Solutions for massive and secure Internet of Things networks

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Outline

- Introduction to the PhD activities
- Uncoordinated access schemes for the IoT
- Multirate ALOHA protocols for Machine-Type Communication

Introduction to the PhD activities

Introduction

- Internet of Things (IoT) paradigm: sensors and microcontrollers are extended into the world of everyday objects and actively exchange information to achieve common goals.
- Cyber-Physical Systems (CPSs): engineered systems that deeply integrate with the physical environment surrounding them.
  - Can be considered a subset of the IoT
  - A CPS is composed by a network of elements that interact with the physical world through computation, communication, and control capabilities.

Challenges

- Traditionally, the design of the cyber and physical parts of a system have been decoupled.
- CPS emphasizes a holistic system view where the focus is on the inter-dependency and interaction of both parts of the system.
- Heterogeneity makes the analysis of these systems a major challenge.
- While many of the techniques presented in the thesis can be applied in general IoT scenarios, the focus is mainly to CPSs applications.

Structure

Networks in CPSs

- Reliable and low-latency message delivery
- Source models for MTC
- Uncoordinated access schemes for the IoT and their optimization
- Strategies to balance energy efficiency and accuracy in monitoring applications

Machine learning techniques for CPS optimization

- Cell traffic prediction using spatio-temporal information
- Dynamic video streaming
- Positioning services

Security in IoT scenarios

- CPSs can harm people or animals and damage things
- Security issues → safety issues
- Enhanced authentication mechanisms

Uncoordinated access schemes for the IoT: approaches and performance

Channel access techniques

Pure ALOHA

- Used by many LPWAN systems, e.g., LoRaWAN, Sigfox
- No collision avoidance mechanism
- Simple to implement

Listen-Before-Talk (LBT/CSMA)

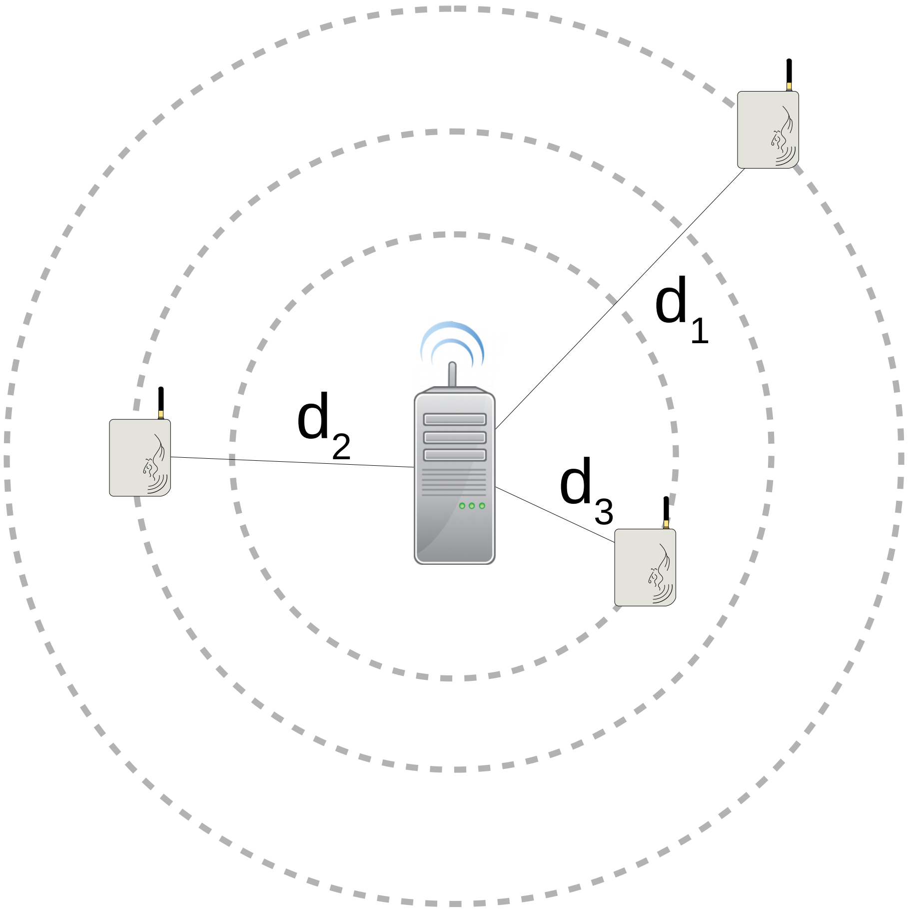
- Used by, e.g., IEEE 802.15.4
- Tries to avoid collisions by listening to the channel
- Hidden / Exposed node problems

