Long-term deployments of communicating mobile sensors for wildlife monitoring*

*Works extracted from : PhD thesis of R. Kuntz, ongoing PhD preparation of J. Beaudaux

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Research and Development of Ad-hoc- and Wireless Sensor Networks for Environmental and Animal Behavioural Monitoring
Crossed Seasons France / South Africa

Associate professor at University of Strasbourg

- **Teaching duty**
  - Networking classes
  - Computer networks and embedded systems Master
- **Research activities**
  - Image Sciences, Computer Sciences and Remote Sensing Lab
    - University of Strasbourg and CNRS Research Unit
    - Network research group, led by Prof. Thomas Noël
  - Ad hoc and WSN, activity scheduling, routing/MAC
  - IP over WSN, SensLAB/FIT platform, wildlife monitoring

STRASBOURG: SELECTED FIGURES

- Founded in 12 B.C.
- 276,063 residents in Strasbourg
- 474,524 residents in the Strasbourg urban Community
- 500 km of cycle paths
- 2hrs20 to Paris by train
- More than 4 million visitors every year

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Motivations and research focus

- **Many existing projects (e.g zebranet, habitat monitoring, badgers, turtles)**
  - No multi-hop communications
  - No (or limited) mobility
  - No geolocation (without GPS)

- **Our research interests in wildlife monitoring**
  - Expertise on networking new kinds of wireless mobile sensors
    - Routing and MAC layers
  - Collecting data for further modelling
    - Mobility
    - Radio topologies

Wildlife monitoring projects

- **ARGOS: high costs, hard to adapt to specific requirements**
- **GPS-based sensors**
  - "Simple" dataloggers, no radio communications
  - High energy-consumption still
  - Long-term deployments? Limited geographic areas (fewer GPS readings)
  - e.g. Electronic Shepherd, UC Davis's Puma Project
- **GPS-free sensors**
  - Radio communications, large areas
  - Need for adapted devices (size and weight especially)
  - Direct communications to fixed infrastructure
  - e.g. Falcons tracking, salmons tracking

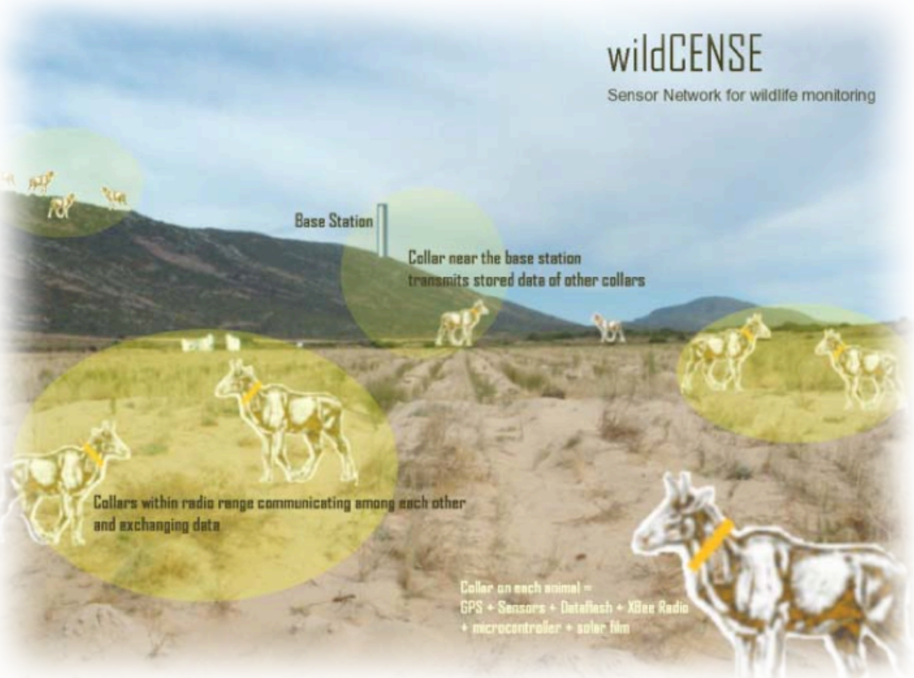
Wildlife monitoring projects

- **Zebra Net (Kenya, 2003): Study zebras at night**
  - Battery for 1 year: if solar array then 200g, else 1kg
  - Communications every 2 hours (for 5 mn, radio range : 1 to 5 km)
  - Routing: None
  - MAC: GPS receiver -> time-slotted transmissions

- **Issues:**
  - 2 hours is too long a period
  - time-synchronization is possible thanks to GPS
  - Large size and weight for many animals (e.g. penguins, storks)

Nilgai tracking

- **WildCENSE project: Monitoring Indian Nilgai and its habitat**
  - Sensing and storing every 3 hours...
  - Routing/MAC: XBee-PRO (time-slotted on-the-shelf protocol)
  - Impossible to use on smaller animals



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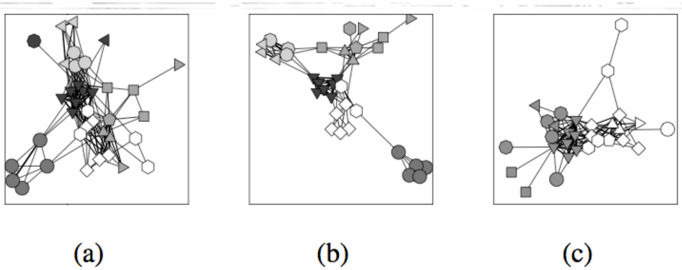
Wildlife monitoring projects

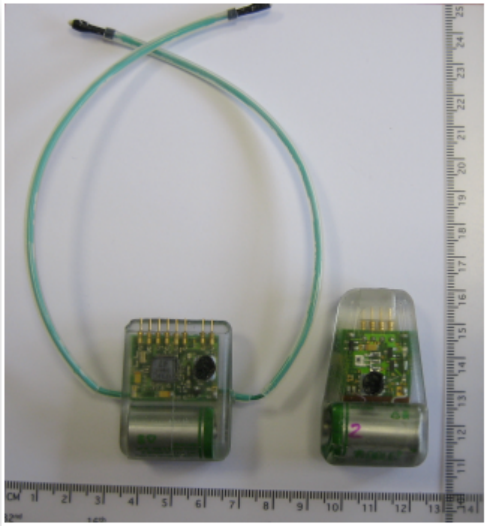
- **The Badger Project (Wytham Woods, Oxfordshire, UK, 2010)**
  - “Regular” data -> RFID storage (tag) and upload (reader)
  - Low-volume data -> multihop communications to 3G gateway
    - Communications every 30mn
    - Routing: Simple tree-based (gradient-like) protocol
    - MAC: Preamble-sampling X-MAC protocol



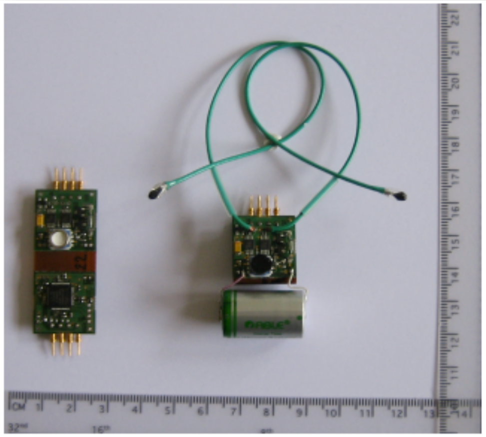
Badger social networks: The shade of a node (node = badger) represents the social community it belongs to while its shape denotes the sett it lives in. Different networks are created by using (a) all co-locations between animals at setts and latrines, (b) only co-locations at setts, and (c) only co-locations at latrines.

Ongoing work: Penguin tracking

- **Currently**
  - Animals equipped at time T and captured again at time T + X months
- **Make such biologgers communicate**
  - Eased download of data, data redundancy
  - Monitoring of the ongoing experiment



Logger PTT2_CC et PTL en résine



Logger PTL sans résine

Long-term deployments for wildlife monitoring
Requirements

- **Hardware**
    - Antenna: Depends on the monitored animal (i.e. body full of water)
    - Size and attachment: e.g. penguins can not wear collars
    - Packaging: e.g. waterproof, temperature/pressure variations
- **Data collect**
    - Time-stamped: strict/relaxed time synchronization
    - Various sampling periods: primary or complex data
    - Fault-tolerant: e.g. logger-to-logger communications for data redundancy
- **Software**
    - Efficiency: Memory write/read actions
    - Long-term: Communication protocol stack, sensing and radio activity mainly

Designing protocols for wireless communications
Medium access control (MAC)

- **Air is a shared resource:** e.g. People willing to discuss in a common area
  - **Diffusion:** all sensors within the communication area of a sending node receive
  - **Solution:** Only one single transmitting node in a given communication area

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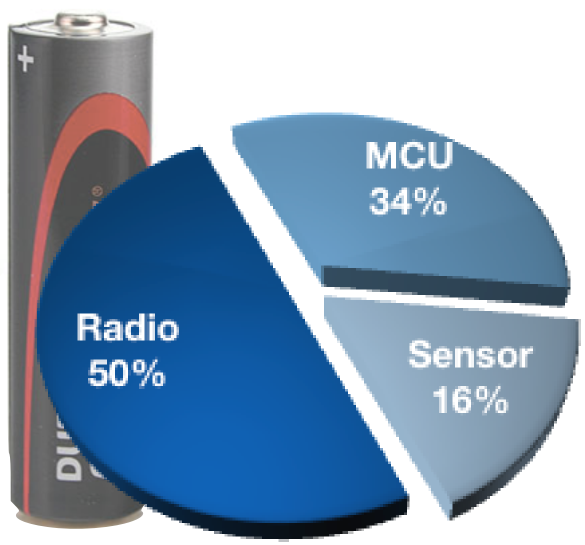

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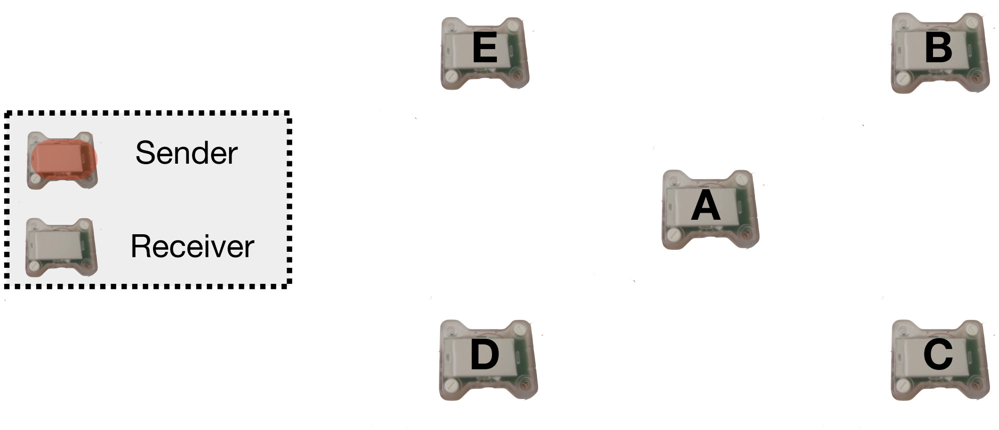

➡ **Idle listening**

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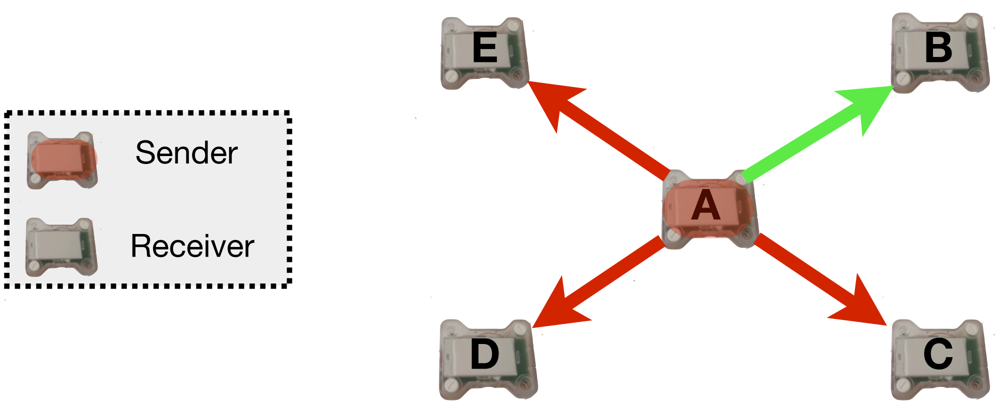

