Energy Efficiency of Wireless Sensor Networks

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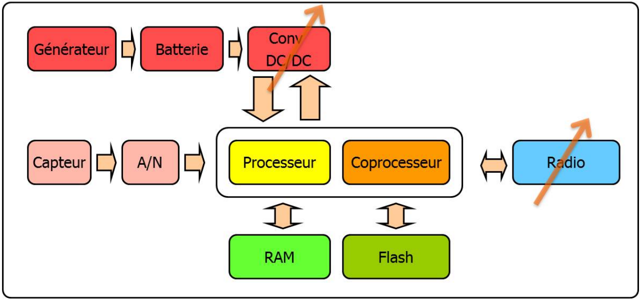
Wireless Sensor Networks

- Wide range of Wireless Sensor Network (WSN) applications
  - Health, buildings and agriculture monitoring, defense, etc
  - 2B€ per year market until 2022
- Set of smart radio nodes generating and relaying messages
- Ad Hoc, fault tolerant networks
- Low cost, low traffic and low power

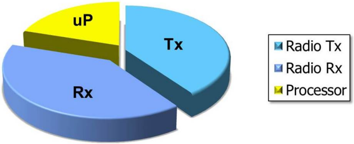
Which parts of a WSN node are energy consuming?

A WSN node is a typical embedded system



Classical power budget

- Radio: 30-70 mW
- Processor: 5-10 mW

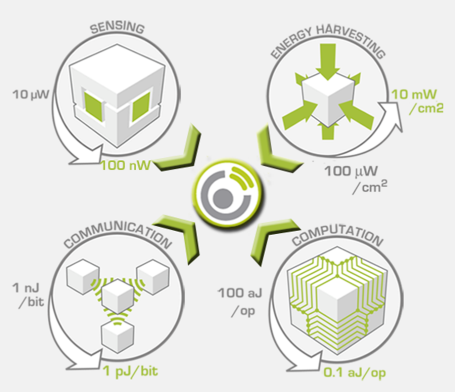


How to design an energy efficient WSN platform?

1. Decrease Transmit Power
- Efficient signal processing
- Error detection and correction

2. Optimize radio activity
- MAC protocols
- Wake-up radio

3. Optimize hardware architecture
- Co-processing, DVFS, power-gating
- Energy harvesting



source: http://www.ga-project.eu/

Goal of future WSNs: reach energy autonomy!

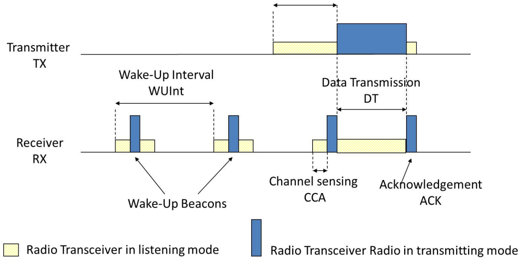
Outlines

CAIRN Team WSN Platform : PowWow

Hardware components

- TI MSP430 Microprocessor
- TI CC2420 Radio transceiver
- Actel Igloo FPGA coprocessor
- Energy harvesting board

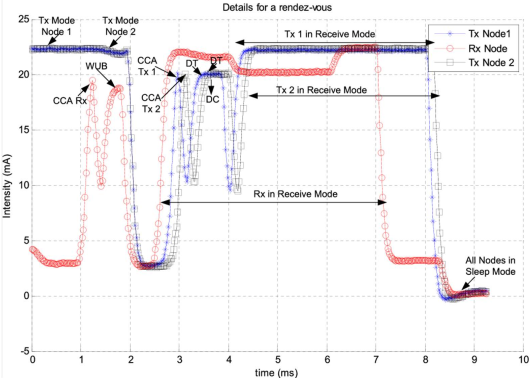
Asynchronous MAC protocol: well suited to low traffic applications



Hybrid energy model

Scenario-based hybrid model [M. Cartron and M.M. Alam PhDs]

