Visit to Verona University
May 14-16, 2014

Alain Pegatoquet
Associate Professor (HDR)

University of Nice Sophia Antipolis
LEAT Laboratory
UMR CNRS 7248

Agenda

- **University of Nice Sophia Antipolis - LEAT**
- **A short bio…**
- **Main research activities**
  - Characterizing Power and Performance at a High Level of abstraction
  - System-level Power Modeling Approach
  - Power Management Techniques for autonomous Wireless Sensor Networks
- **Future works…**

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University of Nice – Sophia Antipolis

- One of the 10 firsts French Universities
- 9 campus
- Global budget (2013): 237 M€

Sophia Antipolis Technopole

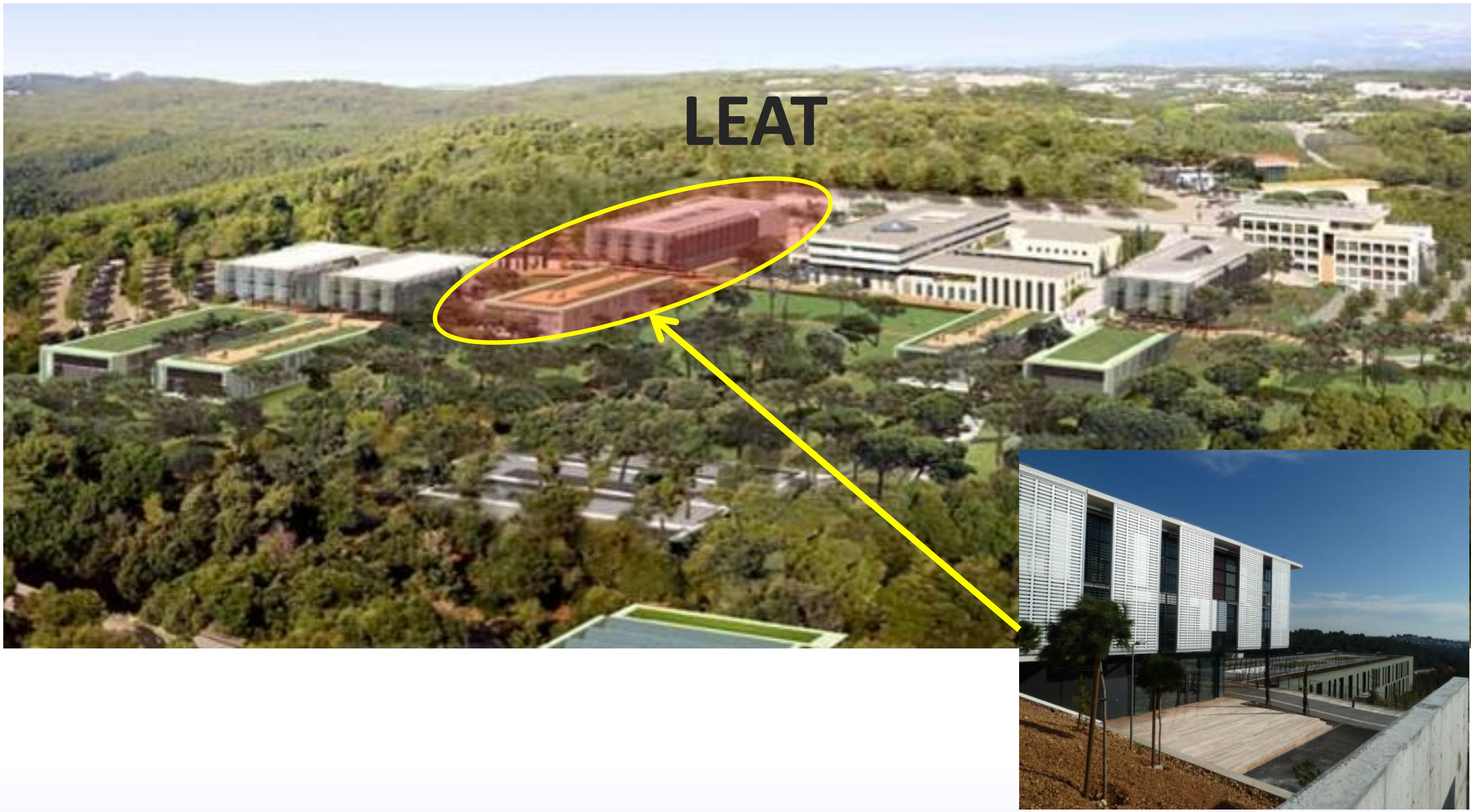
This scientific park has been developing continuously for the past 30 years.

- ✓ **1 500 companies**, with 40% having R&D activities
- ✓ **30 000 employees**
- ✓ **5 000 students**
- ✓ **4 000 public sector researchers**

With its 13 100 employees, the **information technology sector** represents 45% of the employments and 20% of the companies in the park.

Sophia Antipolis Technopole

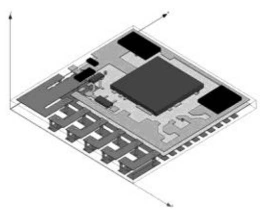
SophiaTech Campus

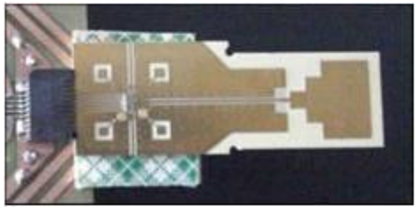


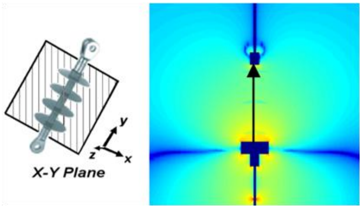
LEAT

A Mixed CNRS-UNS laboratory

- ✓ **76 people** (2013), with 31 permanent staff
- ✓ **3 main activities:**
  - ➢ Antenna Design and Modeling (**CMA**)



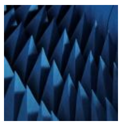


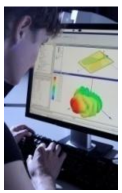


  - ➢ Detection and Imagery System and Antenna related systems (**S2DSDA**)

  - ➢ System Level Modeling and Design of communicating objects (**MCSOC**)

Campus SophiaTech, Sophia Antipolis



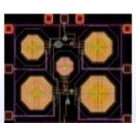


System Level Modeling and Design of Communicating Objects

(MCSOC)

Team leader: Cécile Belleudy

cecile.belleudy@unice.fr



Staff (in 2013)

Permanent Staff (10)


M. Auguin


C. Belleudy


S. Bilavarn


D. Gaffé


A. Giulieri


L. Kwiatowski


F. Muller


A. Pegatoquet


W. Tatinian


F.Verdier

Non-Permanent Staff


H. Affes


N. Trong


U. Cerasani


M. Abdelmouna


O. Mbarek


B. Ouni


C. Chaabane


K. Baathi


H. Nguyen


F. Duhem


C. Foucher


J. Khan


J. Kriegel

4 main activities

- **Power Consumption Modeling and management for communicating objects**
- Reconfigurable and auto-adaptive systems
- Soc validation using synchronous approach
- RF front-end behavioral modeling and design

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- Future works…

Just few words about me

From 2008…

Associate Professor – University of Nice

- **Teaching in Technical Institute of Nice**
  - Electronics, Microprocessors, Computer Science (C, C#), Networks, Linux…
- **Main Research Activities (LEAT)**
  - Power Management for Wireless Sensor Networks *(Andrea Castagnetti & Trong-Nhan Le)*
  - Mobility Management approach for 802.15.4/ZigBee nodes *(Chiraz Chaabane)*
  - High Level approach for Performance and Power Consumption Modeling and Estimation *(Joffrey Kriegel)*
  - ESL Approach for the Design and Verification of Low-Power SoC *(Ons Mbarek)*

Just few words about me

Industry Experience…

- **1995-2000**: *System DSP Engineer* at **VLSI Technology** (then **Philips Semiconductors**) – Sophia Antipolis
  PhD from University of Nice in 1999

- **2000-2003** : *System Engineer* at **Stepmind SA** (a French start-up in Cannes)
  GSM/GPRS/EDGE baseband chipset

- **2003-2008**: *System Engineer* at **Texas Instruments** (in Villeneuve-Loubet)
  Layer-1 DSP team (EDGE)
  Acoustics Technical Leader

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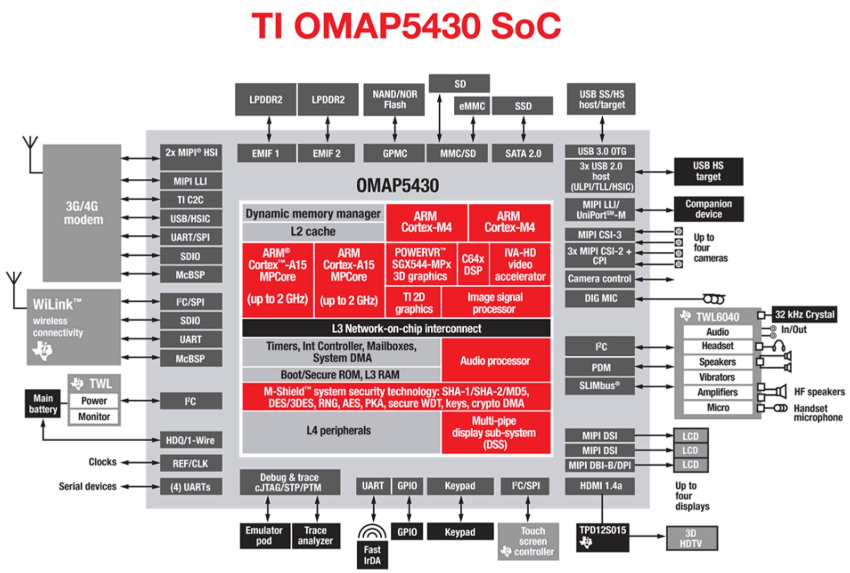
Challenges related to Embedded Systems

- Architectures are more and more **complex** (multiprocessors, multi-cores…)
- More and more **features** (*user experience*), so more software…
- New multimedia or telecommunications **standards**



Architecture
- 6 CPUs
- Accelerators
- Many peripherals
  - Ethernet, USB, HDMI, Audio…

Features
- 2G/3G/4G
- Wifi, Bluetooth
- Video (2D/3D), Camera
- Etc.

