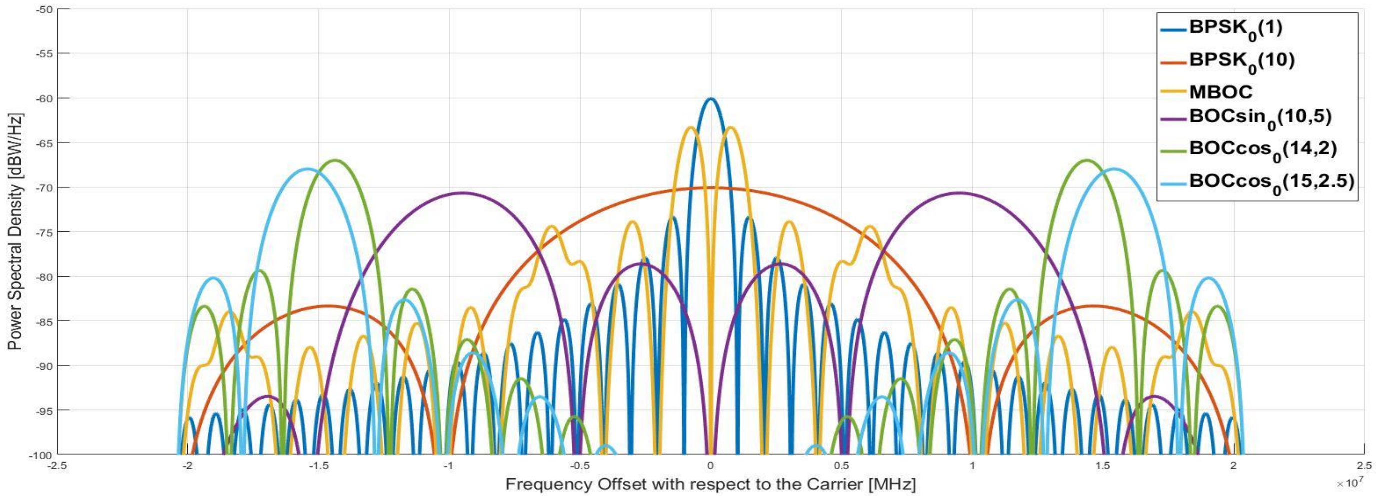


Design new modulation

- Spreading modulation candidates

Already proposed candidates		Proposed candidates	
BOCcos(0.5,0.5) BOCsin(0.5,0.5) BOCsin(4,0.5) BOCcos(4,0.5)	BOCsin(4, 1), BOCcos(4,1), BOCsin(6.5,0.5) BOCcos(6.5,0.5)	BCS[-1,1](0.5) BCS[-1,1,-1](0.5) BCS[-1,-1,-1,1,1](0.5)	BCS[-1,-1, -1, 1, 1](1) BCS[-1,1,-1](1) BCS[-1,-1,-1,1,-1](1)

Current L1 bandwidth spectral occupation



Design new modulation

- Evaluation of the spreading modulation candidates
  - **Radio frequency compatibility**

More interference

SSC Coefficients

Candidates

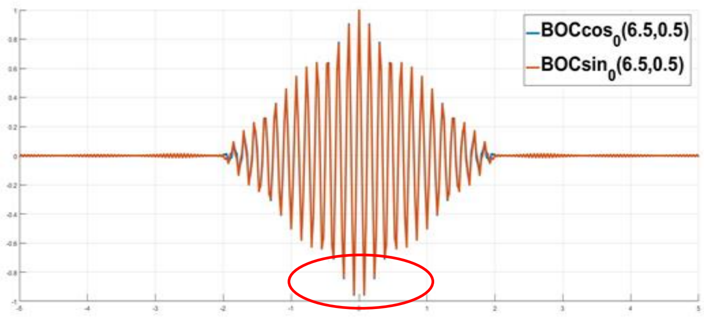
	$BPSK_0(1)$	$BPSK_0(10)$	MBOC	$BOCsin_0(10,5)$	$BOCcos_0(14,2)$	$BOCcos_0(15,2.5)$
$BOCcos_0(6.5,0.5)$	-88.43	-78.27	-79.09	-77.49	-90.91	-90.29
$BOCsin_0(6.5,0.5)$	-85.40	-77.79	-78.46	-77.85	-94.23	-92.64
$BOCcos_0(4,0.5)$	-88.96	-73.54	-87.47	-80.91	-96.51	-94.08
$BOCsin_0(4,0.5)$	-82.93	-73.26	-82.99	-81.20	-95.06	-94.09
$BOCcos_0(4,1)$	-85.95	-73.66	-84.46	-80.46	-93.48	-93.83
$BOCsin_0(4,1)$	-79.92	-73.11	-79.98	-81.00	-92.04	-93.84
$BOCcos_0(0.5,0.5)$	-66.12	-70.48	-65.27	-83.92	-92.96	-93.57
$BOCsin_0(0.5,0.5)$	-63.11	-70.32	-66.52	-86.13	-95.17	-95.79
BCS[-1 1](0.5)	-63.11	-70.32	-66.52	-86.13	-95.17	-95.79
BCS[-1 1 -1](0.5)	-66.75	-70.48	-64.86	-83.92	-92.94	-93.56
BCS[-1 -1 -1 1 1](0.5)	-63.09	-70.32	-66.57	-86.13	-95.17	-95.79
BCS[-1 -1 -1 1 1](1)	-67.39	-70.56	-65.50	-83.12	-91.68	-92.80
BCS[-1 1 -1](1)	-71.40	-70.89	-68.98	-80.90	-88.80	-91.90
BCS[-1 -1 -1 1 -1](1)	-66.11	-70.89	-69.37	-80.90	-91.31	-94.60

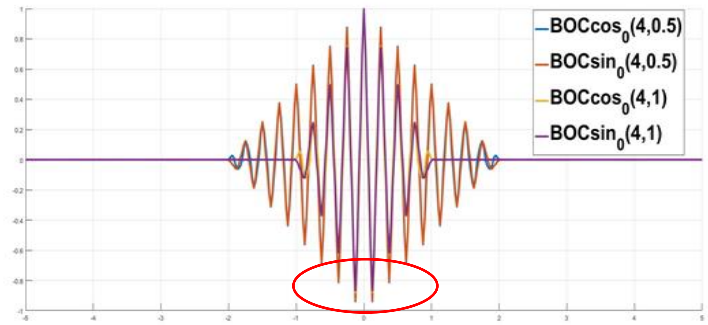
Current signals

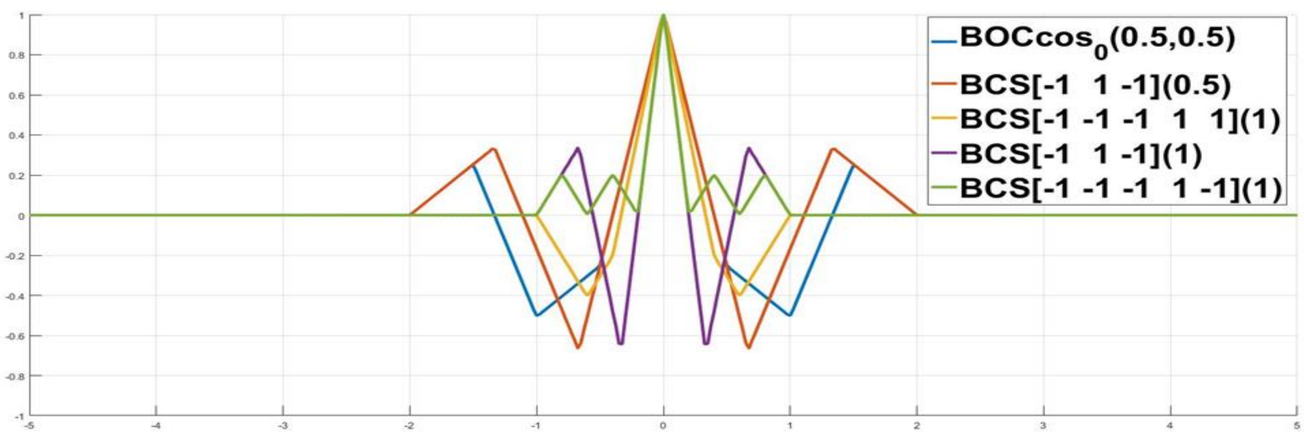
Less interference

Design new modulation

- Evaluation of the spreading modulation candidates
  - **Correlation properties**

