Some opportunities for energy reduction in WSN

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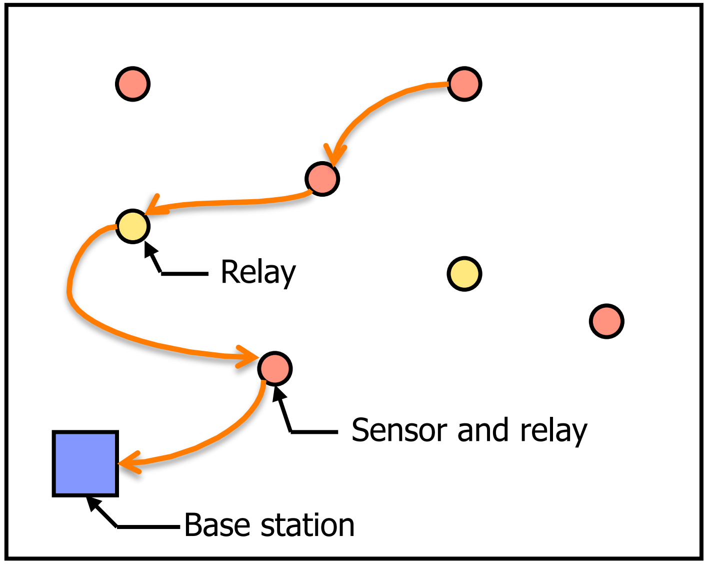
Specific features of WSN

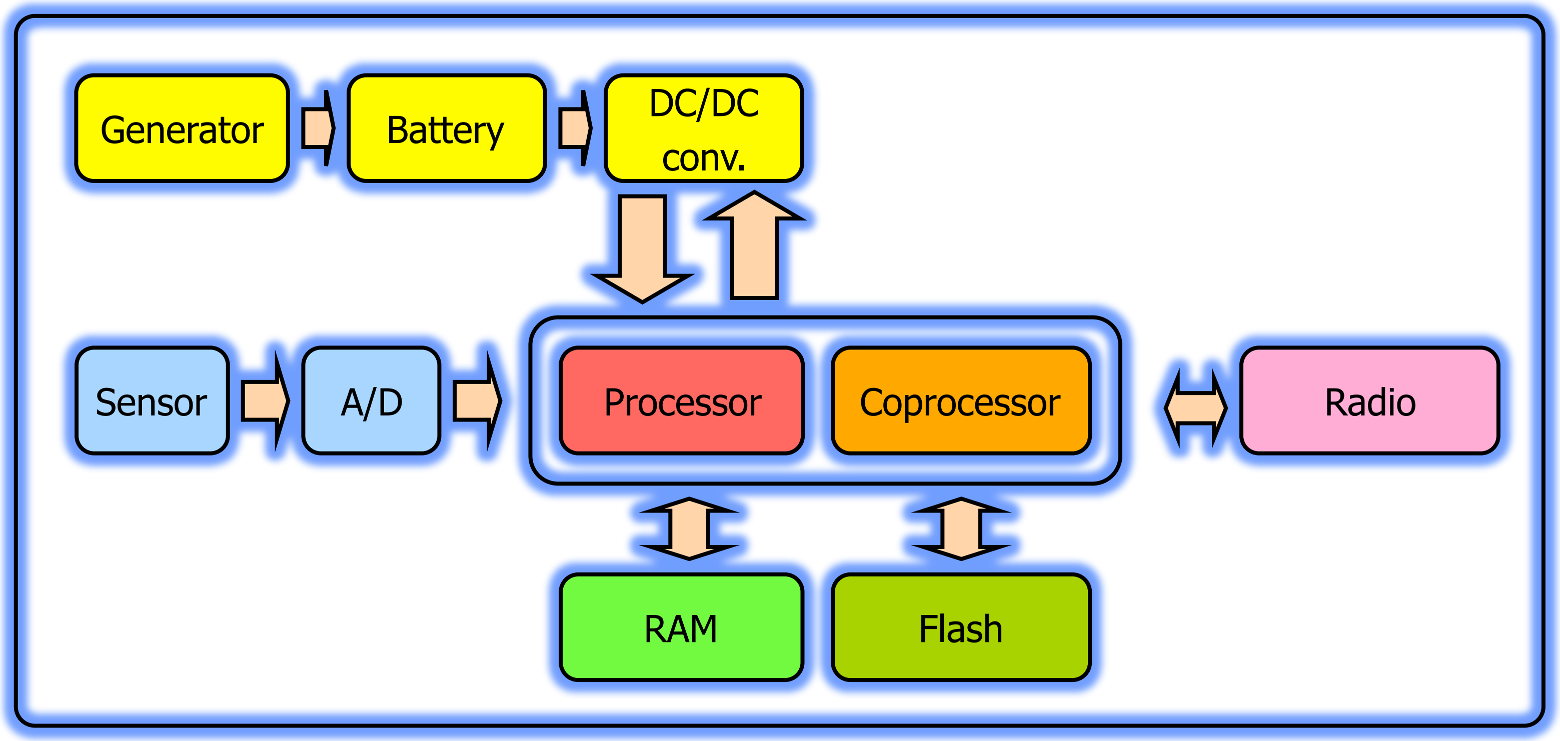
- Dense network of radio communicating nodes
  - Information sensing
  - Message generation and relay
    - Multi-hop routing
  - Long autonomy
  - Simplified deployment, fault tolerance
    - Ad hoc network



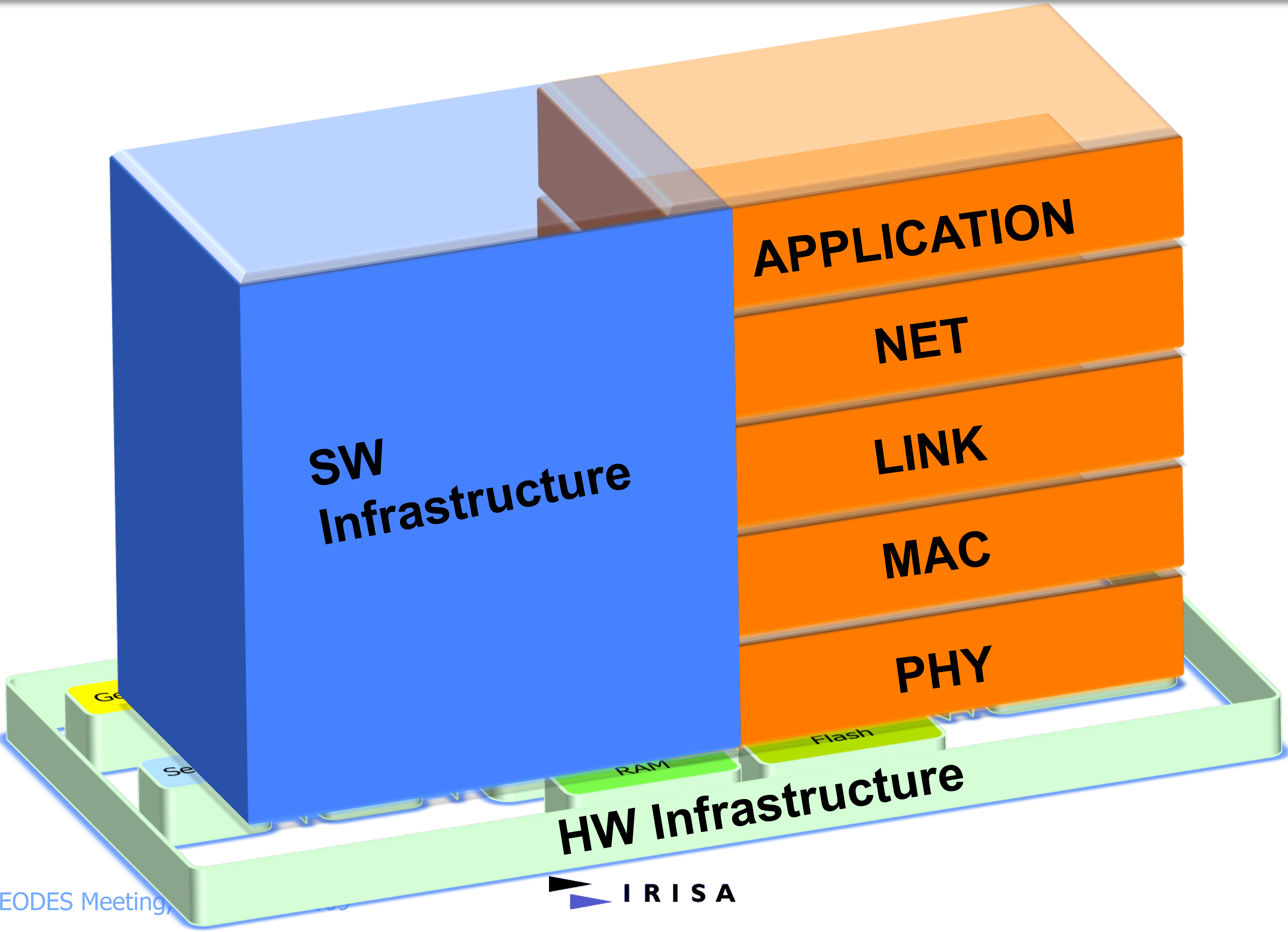
Wireless Sensor Network

- Very low energy consumption
- Low mean distance between nodes
- Limited amount of transmitted data
- Low cost

Generic architecture of a wireless node



Generic architecture of a wireless node



Main Goals

- *How to design and optimize an energy-efficient software and hardware platform for wireless sensor networks ?*
- (1) Decrease transmission (Tx) power
- (2) Optimize radio activity and MAC
- (3) Power optimization of the hardware
- (4) Optimize software stack

Agenda

- Node architecture
  - PowWow HW Platform
  - PowWow SW Platform
  - Energy estimation
- Energy optimization (1)

  Question is “How much (signal) processing can I add to reduce the radio Tx/Rx power in order to optimize the global energy (or autonomy) of the network ?”
  - Cross-layer (MAC/LINK)
  - MIMO Cooperation
- Energy optimization (2)
  - FPGA co-processing
  - Architectural and Circuit Level Optimization

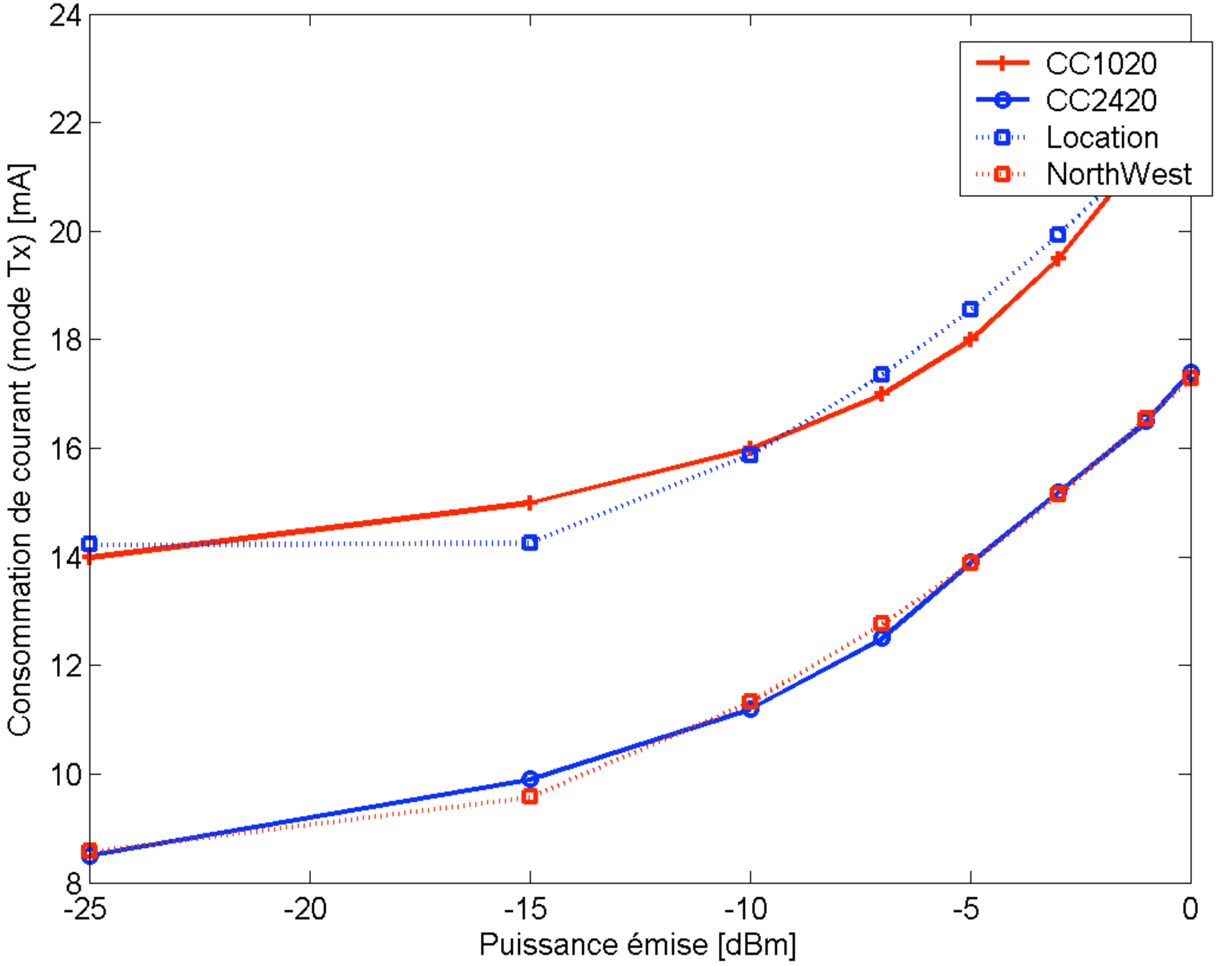
PowWow HW Platform (2008)