- These systems are under **strong constraints**
  - Performance, power consumption, thermal

What are the challenges for the designers?

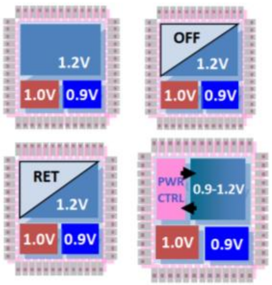
- How to make the right design choices?
  - Need for **methodologies and tools** in **order to evaluate** and validate these choices

- How to **control consumed energy** (increase lifetime)?
  - Smartphones, Tablets
  - Small communicating objects communicants (e.g. sensor networks)

- How to **manage high complexity** of these systems?
  - System-level modeling

Context and Motivations

- Different **techniques** to manage power consumption
  - Power or Clock gating
  - Power or Clock domain partitioning
  - DVFS, Multiple-Voltage

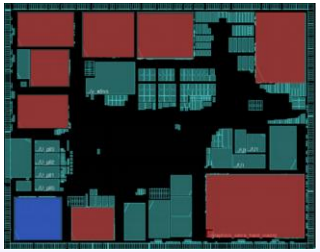


[Keating 2007]

- Implementing these techniques raises **many challenges**
  - How to check that power architecture is correct?
  - Are power consumption and performance still respected?

- Defining an HW/SW architecture optimized in performance/power becomes a **very complex issue** for 2 main reasons:
  - SoC complexity
  - Lack of design tools

Qualcomm Serra

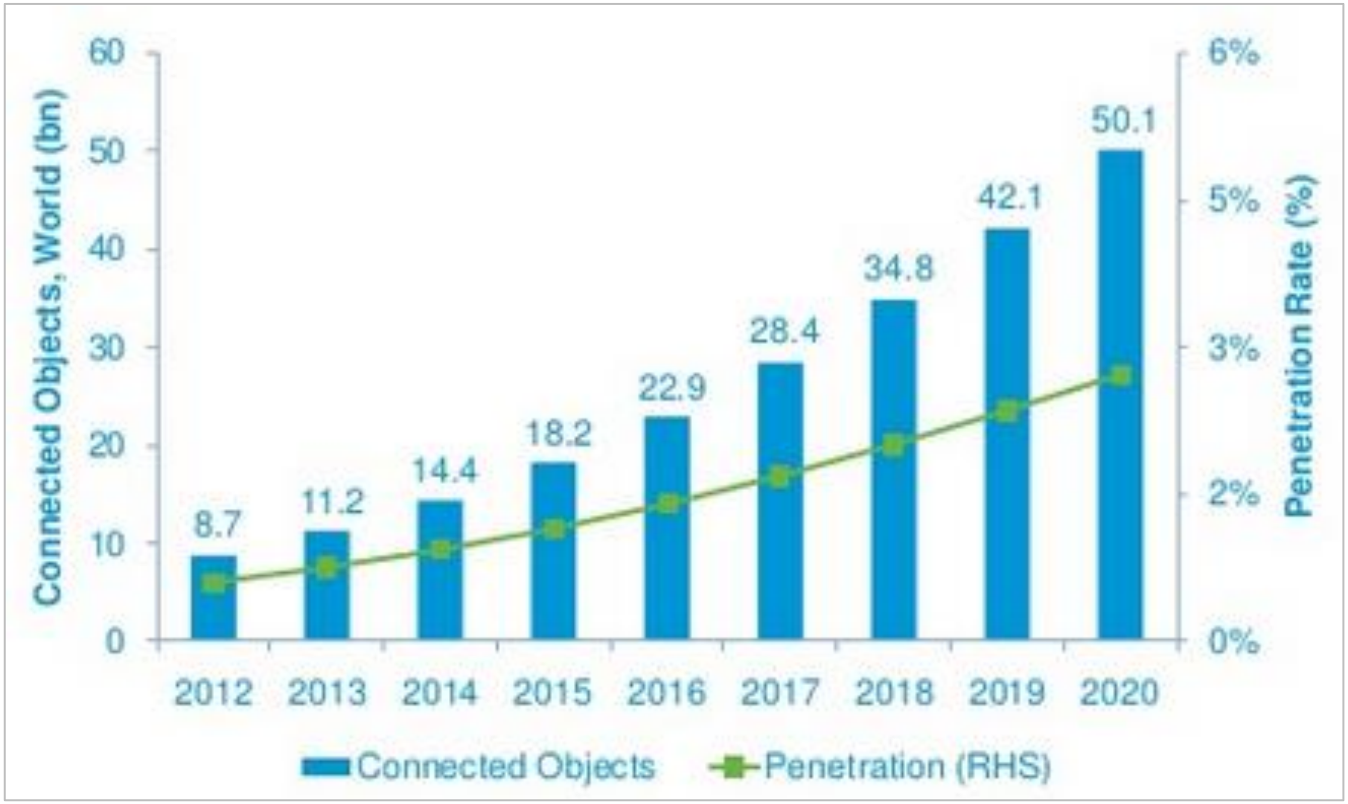


230 clock domain
32 power domain

[Severson 2009]

Towards a Connected World…

- 50 billions connected objects in 2020…

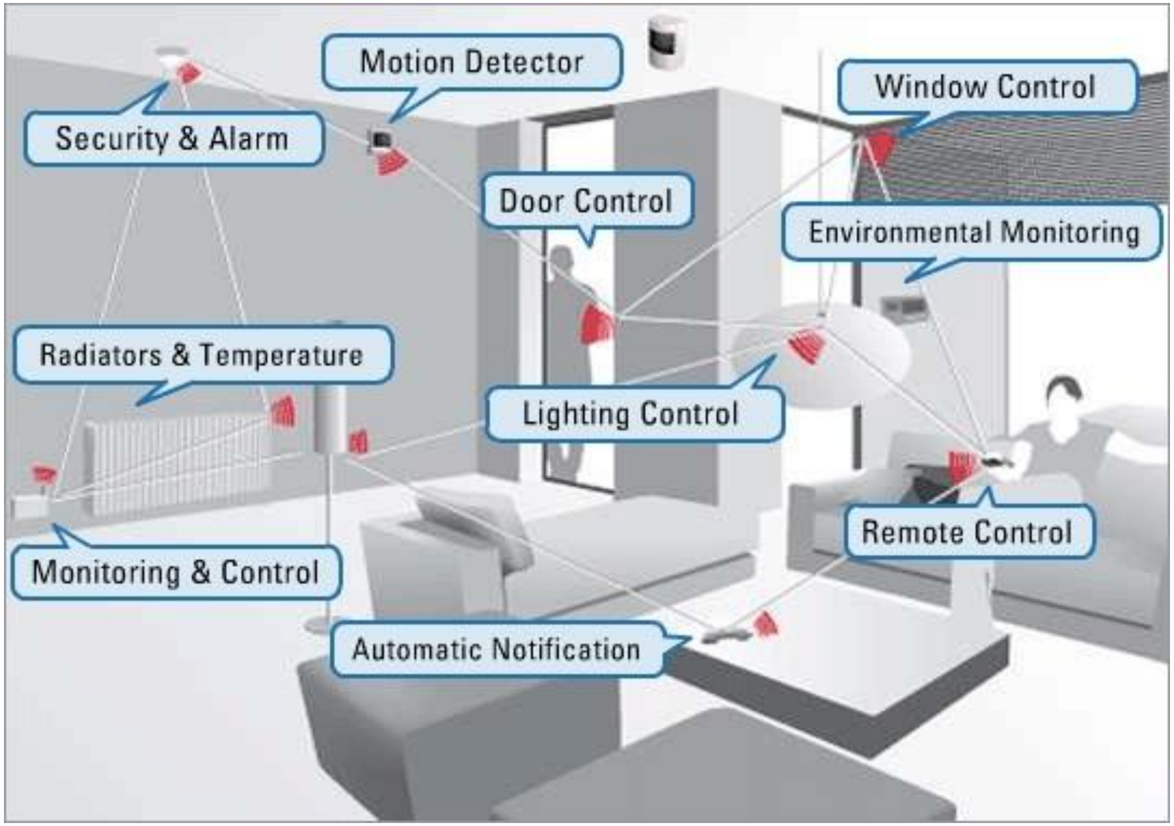


Source: CCS 2013

- What about the overall energy consumption?

Challenges for Energy Autonomous Objects…

- Designing « small » autonomous communicating objects
  - Energy **harvesting** and **storage**
  - Handling nodes activities : **power management**



