Simulation of Heterogeneous IPv6 Infrastructure for Smart Energy Efficient Building

Energy Efficiency (EE): how could we make it work ?

Cedric Chauvenet, Leila Ben Saad, and Bernard Tourancheau

CITI, INSA Lyon
LCIS, Valence,
INRIA, LIG Drakkar, Grenoble
Watteco inc.

Journées SEMBA, 21 Octobre 2011, Valence

Outline

- Context and problem statement
- IPv6 for Building Management Systems (BMS)
- Improving battery powered network duration (lifetime)
- Data collectors (sinks) placement
- Heterogeneous wireless (RF) – Power Line Communication (PLC) networking architecture
- Conclusion and Future works

Context and problem statement

- A huge part of energy consumption
  - 44% of 2007 France's raw energy
- Introduces many new applications
  - Oustide Buildings : SmartGrid
  - Inside Buildings : Energy Management, Home Area Networking, Home Automation...
- Internet of Things (IoT) is emerging :
  - Hardware & Software improvements
- BMS should pay for itself within a few years:
  - Maintenance (Battery replacement)
  - Infrastructure (Wires)
  - Bill of Materials (BoM)

Internet Networking : why ?

- EE improvement often needs interactions between systems
  - control, monitoring, command, alert, pricing, availability, prediction, external services, remote management, ...
- IP is the only widely accepted and proven networking solution
  - robust, open, well known, apps inheritance ...

→Need of IP over Heterogeneous devices

Low power & Lossy Networks

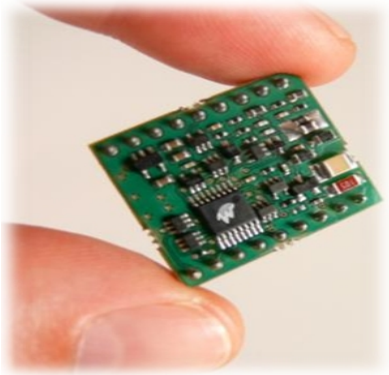
- EE implies Low Power Networks
  - Joules economy applies for BMS too !
- Low Power (often) implies Lossy networks
  - Wireless **and** Wired technolgies
- System on Chip (μC) availability for BMS
  - very constrained resources: power, memory, ...
- No Moore's law for battery technology !
  - NiCd improved by x2 over 30 years…

Power Line Communication

❑ Low Power PLC

- Standard Homeplug:
  - AV: OFDM / 20 - 200Mbps
  - GP: OFDM / 4 - 10 Mbps
- **BUT :**
  - Costly: a few $
  - Power consumption : few Watts
  - Size: Big

- The WPC™ Transceiver from Watteco:
  - Specific Transceiver
  - 10 kbps
- **AND :**
  - 1$
  - 10 mW
  - 25 mm² large prototype



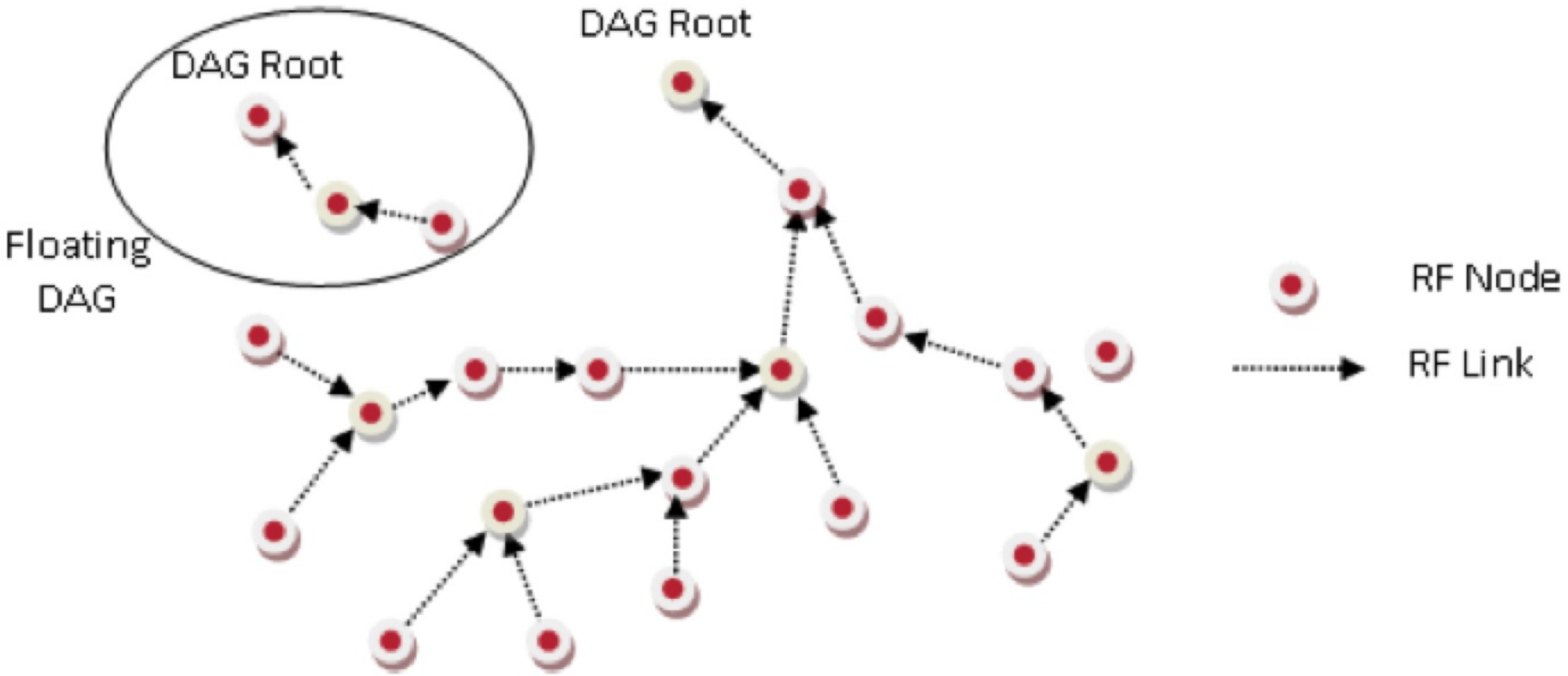
Problem Statement

- Push IP networking into these SoC devices
- Interoperate with all available media
  - wired, Wireless, PLC
- Achieve very long architecture lifetime
  - dozen of years
- Scale to Billion