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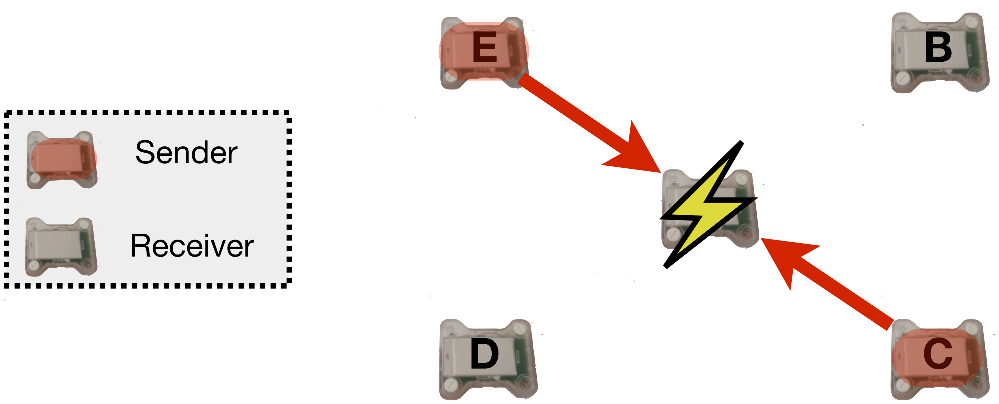

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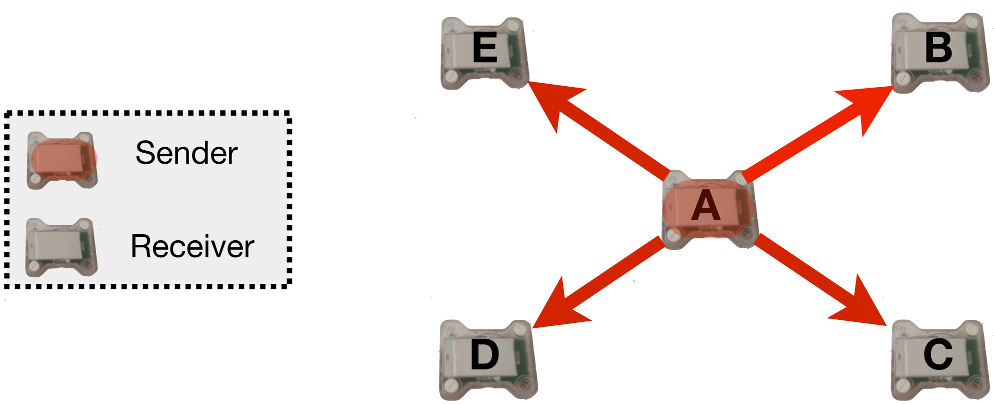

➡ **Idle listening**

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Designing protocols for wireless communications
Medium access control (MAC)

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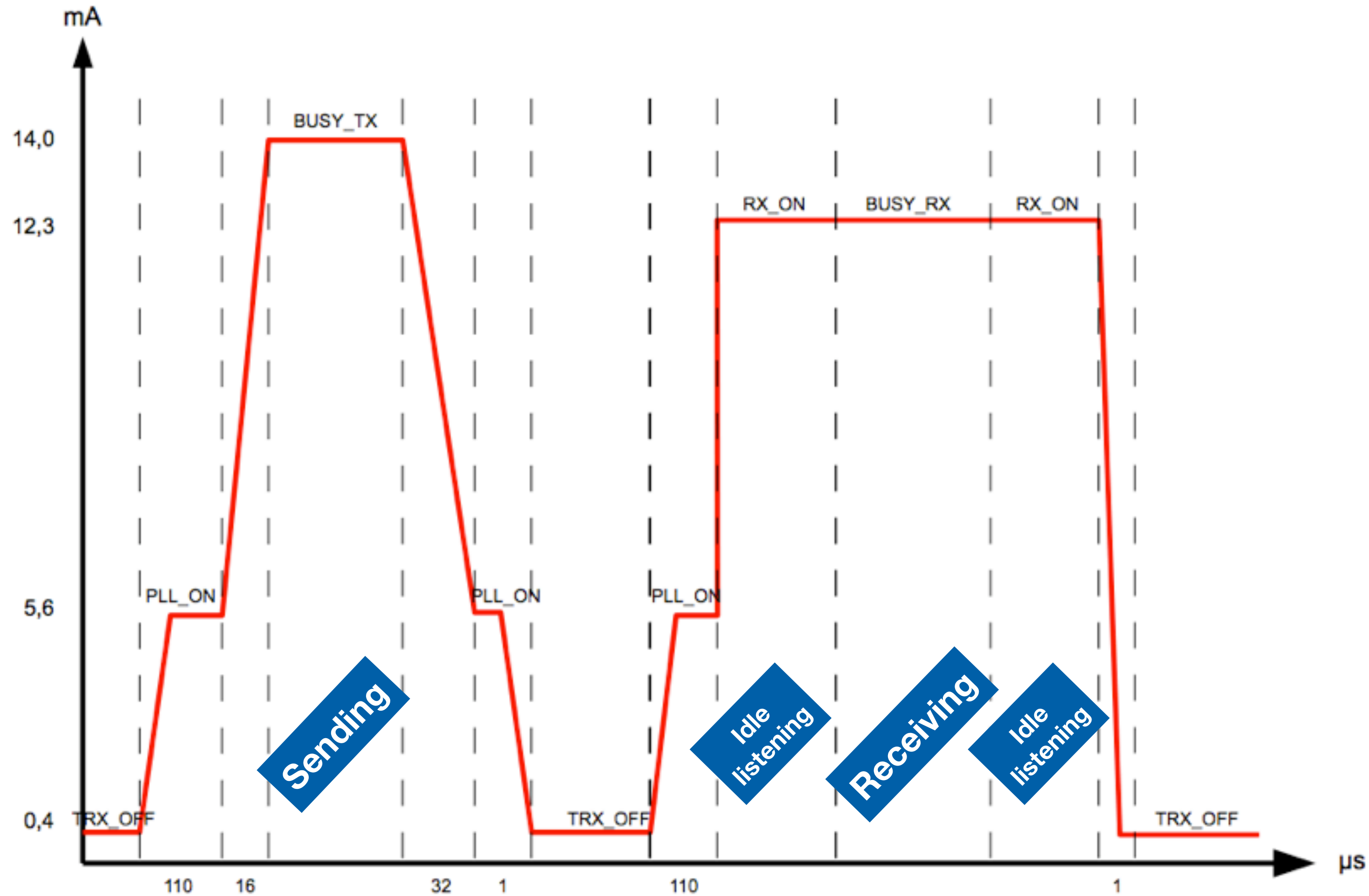
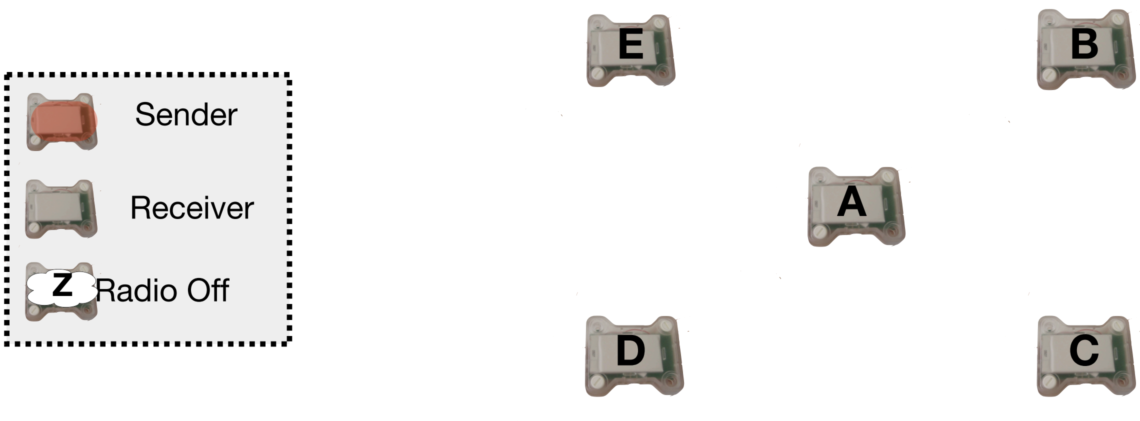


Duty-cycling: MAC layer

- Active/Passive: At which layer ? Application ? Routing ? MAC ?
  - ➡ **Controlling medium access (MAC) for a better radio usage**
  - ➡ **Main assumption: each node works its own MAC, using local information only**



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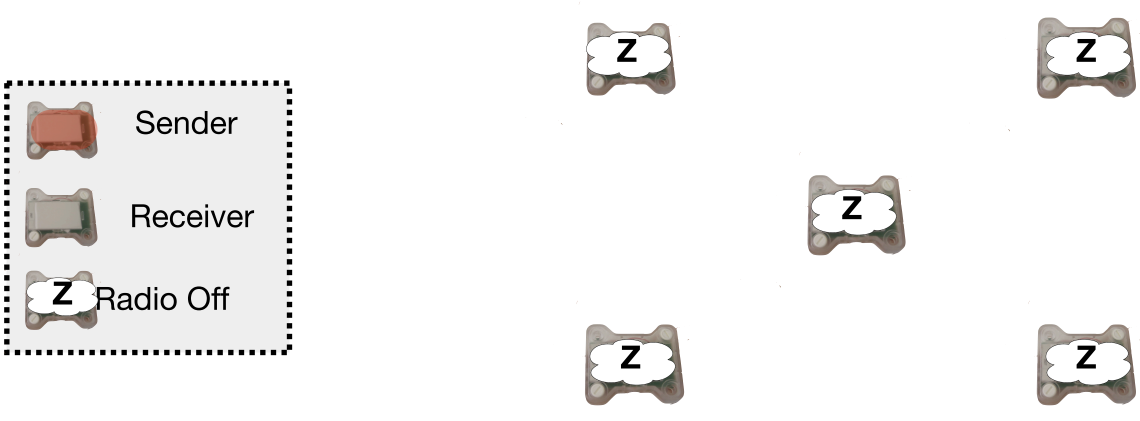

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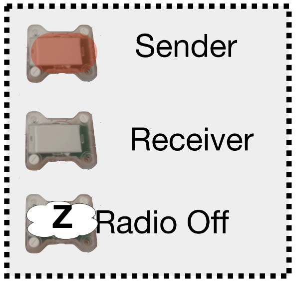