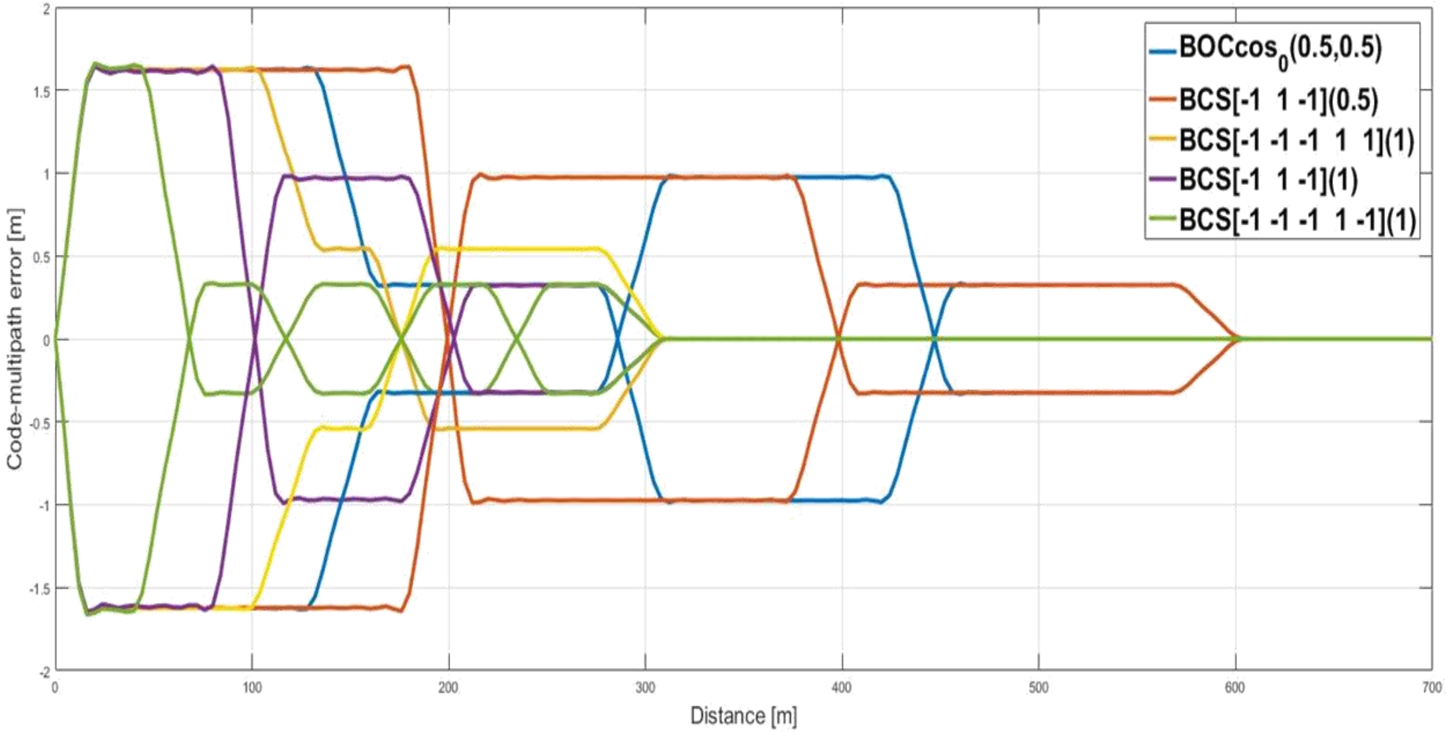






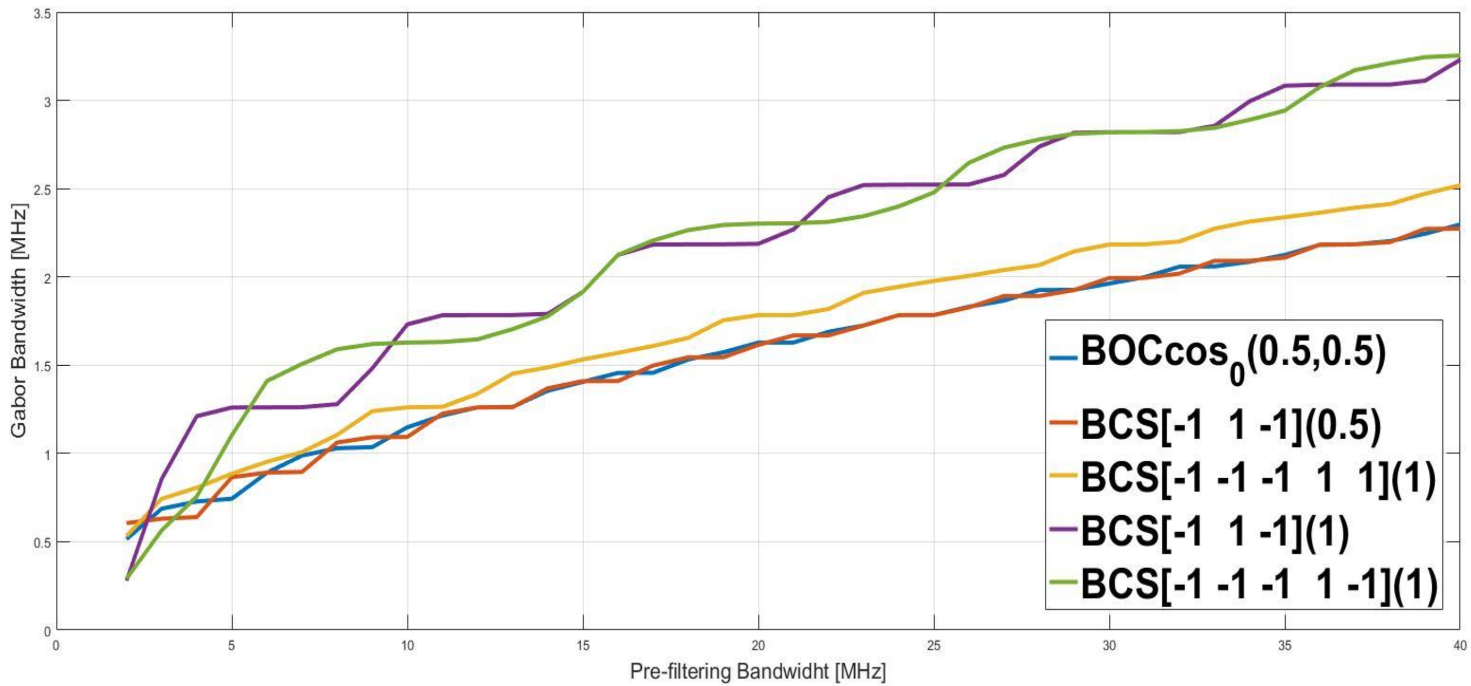
Design new modulation

- Evaluation spreading modulation candidates
  - **Resistance against multipath**



