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

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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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- **Introduction & background**
- Design a new modulation for fast acquisition:
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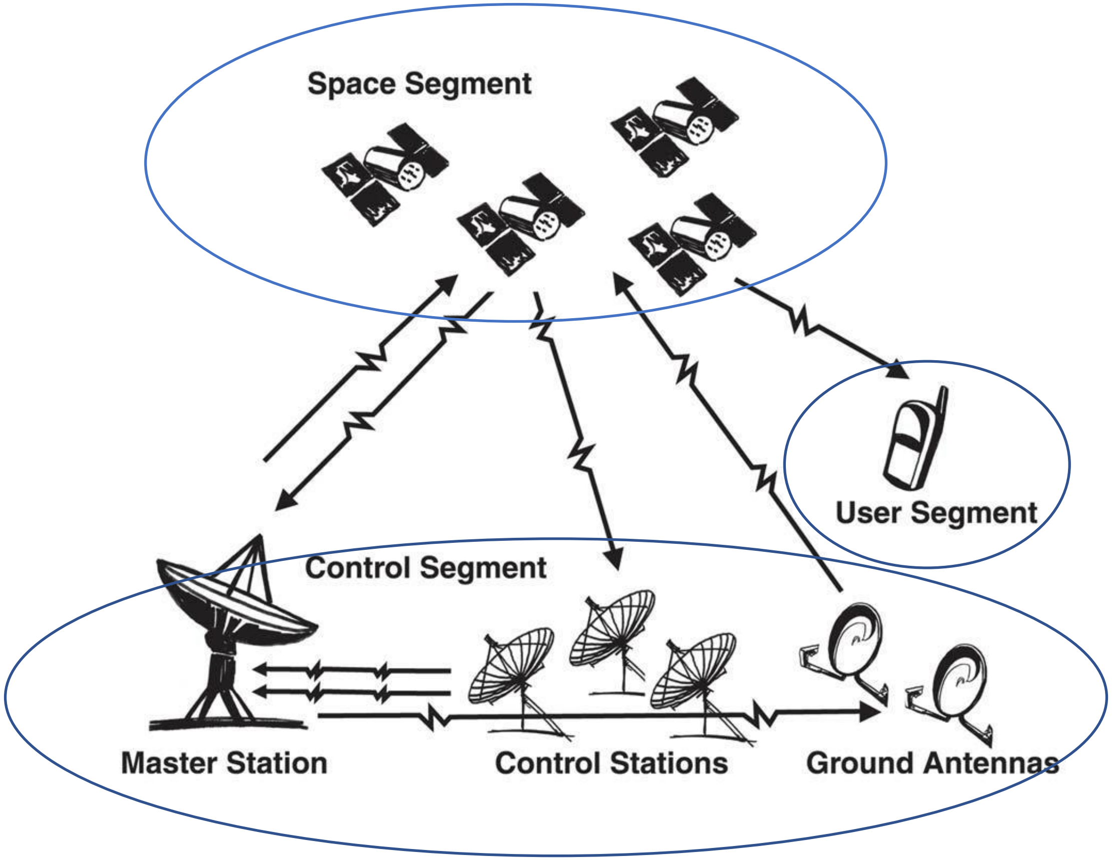
What is GNSS?

Global Navigation Satellite System

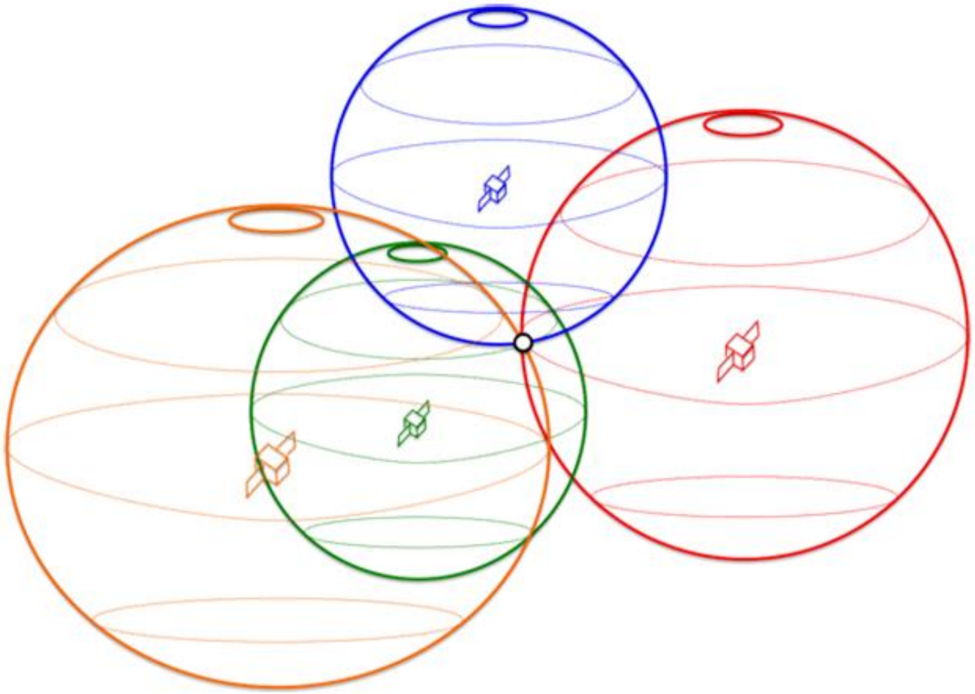
- Position
- Speed
- Time

Global 24/7

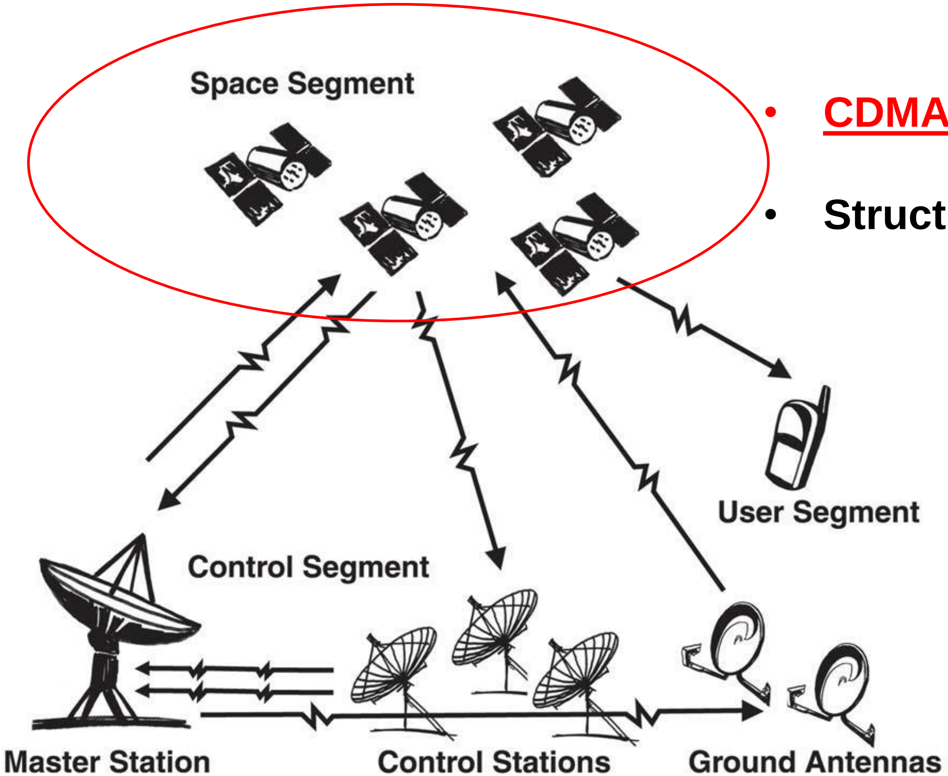
GNSS is 3 Segments system



Positioning

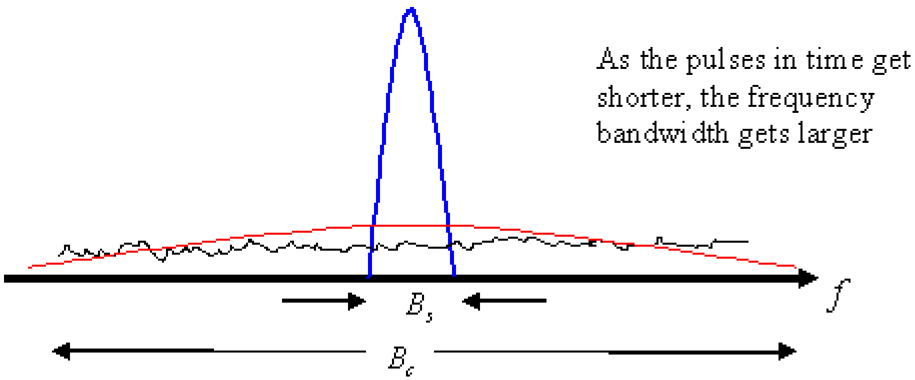


GNSS is 3 Segments system

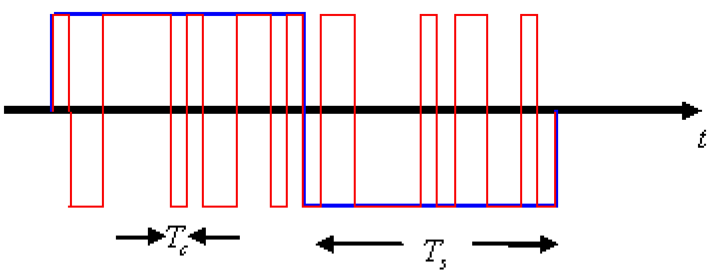


- **CDMA signals**
- **Structure message**

CDMA signal:



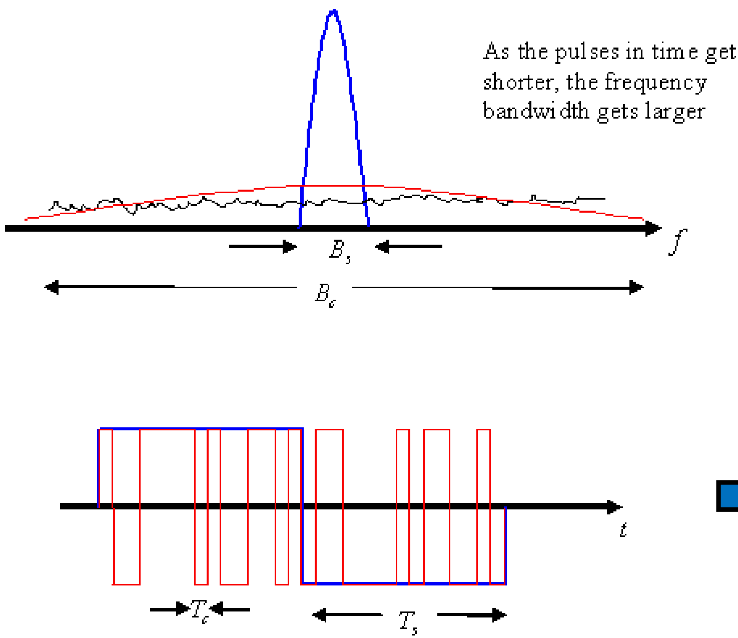
Pseudo Random Noise (PRN) sequence

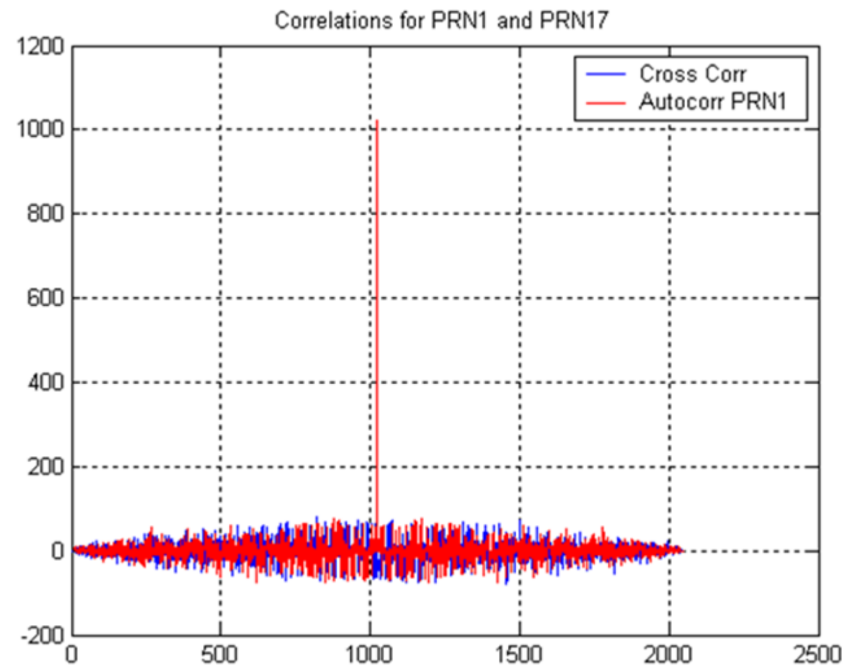


If at the receiver you know the PRN:

- Robust against narrowband interference
- Less Intra-system Interference

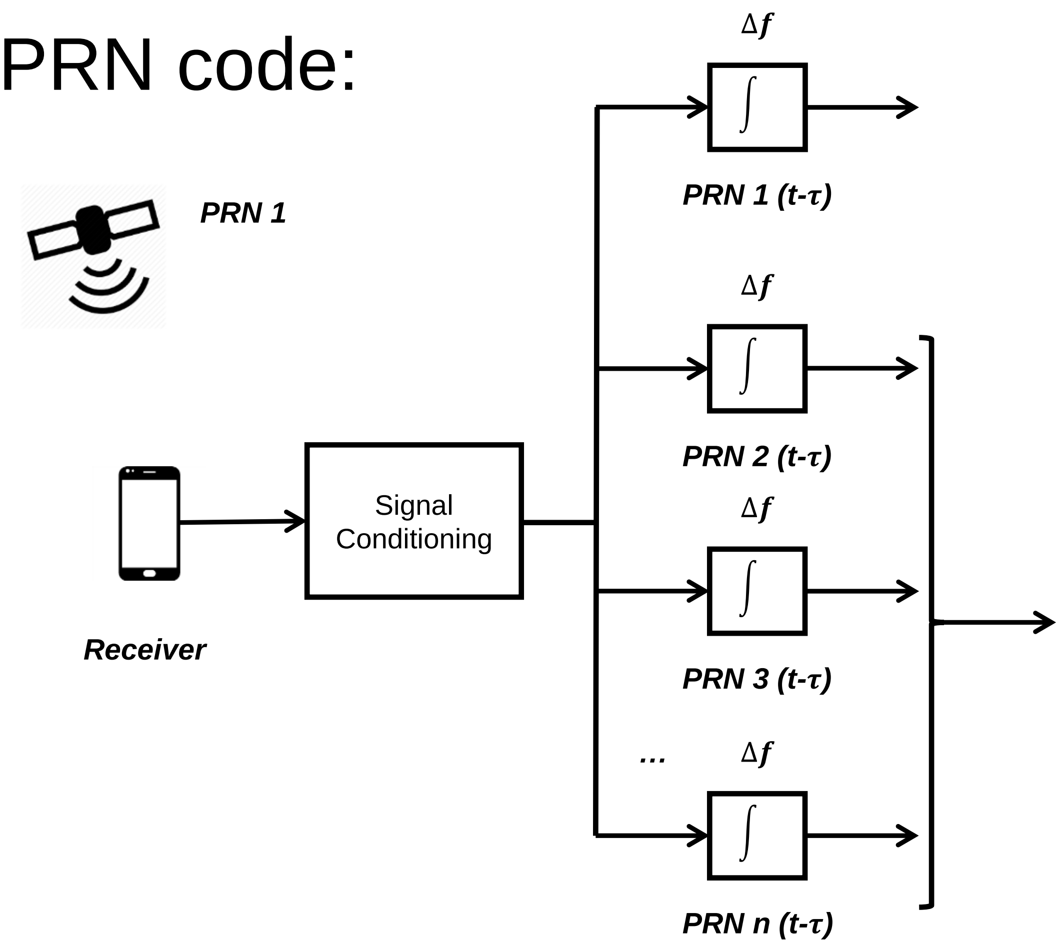
PRN code:

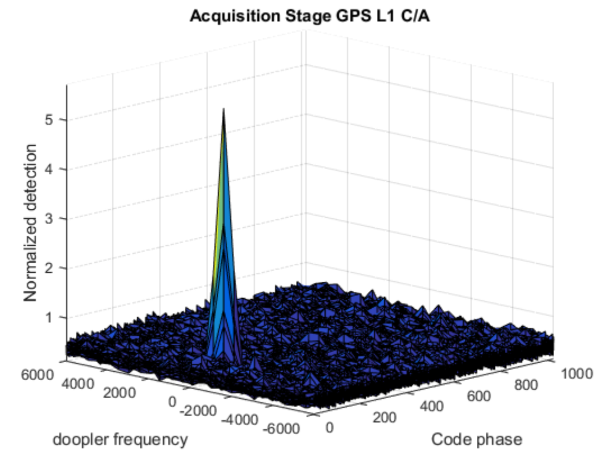

As the pulses in time get shorter, the frequency bandwidth gets larger
f
B_s
B_c
t
T_c
T_s

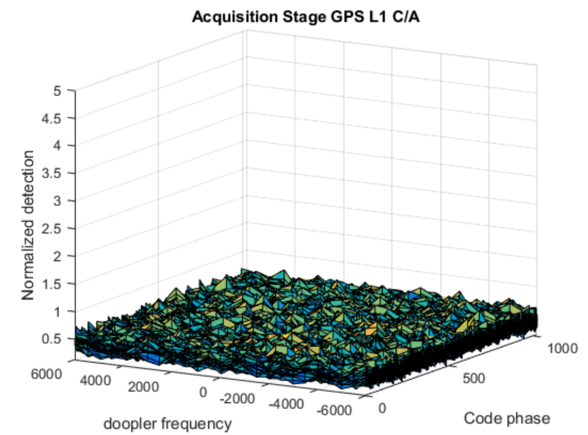

Correlations for PRN1 and PRN17
Cross Corr
Autocorr PRN1
1200
1000
800
600
400
200
0
-200
0
500
1000
1500
2000
2500

Introduction & Background

PRN code:



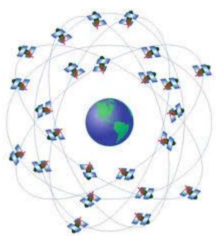




Same modulation?