LBT issues

- In the listening phase, other transmissions may not be detected, because:
  - The transmitting device is too far away.
  - Two devices start the listening phase and, thus, the transmission at the same moment.
- The listening phase requires an additional energy expenditure when trying to transmit.

Simulative scenario

- Single-hop network
- Devices use a rate adaptation (RA) technique:
  - far node → low rate
  - near node → high rate



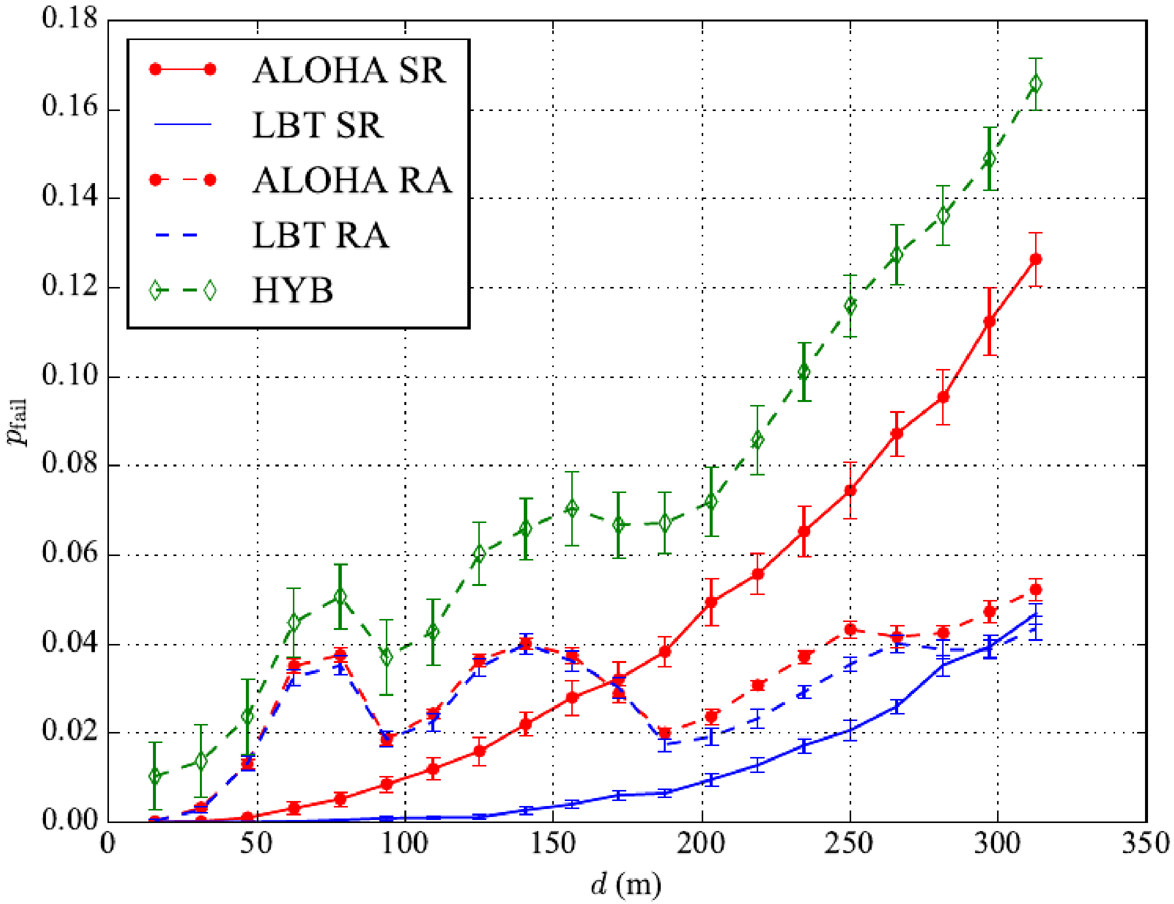
Innovations

- Investigate the efficiency of CSMA/LBT techniques in
  - long-range networks
  - rate-adaptive networks

