Random Access Techniques for Satellite Communications

Selma Zamoum

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November 28th, 2019

Outline

1. Introduction and context
2. Legacy Random Access protocols
3. First contribution: Random SPOTiT
4. Second contribution: Smart SPOTiT
5. Third contribution: Asynchronous Random SPOTiT
6. Conclusion and perspectives

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Role of satellites

- Global coverage of land, oceans and inaccessible areas for terrestrial infrastructures.

→Availability

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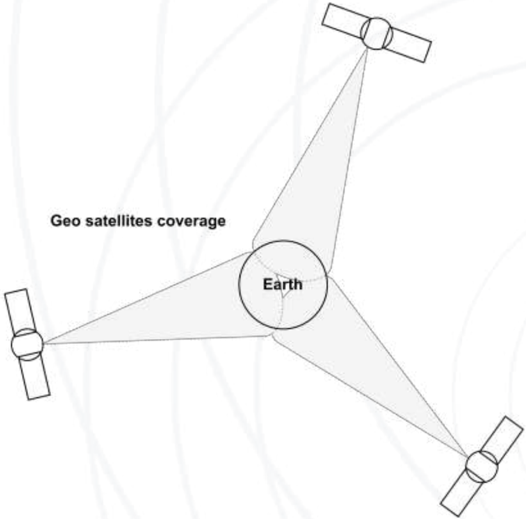

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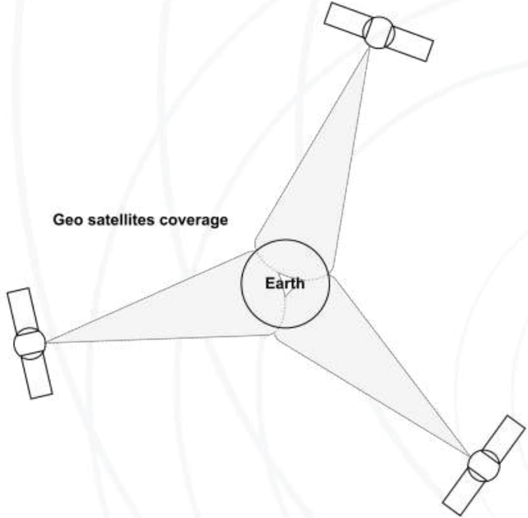

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- Supports large user communities with relatively low cost.

→Availability, scalability, low lost

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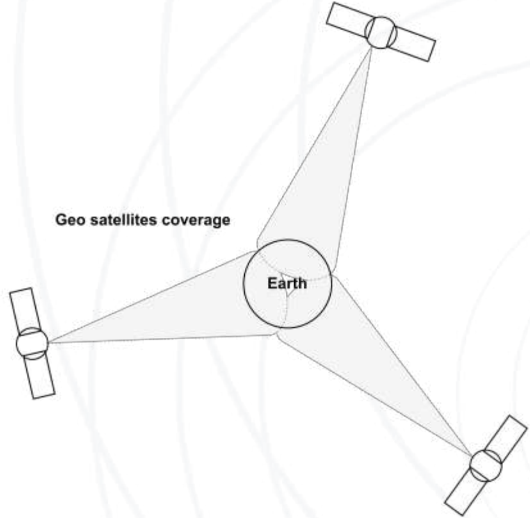


- Global coverage of land, oceans and inaccessible areas for terrestrial infrastructures.
- Supports large user communities with relatively low cost.
- Important redundancy or replacement relays in case of human and natural disasters.

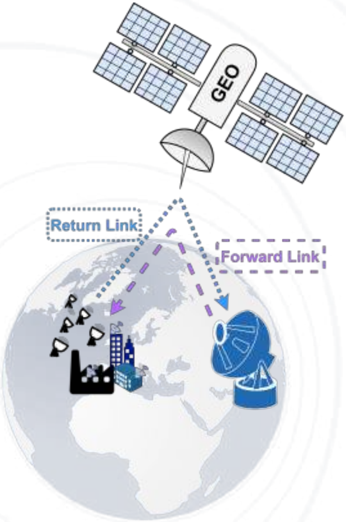
→Availability, scalability, low lost, reliability ...

Satellite services

Navigation, earth & space observation...

Telecommunications
& Multimedia applications

Return Link access



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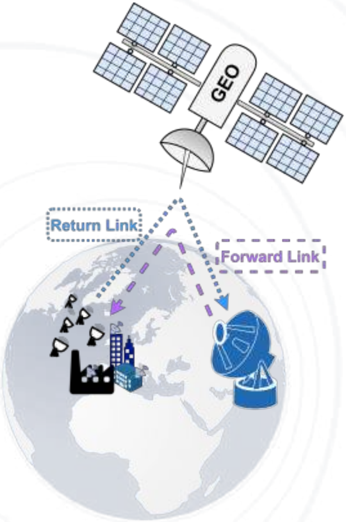
- Fixed Satellite Services (FSS).
- Transmission over Ku or Ka frequency bands.
- Transmissions organized in time-frequency resources.



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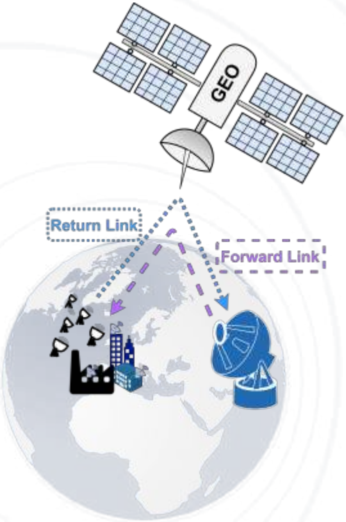
How to access a satellite service?

- Random Access for signaling information and logon (DVB-RCS2).
- Demand Assignment Multiple Access (DAMA) for data transmission.



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500 ms round trip with GEO satellites.

- → Resource reservation and Transmission delays.
- → Inefficient retransmission mechanism.
- → Resource limitation and under-utilization for big users communities applications.

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DAMA techniques are Especially critical for short packet transmissions.

Target:

Low rate interactive applications with sporadic transmissions, SCADA: Supervisory Control and Data Acquisition.

Random Access solution

Using Random Access for data transmissions.

⟹ Collision between signals of different users on the same resource.

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RA challenge: Collision resolution at reception in order to increase the link performance.

Random Access solution

Main focus on recent ALOHA-based RA protocols ⇒

Synchronous & Asynchronous Solutions

Random Access solution

Main focus on recent ALOHA-based RA protocols $\Rightarrow$

Synchronous & Asynchronous Solutions

Both are characterized with:

- Transmission of **multiple replicas** of the same packet in order to have a higher collision-free probability.
- Successive Interference Cancellation (**SIC**) at reception.

Outline

Random Access solution

Main focus on recent ALOHA-based RA protocols ⇒

Synchronous & Asynchronous Solutions

Slotted transmissions

CRDSA[1]: Contention Resolution Diversity Slotted ALOHA.

[1] E. Casini, R. De Gaudenzi and O. Del Rio Herrero, "Contention Resolution Diversity Slotted ALOHA (CRDSA): An Enhanced Random Access Schemefor Satellite Access Packet Networks," in IEEE Transactions on Wireless Communications, April 2007.

Random Access solution

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Synchronous & Asynchronous Solutions

Slotted transmissions

CRDSA[1]: Contention Resolution Diversity Slotted ALOHA.

Unslotted transmissions

ACRDA[2]: Asynchronous Contention Resolution Diversity ALOHA.

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[2] R. De Gaudenzi, O. del Río Herrero, G. Acar and E. Garrido Barrabés, "Asynchronous Contention Resolution Diversity ALOHA: Making CRDSA Truly Asynchronous," in IEEE Transactions on Wireless Communications, Nov. 2014.

