2014 Sino-German Workshop
Bridging Theory and Practice in Wireless Communications and Networking

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We are not afraid of colliding

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German Aerospace Center, DLR

Outline

1. Background
2. Contention Resolution ALOHA (CRA)
3. Enhanced Contention Resolution ALOHA (ECRA)
4. Stability of CRDSA
5. Real-life systems
6. Conclusions

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Random Access Schemes Overview

- Slotted ALOHA (SA) [Abramson1970] is currently adopted as the initial access scheme in both cellular terrestrial and satellite communication networks.
- A more efficient use of the packet repetition is provided by *contention resolution diversity slotted ALOHA* (CRDSA) [Casini2007].
- A generalization of CRDSA is represented by *irregular repetition slotted ALOHA* (IRSA) [Liva2011].
- A generalization of CRDSA/IRSA for "fractional" number of replicas is represented by *coded slotted ALOHA* (CSA) [Paolini2011].

A few unslotted schemes on the same line were also developed by DLR.

- [Abramson1970] N. Abramson, "The ALOHA system - another alternative for computer communications," in *Proc. of 1970 Fall Joint Computer Conf.*, vol. 37, pp. 281–285, AFIPS Press, 1970.
- [Casini2007] E. Casini, R. D. Gaudenzi, and O. del Rio Herrero, "Contention resolution diversity slotted ALOHA (CRDSA): An enhanced random access scheme for satellite access packet networks.," *IEEE Trans. Wireless Commun.*, vol. 6, pp. 1408–1419, Apr. 2007.
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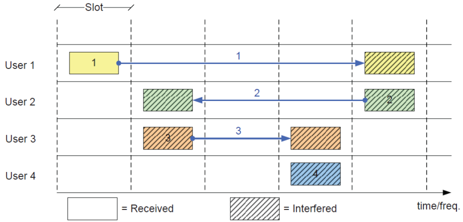
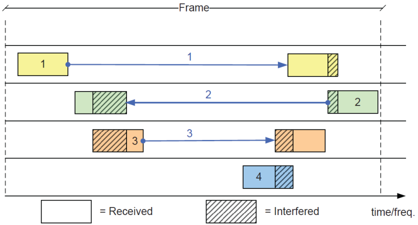
Contention Resolution Diversity Slotted ALOHA (CRDSA)

- Each user sends two replicas of the same packet in the same frame.
- Each of the transmitted twin replicas has a pointer to the slot position where the respective copy was sent.
- Idea: adopt interference cancellation (IC) to resolve collisions.
  - If a packet replica is detected and successfully decoded, the pointer is extracted and the interference contribution caused by the packet replica on the corresponding slot is removed.
  - Procedure iterated, hopefully yielding the recovery of the whole set of packets transmitted within the same MAC frame.
- Peak normalized throughput:
  $T \simeq 0.55$ (CRDSA with 2 replicas) and
  $T \simeq 0.68$ (CRDSA with 4 replicas)
  versus $T = 1/e \simeq 0.37$ achieved by SA.

Outline

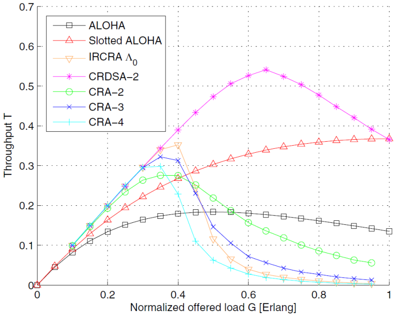
CRDSA and CRA Examples

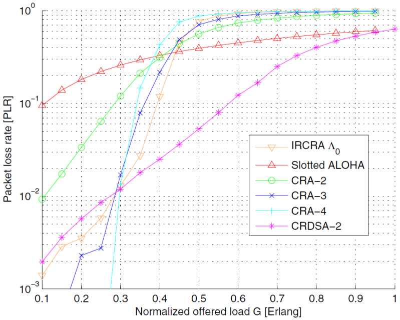




CRA Performance

uncoded CRA: Packet reception is successful if one fully interference-free replica is received