- Understand what factors influence performance the most

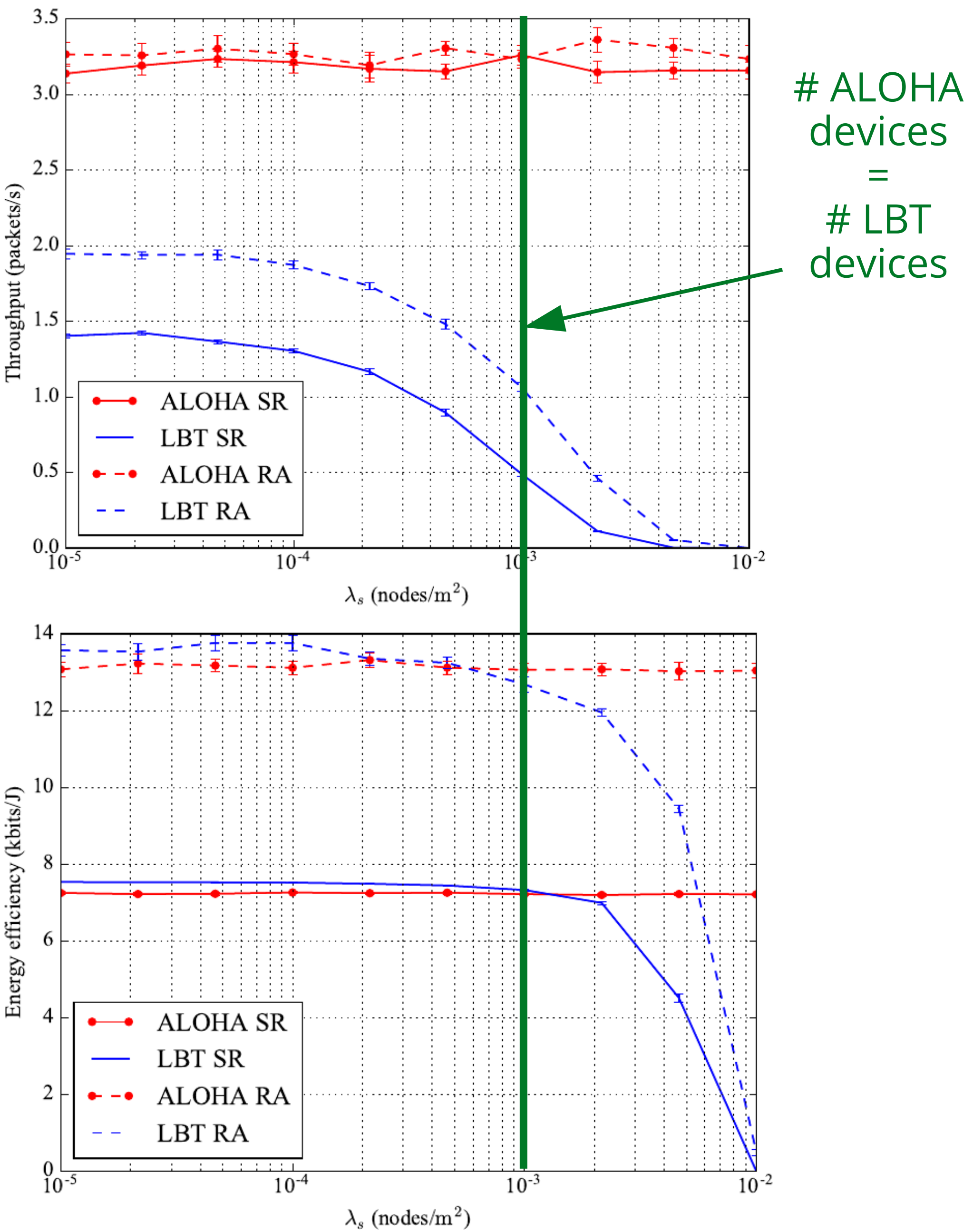
ALOHA vs Listen-Before-Talk

- LBT offers better performance over ALOHA, but this advantage disappears in rate adaptive scenarios



Coexistence issues

- Current deployments see a mixture of different technologies
- ALOHA does not suffer from throughput and efficiency loss when coexisting with LBT
- ALOHA dominant, LBT recessive



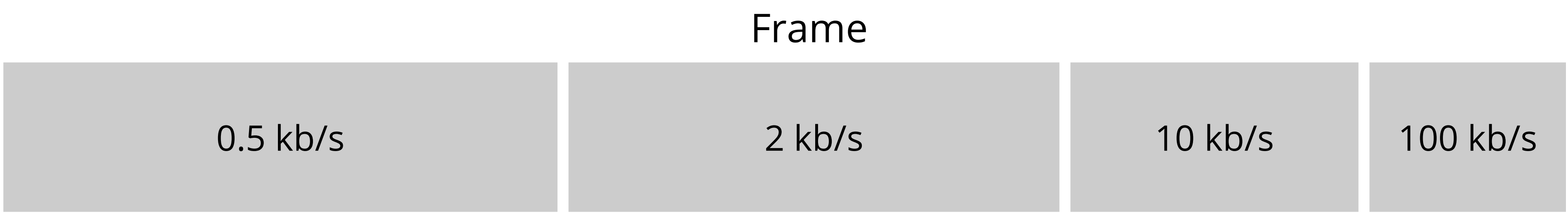
Lessons learned

- The use of multiple rates is mandatory for great performance
- In RA scenarios, performance between ALOHA and LBT is comparable
- ALOHA has less coexistence issues than LBT

Multi-rate ALOHA Protocols for Machine-Type Communication

Multirate-Split Slotted ALOHA (MSSA)

- Time is divided in frames, each one contains many transmission windows, one for each bitrate
- In each window, access according to a slotted ALOHA protocol
- The number of slots in each window is optimized to get max throughput