IPv6 stack for Sensor Networks

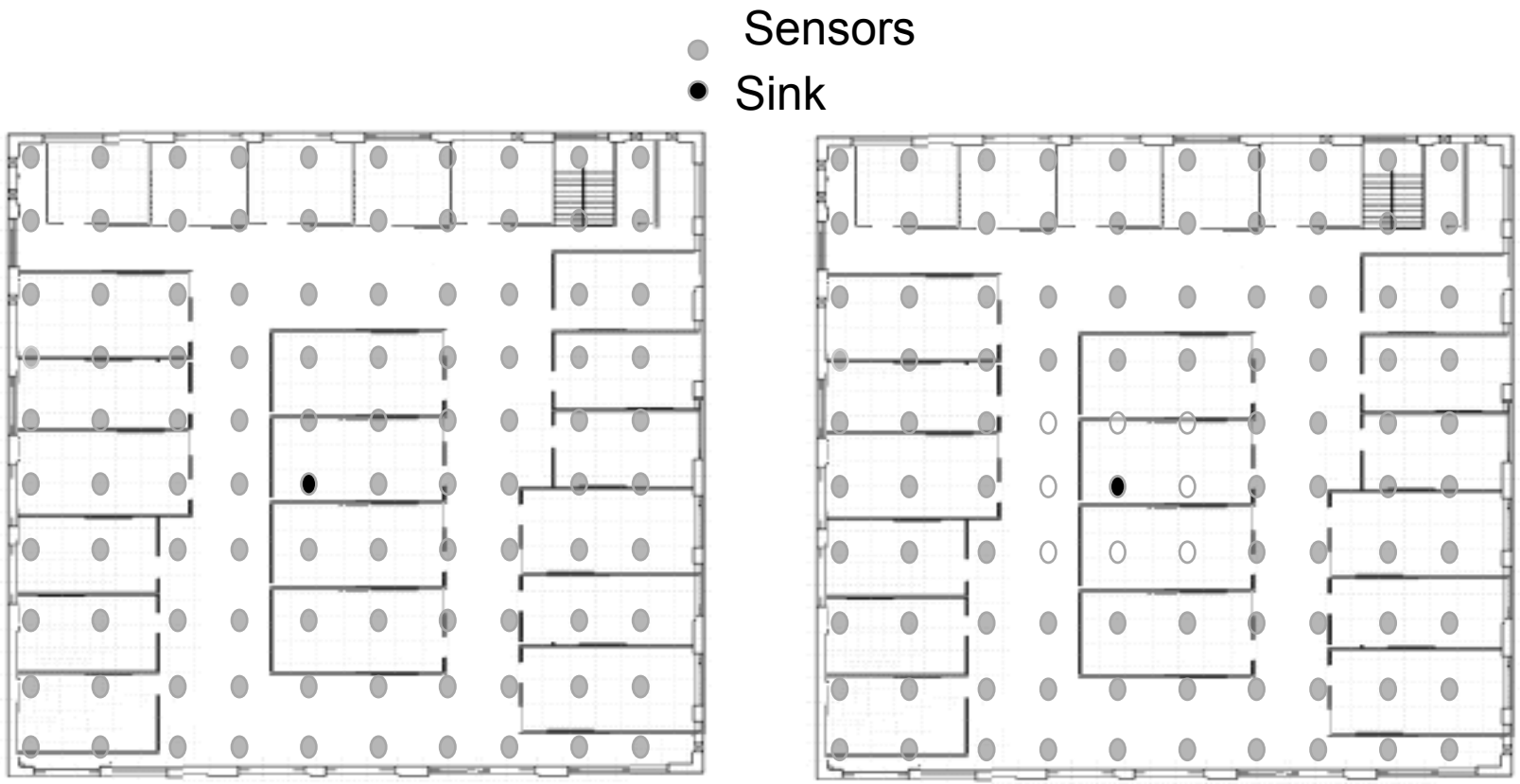
- IPv6 scales up to 2^{128} nodes >10^{23} / m^2
- IEEE Standards
  - 802.15.4 / P1901.2 (In progress)…
- IETF “standardization” working groups
  - 6LowPAN for networking, ROLL for routing
- IPv6 Routing Protocol for Low power and Lossy Networks (RPL)
  - distance vector routing protocol
  - physical medium agnostic (route-over)
  - provision made for LLNs

RF Topology using RPL



Energy hole problem in buildings

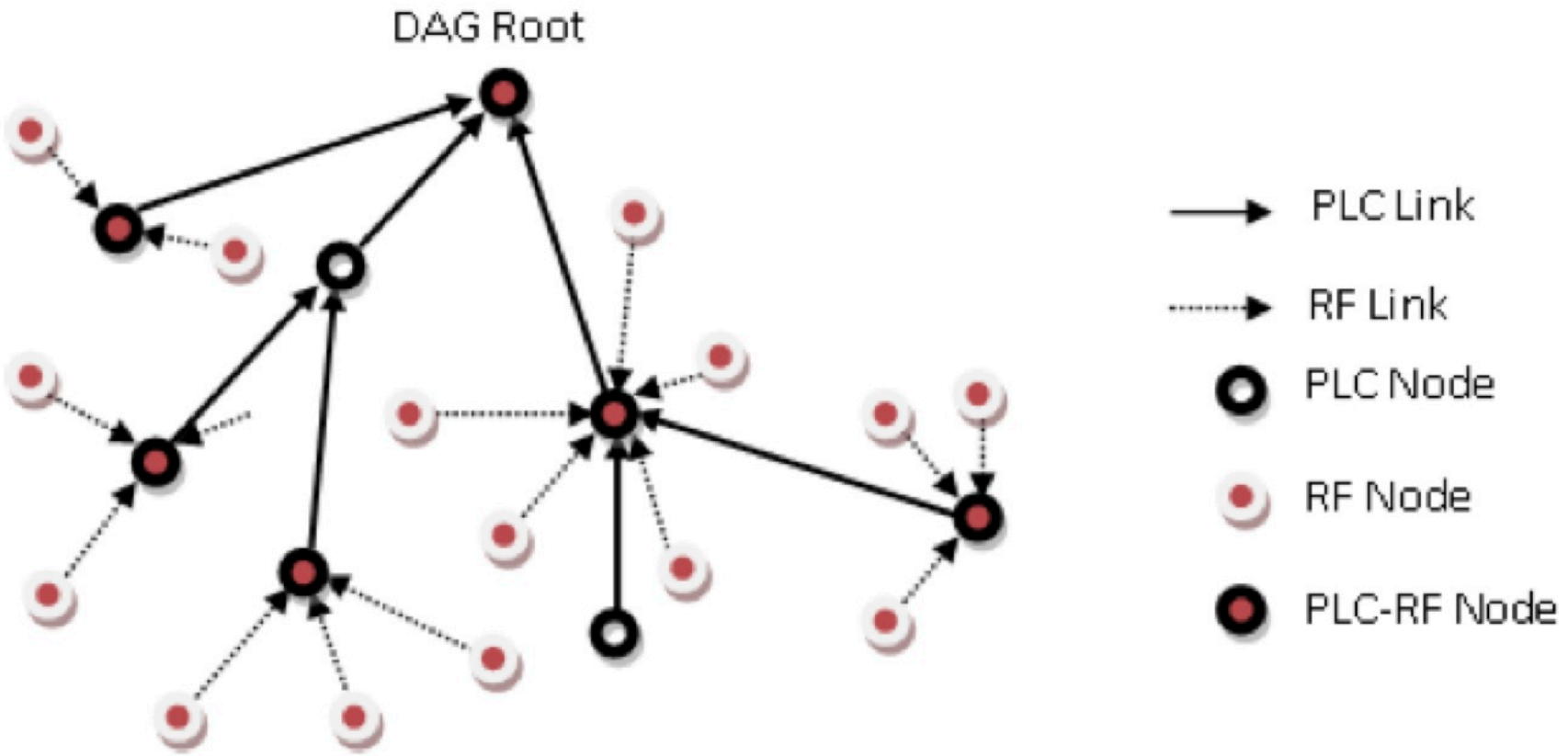
- Short range wireless battery powered networks
- High forwarding load near the sink
  - Whatever the multi-hop protocol used