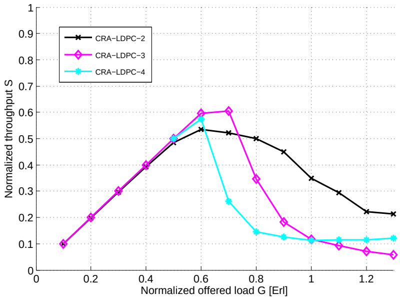


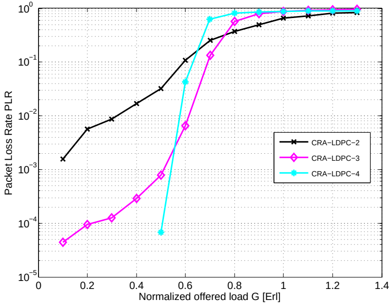


DLR

CRA Performance

coded CRA: QPSK with an LDPC (1024,512), SNR=10 dB
One replica may still be decoded if partly interfered (depending on the code)



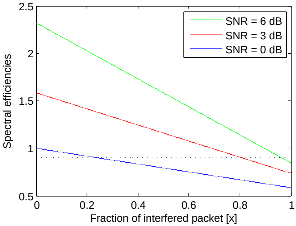


CRA Performance

- For unslotted schemes, there is a trade-off between throughput and spectral efficiency, η:
  - lowering η (w.r.t. channel capacity) brings more robustness to interference (collisions), and thus increases the throughput,
  - the optimal η depends on the SNR.
- Let's consider a benchmark threshold, from the Shannon bound computed over portions of the packet with uniform SN(I)R:

$$\mathbb{C}(x) = (1-x)\log_2(1+\text{SNR}) + x\log_2(1+\text{SNIR})$$

where x is the fraction of the packet interfered by 1 user with same TX power.



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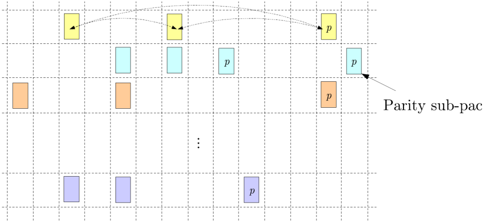
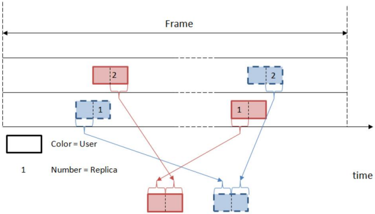
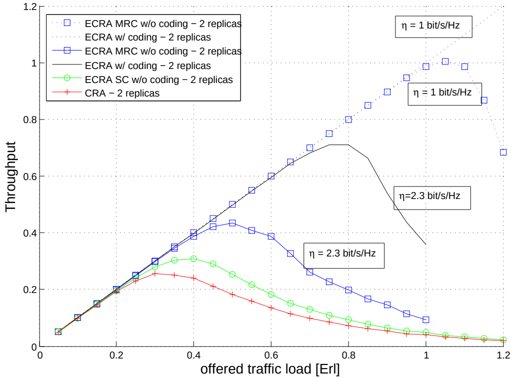
Coded slotted ALOHA (CSA) and ECRA Examples





ECRA Performance



- Different techniques are possible to encode/decode the *replicas*:
  - Selection Combining (SC),
  - Maximum-Ratio Combining (MRC),
  - Single codeword split over multiple packets,
  - Pkt-level code over the replicas (ECRA+?).
- Gains depend on η and SNR.
- For some schemes there is an additional coding gain.

CRA and ECRA: Summary

- CRDSA and IRSA exploit repetitions and SIC in the slotted case.
- CSA builds codewords over multiple packets/slots and attempts decoding, even if some packets/slots are erased.
- It is possible, by means of Graph-Based Density Evolution Analysis, to derive a *Capacity Bound*, i.e. the maximum reliable throughput for a given repetition rate [PaoliniLiva2011].

- CRA and Irregular-Repetition CRA (IRCRA) exploit repetitions and SIC in the unslotted case.
- ECRA(+) breaks one (or builds pkt-level) codeword over multiple unslotted replicas, and attempts joint decoding over them (pkts may be partially interfered).
- Is it possible to derive a dual model for the unslotted case?

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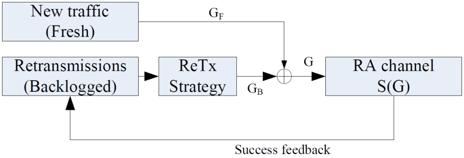
CRDSA with retransmissions

- Retransmission (ReTx) mechanism ensure a reliable packet delivery, but create *instability* problems.
- New (*fresh*) transmissions occur with probability p_0.
- Retransmission occur with probability p_r in every transmission opportunity (geometric distribution).
- We have finite user population M, and frames of N_S slots.
- Total load determined by two components:
  - Fresh offered traffic fluctuates statistically;
  - Retransmissions add on top of fresh transmissions (backlogged traffic).
- Question: How are the stability properties of CRDSA w.r.t. slotted ALOHA? Is the gain in throughput achieved at the cost of stability?