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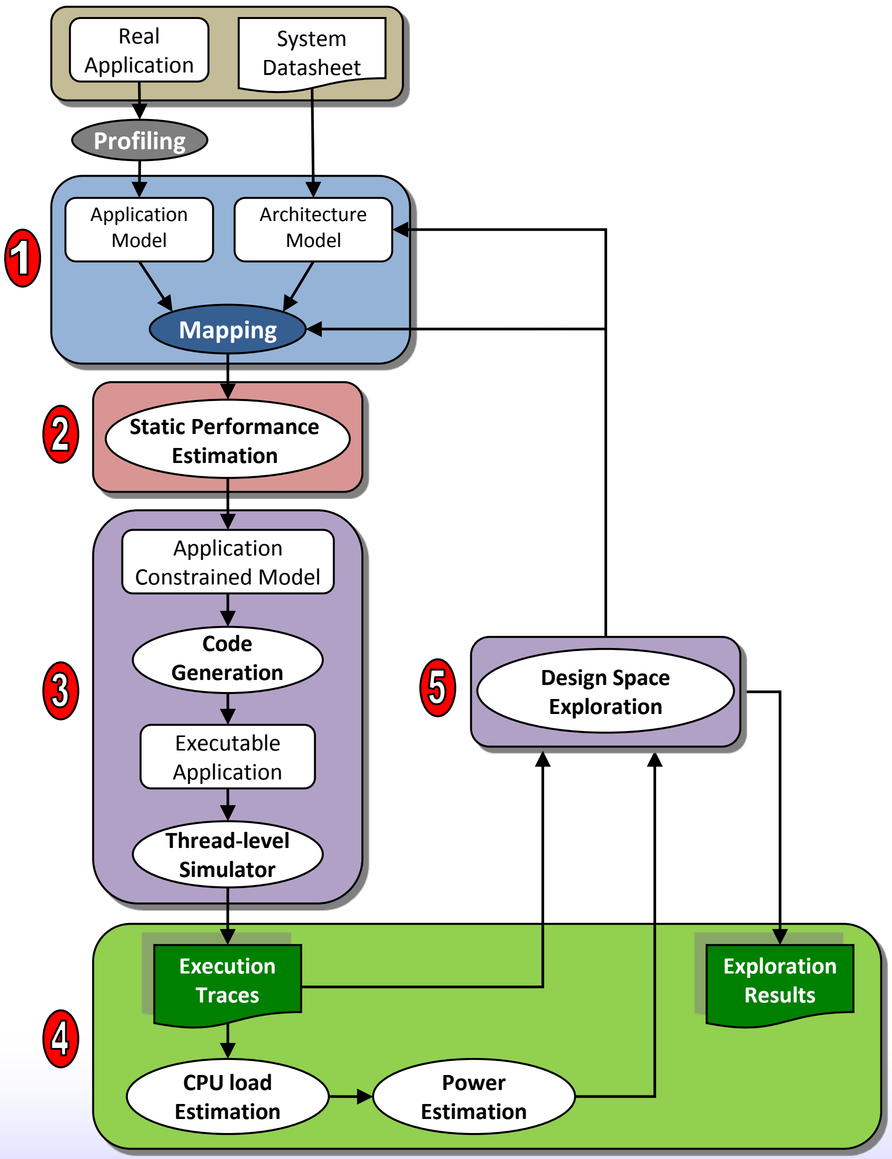
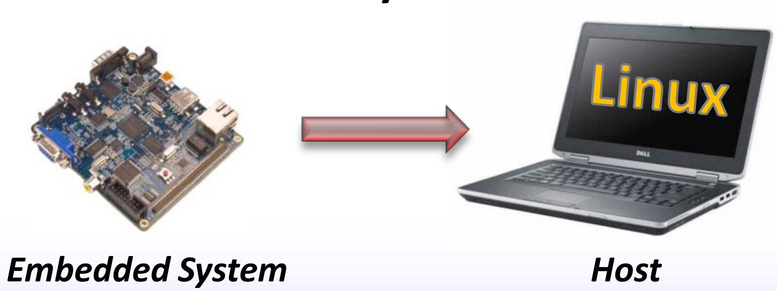
Methodology Overview



[Kriegel 2011]

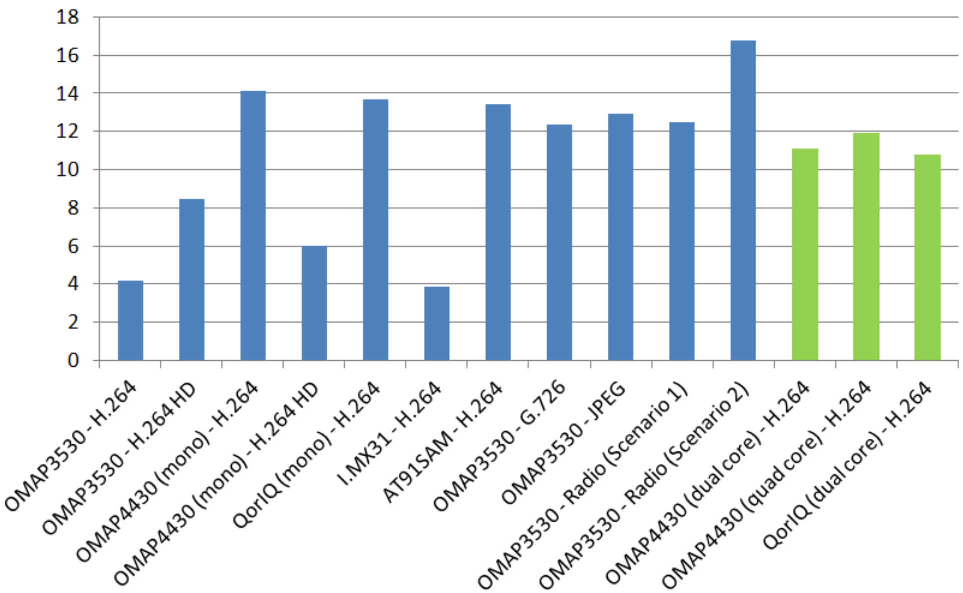
- **Objectives**
  - Estimate performance and energy consumption
- **Industrial Constraints**
  - Use of industrials datasheet
  - Develop models rapidly
  - Rapid estimation
  - Explore different architectures in order of minutes
  - Estimation errors less than 20%
- **A 5-step Methodology**
- **Y-chart Model**
- **Execution on a host system**



[Kriegel 2012]

Estimation Results

- Performance Estimation Error Margin (in %)



- Accurate estimations (<20%) **despite** the level of abstraction.
- **Optimistic** estimations (likely due to cache model and OS).

- Power Consumption Estimation from a **coarse grain model**

Application	Frequency (MHz)	Measured Energy (mJ)	Estimated Energy (mJ)	Error (%)
H.264 Decoder for 8FPS	600	1736	1759	1,3
	550	1340	1403	4,7
	500	1020	1070	4,9
JPEG Encoder	600	107,6	91,9	-14,6
	500	77,2	66,1	-14,5

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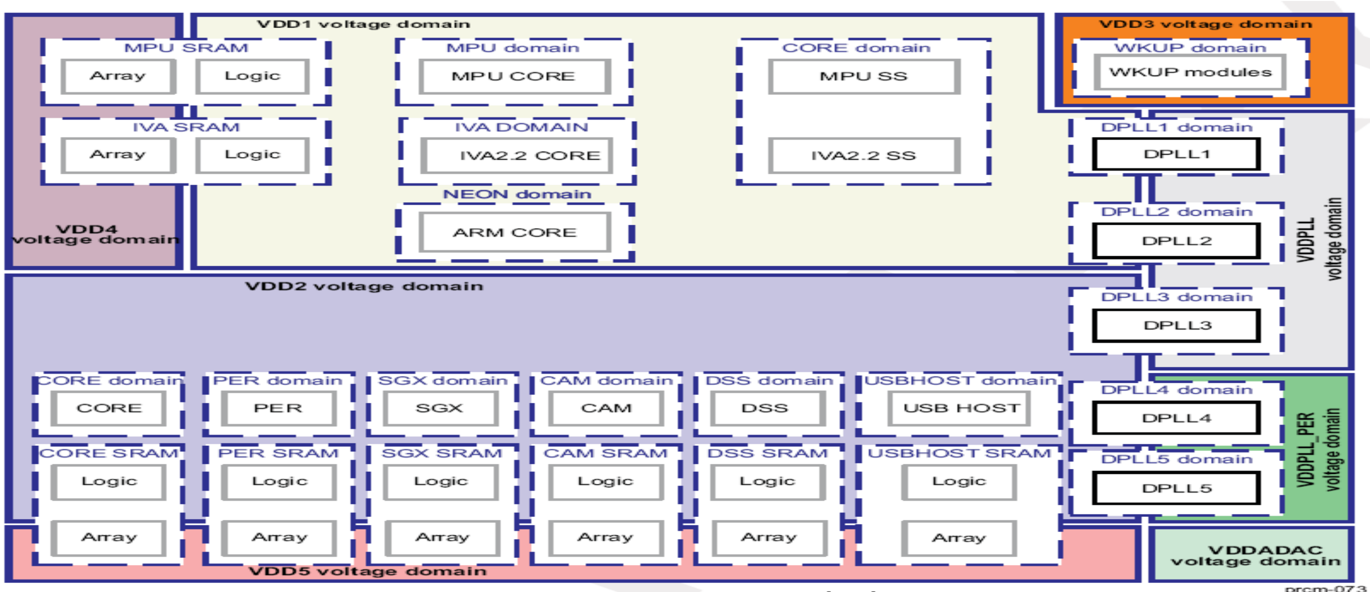
Power and Clock Domains Partitioning

- OMAP3530 from Texas Instruments as an example



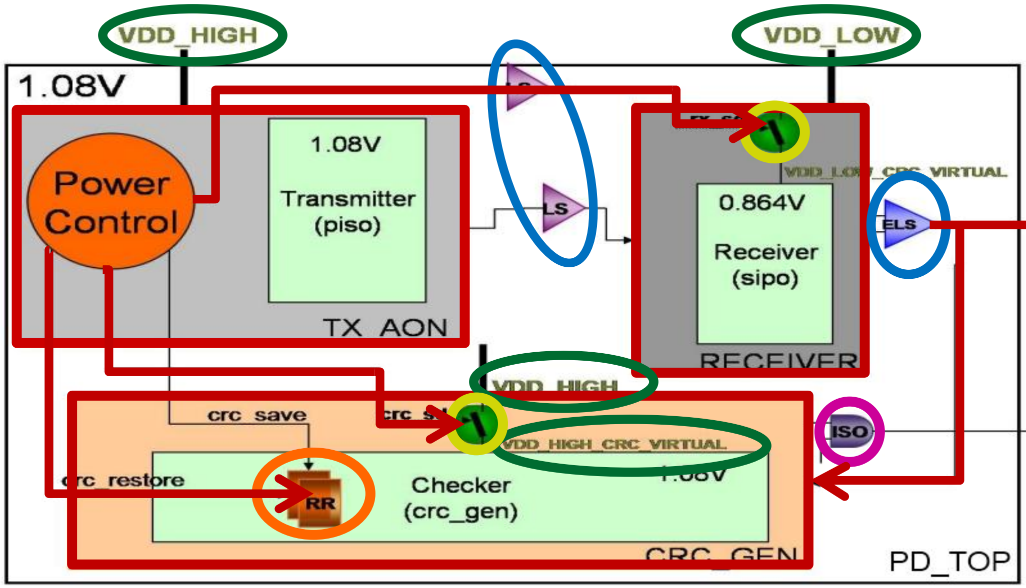
Texas Instruments OMAP3530 Block Diagram

WTSD
Wireless Terminals Software Development.