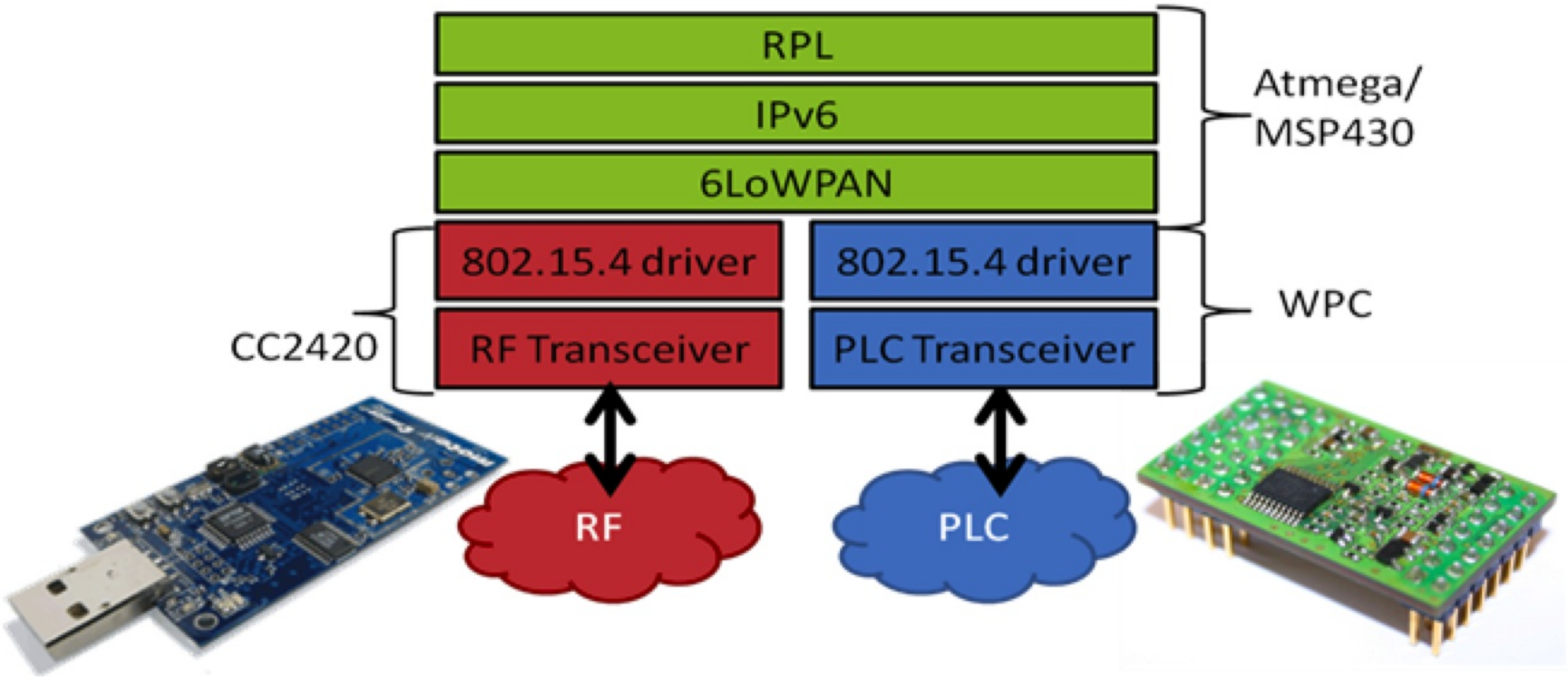
Network Lifetime Optimization

- Integer Linear Programming (ILP)formulation to determine the best placements for the sink [SensorComm09]
- Heuristics to scale the approach [NTMS09]
- ILP for RPL sink placement [SensorComm11]
- IPv6 communication stack on PLC [SmartGridCom10]
- Replace sink by RF-PLC nodes
- IPv6 communication stack for RF-PLC nodes