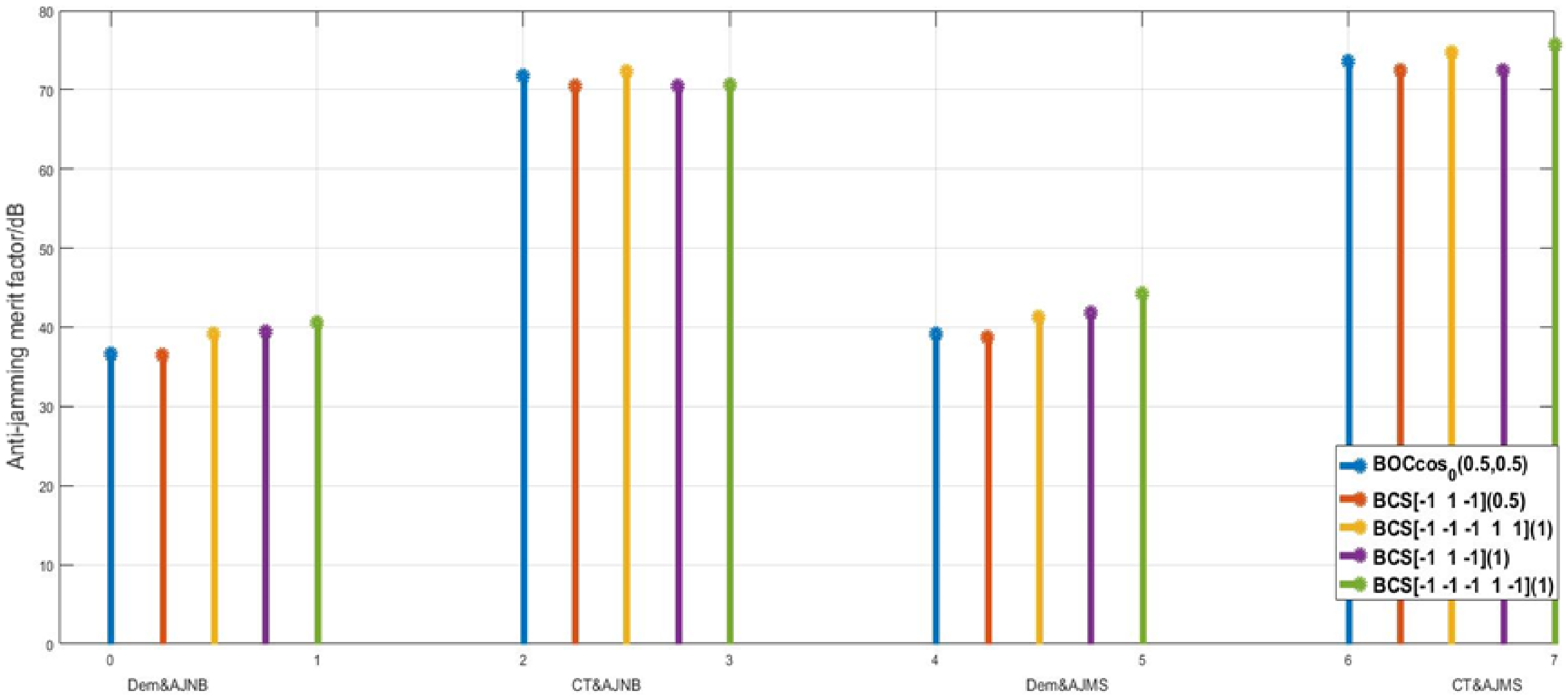
Design new modulation

- Evaluation of the spreading modulation candidates
  - **Ranging Performance**

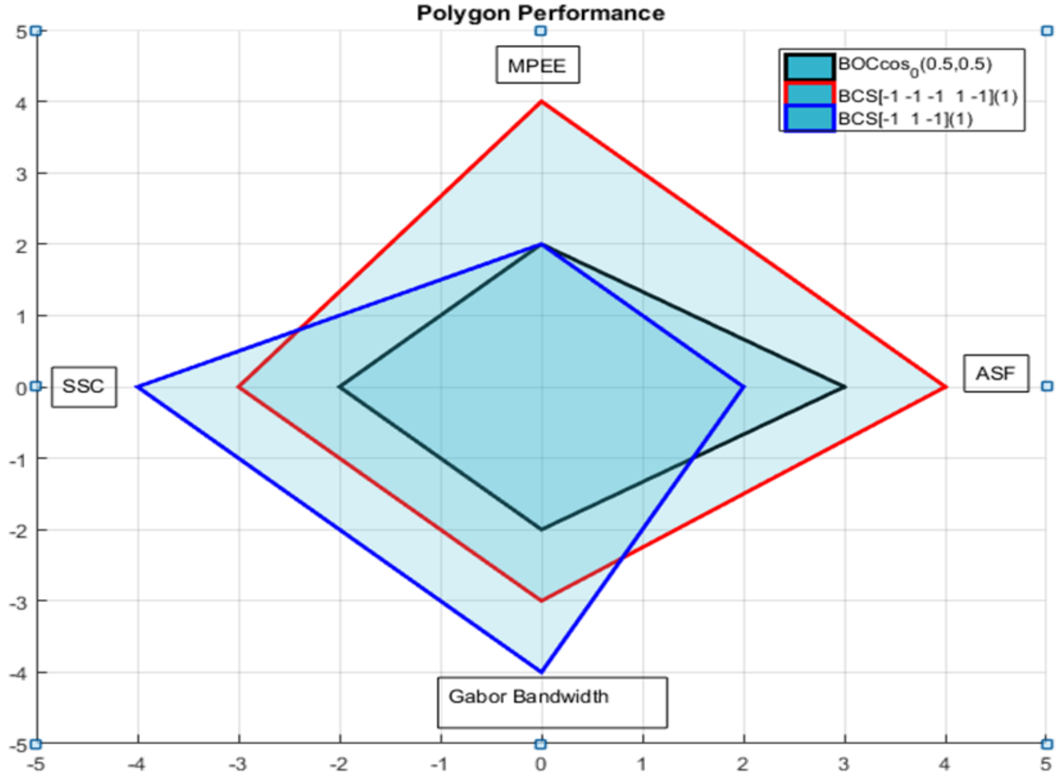


Design new modulation

- Evaluation of the spreading modulation candidates
  - **Anti-Jamming coefficients**



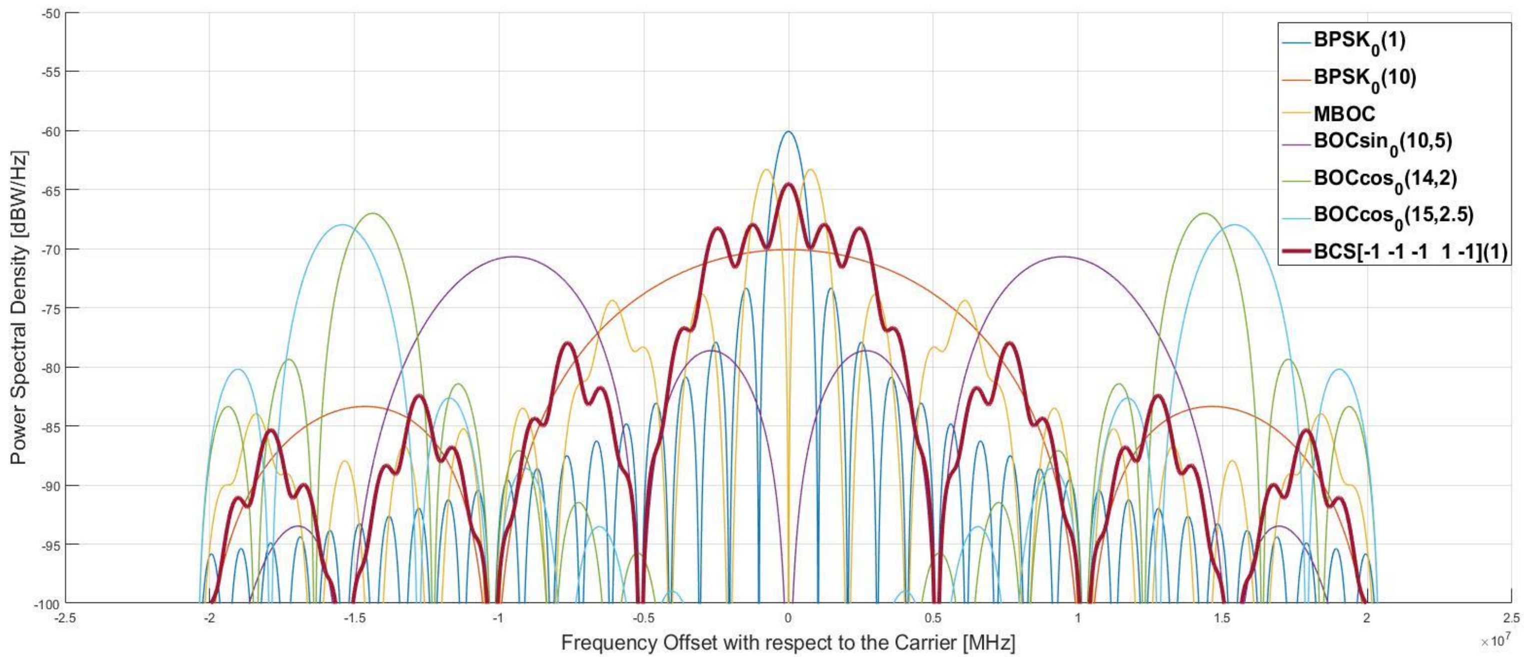
- Evaluation of the spreading modulation candidates
  - **Polygon performance**



Design new modulation

- Evaluation of the spreading modulation candidates

BCS[-1,-1,-1,1,-1](1)



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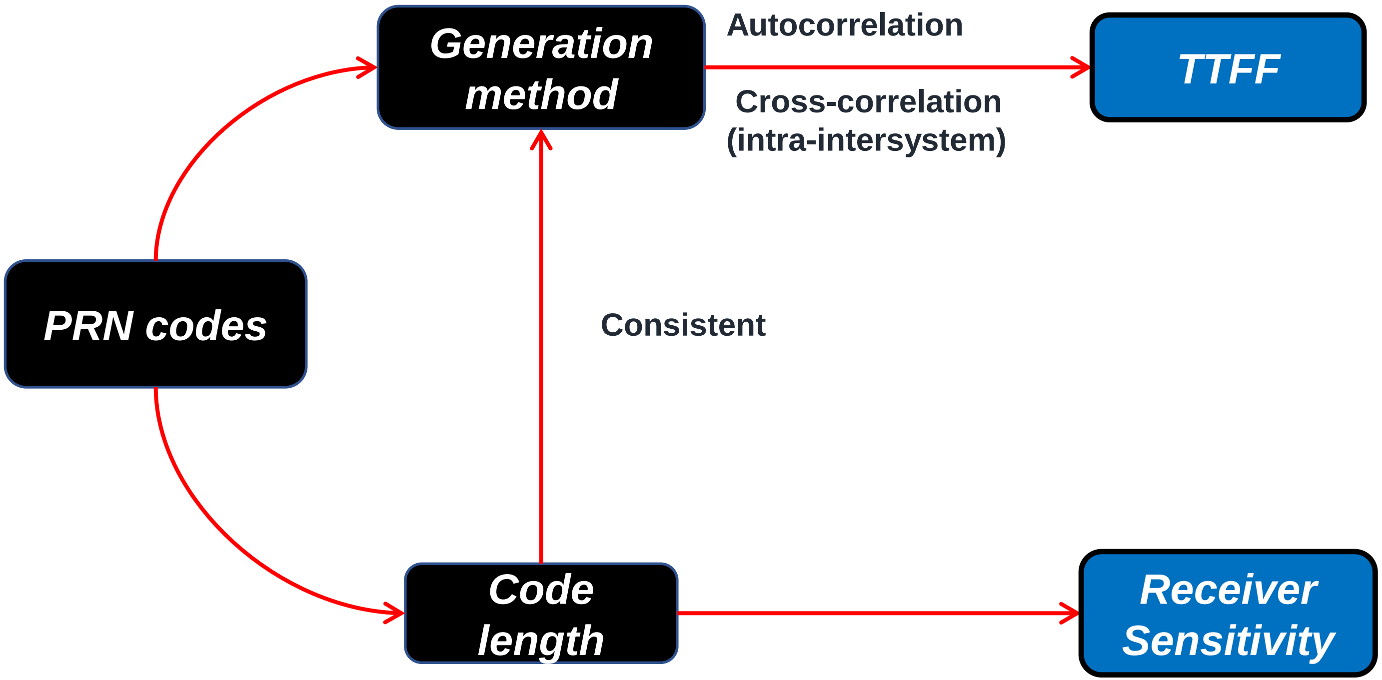
Design new PRN codes



Design new PRN codes

- PRN codes criteria for design

Criteria	Equations
Acquisition Criterion	$MEWSD^{MP} = mean(\sum_{n_{foffs}} \sum_{\substack{l=1 \\ ACF^e(l,f_{offs})>\Phi_{min}}}^{N-1} (ACF^e(l,f_{offs}) - \Phi_{min})^2)$ $MEWSD^{CT}{}_{i,j} = mean(\sum_{n_{foffs}} \sum_{\substack{l=1 \\ CC^e(l,f_{offs})>\Phi_{min}}}^{N-1} (CC^e(l,f_{offs}) - \Phi_{min})^2)$
Tracking Criterion	$MF_i^{MP} = \frac{1}{n_{foffs}} (\sum_{n_{foffs}} (\sum_{l=1,2,N-2,N-1} (AC_i{}^e(l,f_{offs}))^2)$ $MF_{i,j}{}^{CT} = \frac{1}{n_{foffs}} (\sum_{n_{foffs}} (\sum_{l=0}^{N-1} (CC_{i,j}{}^e(l,f_{offs}))^2)$
Robustness Against Narrow-Band Interferences Criterion	$ELW = 10\log(\frac{1}{n} \sum_{\substack{k=-\frac{n}{2} \\ A_k>\sqrt{n}}}^{\frac{n}{2}} (A_k - \sqrt{n})^2)$