- Existing tools/formalisms at **RTL level** (UPF, CPF)
- But these formalisms **do not exist at SystemC/TLM level** (ESL).
- Easier to **manage complexity** of these systems at ESL
- **Rapid** simulation
- Better optimizations **opportunities** **[Mentor 2010]**

UPF standard for Power Specification

- Main concepts defined by UPF (Standard IEEE 1801-2009)



UPF Concepts examples

	VDD_HIGH	VDD_LOW	VDD_HIGH_ CRC_VIRTUAL	VDD_LOW_ CRC_VIRTUAL
PRE_BOOT	High_Voltage	Low_Voltage	CRC_OFF	RX_OFF
CRC_ON	High_Voltage	Low_Voltage	High_Voltage	RX_OFF
RX_ON	High_Voltage	Low_Voltage	CRC_OFF	Low_Voltage
ALL_ON	High_Voltage	Low_Voltage	High_Voltage	Low_Voltage

Power State Table (PST) example

Supply Nets

Power Domains

Power Switches

Retention Registers

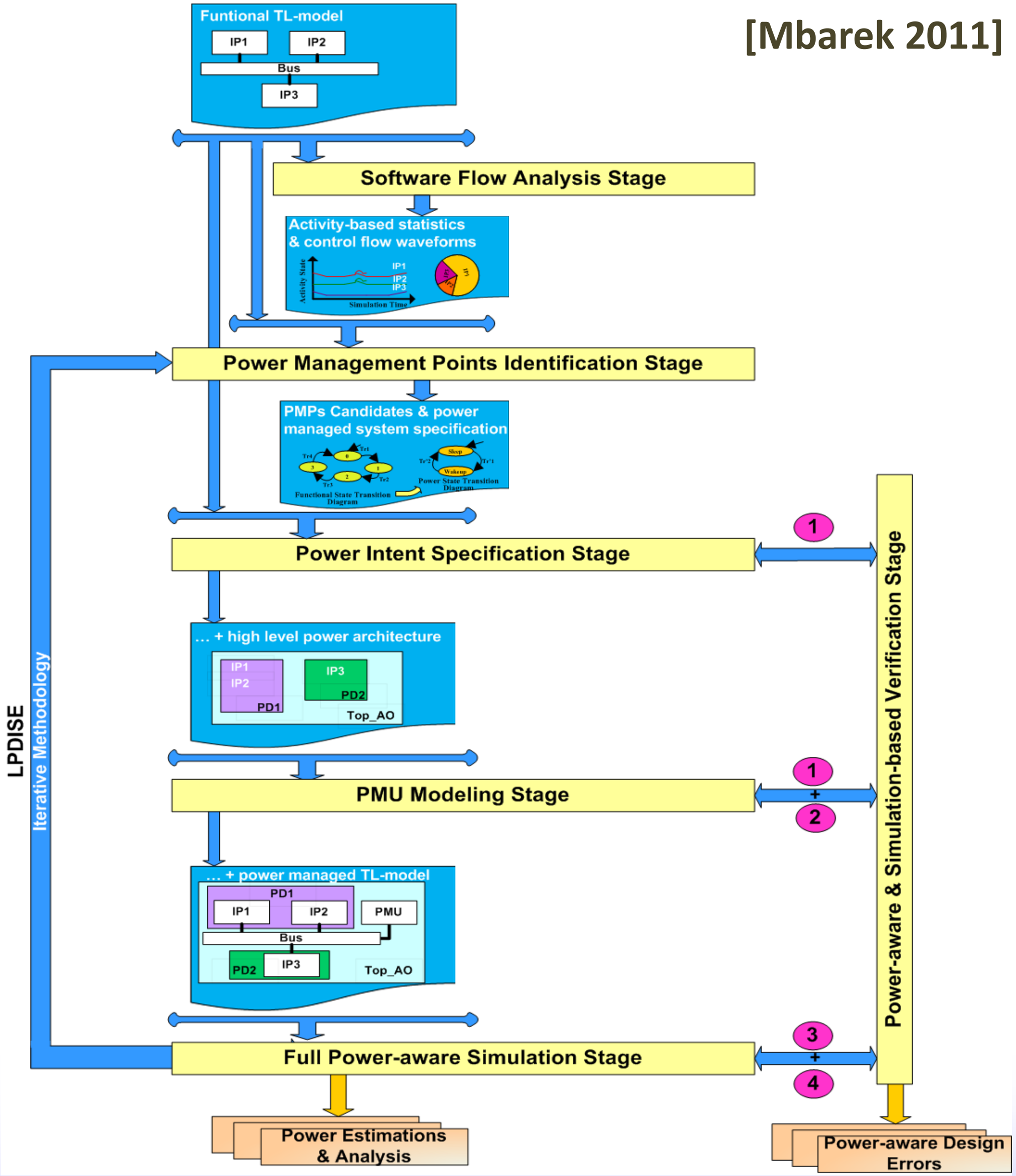
Level Shifters

Isolation Cells

Global Flow of our Power-Aware Methodology

- A methodology to add **power intent** and **power management capabilities** to existing TL-models.
- **5 stages processed sequentially**, and an **orthogonal stage** dedicated to verification.
- An iterative methodology for **power intent exploration**.

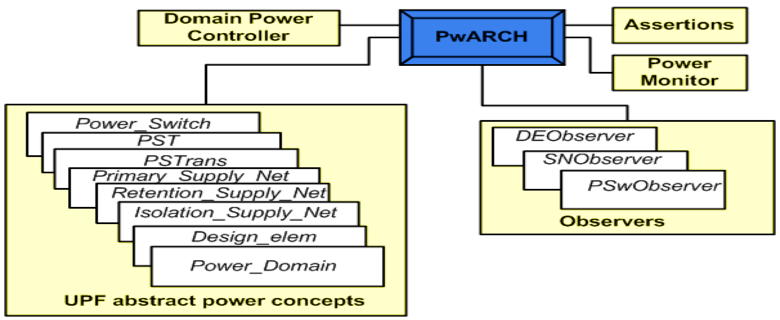
[Mbarek 2011]

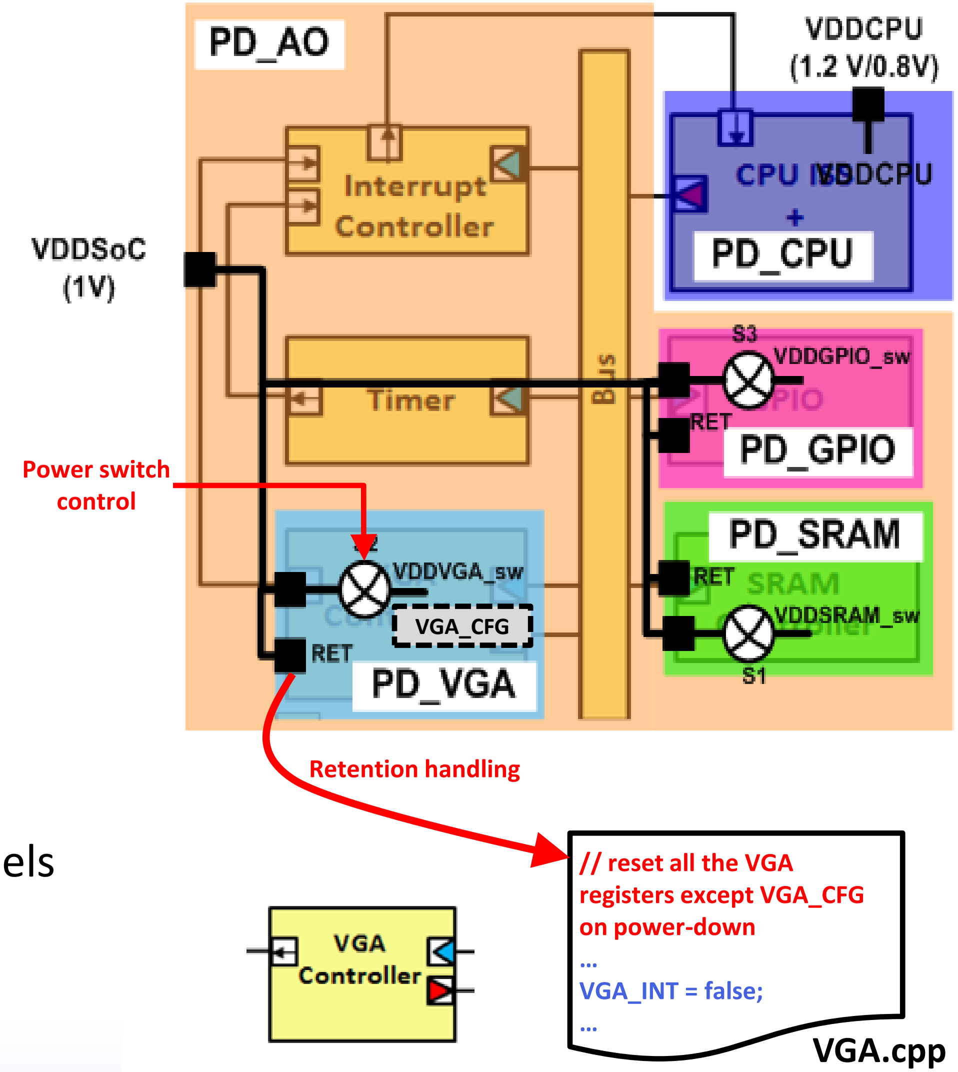


Stage 3 : Power Intent Specification

[Mbarek 2012a]

- Objective: adding power architecture elements (***power intent***) on top of functional TL models.
- Abstraction UPF standard at TLM level (**PwARCH**).