- Modular board design
  - Mother board MSP430
  - Daughter board for
    - CC2420
    - FPGA
    - Sensors
    - DVFS

- Microprocessor
  - TI MSP430
  - Fclk: 5 MHz
  - Valim: 2.7 - 3.6 V
  - RAM/Flash: 5 Ko/55 Ko
  - 500uA/MHz@3V
  - 330uA/MHz@2.2V
  - Low Power Modes
    - 50uA, 11uA, 1.1uA, 0.1uA

- Radio transceiver
  - TI CC2420
  - 802.15.4/ZigBee compliant
  - Frequency: 2.4 GHz
  - Sensitivity: -95 dBm
  - Max rate: 250 Kbits/s
  - Chip rate: 2 Mchips/s
  - PTx: 25 dBm to 0 dBm
  - Tx Power 17.5mA at 0 dBm
  - Rx Power 18.8mA
  - Idle/Down 426uA/20uA

Chipcon Radio Tranceivers



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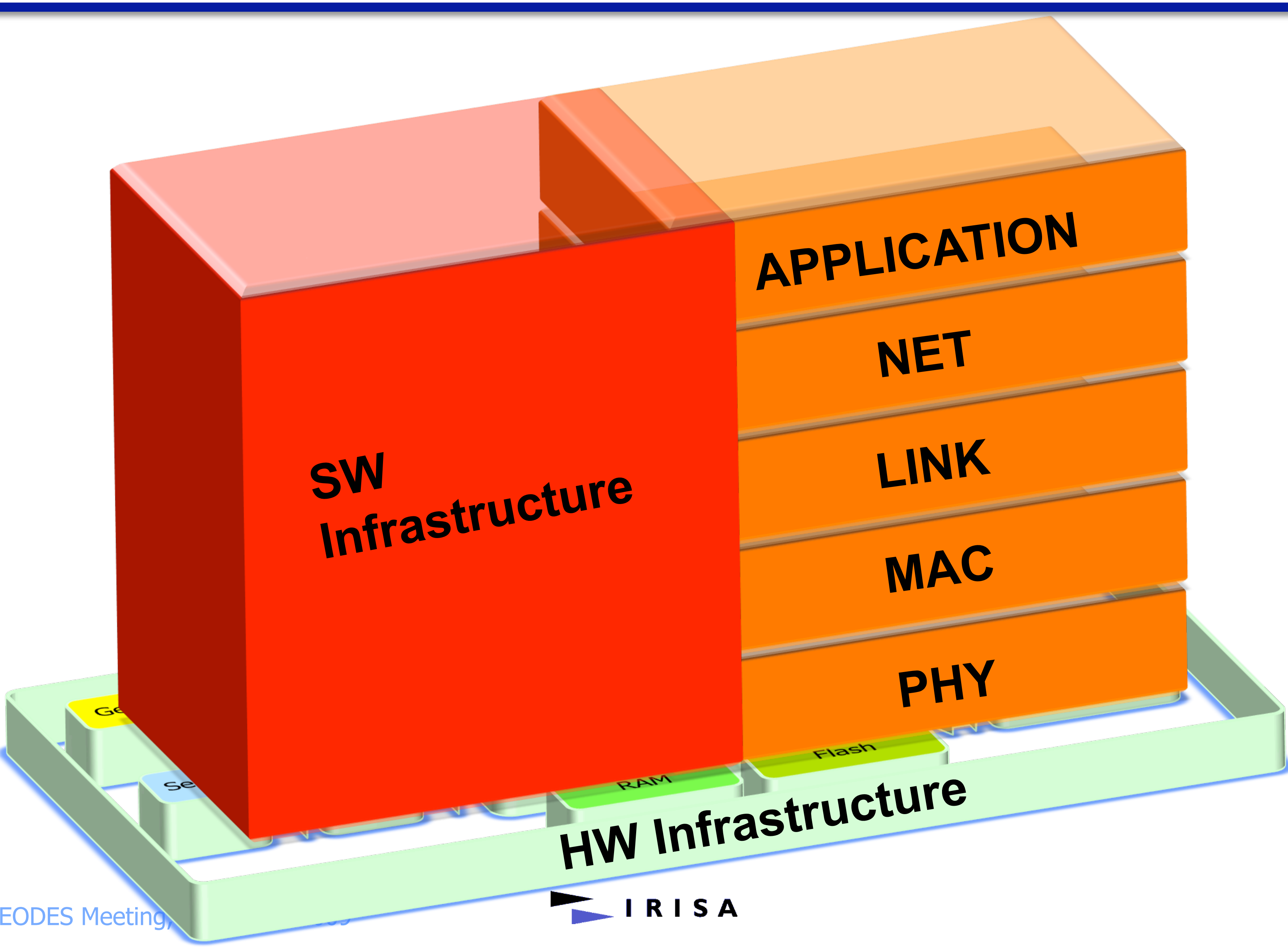
Power optimization of a wireless node

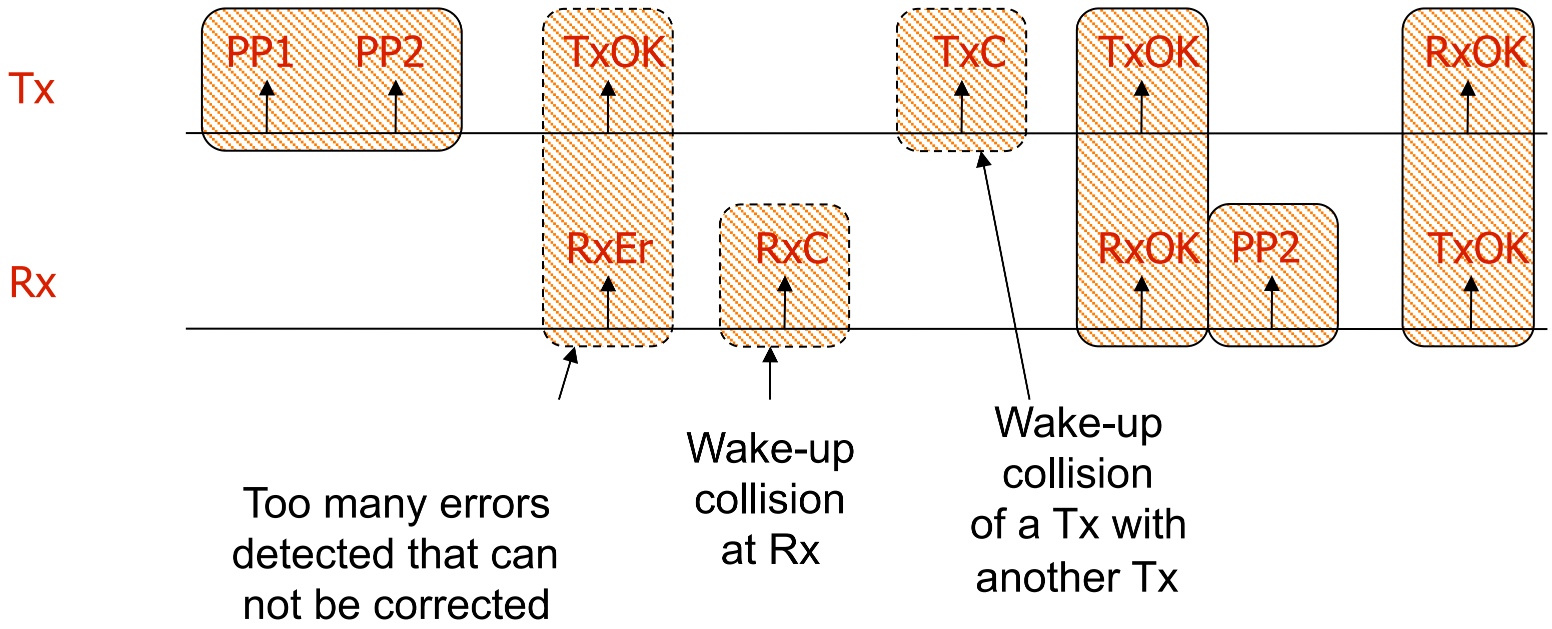


PowWow SW Framework

- PowWow: Power optimized hardware/software frameWork for Wireless motes
- Open source software developed at IRISA/CAIRN
- Based on Protothread library and Contiki
  - Event-driven programming
  - Flexibility, compactness of code
- HAL, PHY, LINK, MAC, NETW, Application API
  - FEC/ARQ, geographical routing, positioning
  - Modes: broadcast, flooding, direct/multi-hop with/without ACK
  - Configurable packet structure
- Memory efficiency
  - 6 Kbytes (HAL-NETW) + 5 Kbytes (APPLICATION)
- Tx power management
- Over-the-air re-programmation (and reconfiguration)
- Available at http://powwow.gforge.inria.fr in june 2009

Power estimation

- Analytical approach based on software profiling and power measurements of a set of scenarios
  - e.g. MAC events



PP1/2: Process Packet Phase ½
RxEr: Rx Packet with error
TxOK/RxOK: Normal Tx/Rx
TxC/RxC: Tx/Rx with collision

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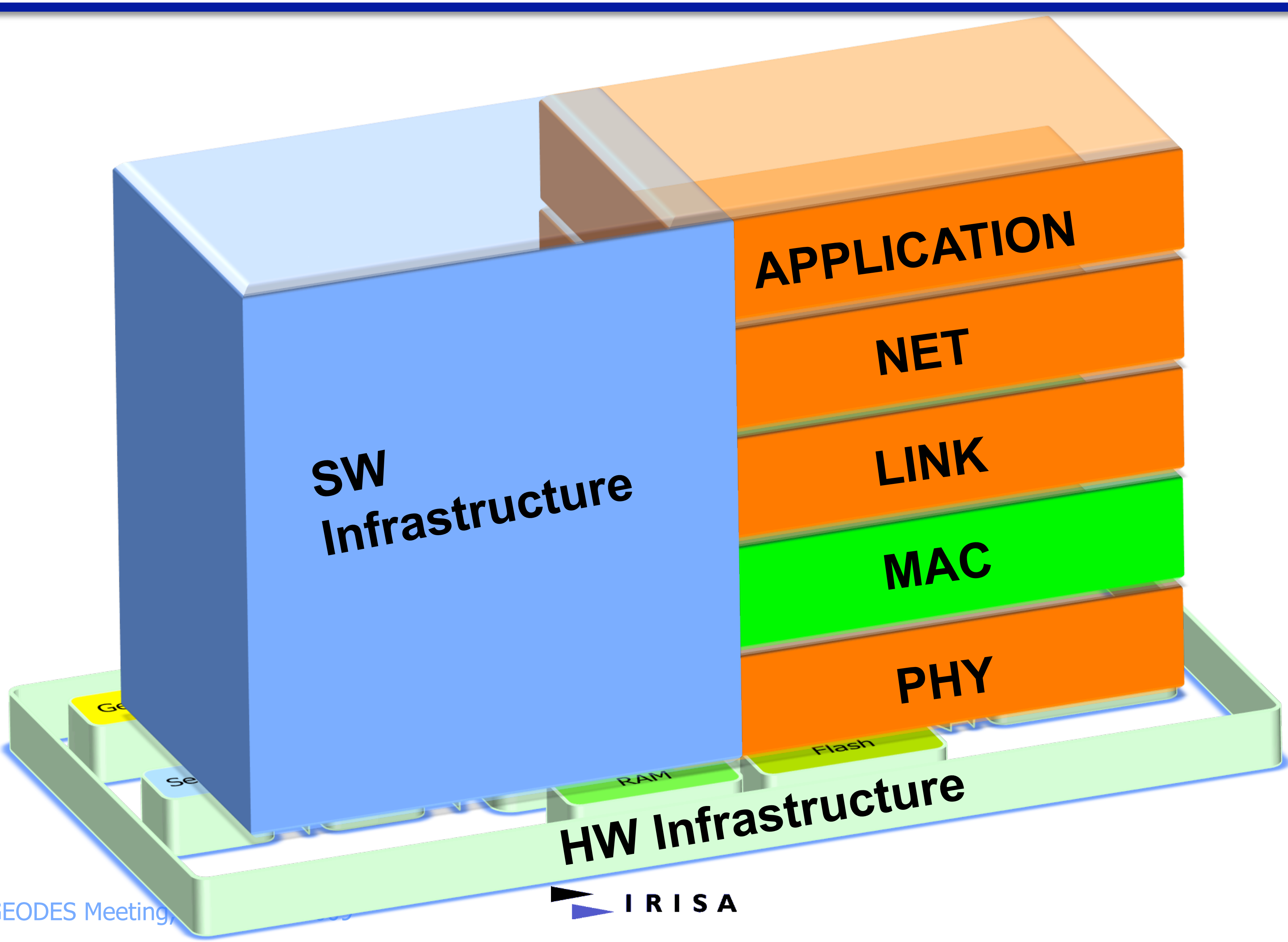
Power estimation