- PRN codes assessment

Criteria
$AMEWSD^{MP}$
$AMEWSD^{CT}$
AMF^{MP}
AMF^{CT}
$AELW$

→

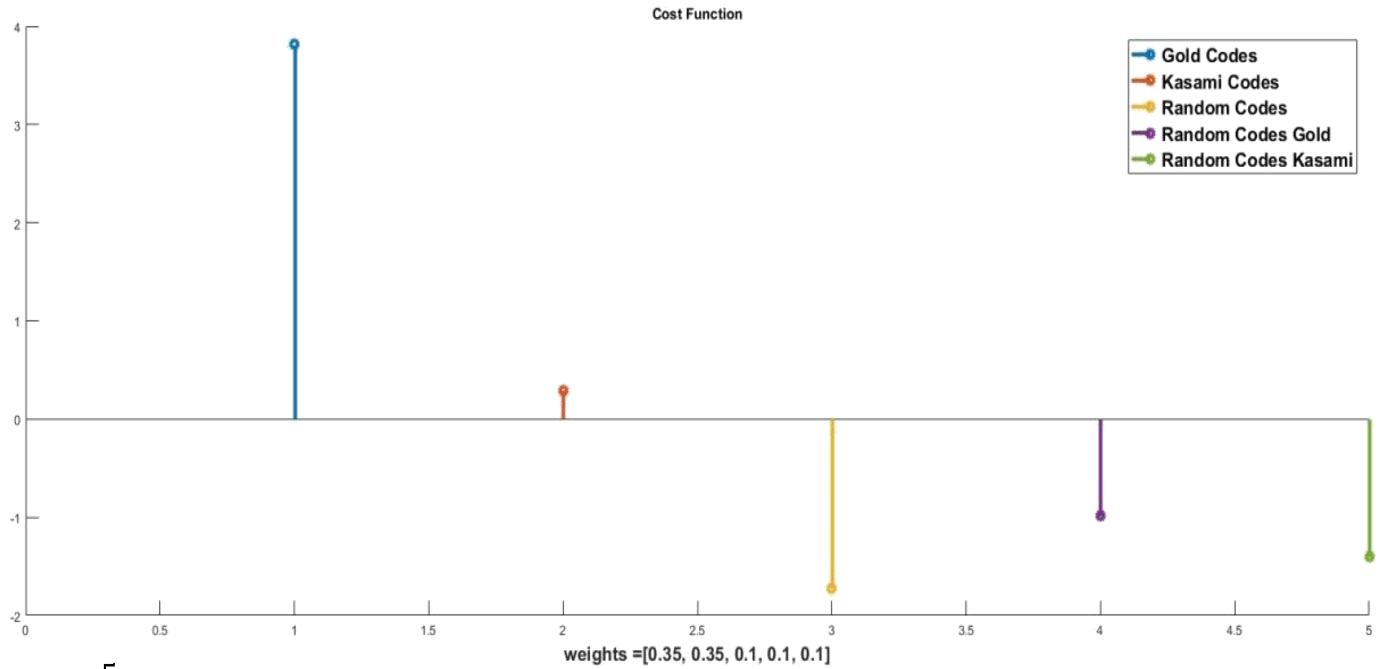
Candidate
Gold Codes
Kasami Codes
Random Sequences
Random Sequence Init Gold Codes
Random Sequence Init Kasami Codes

$$R_i = \sum_{j=1}^{5} -w_j \frac{\overline{cv_j} + cv_{i,j}}{\overline{cv_j}} \quad for\ i = 1,2, \dots K$$

$$\boldsymbol{Weight} = [\mathbf{0.2, 0.2, 0.2, 0.2, 0.2}]$$

Design new PRN codes

- PRN codes assessment



$$R_i = \sum_{j=1}^{5} -w_j \frac{\overline{cv_j} + cv_{i,j}}{\overline{cv_j}} \; for\ i = 1,2, \dots K \qquad \boldsymbol{Weight} = [\mathbf{0.35, 0.35\ 0.1, 0.1, 0.1}]$$

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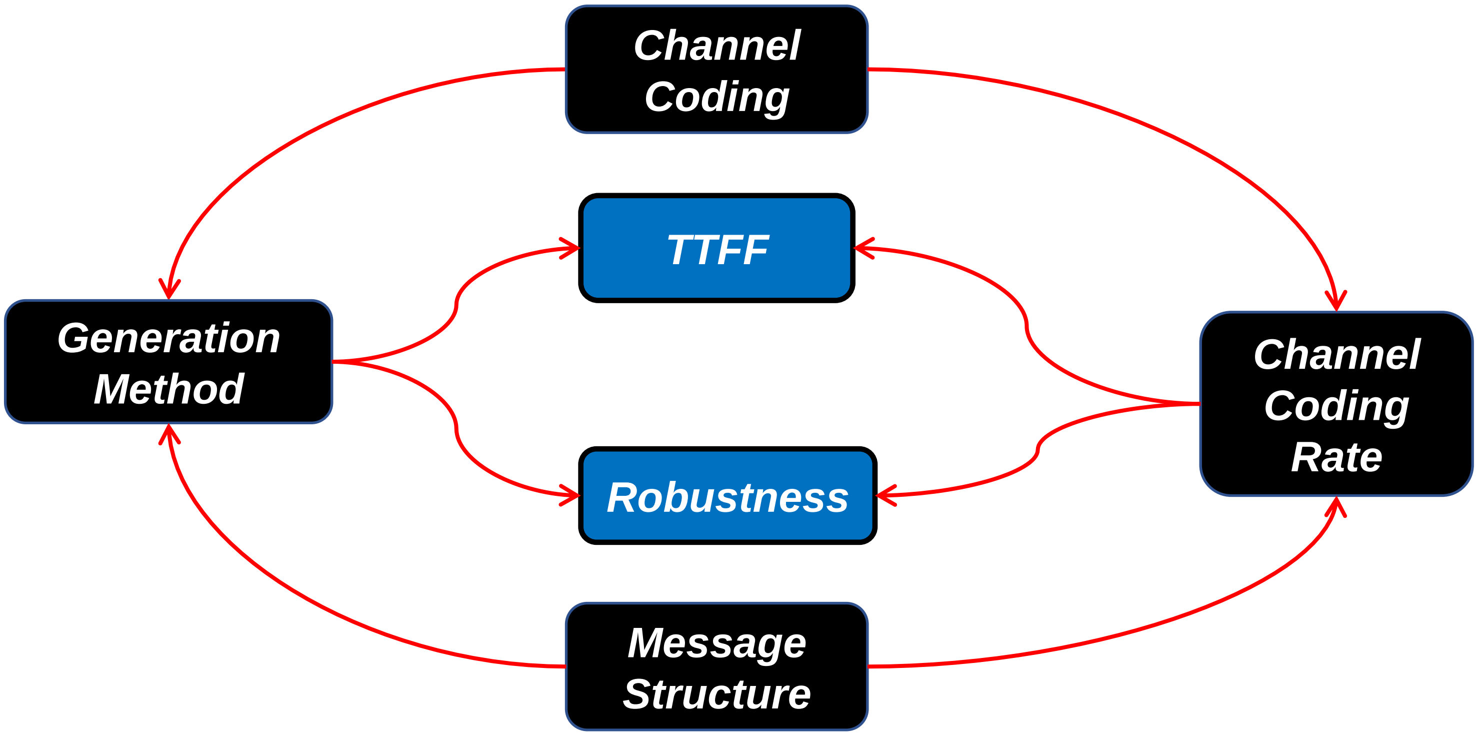
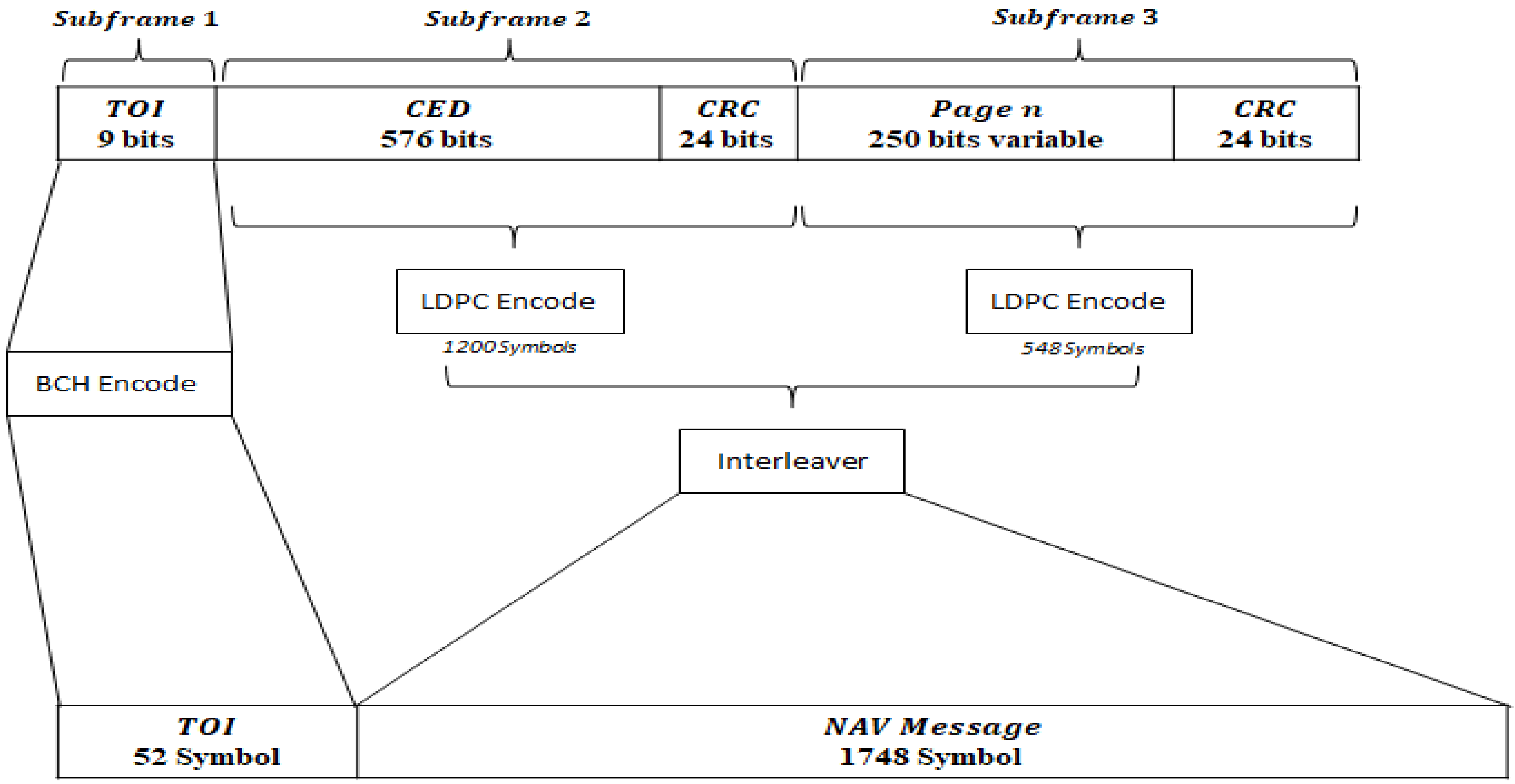
Co-design message structure and channel coding



- What do we need ?