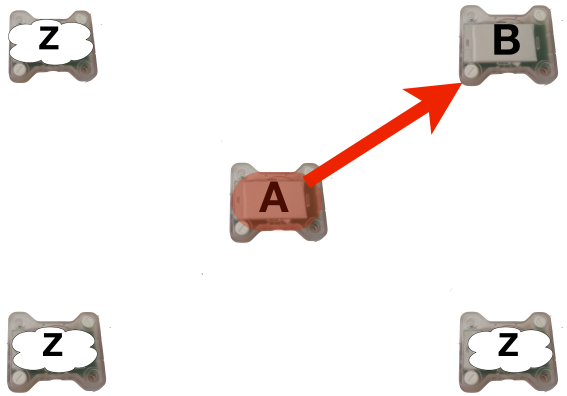

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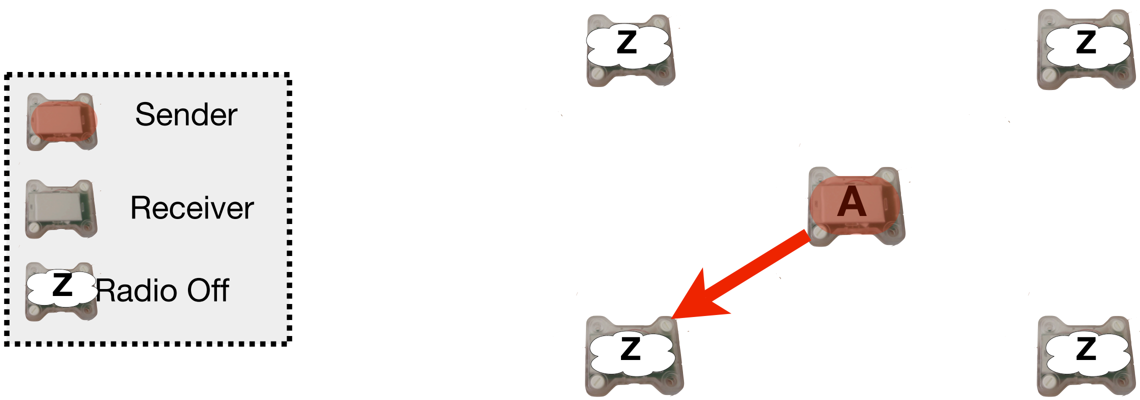
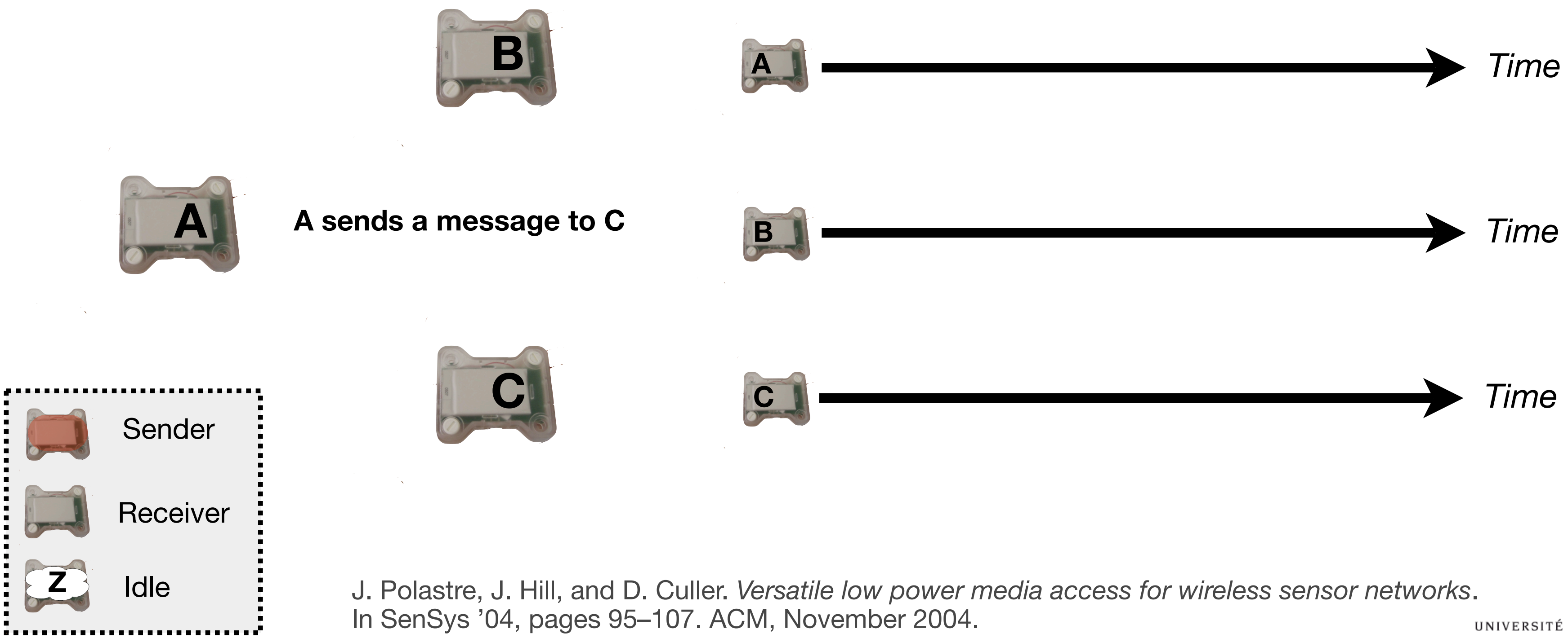


- **Connectivity** between loggers must be ensured + fairness regarding **latency** and **scalability**
  - ➡ 2 main types of MAC protocols: synchronized, **preamble-sampling**

Preamble-sampling MAC protocols

- **Low Power Listening (LPL): no time-synchronization (B-MAC)**
  - **Sampling** periods
  - Use of a **preamble** before any data transmission



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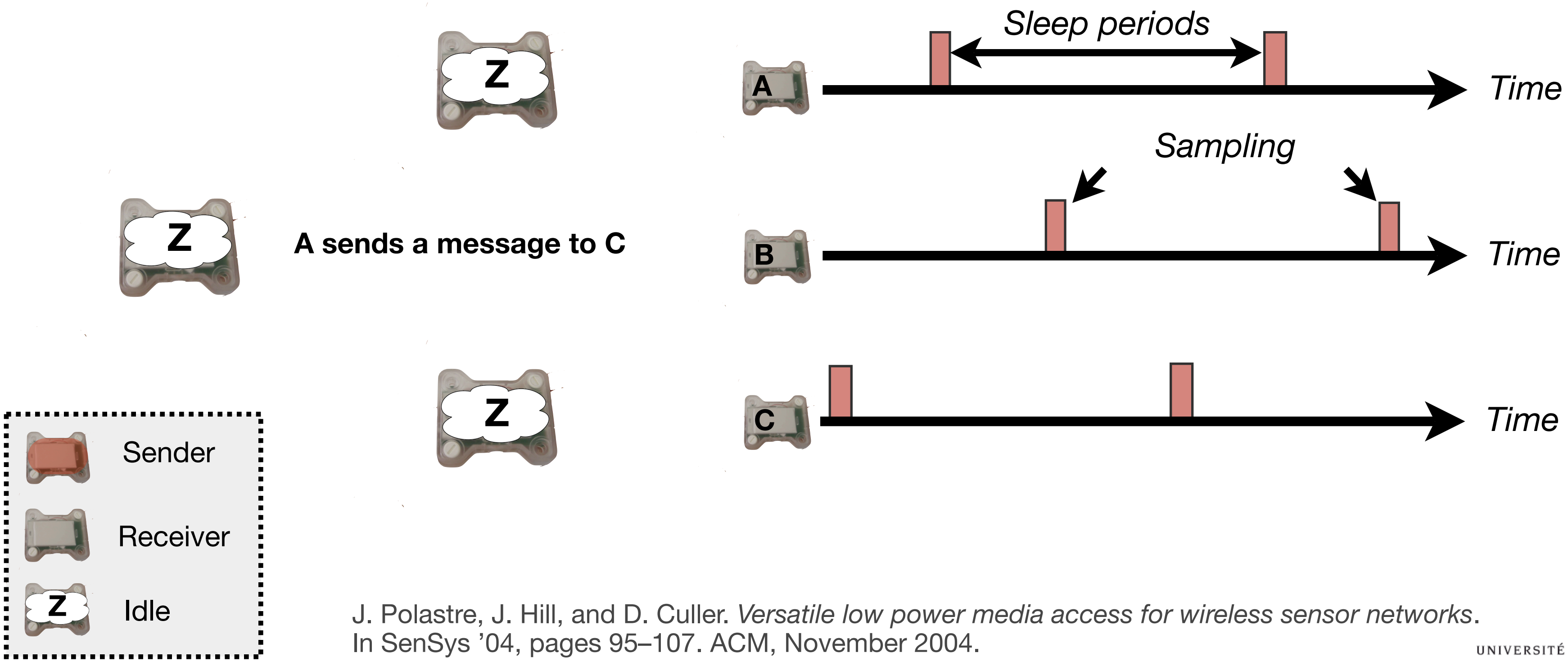

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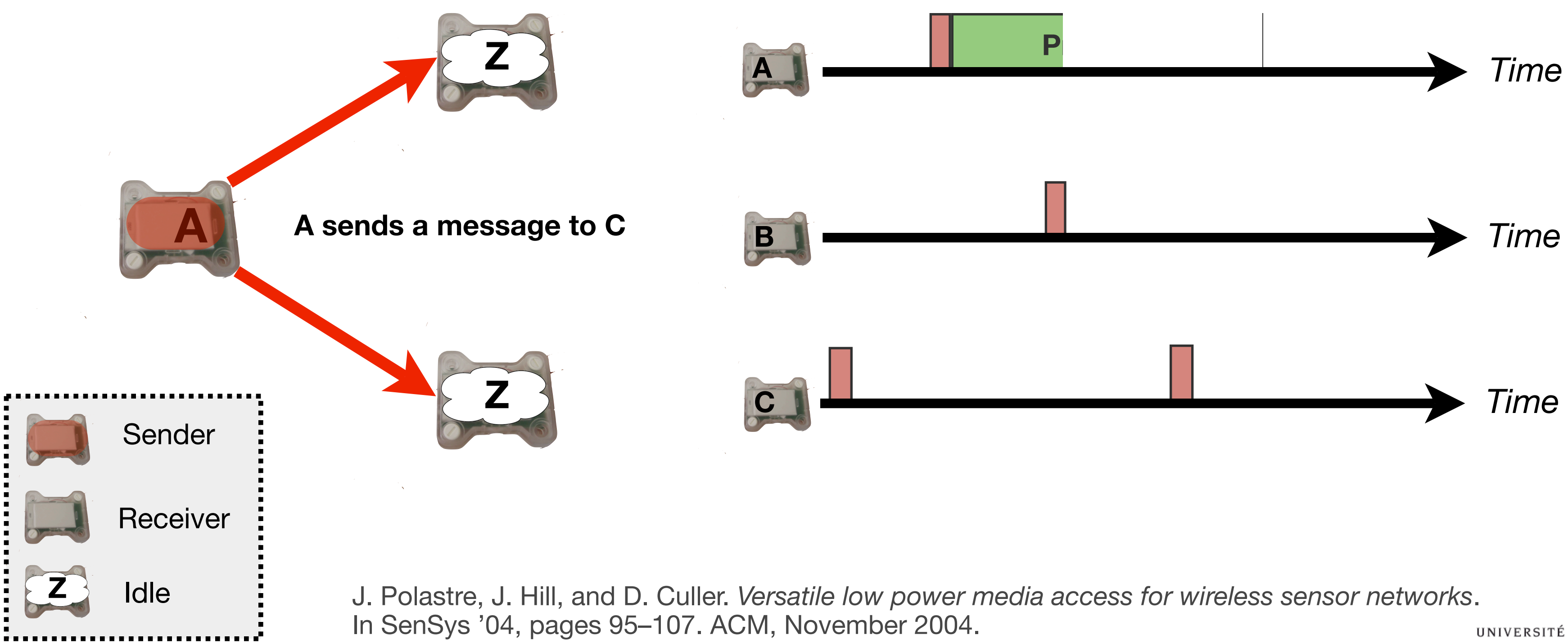