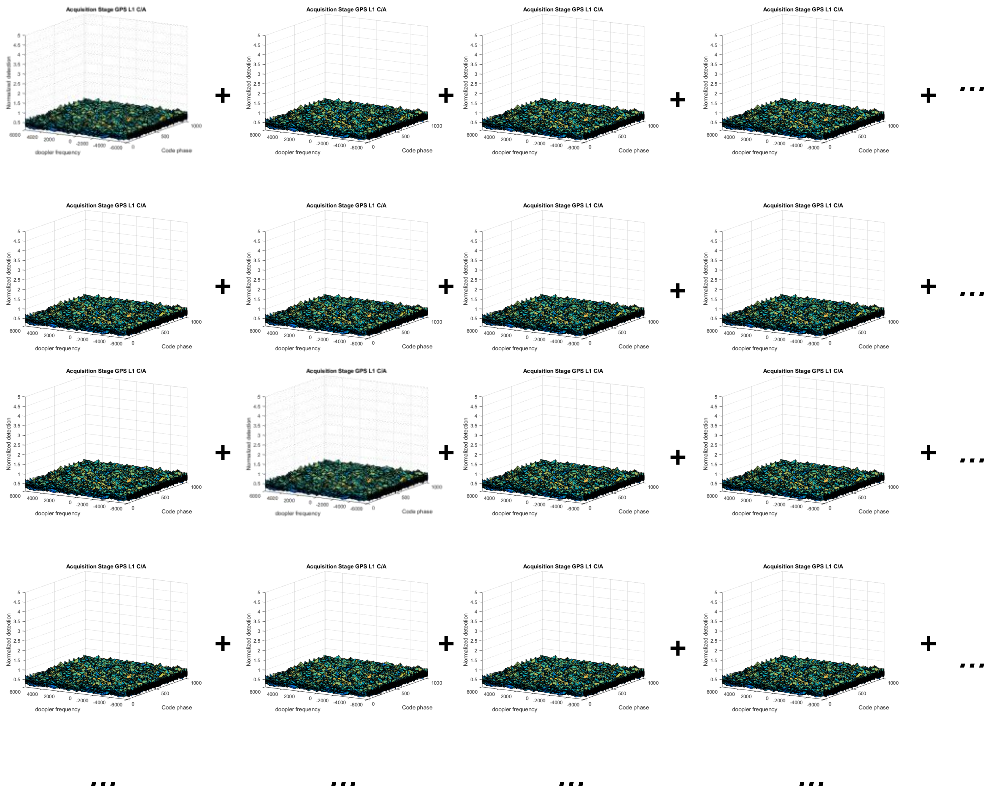
30 Satellite/ per constellation

4 Global constellation



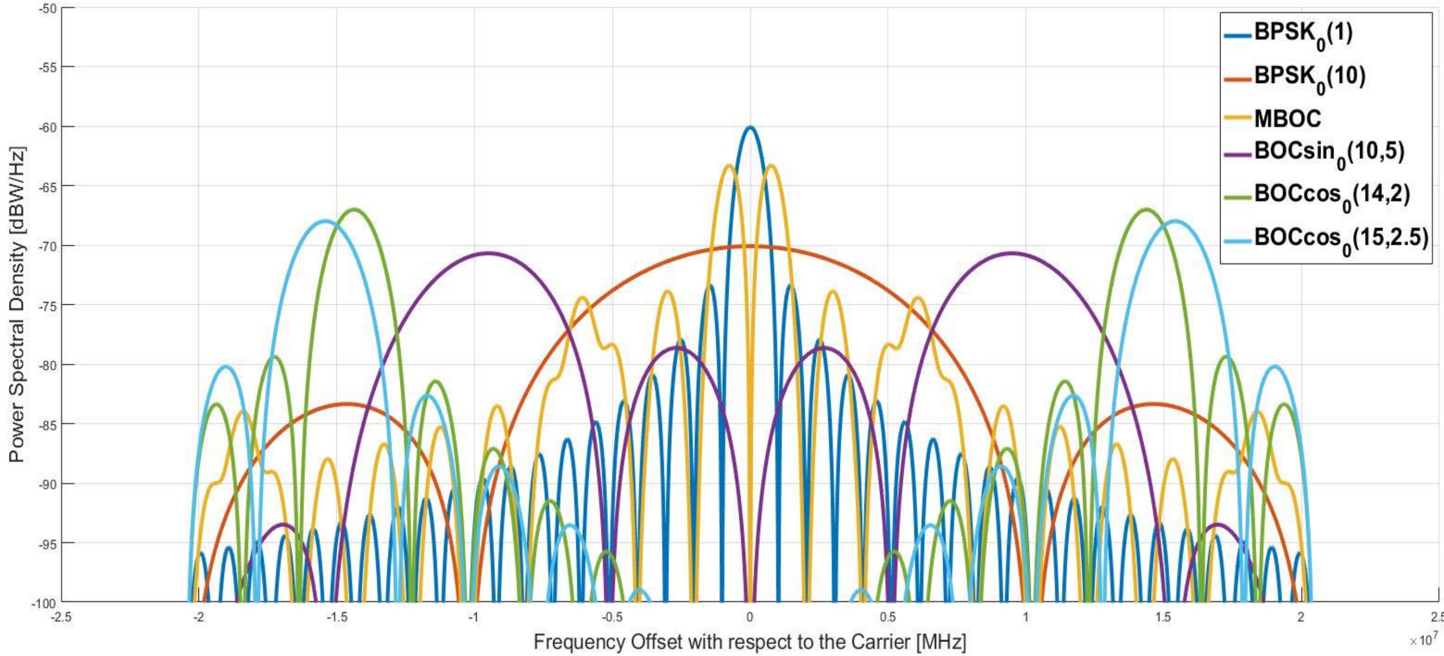
6/7 Signal per band

Number of PRNs?

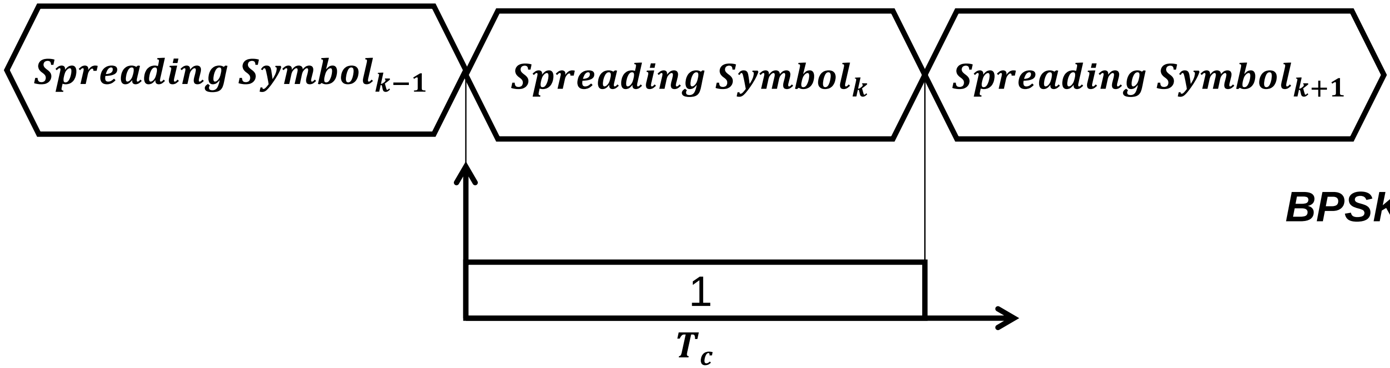


Same modulation?

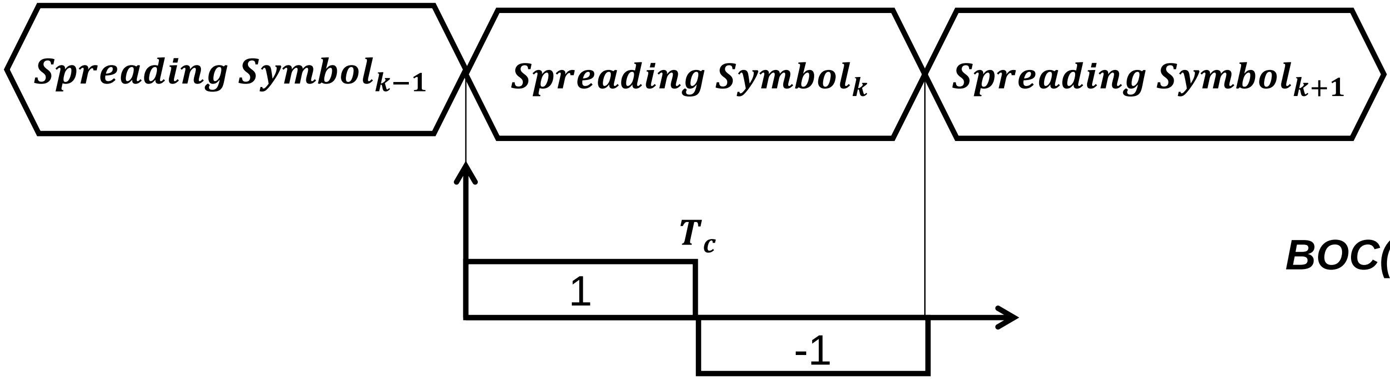
Current L1 bandwidth spectral occupation



Spreading modulation / CDMA signal:

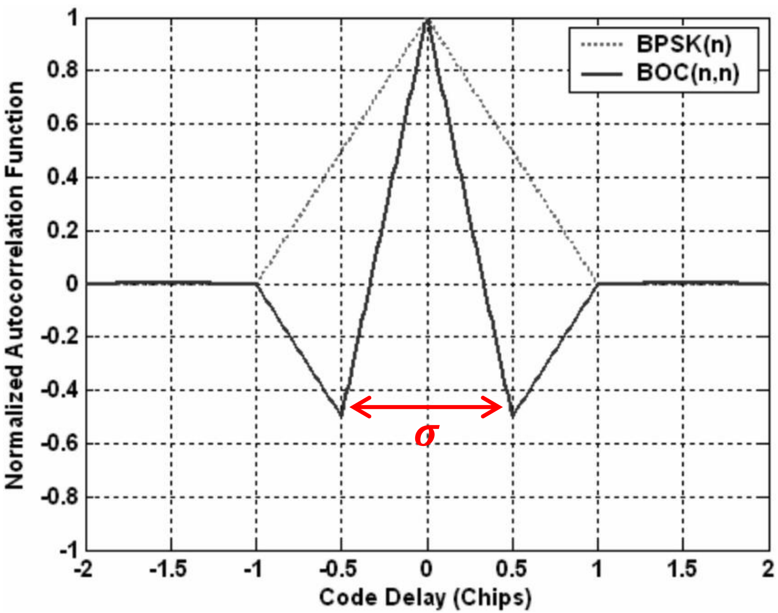


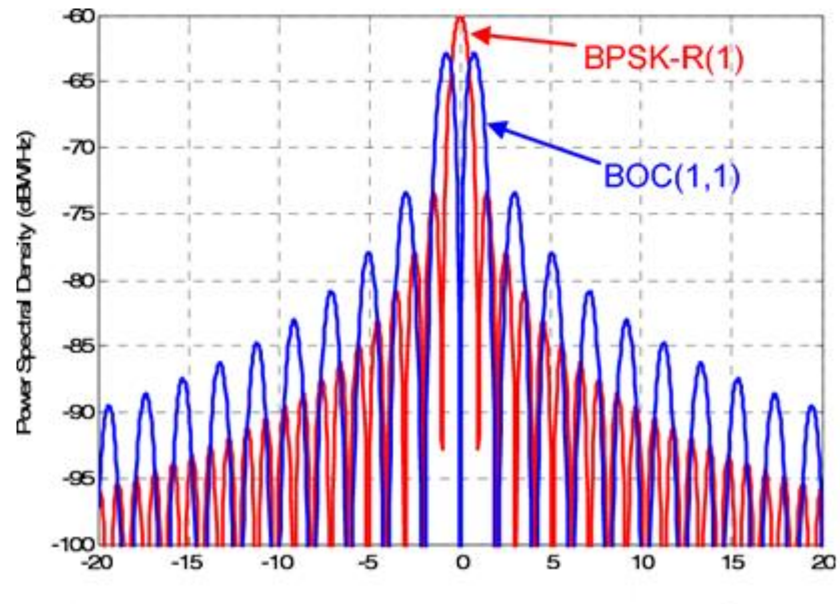
BPSK



BOC(1,1)

Spreading modulation / CDMA signal:





$\boldsymbol{\sigma \propto 1/precision}$

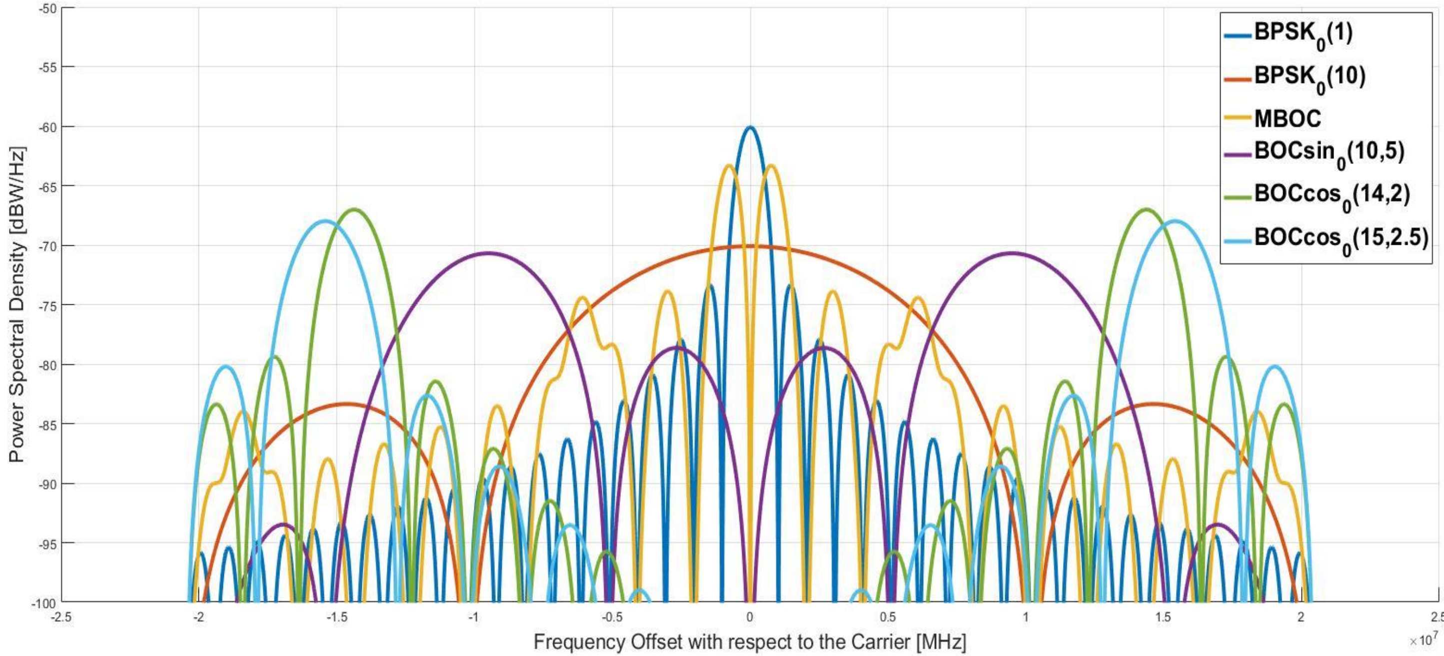
$\boldsymbol{GPS\ C/A}$

$$\Delta t = 0.5\ chip = 9.775171 \cdot 10^{-7}$$

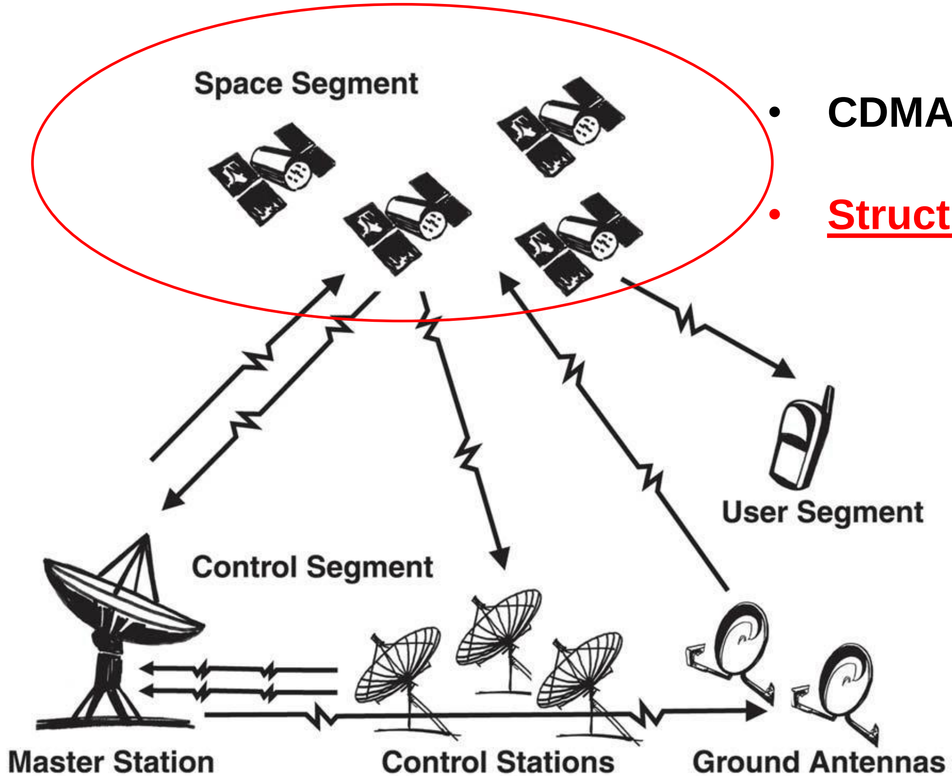
$$\Delta D = \left(9.775171 \cdot 10^{-7}\right) * 3 \cdot 10^{8} = 293{,}255m$$

Spreading modulation / CDMA signal: New Signal

Current L1 bandwidth spectral occupation



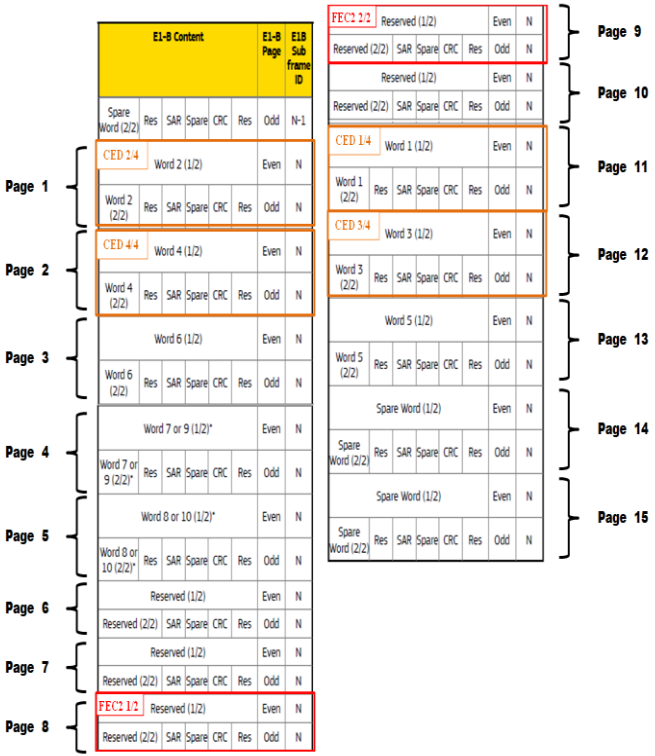
GNSS is 3 Segments system

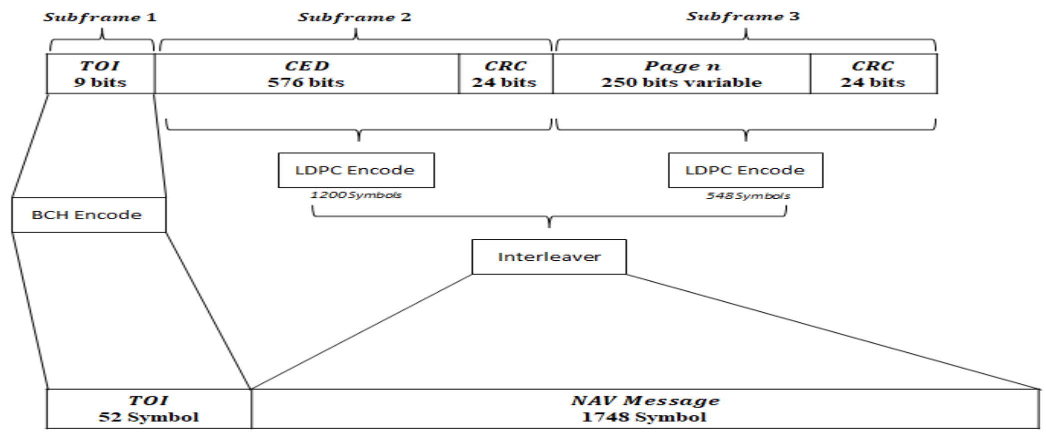


- **CDMA signals**
- **Structure message**

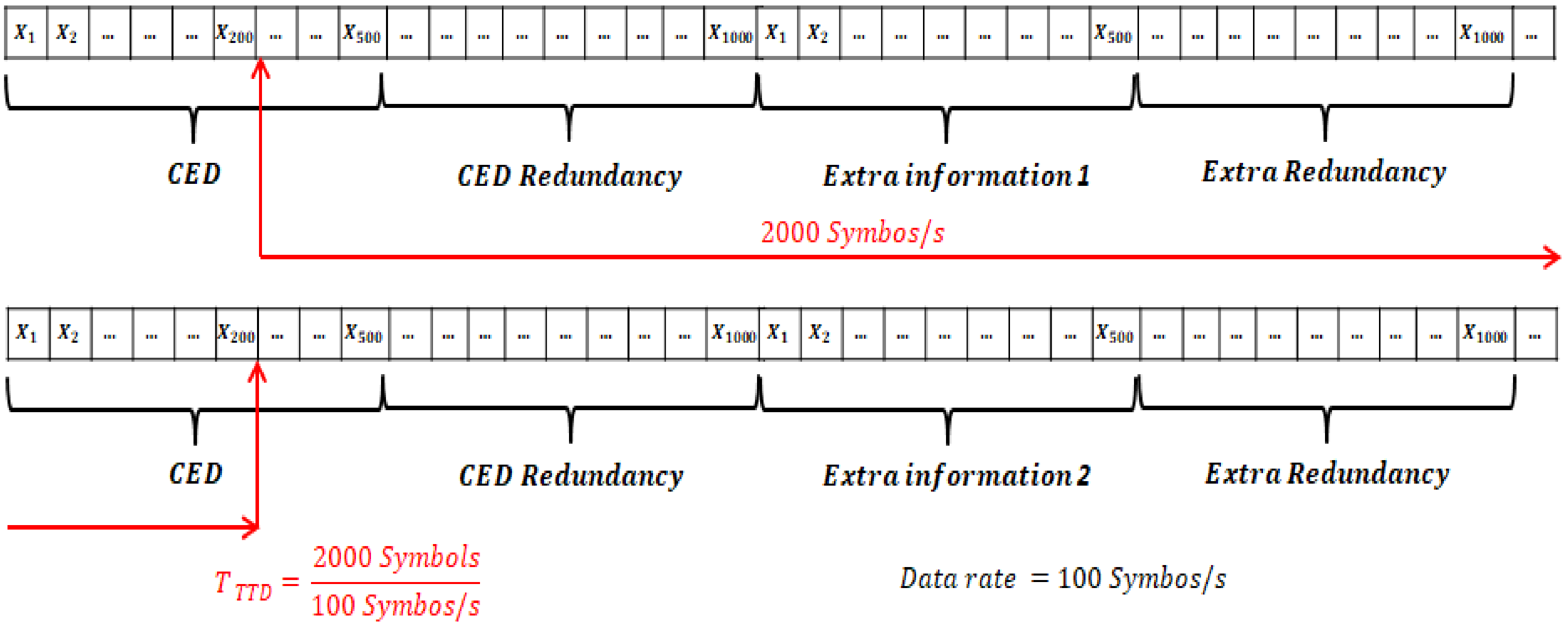
Effect of each satellite

Structure of the message: CED





Structure of the message: Acquisition problem



Today: We are going to design a new signal

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

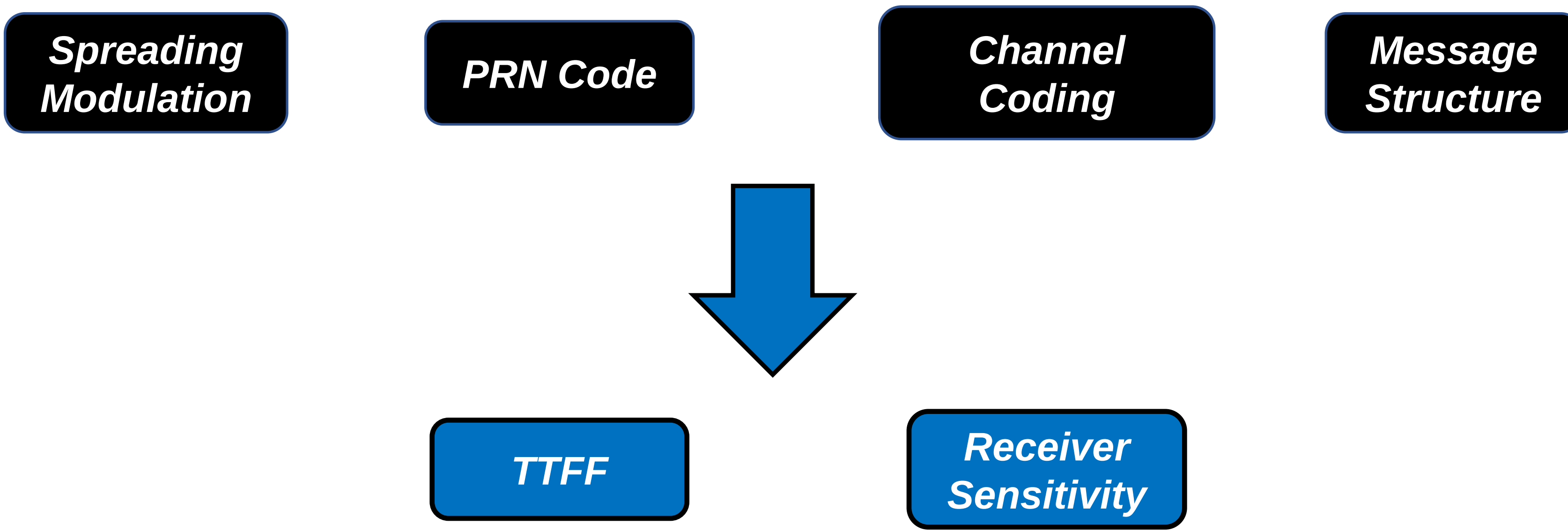
Spreading Modulation

PRN Code

Channel Coding

Message Structure

New signal to improve the TTFF and the receiver sensitivity



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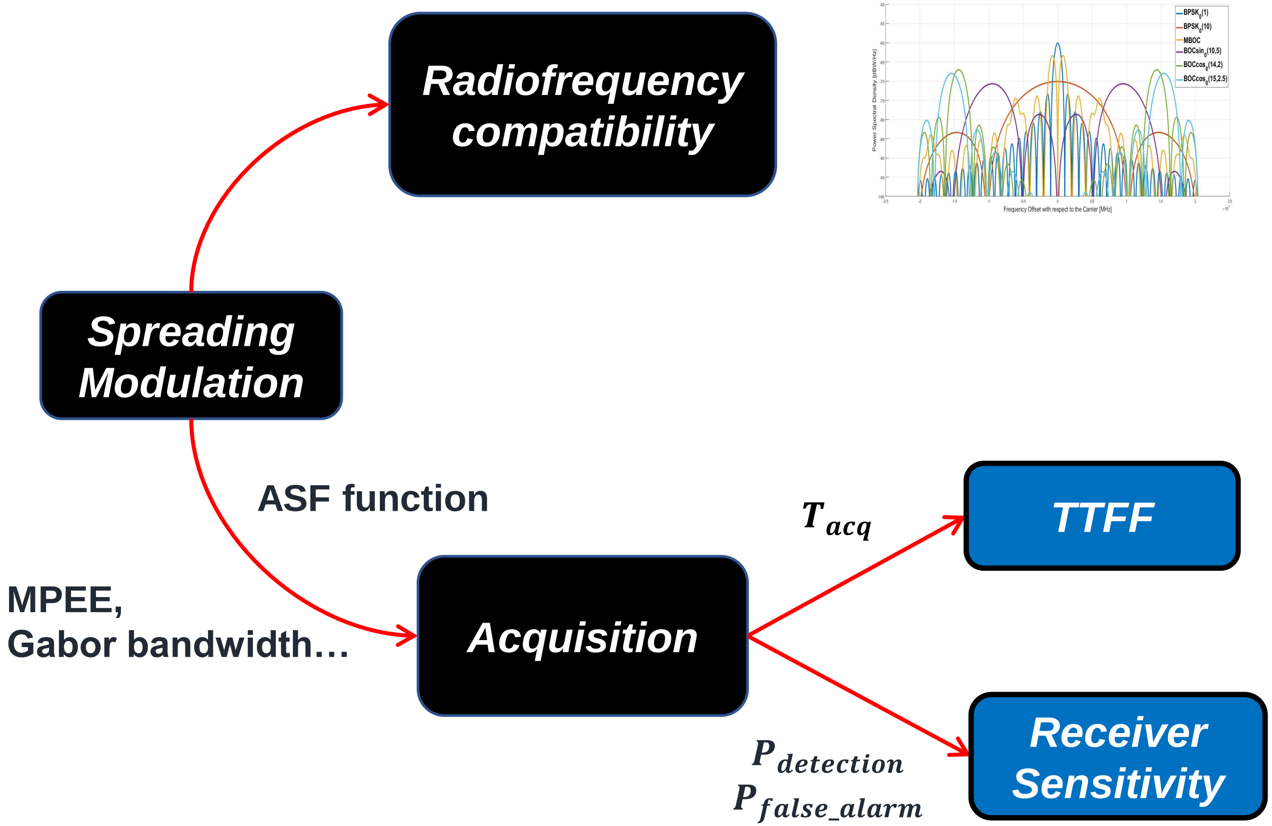
Design new modulation