CRDSA with retransmissions

- Let us define a Markov chain with state variable, $X_B(l)$, the number of users in backlog at time l.
- The major differences to the slotted ALOHA (SA) analysis by Kleinrock are:
  - We don't have a closed-form expression for the throughput,
  - In SA the number of backlogged users, X_B can decrease of 1 per slot, in CRDSA of more than 1.
- we are interested in the drift, $d(x_B) = \mathbb{E}\{X_B(l+1) - X_B(l) | X_B(l) = x_B\}$.
- It is:

$$d(x_B) = \mathbb{E}\{\Phi\} - \mathbb{E}\{\Upsilon\}$$

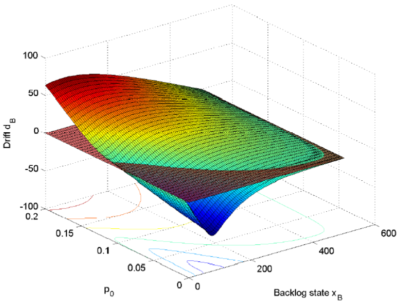
where Φ is the number of fresh transmissions, and
Υ is the number of successful transmissions, per frame

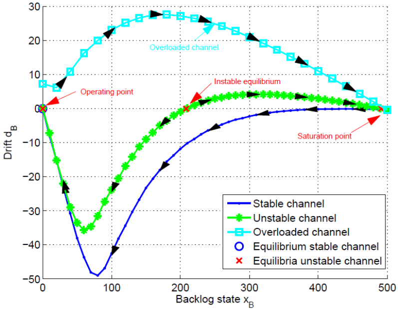
- Then:

$$d(x_B) = (M - x_B)p_0 - N_S T(G(x_B))$$

where $G(x_B) = (M - x_B)p_0 + x_B p_r$.

CRDSA with retransmissions



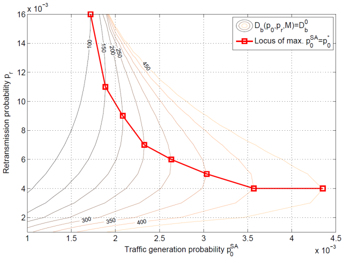


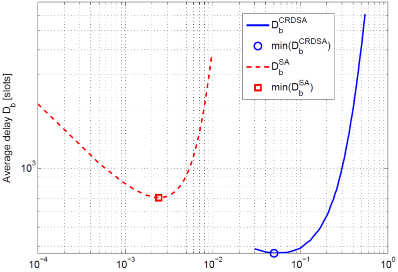
DLR

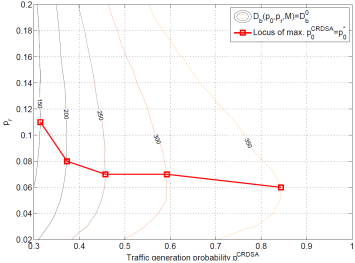
Retransmissions: CRDSA vs. SA

Select optimum p_r such to:

- Minimize the average delay D_b^x, for fixed user population M and fixed p_0
- Maximize the size of the user population M, for fixed p_0 and average delay D_b
- Maximize the supported p_0, for fixed M and D_b







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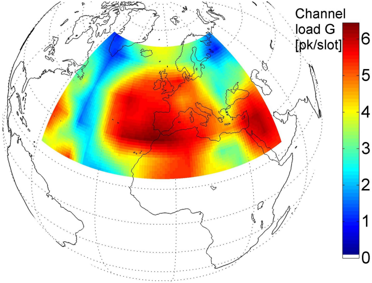
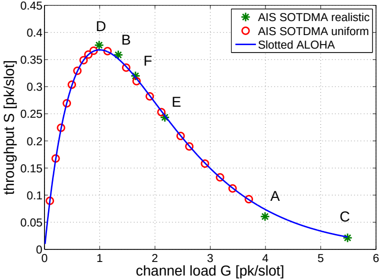
Automatic Identification System (AIS)