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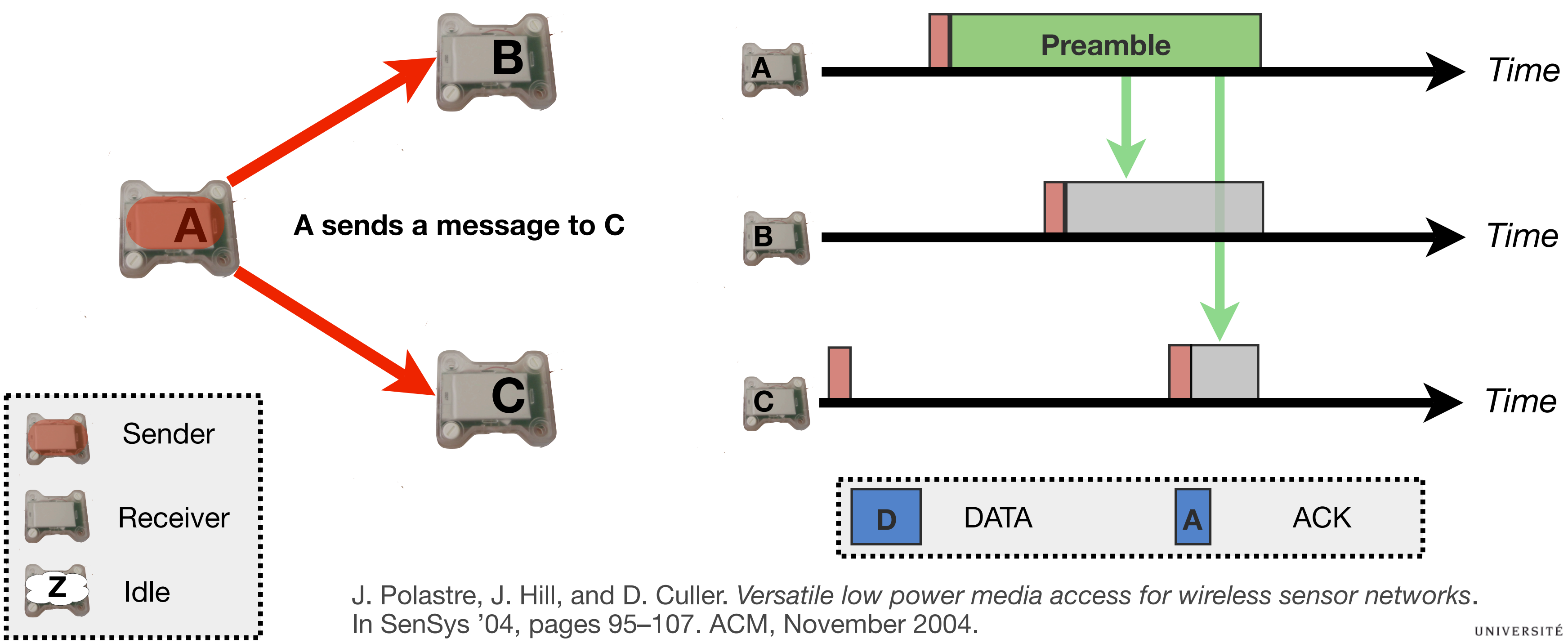

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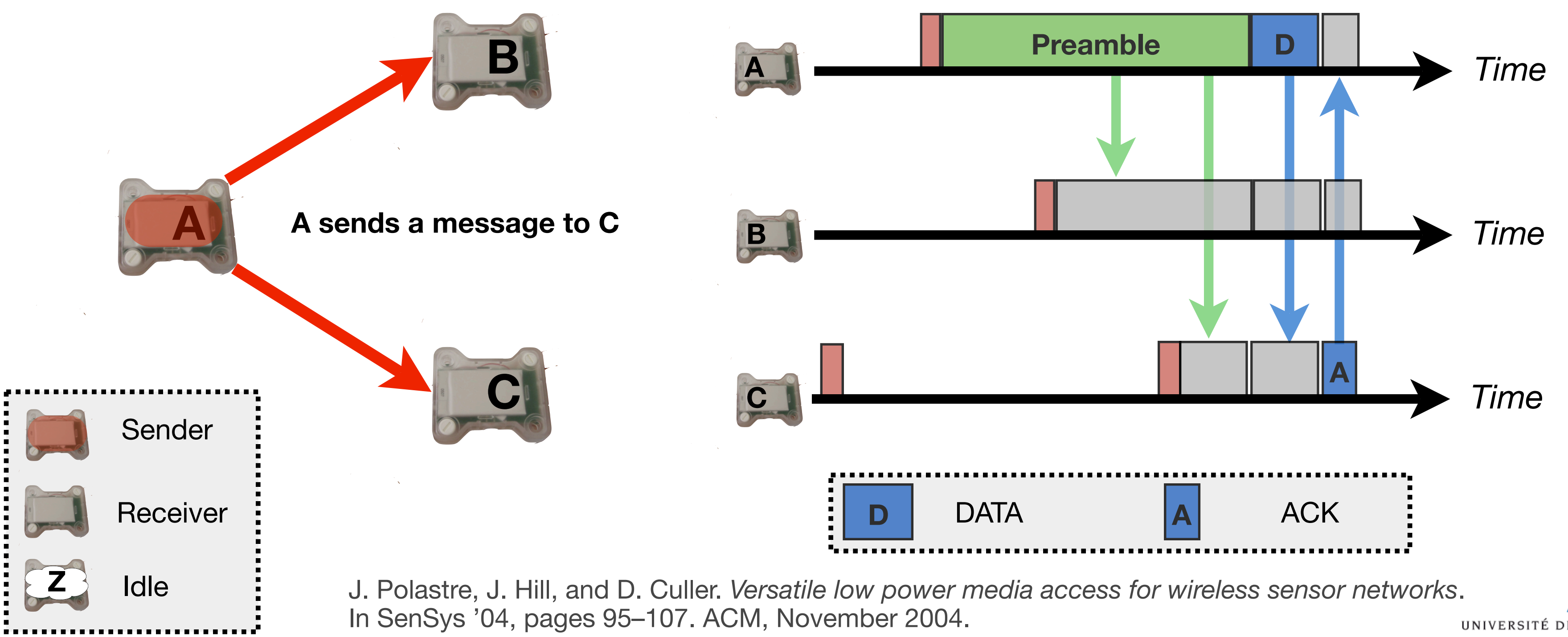

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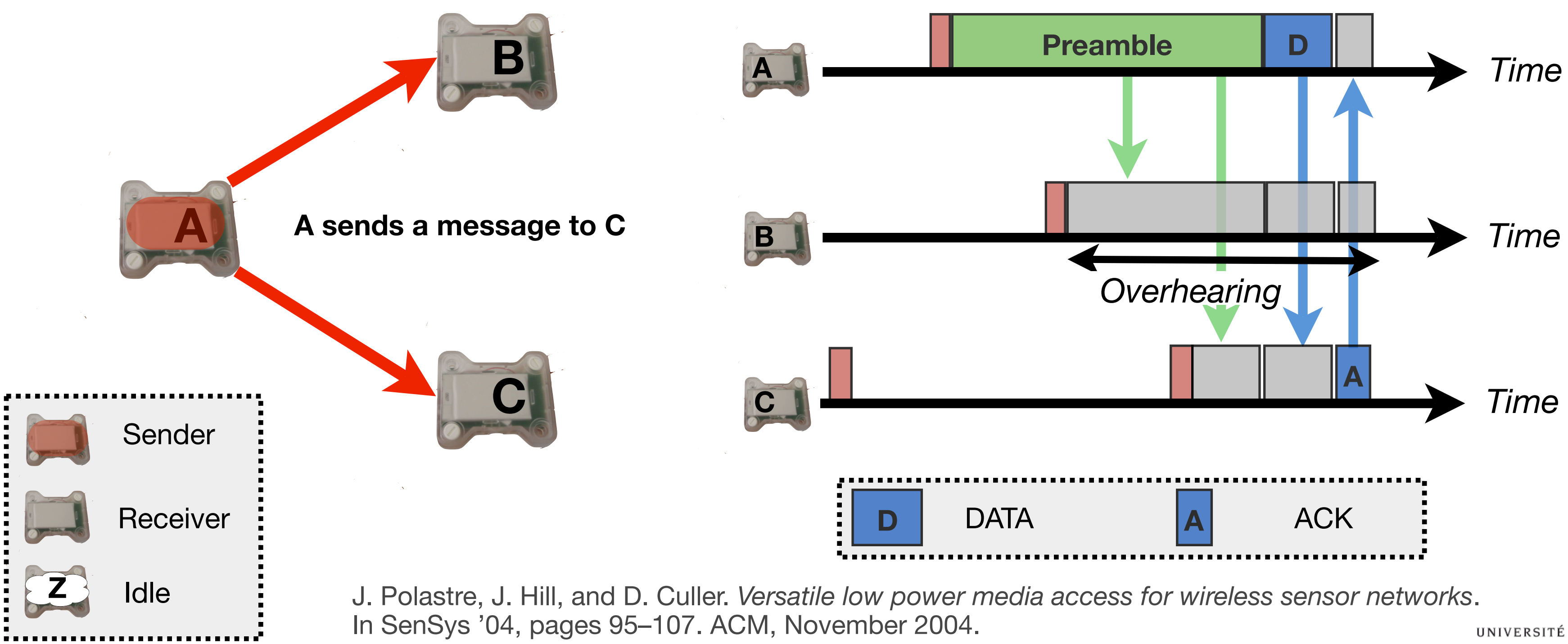

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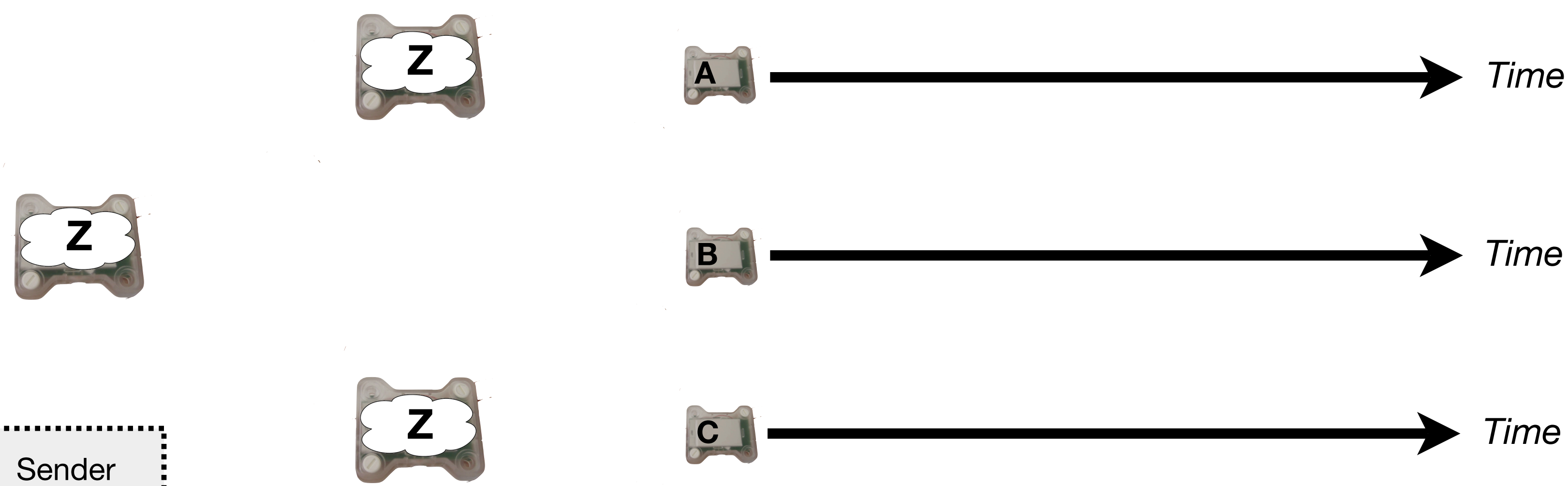
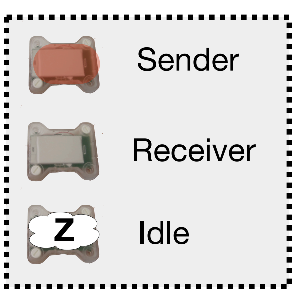
- **X-MAC divides preambles in several micro-frames:**
  - Includes **destination** related information





