leti

innovation for industry

IoT et Réseaux de Capteurs Autonomes : encore quelques challenges …

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Introduction to Autonomous RF

- Wide variety of RF communications
  - Cellular communications
    - Smartphone makes everything
      - 4G / LTE is very power hungry
      - Throughput of Data is growing very fast

.... always connected

  - WLAN
    - Indoor use / Main powered

.... always connected

  - WPAN
    - Cable replacement – Multimedia (5.8 GHz / 60 GHz)
    - Wireless Sensor & Actuator Networks

.... battery powered

- Challenges to drastically reduce power consumption

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Motivation – Internet of Thing

- Most-demanding field for power reduction
  - Some applications will not exist because :
    - Years life-time - battery replacement
    - Uncollected Batteries

Manpower Limitation

Waste Management

  - Energy Autonomy
    - Batteryless – Energy Scavenging
    - RF communication alone

1 µW

10 mW

… still **more energy** required for **sensors & processing**

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Research Paths for IoT

Technology

- Technology shrink
- Benefit from **F_T ↗**

…. but leakages and lead app. ….

Protocol

- Cooperative & standards
- Interoperability

…. but **overhead** ….

Research breakthrough required for power reduction !!!

Design

- Technology pulled
- Easy **Digital-Analog mix**

…. but tuneability ….

RF Architecture

- Always at the **best fit**
- Efficiency & Performance

…. but dynamically ….

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Technology Trends

- Technology push
  - From 130nm to **65nm**

    … & beyond to FD-SOI 28nm
  - Very-high volumes envisioned ➔ very small nodes
  - Benefit from natural down-scaling
    - Better **Active Modes** consumption / Higher F_T
    - Make use of **more digital process**
  - More active blocks integration – less passives

- Versatility & reconfigurability
  - Adopt a **digital-oriented** architecture
    - Limit the analog front-end to 50 % of the surface
  - Co-simulation of analog & digital for an Overall Performance split

- High-Quality Factor external passives
  - Front-End channel filtering
  - New concepts for new performance ? ➔ the **Holy Graal** !

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Technology Trends - leakages

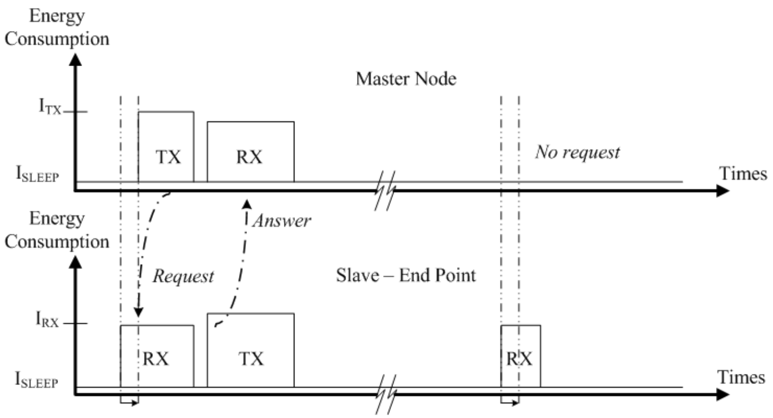
- High impact of **Sleep Currents** for Low Duty Cycle$_{TIME}$

$$I_{Mean}/I_{Active} \approx DC_{Time} + 1/Ratio_{Current}$$

  - DC_{Time} = 1% and $R_{Current}$ = 100 ➔ 2%
  - DC_{Time} = 0.1% and $R_{Current}$ = 1000 ➔ 0.2%
  - DC_{Time} = 0.01% and $R_{Current}$ = 10000 ➔ 0.02%

- Reduce **Idle mode** Currents

  & **minimize leakages**



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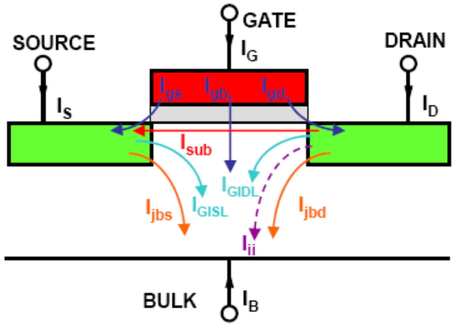
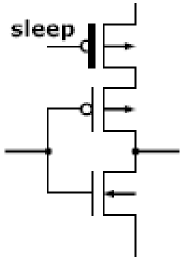
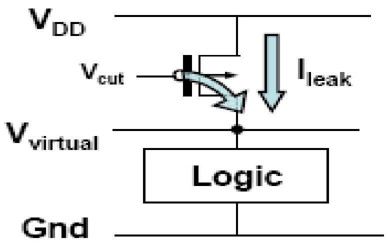
Technology Trends - leakages



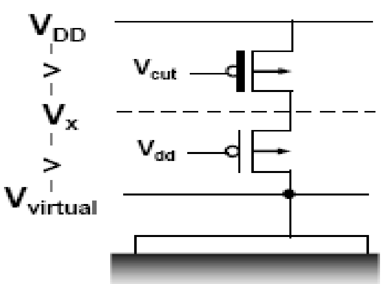
- Reduce VDD
  - Reduce leakages & dynamic power

$$P = \alpha f C V_{DD}^{2} + I_{SC} V_{DD} + I_{leakage} V_{DD}$$





- Minimize leakages
  - Power-Gating to cut-off leakages
    - .... but transitor stacking issues
  - Ultra Cut-Off with V_{gate} above V_{DD}
    - .... but longer settling times & only sub-threshold leakages



- Minimize Short Circuit
  - Mandatory when involving more digital activity

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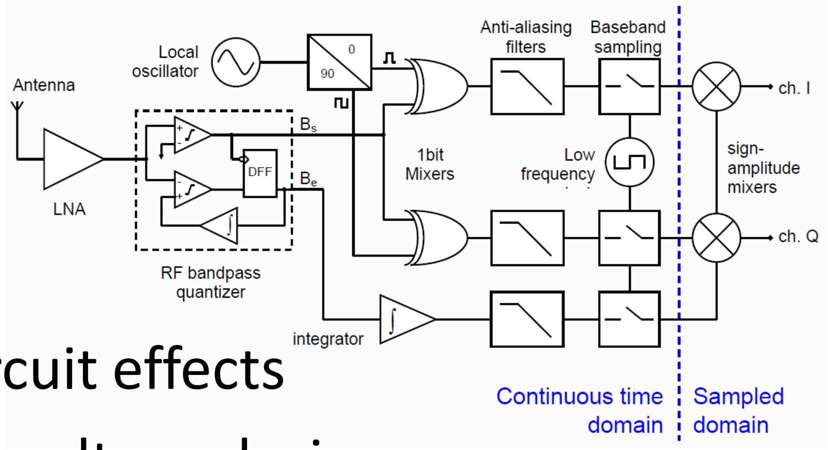
Technology - Digital-Oriented RF

- Mandatory use of pure-Digital techniques
  to address 65 nm / 40 nm / 32 nm / 28 nm…

… looks like its digital …



- Leakages reduction & Short Circuit effects
- Dynamic VDD adaptation : low-voltage design
- FD-SOI new benefits : parasitics ↘, frequency ↗