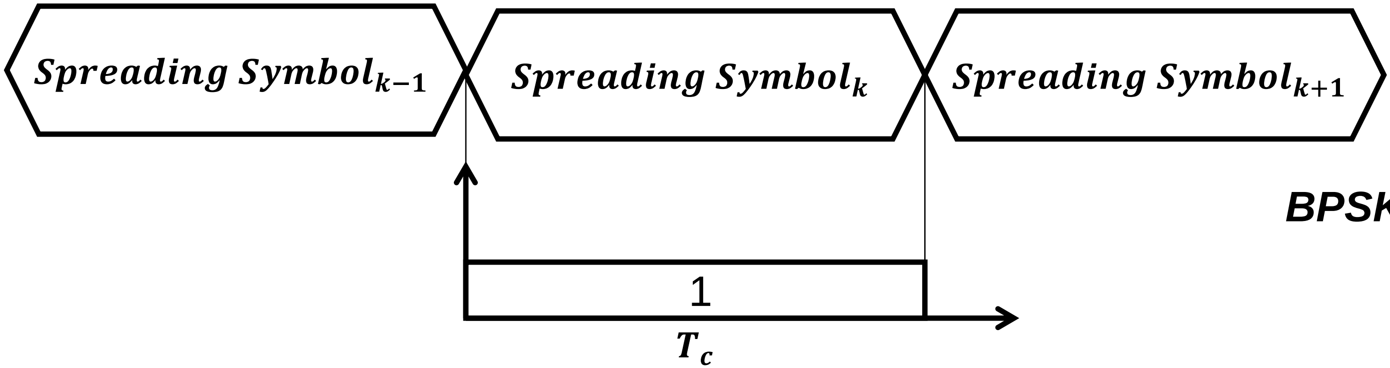
Design new modulation

- Spreading Modulation Criteria for Design

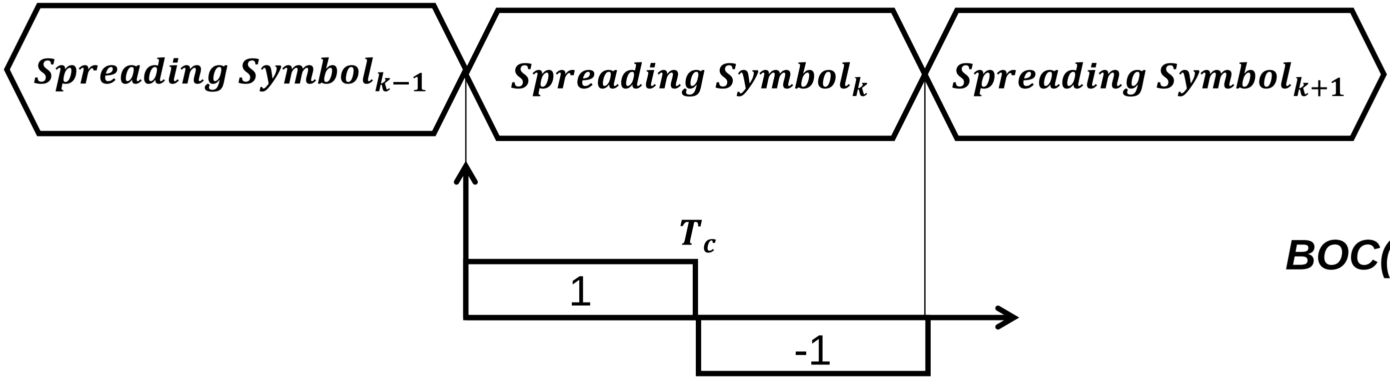
Figure of Merit	Criteria
Radio Frequency Compatibility	SSC
Correlation Properties	ACF
Resistance Against Multipath	MPEE
Ranging Performance	Gabor bandwidth
Anti-Jamming Capability	Demodulation & anti-jamming of narrowband Code tracking & anti-jamming of narrowband Demodulation & anti-jamming of matched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

Design new modulation

- Standard spreading modulations:



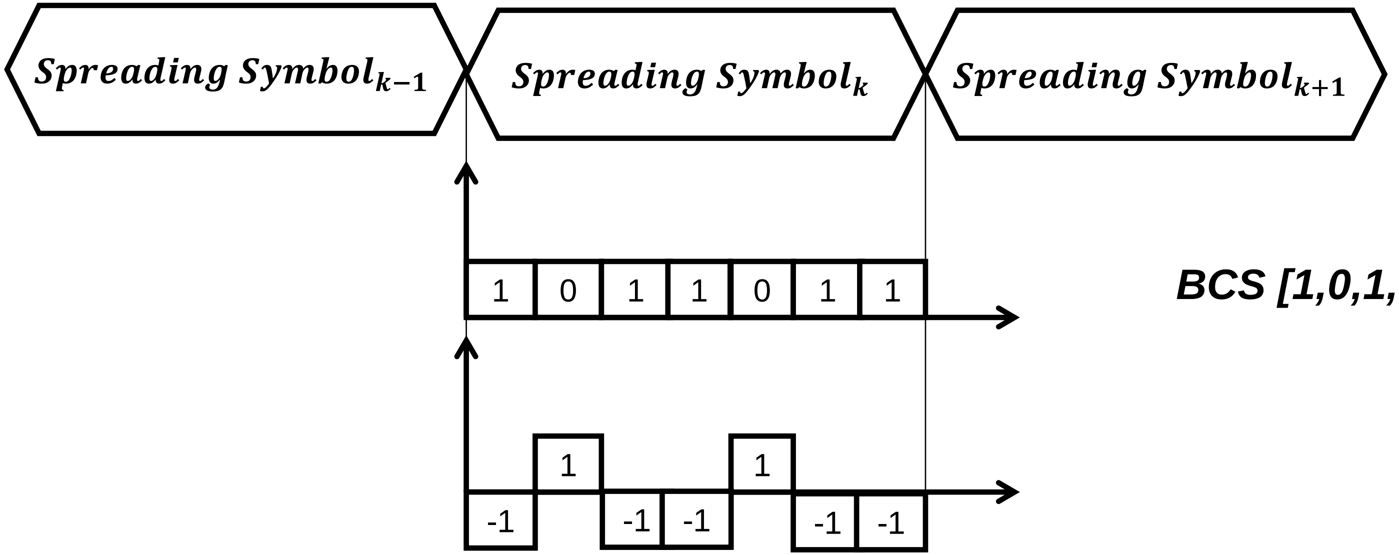
BPSK



BOC(1,1)

Design new modulation

- Binary Coded Symbol (BCS)
  - Spreading modulation candidate



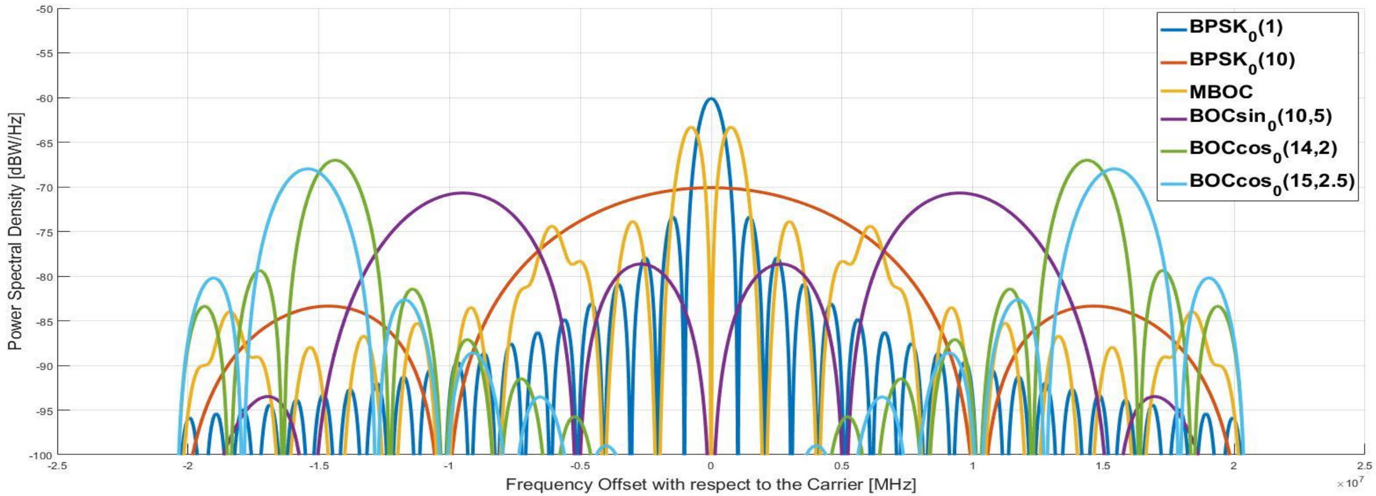
BCS [1,0,1,1,0,1,1]

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**

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

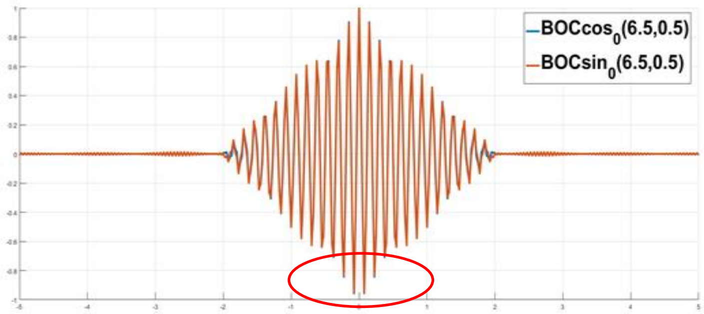
Current signals

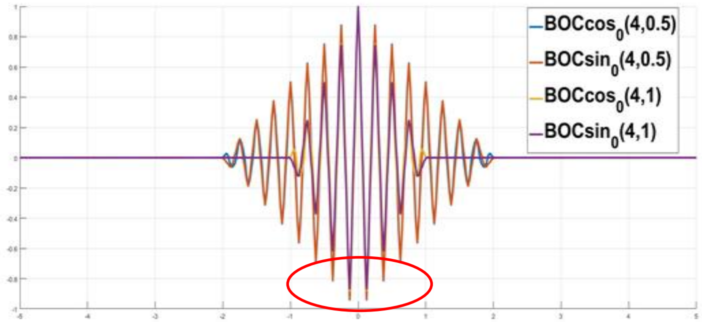
More interference

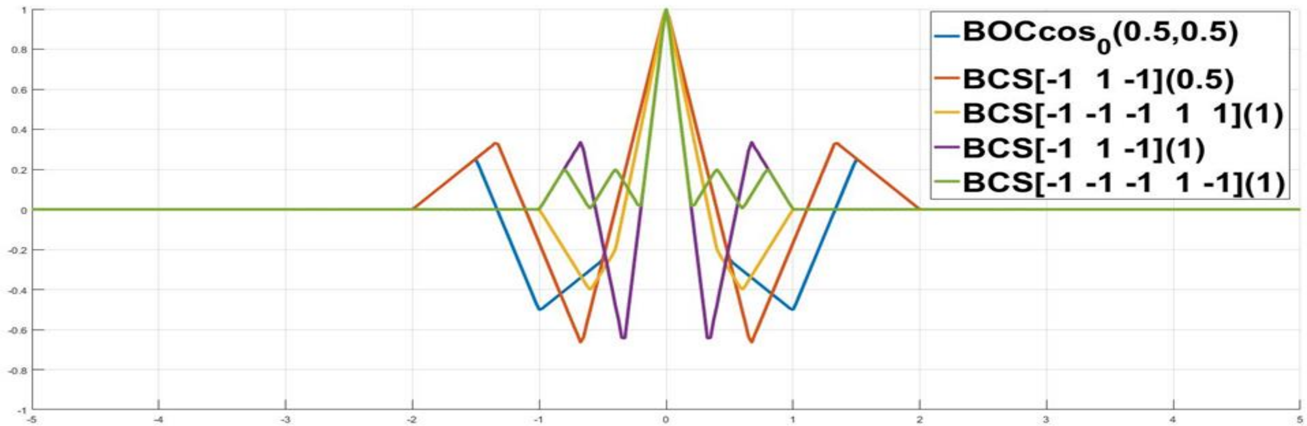
Less interference

Design new modulation

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



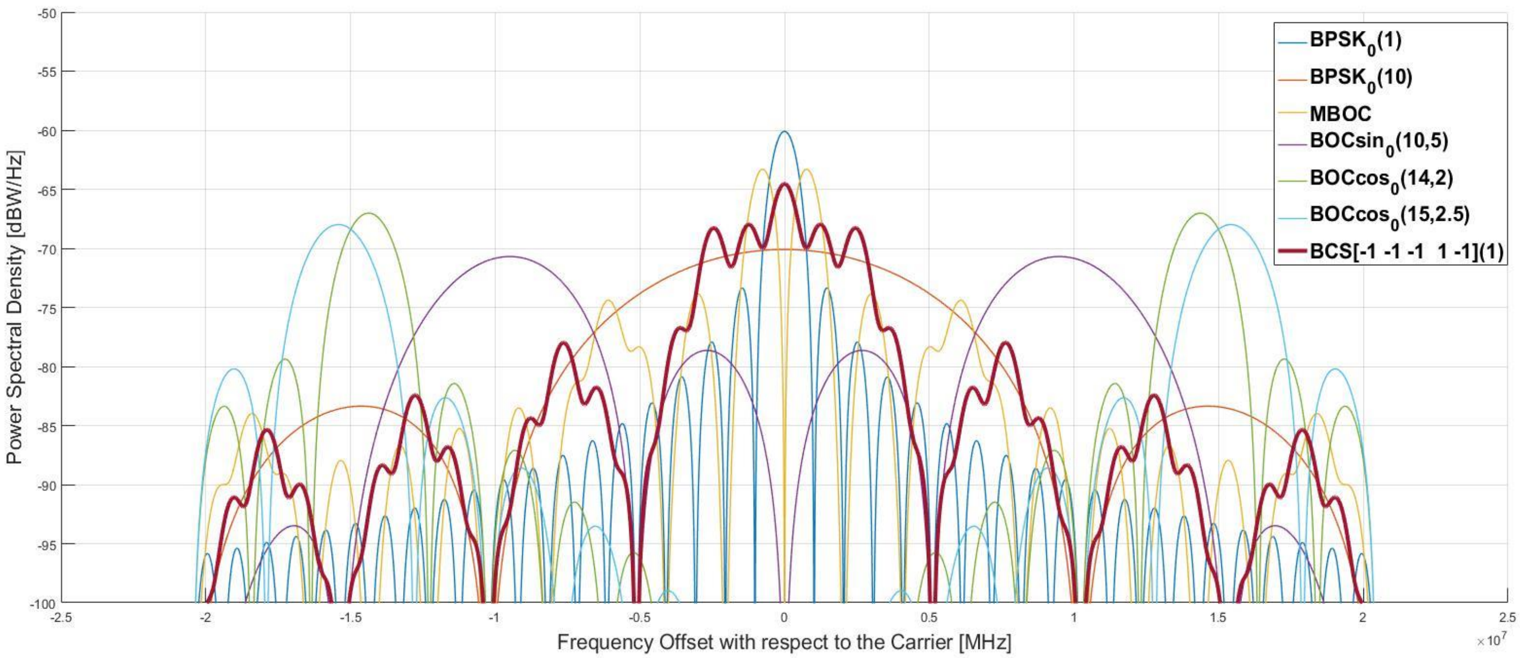




Design new modulation

- Evaluation of the spreading modulation candidates

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



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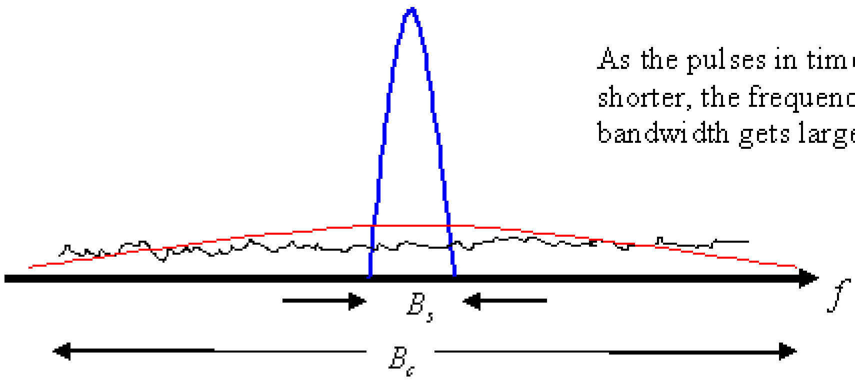
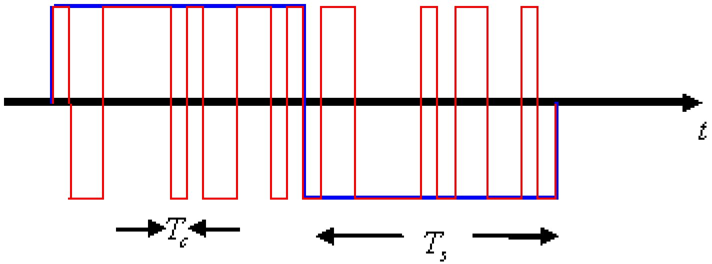
CDMA signal:



If at the receiver you know the PRN:

- Robust against narrowband interference
- Less Intra-system Interference

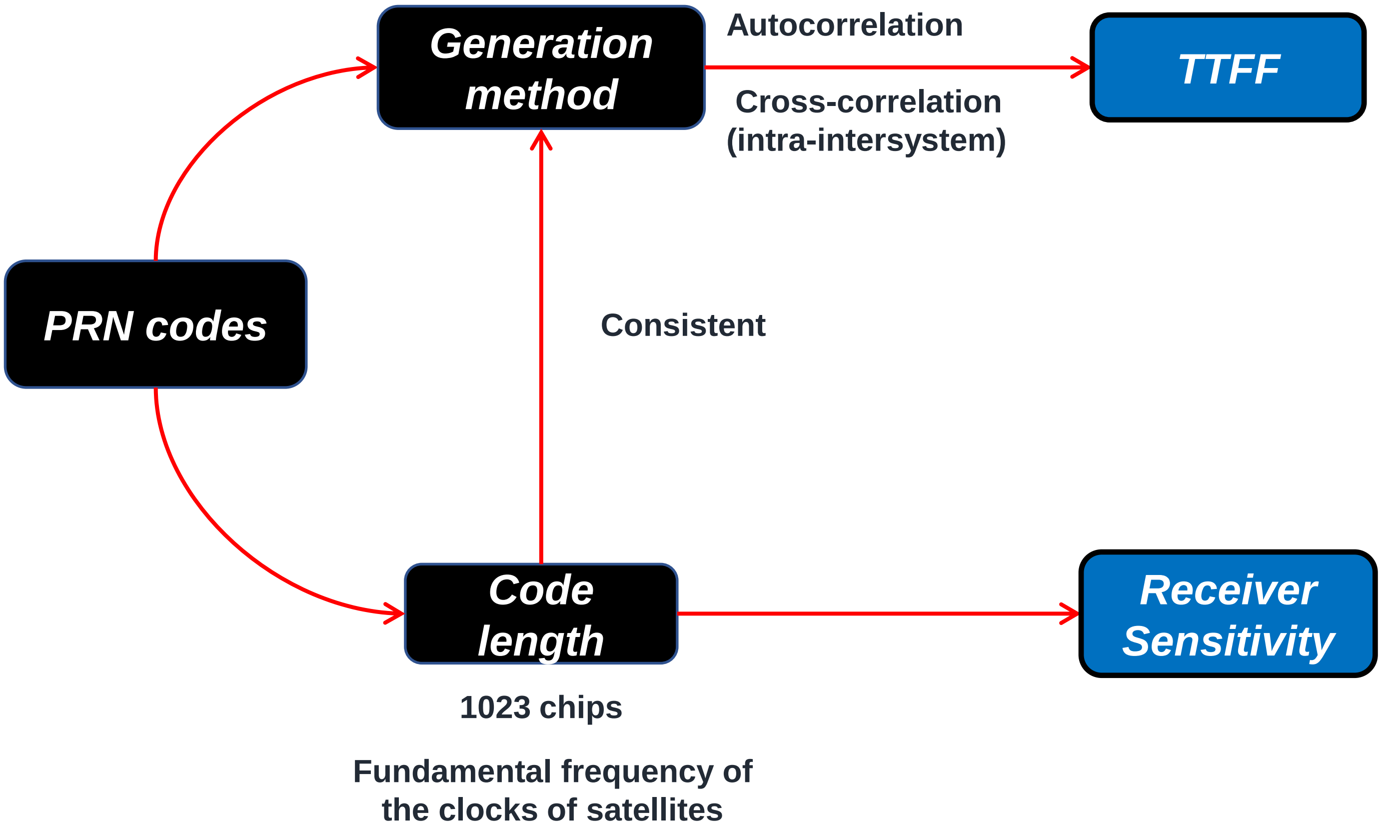
Pseudo Random Noise (PRN) sequence



GPS: Gold codes

- Good Autocorrelation
- Good Cross-correlation

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	$ELW = 10\log(\frac{1}{n} \sum_{\substack{k=-\frac{n}{2} \\ A_k>\sqrt{n}}}^{\frac{n}{2}} (A_k - \sqrt{n})^2)$

Design new PRN codes

- PRN codes assessment

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

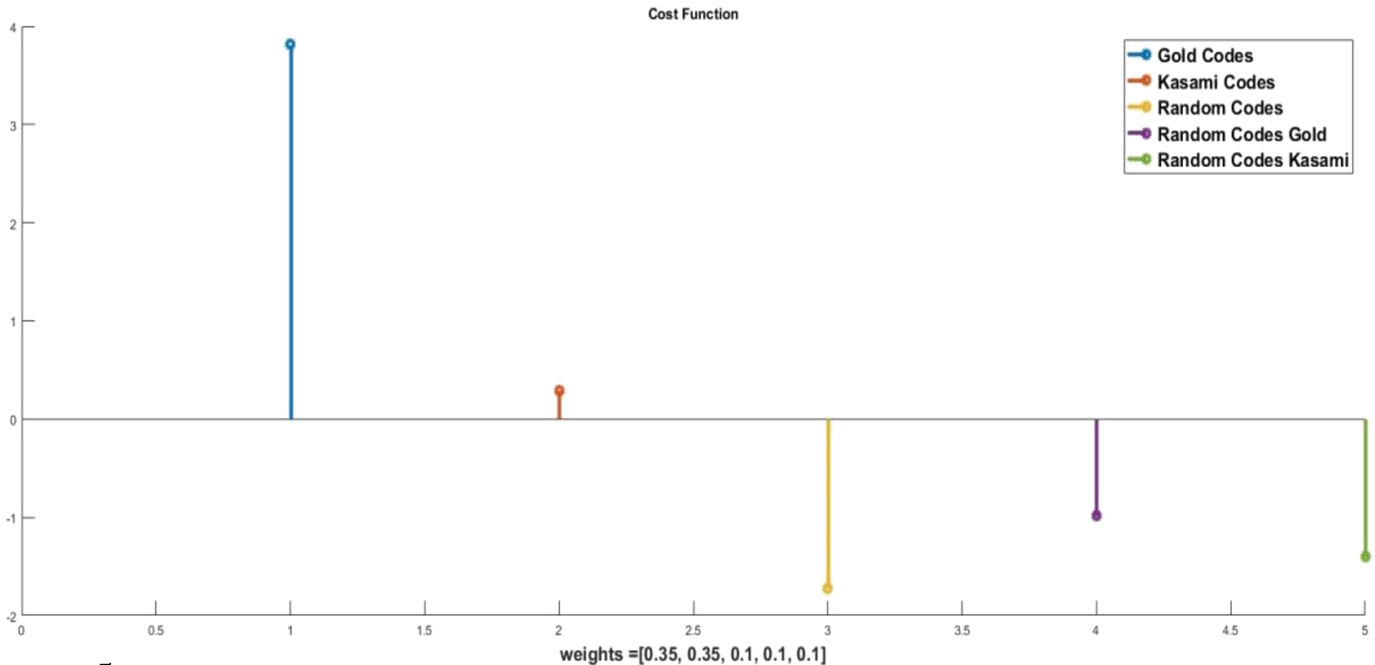
Candidate
Gold Codes
Kasami Codes
Random Sequences-Genetic algorithm (GA)
Random Sequence Init Gold Codes (GA)
Random Sequence Init Kasami Codes (GA)

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

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

Design new PRN codes

- PRN codes assessment



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

$$\boldsymbol{Weight} = [\mathbf{0.35, 0.35\ 0.1, 0.1, 0.1}]$$

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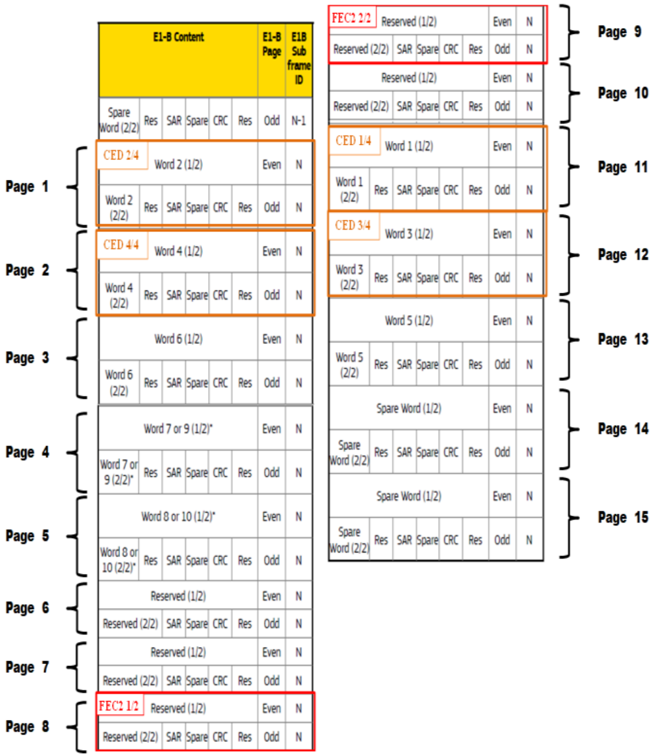
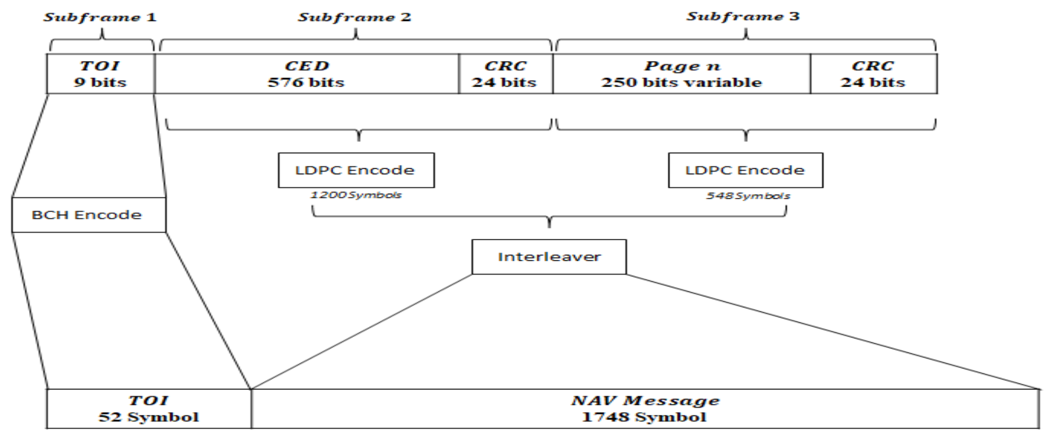
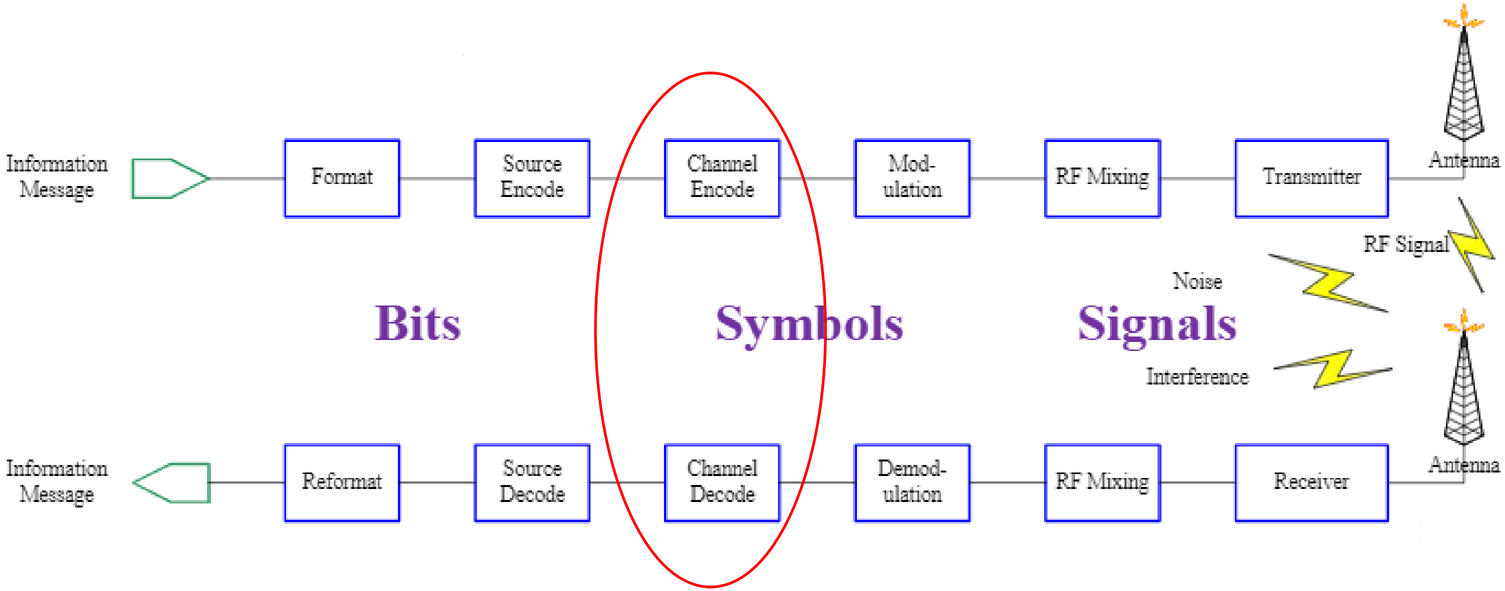
Structure of the message: CED





Introduction to channel coding:



Extra data to enhance the reliability of a communication system

Introduction to channel coding:

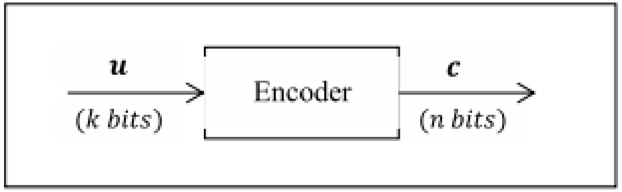


Figure 31 : Classical encoder representation

$$u = (u_0, u_1, \dots, u_{k-1})$$

$$c = (c_0, c_1, \dots, c_{n-1})$$

Generator Matrix G_β:

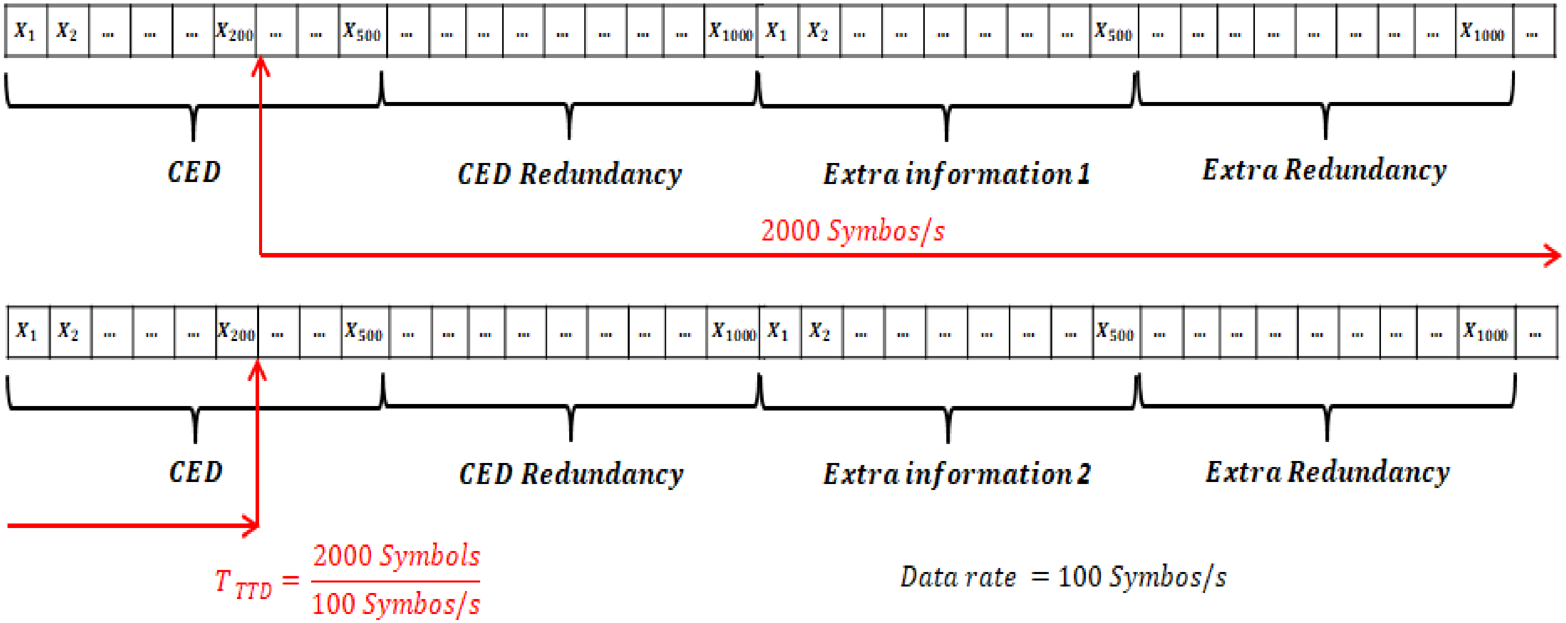
Parity check matrix H_β:

$$c = u \cdot G_\beta$$

$$G_\beta \cdot {H_\beta}^T = 0$$

$$c \cdot {H_\beta}^T = 0$$

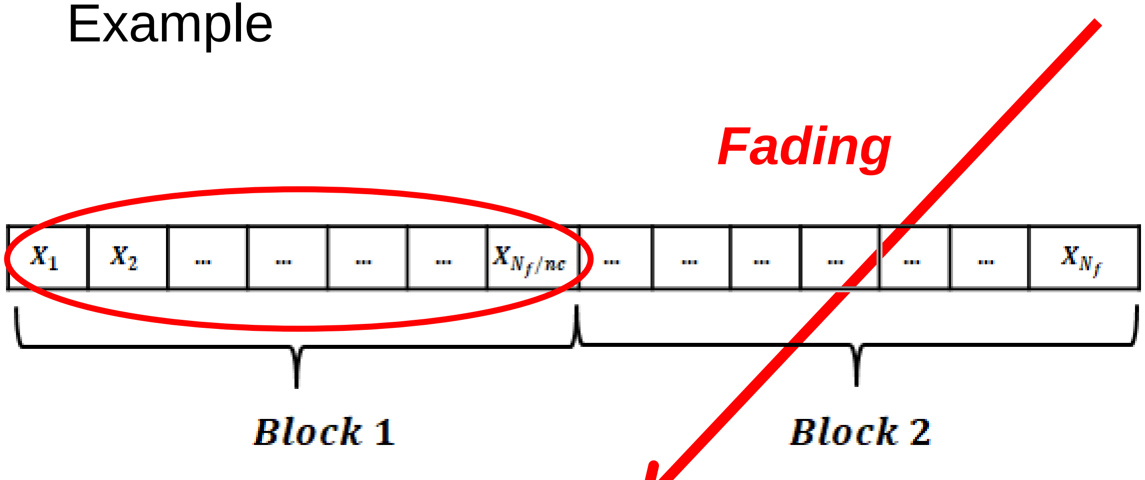
Structure of the message: Acquisition



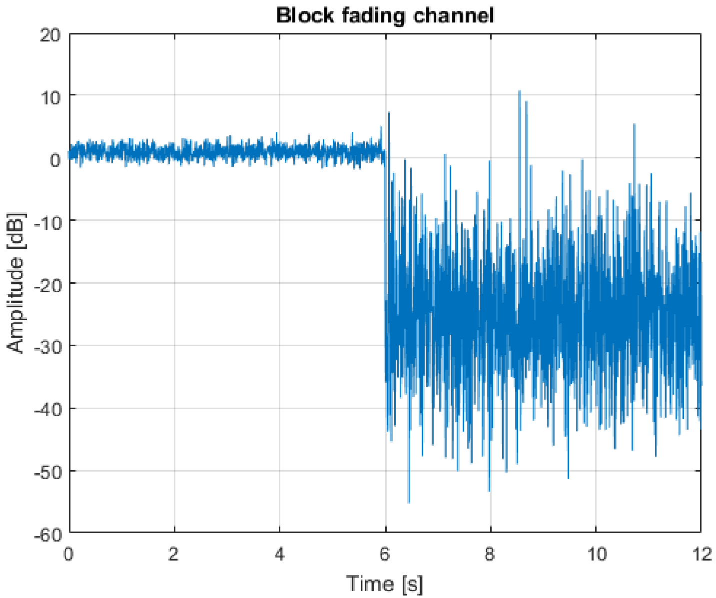
Find a co-design where the CED can be decoded even if some part of the message has not been received.

Block fading with erasure channel model

Example



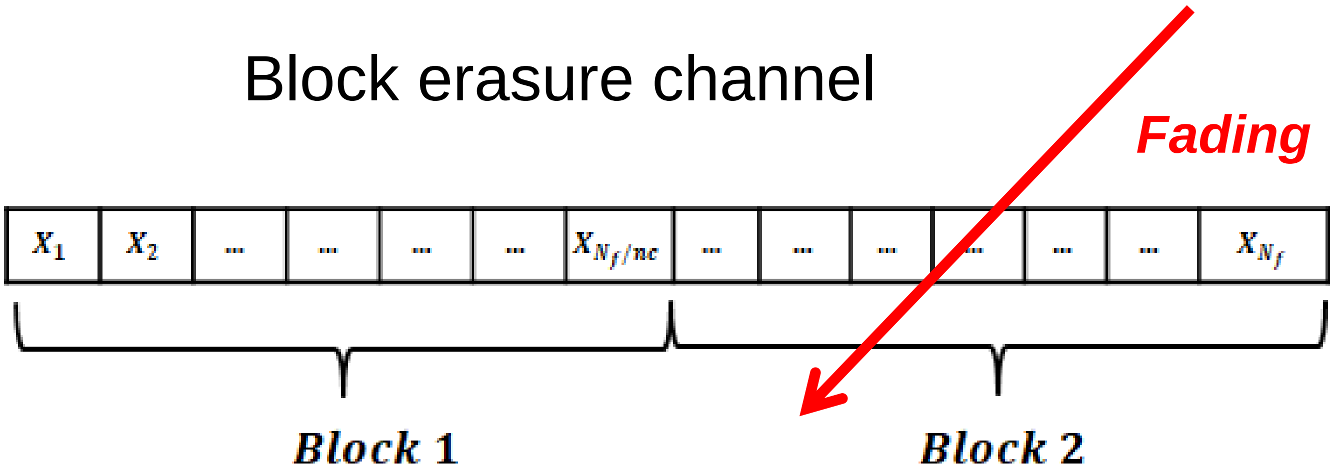
We recover the information



Amplitude of block fading channel

Block fading with erasure channel model

Block erasure channel

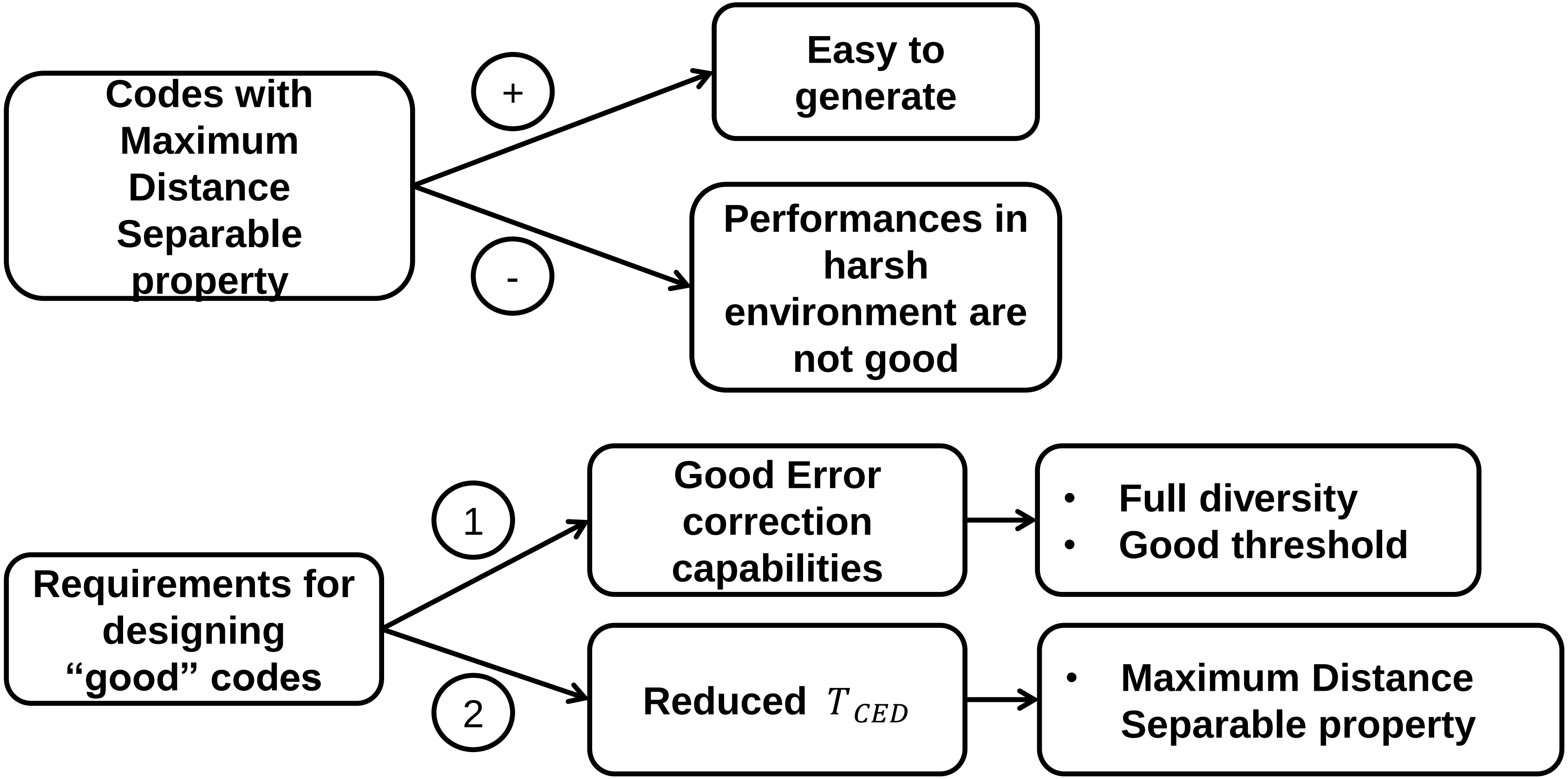


Fading = not have already received the information

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
- Protograph Root codes

LD-MDS codes

Example:

1200

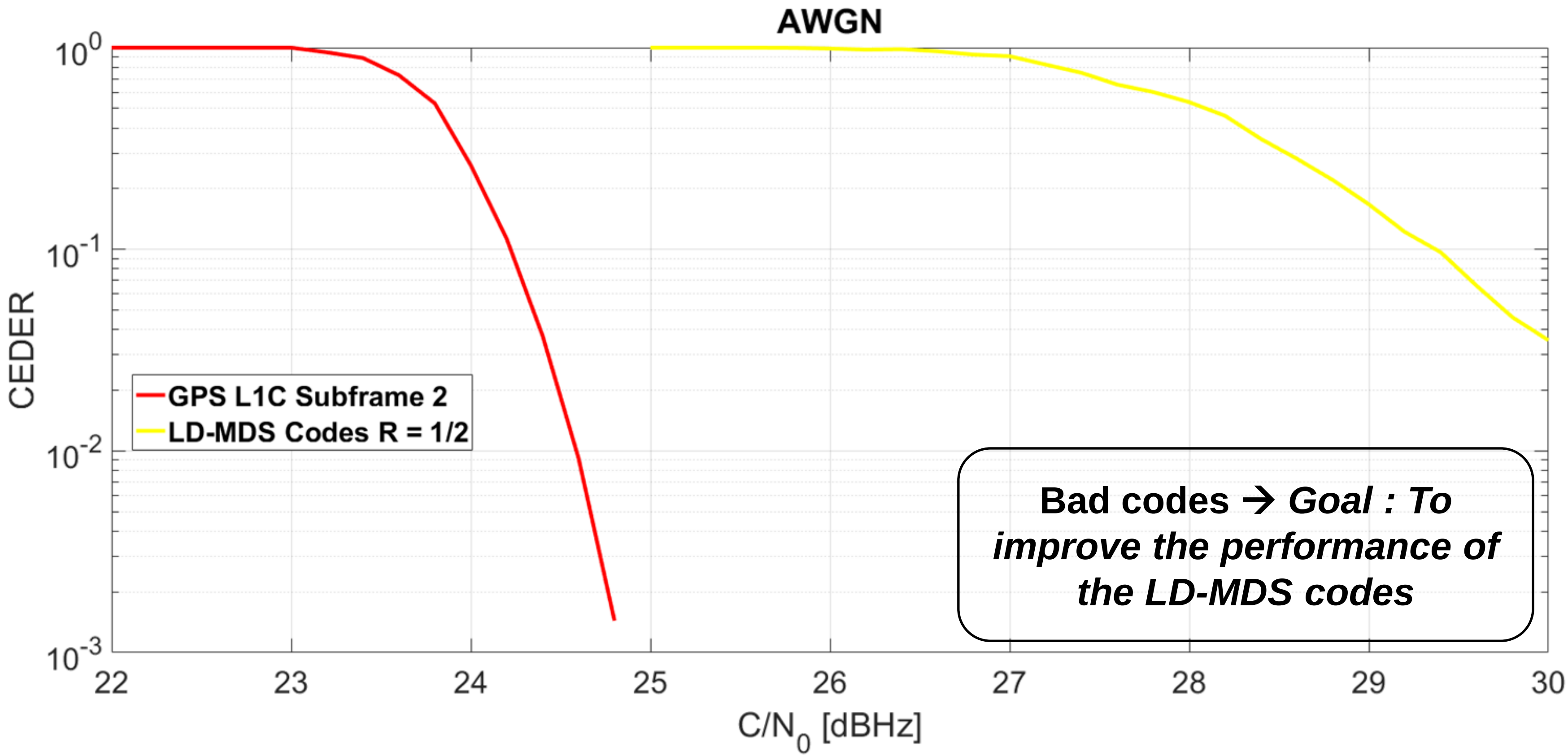
$$H_\beta = \begin{pmatrix} I & I & I & 0 \\ \beta_1 & \beta_2 & 0 & I \end{pmatrix}$$

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
10^0
10^{-1}
10^{-2}
10^{-3}
22
23
24
25
26
27
28
29
30
C/N$_0$ [dBHz]
GPS L1C Subframe 2
LD-MDS Codes R = 1/2
Bad codes → Goal : To improve the performance of the LD-MDS codes

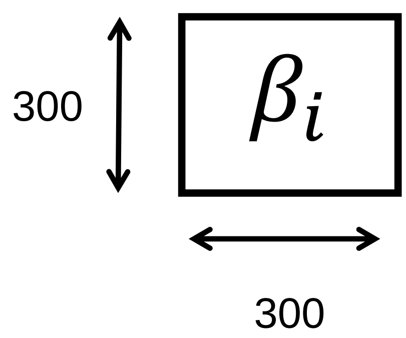
MDS codes

Example:

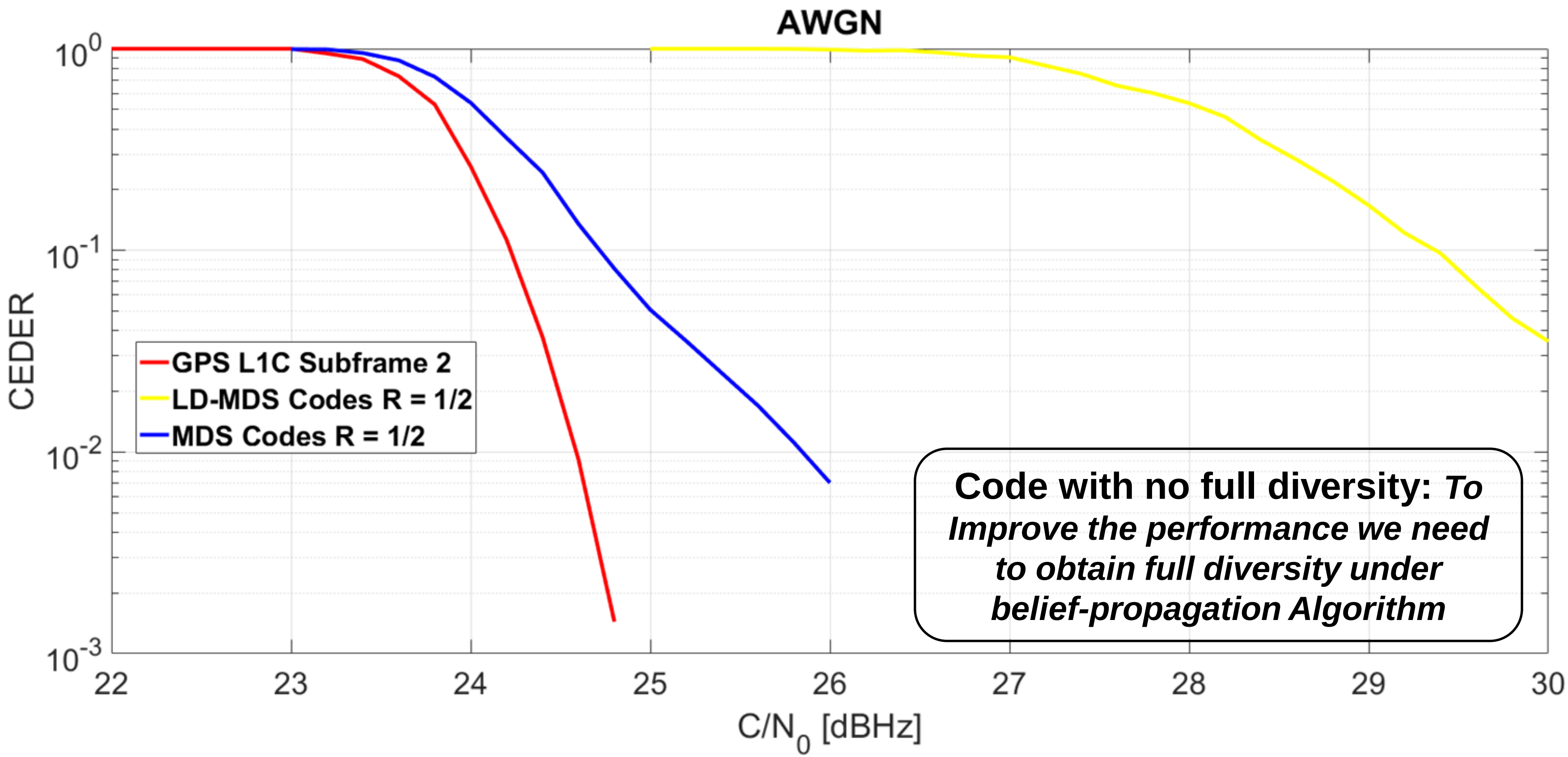
1200

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

600



MDS codes

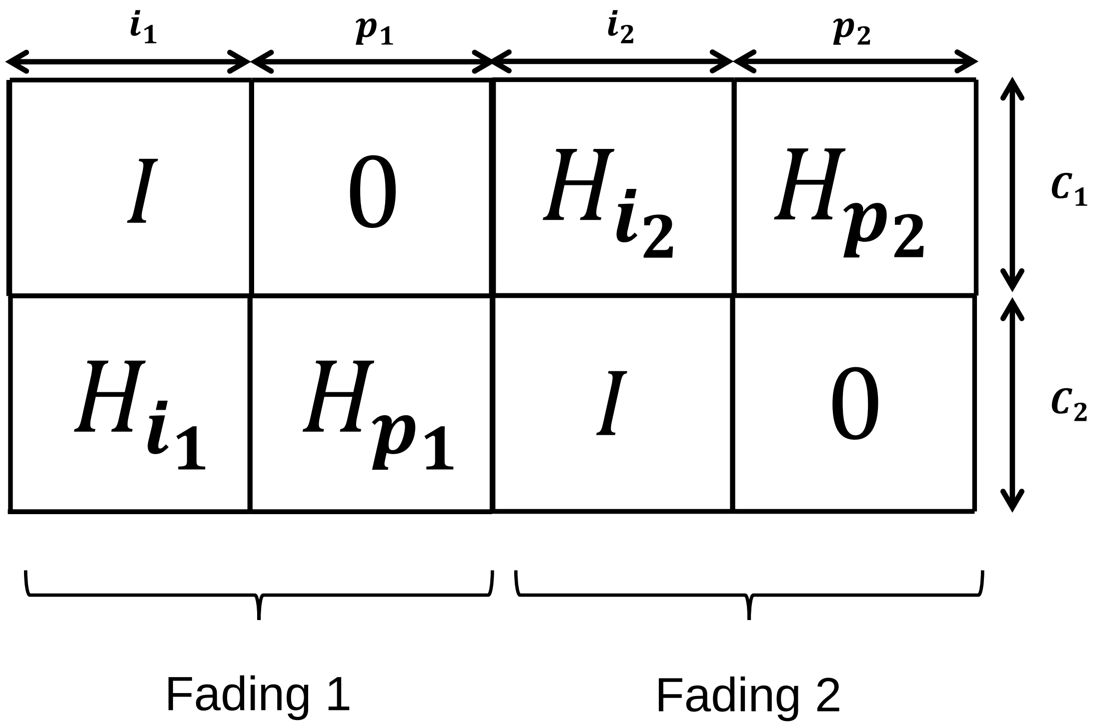


Code with no full diversity: ***To Improve the performance we need to obtain full diversity under belief-propagation Algorithm***

Regular-Root codes

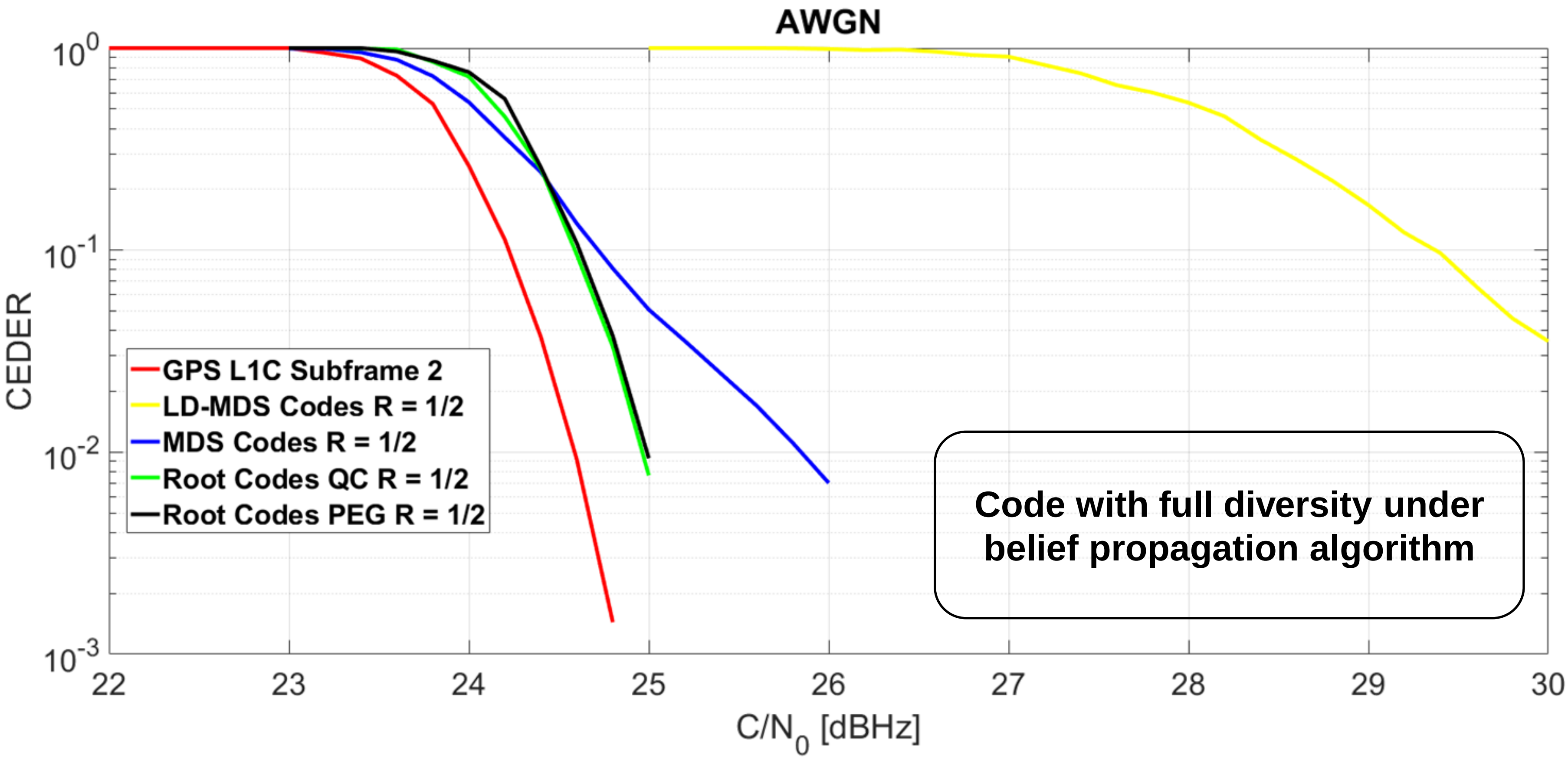
They have full diversity property under BP algorithm

Example:



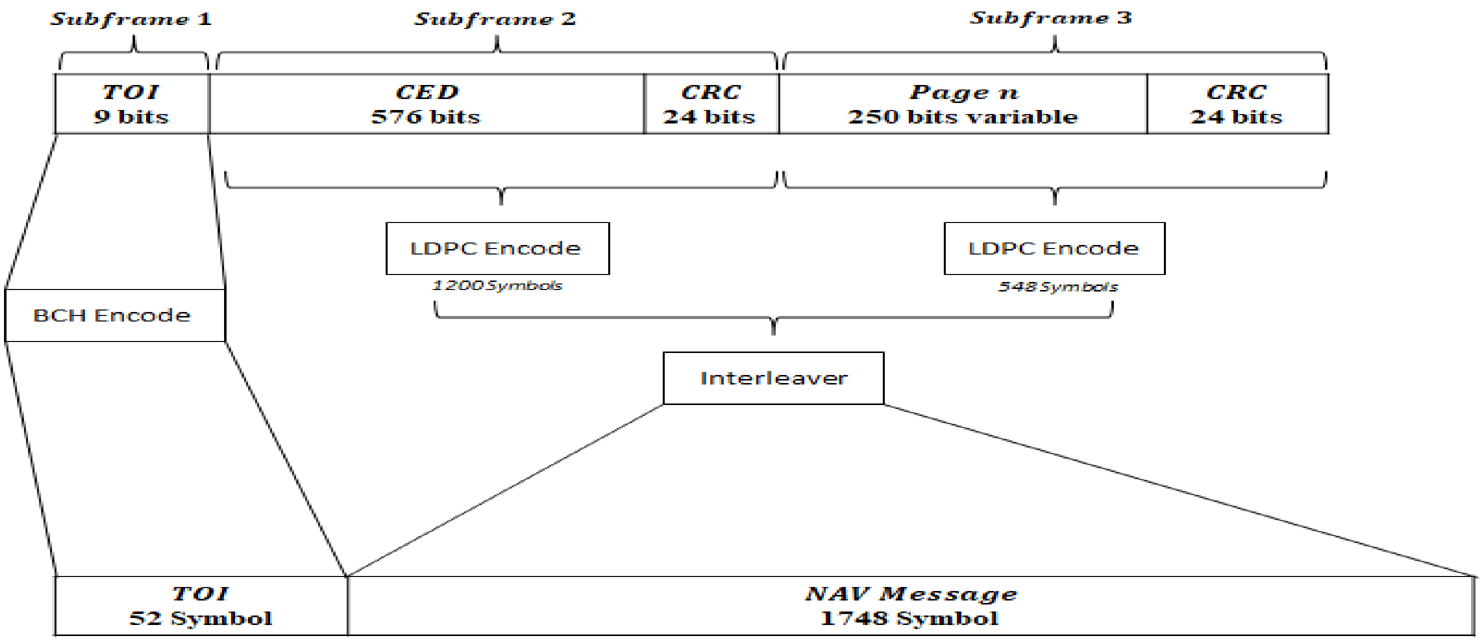
We don't need erasure algorithm → Running BP algorithm, we retrieve the information

Regular-Root codes



Results

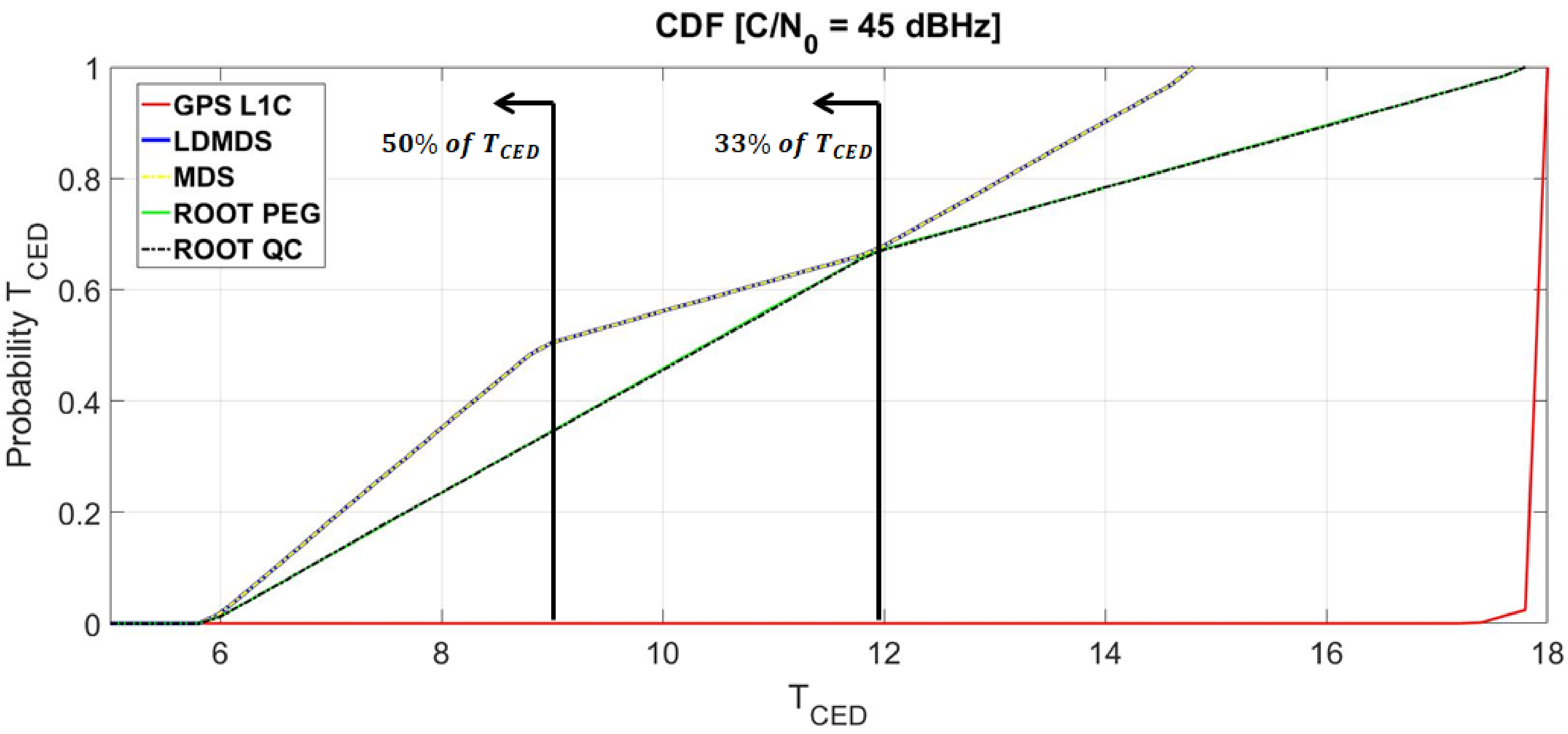
Cumulative Distribution Function (CDF)