Synchronous ALOHA RA techniques

CRDSA Characteristics:

- Multiple packet replicas transmission.
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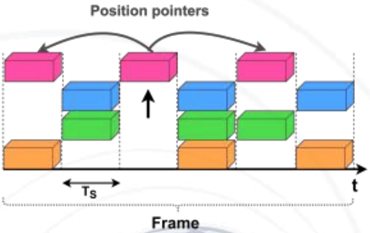

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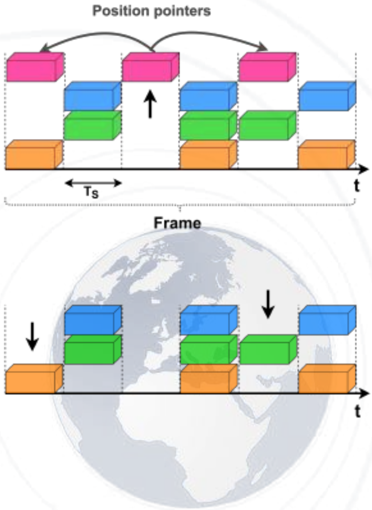

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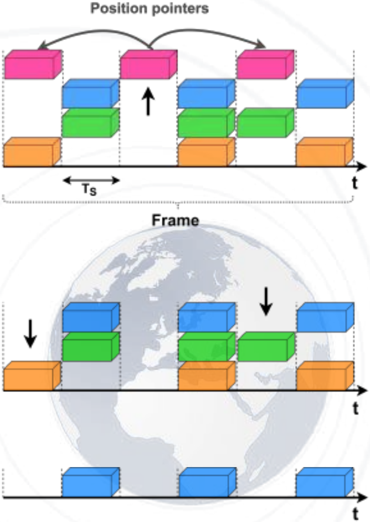
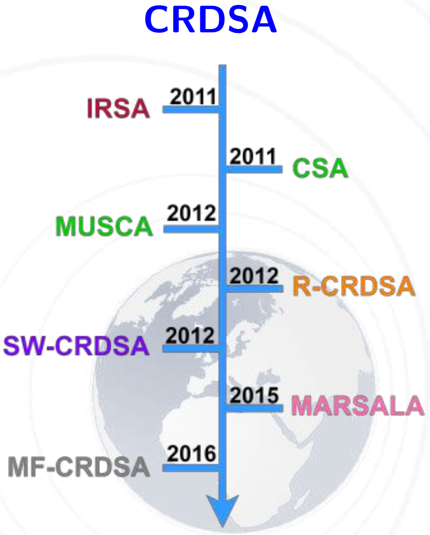


Synchronous ALOHA RA techniques

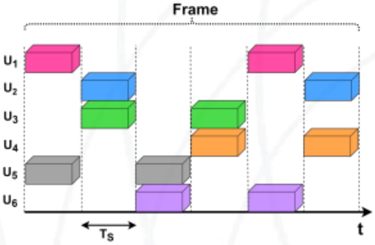
Other characteristics:

- multiple packet replicas transmission.
- Successive Interference cancellation.
- Irregular number of packet replicas.
- Packets encoding.
- Reservation scheme.
- Sliding window with a slotted frameless scheme.
- Replicas localization and combination prior to decoding.
- Multi-frequency sub-band investigation.



CRDSA's deadlock and role of MARSALA

A deadlock for CRDSA



Solution: MARSALA[3]

1. Localize replicas with correlations.
2. Combine replicas of the same packet before decoding.

[3] H. Bui, K. Zidane, J. Lacan and M. Boucheret, "A Multi-Replica Decoding Technique for Contention Resolution Diversity Slotted Aloha," 2015 IEEE 82nd Vehicular Technology Conference (VTC2015-Fall), Boston, MA, 2015.

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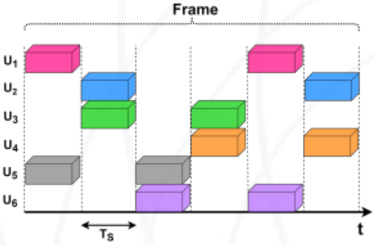

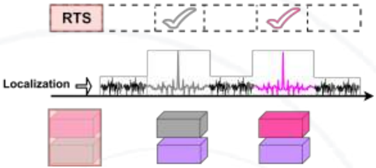

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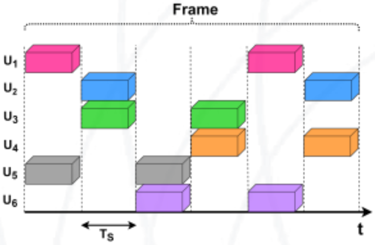

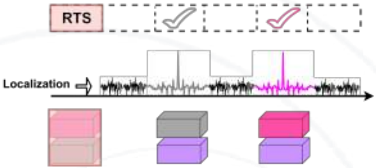

SIR comparison when packets are equipowered

Solution: MARSALA[3]

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Before MARSALA:

$$\mathbf{SIR_{BM}} = \frac{\mathbf{P_{U_5}}}{\mathbf{P_{U_1}}} = 1$$

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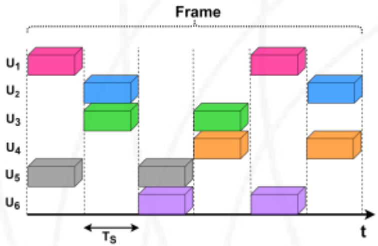

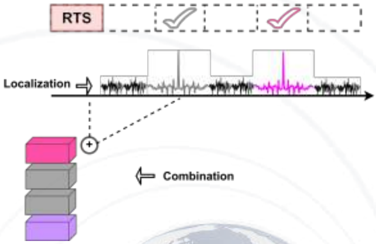

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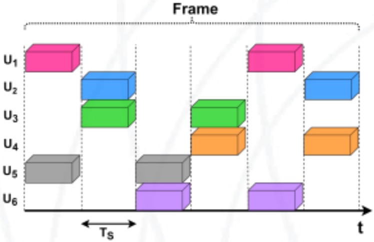

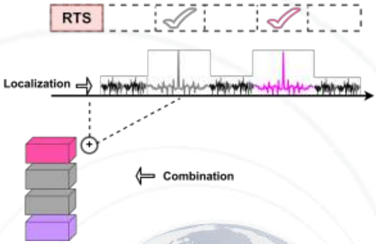

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SIR comparison when packets are equipowered

After combination of MARSALA:

$$\mathbf{SIR_{WM}} = \frac{\mathbf{4 \times P_{U_5}}}{\mathbf{P_{U_1} + P_{U_6}}} = 2$$

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Hypothesis & system parameters

Perfect channel estimation, demodulation and decoding is assumed for SIC.

- QPSK modulation.
- 3GPP turbo coding of rate 1/3.
- Packet payload of 150 symbols.
- Gold code preambles of 31 symbols.
- AWGN channel, $E_S/N_0 = 10\text{dB}$.
- Same power for all packets.
- 100 time slots per frame.

Problem 1: complexity related to replicas localization

Number of data correlations for one packet decoding on the slot of reference

$$N_{\mathrm{MARSALA}}^{\mathrm{Corr}(1),1} = \underbrace{(N_{\mathrm{S}} - 1)}_{\text{Global localization}} + \underbrace{\sum_{i=1}^{N_{\mathrm{R}}-2} (N_{\mathrm{R}} - 1) \times N_{\mathrm{Coll}}^{\mathrm{Ref}}(1) - i}_{\text{Replicas association}}$$

N_S: number of slots, N_R: number of replicas, N_{Coll}^{Ref}: number of collided packets on the reference time slot.

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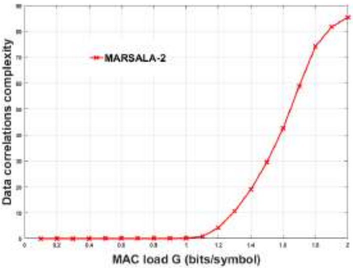

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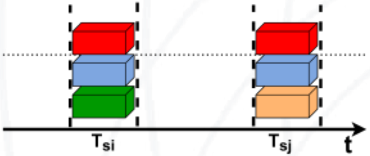
Problem 2: loop phenomenon



The signal combination for the red packet in an equi-powered environment, in the worst case scenario, results in:

$$\mathrm{SIR}_{\mathrm{red}} = \frac{4 \times P}{4 \times P + P + P} = \frac{2}{3}$$

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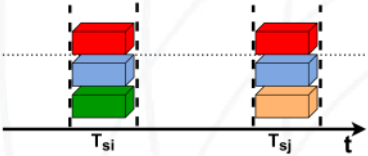

Loop phenomenon → a lower SIR
→ lower packets' decodability
→ error floor

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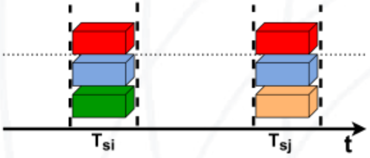

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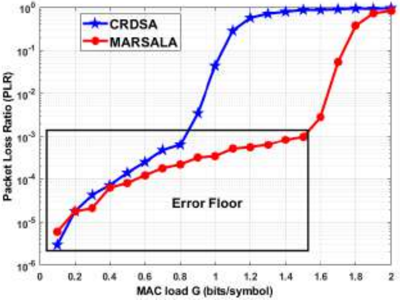

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Problem 2: loop phenomenon

The loop phenomenon is less significant when the number of replicas is high.

↓

A high number of replicas induces a higher association complexity.

Solution: SPOTiT

Shared Position Technique for Interfered Random Transmissions (SPOTiT).

1. Random SPOTiT is proposed to mitigate the localization complexity.
2. Smart SPOTiT and Asynchronous Random SPOTiT are mainly proposed to solve the loop phenomenon problem and enhance the system performance.