… this is the Holy Graal …

… and **RF Front-End** / **IF Channel filter** tuned

to **alleviate** further **analog blocks** in the chain

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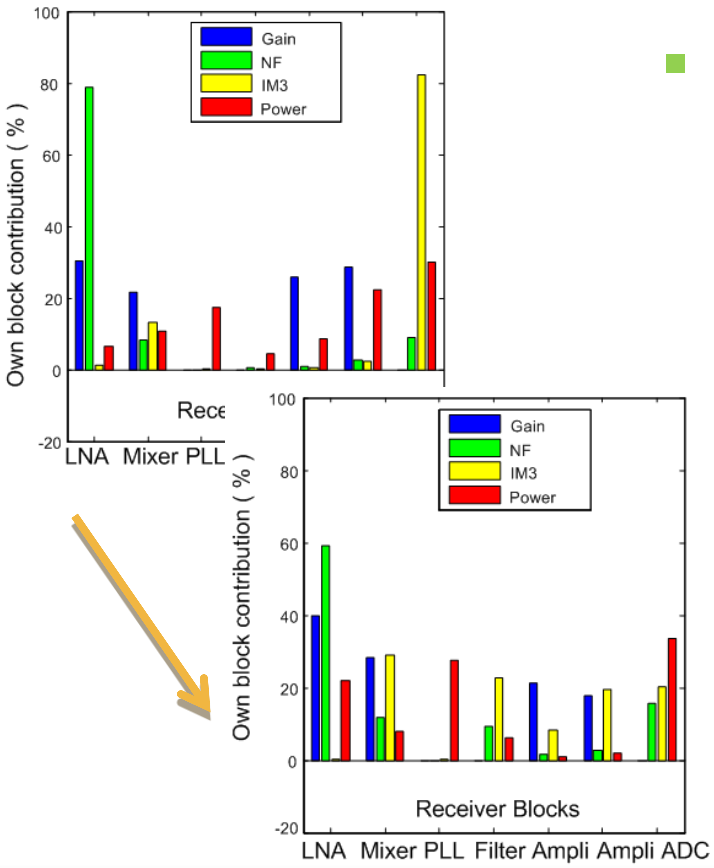
RF Architecture Optimization

- Make use of Tuneable filter
  - Drastically alleviates the IC Front-End by **removing jammers**
  - Bandwidth can **be tuned** dynamically



- Consider the whole RF chain
  - Optimizing **the whole chain**

    …rather than optimizing blocks
  - Get rid of usual Figure-of-Merit
    - For a given spec,

      not **always** at its best

      not the **only one** of interest
  - Make a link between **System Parameters**

    & **IC design**

From *business as usual*
… to *green-driven performance*

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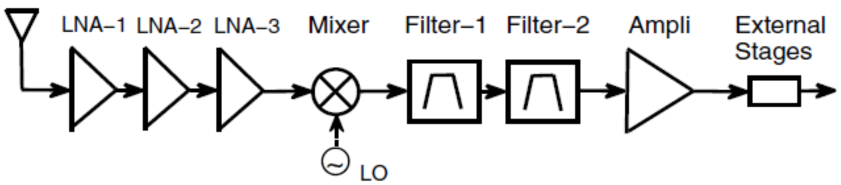
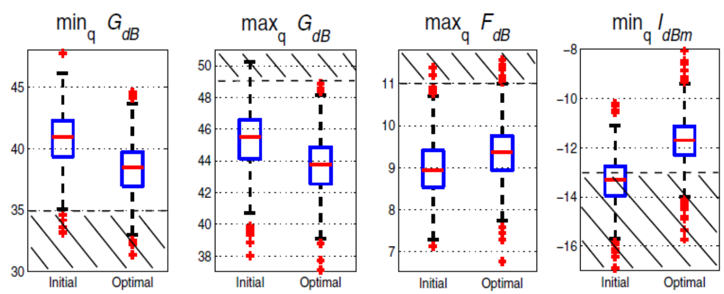
RF Architecture Optimization

- Classical approaches might be limited
  - Design parameters: biasing, voltage, gain etc …
  - Environmental parameters : temperature, Crystal ageing, drifts …
  - Technological parameters : V_{th}, transistor mismatches …





- New methods - statistical approach
  - Meta-modelling of the blocks
  - Parametric optima for the whole chain
  - Stochastic-gradient method

to solve a concave behavior

Current own internal development & LJK-UJF partnership

… a lot of room to further improve power consumption
factor of **10** as a research target

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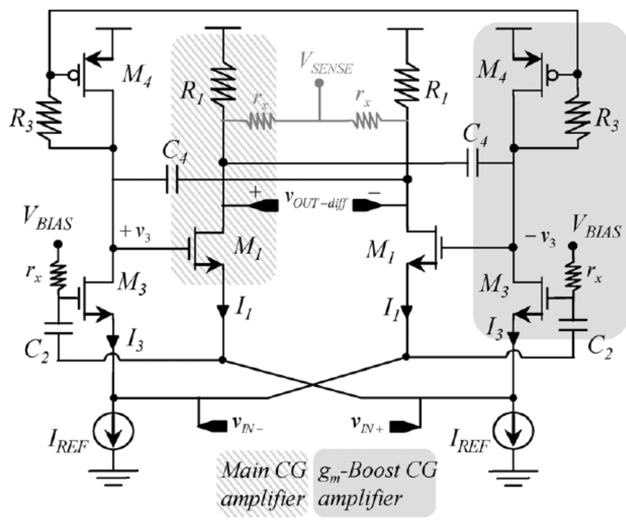
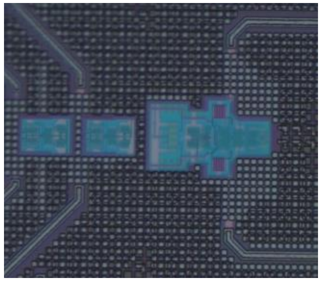
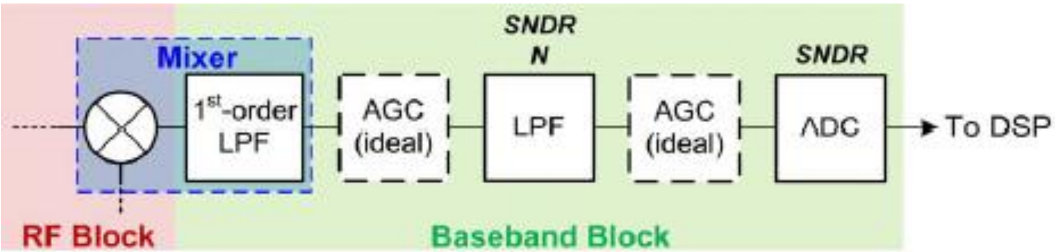
Low Power RF Design



- Low-Power / Small Footprint design
  - Benefit from natural down-scaling
    - Low-Power consumption

    … but **small silicon surface** - inductorless
- New paradigms
  - Integrated narrow-band active filters
  - **Digital-oriented** architecture / reduced pure-analog functions
  - Low-Power ADC for **Software Defined Radio**
  - **Below-1V** design
  - Multi-standards compliant blocks





- New features
  - Block specifications adapted to the overall Front-End context
  - **Tuneable parameters** the average power consumption

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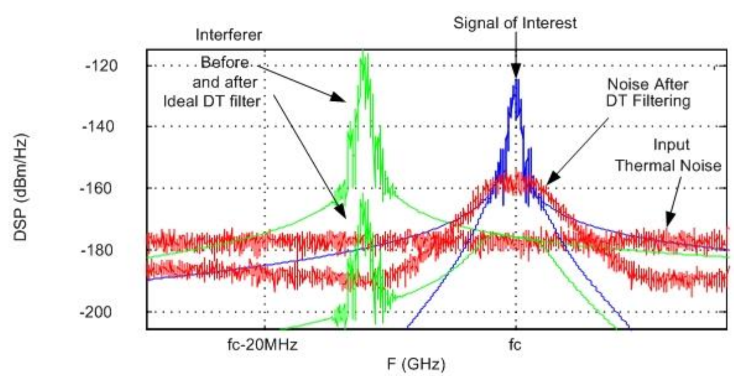
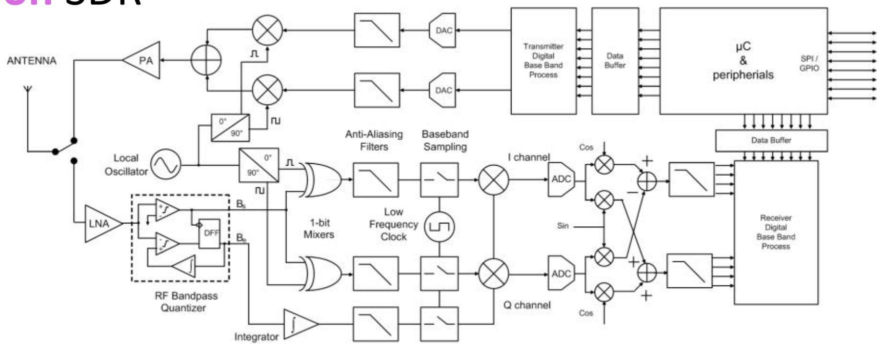
Low Power RF Design