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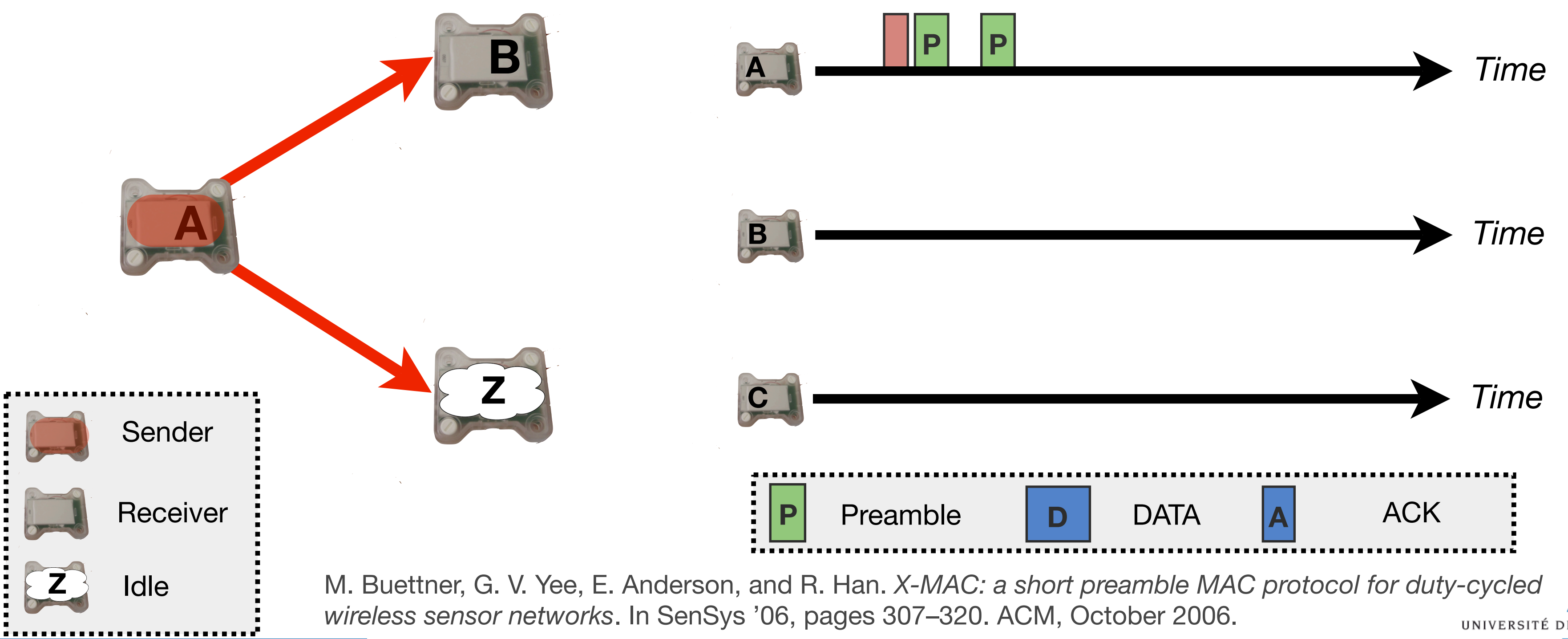

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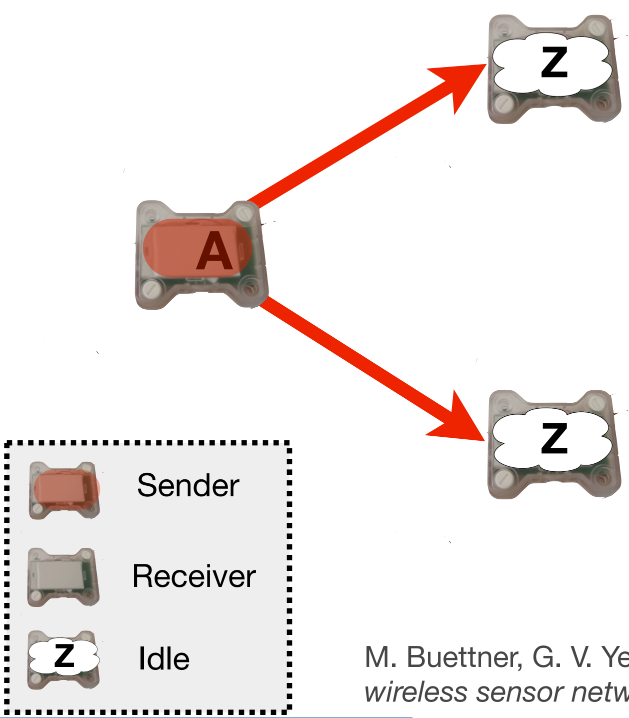

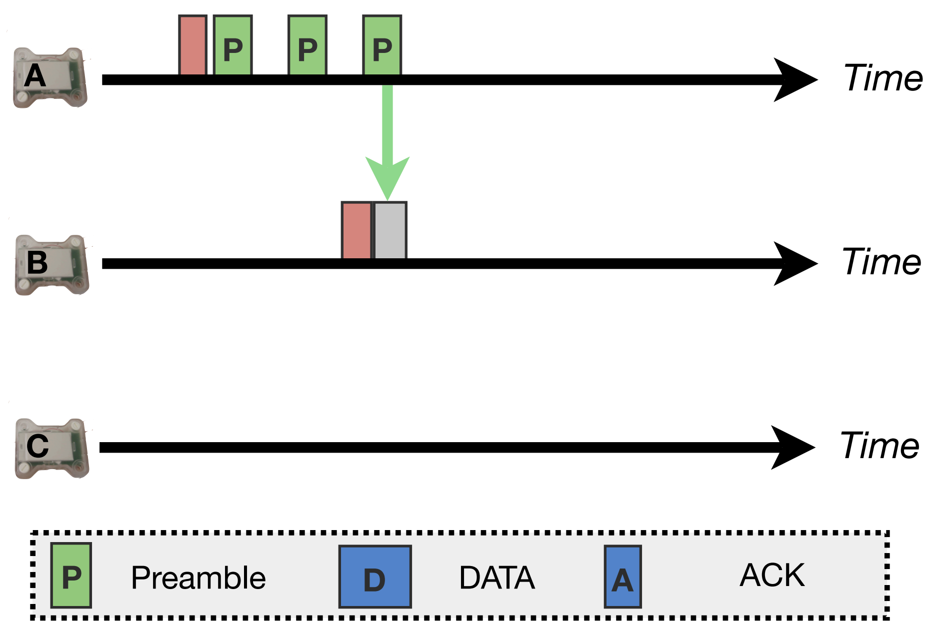

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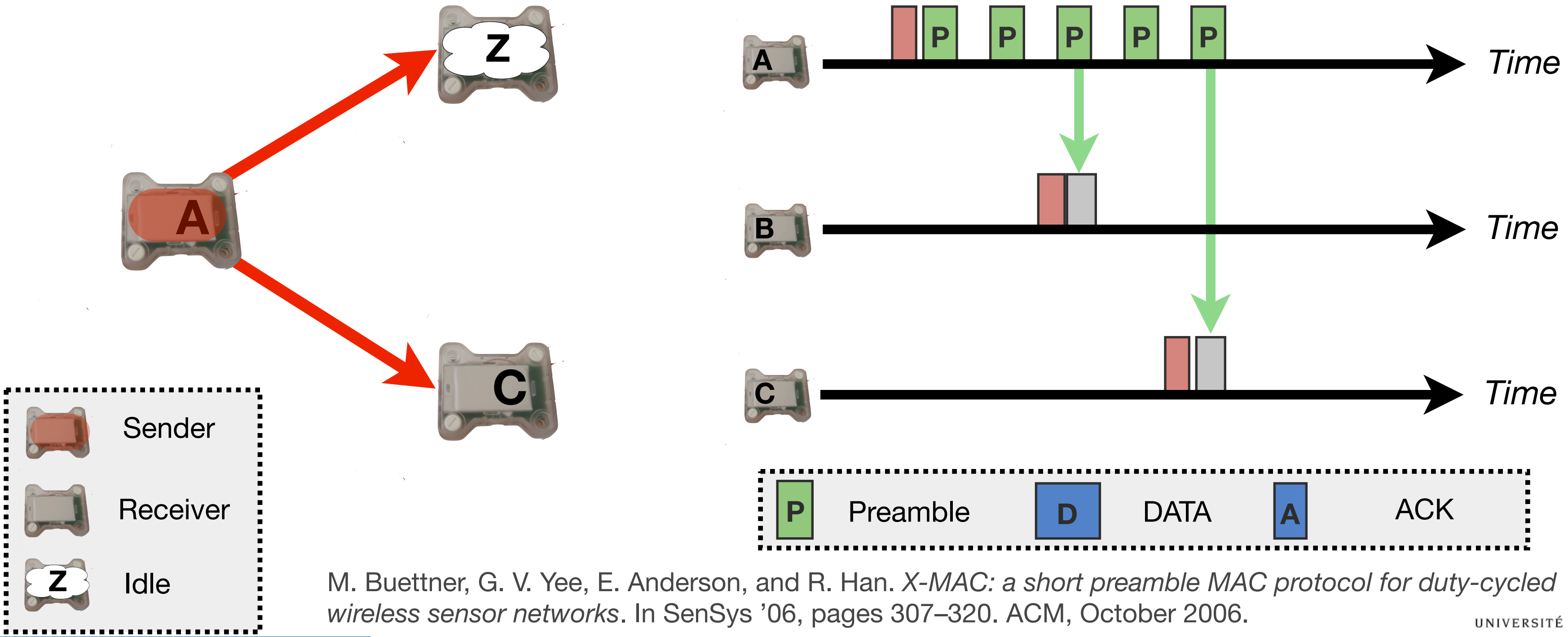

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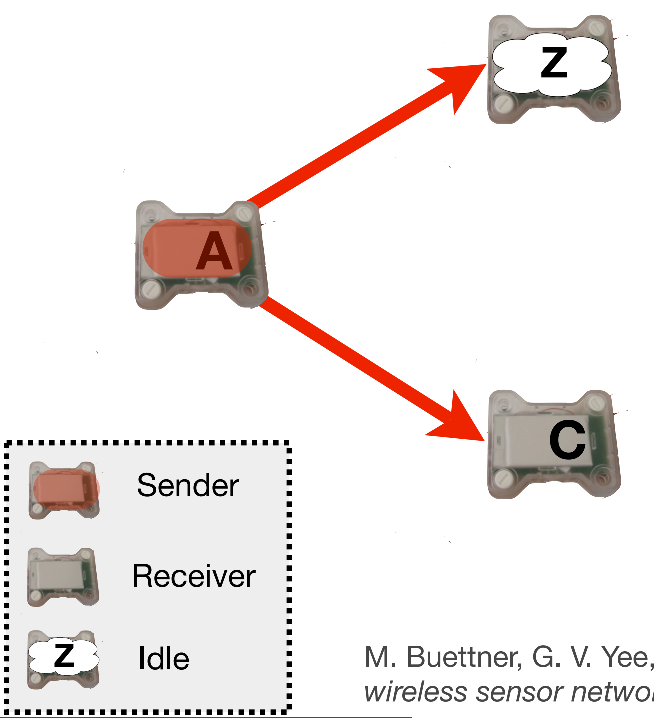