- Power components **behavior and their control** (interface with functional) are also specified.
- Static/dynamic power estimation models

$$P_{DE\_dynamic}(t) = C'.V^2(t).f_{clock}\ (in\ Watt)$$

$$P_{DE\_static}(t) = V(t).I_{leakage}\ (in\ Watt)$$

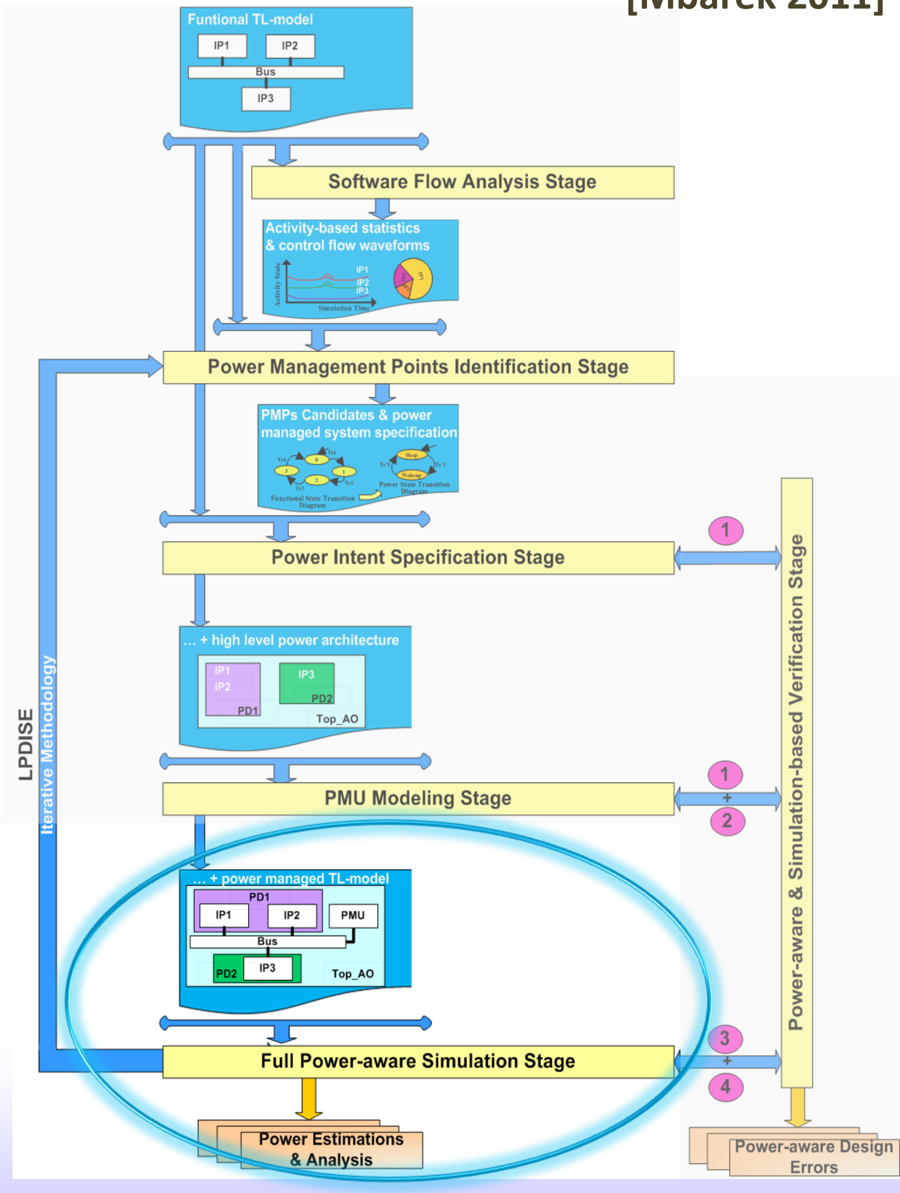
$$P^j_{PD\_dynamic} = \sum_{i=0} P^i_{DE\_dynamic}(t) + \sum_{k=0} P^k_{DE\_dynamic}(t)$$

$$P^j_{PD\_static} = \sum_{i=0}^{i\neq NbFM(j)} P^i_{DE\_static}(t) + \sum_{k=0}^{k\neq NbNES(j)} P^k_{DE\_static}(t)$$

Stage 5 : Power-Aware Simulation

- Objective:
  - Check **consistency between functional code** (augmented with commands that change power states) **and the power intent**.
  - Evaluate power consumption of the system
- Some mechanisms allow to automatically **update power equations** during the simulation.

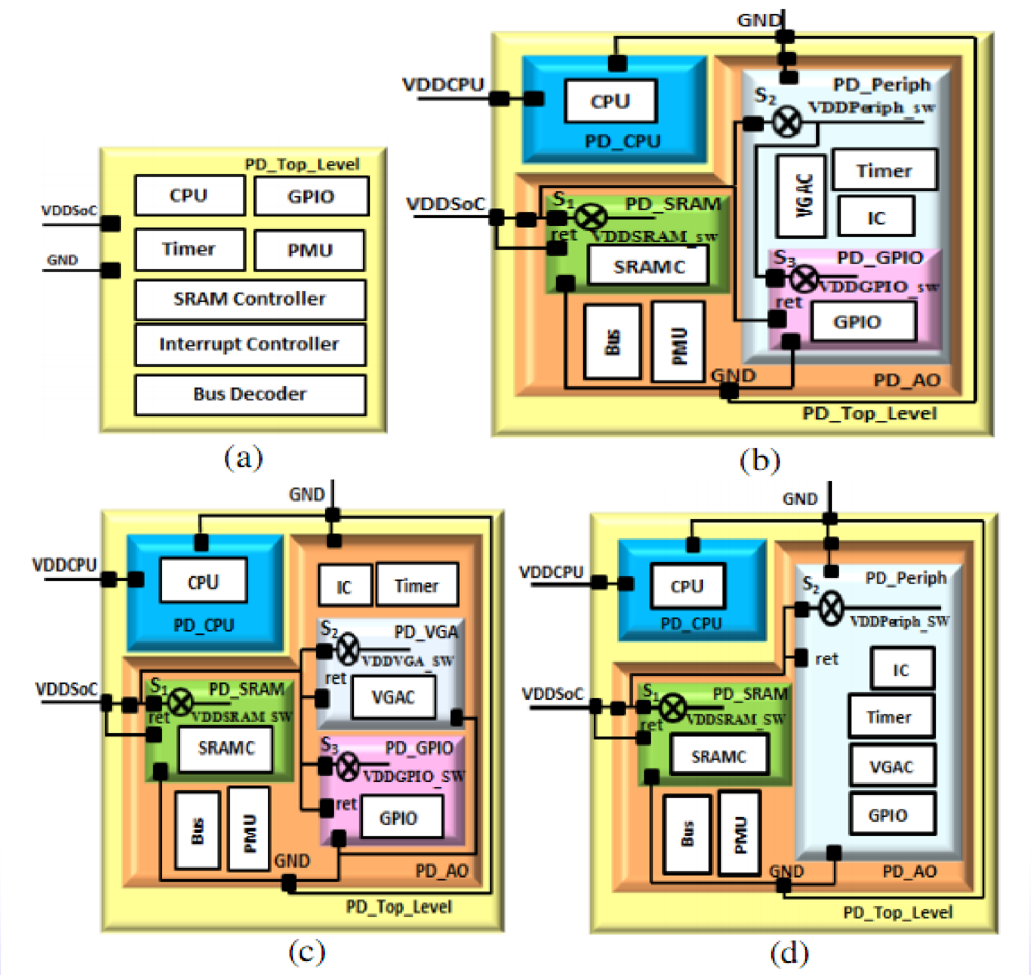
[Mbarek 2011]



Application on a White-Box Case Study

[Mbarek 2012b]

- Apply a **source code instrumentation** approach
- Using **PwARCH** library



<u>3 power alternatives</u>

- (b), (c) and (d) provide **90% of energy-savings** compared to (a) having no power partitioning.

<u>Simulation Time</u>

- Only **0,03% slower** than (a)

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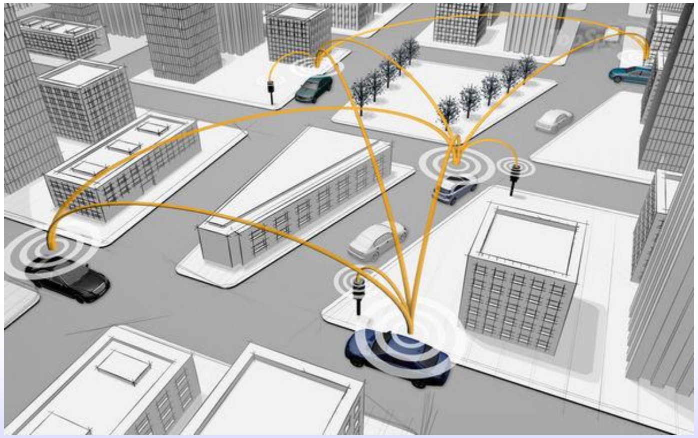
What kinds of issues are addressed?

- Communicating objects able to **collect and process data** (wireless sensor networks)
- **Deployment** of these objects has just started…

- Power-autonomous objects
  - Harvesting
  - Storage
- An optimized power consumption management (power manager)

Source: SensLab

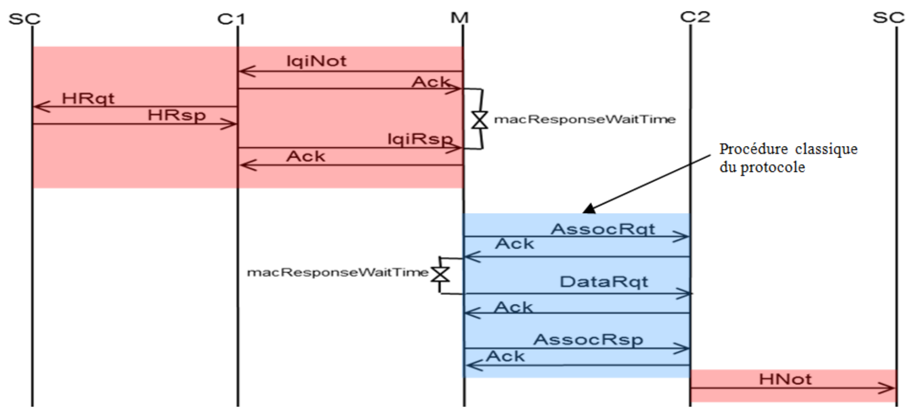
- Mobility of these objects



Source: Mercedes

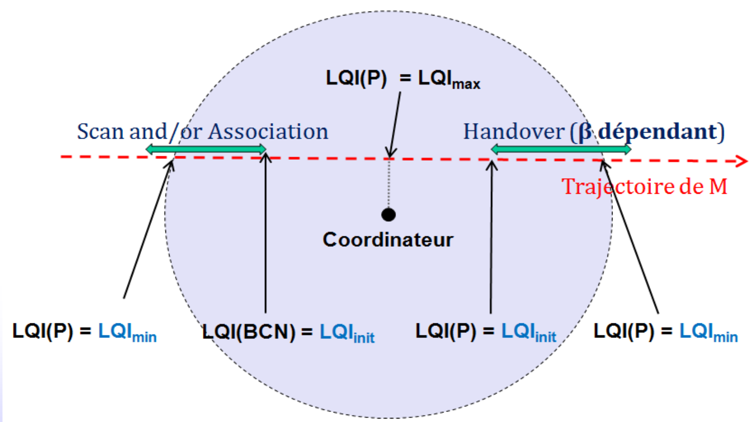
Mobility Management for 802.15.4 standard

- Mobility is **not handled efficiently** by the 802.15.4 standard.
- An approach allowing **to anticipate change of cell** and to perform a **speculative selection** of the next coordinator.