Current own internal development
& University of Columbia partnership

- Direct Quantization
  - Very dense - digital-oriented architecture
  - Easy porting from one CMOS techno to another
  - No Sampling – No Clock
    - Low-Power consumption

  … a real **low-power consumption** SDR





- Sub-Sampling Architecture
  - Potentially High-End thanks to narrow-band external filters
  - Integrated FIR / IIR process
  - Actual **Low-Power 8-bit / 40 MHz ADC** implementation

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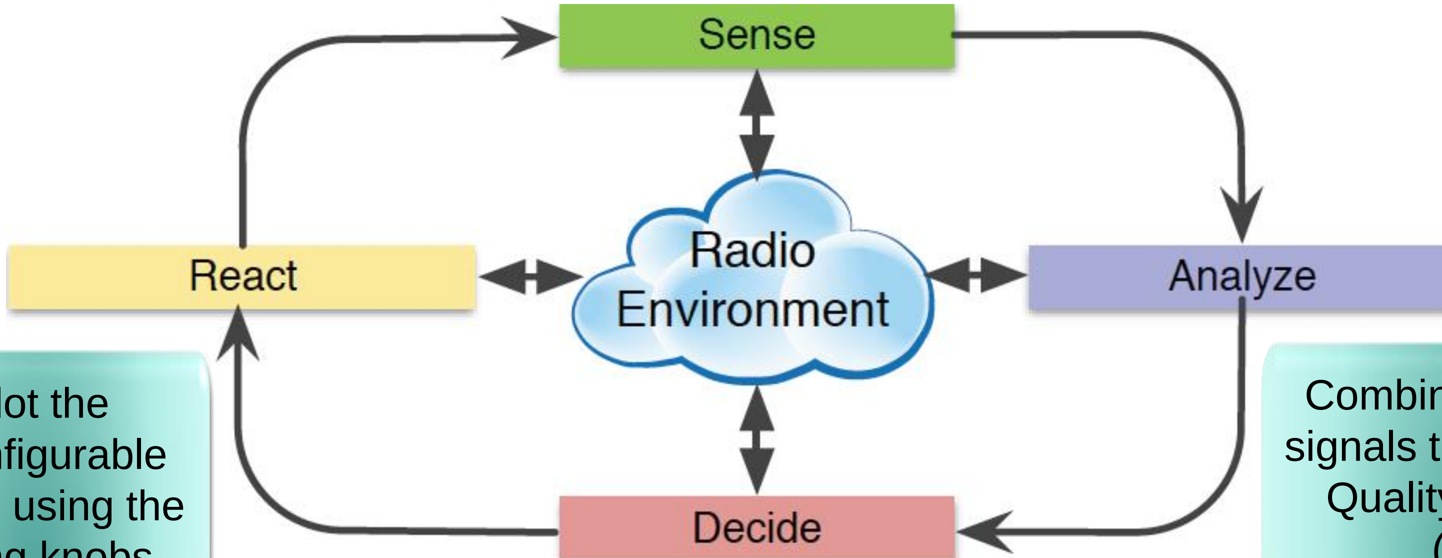
Reconfigurable Transceiver

Define sensing blocks and signals



Pilot the reconfigurable blocks using the tuning knobs

Combine the sense signals to build a Link Quality Estimator (LQE)

Define reconfiguration thresholds and strategy
Intra- or Inter-frame reconfiguration

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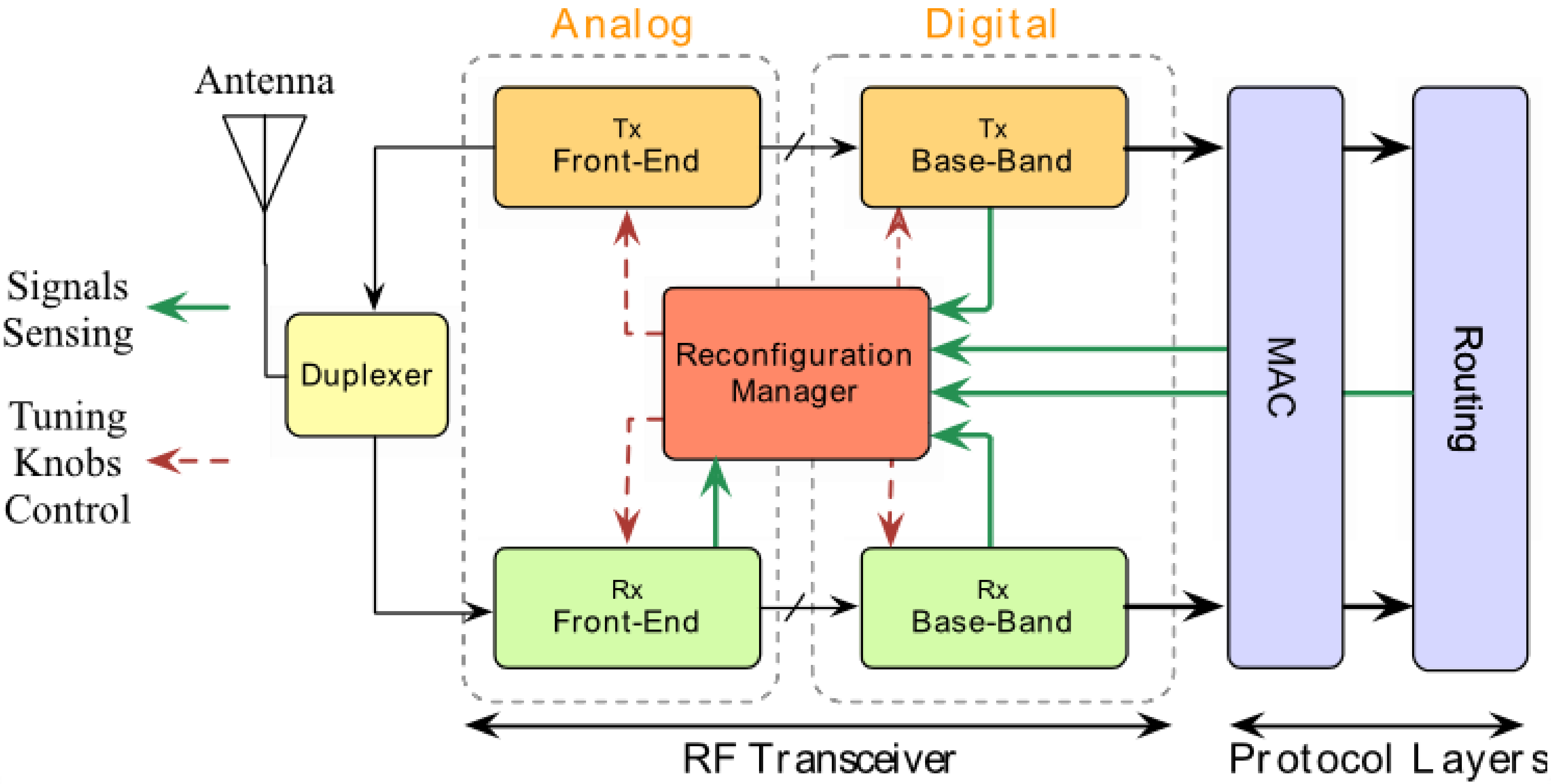
Reconfigurable Transceiver