MSSA optimization problem

of pcks with i-th rate

$$\max_{n_1,\ldots,n_k} \sum_{i=1}^{k} G_i T_F e^{-\frac{G_i T_F}{n_i}}$$

time-on-air of pck

$$\text{s.t.} \quad \sum_{i=1}^{k} n_i \frac{L_{\text{pck}}}{r_i} \leq T_F$$

$$\{n_i \in \mathbb{N};\ i = 1, \ldots, k\}.$$

# of slots for i-th rate

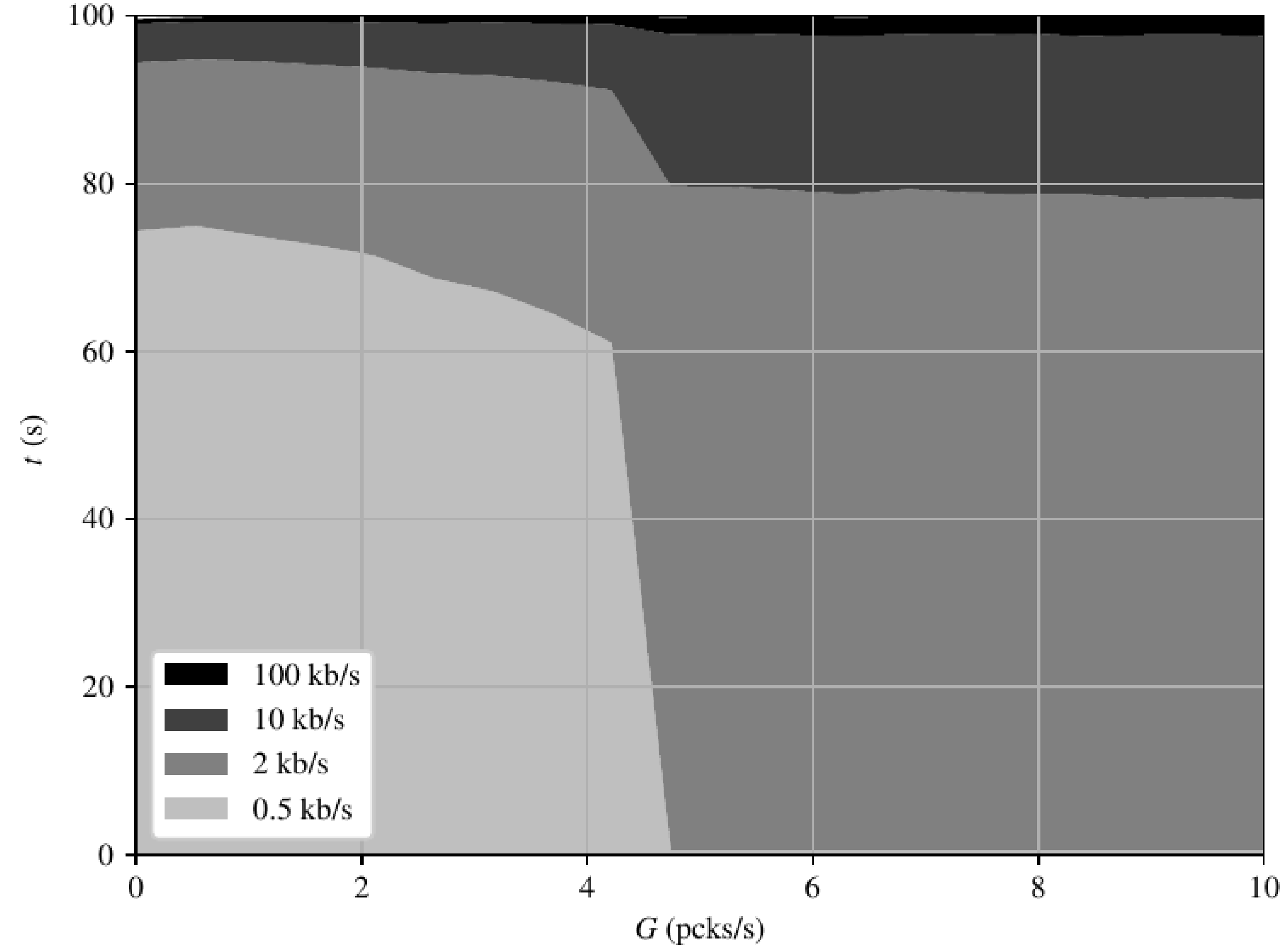
Solved using the heuristic *Differential Evolution* technique

Frame

0.5 kb/s	2 kb/s	10 kb/s	100 kb/s

MSSA optimization results

Time reserved for each rate, for different values of the offered traffic.