[Chaabane 2012a]

- Cell change is triggered by a defined threshold (**$LQI_{Threshold}$**)

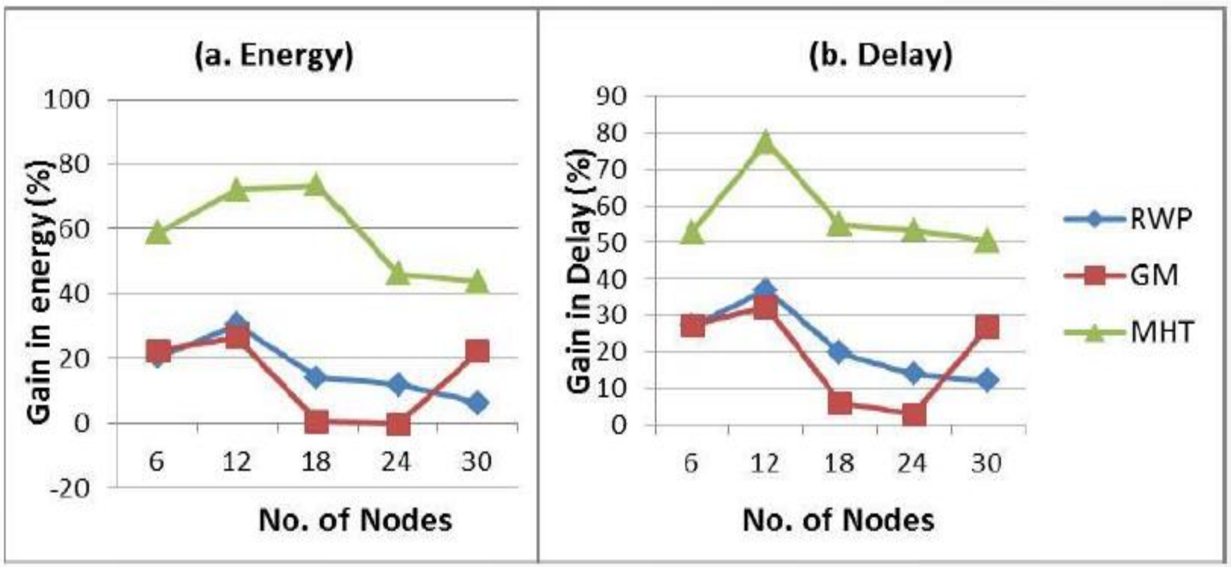


$$LQI_{Threshold} = LQI_{Init} - \frac{(LQI_{Init} - LQI_{Min})}{\beta}$$

[Chaabane 2012b]

Mobility Management for 802.15.4 standard

- **Gains in energy and latency** (for different mobility scenarios and number of nodes)



Simulations Ns-2

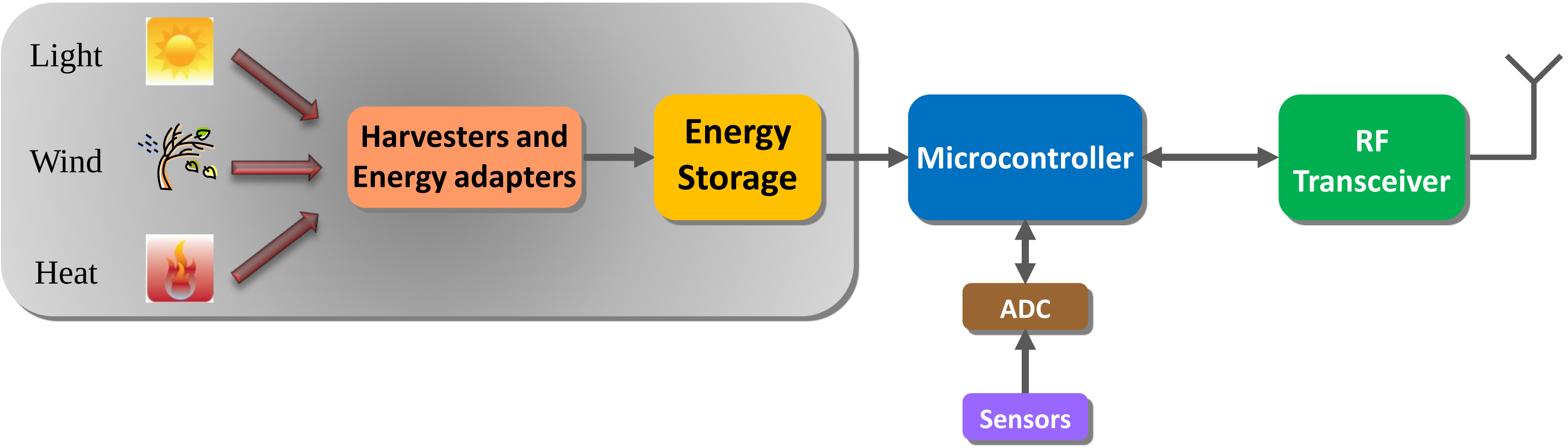
[Chaabane 2013]

RWP : Random Way Point
GM : Gauss-Markov
MHT : Manhattan

- Rate adaptation and mobility management [Chaabane 2014]

- Energy-autonomous objects…

Designing Autonomous Communicating Objects

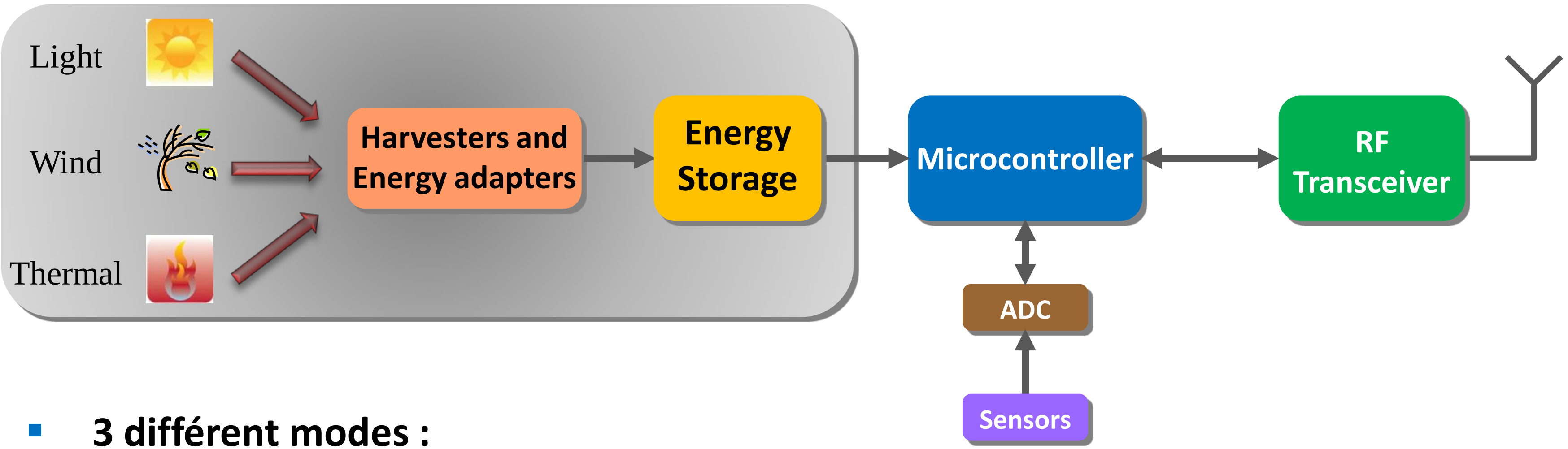


- **Energy Harvesting**: a **new paradigm** for power management
  - The objective is **no more to reduce as much as possible** the consumed energy to prolong the system lifetime…
  - But rather to **balance** (in average) the consumed energy and the harvested energy in order to optimize performance (i.e. QoS)

    ➔ **E**nergy **N**eutral **O**peration (**ENO**)

    Harvested Energy = **Consumed** Energy
  - The system lifetime can (in theory) lasts forever...

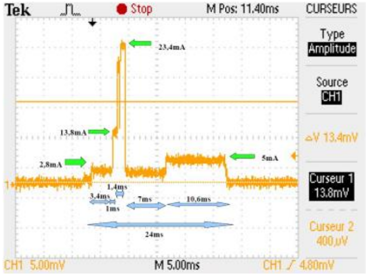
Designing Autonomous Communicating Objects



- **3 différent modes :**
  - Energy-**neutral** $E_H = E_C$
  - **Negative**-Energy $E_H < E_C$
  - **Positive**-Energy $E_H > E_C$
- **Harvested Energy** (environment) : availability is hard **to control**
- **Consumed Energy** : **controllable**
  - PHY, MAC, NWK layers
  - RF chip (TX power)
  - Low Power Modes ➔ **Power Manager**

Power Manager

- How to **control the power consumption** of the communicating object?
  - Adapt the wake-up period of the node (T_{wi})
  - Transmit Power (P_{TX})
- **Consumed Energy** models
  - Off line characterization of **nodes activities** (**L**ook-**U**p **T**able)
  - Depends on **scenario** or **functional modes**



- **Harvested Energy** models
  - Either **predictions** or **measures** (ex. light sensor)



- Which kind of **energy storage** element to use?
  - Battery or super capacitor?