- Conceptual reconfigurable transceiver



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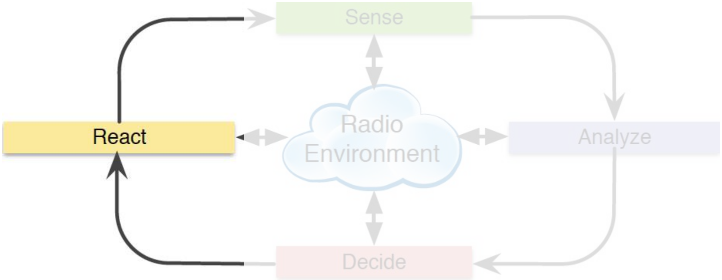
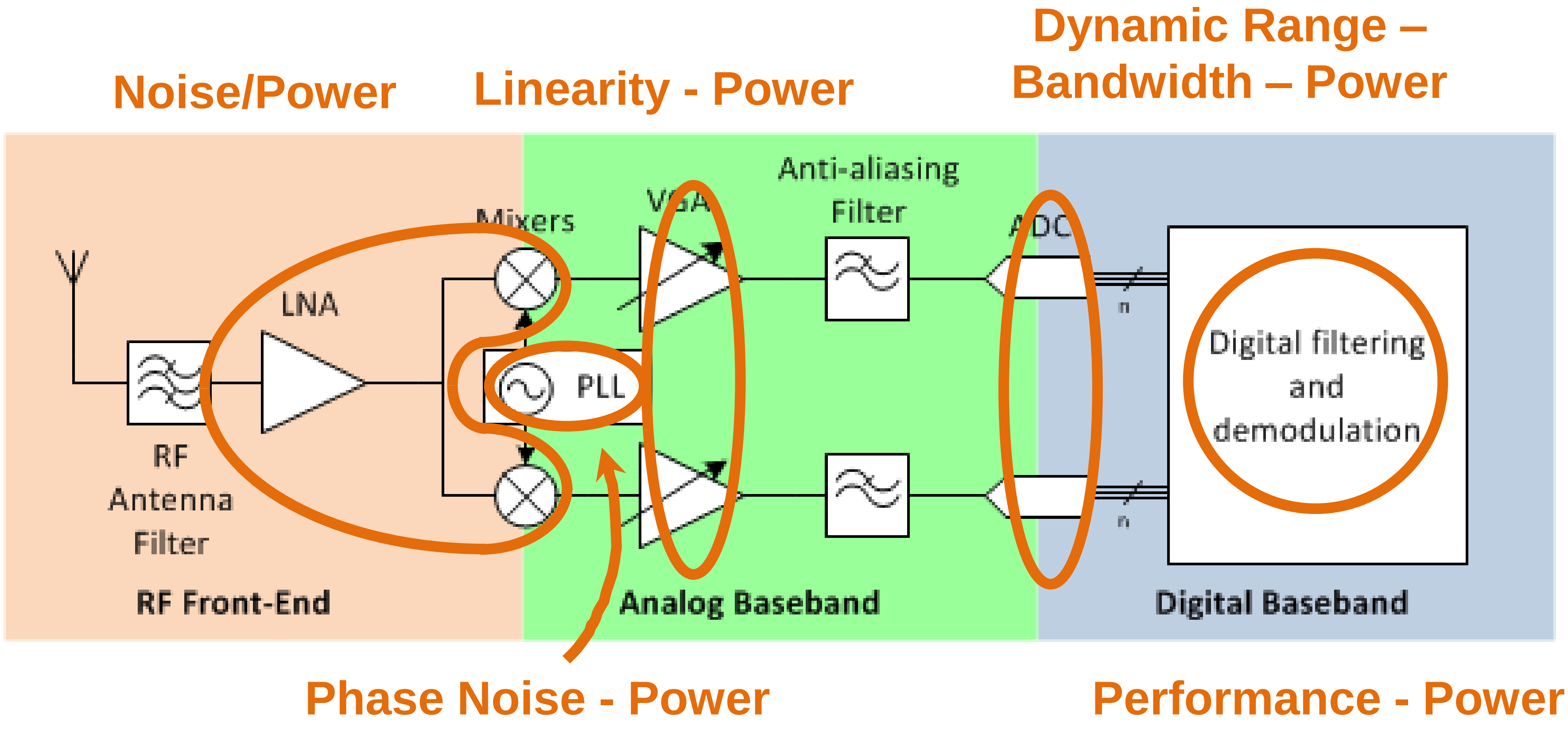
Reconfigurable Receiver



- REACT
  - Identify blocks with good power consumption /performance trade-offs
    - Example of Zero-IF RX with digital channel selection



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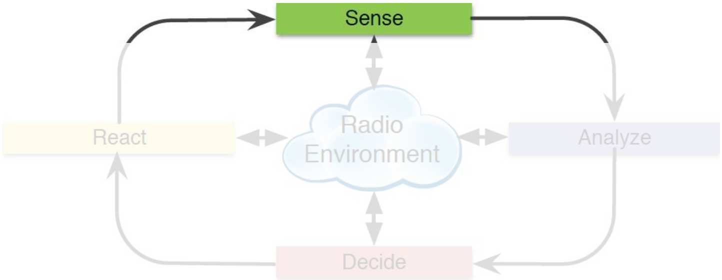
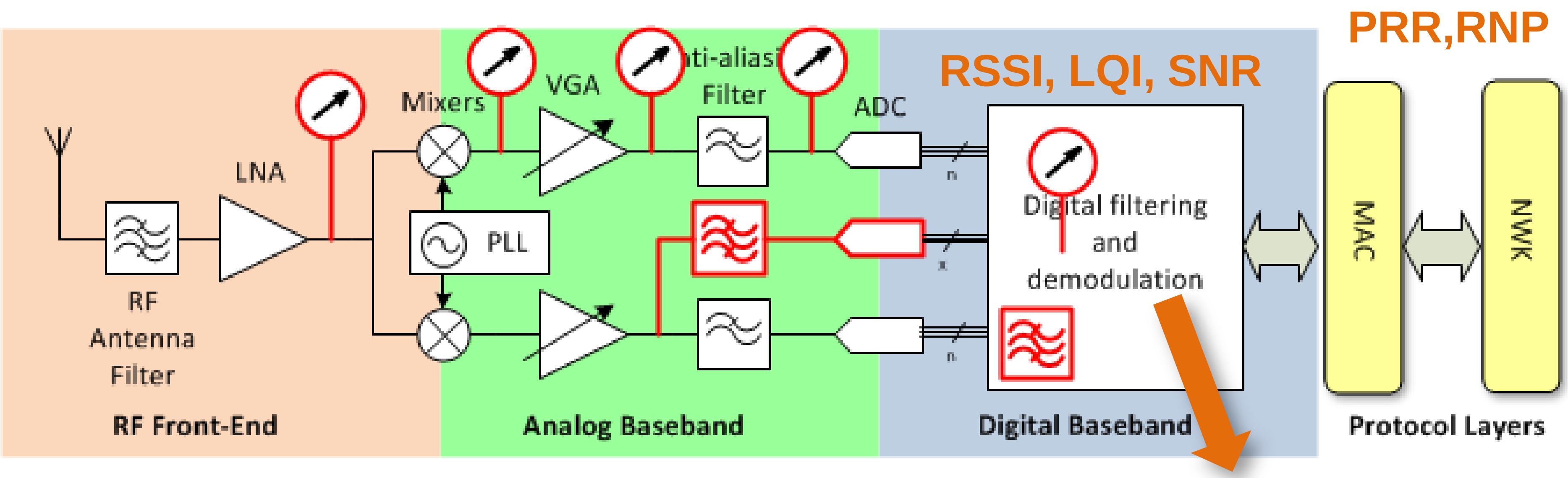
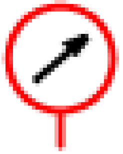
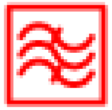
Reconfigurable Receiver



- SENSE
  - Define signals that will extract information concerning link quality
    - For example : RSSI, LQI, SNR, PRR, RNP