Energy consumption of event cycles [J]

	CBT	T	WUR	WUC	DC	TIM
Rx soft	5.3e-8	5.3e-8	1.2e-4	1.2e-4	5.3e-8	5.3e-8
Tx soft	4.1e-8	1.2e-3	1.0e-8	4.1e-8	6.9e-4	4.1e-8
clock	5.5e-7	5.5e-7	5.5e-7	5.5e-7	5.5e-7	5.5e-7
LINK	4.8e-7	0	4.8e-7	0	0	0
NETWORK	4.8e-7	0	0	0	0	0
Req_neighb	0	0	0	0	0	0
Ans_neighb	0	0	0	0	0	0
positionning.	0	0	0	0	0	0
listen target	0	0	0	0	0	0
scheduler	3.7e-7	3.7e-7	3.7e-7	3.7e-7	3.7e-7	3.7e-7
Tx HF	0	2.32e-3	2.32e-3	0	0	0
Rx HF	0	5.2e-2	3.1e-3	3.1e-3	5.2e-2	0

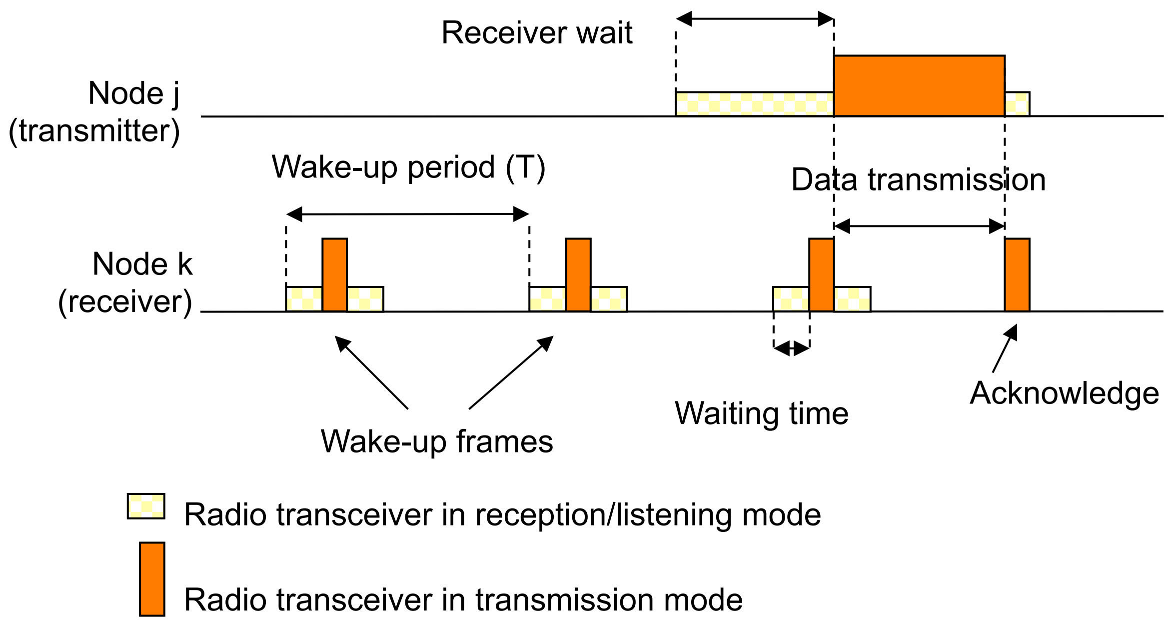
CBT: Calculation Before Transmission
T: Transmission
WUR: Wake Up with Reception
WUC: Wake Up with Collision
DC: Data Collision
TIM: Timer

Power optimization of a wireless node



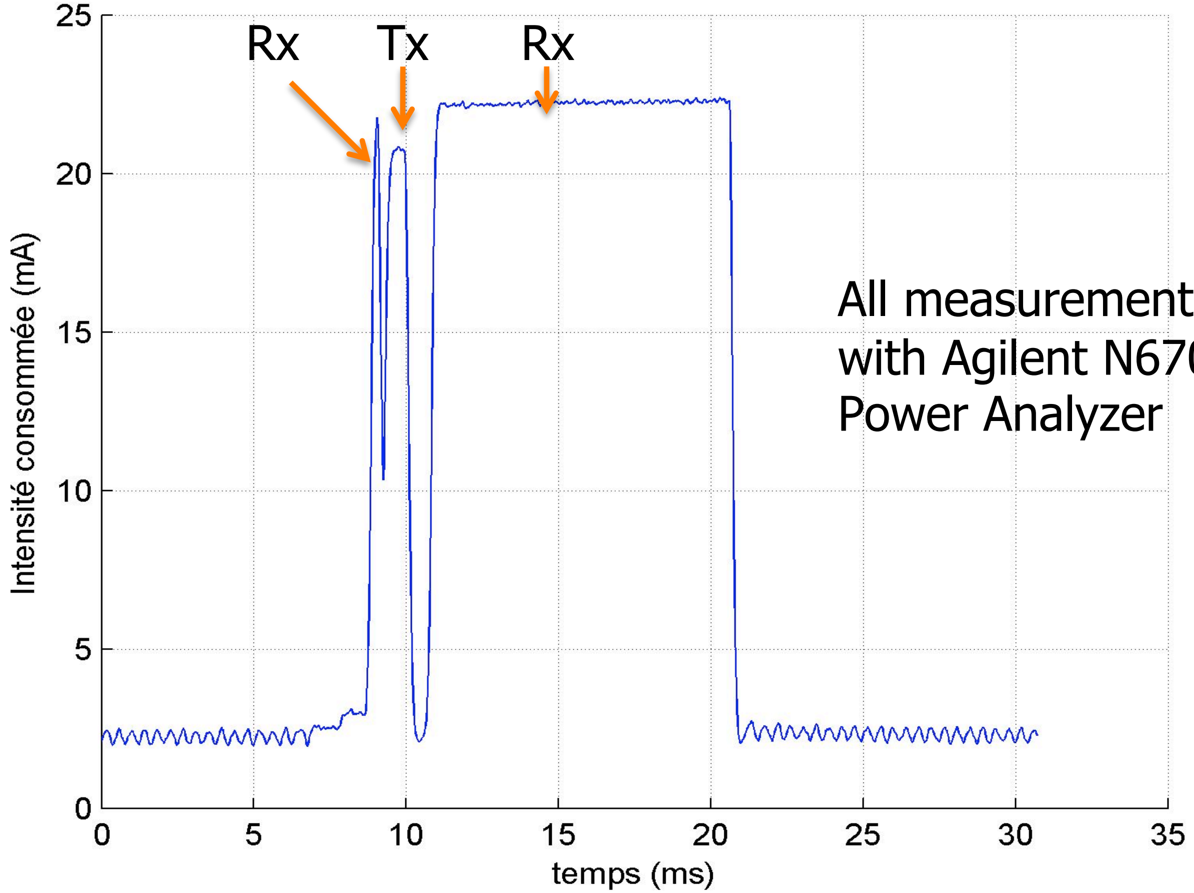
MAC layer

- MAC layer
  - Asynchronous RDV scheme initiated by receiver
  - RICER (Receiver-Initiated CyclEd Receiver) [Lin05]



Power Measurements on PowWow HW

- Wake-up and channel sensing



All measurements realized with Agilent N6705A DC Power Analyzer

Power Measurements on PowWow HW

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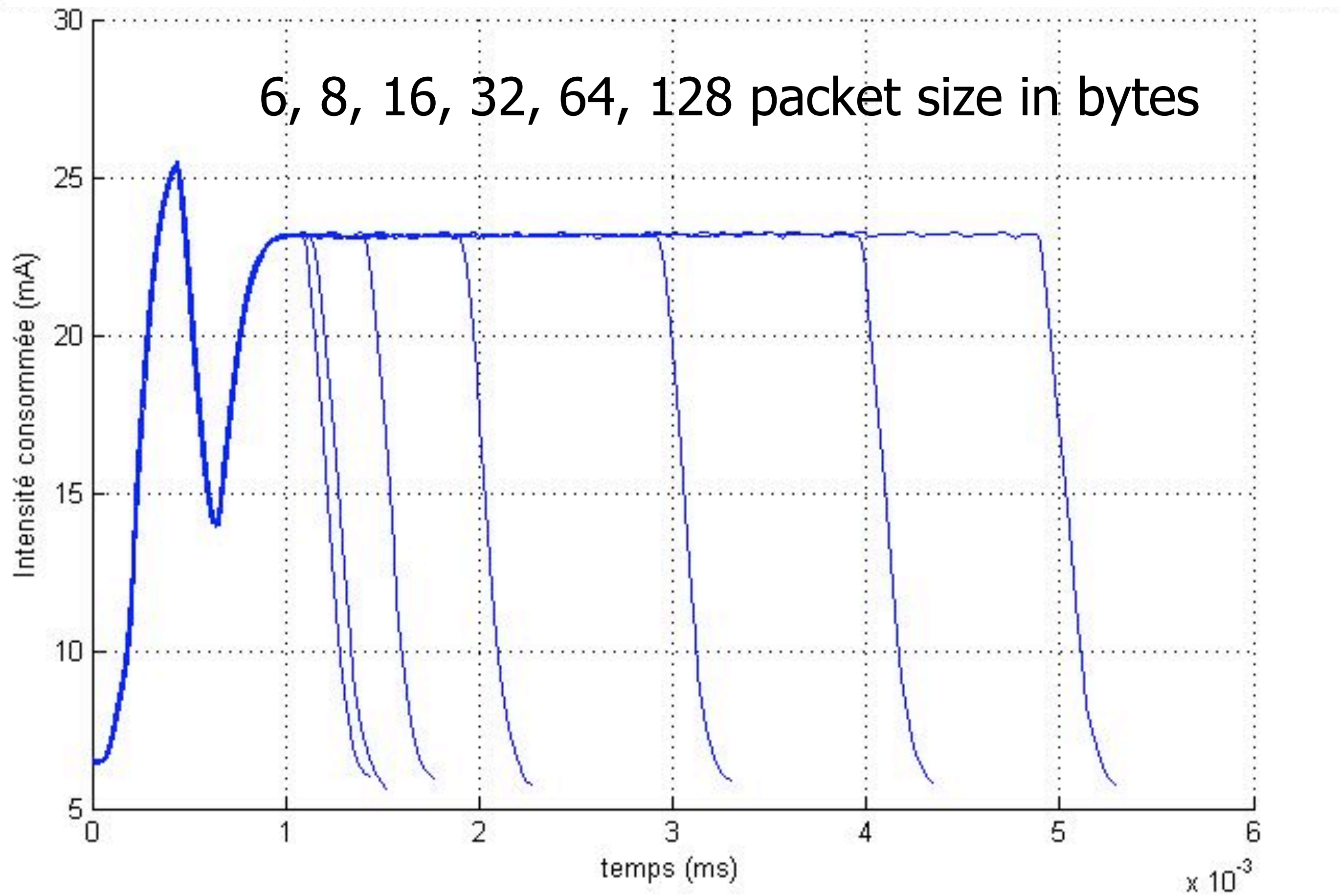
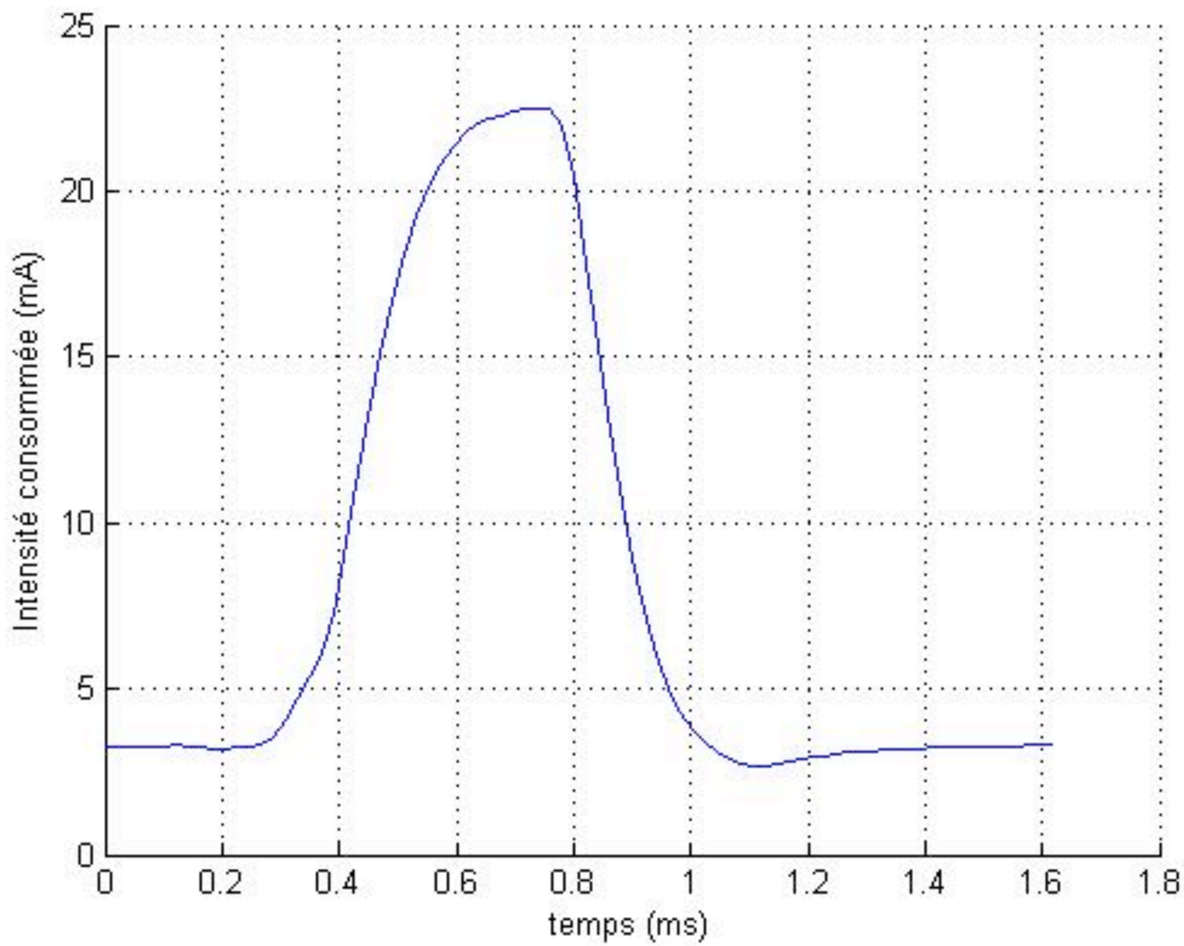