RF-PLC Topology

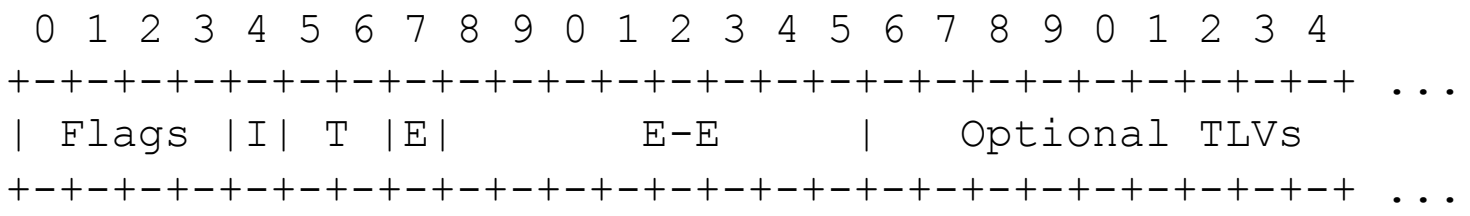


RF-PLC communication stack for BMS



Energy Metric in RPL

- Defined in draft-ietf-roll-routing-metrics-19

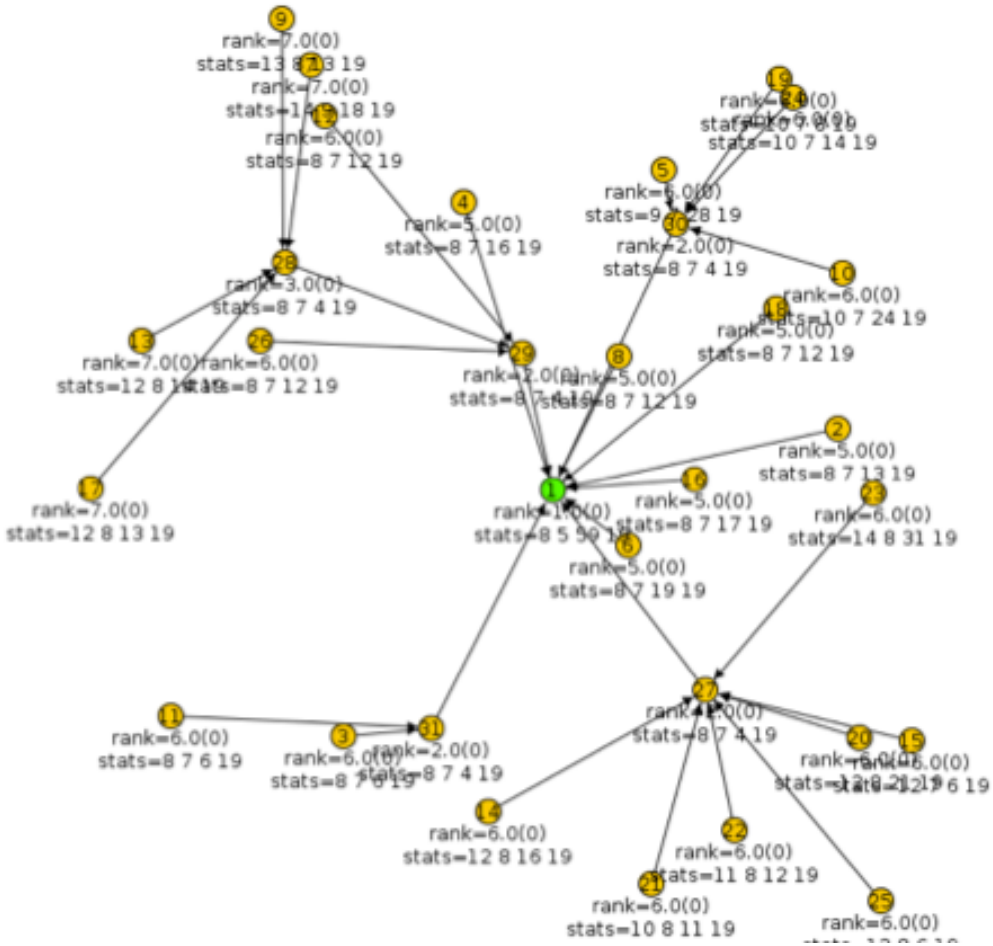


- The E-E field contains an Energy Estimation
- The DAGRoot (on mains) set E-E at 255
- The best parent has the higher E-E value

  (if equality, we select the parent with the lower rank)
- The metric is aggregated along the path
- E-E=min{Parent_Metric ; Energy_Estimation}
  - Node on Mains : Energy_Estimation = 255
  - Node on Battery : Energy_Estimation = % of Remaining Energy
  - Parent_metric = E-E advertised by the Parent

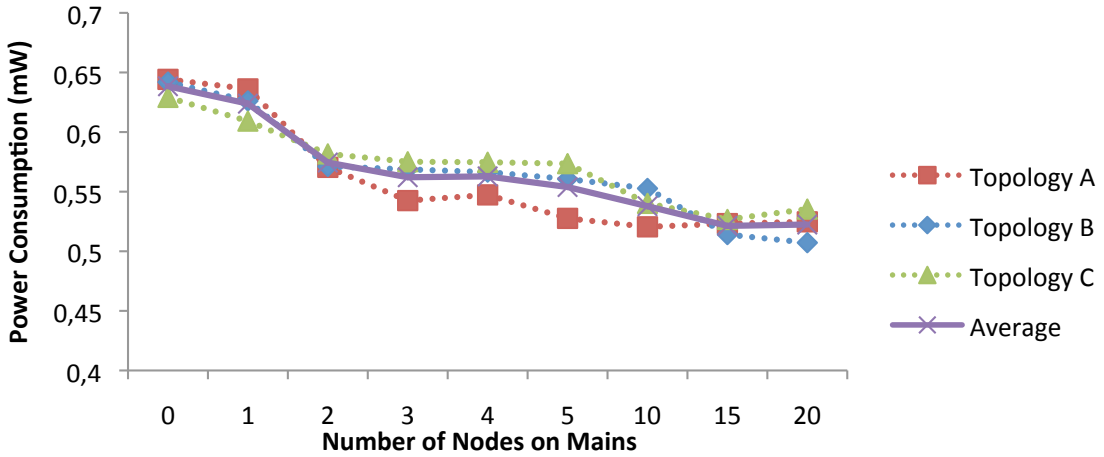
Simulation of the Energy Metric

- Simulation experiment on 30 sensor nodes
  - Cooja Simulator
  - Contiki 2.5
  - Distance Loss Medium
  - Time = 1,000 s
  - 1 Packet/minute
  - 107 Bytes Packets
  - ContikiMAC Duty Cycling