- Real-Time measurements for scenarios
- Analytic expressions for traffic parameters
- Accurate energy consumption estimation [EURASIP_JES_11]



Energy Optimization Methodology

Algorithm Library

- Channel coding
- Compression
- Modulation
- Cooperation
- Medium access
- Routing

Target

- Microrocessor
- FPGA
- Power-gating
- DVFS

Energy Optimization Methodology

Application constraints

Network topology

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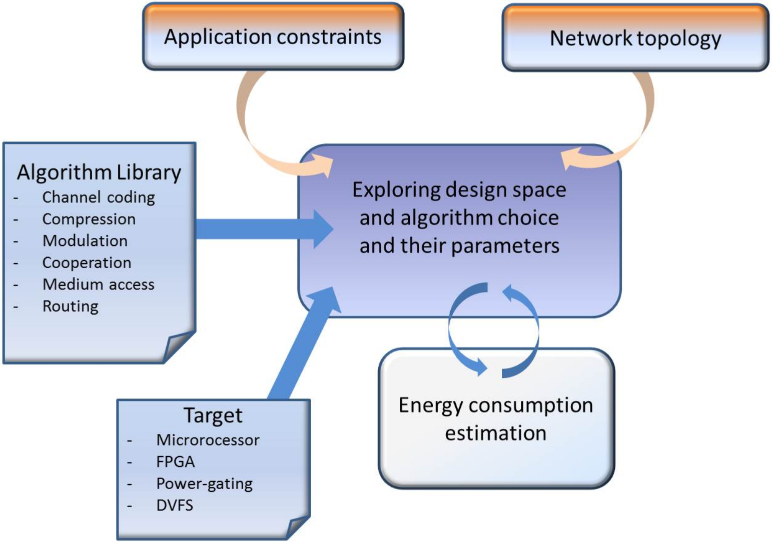
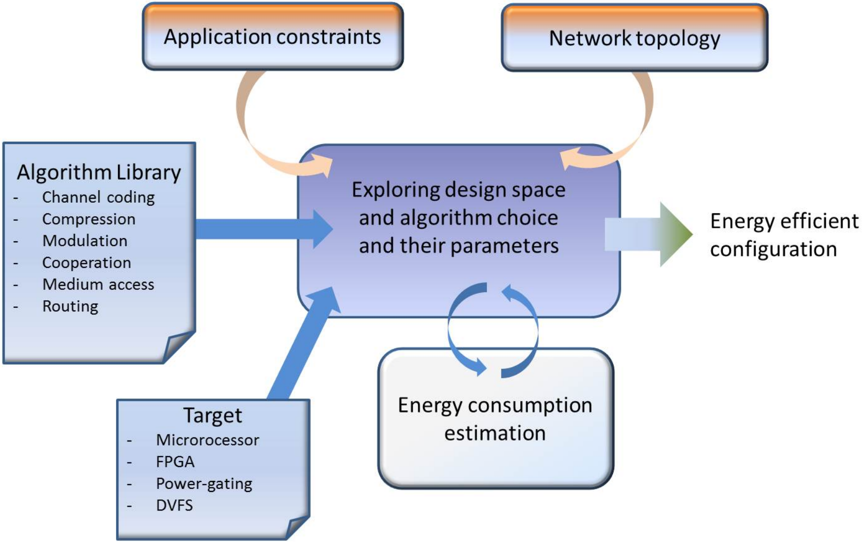
Energy Optimization Methodology



Energy Optimization Methodology



Adaptive PHY and MAC layers

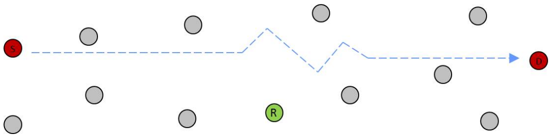
Transmit power optimization [M. Cartron PhD]

- Lifetime increase through static TX power tuning
- Different coding schemes investigated (implementation on low-power FPGA)
- Dynamic TX power adaptation

Wake-up interval optimization [M.M. Alam PhD]

