Solutions for massive and secure Internet of Things networks

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PhD Supervisor: Prof. Andrea Zanella
• 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.
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 $\rightarrow$ low rate
  - near node $\rightarrow$ 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

| Frame | 0.5 kb/s | 2 kb/s | 10 kb/s | 100 kb/s |
MSSA optimization problem

Solved using the heuristic *Differential Evolution* technique

\[
\text{max } \sum_{i=1}^{k} G_i T_F e^{-\frac{G_i T_F}{n_i}}
\]

s.t.

\[
\sum_{i=1}^{k} n_i \left( L_{pck} \frac{L_{pck}}{r_i} \right) \leq T_F
\]

\[\{n_i \in \mathbb{N} \ ; \ i = 1, \ldots, k\}\]

Frame

- 0.5 kb/s
- 2 kb/s
- 10 kb/s
- 100 kb/s
Time reserved for each rate, for different values of the offered traffic.
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

\[
\bar{T}_F \geq \frac{L_H}{r_1} + \sum_{i=1}^{k} n_i L_{RM} + G_i \bar{T}_F e^{-\frac{G_i \bar{T}_F}{n_i}} (L_{pck} + L_{RM}) + L_F
\]

- Avg. frame duration
- Size of reservation msg.
- # of successful reservations
- Length of each reservation grant
- # of reservation slots for i-th rate
- Pck length
- Rate-switching flag size
- Frame

<table>
<thead>
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<th>RW</th>
<th>Data slot 1</th>
<th>Data slot 2</th>
<th>Data slot 3</th>
<th>Data slot 4</th>
<th>Data slot 5</th>
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<td>Beacon</td>
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</table>
Time reserved for each rate, for different values of the offered traffic.
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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