17,48 S

Results

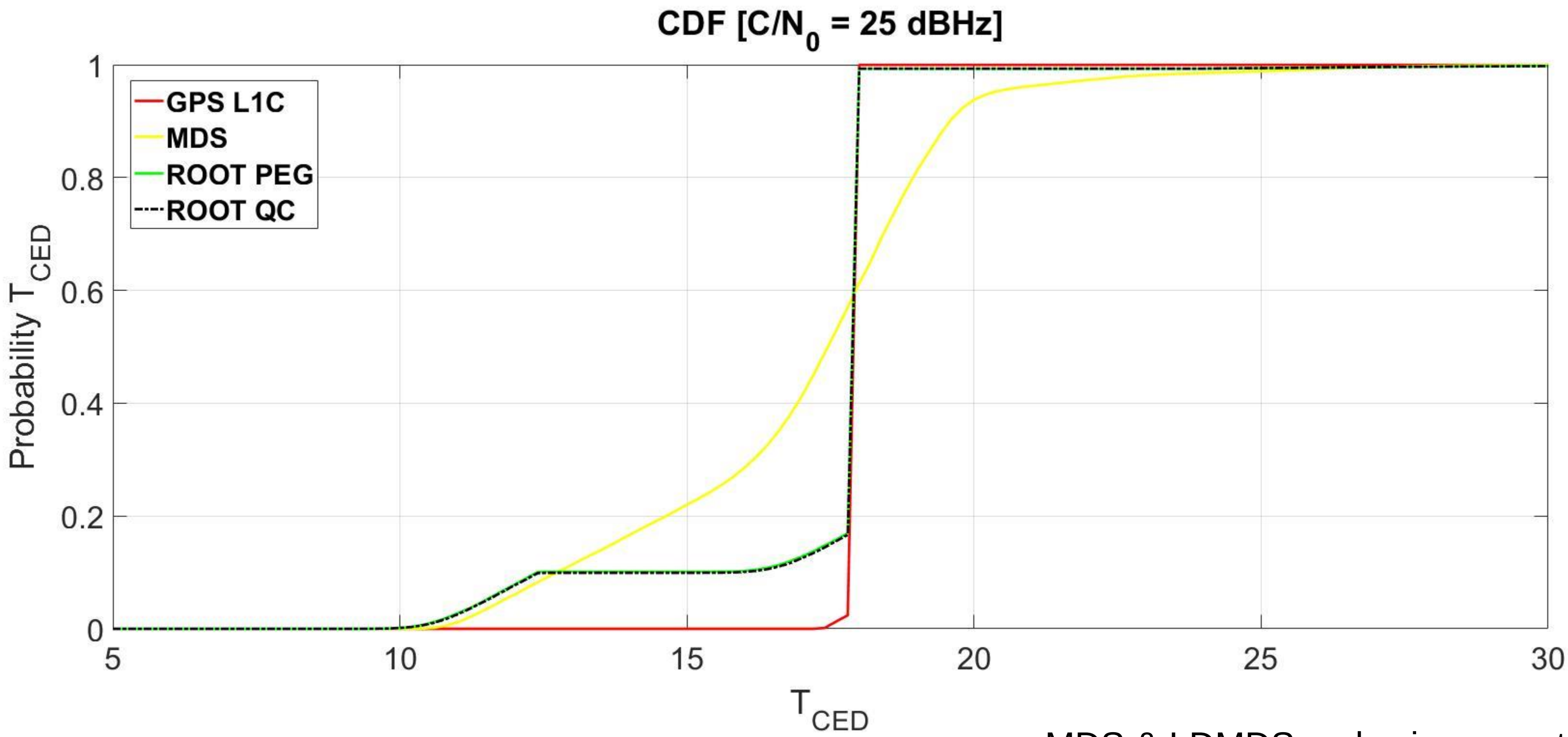
Cumulative Distribution Function (CDF)



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

Results

Cumulative Distribution Function (CDF)

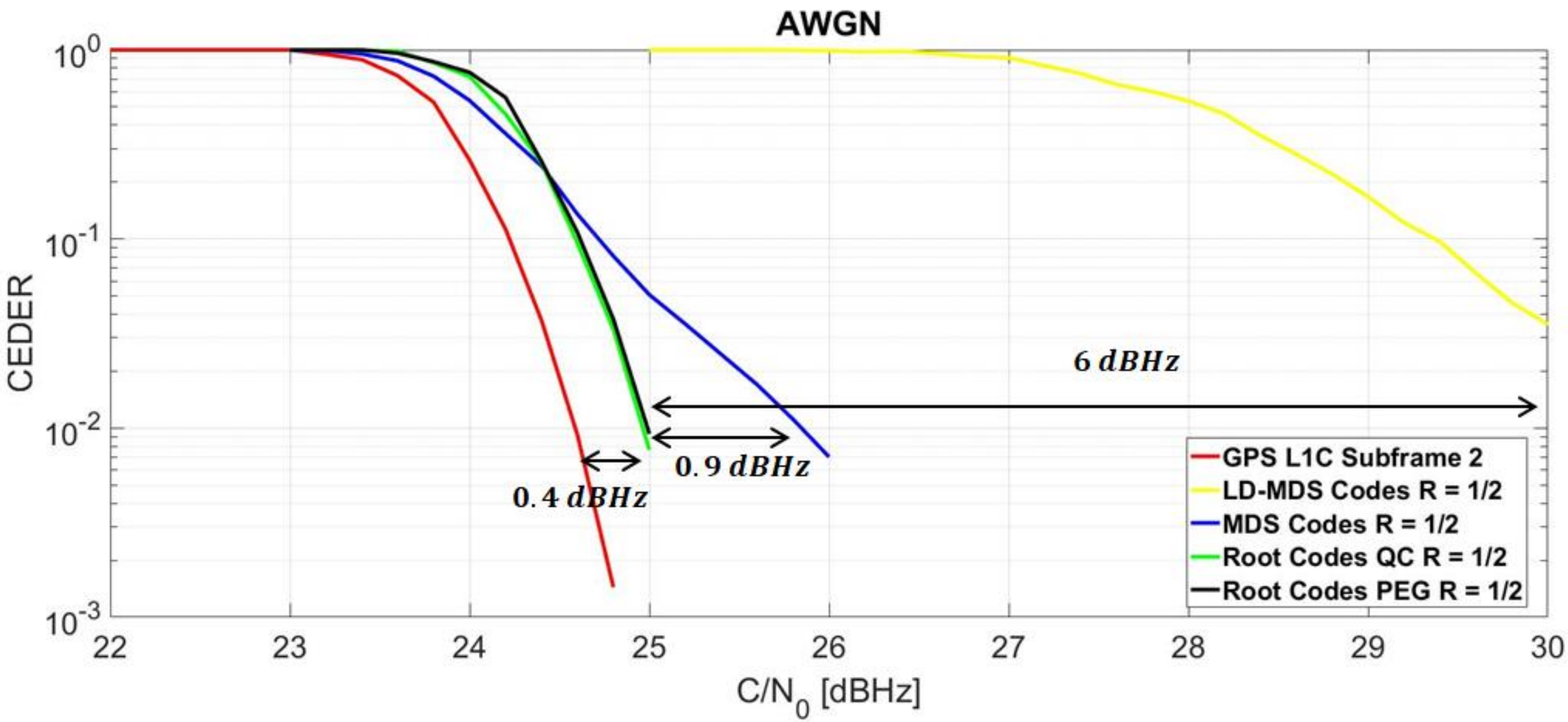


Under harsh channel conditions:

MDS & LDMDS codes increase the T_{CED}

Root codes reduce the T_{CED}

Results


AWGN
10^0
10^{-1}
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CEDER
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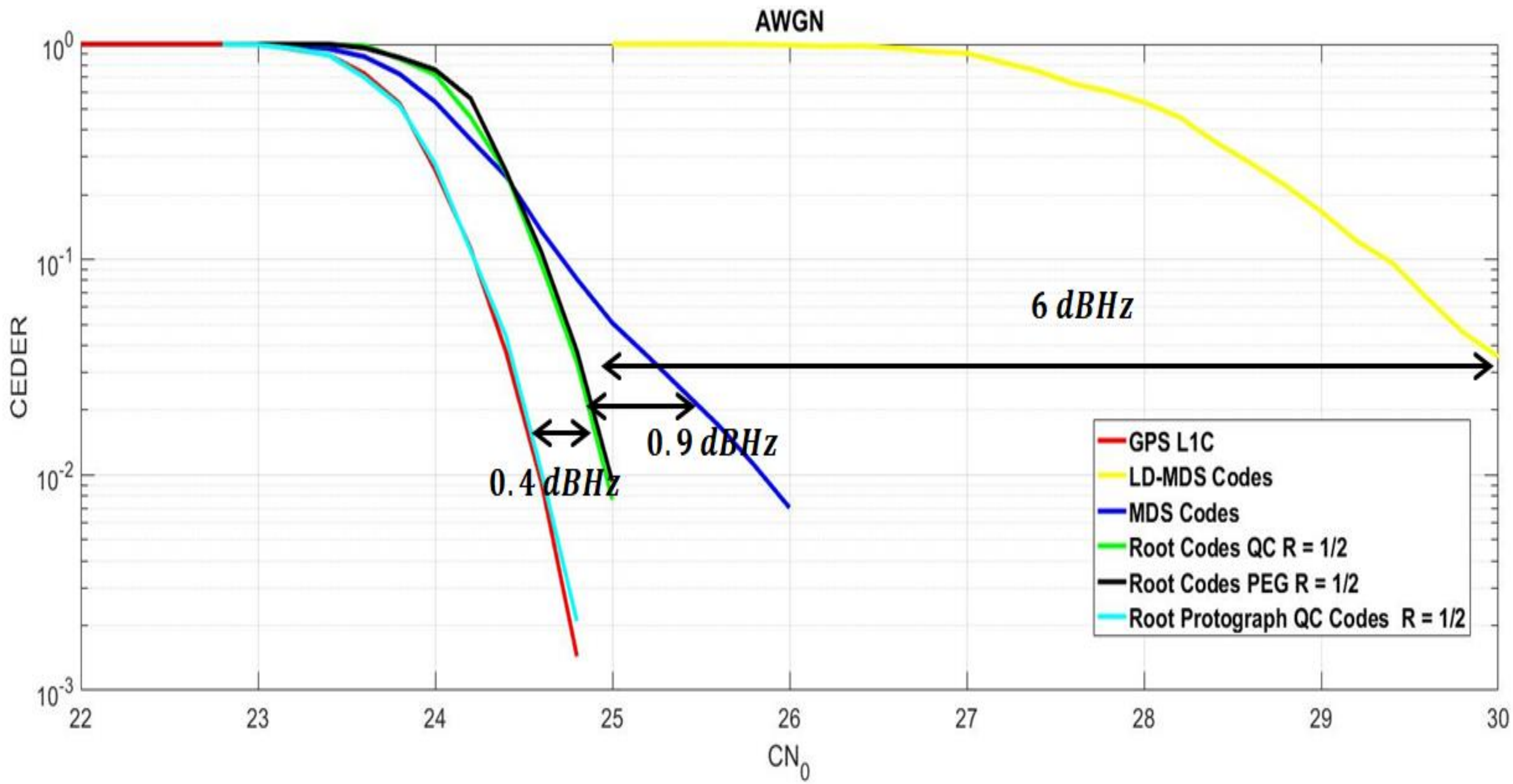
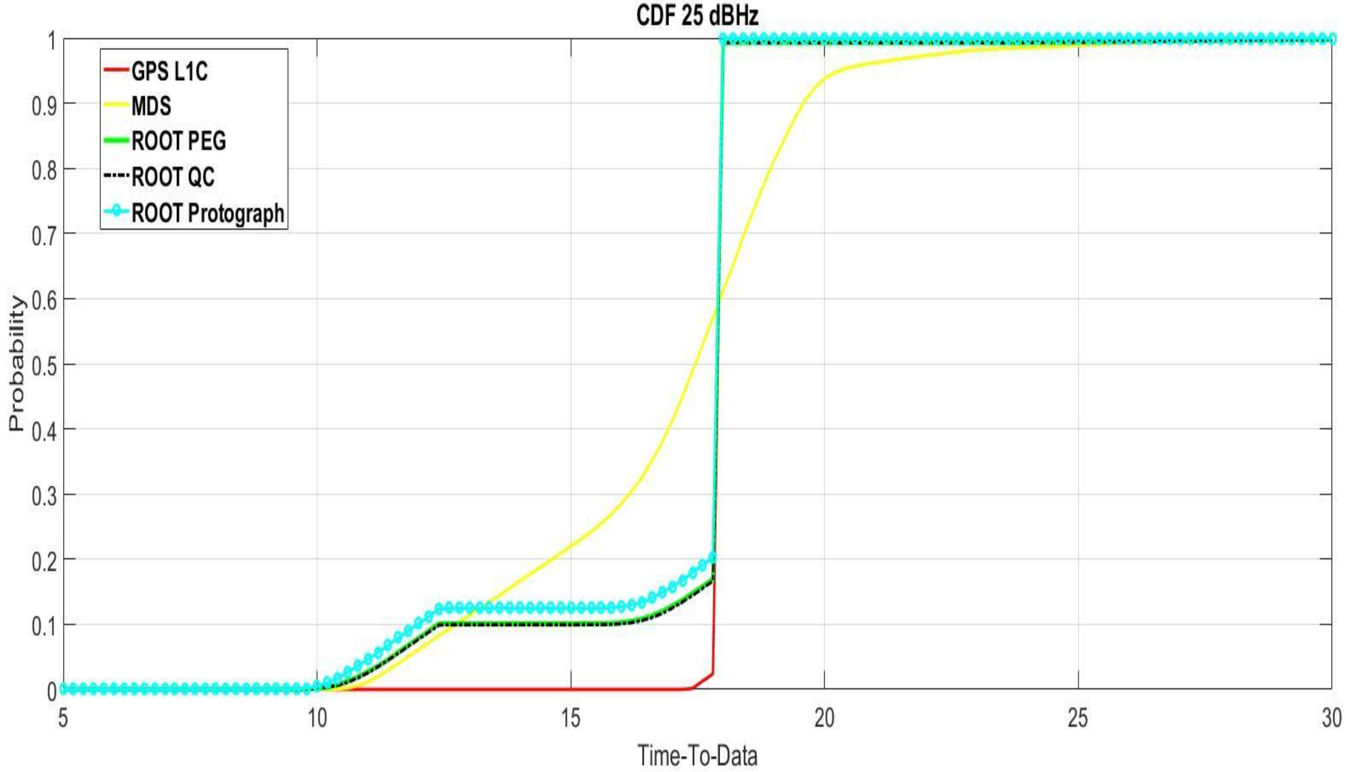
24
25
26
27
28
29
30
C/N0 [dBHz]
6 dBHz
0.9 dBHz
0.4 dBHz
GPS L1C Subframe 2
LD-MDS Codes R = 1/2
MDS Codes R = 1/2
Root Codes QC R = 1/2
Root Codes PEG R = 1/2

Results

Protograph-Root codes



Protograph-Root codes



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 :
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  - Full diversity Codes
- **Conclusion**
- 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**
  - Regular root-codes:
    - MDS property under BP algorithm
    - Full diversity

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

Content

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Future Lines

- Next step:
  - Use of protograph code to improve the channel coding
  - Rate compatible property
  - Multiplexing the new signal
  - How to compute the LLR in real scenarios
  - Work with M-ary modulation (CSK modulation)
  - Work with non-binary codes

thank you!

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