- Designed in the 90's to identify vessels, in order to improve safety and sea surveillance.
- Physical layer: 2 VHF channels ~ 160 MHz, with 9.6 Kbit/s bit rate, GMSK, no FEC.
- MAC: mainly based on Self-Organized TDMA (SOTDMA), clusters of transmitters can prevent collisions, hidden terminal problem remains, but unlikely.
- Range up to ~ 70 Km: designed for ship-to-ship or ship-to-shore communications.
- Today a few satellites exist that listen to AIS messages:
  - Vesselsat, 3 satellites (Luxspace/Orbcomm),
  - AISSat-1 (Norwegian),
  - Canadian-based exactEarth operates the largest network (5 satellites),
  - AAUSAT3, a cubesat from Aalborg Univ. (Denmark), with a traditional and an SDR-based receiver,
  - DLR AISat, with an helical antenna, to be launched in 2014,
  - ...

Automatic Identification System (AIS)

- At the satellite AIS traffic is seen as a Slotted ALOHA channel [Clazzer2014].
- A wide range of MAC channel load is perceived by a LEO satellite along its orbit.
- High-load regions (i.e. densely ship populated area) translate into poor tracking frequency for the vessels.
- Optimization of AIS-pkt transmission rates is possible, to maximizes the tracking frequency from the satellite (exploiting simple properties of SA).

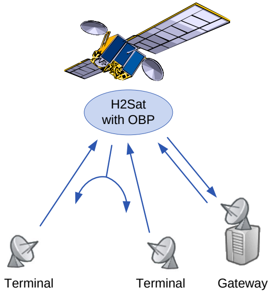




- [Clazzer2014] F. Clazzer, A. Munari, M. Berioli, F. Làzaro Blasco, "On the Characterisation of AIS Traffic at the Satellite," to appear at *OCEANS'14 MTS/IEEE*, Apr. 2014.

Heinrich Herz Satellite (H2Sat)

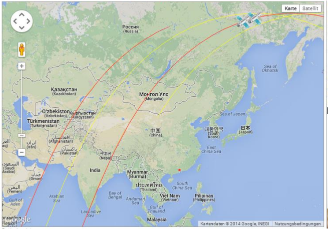
- Features:
  - Geostationary Satellite, being developed under German funding (DLR)
  - Ka band (~ 30 GHz uplink, ~ 20 GHz downlink)
  - Launch expected beginning 2017
- The availability of a small On-Board Processing (OBP) payload is under study:
  - Reconfigurable for different experiments,
  - A/D & D/A-converters, Memory, Processor,
  - Temporarily switchable to transparent Transponder,
  - operating under real Ka-band conditions.



Other systems

- Cubesats (currently 133 on Wikipedia, counting planned, launched, and under development),
  - started in 1999 by California Polytechnic State University (Cal Poly) and Stanford University, with the idea to standardize a picosat shape to fit in a given Orbital Deployer (10 x 10 x 30 cm)),
  - very cheap to develop (many COTS components available), and to launch (standard shape), a few months of life can be considered for a well-developed one,
  - easy and exciting way to have a on-field test of communication system, a few SDR-based ones are already flying.

- Global Sensor Network, funded by the Australian Space Research Program (ASRP):
  - IEEE Comm. Magazine Dec 2013, Newsletter.
  - Project awarded to Prof. Alex Grant, Univ. of South Australia, Institute for Telecommunications Research.



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Conclusion

- Novel schemes for the unslotted Aloha show promising performance.
- The trade-off between spectral efficiency and throughput is not fully understood, yet.
- A comprehensive analysis from a theoretical point of view would be desirable (in a way similar to what was done for the slotted cases?).
- There are a number of (satellite) systems where these schemes would be good candidate solutions, and a few scenarios that would allow their (SDR-based) implementation and test under real conditions.

References

- **CRA:** C. Kissling, “Performance Enhancements for Asynchronous Random Access Protocols over Satellite,” IEEE ICC, June 2011.
- **CRA with coding:** C. Kissling, F. Clazzer, “LDPC Code Performance and Optimum Code Rate for Contention Resolution Diversity ALOHA,” IEEE Globecom, Dec. 2013.
- **ECRA:** F. Clazzer, C. Kissling, “Enhanced Contention Resolution Aloha - ECRA,” Proceedings of 9th International ITG Conference on Systems, Communication and Coding (SCC), Jan. 2013.
- **CRDSA Stability:** C. Kissling, “On the Stability of Contention Resolution Diversity Slotted ALOHA,” submitted to the *IEEE Trans. Commun.*, http://arxiv.org/abs/1203.4693.

谢谢

Thank you!