Power Measurements on PowWow HW

- Wake-up and channel sensing with collision



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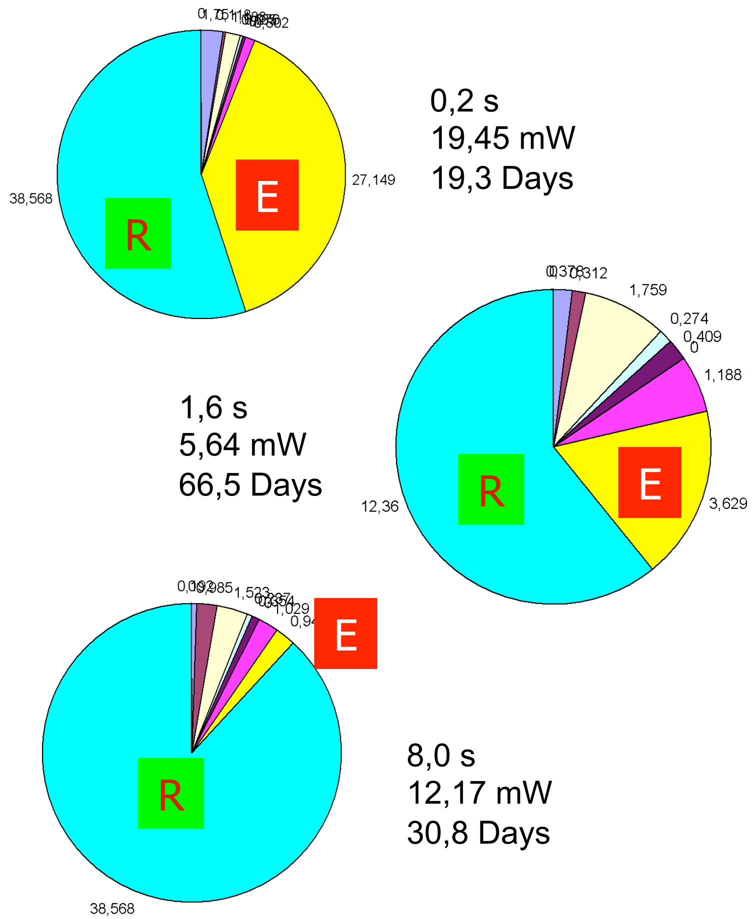
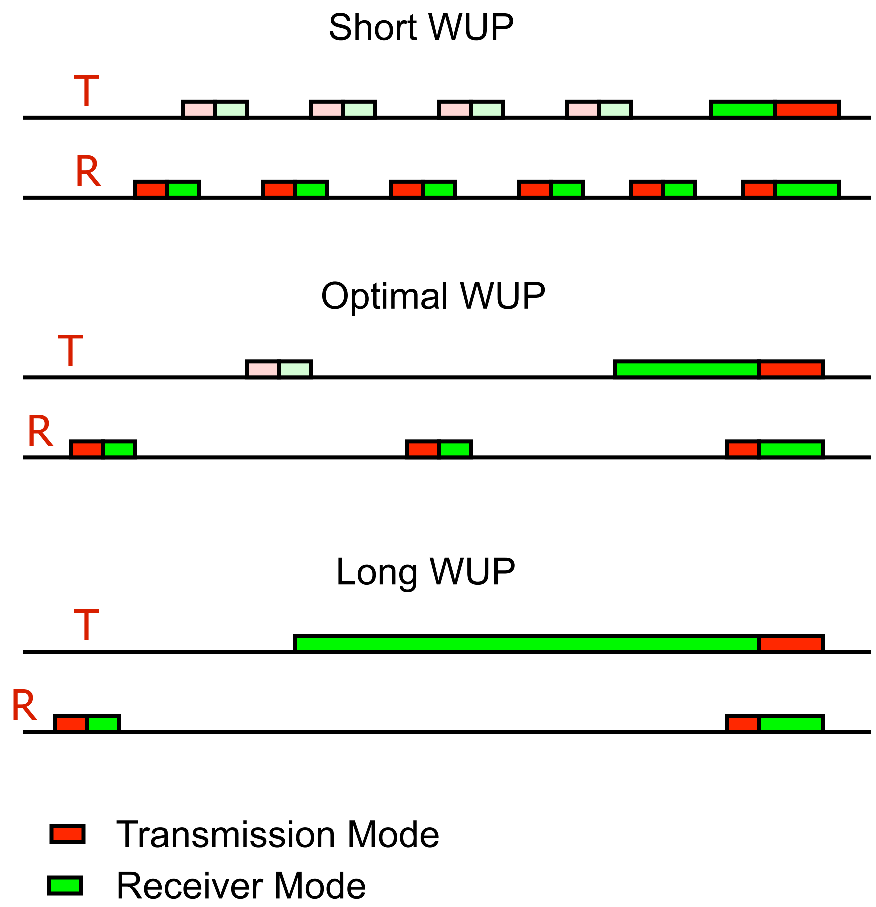
Results on MAC parameter optim.

- Wake-up period influence





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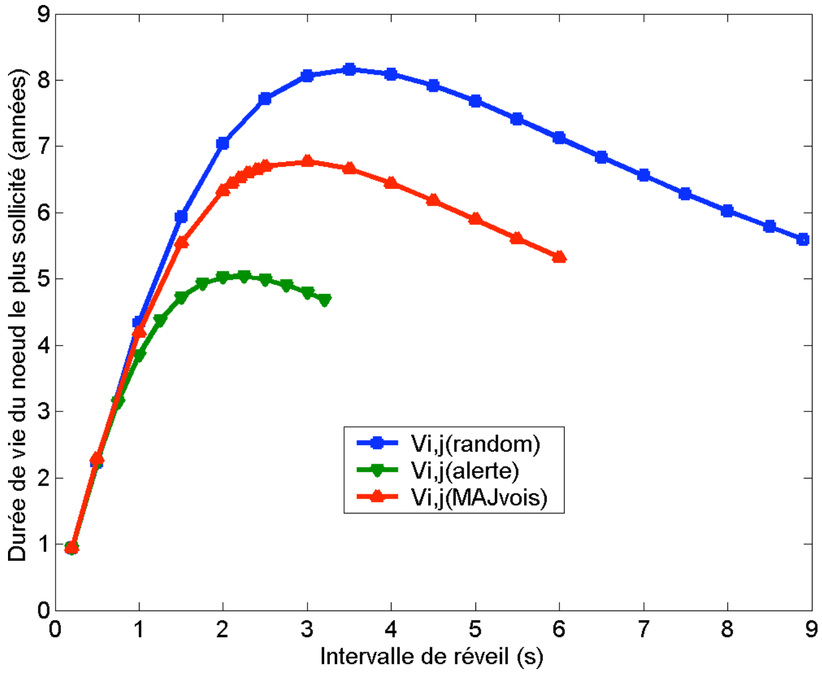
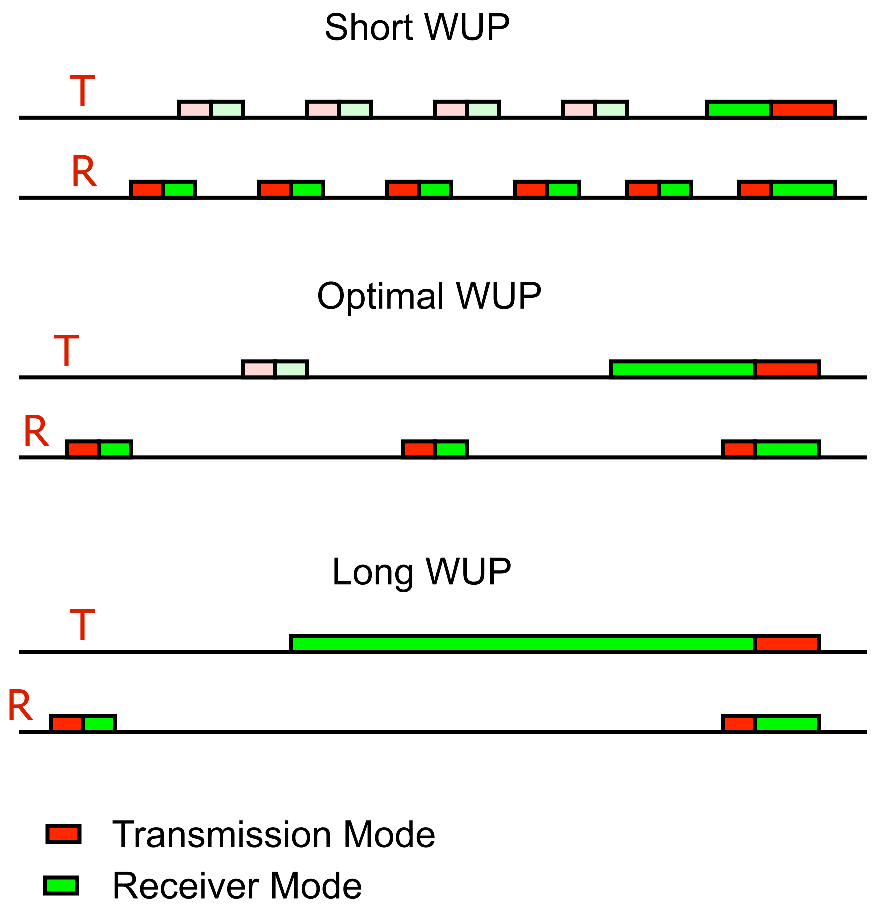
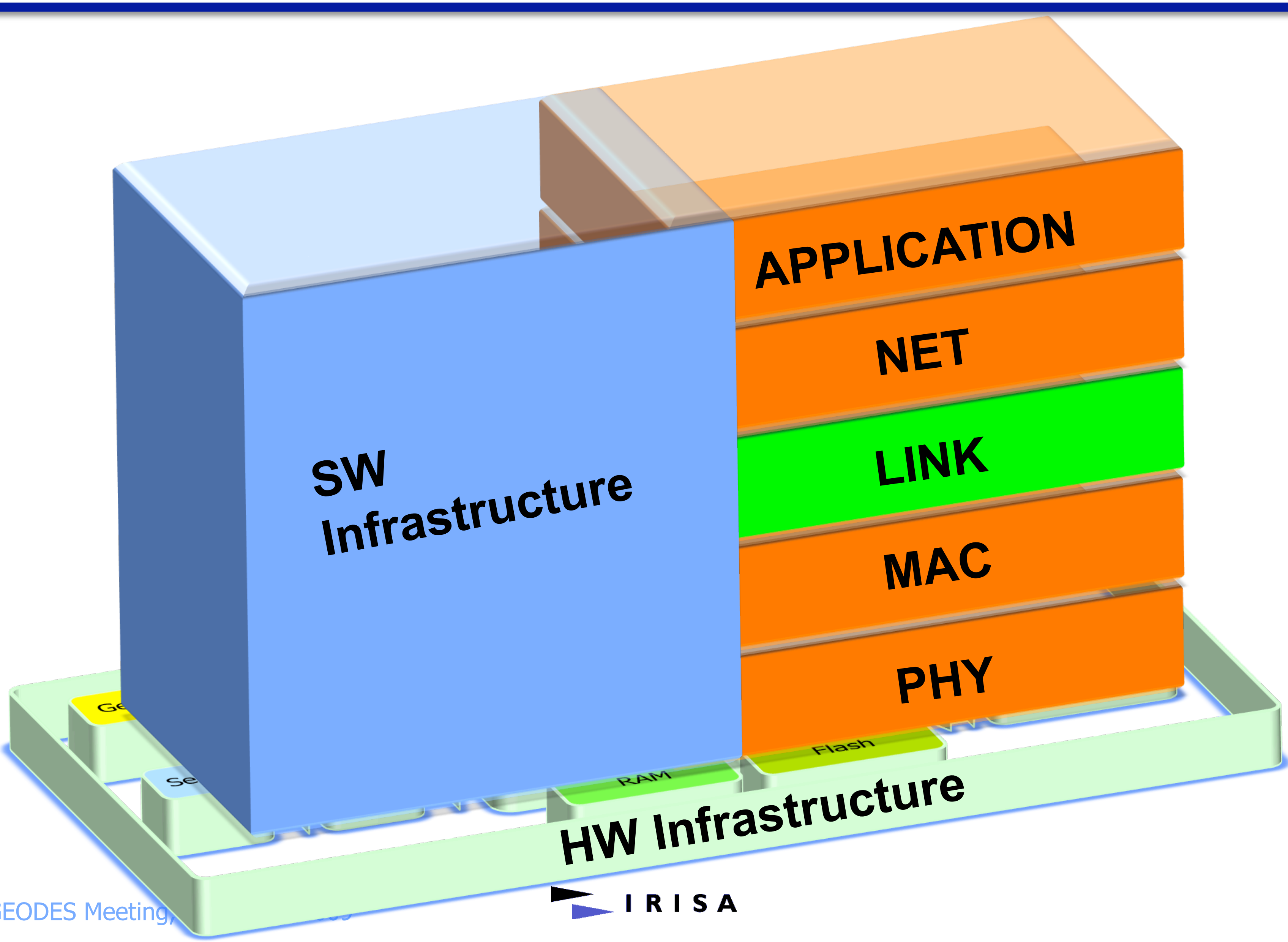