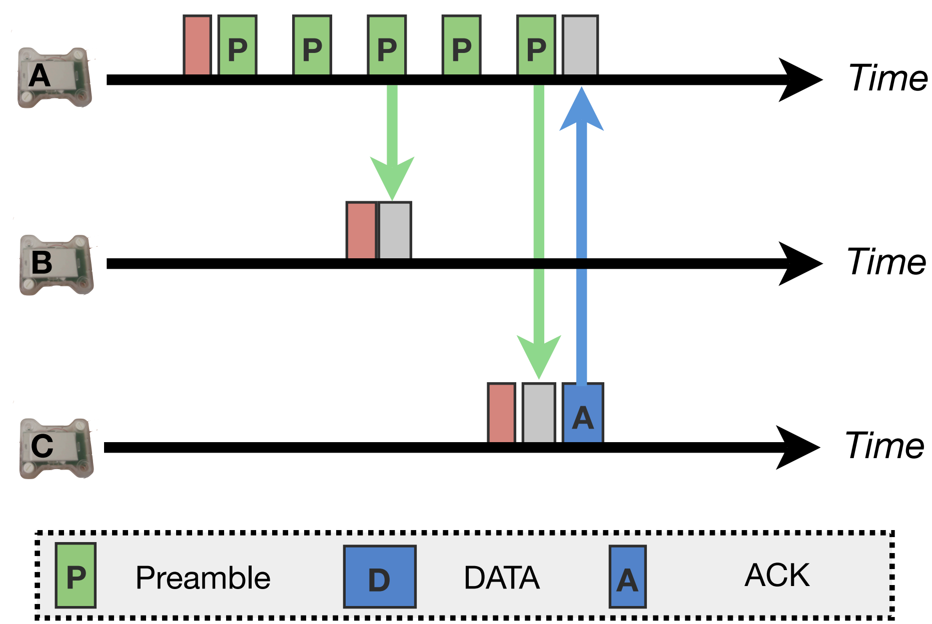

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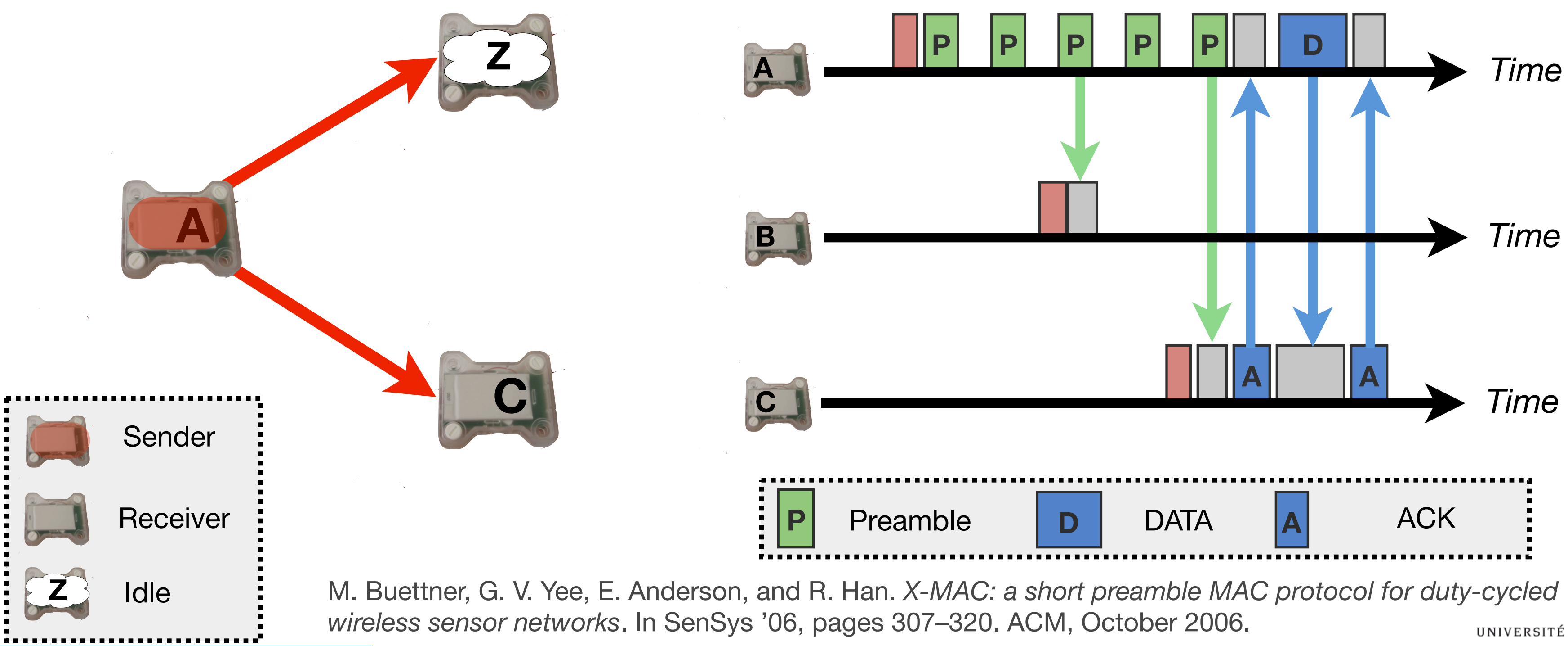
➡ **Scalable** and **robust to topological modifications** (e.g. faults, mobility)



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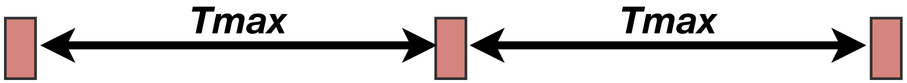
Preamble-sampling MAC protocols: Challenges

- **Goal: Having routing paths composed of energy-efficient links only**
  - Short LPL (100 ms): frequent wake-ups and short preambles
    - Cost for receivers (sampling): OK if most of nodes are transmitting

  - Long LPL (500 ms): less frequent wake-ups but longer preambles
    - Cost for senders: OK if most nodes are not transmitting



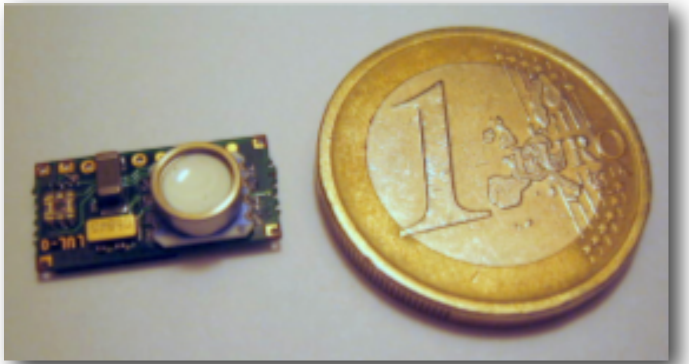
- **Problems**
  - How to set LPL mechanisms based on energy/delay compromises ?
  - How to deal with opposite traffic patterns ?

➡ **Goal: Automatically tune LPL for nodes involved in communications**

Communications among mobile biologgers

- **Last requirement:** Detailed information for accurate design of protocols

Scenario	#loggers	#sink stations	Contact duration with sinks	Contacts with other loggers	Primary data to be stored	Complex data to be stored	Deployment duration
Storks	50	1 per nest	7h / day	10 / days (15s each)	275kb / day	125Mb / day	1 year
Penguins	100	1 to several per area	> 1h / day	50 / day (10s-10h each)	1.2Mb / day	125Mb / day	3 months



Protocols to be designed: **MAC** and routing layers

MAC: Adapting LPL configuration

- **Proactive approaches**
  - Using
    - Routing information
    - Application criteria

- **Reactive approaches**
  - Induced traffic

MAC: Adapting LPL configuration

- **Proactive approaches**
  - Using
    - Routing information
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- **Reactive approaches**
  - Induced traffic

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Proactive approach

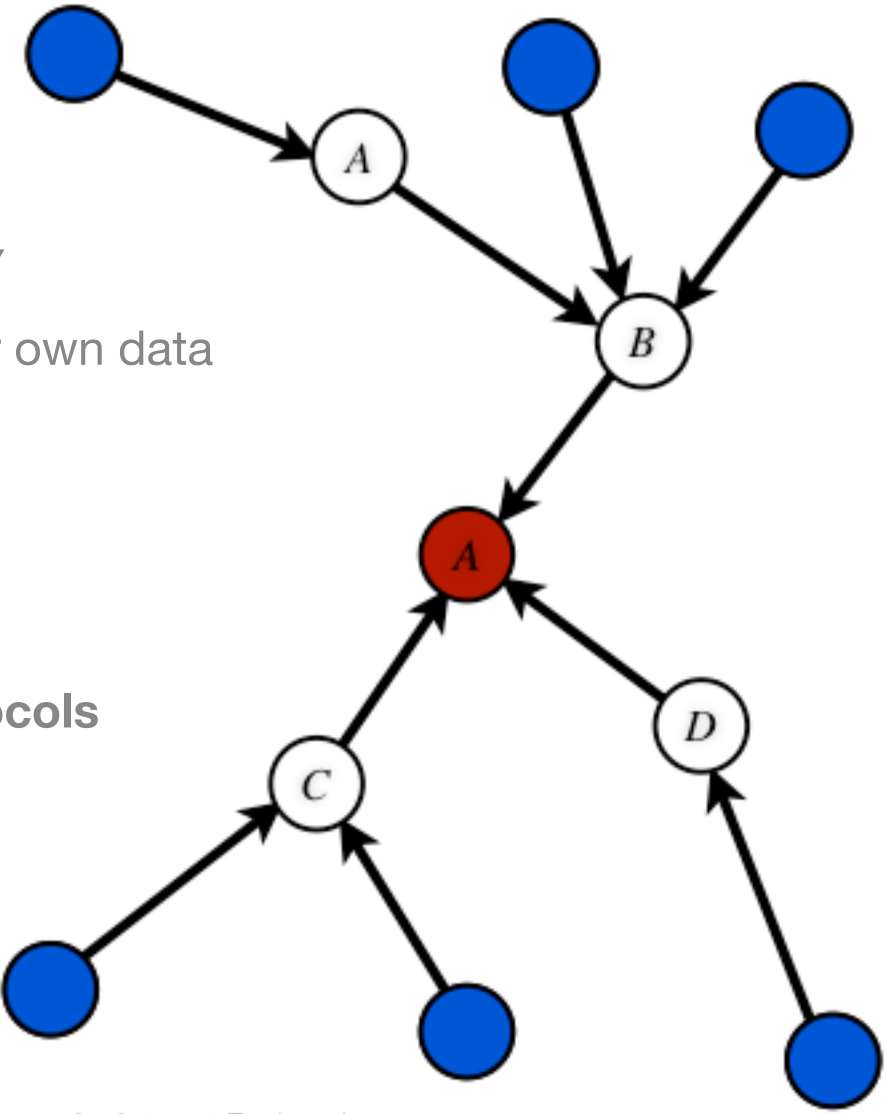
- **Using routing information**
  - Root of the tree-based routing structure -> sink station
  - Leafs: sending their own data only
  - Remaining nodes:
    - Sending their own data
    - Relaying data of associated nodes (e.g. sons, grand-sons)

- **Using application criteria**
  - e.g. Coverage, connectivity, density control

Using routing information

- **Leaf nodes become *sensing-only***
  - Only sensing and sending their own data
  - Not relaying data packets
  - ➡ Configured with long LPL

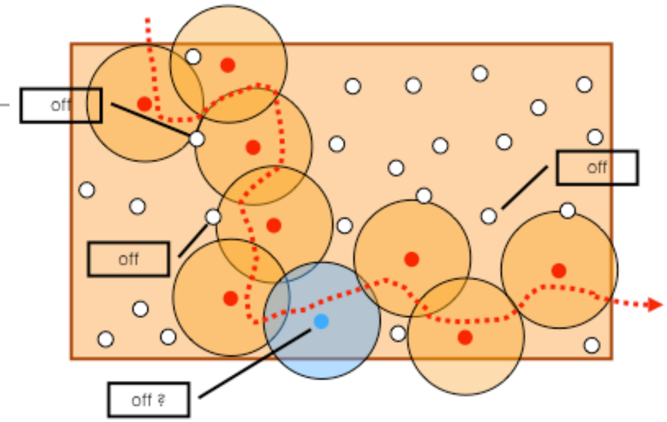
- **Usable with several routing protocols**
  - RPL (IETF)
  - Gradient-based approaches

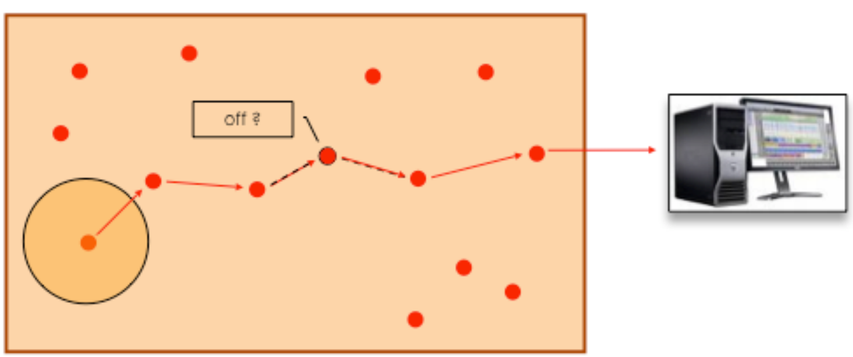


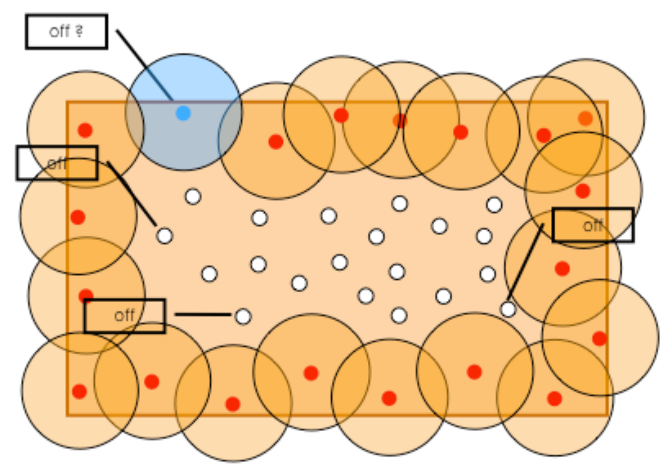
T. Winter et al. , *RPL: IPv6 routing protocol for low power and lossy networks*, Internet Engineering Task force Request For Comments (RFC) 6550, 2012.
C. Intanagonwiwat, R. Govindan, D. Estrin, J. Heidemann, and F. Silva, *Directed diffusion for wireless sensor networking*, IEEE/ACM Transactions on Networking (ToN), 2003.