All of the variants of SPOTiT rely on **sharing information** about **packets' locations** with the receiver prior to transmission.

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General concept & mechanism:

Goal:

- Reduce the localization complexity.

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General concept & mechanism:

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Tracks:

- Design a system that requires less correlations in the localization process.
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Proposed solution:

- Rely on a **shared information** concerning **packets locations** between the **receiver** and each of the **transmitters** using a PRNG.

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- Complementary to CRDSA.

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General concept & mechanism

Transmission

PRNG: PseudoRandom Number Generator, **HID:** Hardware IDentifier

General concept & mechanism

Transmission

Reception

Users	HIDs
U_1	HID_1
U_2	HID_2
U_3	HID_3
U_4	HID_4
....	....
....	....

→ **PRNG** →

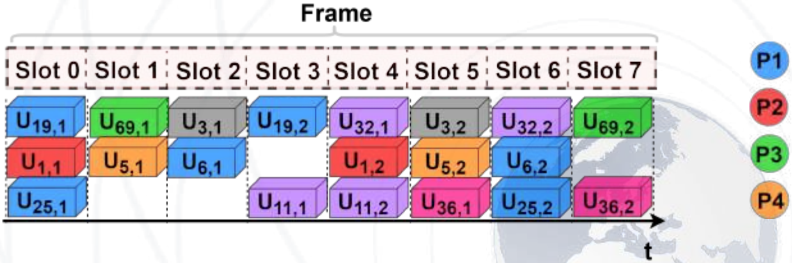
Users	Position1	Position2	Preamble
U_1	S(1,1)	S(1,2)	P_{U1}
U_2	S(2,1)	S(2,2)	P_{U2}
U_3	S(3,1)	S(3,2)	P_{U3}
U_4	S(4,1)	S(4,2)	P_{U4}
....	....	....	....
....	....	....	....

Receiver's information table

PRNG: PseudoRandom Number Generator, **HID:** Hardware IDentifier

Outline

Decoding example



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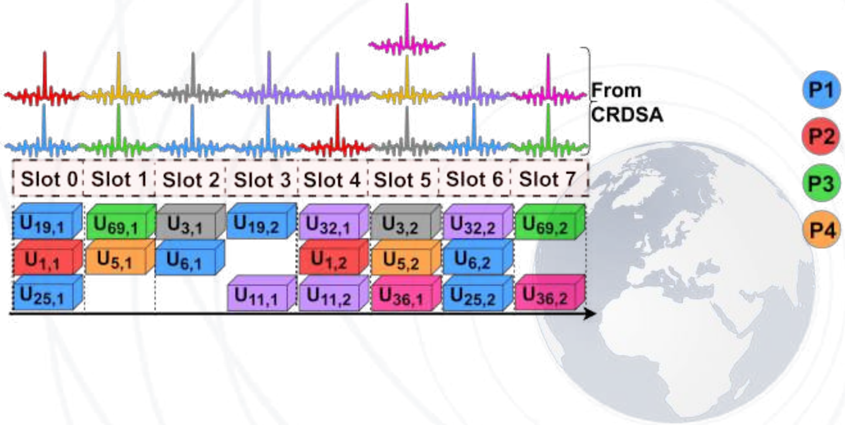

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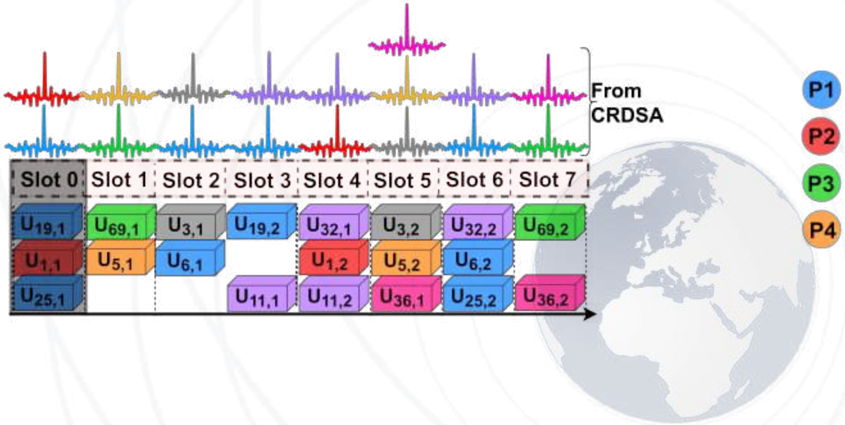

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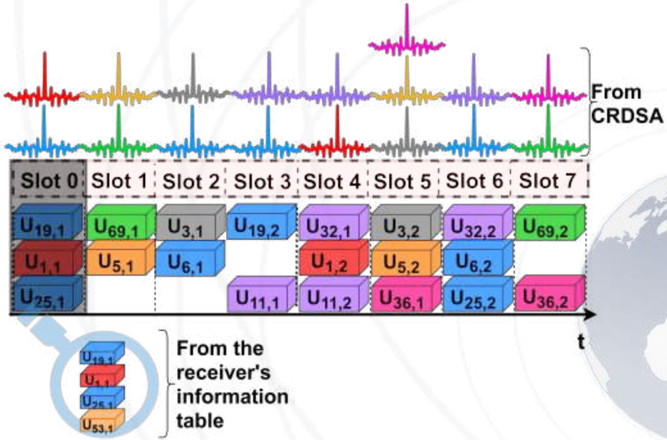
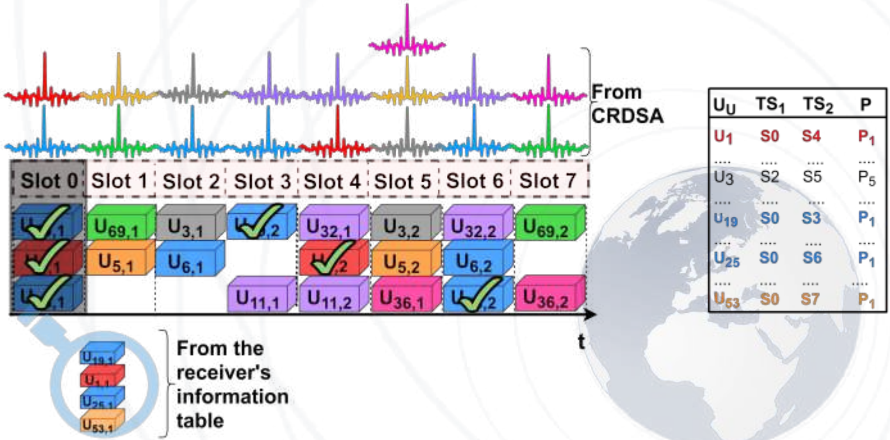


U_U	TS_1	TS_2	P
U_1	S0	S4	P_1
....	....	....	....
U_3	S2	S5	P_5
....	....	....	....
U_{19}	S0	S3	P_1
....	....	....	....
U_{25}	S0	S6	P_1
....	....	....	....
U_{53}	S0	S7	P_1

Decoding example



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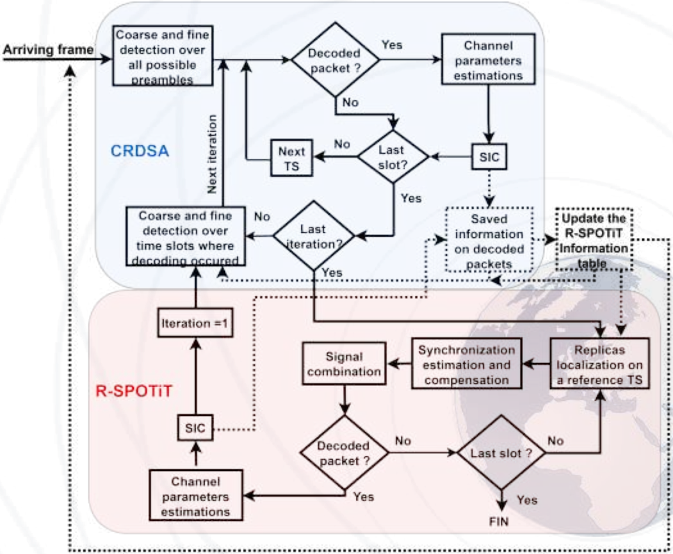
General algorithm



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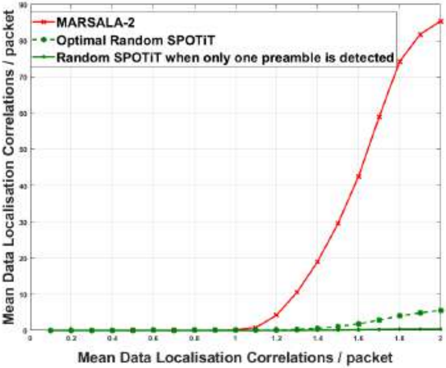
Overall system performance

Number of data correlations



Equipowered packets of 150 symbols, 100 time slots per frame, 3GPP turbo coding of rate 1/3, QPSK modulation
Gold code preambles of 31 symbols, AWGN channel, E_S/N_0 = 10dB, 2 replicas/packet.