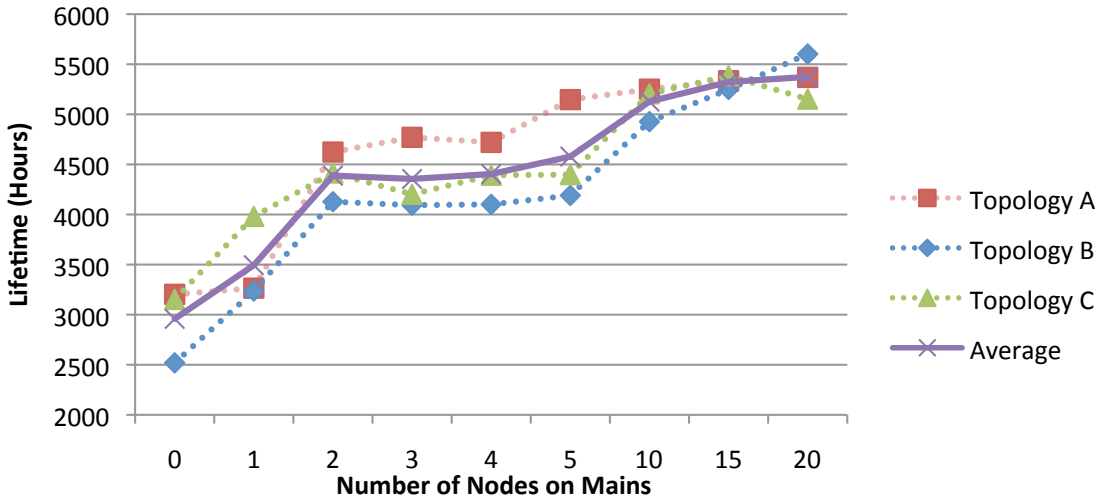


Energy Metric Results

Average Power Consumption of Battery Nodes Vs Nb of nodes on mains

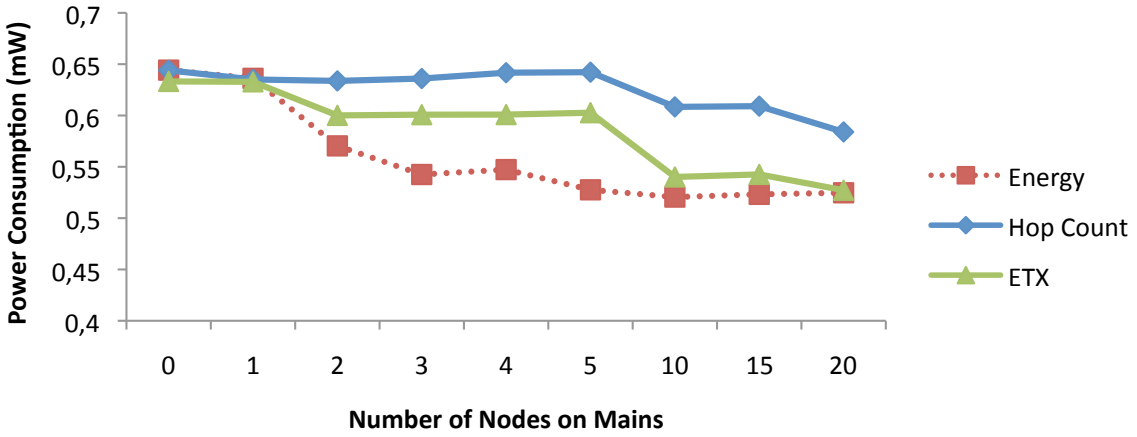


Lifetime Projection Vs Nb of nodes on mains

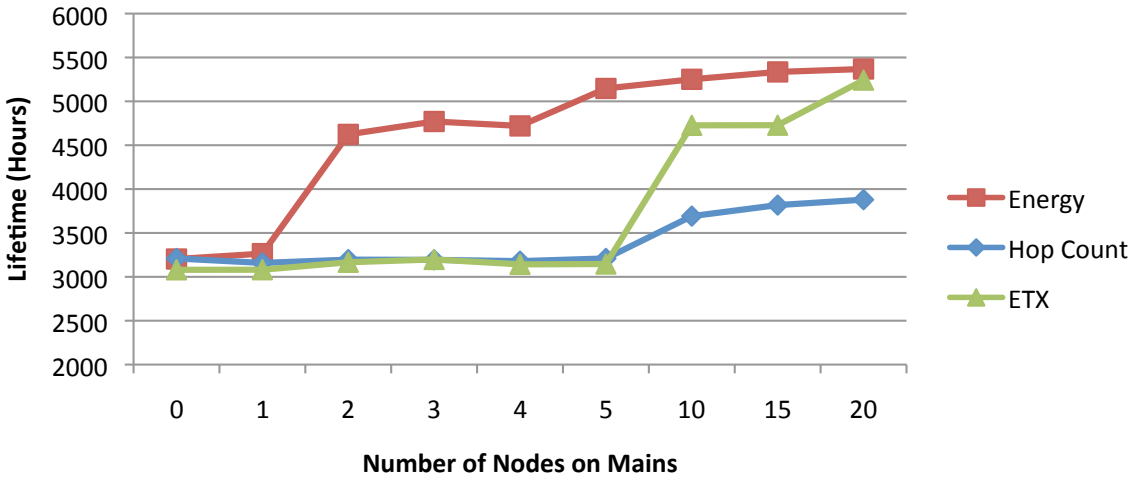


Metrics Comparison

Average Power Consumption of Battery Nodes Vs Nb of nodes on mains in Topo A

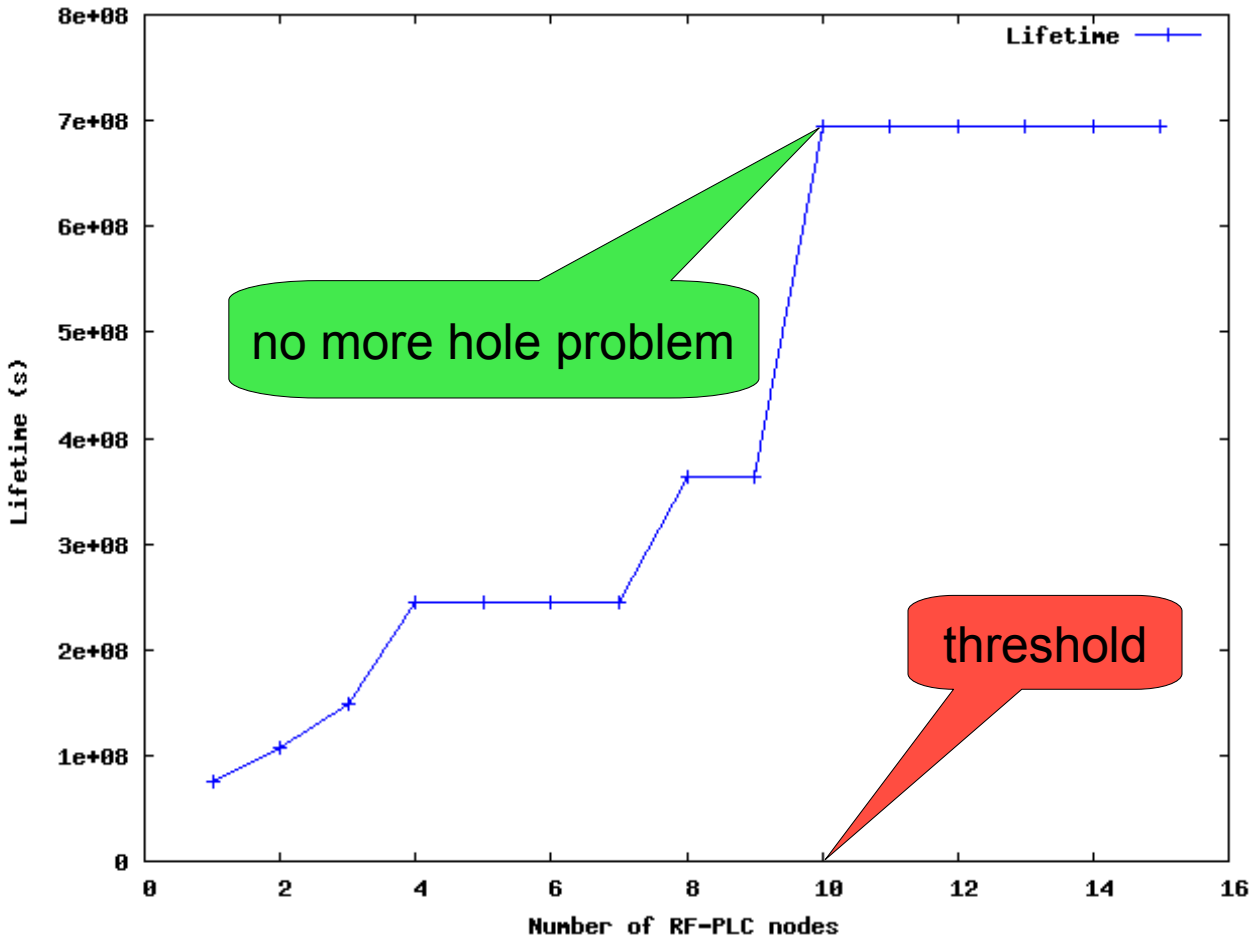


Lifetime Projection Vs Nb of nodes on mains



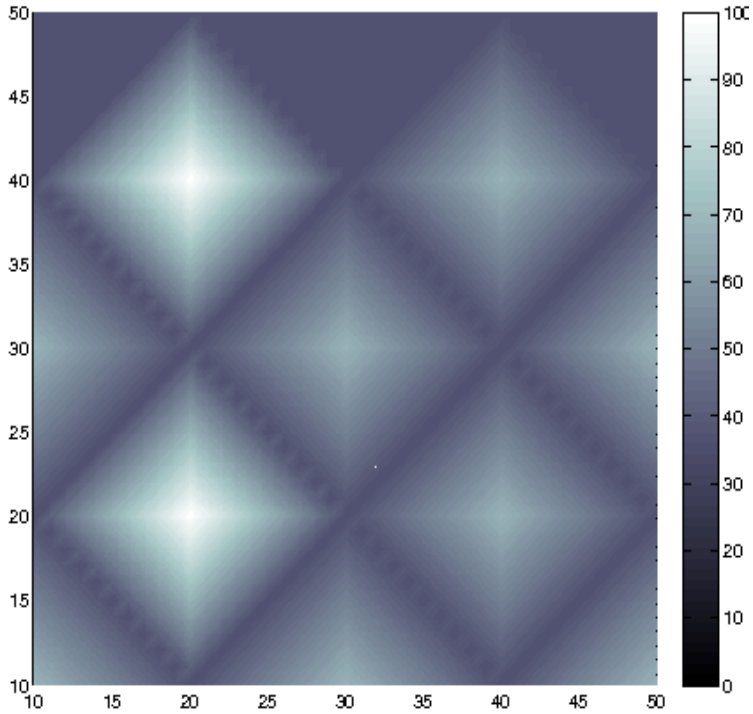
RF-PLC nodes for wireless clusters

- Simulation experiment on 25 sensor nodes
  - Wsnet Simulator
  - Hop Count
  - 5x5 Grid
  - Ideal Medium
  - 1 Packet/minute
  - 46 Bytes/minute
  - No Duty Cycling