Using application criteria

- **Possible criteria**
  - e.g. Target tracking, Border coverage, Point of interest / Area coverage, Density control
  - Network connectivity
- **Active nodes:** Short/reactive LPL
- **Passive nodes:** Long/energy-efficient LPL

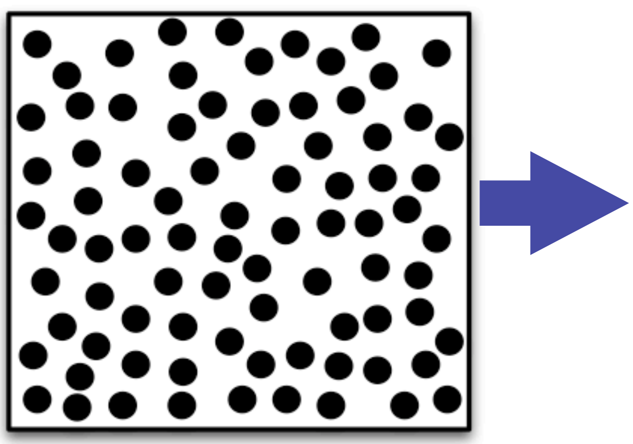


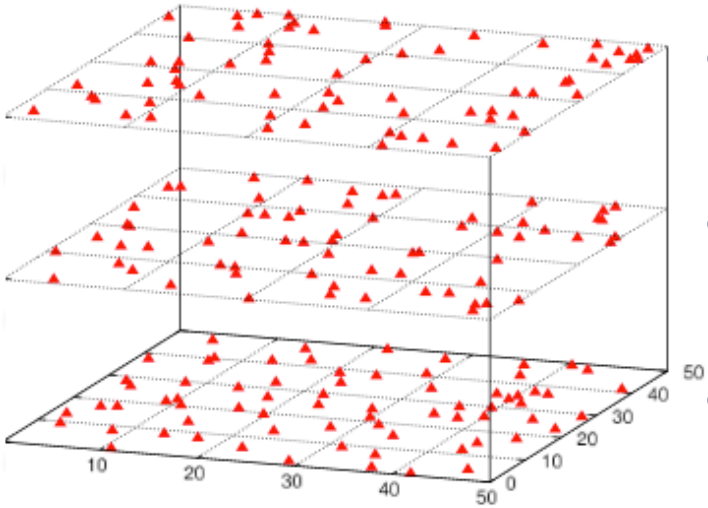




Using application criteria

- **Sleep depth: Partitioning the network into disjoint subsets**
  - One subset = One sleep depth = One LPL configuration
  - The lower the layer, the deeper the sleep
  - Nodes of layer *n* can communicate with nodes of any layer *i* while *i* < *n*
  - Density control: If *x* neighbors on layer *i*, then layer *i*-- (timeout)





Config LPL 1 (Tmin)

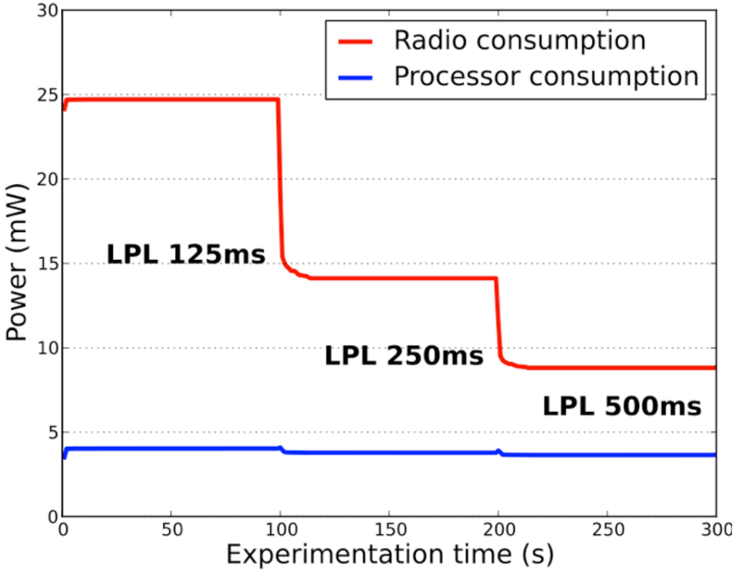
Config LPL 2

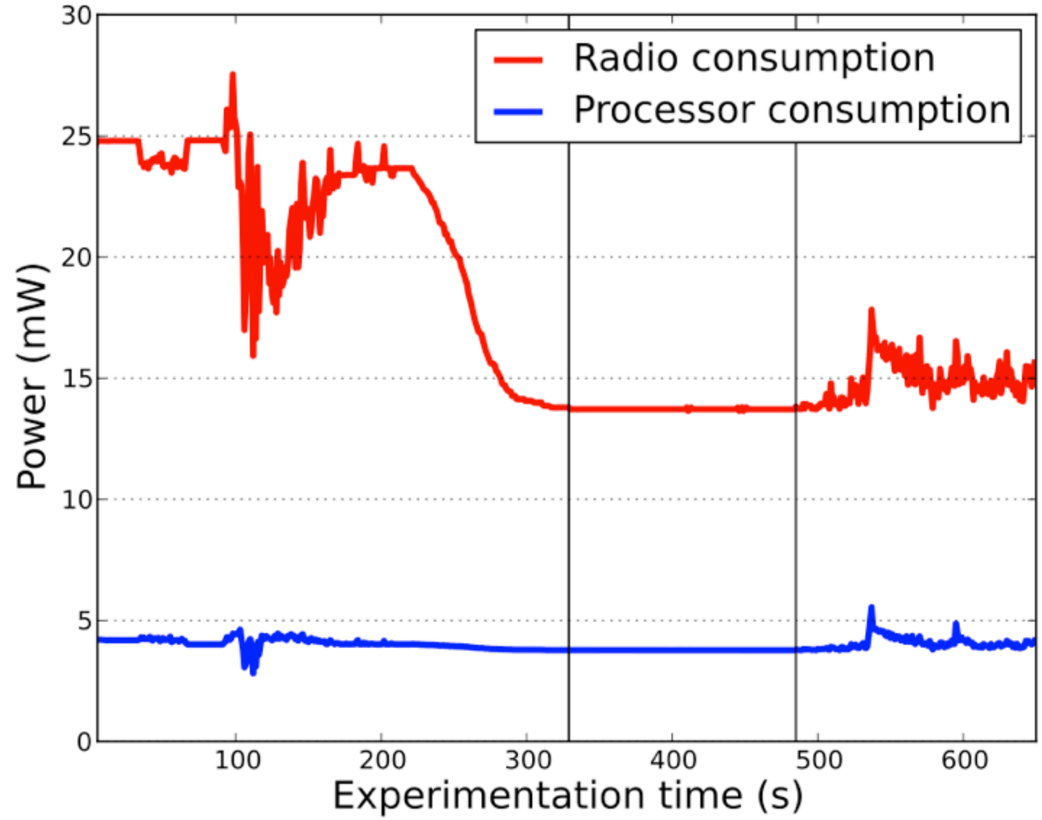
Config LPL 3 (Tmax)

Multiple Coverage with Controlled Connectivity in Wireless Sensor Networks. J. Beaudaux, A. Gallais and T. Razafindralambo. In Proc. ACM PE-WASUN'10 - Bodrum, Turquie, October 2010.

Energy consumption

- **Construction layers/gradient structure**
- **Consumption under “idle” and relaying states (traffic induced)**





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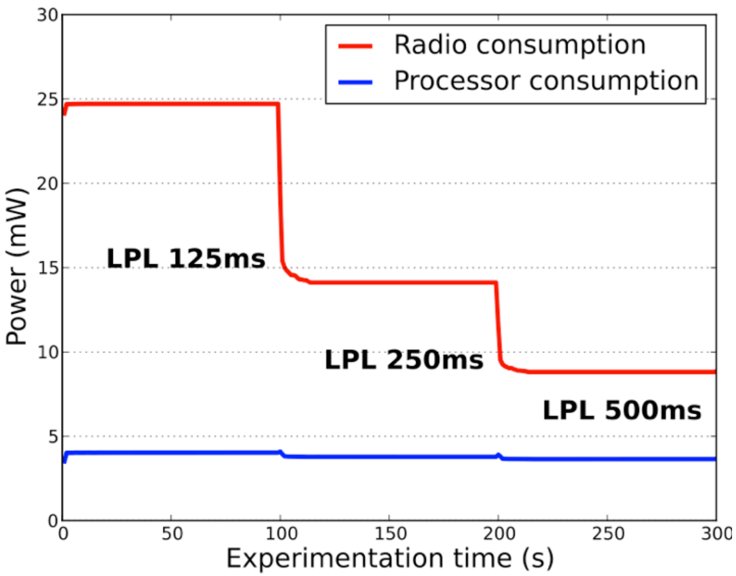