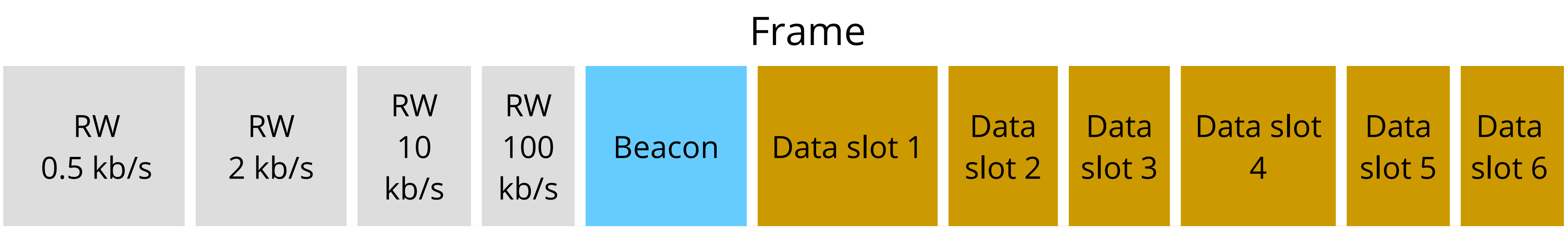


Frame

0.5 kb/s	2 kb/s	10 kb/s	100 kb/s

Multirate ALOHA Reservation Protocol (MARP)

- Time is divided in frames, each one contains
  - reservation windows, one for each rate: access according to a slotted ALOHA protocol (with #slots optimized to provide the best throughput)
  - a beacon with resource grants
  - collision-free data slots



MARP optimization problem

- Same as MSSA, except for the frame duration, and hence for the constraint on number of slots