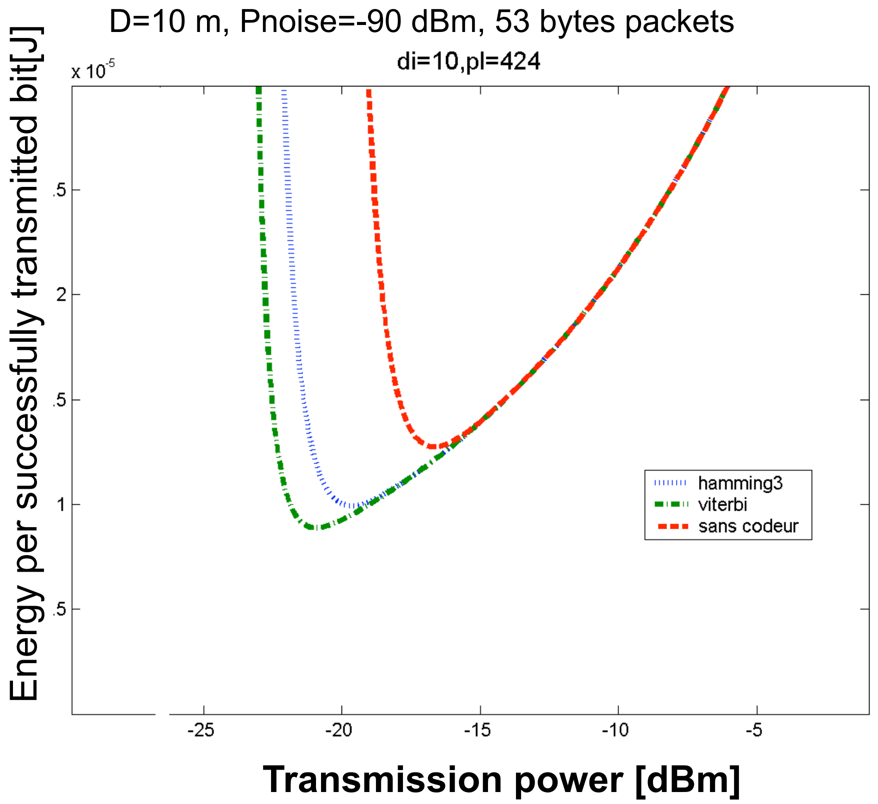


Power optimization of a wireless node



Performance/energy joint modelling

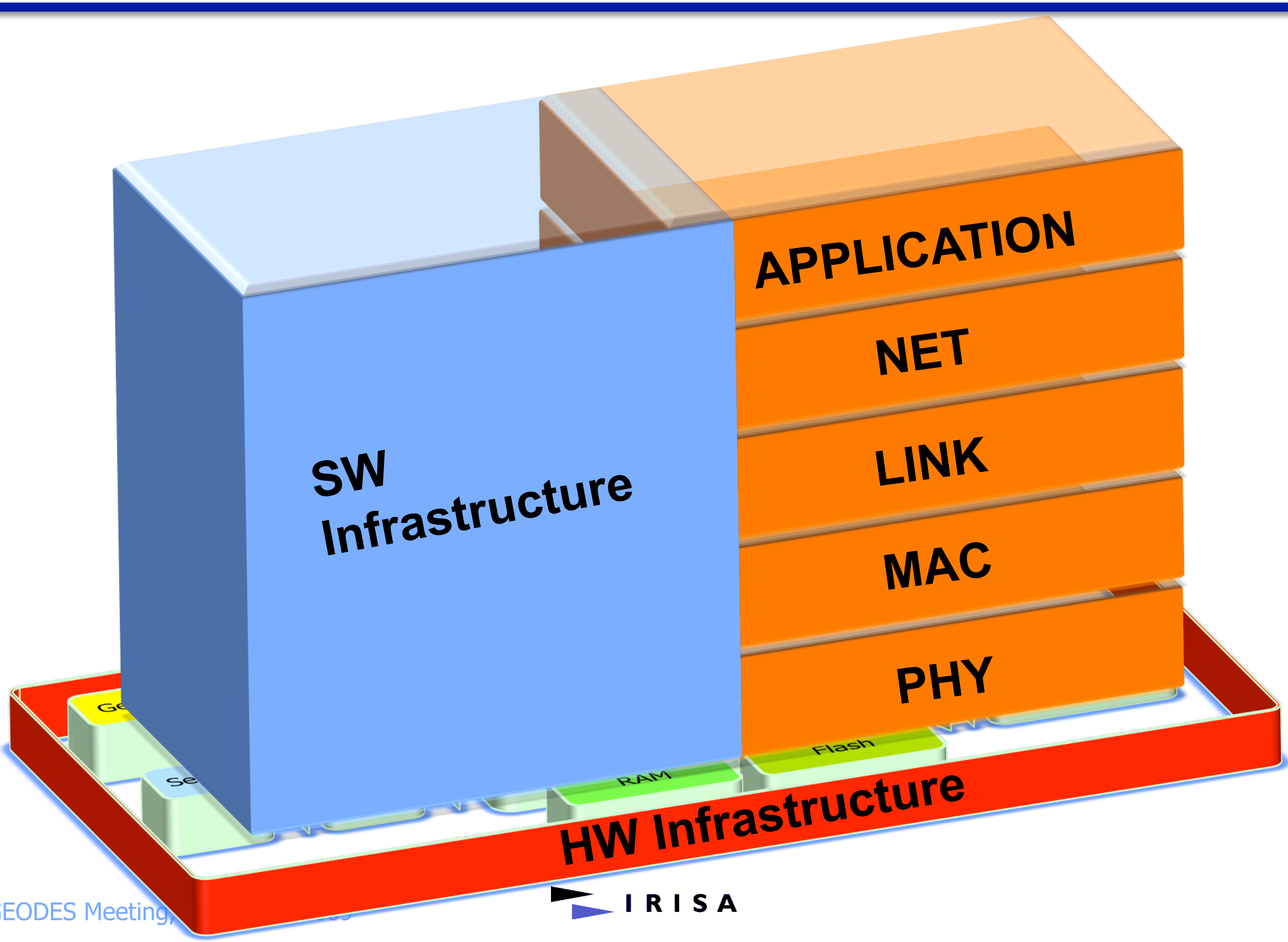
- Energy per successfully transmitted bit



CC1020 transceiver

[Sentieys08] O. Sentieys, O. Berder, P. Quemerais and M. Cartron, Wake-up Interval Optimization fo Sensor Networks with Rendez-vous Schemes, Workshop on Design and Architectures for Signal and Image Processing (DASIP'07), November 2007.

Power optimization of a wireless node

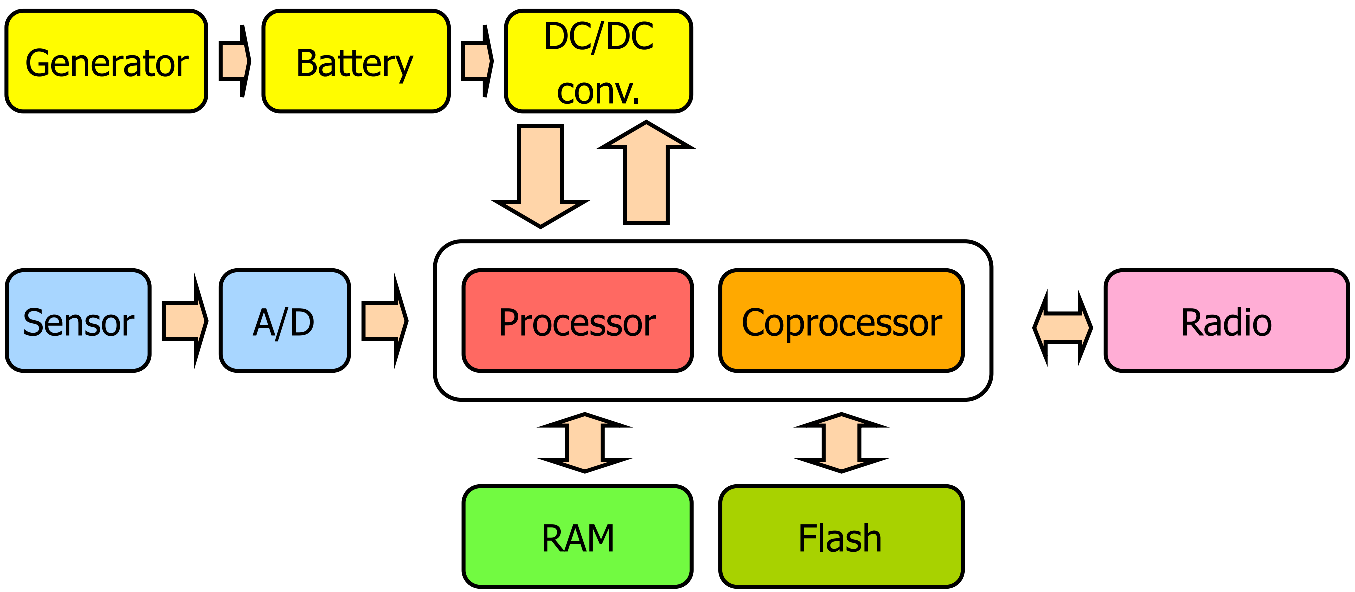


HW Platform Energy Optimization

- Co-processing
- Dynamic Voltage Scaling
- Power Gated FSM
- Dynamic Precision Scaling

PowWow **V2**

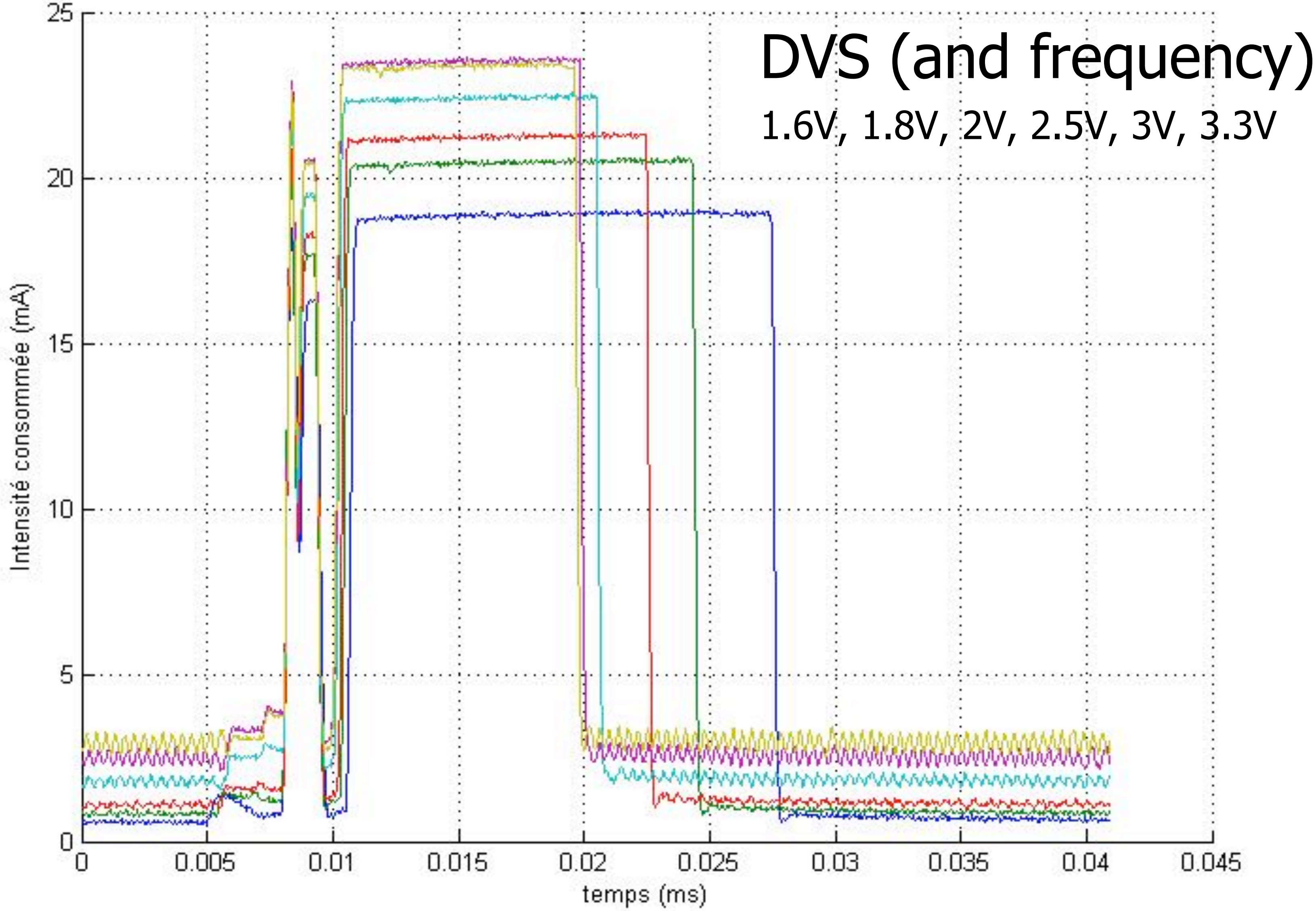
- FPGA
- DVS
- “Wake-Up Radio”