RSS meters


Parallel filtering paths

→CIR
→CRC_FAIL
→Noise Floor

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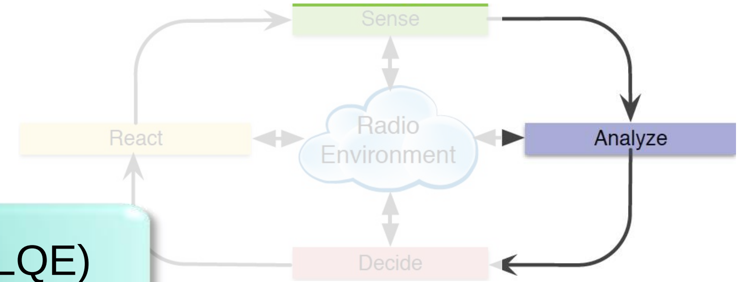
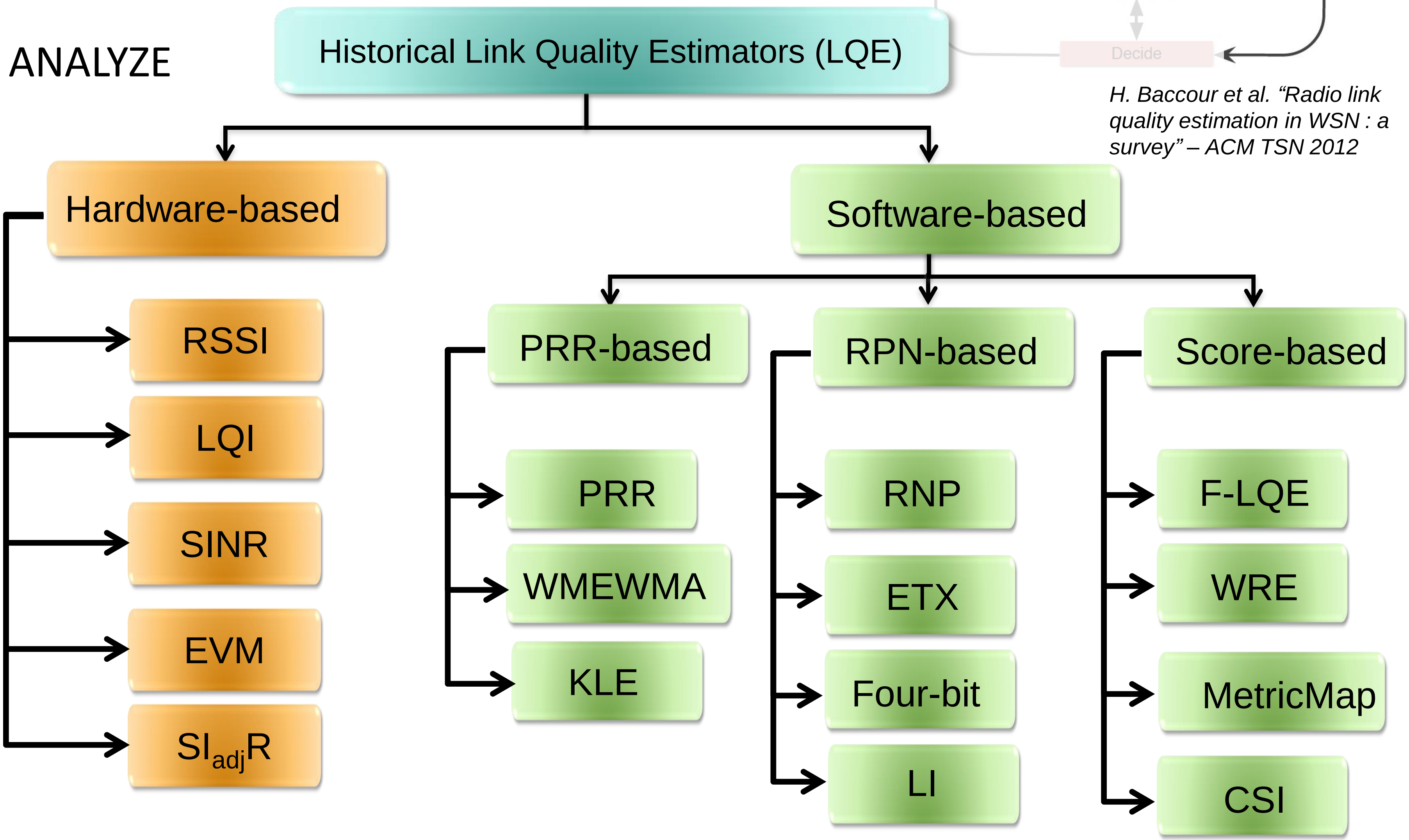
Reconfigurable Receiver



- ANALYZE

H. Baccour et al. "Radio link quality estimation in WSN : a survey" – ACM TSN 2012



- Use **new** or a **combinaison** of these metrics ? Implementation cost ?

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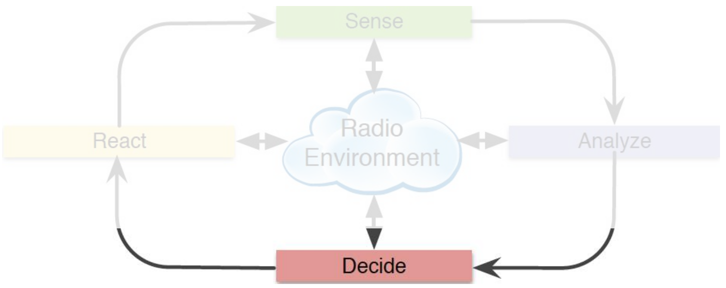
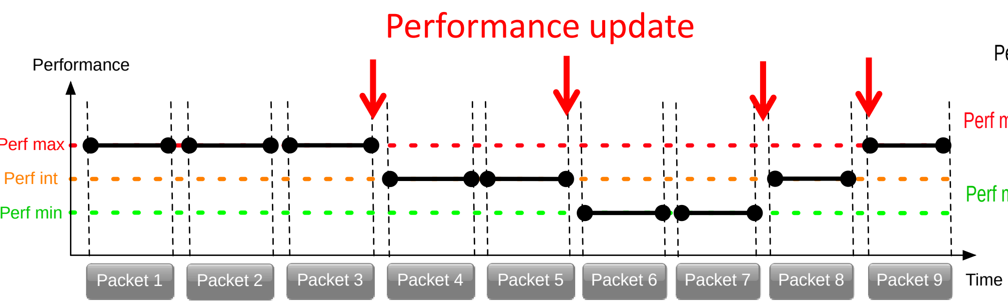
Reconfigurable Receiver

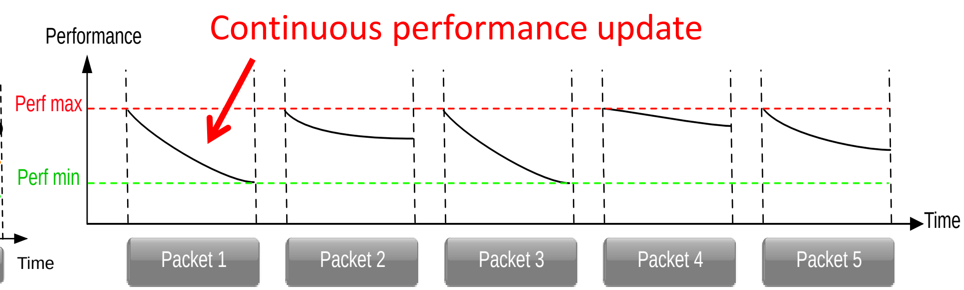


- DECIDE
  - Define reconfiguration thresholds and algorithm
  - Two principal types of reconfiguration

- Static reconfiguration
  - Inter-frame reconfiguration



- Dynamic reconfiguration
  - Intra-frame reconfiguration



- Periodic update of receiver performance based on observation windows
- Employs software or hybrid LQE
- Increased PER

- Requires a fast LQEHW and low computation delay
- Always starts in high-perf. mode
- Requires LQE thresholds
- No inherent loss of sensitivity
- Feasibility ?