$$\overline{T}_F \geq \frac{L_H}{r_1} + \sum_{i=1}^{k} \frac{n_i L_{\mathrm{RM}} + G_i \overline{T}_F e^{-\frac{G_i \overline{T}_F}{n_i}} (L_{\mathrm{pck}} + L_{\mathrm{RM}}) + L_F}{r_i}$$

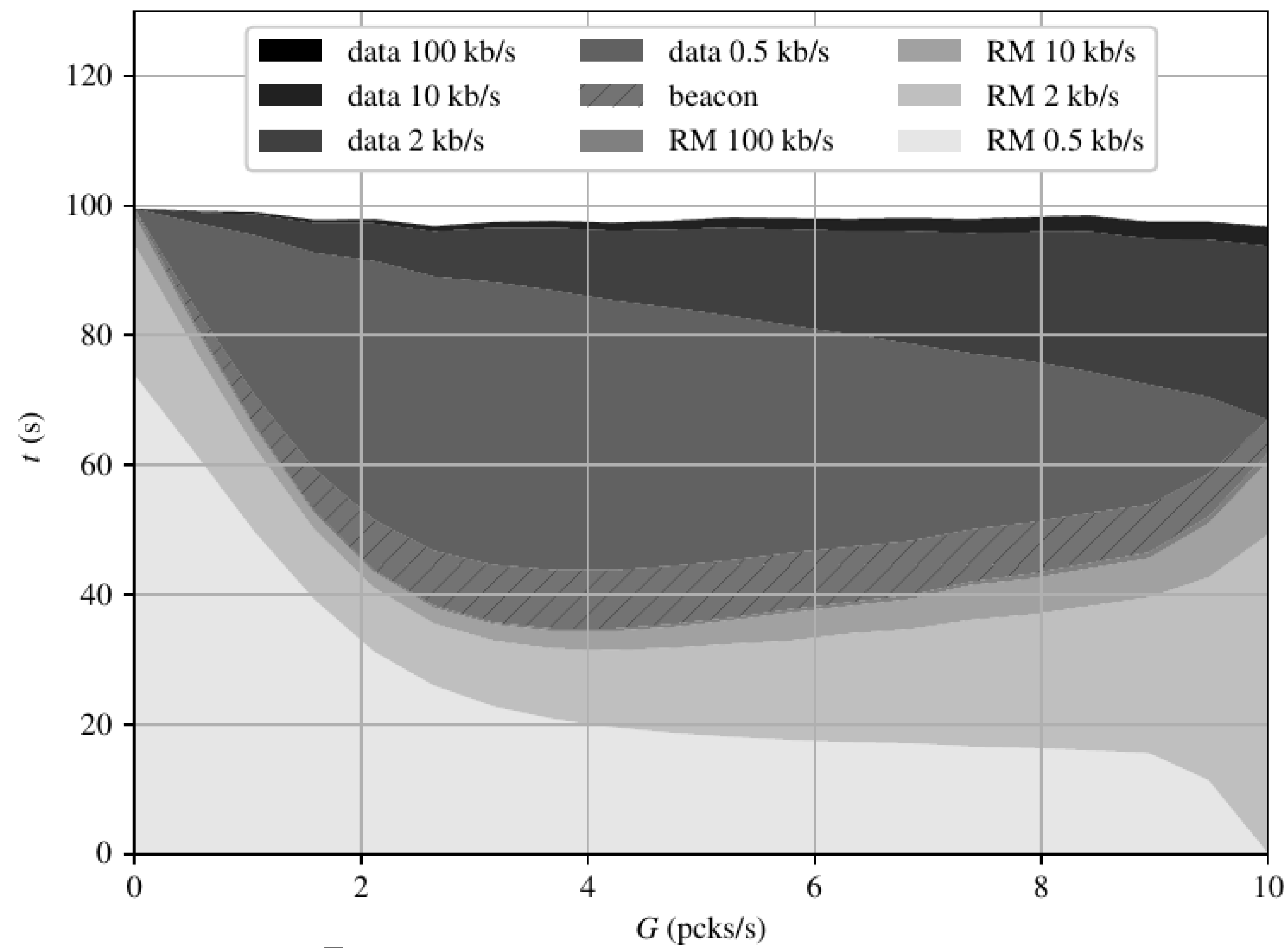
- $\overline{T}_F$: avg. frame duration
- L_H: time-on-air of beacon header
- n_i: # of reservation slots for i-th rate
- L_{RM}: size of reservation msg.
- $G_i \overline{T}_F e^{-\frac{G_i \overline{T}_F}{n_i}}$: # of successful reservations
- L_{pck}: pck length
- L_{RM}: length of each reservation grant
- L_F: rate-switching flag size