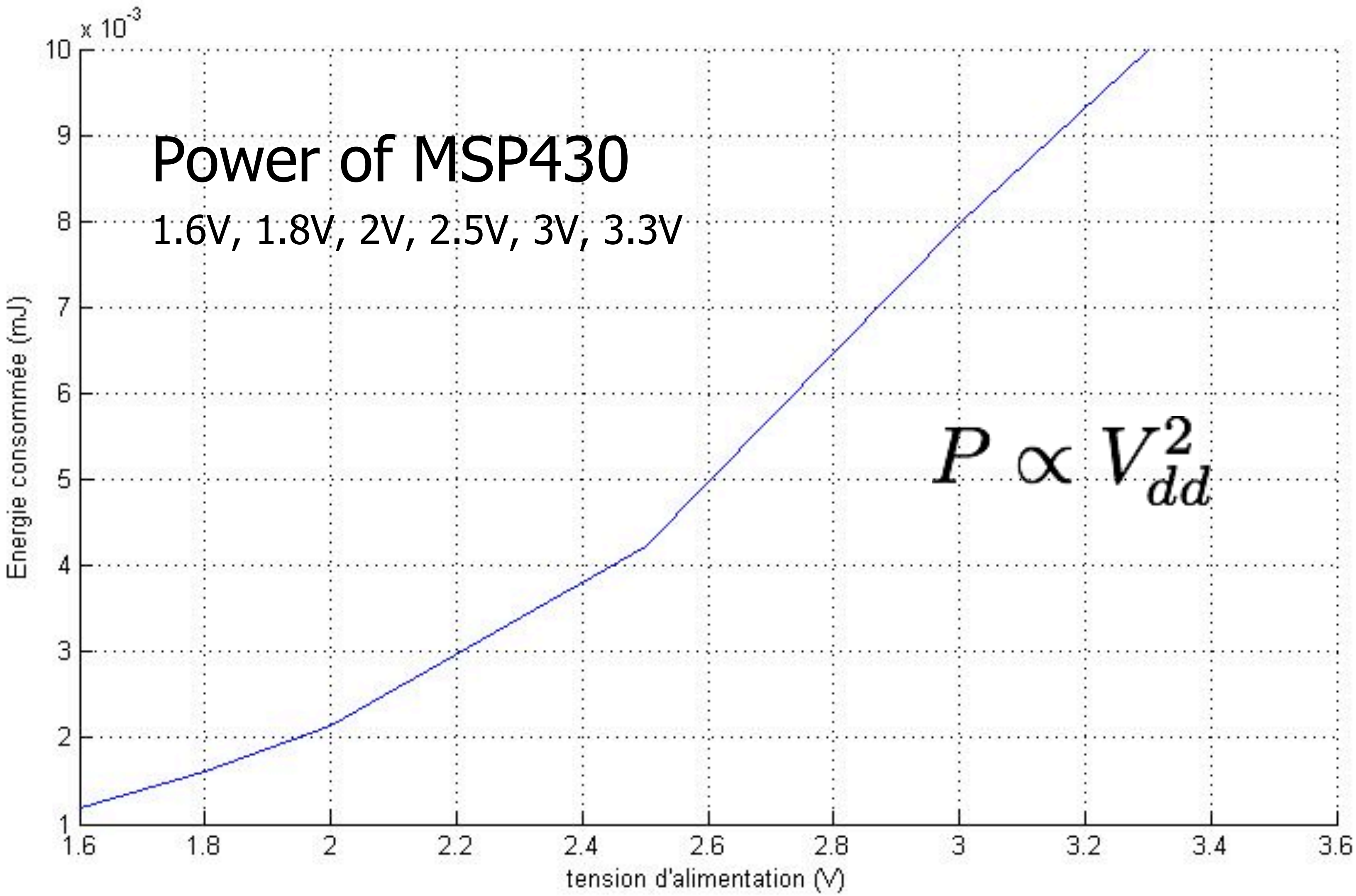
Coprocessing with Low Power FPGA

- Actel Igloo FPGA
  - AGL125, 130nm, 125kgates
  - 32kbits RAM, 1 kbits Flash, PLL
  - 1.2V (0-1.65V)
  - 2.2uW/16uW/1-30mW (sleep/freeze/run)
  - Implemented Viterbi for link layer: 5mW
- FPGA power efficiency on CRC32
  - CRC32 on MSP430
    - o E_{msp} = 150µs x 20mW = 3µJ (at 8MHz)
  - CRC32 on Actel Igloo AGL125
    - o 125k gates, 36kbits RAM,
    - o E_{igloo} = 0,8µs x 5mW = 0,004µJ (at 20MHz, including I/O)
    - o Energy saving = 150/0,8x20/4 = **750**

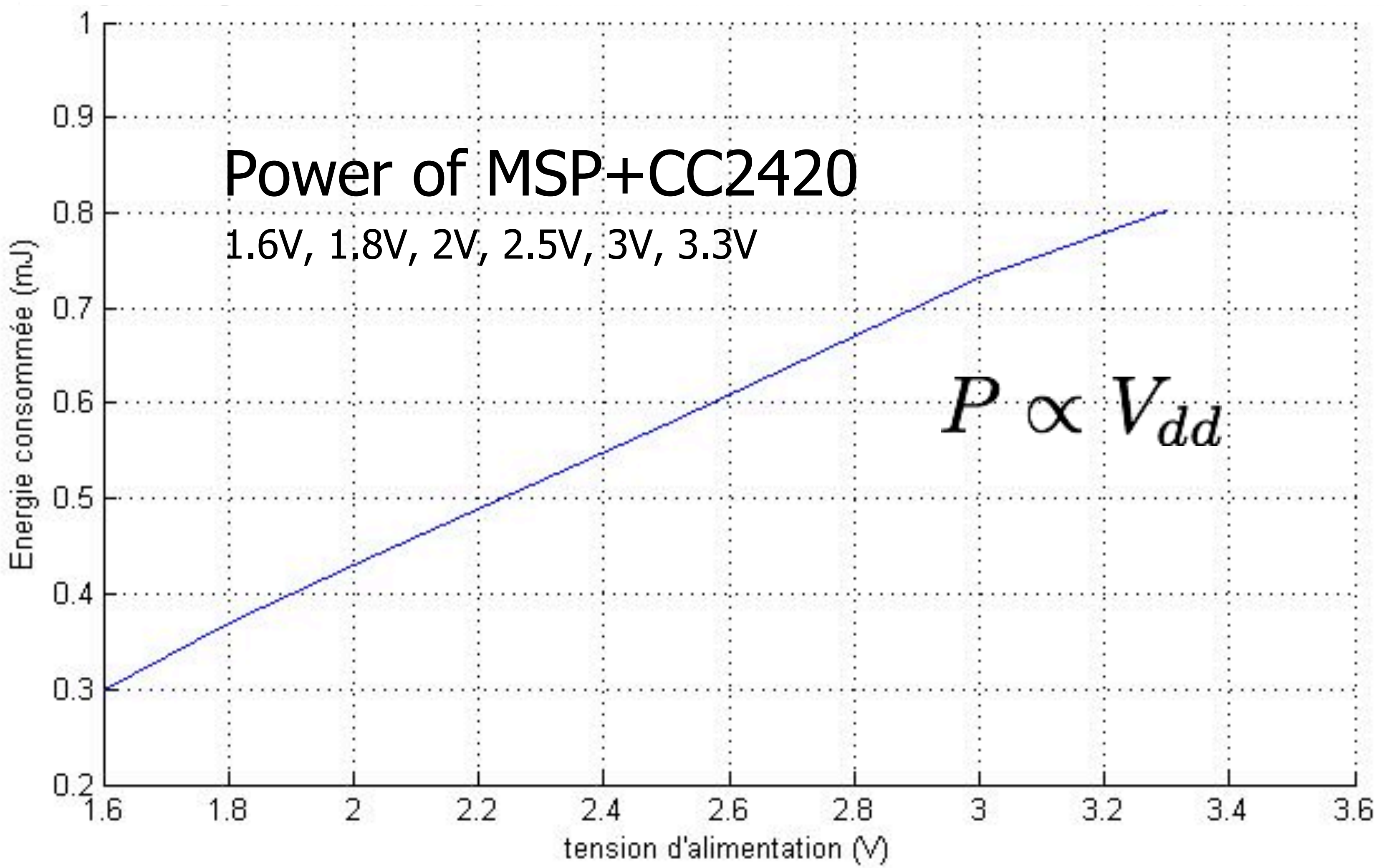
Dynamic Voltage Scaling (1/3)



Dynamic Voltage Scaling (2/3)

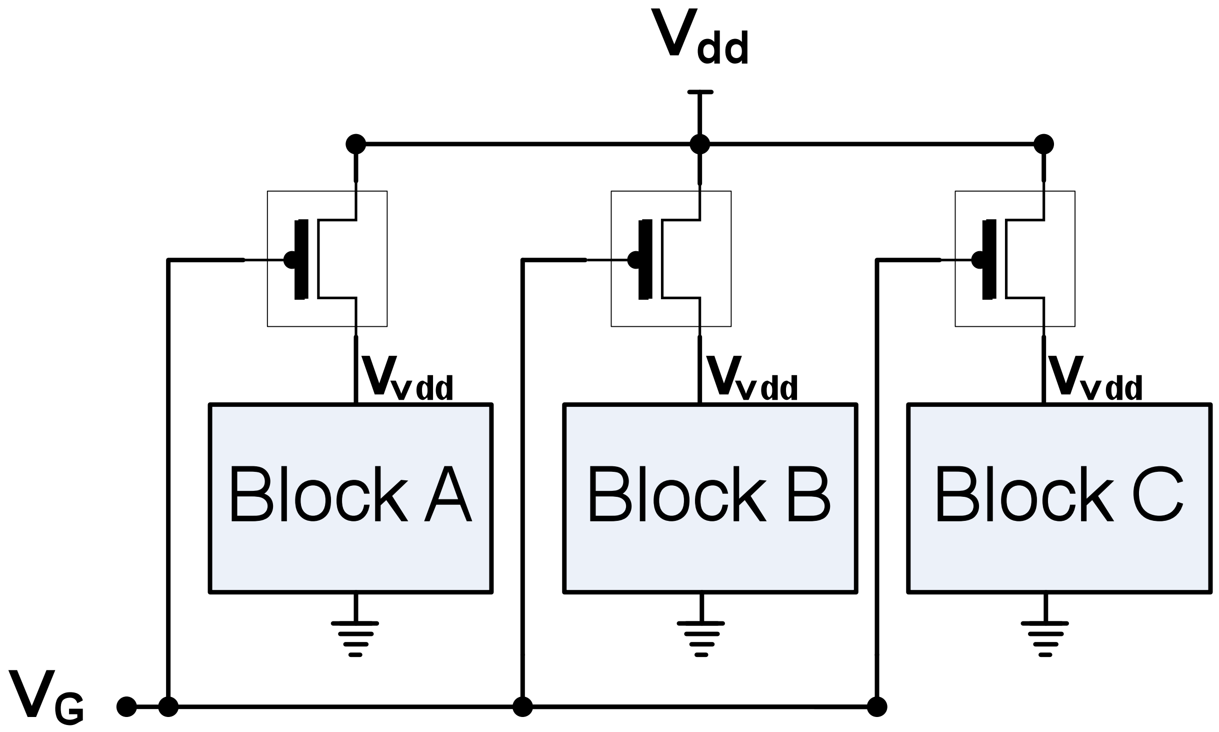


Dynamic Voltage Scaling (3/3)