  - CRC (Cyclic Redundancy Check) which provides information about the integrity of the message.
  - Good error correction capabilities under harsh channel conditions.
  - Under good channel conditions, be capable of retrieving the CED with just the CED redundancy data (thanks to this capability we are able to reduce the T_{CED}).

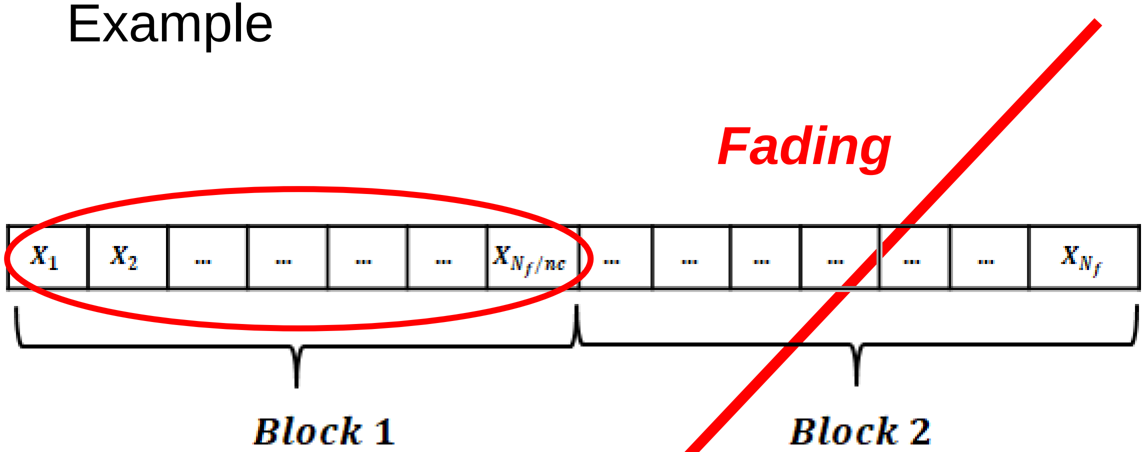
Co-design message structure and channel coding



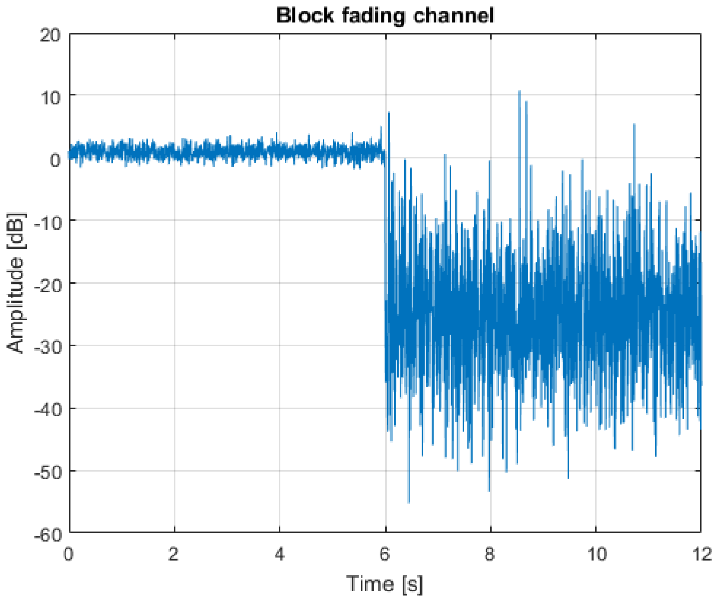
GPS L1C Message Structure

Block fading channel model

Example



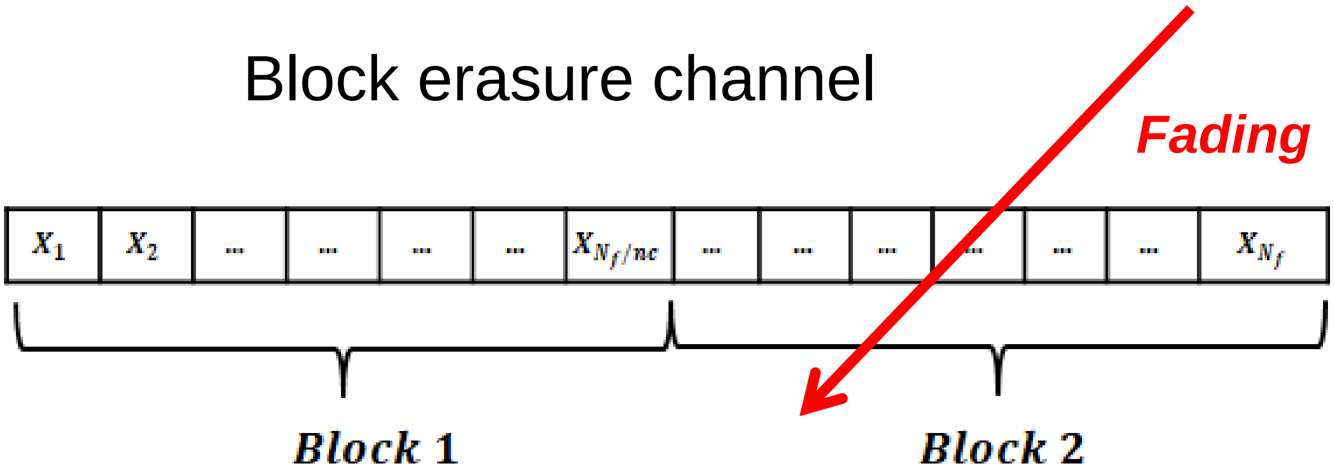
We recover the information



Amplitude of block fading channel

Block fading channel model

Block erasure channel

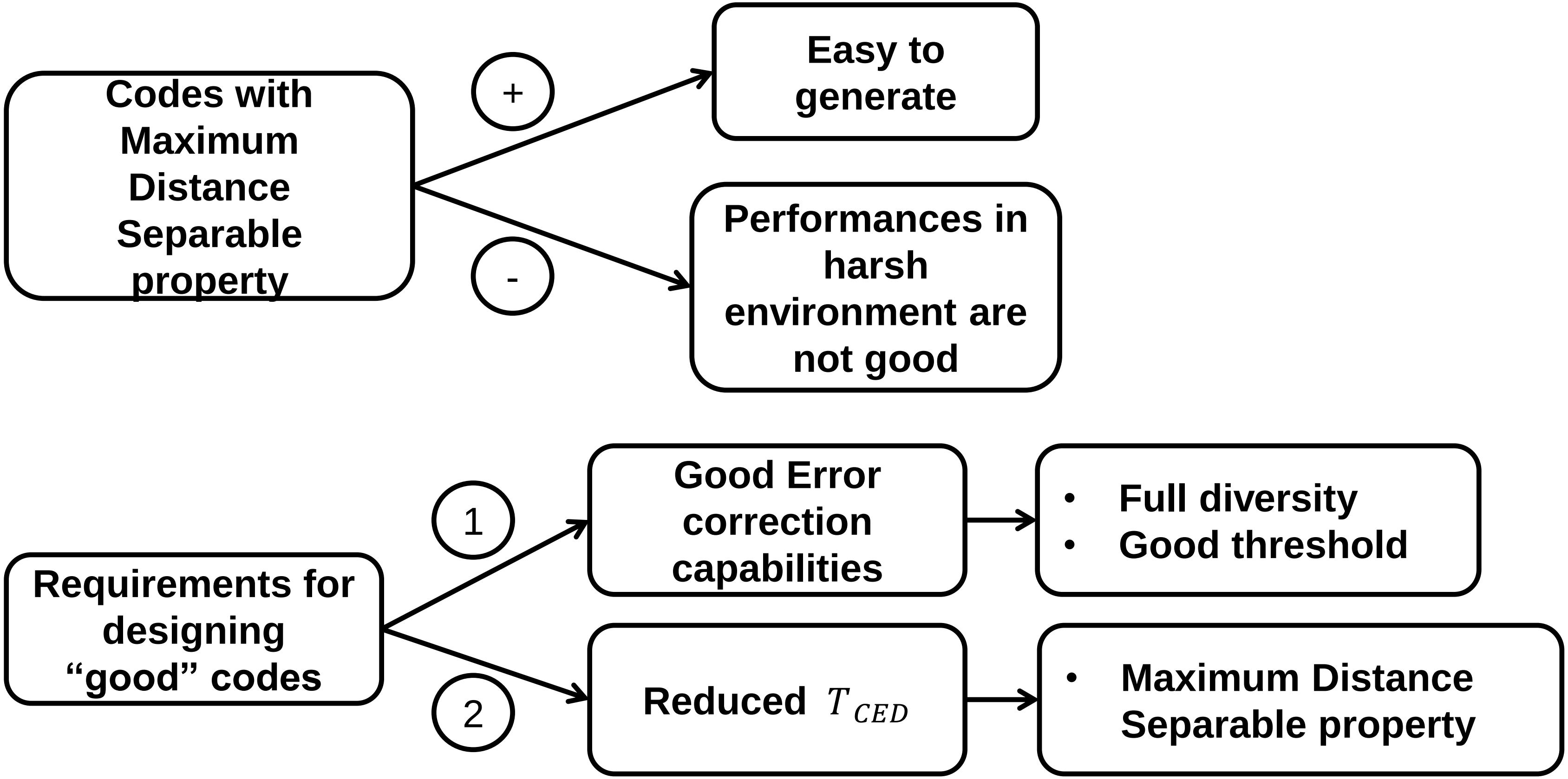


Fading = not have already received the information

but we are able to retrieve the information with the first part

Maximum distance separable (MDS) property

Block fading channel model



Co-design message structure and channel coding

- Lowest Density-Maximum Distance Separable (LD-MDS) codes
- Maximum Distance Separable (MDS) codes
- Regular Root codes