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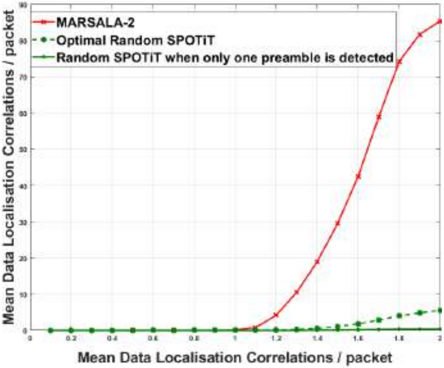
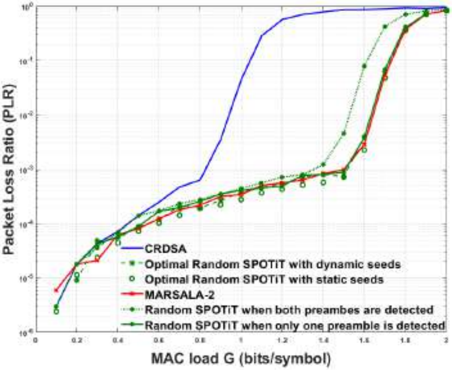


Packet Loss Ratio



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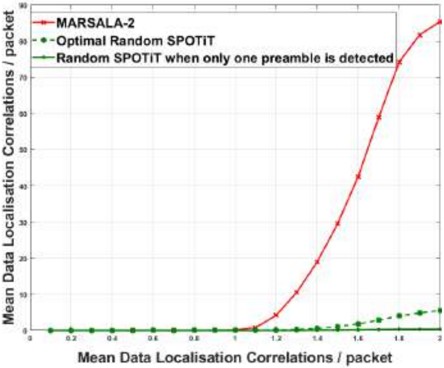
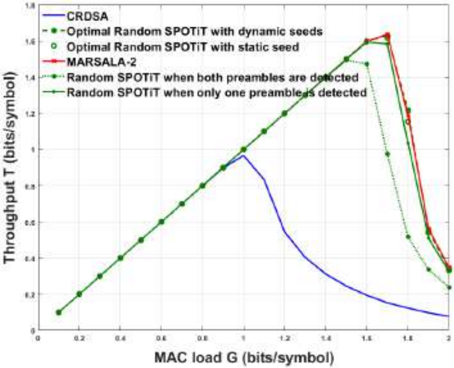


Throughput



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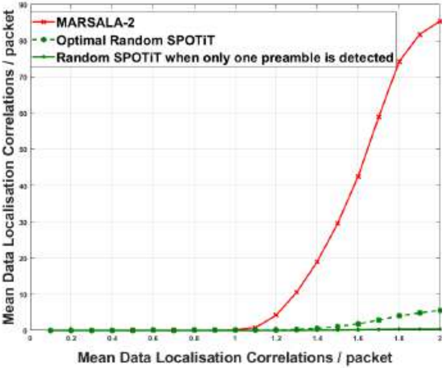

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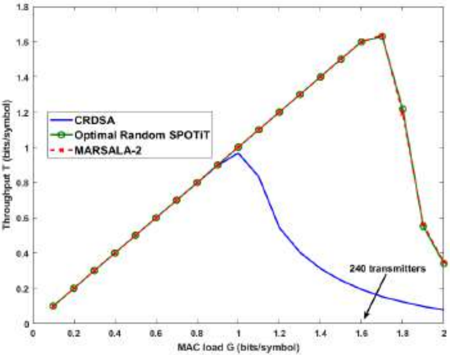

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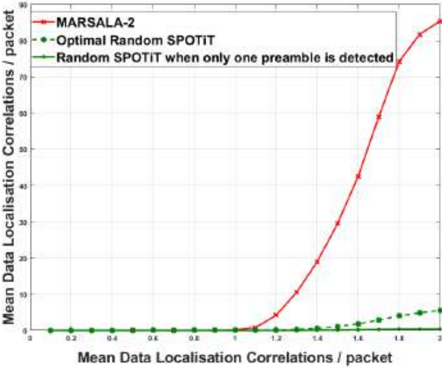

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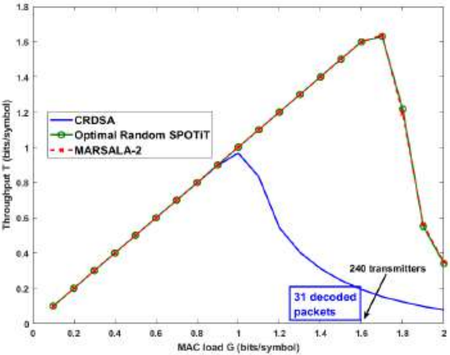

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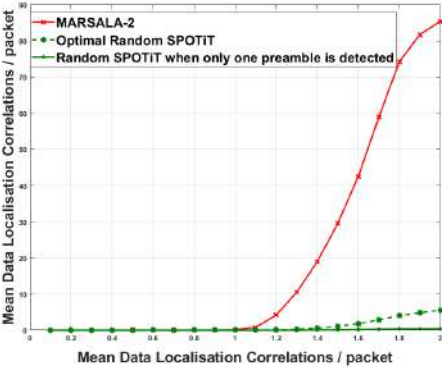

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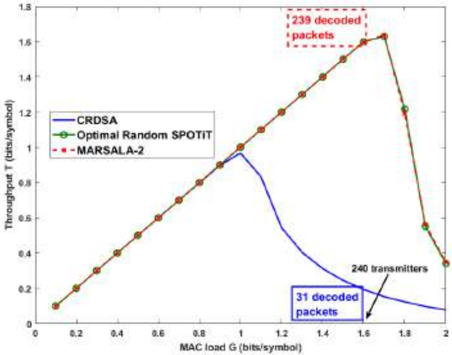

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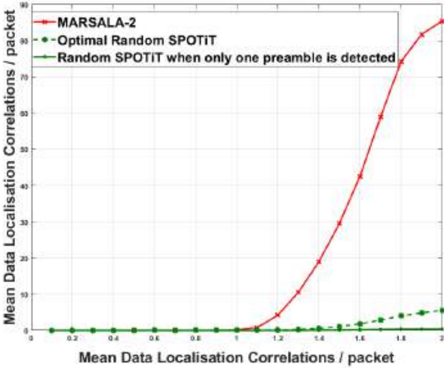

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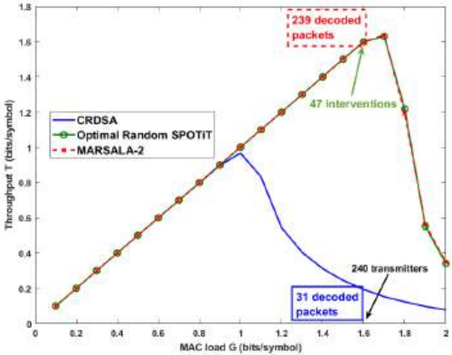

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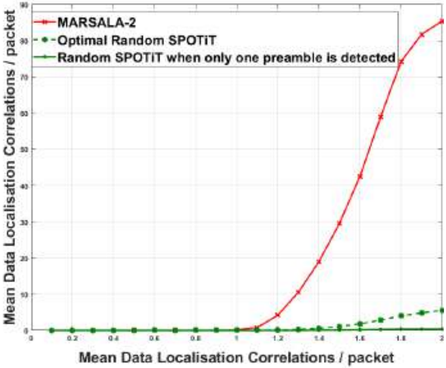

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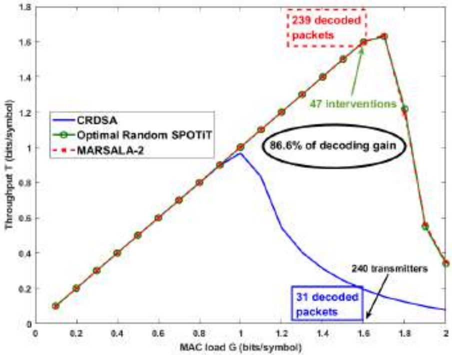

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Overall frame complexity

Number of total correlations per frame

$$\mathbf{C_T} = \sum_{\delta=1}^{\boldsymbol{\Delta}} \left(\sum_{\mathbf{it}=1}^{\mathbf{N}_{\mathrm{it}}} \mathbf{C}_{\mathrm{P}}(\delta, \mathbf{it}) + \sum_{\lambda=1}^{\boldsymbol{\Lambda}} \mathbf{C}_{\mathrm{D}}(\delta, \lambda) \right)$$

Where:

δ: frame analysis index.

it: index of CRDSA iterations.