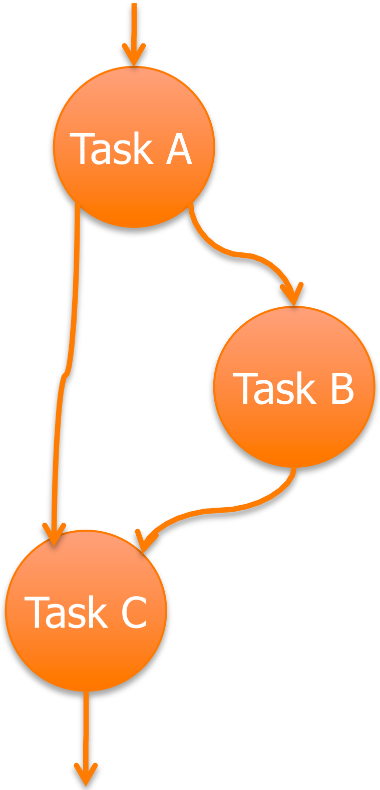
Power Gated Controllers (1/4)

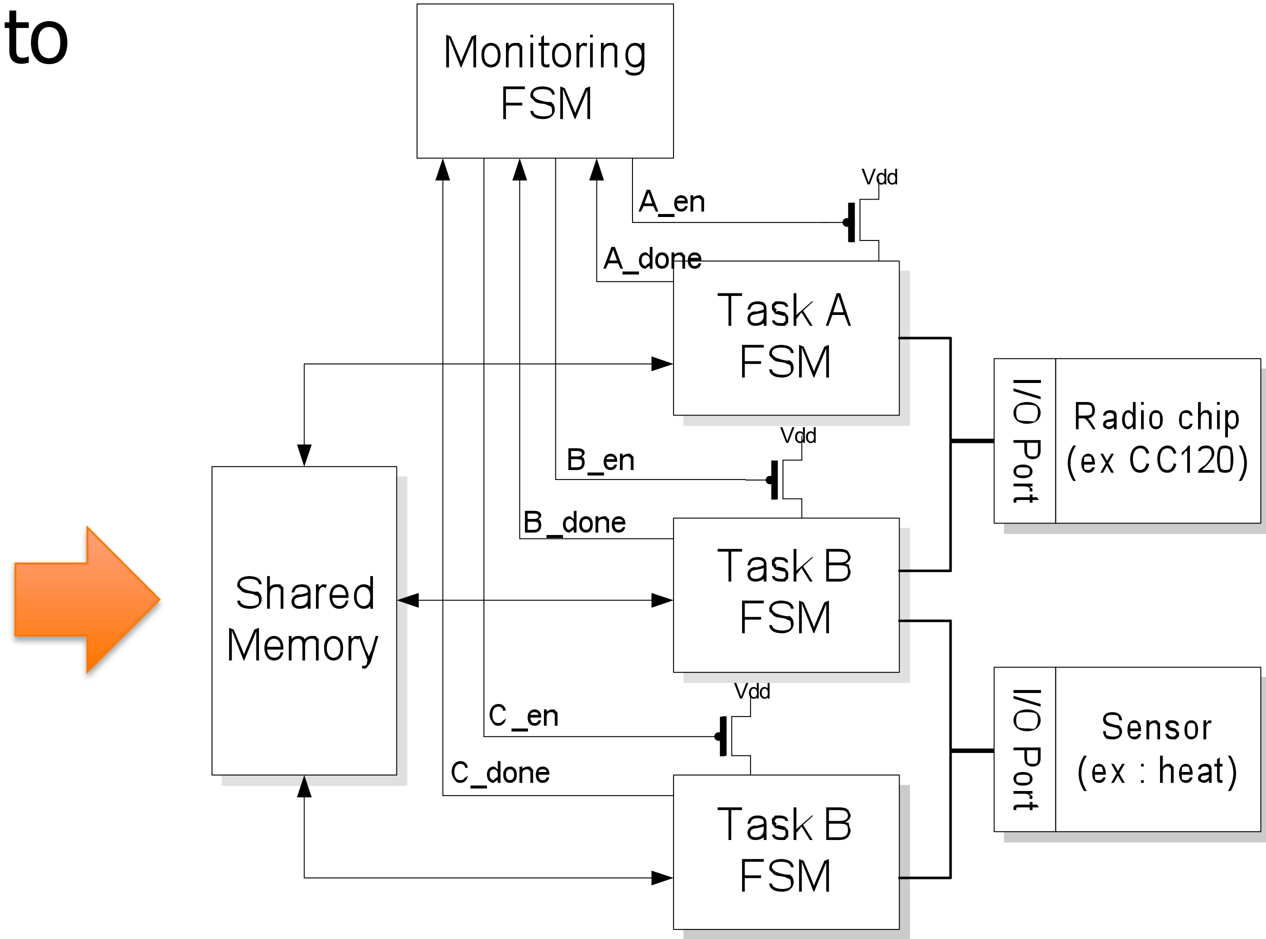
- Power Gating Principle



Power Gated Controllers (3/4)

- Task graph to gated FSM





(a) System level view of an application mapping

IRISA [A. Pasha Thesis]

Power Gated Controllers

- Power gain versus MSP430 software execution

Name	ROM		Hardware Task		IGLOO	
	Size (Bytes)	Power (μW)	Power (μW)	Gain (x)	Power (μW)	Gain (x)
s832[a]	1770	480	227	194	3710	11
tbk[a]	7266	600	234	188	3665	12
s820[a]	1628	480	221	199	3857	11
s1494[a]	2492	480	247	178	5590	7
r30[b]	608	480	211	208	3244	13
r42[b]	932	480	221	199	3323	13
r66[b]	1428	480	242	181	4024	11
r96[b]	1998	480	254	173	4076	10
r147[b]	2818	480	286	153	6897	6

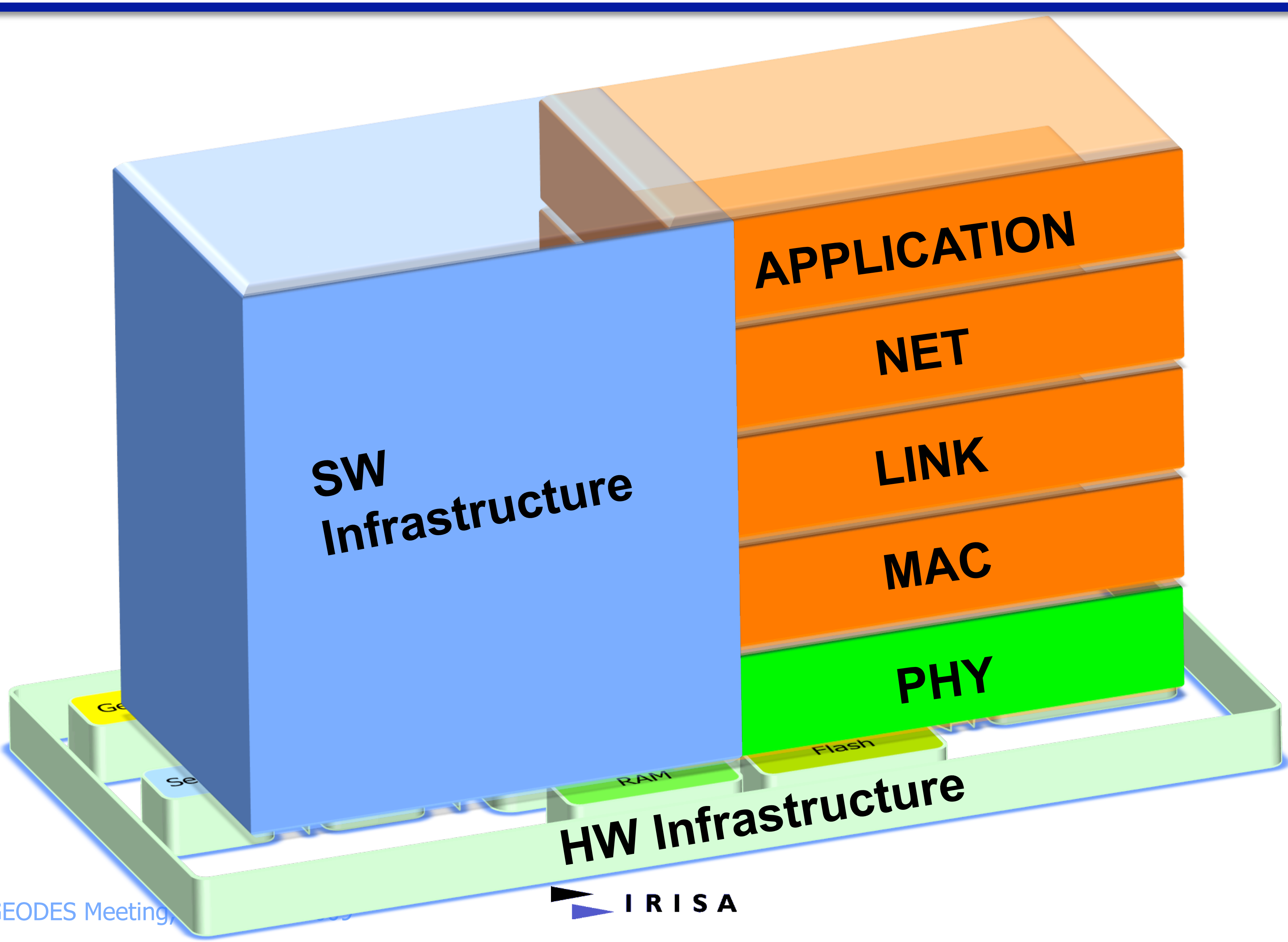
TABLE I

SUMMARY OF DYNAMIC POWER CONSUMPTION FOR VARIOUS TARGETS.

[a] LGSynth'93 Benchmark FSM
[b] Randomly generated FSM

*[Pasha09] A. Pasha, S. Derrien, and O. Sentieys, "*Ultra Low-Power FSM for Control Oriented Applications*", IEEE Int. Symp. on Circuits ans Systems, ISCAS, Taipei, Taiwan, 2009.*

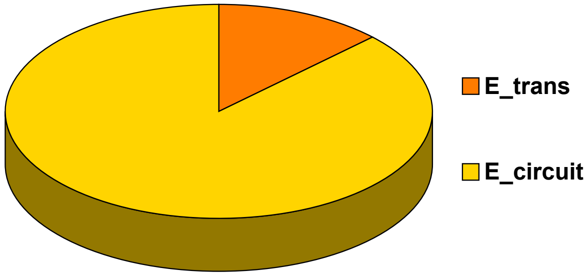
Power optimization of a wireless node



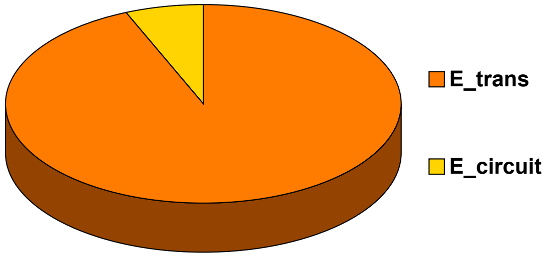
Global energy consumption

Total energy = Transmission Energy + Circuit Energy

$$E_{total\ SISO} = E_{pa} + E_c = (P_{pa} + P_c)N_b / R_b$$



d=10m, SISO



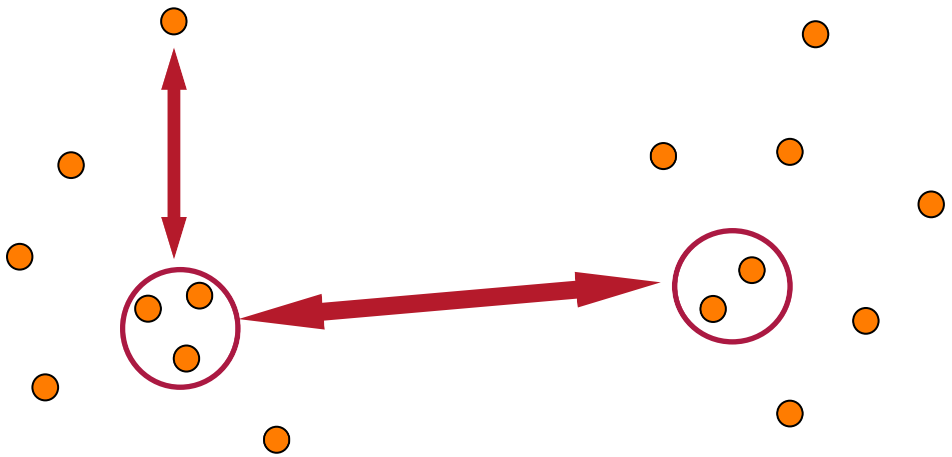
d=100m, SISO

Cooperative MIMO using STC for WSN

- MIMO space-time coding => Diversity gain
  - Reduces the error rate or transmission energy
- In WSN: Limited size or limited cost of each wireless sensor node
  - Each node can support only one antenna