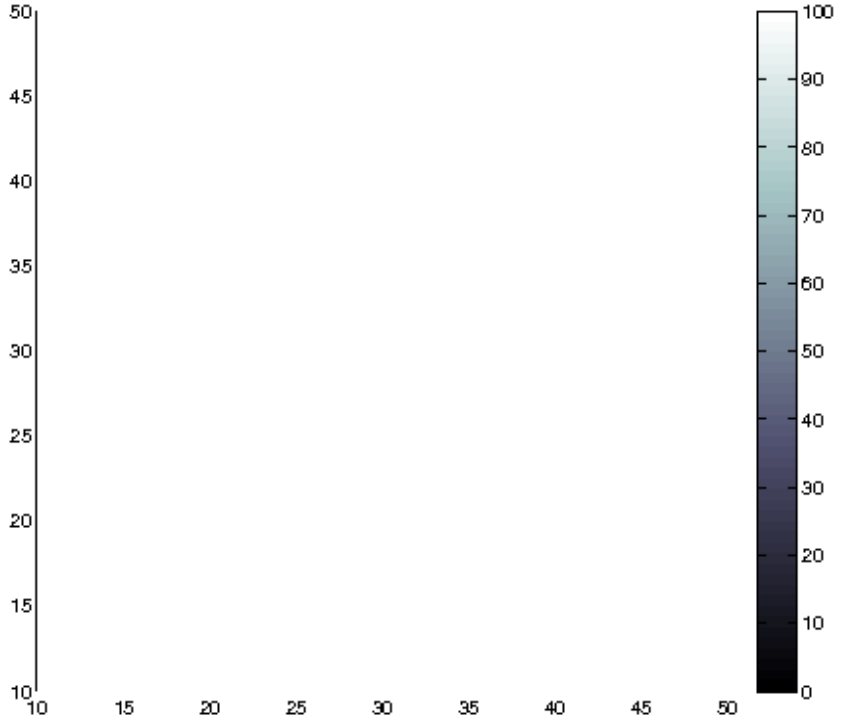


Node residual energy

- 6 RF-PLC nodes

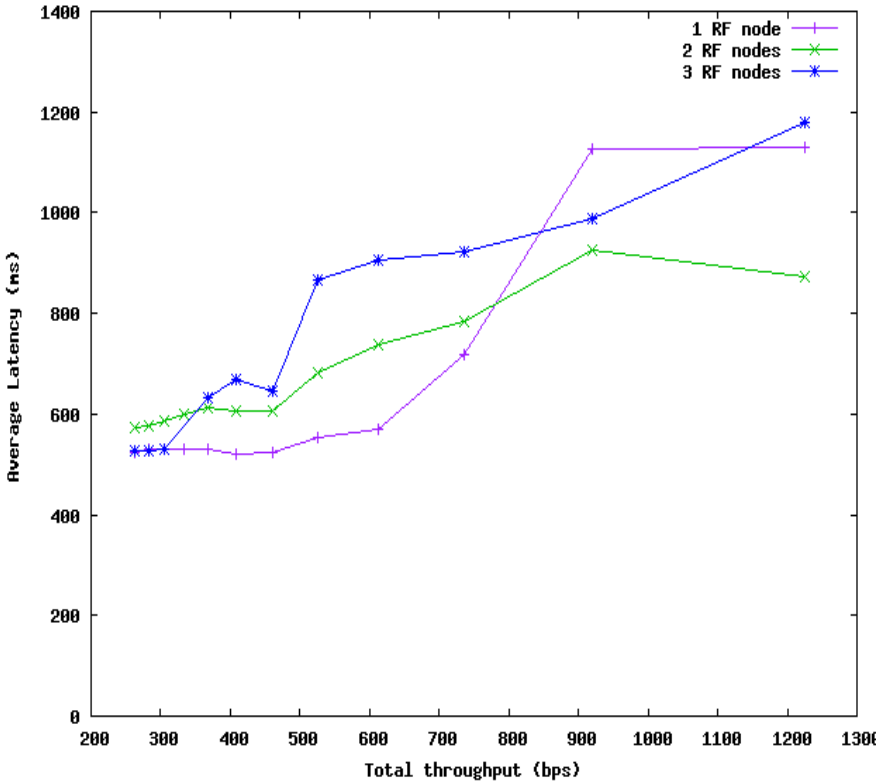


10 RF-PLC nodes

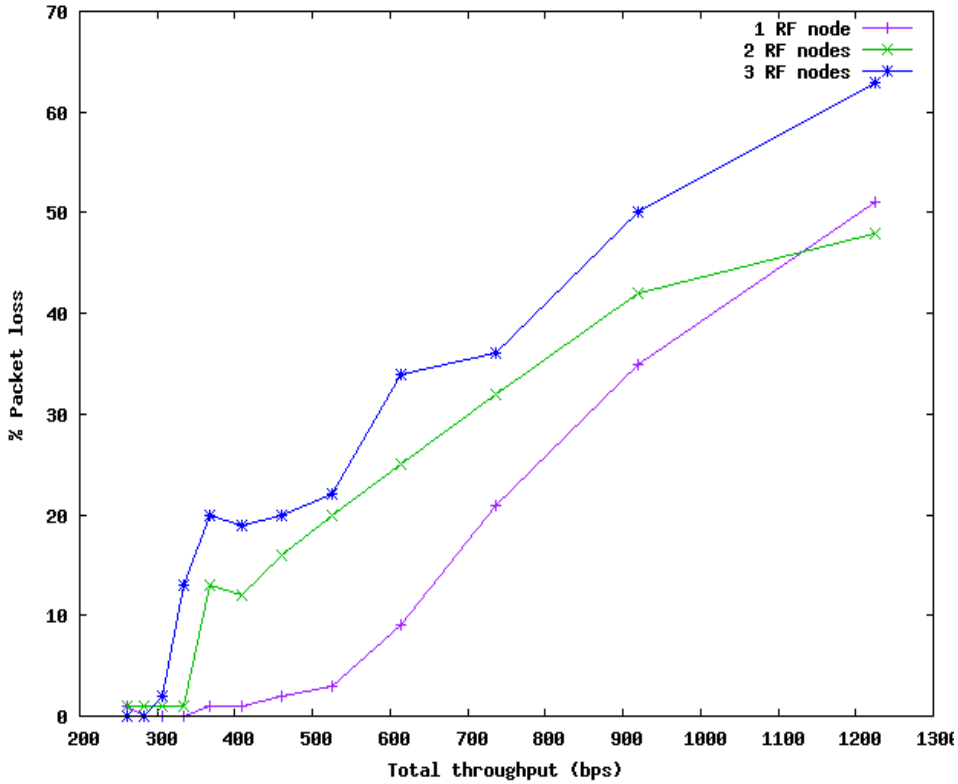


PLC Network Performance issue

- Latency



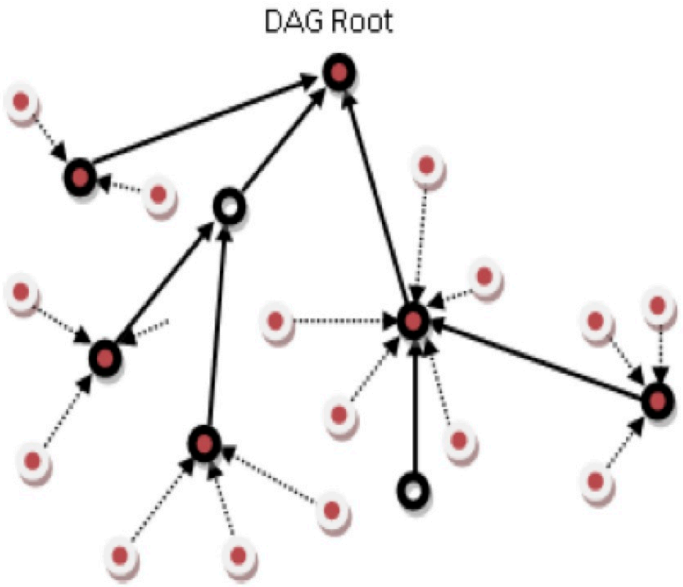
Packet-loss

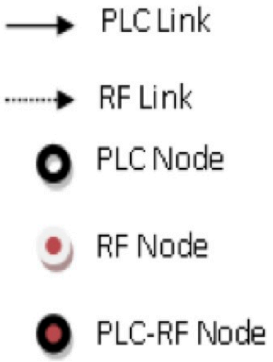


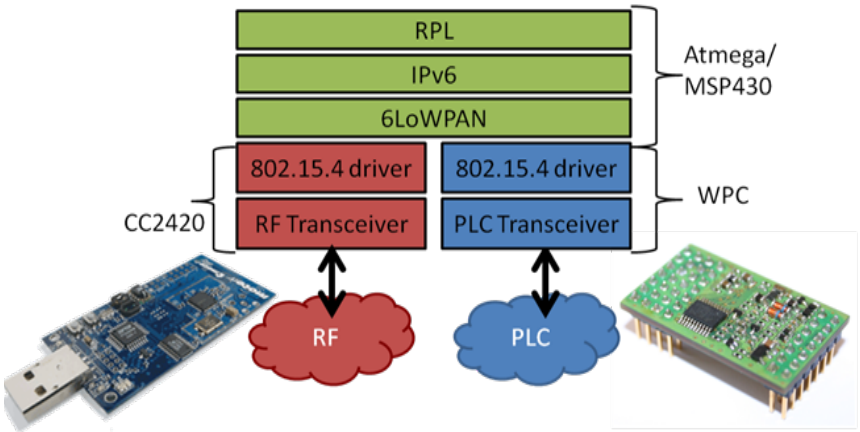
Conclusion

- Smart BMS needs networks