LD-MDS codes

Example:

1200

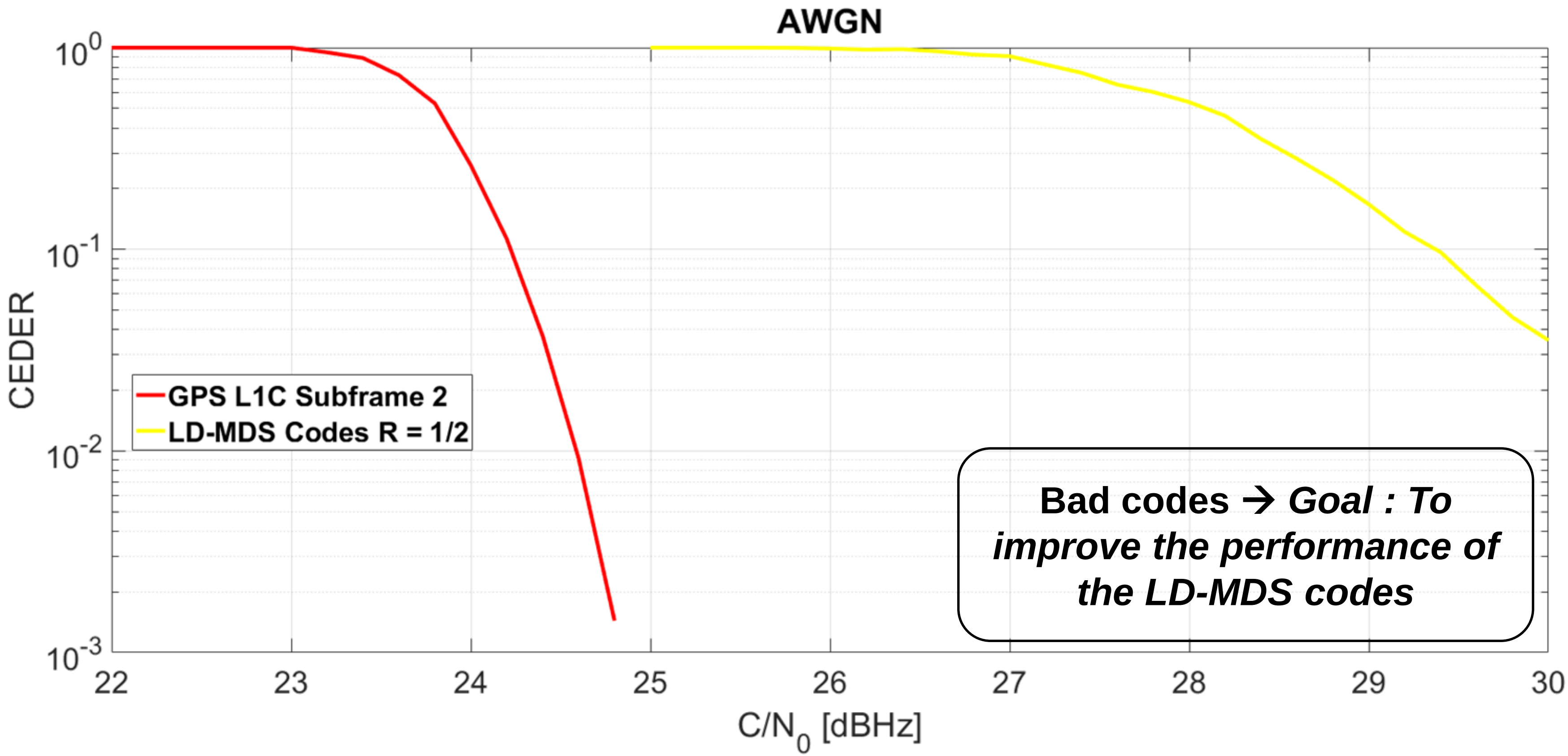
$$H_\beta = \begin{pmatrix} I & I & I & 0 \\ \beta_1 & \beta_2 & 0 & I \end{pmatrix}$$

600

k1 k2 k3 k4

With any 2 error-free-blocks we retrieve the information → Erasure algorithm
In case of errors with more than 2 blocks → BP Algorithm

LD-MDS codes


AWGN
CEDER
C/N0 [dBHz]
GPS L1C Subframe 2
LD-MDS Codes R = 1/2
10^0
10^-1
10^-2
10^-3
22
23
24
25
26
27
28
29
30
Bad codes → Goal : To improve the performance of the LD-MDS codes

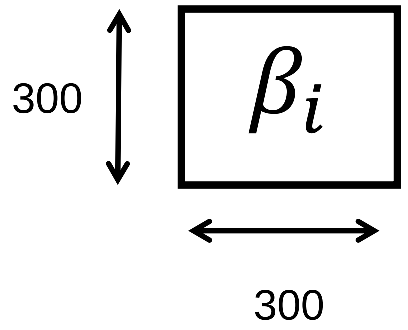
MDS codes

Example:

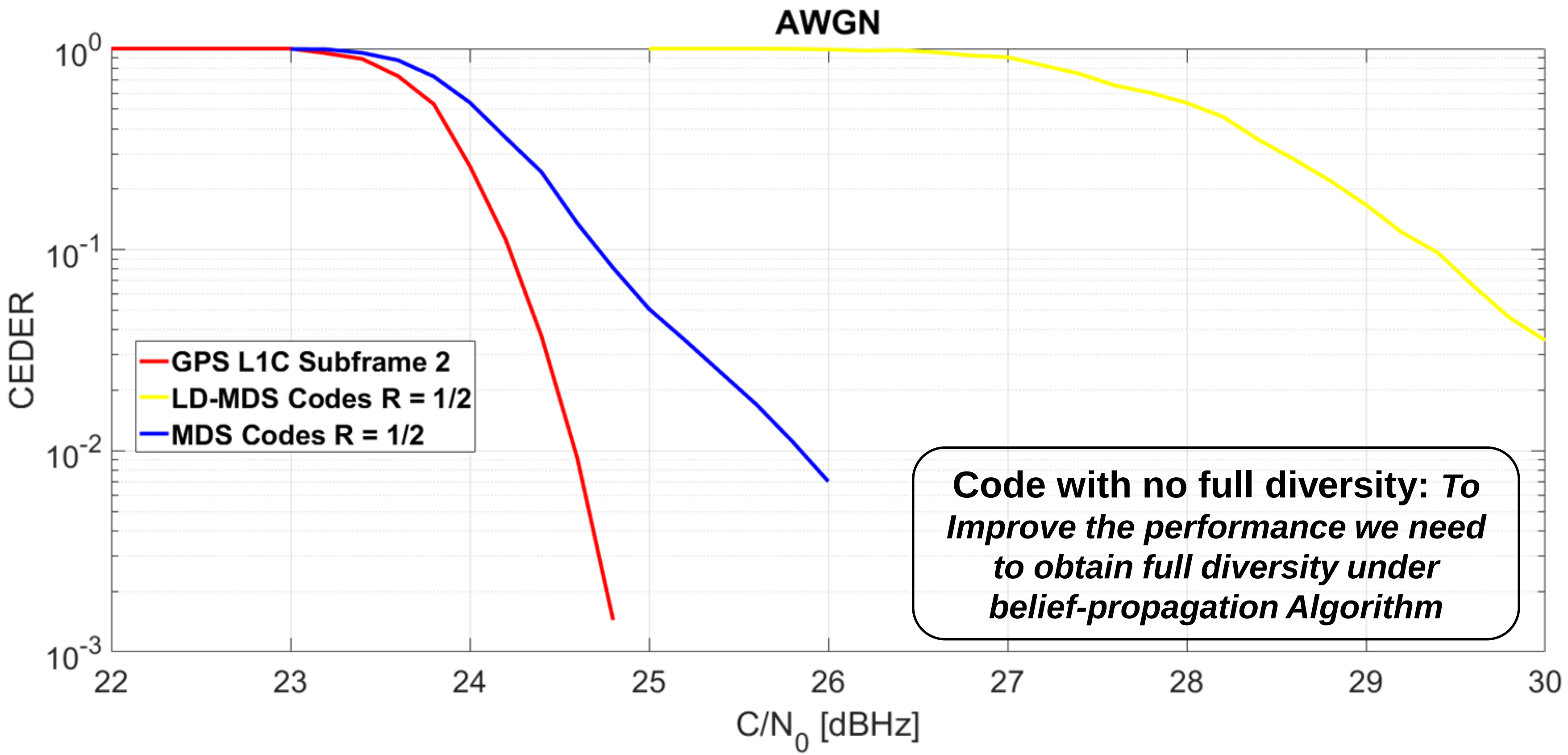
1200

$$H_\beta = \begin{pmatrix} \beta_1' & \beta_2' & I & 0 \\ \beta_1 & \beta_2 & 0 & I \end{pmatrix}$$