=> Direct application of MIMO transmission technique is not practical

Individual nodes can cooperate → **Cooperative MIMO technique**



- Diversity gain of MIMO STBC
  - Energy efficiency of MIMO technique for long range transmission

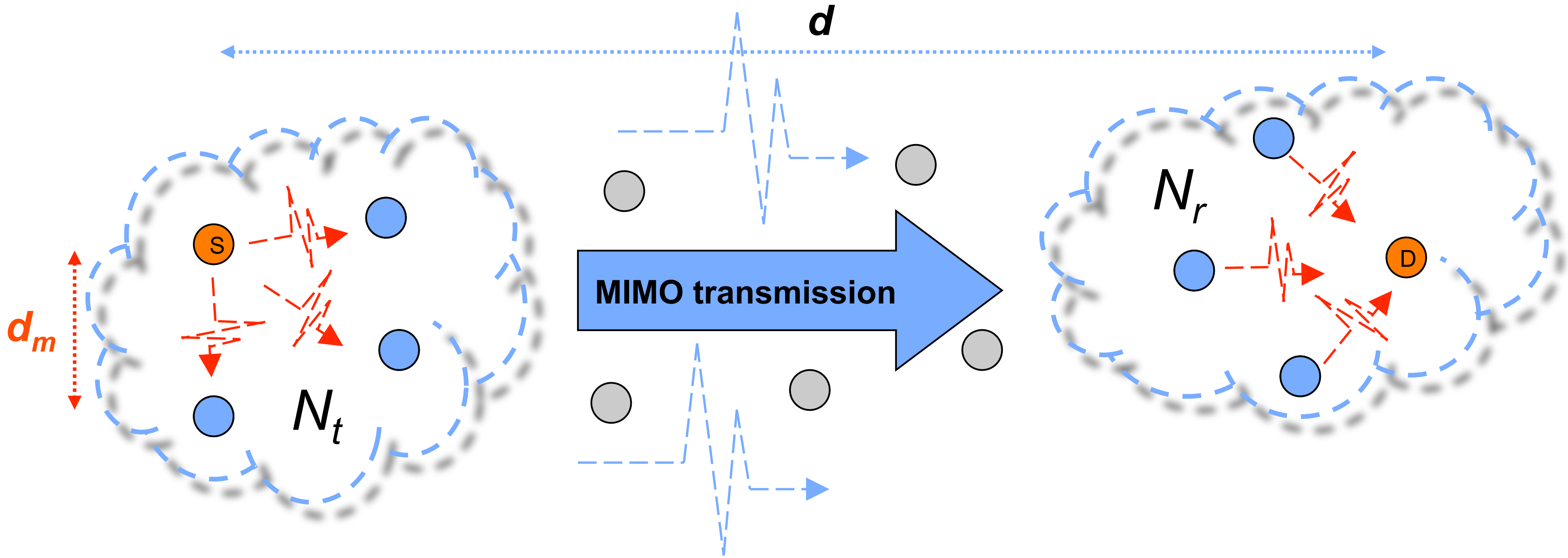
[T.D. Nguyen Thesis]

Cooperative MIMO technique

- Three phases of cooperative MIMO communications
  - Phase 1: Local data exchange
  - Phase 2: Cooperative MIMO transmission
  - Phase 3: Cooperative reception

$d_m \ll d$

$d_m = 1..10$ m

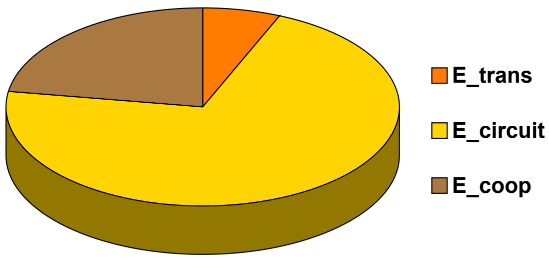


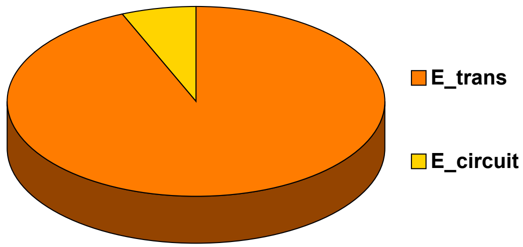
Cooperative MIMO

- Total energy = Transmission Energy + Circuit Energy + Cooperation Energy

$$E_{coopT_x} = N_b E_{pb_{coopT_x}} \qquad E_{coopR_x} = N_{sb}(N_r - 1) N_b E_{pb_{coopR_x}}$$

$$E_{total} = E_{pa} + E_c + E_{coopT_x} + E_{coopR_x}$$

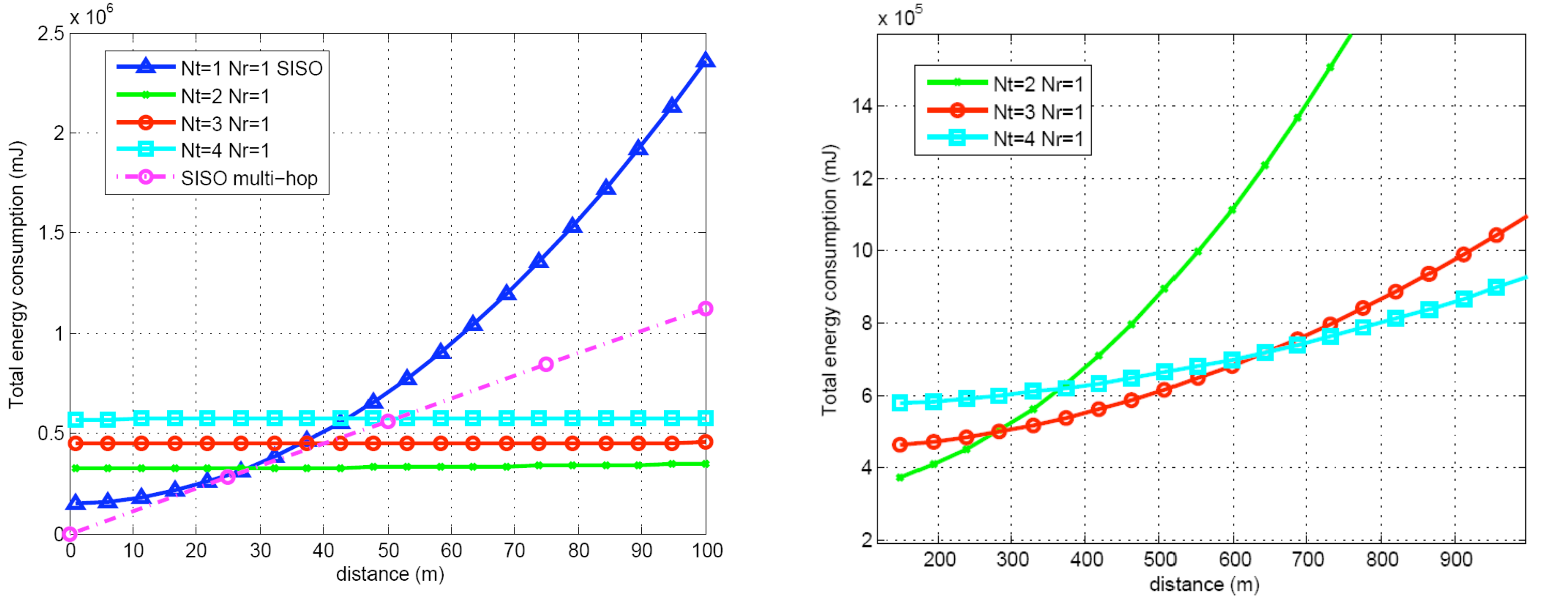




d=100m, MISO 2-1

d=100m, SISO

Energy consumption of cooperative MIMO



- Cooperative MIMO technique is more energy efficient than SISO and multi-hop SISO techniques for long distance transmission [1,2]

[Nguyen08] T. Nguyen, O. Berder, and O. Sentieys, "Impact of transmission synchronization error and cooperative reception techniques on the performance of cooperative MIMO systems ", IEEE International Conference on Communications ICC, Beijing, China, 2008.

[Nguyen07] T. Nguyen, O. Berder, and O. Sentieys, "Cooperative MIMO schemes optimal selection for wireless sensor networks," IEEE 65th Vehicular Technology Conference, VTC-Spring, pp. 85–89, 2007.

Summary

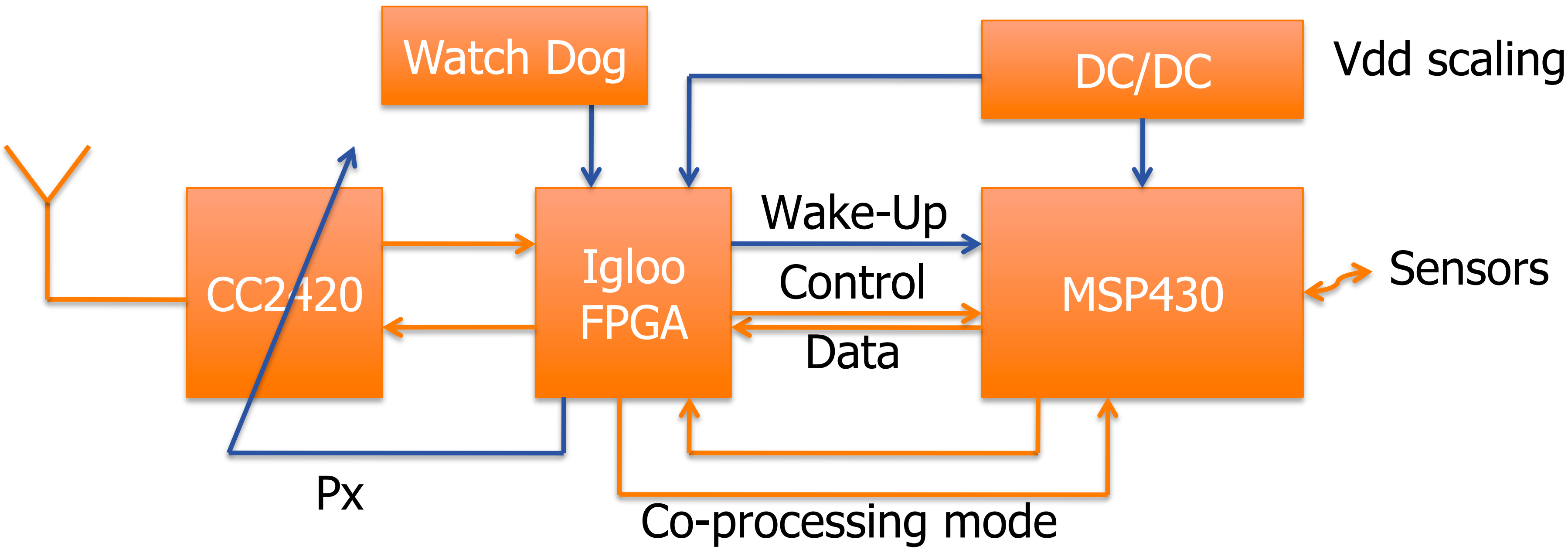
- Energy minimization in WSN
  - Complex cross-layer problem
  - Good adequacy between light software and dedicated platform

- Advanced signal processing vs. transmission power
  - Error correcting codes
  - Cooperative MIMO techniques

- Power estimation on heterogeneous platforms
  - Power/Performance models
  - Influence of power management (Vdd scaling)
  - FPGA co-processing
  - Dynamic precision scaling, Power gating

Perpectives

- PowWow Version 2 includes
  - FPGA for low-level processing and hardware acceleration
  - Voltage scaling
  - Wake-up for ultra-low-power modes



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[Nguyen07] Tuan-Duc Nguyen, Olivier Berder and Olivier Sentieys, Cooperative MIMO schemes optimal selection for wireless sensor networks, *IEEE VTC-Spring*, 2007.

[Sentieys07] O. Sentieys, O. Berder, P. Quemerais and M. Cartron, Wake-up Interval Optimization for Sensor Networks with Rendez-vous Schemes, *Workshop on Design and Architectures for Signal and Image Processing (DASIP),* 2007.

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[Nguyen08b] T. Nguyen, O. Berder, and O. Sentieys, Efficient space time combination technique for unsynchronized cooperative MISO transmission, *IEEE VTC-Spring*, 2008.

[Lin05] E.Y Lin, J. Rabaey, S. Wiethoelter, and A. Wolitz. Receiver Initiated Rendez-vous Schemes for Sensor Networks. In Proc. of IEEE Globecom 2005, 2005.

[Lin04] E.Y. Lin, J. M. Rabaey, and A. Wolisz. Power-Efficient Rendez-vous Schemes for Dense Wireless Sensor Networks. In IEEE International Conference on Communications ICC 2004, 2004.

[Menard08A] D. Menard, R. Rocher, O. Sentieys, and O. Serizel. Accuracy Constraint Determination in Fixed-Point System Design. EURASIP Journal on Embedded Systems, 2008.

[Menard08B] D. Menard, R. Rocher, and O. Sentieys. Analytical Fixed-Point Accuracy Evaluation in Linear Time-Invariant Systems. IEEE Transactions on Circuits and Systems I, 55(1), November 2008.