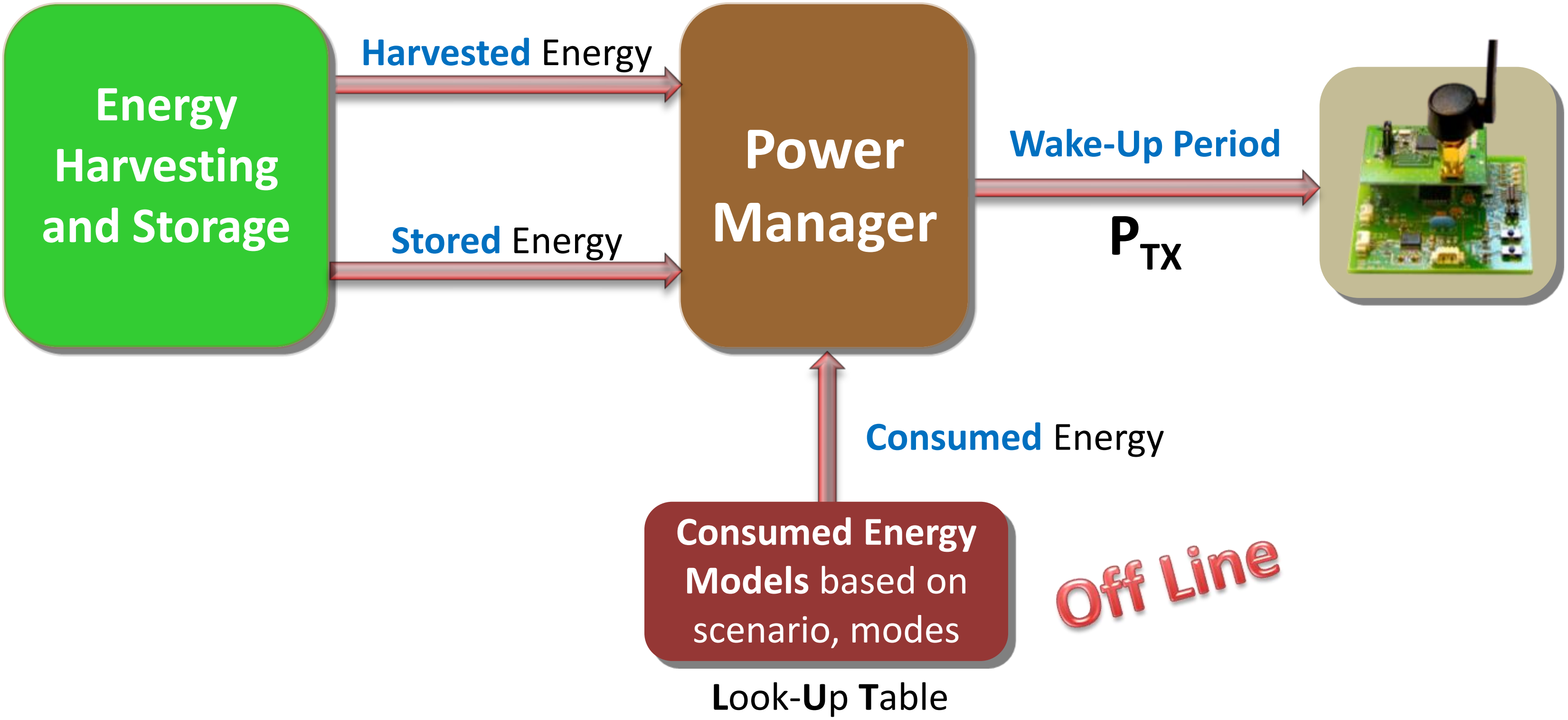
[Cymbet 2011]

- − **500** recharge cycles
- − Difficult to know the state of charge with accuracy
- + **Low leakage current and big capacity**

[HZ202F 2013]

- + **500 000** recharge cycles
- + Easy to know the state of charge
- − High leakage current

Power Manager



- Constraints for power management
  - → **Low complexity** (efficient models)
  - → $T_{PM} = n * T_{WI}$

Closed-Loop Power Manager (CL-PM)

- CL-PM is adapted to a **solar harvesting system** (outdoor)
- **2 power management strategies** are available :
  - During the daytime ($\beta > \beta_{th}$)
    → **Energy Neutral PM** is used
  - During the nighttime ($\beta \leq \beta_{th}$)
    → **Negative-Energy PM** is used
- A **Zero Energy Interval** (**ZEI**) predictor (function of β) is also used.
- In ENO condition, **SoC(t) is constant** over the time :

$$SoC(t) = SoC(t + n\,T_{wi}) - Q_{pm}$$

$$T_{wi} = \left\lceil \frac{Q + Q_{pm}/n}{\beta - K_{leak}} \right\rceil$$

[Castagnetti 2012a]
[Castagnetti 2012b]

During the night…

- Issue: determine the next wake-up period of the node (T_{wi}) in order to **avoid a full discharge** of the battery
- The following parameters are defined:
  - **t*** : start of a zero-energy interval (ZEI)
  - **SoC(t*)** : battery state of charge when ZEI starts,
  - **M** : a battery discharge margin
- Required condition to avoid a full discharge of the battery:

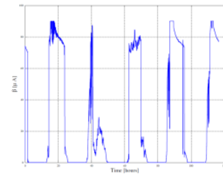
$$SoC(t^*) - (\alpha + K_{leak}) D_{ZEI} \geq SoC_{\min} + M$$

$$T_{wi} \geq \frac{Q D_{ZEI}}{SoC(t^*) - K_{leak} D_{ZEI} - (SoC_{min} + M)}$$

[Castagnetti 2012a]

Performance Analysis

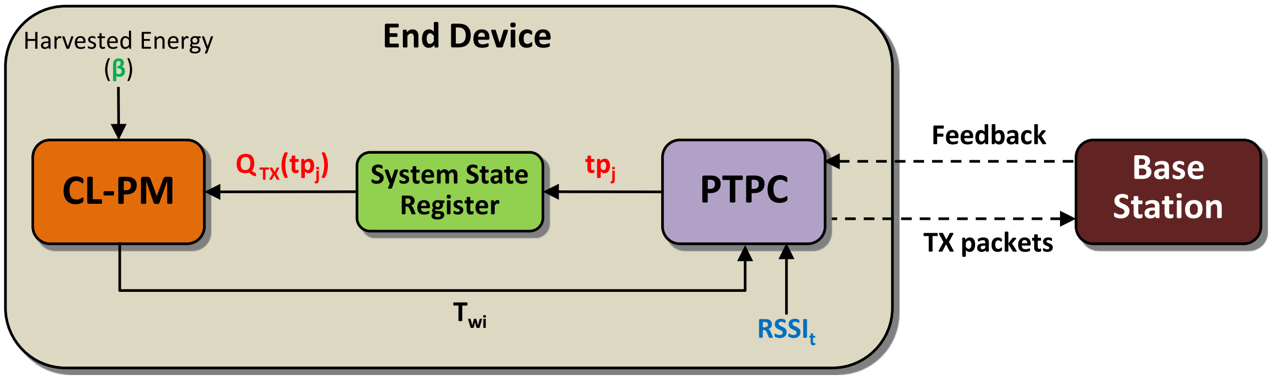
- CL-PM has been simulated with a 5 days profile of solar energy harvesting



	<Rd> [bit/s]	Rd_{max} [bit/s]	Rd_{min} [bit/s]	<SoC> [µAh]	B_f
Kansal	29.55	132	0	65.81	9
CL-PM	45.87	132	0.37	69.27	0

- Using the Closed-Loop power manager, **the throughput is improved by around 50%** compared to **[Kansal 2006]**.
- With CL-PM, battery is never fully discharged (no ***battery failures***).
- CL-PM provides a better **QoS** during the night…

A Joint Duty-Cycle and Transmission Power Management Approach for EH-WSN (CLPM-PTPC)



- According to the **received signal strength** (RSSI), the PM will adapt the transmit power of the node, thus its power consumption…
- CL-PM determine the next wake-up period (**T_{wi}**) according to the new transmission power (**$Q_{TX}(tp_j)$**)
- This approach provides up to **26% energy saving**

PowWow

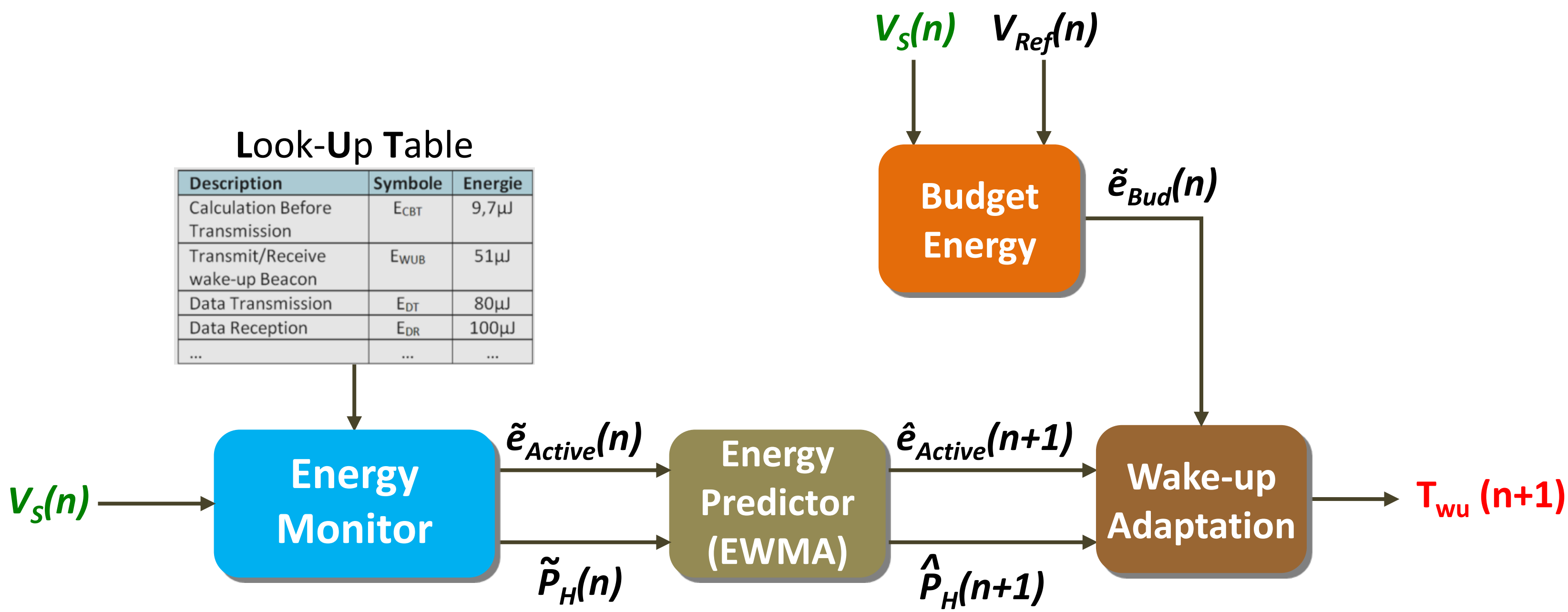
	Speed [m/s]	**PRR** (%)	**E_u** [µJ]	**Energy Gain** (%)
CLPM-Fixed	0.2	97	210	
	0.4	95	196	
CLPM-PTPC	0.2	93	155	26.2
	0.4	89	160	23.6

- An approach adapted for mobiles nodes.