- Static adaptation to application constraints [DASIP07]
- Traffic-Aware Dynamic MAC protocol [IEEE_JETCAS_12, IWCLD11, BSN11]
  - Definition of Traffic Status Registers
  - Self-adaptive algorithm
  - Significant reduction of idle listening

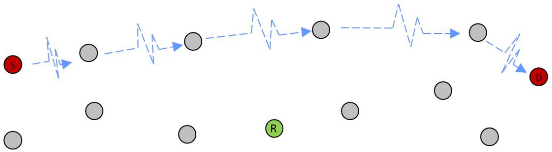
Cooperative strategies



Which one to choose between

- Direct transmission: fast but energy consuming (when possible)

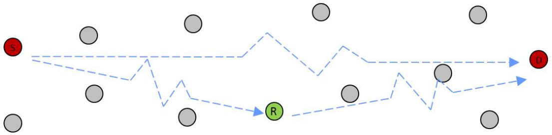
Cooperative strategies



Which one to choose between

- Direct transmission: fast but energy consuming (when possible)
- Multi-hop: variable latency

Cooperative strategies



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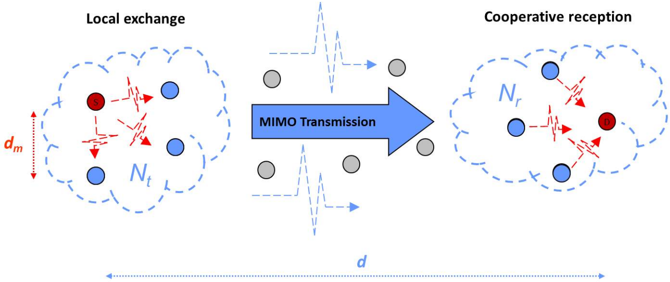
- Direct transmission: fast but energy consuming (when possible)
- Multi-hop: variable latency
- Cooperative relay: simple, reliable

Cooperative strategies



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- Direct transmission: fast but energy consuming (when possible)
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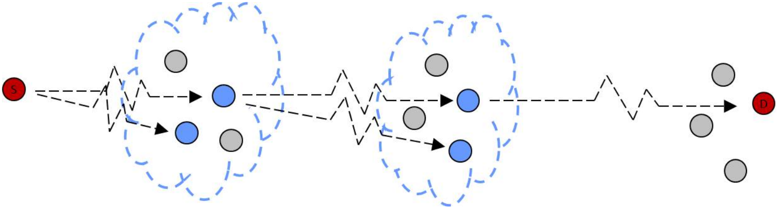
- Cooperative MIMO: efficient but synchronization requirement and complex reception

Cooperative strategies

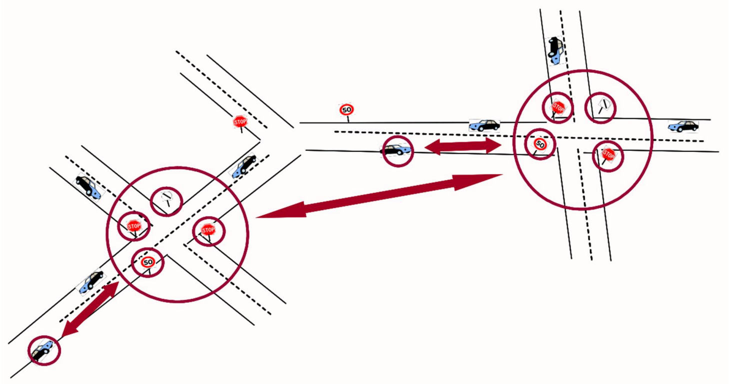


Which one to choose between

- Direct transmission: fast but energy consuming (when possible)
- Multi-hop: variable latency
- Cooperative relay: simple, reliable
- Cooperative MIMO: efficient but synchronization requirement and complex reception
- Opportunistic relaying: reliable but variable latency