$\mathbf{C}_{\mathrm{P}}$: number of preamble correlations during CRDSA.

λ: usage of the complementary process index.

$\mathbf{C}_{\mathrm{D}}$: number of data correlations during R-SPOTiT/ MARSALA.

Overall system performance

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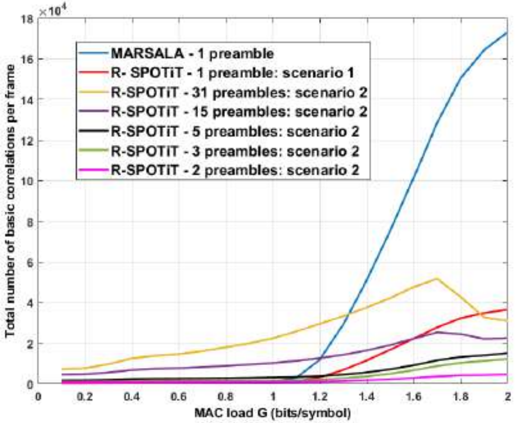

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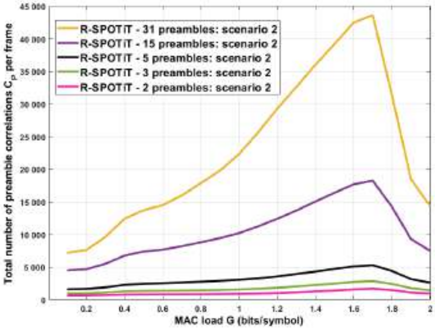
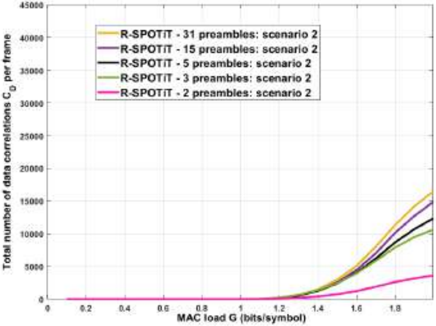
Preamble Correlations complexity



Data Correlations complexity



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Outline

1. Introduction and context
2. Legacy Random Access protocols
3. First contribution: Random SPOTiT
4. **Second contribution: Smart SPOTiT**
5. Third contribution: Asynchronous Random SPOTiT
6. Conclusion and perspectives

Outline

General Principle

Goal:

- Manage and eliminate data loops between packets with packet simple localization.

[5] S. Zamoum, J. Lacan, M. Boucheret, M. Gineste and J. Dupe, "Deterministic Distribution of Replicas Positions for Multiuser Random Transmissions in Satcoms," 2018 IEEE Global Communications Conference (GLOBECOM), Abu Dhabi, United Arab Emirates, 2018

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Proposed solution:

- The receiver **communicates** to each transmitter the **replicas' positions** for its packets, in a way that **no loops** can be created and insures a **simple packet localization** procedure.
- **Better Packet Loss Ratio** performance are expected.

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System parameters

A distribution based on a power of two number of slots.

$\mathbf{N_S}$: number of time slots per frame.

$\mathbf{N_P} = \frac{N_S}{2}$: number of preambles.

$\mathbf{N_R}$: number of replicas.

$\mathbf{N_U} = \frac{N_S \times (N_S - 1)}{2}$: number of users.

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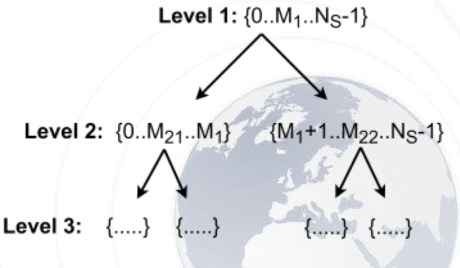
Distribution of time slots positions for each level

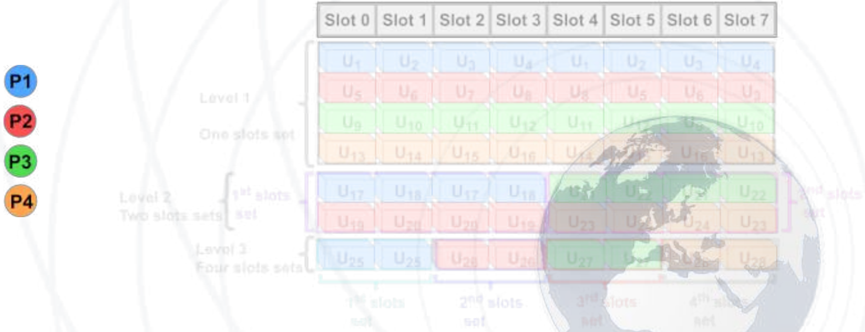


At each level, there are N_P preamble groups.

Outline

Optimal distribution example

Worst case scenario of the frame structure



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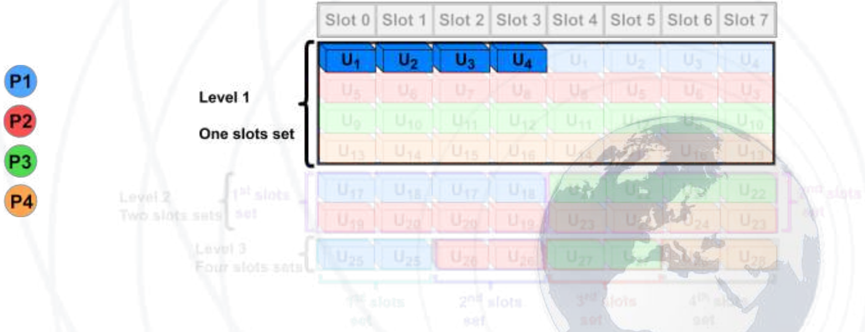

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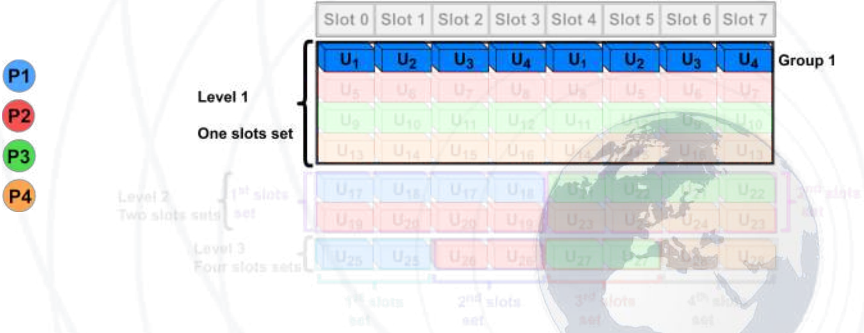

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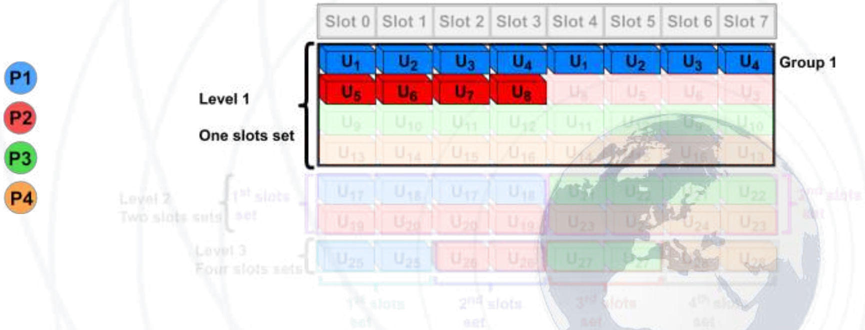
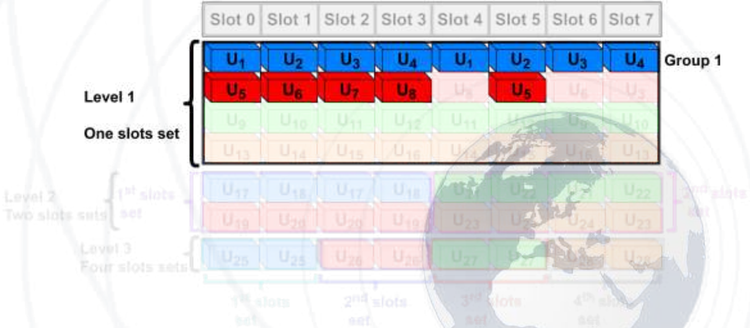