- Wireless and PLC IPv6 heterogeneous networks architecture is a good candidate
- RF-PLC nodes can solve the wireless network hole problem if
  - their number is large enough
  - their placement is optimized
- PLC performance can be an issue
- Study RF-PLC routing for improvement

Thanks for your attention

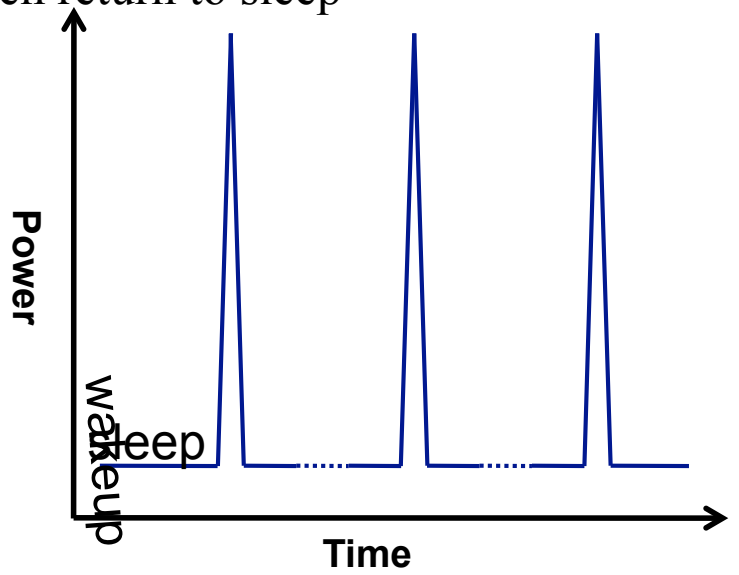






Power Budget example for a year on 2xAA batteries with 10 minutes sampling rate ...