Frame

RW 0.5 kb/s	RW 2 kb/s	RW 10 kb/s	RW 100 kb/s	Beacon	Data slot 1	Data slot 2	Data slot 3	Data slot 4	Data slot 5	Data slot 6

MARP optimization results

Time reserved for each rate, for different values of the offered traffic.



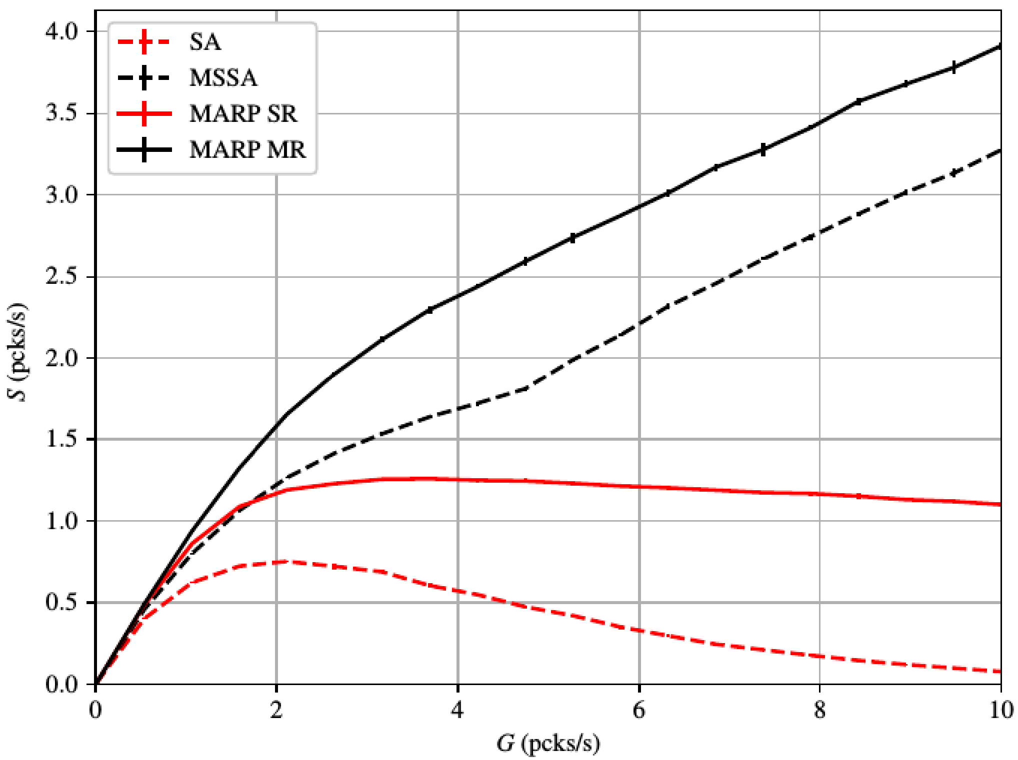
Frame

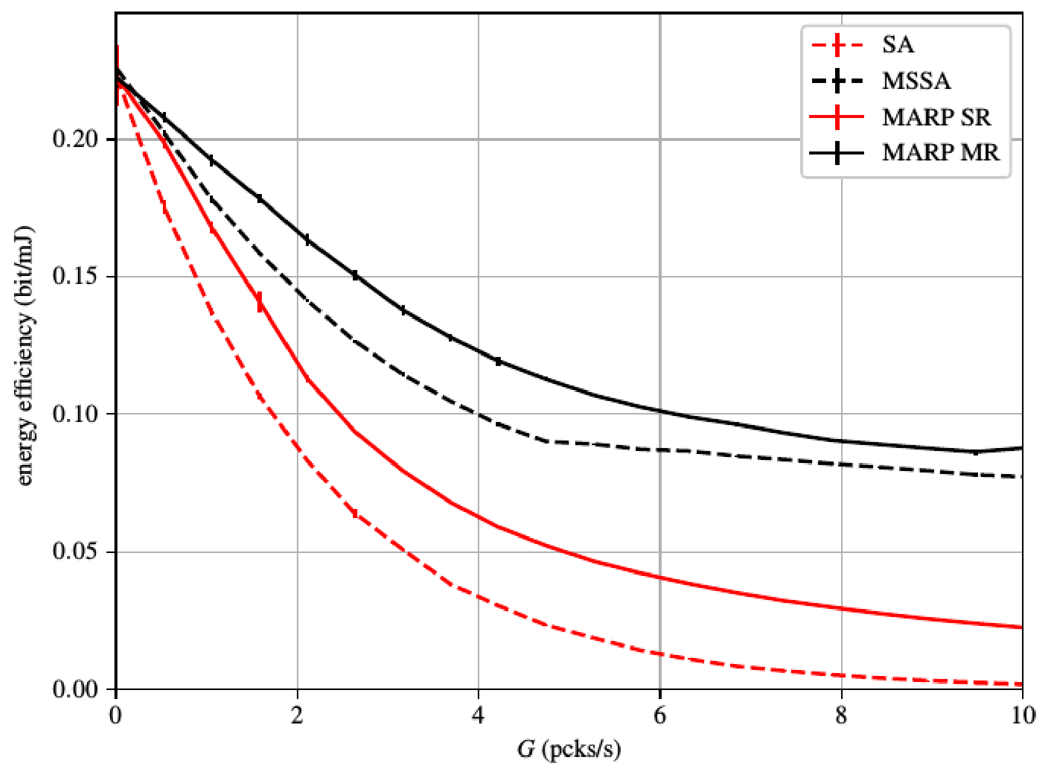
Novelties of the proposals

- **Splitting of access resources** based on the node’s data rates
- Transmission of **control information at the same rate of** the associated **data** packets
- **Dynamic adaptation of the frame duration and organization** to the rate-distribution of the channel access requests

Performance of MSSA and MARP

(**reservation-based**) MARP achieves both better throughput and energy efficiency than the (**SA-based**) MSSA protocol





Conclusions

- Our protocols provide **higher throughput** and make it possible to sustain **higher traffic** than slotted ALOHA.
- **MARP** achieves the **best performance** when the **traffic offered** to the channel becomes **critical**.

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