600



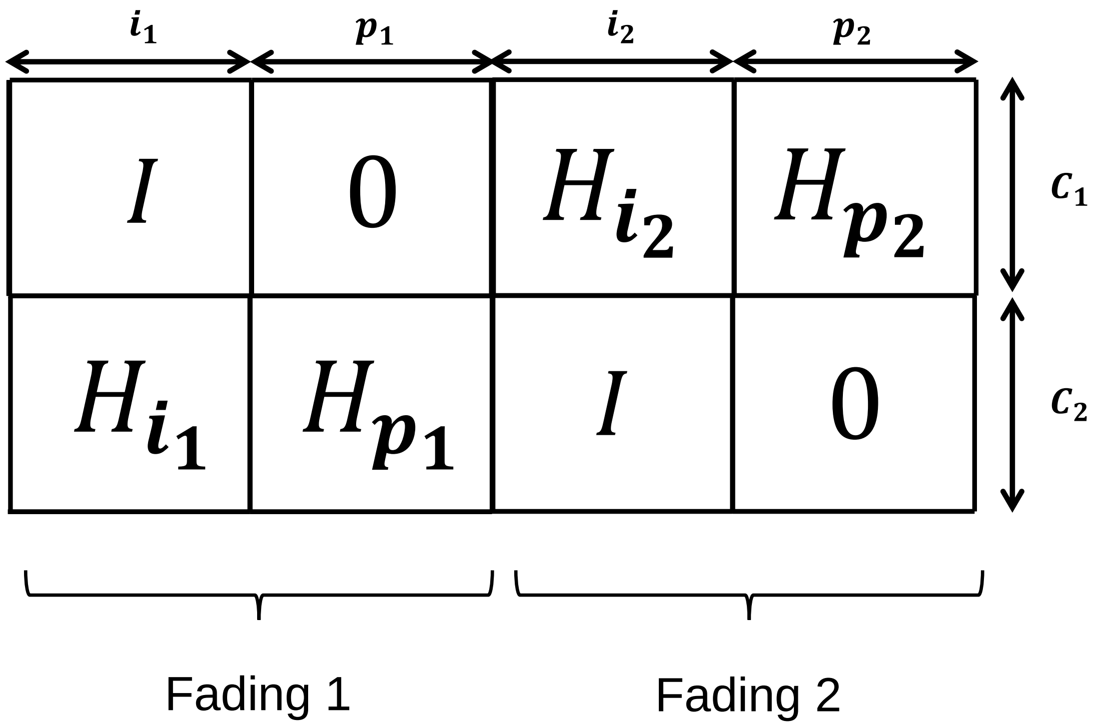
MDS codes


AWGN
CEDER
10^0
10^-1
10^-2
10^-3
22
23
24
25
26
27
28
29
30
C/N0 [dBHz]
GPS L1C Subframe 2
LD-MDS Codes R = 1/2
MDS Codes R = 1/2
Code with no full diversity: *To Improve the performance we need to obtain full diversity under belief-propagation Algorithm*

Regular-Root codes

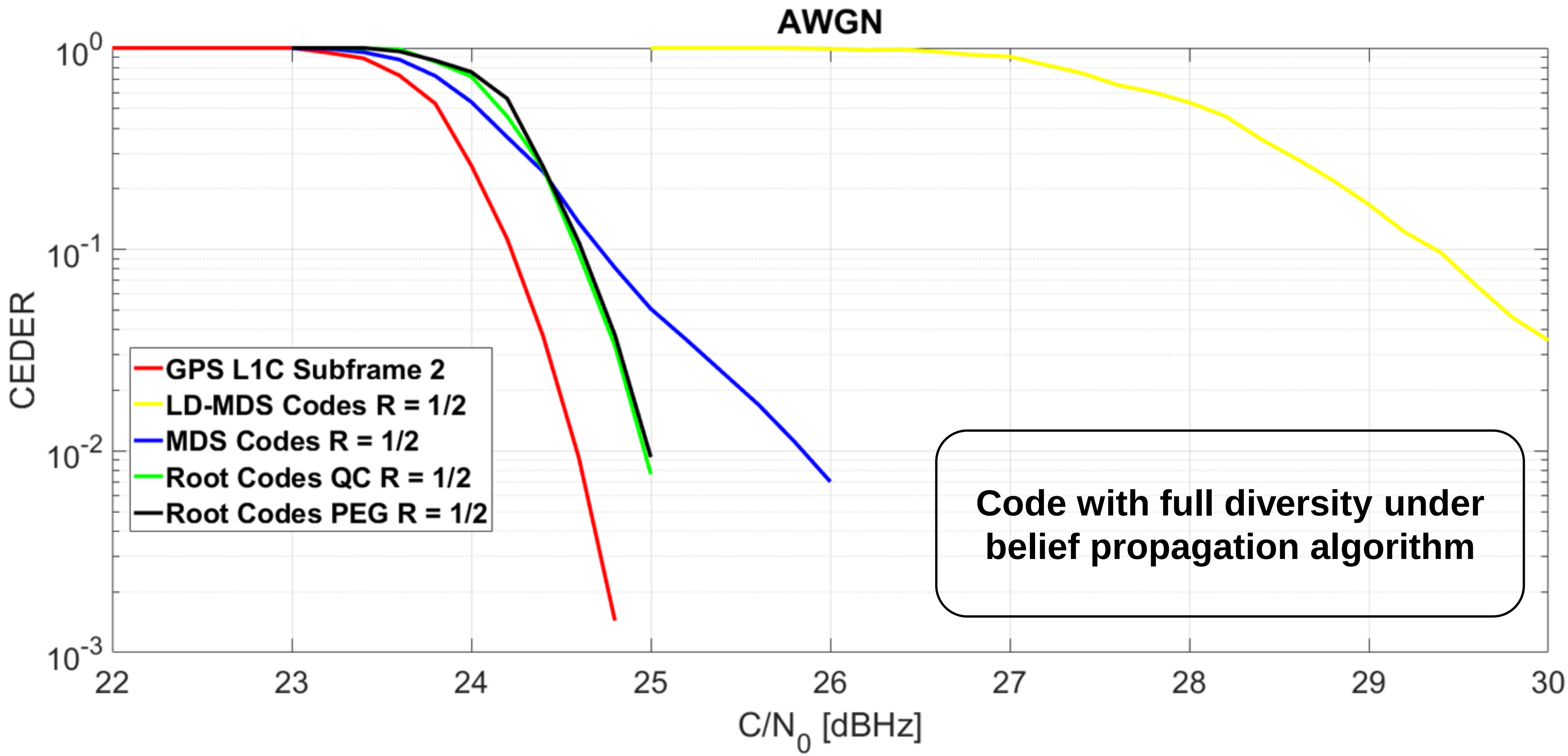
They have full diversity property under BP algorithm

Example:

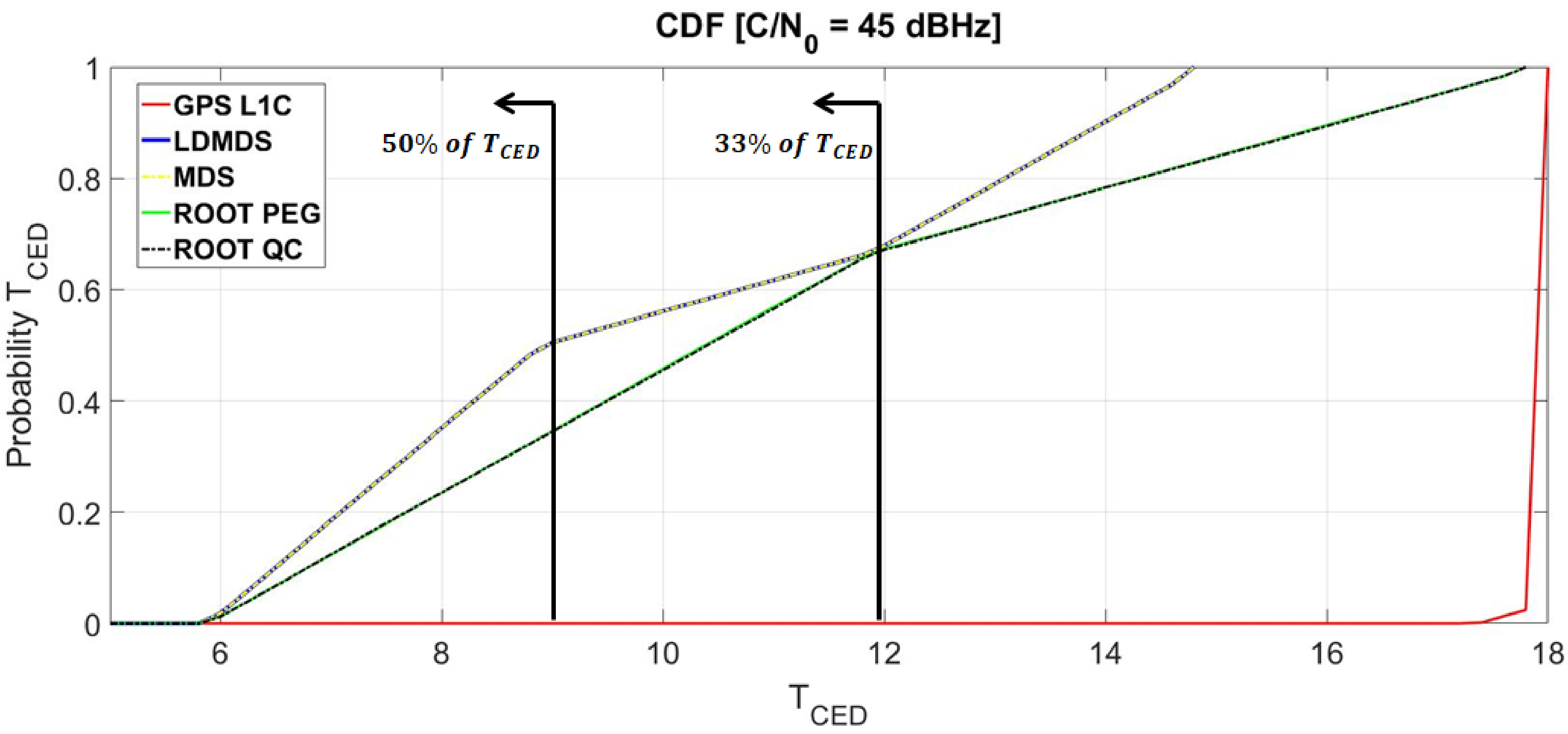


We don't need erasure algorithm→ Running BP algorithm, we retrieve the information