- Sleep
  - Majority of the time
  - µC Telos: 2.4µA
- Wakeup
  - As quickly as possible to process and communicate then return to sleep
  - RF Telos: 290ns typical, 6µs max
- Active
  - Get your work done and get back to sleep
  - Telos: 4-8MHz 16-bit + RF 256kbit/s
  - Radio sending 1 byte: 1.5µJ
  - Flash writing 1 byte: 3µJ



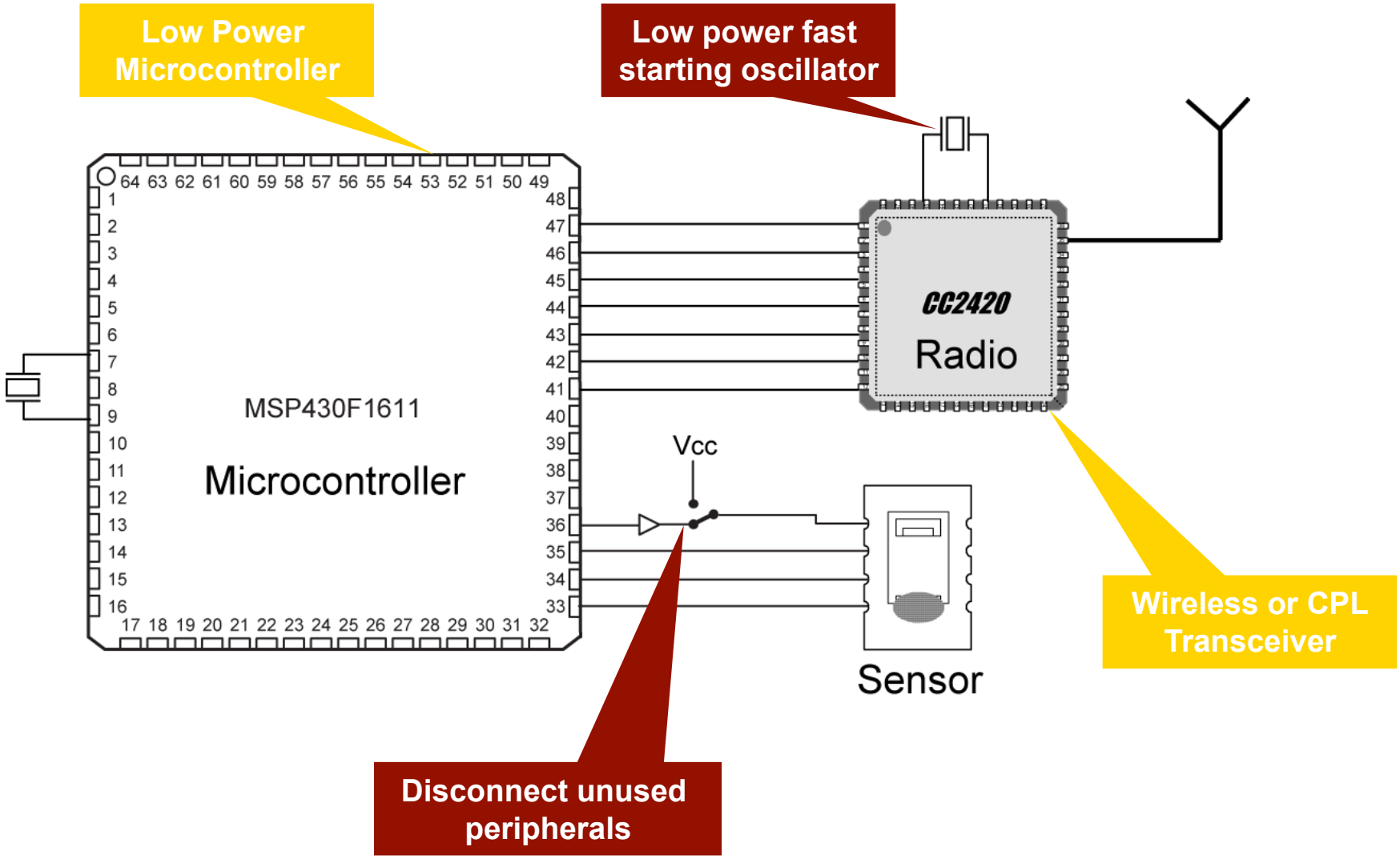
Some Bibliography

- [1] J. Tripathi, J. de Oliveira, and J. Vasseur, “Performance Evaluation of Routing Protocol for Low Power and LossyNetworks (RPL),” IETF, Draft, January 20
- [2] M. Nuvolone, “Stability analysis of the delays of the routing protocol over low power and lossy networks,” Master’s thesis, Sweden Royal Institute of Technology, 2010.
- [3] T. H. Clausen and U. Herberg, “Comparative Study of RPL-Enabled Optimized Broadcast in Wireless Sensor Networks,” INRIA, Tech. Rep. 7296, 2010.
- [4] T. H. Clausen and U. Herberg, “Multipoint-to-Point and Broadcast in RPL,” INRIA, Tech. Rep. 7244, 2010
- [5] N. Tsiftes, J. Eriksson, and A. Dunkels, “Low-power wireless IPv6 routing with ContikiRPL,” in International Conference on Information Processing in Sensor Networks. ACM/IEEE, 2010

Adaptation of IEEE 802.15.4 over PLC

	LR – WPAN	PLC-PAN
Data-rate	Over-the-air data rates of 250 kb/s, 100kb/s, 40 kb/s, and 20 kb/s	10 kb/s
Star, P2P or Mesh	OK	OK
CSMA-CA	OK	OK
Fully acknowledged	OK	OK
Link quality indication (LQI)	OK	OK
Channels	16 channels in the 2450 MHz band, 30 channels in the 915 MHz band, 3 channels in the 868 MHz band	1 channel (2 - 4 Mhz) (4 channel in progress)
Power ressource	- - (Limited to battery)	+ + (Main powered)
Mobility	+ + (No Cord)	- - (Limited to the cord)

SoC type Architecture



Hardware Platforms

Commercial Off The Shelf Components (COTS)

WeC 99
"Smart Rock"

Small microcontroller
8 kB code
512 B data

Simple, low-power radio
10 kbps ASK

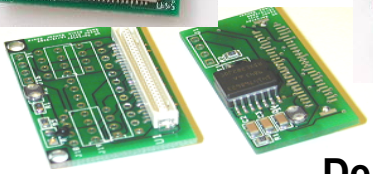
EEPROM (32 KB)

Simple sensors

Rene 11/00

Dot 9/01

Mica 1/02



Demonstrate scale

- **Designed for experimentation**

-sensor boards

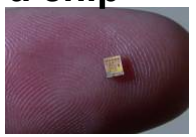
-power boards

NEST open exp. Platform
128 kB code, 4 kB data
40kbps OOK/ASK radio
512 kB Flash

Telos 4/04
Robust
Low Power
250kbps
Easy to use

Mica2 12/02
38.4kbps radio
FSK

Spec 6/03
"Mote on a chip"



RF Simulator

- The simulator: WSnet
- Why WSnet ?
  - Dedicated to WSNs
  - Mobility module already implemented
  - Easy to add any new module
  - Hardware Emulation
- Implemented features
  - DODAG building
  - Rank computing
  - Packets forwarding
  - DAG repair

PLC Simulator

- The simulator : COOJA
- Why COOJA ?
  - Integrated into the Contiki
  - ContikiRPL implemented
  - Hardware Emulation (MSPsim, Avrora): Enable to run compiled codes (.hex or .elf)
- Implemented modules :
  - PLC Node (Hardware, Implementation, Synchronisation)
  - PLC medium