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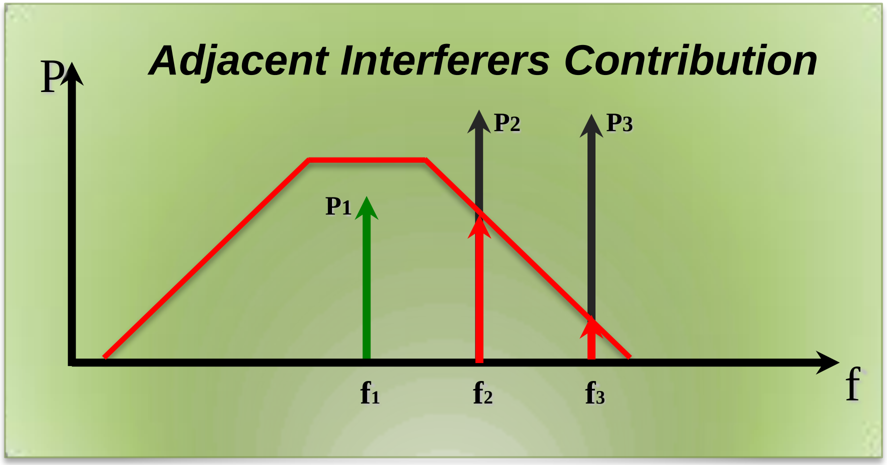
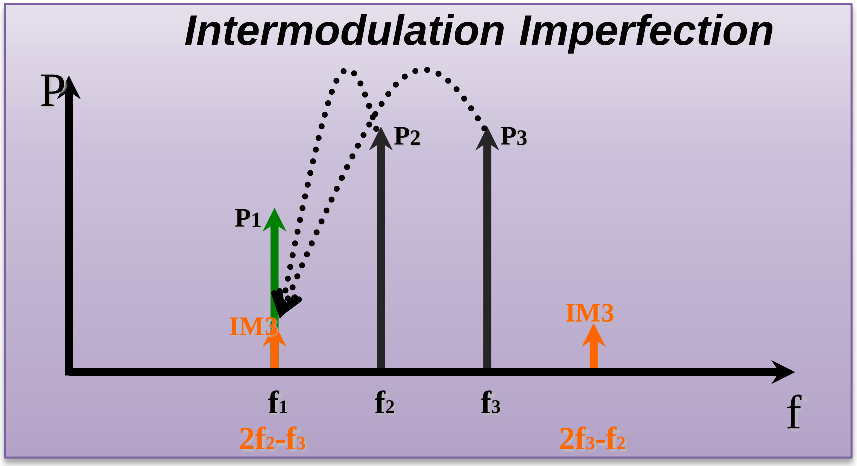
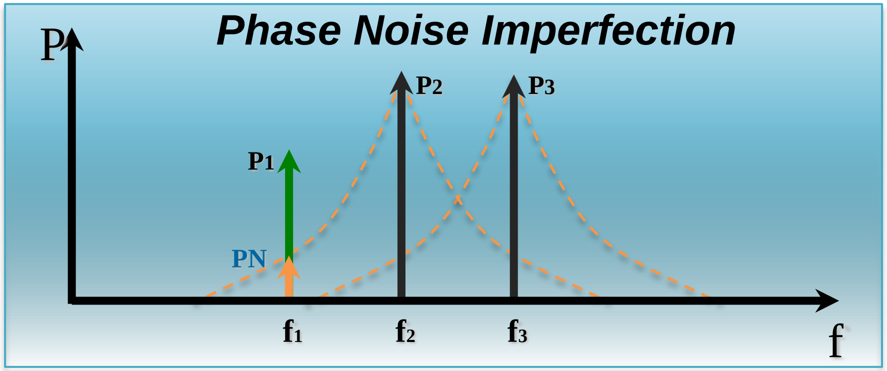
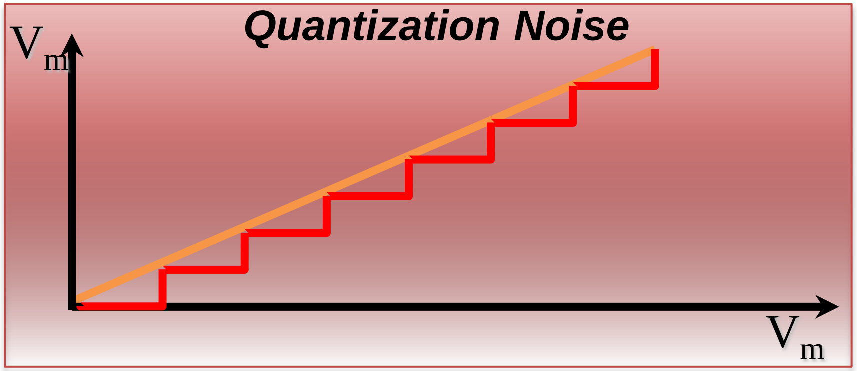
EnvAdapt - New SINR Calculation Block

- In addition to co-channel interference
- Non-negligeable impact at low SINR









$$\text{SINR}=\frac{P_{received}}{N_i+\sum_{k\neq i,j}\alpha_{jk}P_k+\sum_{k\neq i,j}\sum_{l\neq i}\gamma_{kl,i}P_kP_l^{2}+\sum_{k\neq i,j}P_{PN}+QN}$$

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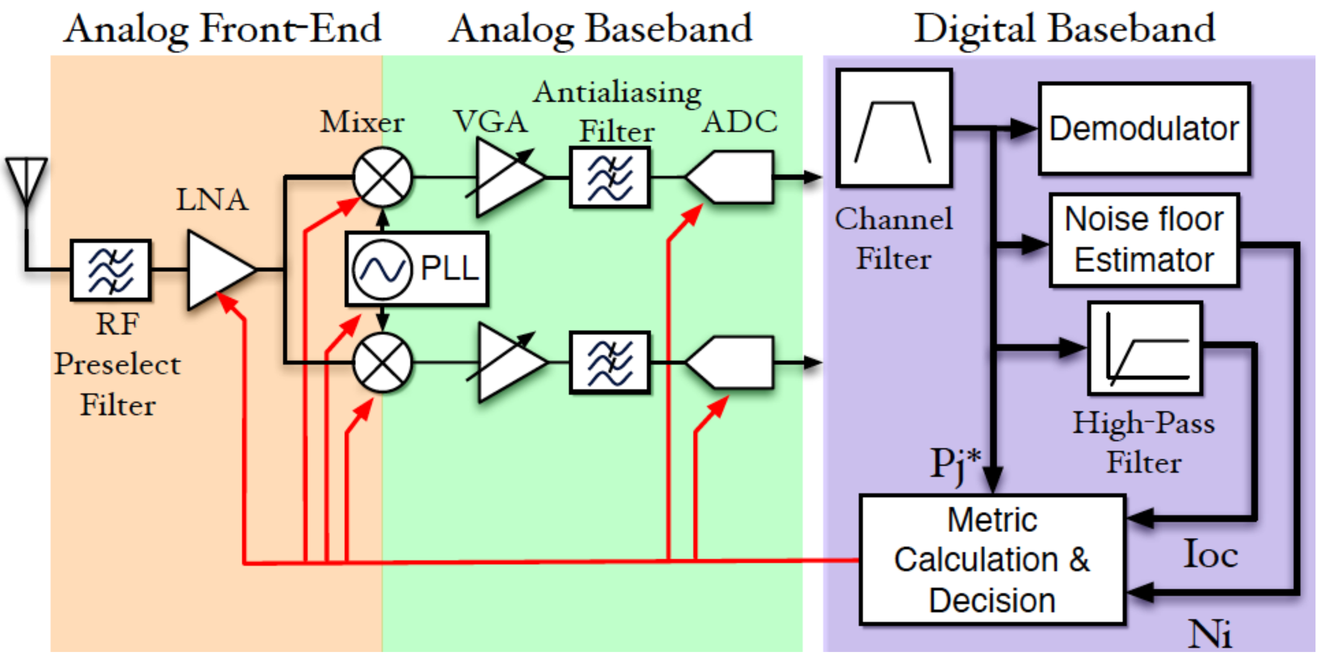
EnvAdapt - Example

- Zero-IF Architecture
  - Digital channel section with **reconfigurable** LNA, Mixer, VCO, ADC



Power/performance models of the analog blocks are defined based on Figures of Merit for a target technology node.

Mode	Pdc [mW]	NF [dB]	IIP3 [dBm]	PN [dBc/Hz]	ENOB [bit]
High	22.6	4.6	-26	-114	9
Moderate	10.5	7	-27	-110	6
Low	4.5	14.7	-29	-95	3

Three Power/performance modes are defined.