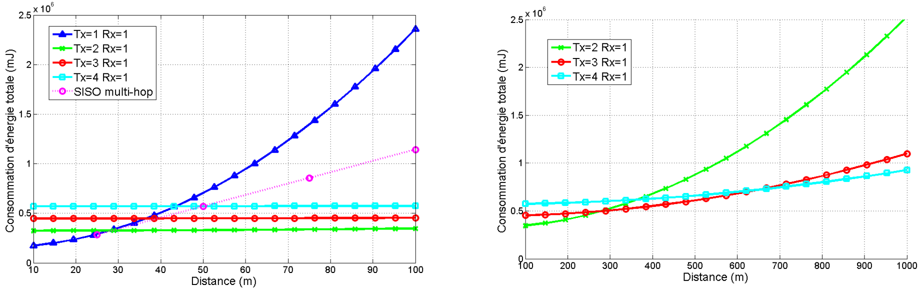
ITS Application Context

- Application constraints and network topology can drive cooperative scheme choice
- Infrastructure to Vehicle (I2V) Communications in CAPTIV[1]
- Cooperative MIMO well suited to crossroads configuration



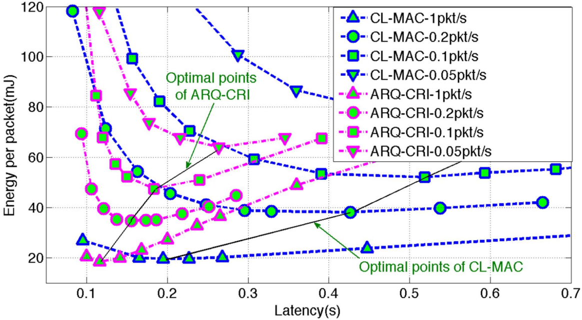
[1] Cooperative strAtegies for low Power wireless Transmissions between Infrastructure and Vehicles

Energy efficiency of cooperative MIMO [T.D. Nguyen PhD]



- Energy models (literature, transceiver characteristics)
- Cooperative MISO more energy efficient from 30 meters
- Cooperation at the receiver not really energy efficient

Cooperative relaying protocols [Q.V.L. Tran PhD]



ARQ-CRI MAC protocol [D.L. Nguyen Ms Thesis, ICC13]

- Automatic Repeat Request Cooperative Receiver Initiated
- For low traffic, ARQ-CRI far more energy efficient
- For higher traffic, same energy but lower latency for ARQ-CRI
- For each optimal point, best energy-delay trade-off

Implementation of cooperative techniques

This recent research domain lacks...

experimental platforms!

- Proof of concept with real conditions
- Validating implementation problems such as:
  - Synchronization needs (virtual MIMO for instance)
  - Channel state information transmission in MH networks
- Self-tuning to find experimentally best strategies

Equipex Future Internet of Things

- More than 50 software defined radio nodes (some MIMO compliant)

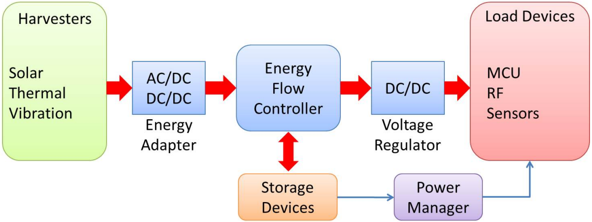
AMI ADEME EGUISE

- Electric vehicles management
- Onboard multistandard radio nodes for communication

Towards a complete autonomy of wireless nodes

Power manager design [GRECO, N.L. Trong PhD]

- Multi-source harvesting hardware
  - Light, Heat, Moves, RF, Bio ...
- Prediction algorithms
- Energy neutral operations
- Efficient implementation



Fit-Cortex lab in a nutshell

FIT Future Internet (of Things)

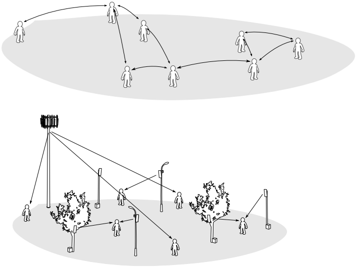
www.fit-equipex.fr
www.cortexlab.fr

Cortex lab - Experimental wireless testbed

- Isolated room
- Worldwide web access
- Phy-layer programming capabilities

Applications:

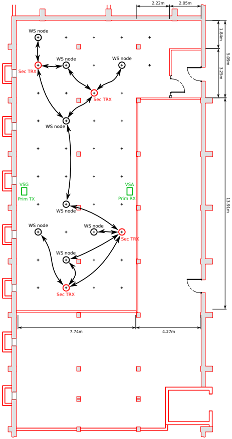
- Ad-hoc network,
- Primary-secondary cognitive radio networks
- Dynamic spectrum access
- Distributed MIMO
- ...

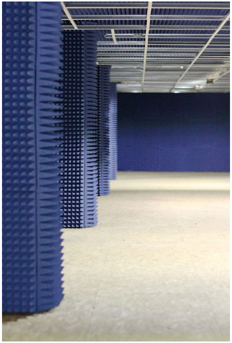


Experimentation Room

3 years of deployment - 7 years of exploitation - Total investment of 1M€

- $\sim$ 200 m^2 in experimentation room area
- Operating between 300 MHz - 3 GHz (for SDR cards)
- 28 MHz of bandwidth
- $\sim$ 500 m^2 of electromagnetic isolation material
- $\sim$ 300 m^2 of radio absorbers





⇒ Aprox. 80 nodes in two types (Software Defined Radio and Sensor)

Node technologies

- Sensor network nodes (SensLAB):
  - 2.4 and 5 GHz ISM band
  - Power over ethernet
  - Possibility to deploy custom firmwares
- Flexible Software Defined Radio nodes:
  - CPU and FPGA radio block interchangeability
  - Wide-band RF (300 MHz - 3 GHz)
  - Possibility to switch to home-made RF
  - MIMO and SISO availability

and...

- Remote accessibility
- Remote management
- Open source (no closed IPs or licenses)
- Total budget of about 300 k€

Cairn's involvement: Towards smart radio nodes...

Challenge

Prototyping a remote implementation of wireless protocols/radio on a hardware FPGA platform.

Design methodology: full FPGA software defined radio

Goal: FPGA design from high level specifications.

- low power and high operating frequency / processor-based SDR
- easy programming and rapid prototyping / direct FPGA design
- Design flow leveraging High Level Synthesis tools [VTC13]

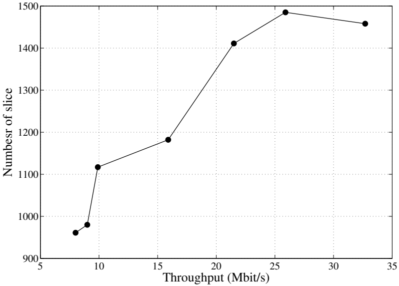
Algorithm

Goal: reduce energy consumption of the node

- Low power OFDM receiver using variable bitwidth
- Spectrum agility in BAN [CROWNCOM14]

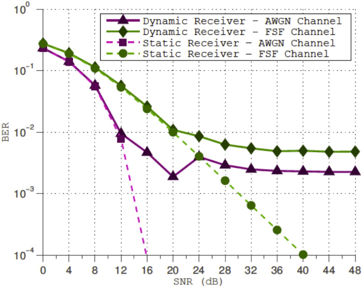
Some results on an IEEE 802.11a receiver...

Fast prototyping
from high-level description



Design space exploration ⇒ area gain

Adapt accuracy based on
channel and noise estimation



Up to 64% of energy saved

Conclusions

WSN Energy optimization

- Radio consumption is a real problem!
- Energy optimization is complex and cross-layer
- Adaptive and cooperative techniques are promising but difficult to implement

Software Defined Radio for WSN

- Potential solution for all these adaptive techniques
- Cognitive radio deals with interferences
- Still energy consuming but not so much
- Exploration of low power hardware processors for SDR based WSN

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Thanks for listening !