Optimal distribution example

Worst case scenario of the frame structure

P1
P2
P3
P4



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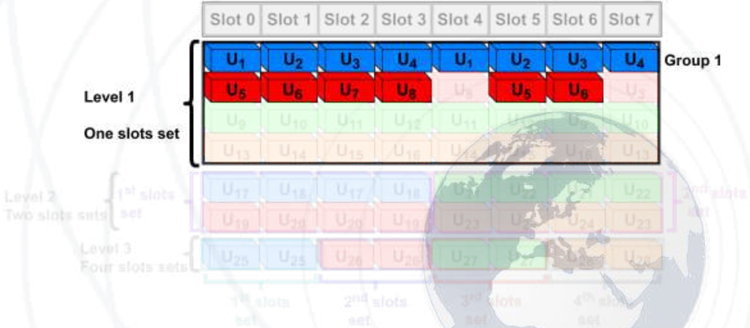

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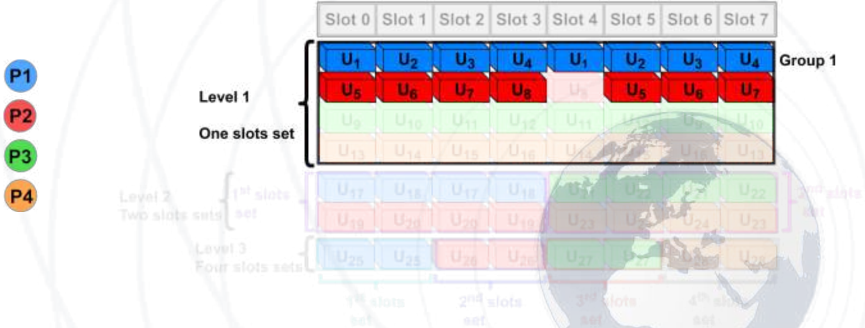

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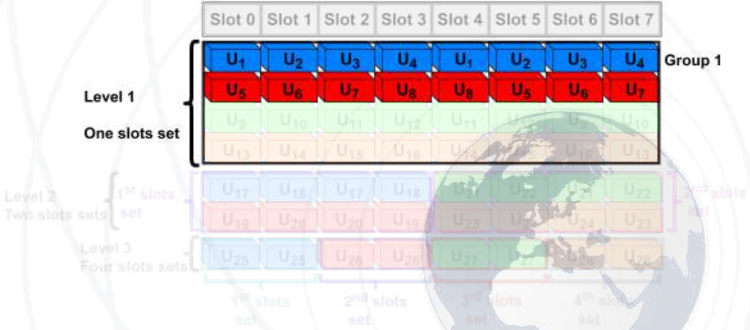

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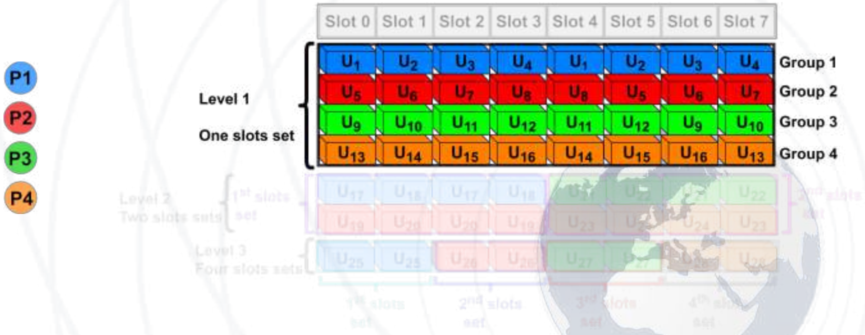

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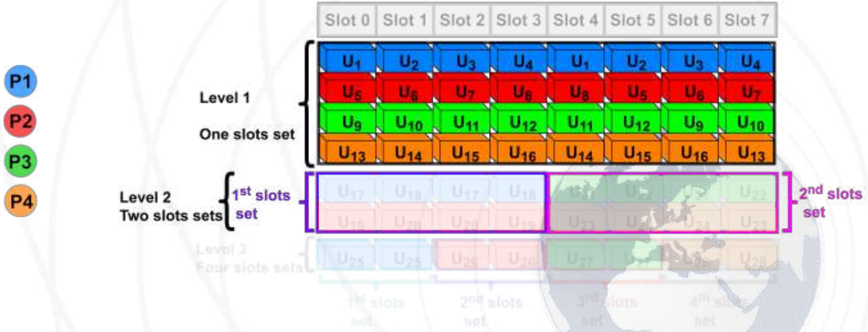

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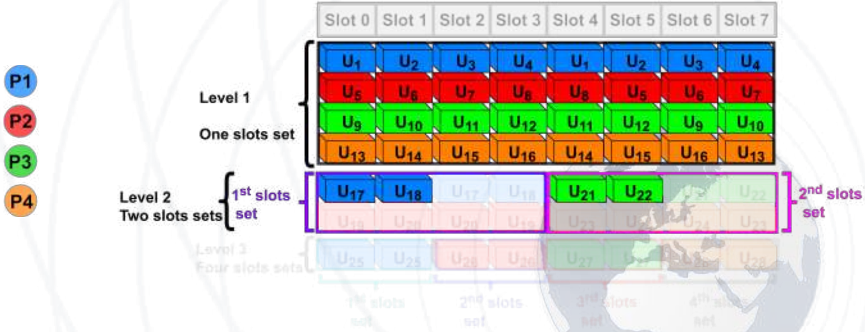

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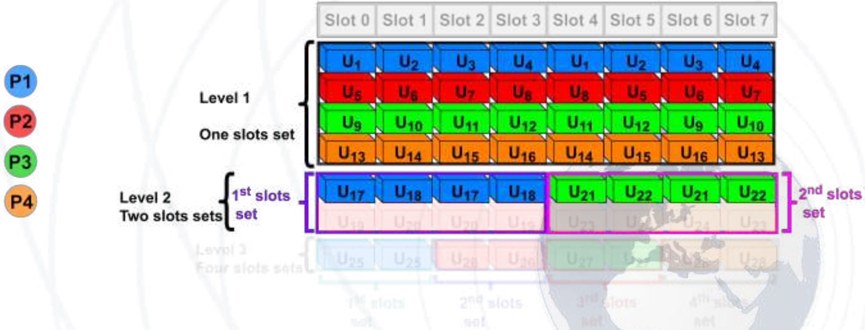

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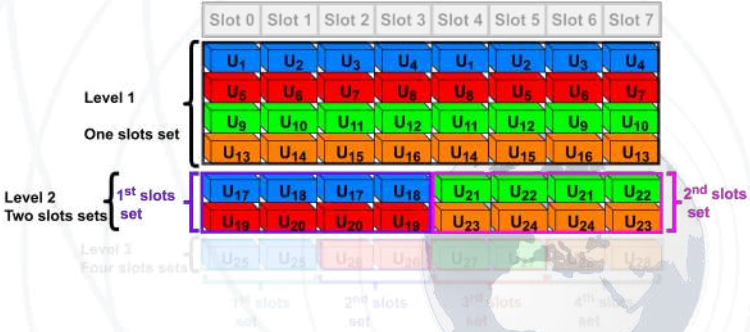

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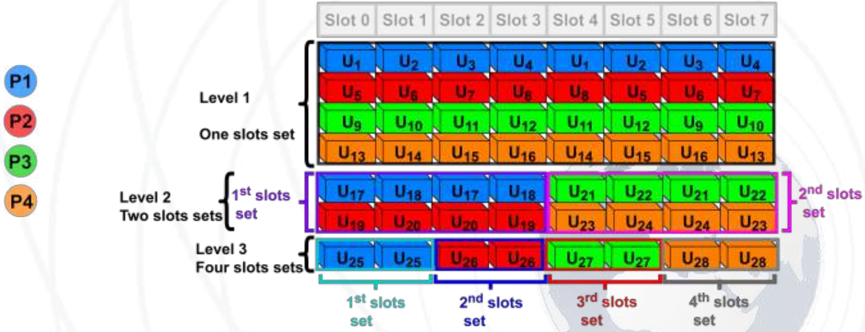

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Worst case scenario for the blue preamble

For each localized packet, replicas combination is performed prior to decoding.