Regular-Root codes



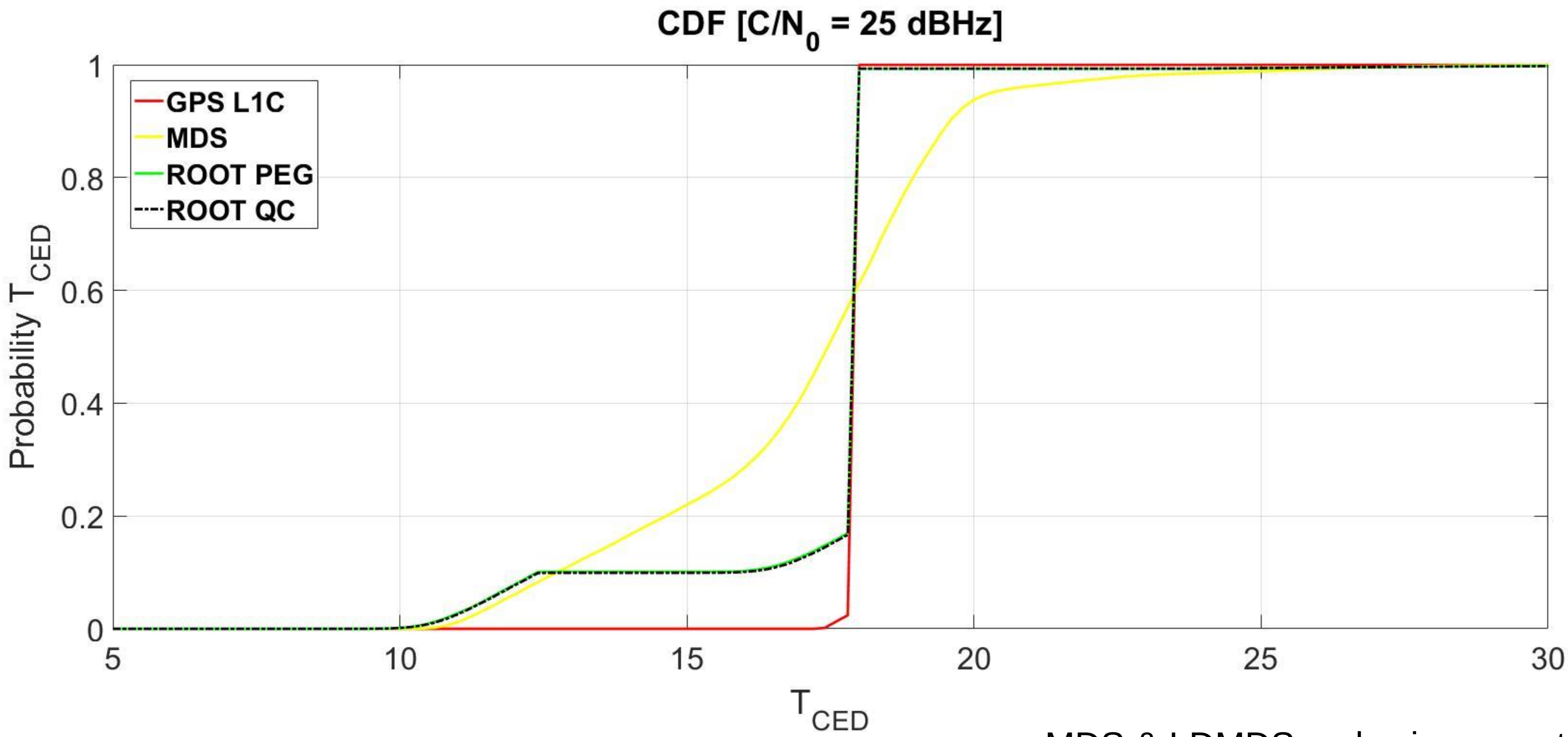
Cumulative Distribution Function (CDF)



Under good channel conditions, we reduce the T_{CED}

Results

Cumulative Distribution Function (CDF)

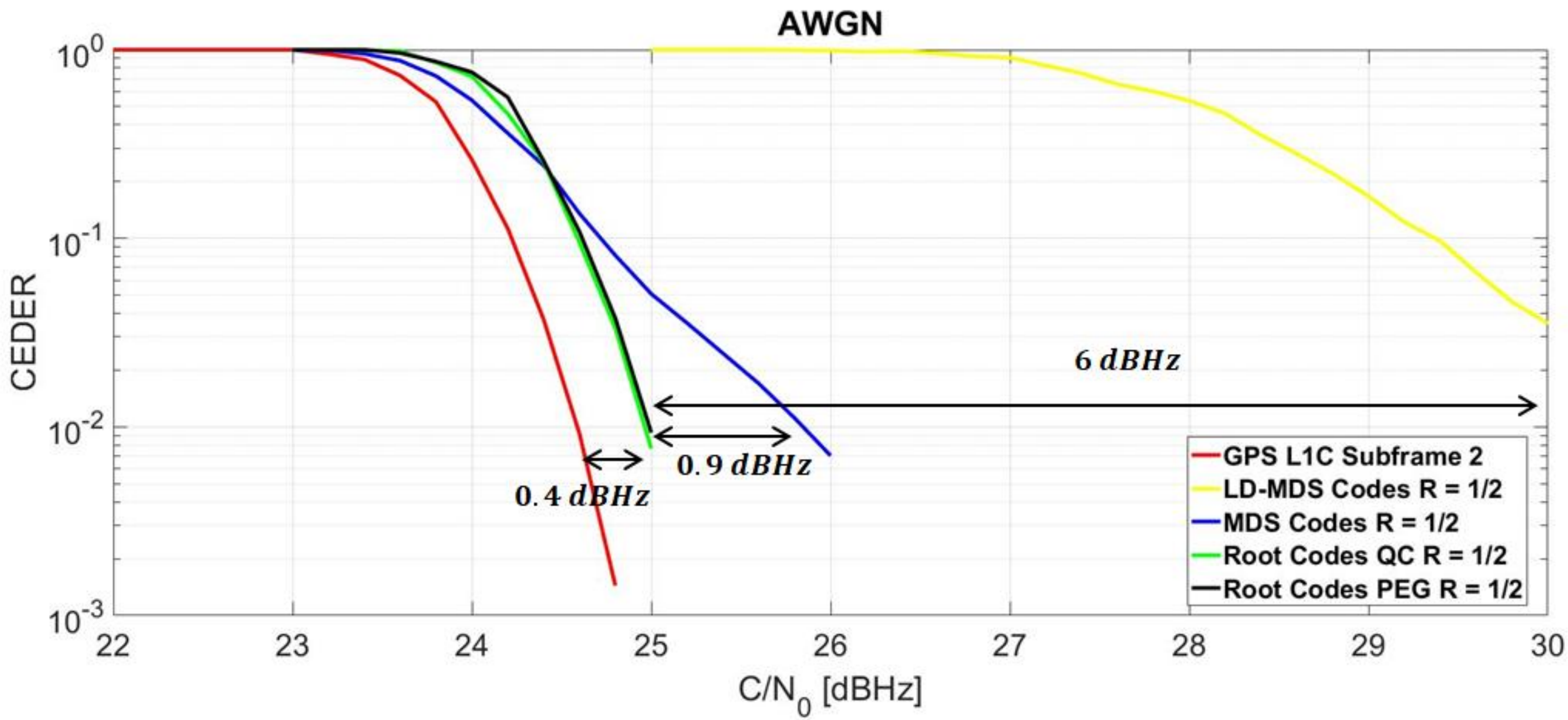


Under harsh channel conditions:

MDS & LDMDS codes increase the T_{CED}

Root codes reduce the T_{CED}

Results



AWGN
CEDER
10^0
10^{-1}
10^{-2}
10^{-3}
22
23
24
25
26
27
28
29
30
C/N$_0$ [dBHz]
6 dBHz
0.9 dBHz
0.4 dBHz
GPS L1C Subframe 2
LD-MDS Codes R = 1/2
MDS Codes R = 1/2
Root Codes QC R = 1/2
Root Codes PEG R = 1/2

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- Future Lines

Conclusion

- Objective : Design a new signal to improve the acquisition phase
  - To improve the receiver sensitivity and to reduce the TTFF*
- Results:
  - BCS[-1,-1,-1,1,-1](1) → **Improve of the receiver sensitivity**
  - Random Sequences PRN codes → **Reduction of the TTFF and easing the acquisition phase vs GPS L1C**
  - Regular root-codes:
    - MDS property under BP algorithm
    - Full diversity

    → **High Reduction of the TTFF with good data demodulation vs GPS L1C**

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Future Lines

- Next step:
  - Multiplexing the new signal

thank you!

Lorenzo Ortega

lorenzo.ortega@tesa.prd.fr