''Power Reconfigurable Receiver Model for Energy-Aware Applications'', A. Didioui, C. Bernier, D. Morche, O. Sentieys, MWCAS2013

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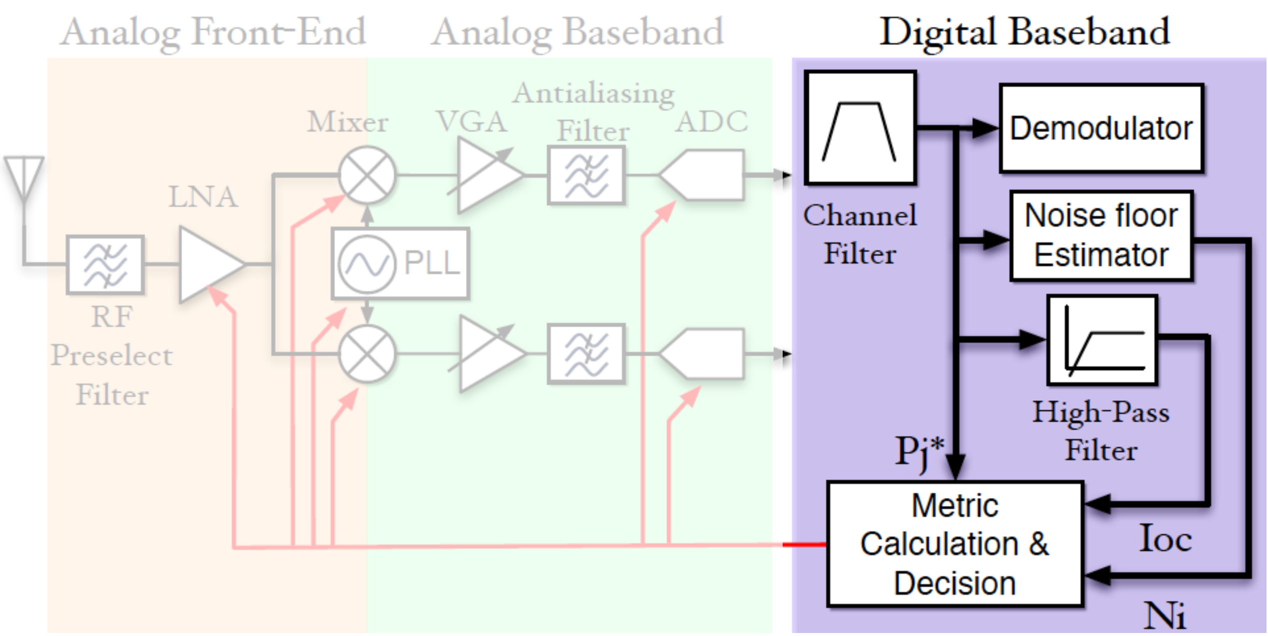
EnvAdapt - Example

- Zero-IF Architecture
  - Digital channel section with **reconfigurable** LNA, Mixer, VCO, ADC



Low complexity – LQEHW - calculation in the D-BB

$$\text{SINR}=\frac{P_{received}}{N_i+\sum_{k\neq i,j}\alpha_{jk}P_k+\sum_{k\neq i,j}\sum_{l\neq i}\gamma_{kl,i}P_kP_l{}^2+\sum_{k\neq i,j}P_{PN}+QN}$$

$$\text{LQE}_{\text{HW}}=\frac{P_{received}+\sum P_{Co-channel}+\sum_{k\neq i,j}\sum_{l\neq i}\gamma_{kl,i}P_kP_l{}^2+\sum_{k\neq i,j}P_{PN}}{N_i+\sum_{k\neq i,j}\alpha_{jk}P_k+QN}$$

"Power Reconfigurable Receiver Model for Energy-Aware Applications", A. Didioui, C. Bernier, D. Morche, O. Sentieys, MWCAS2013

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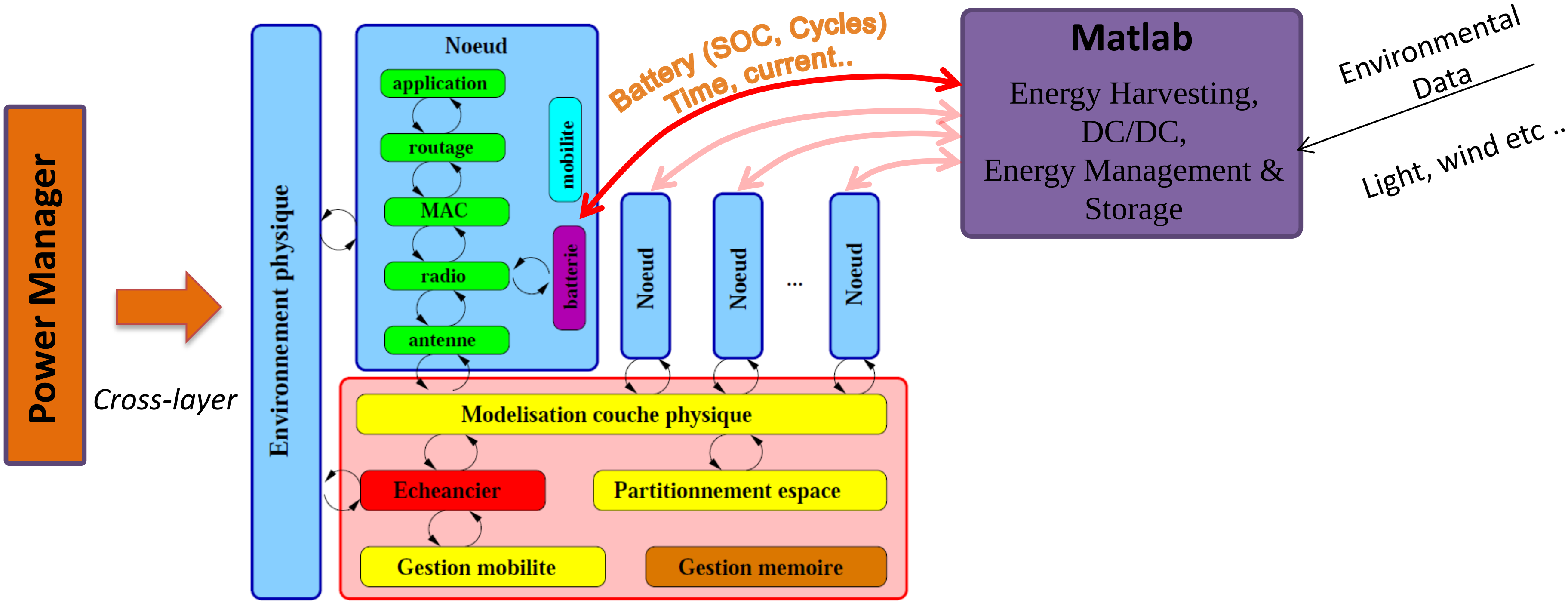
HarvWSNet

- Simulation environment considering both
  - **Discrete time** events (ex : packet transmission) ➔ WSNet
  - **Continuous time** events (ex : energy harvesting ➔ Matlab



*"**HarvWSNet: A Co-Simulation Framework for Energy Harvesting Wireless Sensor Networks**", Amine Didioui, Carolynn Bernier, Dominique Morche, and Olivier Sentieys, IEEE ICNC, 2013*

*"**Prototyping an Energy Harvesting Wireless Sensor Network Application Using HarvWSNet** " Florian Broekaert, Amine Didioui, Carolynn Bernier, Olivier Sentieys, 3rd Workshop on Ultra-Low Power Sensor Networks (WUPS) 2013.*