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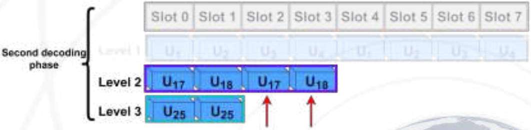

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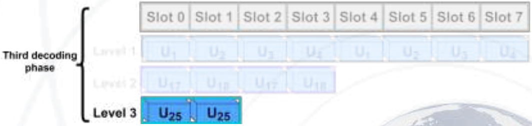

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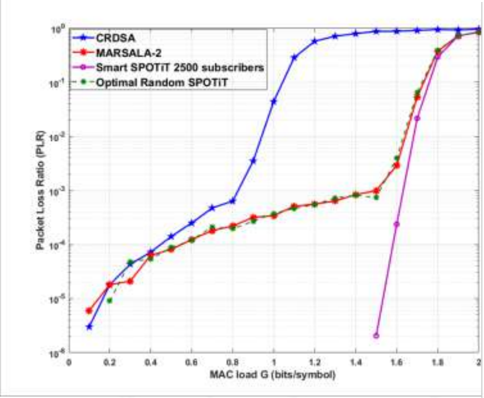
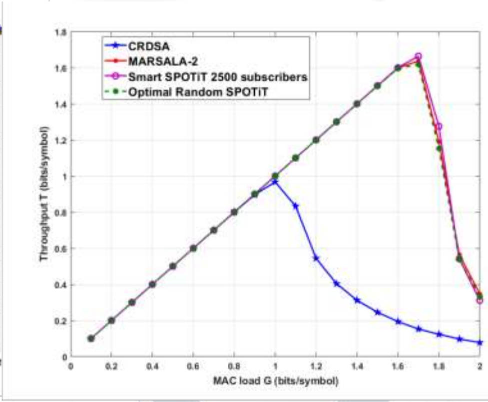
Smart SPOTiT Performance

Packet Loss Ratio



Throughput (bits/symbol)



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Irregular Smart SPOTiT

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The loop-free configuration does not depend on the number preambles

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- Construct the irregular scheme with the **same number of levels** as in the regular method. The number of users is $\overline{N_U}$.

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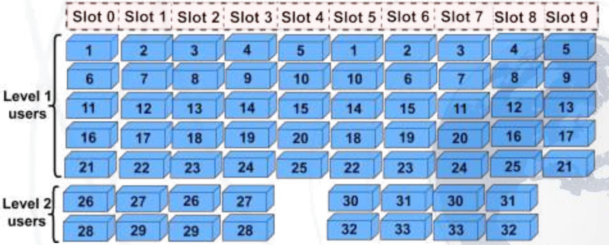

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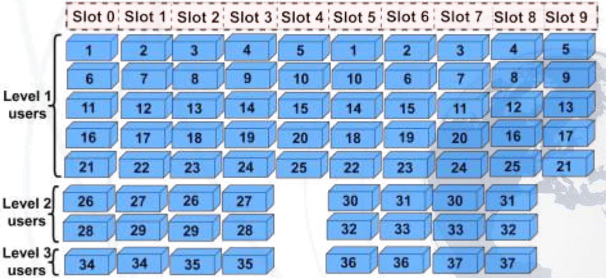

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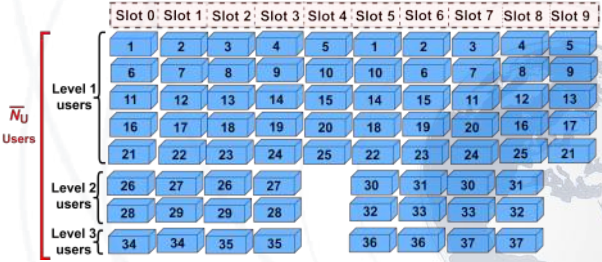

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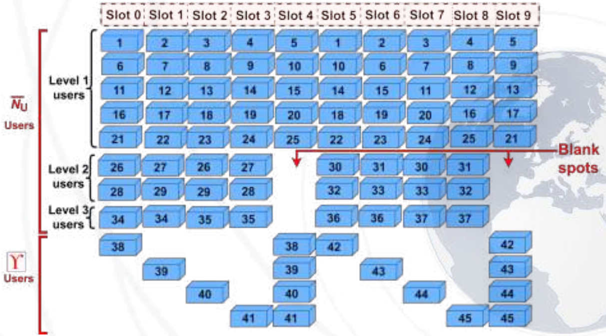

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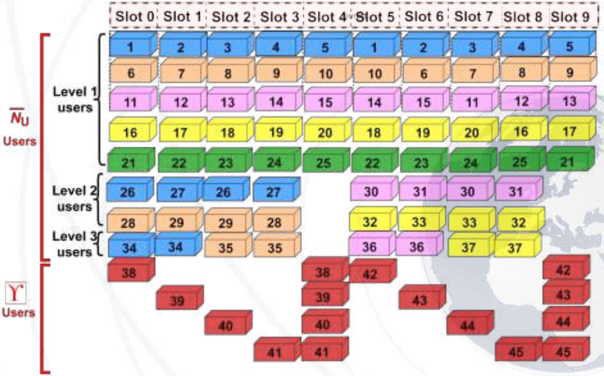

Irregular number of users and preambles

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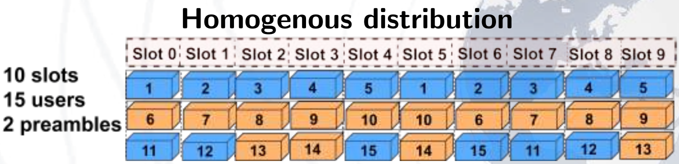

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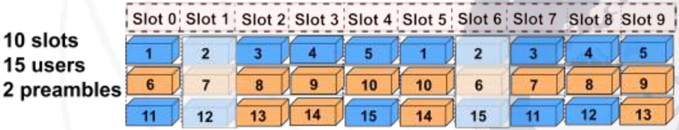

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  ⇒ A homogeneous distribution of users and preambles is maintained.

Outline

Extension of Smart SPOTiT

Critical applications with a **PLR target**

Extension of Smart SPOTiT

Critical applications with a **PLR target**

Problem⇒ **loop phenomenon**

Extension of Smart SPOTiT

Critical applications with a **PLR target**

Problem⇒ **loop phenomenon**

Approach⇒ a permanently loop-free configuration

Extension of Smart SPOTiT

Diagonal method

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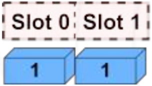

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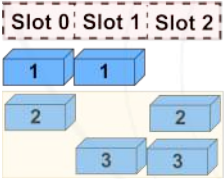

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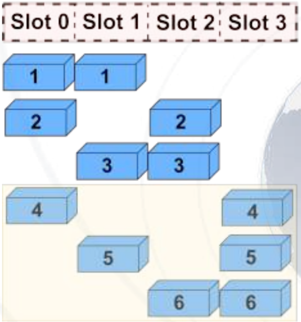

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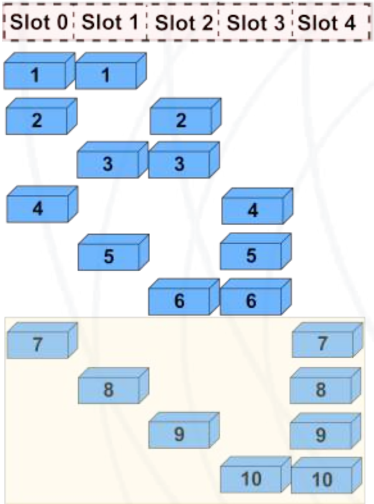

- Better PLR performance.

When the number of users is important

- The **frame** might be **longer** than in traditional systems.
- The **transmission time** might be **longer**.

Outline

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ACRDA Asynchronous environment

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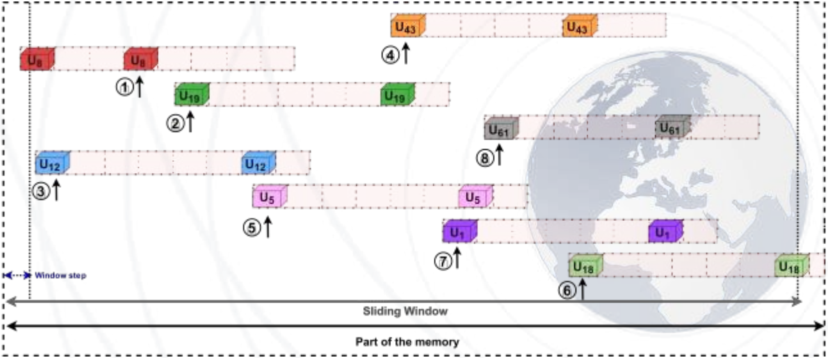

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Enhanced Contention Resolution Aloha

- ECRA[5] is based on two decoding phases:

[5] F. Clazzer and C. Kissling, "Enhanced Contention Resolution Aloha - ECRA," SCC 2013; 9th International ITG Conference on Systems, Communication and Coding, München, Deutschland, 2013.

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- The localization **complexity** is higher when the distances between replicas are great.

[5] F. Clazzer and C. Kissling, "Enhanced Contention Resolution Aloha - ECRA," SCC 2013; 9th International ITG Conference on Systems, Communication and Coding, München, Deutschland, 2013.

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Asynchronous Random SPOTiT

- **AR-SPOTiT**[6]: an asynchronous version of R-SPOTiT.