[Castagnetti 2014]

An Energy-Source Independent Power Manager

- An Approach based on a Power Manager
  - ➔ using a **SuperCap** to store energy
  - ➔ **independent** of the energy harvesting system



Look-Up Table

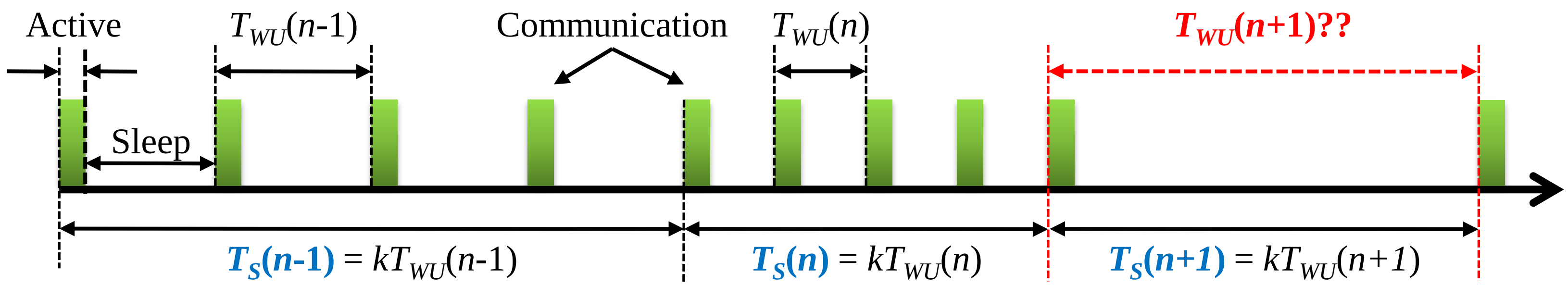
Description	Symbole	Energie
Calculation Before Transmission	E_{CBT}	9,7µJ
Transmit/Receive wake-up Beacon	E_{WUB}	51µJ
Data Transmission	E_{DT}	80µJ
Data Reception	E_{DR}	100µJ
...	...	...

[Trong-Nhan Le 2013b]

EWMA : **E**xponentially **W**eighted **M**oving **A**verage

Managing Power in Energy Neutral Condition

- **Wake-up period dynamic adaptation**



- **ENO condition for the next time slot (n+1)**

$$\hat{e}_H(n+1) + \tilde{e}_{Bud}(n) = \tilde{e}_{Leak}(n+1) + \frac{1}{\eta}\hat{e}_C(n+1)$$

- **Next wake-up period**

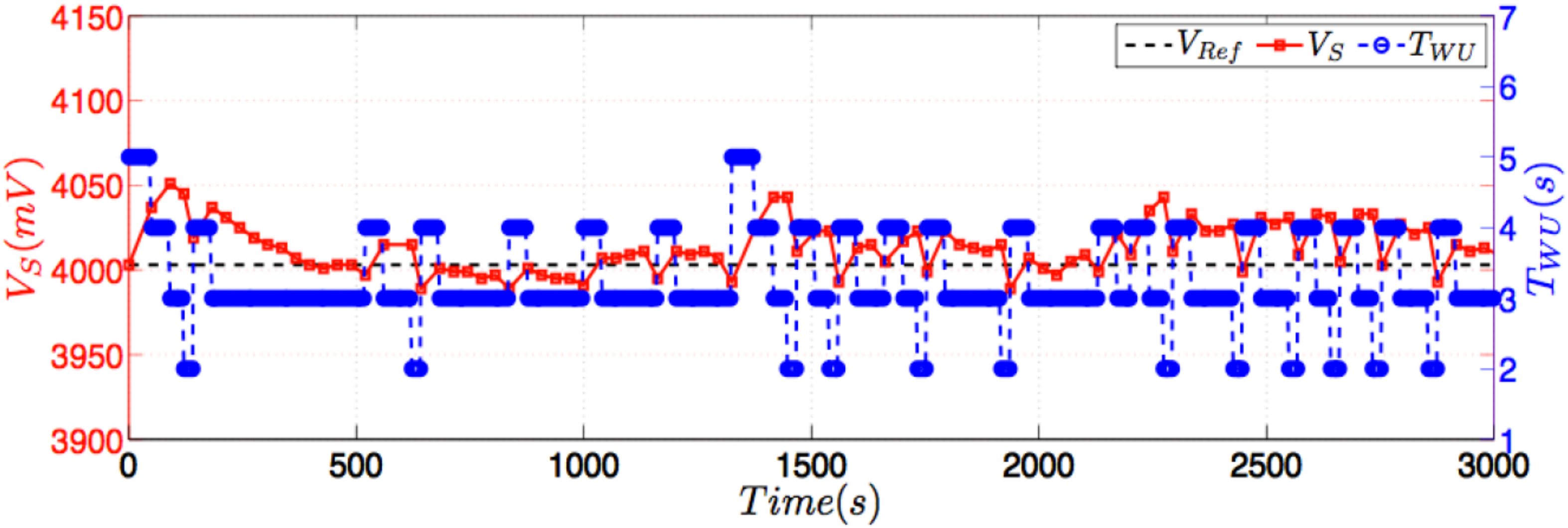
$$T_{WU}(n+1) = \frac{\left[\hat{e}_{Active}(n) - \eta\tilde{e}_{Bud}(n)\right]/k}{\eta\left[\tilde{P}_H(n) - P_{Leak}\right] - P_{Sleep}}$$

[Trong-Nhan Le 2013c]

Experimental Results

- The Power Manager performs adaptations on a wireless sensor network hardware **platform** (PowWow)
- **Thermal energy** is harvested (heat from a laptop power adapter)

k = 10, $\mathbf{C_S}$ = **0.09**F, **α** = 0.6, $\mathbf{V_{Ref}}$ = 4V



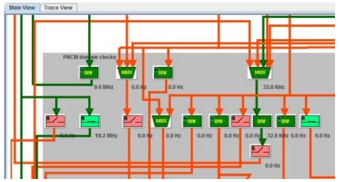
[Trong-Nhan Le 2013c]

Agenda

- **University of Nice Sophia Antipolis - LEAT**
- **A short bio…**
- **Main research activities**
  - Characterizing Power and Performance at a High Level of abstraction
  - System-level Power Modeling Approach
  - Power Management Techniques for autonomous Wireless Sensor Networks
- **Future works…**

Low Power Soc Design

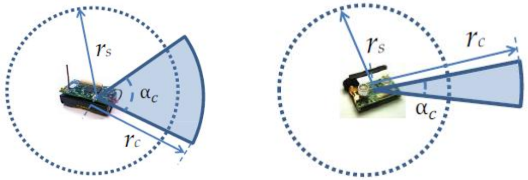
- Investigate techniques having a strong impact on power **consumption**, **temperature** and **performance**:
  - Power gating, Clock gating, DVFS…
- Propose an approach for **modeling these techniques and evaluate their impact** on power, performance and thermal dissipation
  - Example: How to describe a clock-tree and its constraints at TLM?



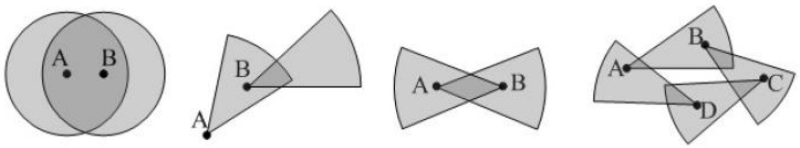
- A more **distributed and hierarchical** power management

Smart and Energy-efficient Communicating Objects

- **Directive**, **reconfigurable** antennas

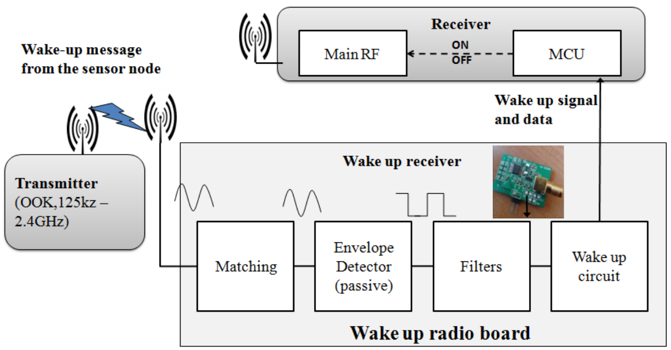


[Yuz 2011]



CMA Team from LEAT

- RF communication : using a **Wake-Up Radio**

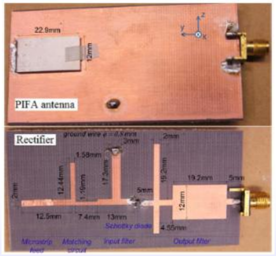


  - **53%** power saving
  - **82%** throughput increase

UCC
Coláiste na hOllscoile Corcaigh, Éire
University College Cork, Ireland

[Trong-Nhan Le 2013a]

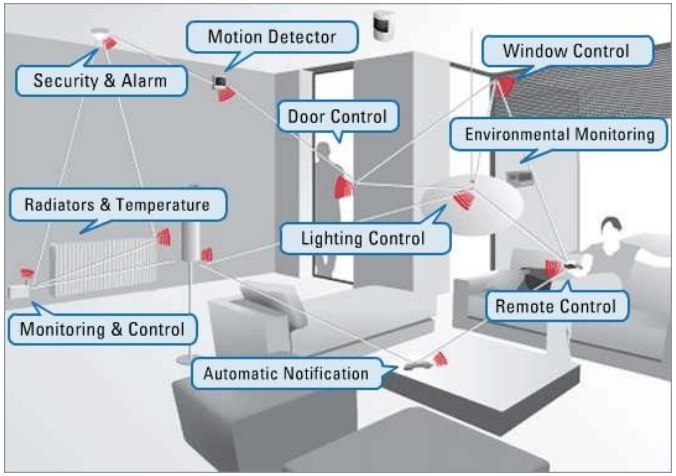
- Energy **harvesting**
  - Rectenna
  - Using multiple harvesters



[Hoang 2013]

Smart and Energy-efficient Communicating Objects

- How to guarantee **interoperability** of these objects?



- Need for a **global design approach**…
  - What are the **global impact** of local choices?
  - **Joint simulation** of the network (OMNET++, SCNSL) and the communicating object (modeled in SystemC-TLM)
  - Simulate the **binary code** (ISS)
- Need for collaborations!

Thank you
for your attention


Questions

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