Introduction

Motivation
- Energy is a key issue in Wireless Networked Control Systems (NCS).
- Up to 80% of the total power is consumed by the radio unit.
- Reliability and latency can be balanced to save energy and to meet control requirements.

Goal of this work
- Literature survey to identify how energy can be saved in Wireless Networked Control Systems.

Approach
- Focus on energy-aware communication and control.
- Use of four layers architecture, the NCS stack.
- Physical layer – Radio modulation,
- Data Link (MAC) layer – Medium sharing,
- Network (routing) layer – Data routing,
- Application layer – Source coding and control.

Physical layer

Power control[1,2,3]
- Change transmission power to improve communication quality.
  Objective
  - Increase reliability
  - Limit interference
  - Face a varying channel
  Limitation
  - Extra communication for the control may cost more than the saved energy

Bit rate control[4,5]
- Switch modulation characteristics.
  Objective
  - Decrease error rate
  - Some energy consumption
  Limitation
  - Synchronization of transmitter and receiver
  - Increase latency

Data Link (MAC) layer

Activity mode management[6]
- Activity mode is a state of activity of the node (ON, Idle, OFF) where some components are turned off.
  Objective
  - Trade-off energy/awareness
  - Avoid idle-listening state
  Limitation
  - TDMA scheduling not scalable
  - Control is not trivial

MAC protocol tuning[7,8,9,10]
- Adapts parameters of the protocol (e.g. slot length, sleep and listening times).
  Objective
  - Balance reliability and latency to meet control requirements
  - Minimize energy consumption
  Limitation
  - No existing protocol dedicated to NCS

Network layer

Energy efficient routing[11,12]
- Efficiency metric is the network life-time.
  Objective
  - Choose the less costly path
  - Ensure quality of service
  Limitation
  - No existing protocol dedicated to NCS
  - No consideration about the application

Network coding[13]
- Nodes perform some processes on the data before relaying it.
  Objective
  - Limit the amount of data in the network
  - Recover from network failures
  Limitation
  - Not common in NCS
  - Strongly depends on data type and application

Application layer – Quantization and source coding

Quantization and rate constraints[14,15]
- Quantization from analog phenomena to digital data introduces loss. Traffic is bounded in a network.

Source coding[16,17]
- Compress the data measured by the sensor.
  Objective
  - Limit the amount of data and/or the occurrence of communication
  Limitation
  - Conflict between source coding and network coding

Conclusion and future directions

Conclusion
- Cross-layer design is imperative to satisfy application requirements with limited energy resources.
- Such designs already exist (RFID wake-up hardware, Network Aware Source Coding, Distributed Source Coding, battery aware MAC protocols).
- But almost no work considers the four layers in the stack. There is a need for a protocol dedicated to NCS.

Future directions
- Management of activity modes in the framework of NCS:
  - Focus: adapt the activity modes to meet the control requirements (trade-off between energy and performances),
  - Goal: avoid waste of energy caused by idle-listening state.

References