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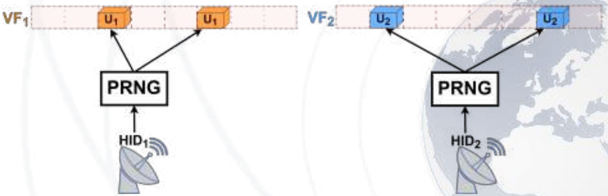

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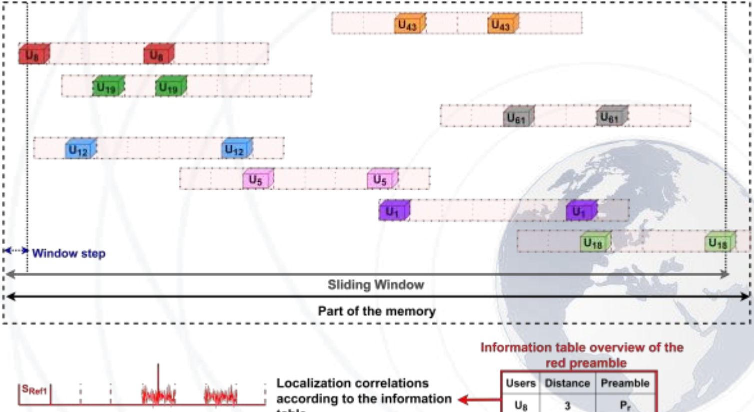
Asynchronous Random SPOTiT

Reception: the **distance** between replicas and used **preamble** are known



Users	Distance	Preamble
U_8	3	P_r
U_{27}	5	P_r

Outline

Preamble detection complexity

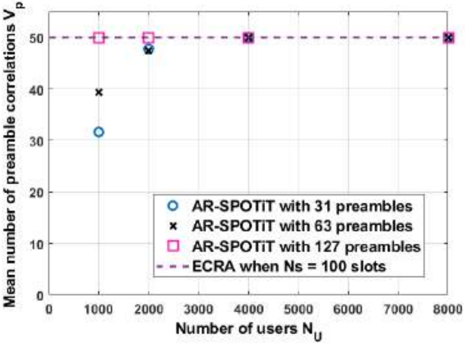
Scenario

- ECRA with a **single preamble**.
- AR-SPOTiT with $\mathbf{N_{\mathrm{P}}}$ **preambles**.
  - Energy detection is performed after ACRDA and ECRA's SIC phase are locked.

$$\nu_{\mathrm{p}} = \begin{cases} \dfrac{N_{\mathrm{S}}}{2} & \text{if ECRA} \\ \min\left(\dfrac{N_{\mathrm{P}}^2 + N_{\mathrm{U}}}{2N_{\mathrm{P}}}, \dfrac{N_{\mathrm{S}}}{2}\right) & \text{if AR-SPOTiT} \end{cases}$$

Preamble detection complexity

Mean number of preamble correlations



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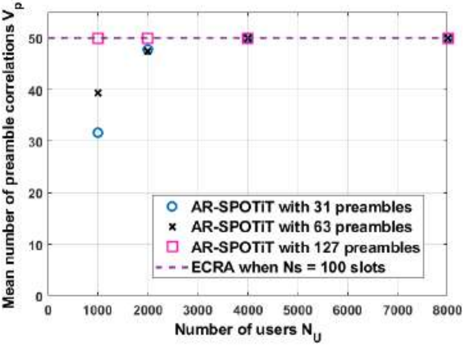
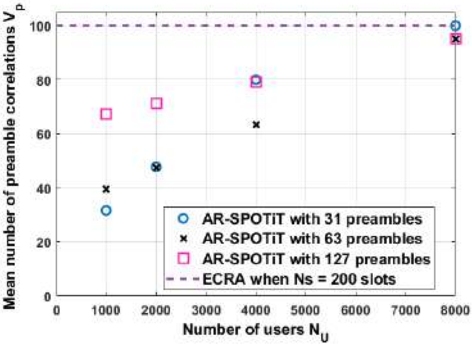
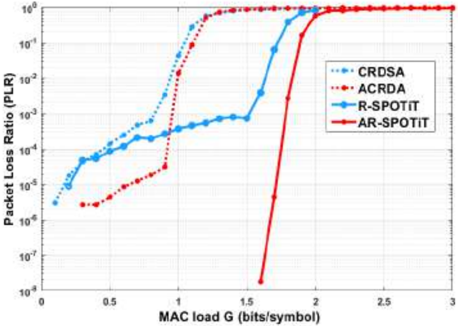




Outline

Performance evaluation

Packet Loss Ratio



Equipowered packets of 150 symbols, 100 virtual time slots per virtual frame, 3GPP turbo coding of rate 1/3, QPSK modulation, gold code preambles, AWGN channel, E_S/N_0 = 10dB, 2 replicas/packet.

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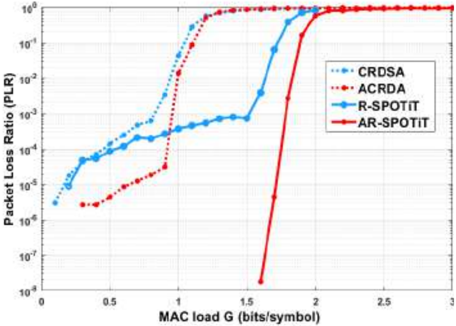
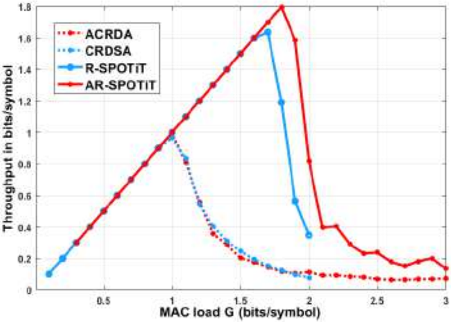


Throughput



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- A permanently loop-free dynamic system configuration of the **Extended S-SPOTiT** regardless of the number of users → transmission delay
- Loop phenomenon mitigation, replicas localization in an asynchronous environment, and better PLR and throughput performance with **AR-SPOTiT** → asynchronous complexity

Future work & Perspectives

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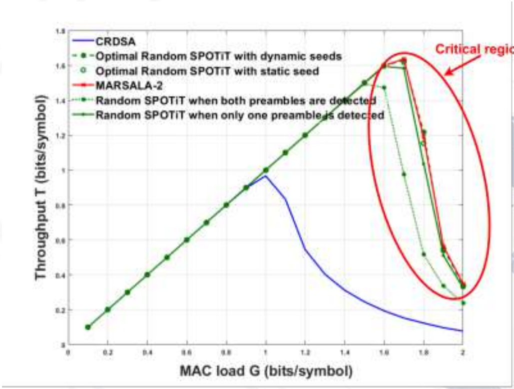
- Assess the preamble detection using a different type of orthogonal codes, as Zadoff-Chu sequences.

Future work & Perspectives

- A retransmission algorithm at the critical region of the throughput:



List of contributions

Patent

- S. Zamoum, M. Gineste, J. Lacan, M-L. Boucheret et J-B. Dupe, “procédé et système de transmission de packets de données à travers un canal de transmission (RA) à accès aléatoire”, N° 071277 FR RQDLV 14-05-18 YTA-LRE, May 2018.

International conferences

- S. Zamoum, J. Lacan, M-L. Boucheret, J-B. Dupe, M. Gineste, “Shared Position Technique for Interfered Random Transmissions in Satellite Communications”, 9th Advanced Satellite Multimedia Systems Conference and the 15th Signal Processing for Space Communications Workshop (ASMS/SPSC), 2018.
- S. Zamoum, J. Lacan, M-L. Boucheret, M. Gineste, J-B. Dupe, Deterministic “Distribution of Replicas Positions for Multiuser Random Transmissions in Satcoms”, IEEE Global Communications Conference (GLOBECOM), 2018.
- S. Zamoum, J. Lacan, M-L. Boucheret, J-B. Dupe, M. Gineste, “Asynchronous Packet Localization with Random SPOTiT in Satellite Communications”, The 22nd International Symposium on Wireless Personal Multimedia Communications (WPMC), 2019.

Journals

- S. Zamoum, J. Lacan, M-L. Boucheret, J-B. Dupe, M. Gineste, “Complexity Analysis of Recent Aloha Random Access Techniques in Satellite Communications”, International Journal of Satellite Communications and Networking, Submitted, 2019.
- S. Zamoum, J. Lacan, M-L. Boucheret, J-B. Dupe, M. Gineste, “Irregular Scheme and Extension of Smart SPOTiT for Satellite Communications”, IEEE Transactions on Communications, to be submitted.

Thank you for your attention ☺