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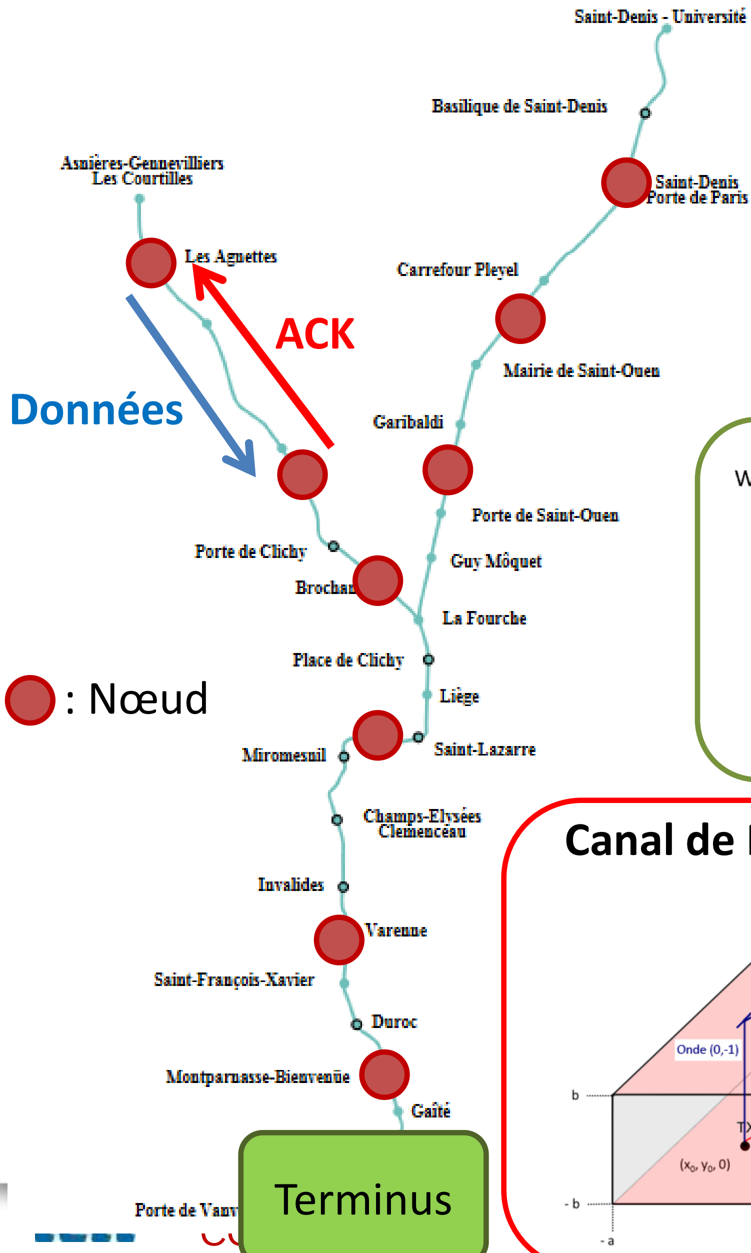
Scénario Métro Parisien Ligne 13

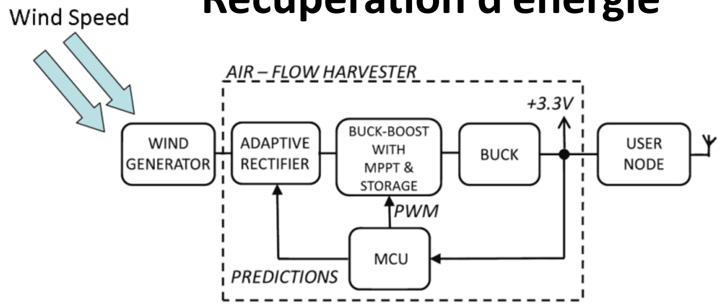


Passage variable des trains

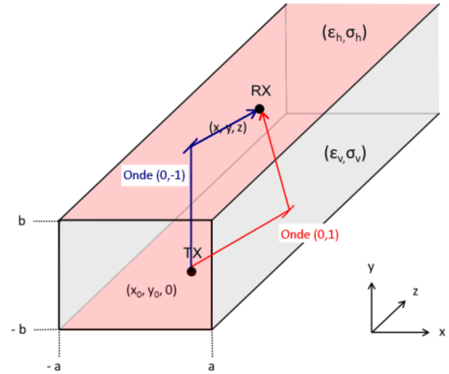
Fonctionnement des trains, début : 5h30 fin : 0h37

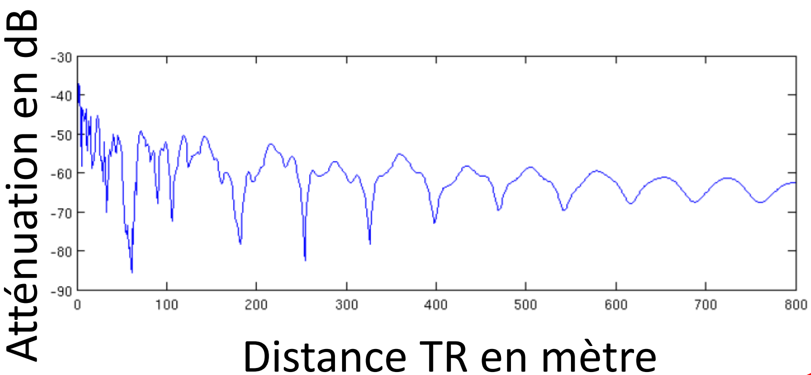
Période	Fréquence Trains
Heure creuse	4 minutes
Soirée	8 minutes
En pointe	90 secondes

Récupération d'énergie



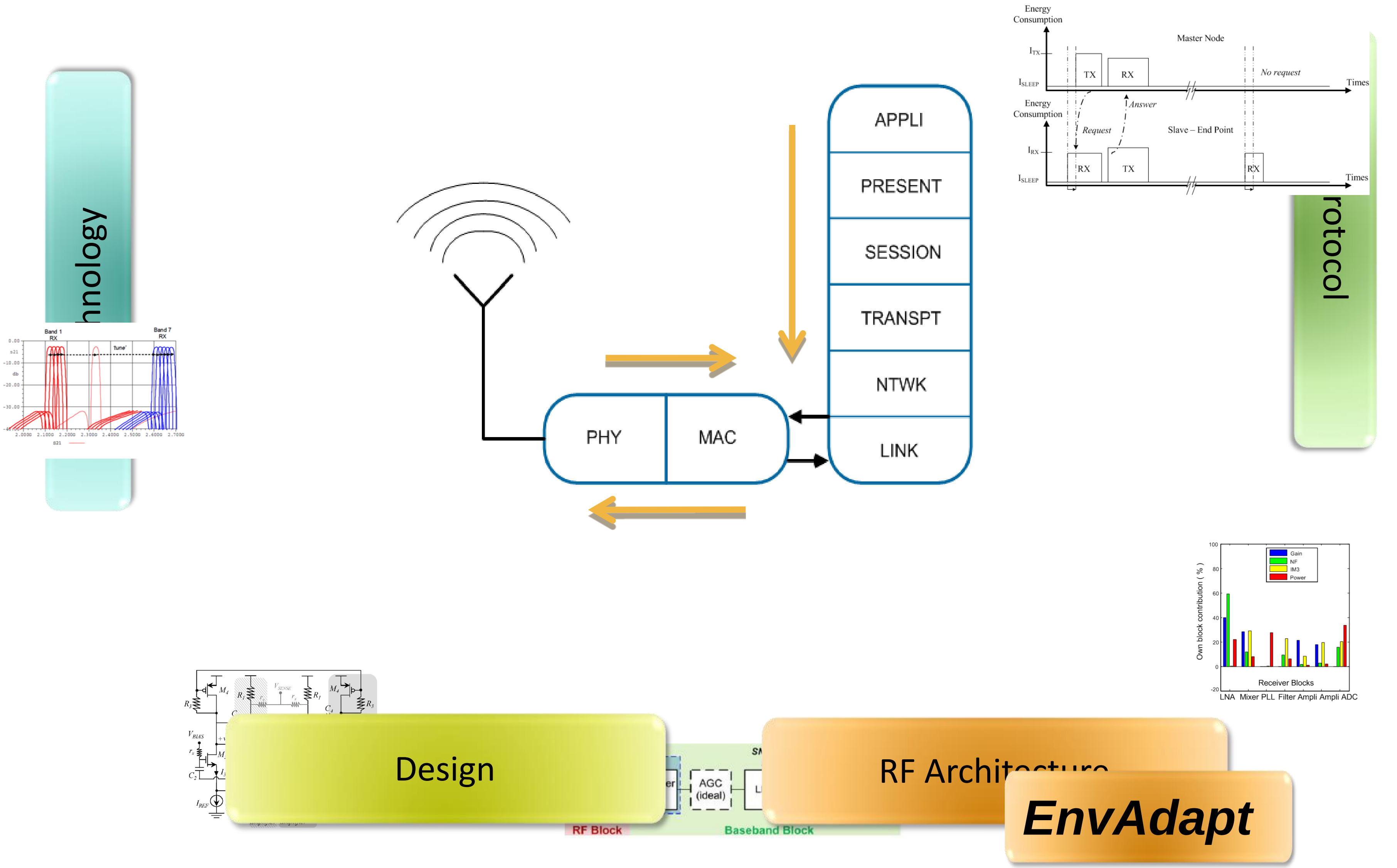
Canal de Propagation : Tunnel => Multipath effect





RF Going GREEN, actually …

HarvWSNet



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