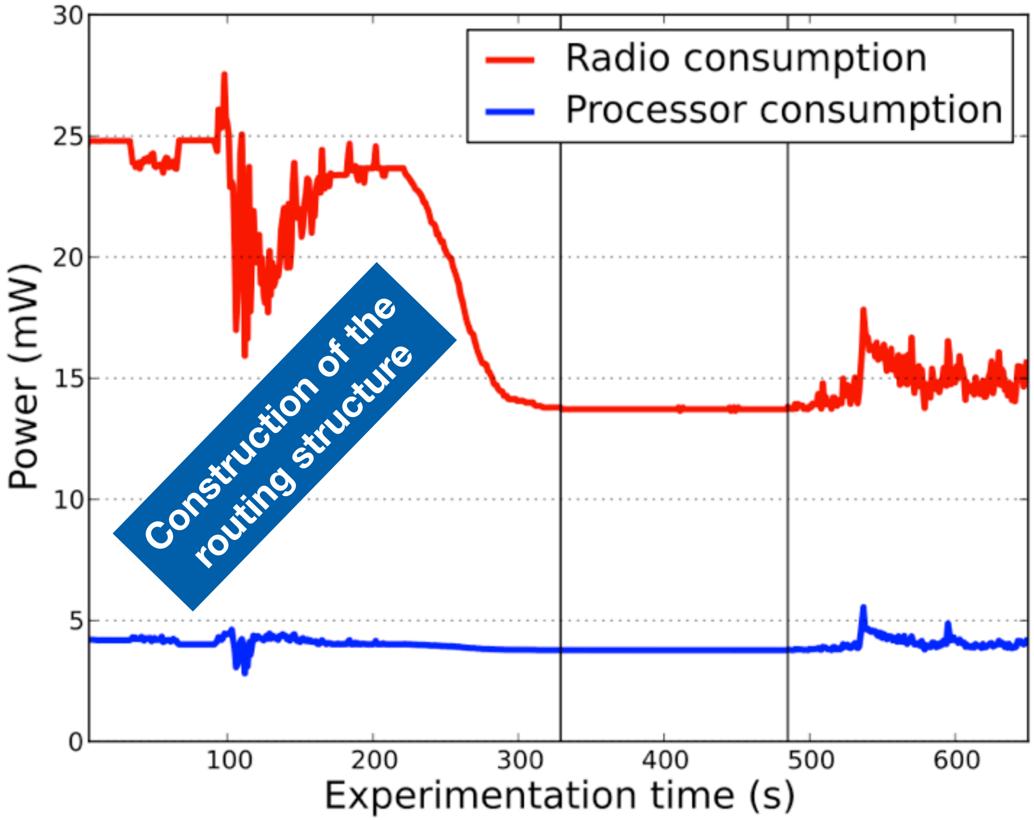

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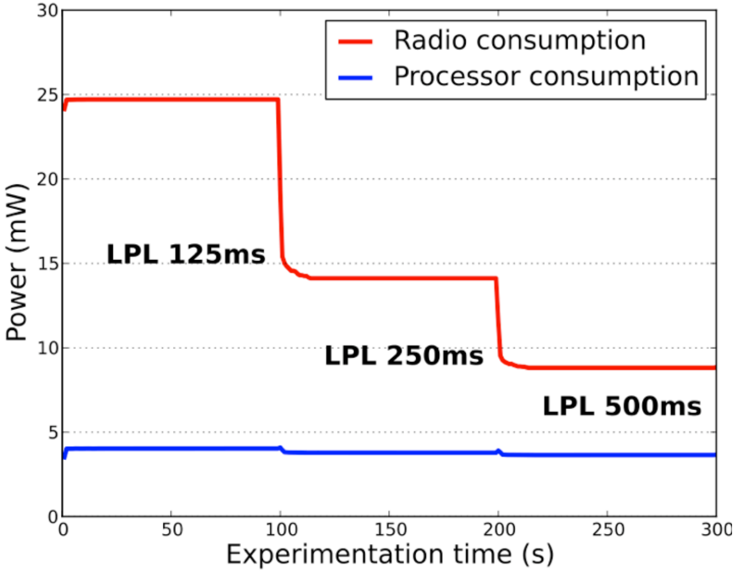

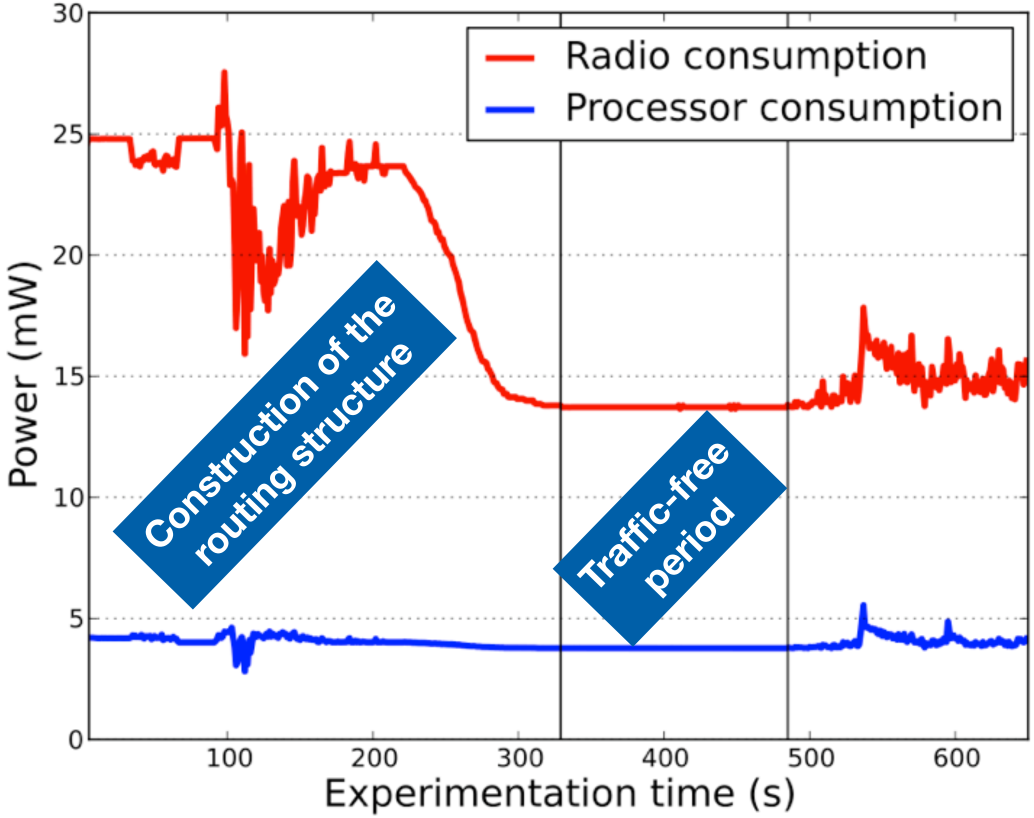

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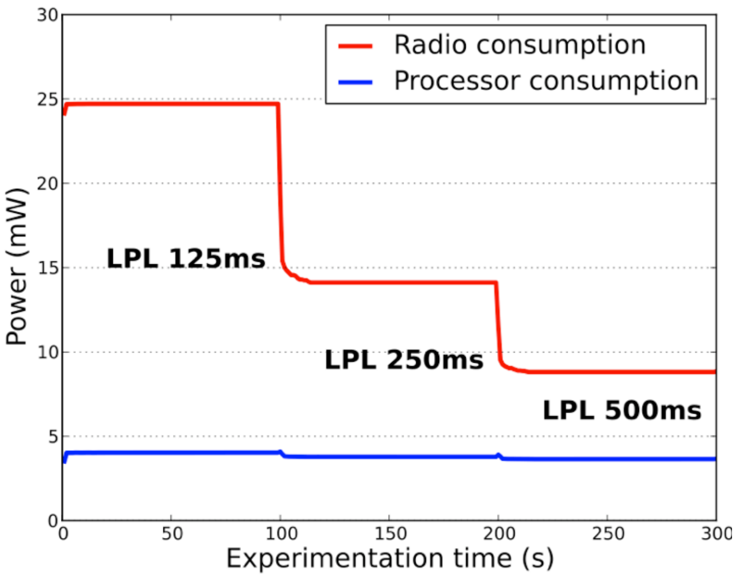

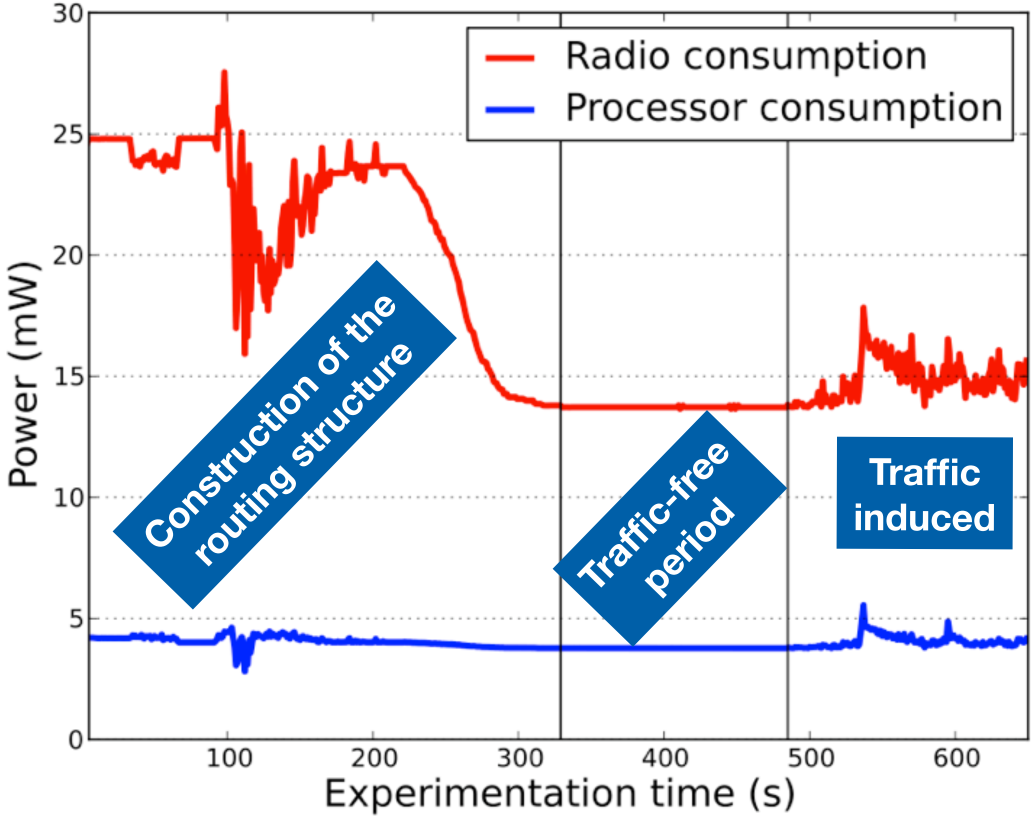

MAC: Adapting LPL configuration

- **Proactive approaches**
  - Using
    - Routing information
    - Application criteria

- **Reactive approaches**
  - Induced traffic

MAC: Adapting LPL configuration

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Reactive approach

- **Default: Nodes fully asleep (long sampling periods and long preambles)**
- **Problem: Cost of the preamble before each TX along the routing path**
- **Idea: split LPL in 2 distinct values**
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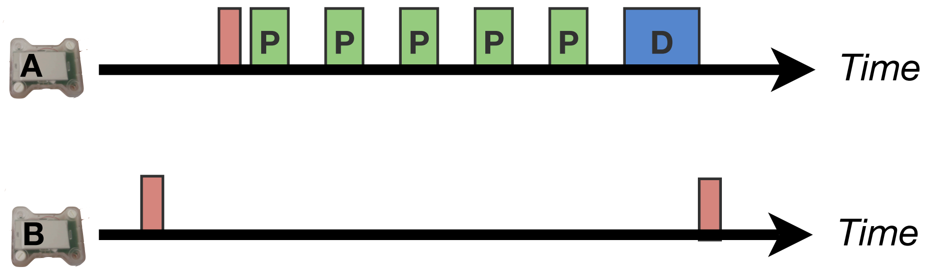
  - Using short preamble along routing path (Tmin): EE links along the way
- **Constraint : Preserving network connectivity by preventing node isolation**



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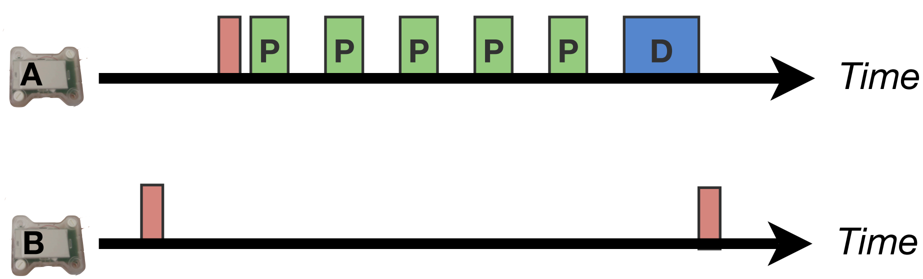

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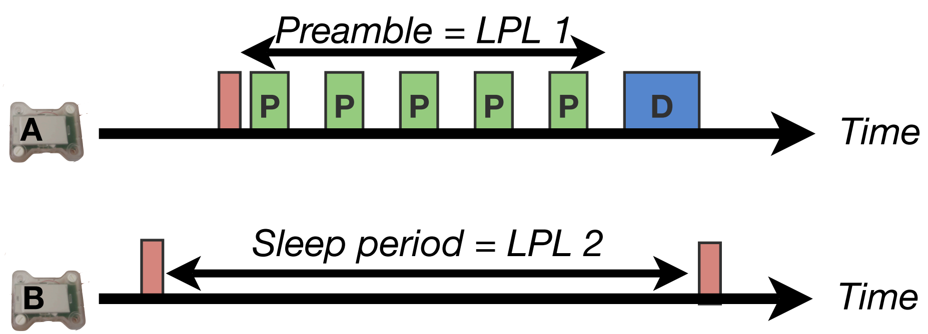
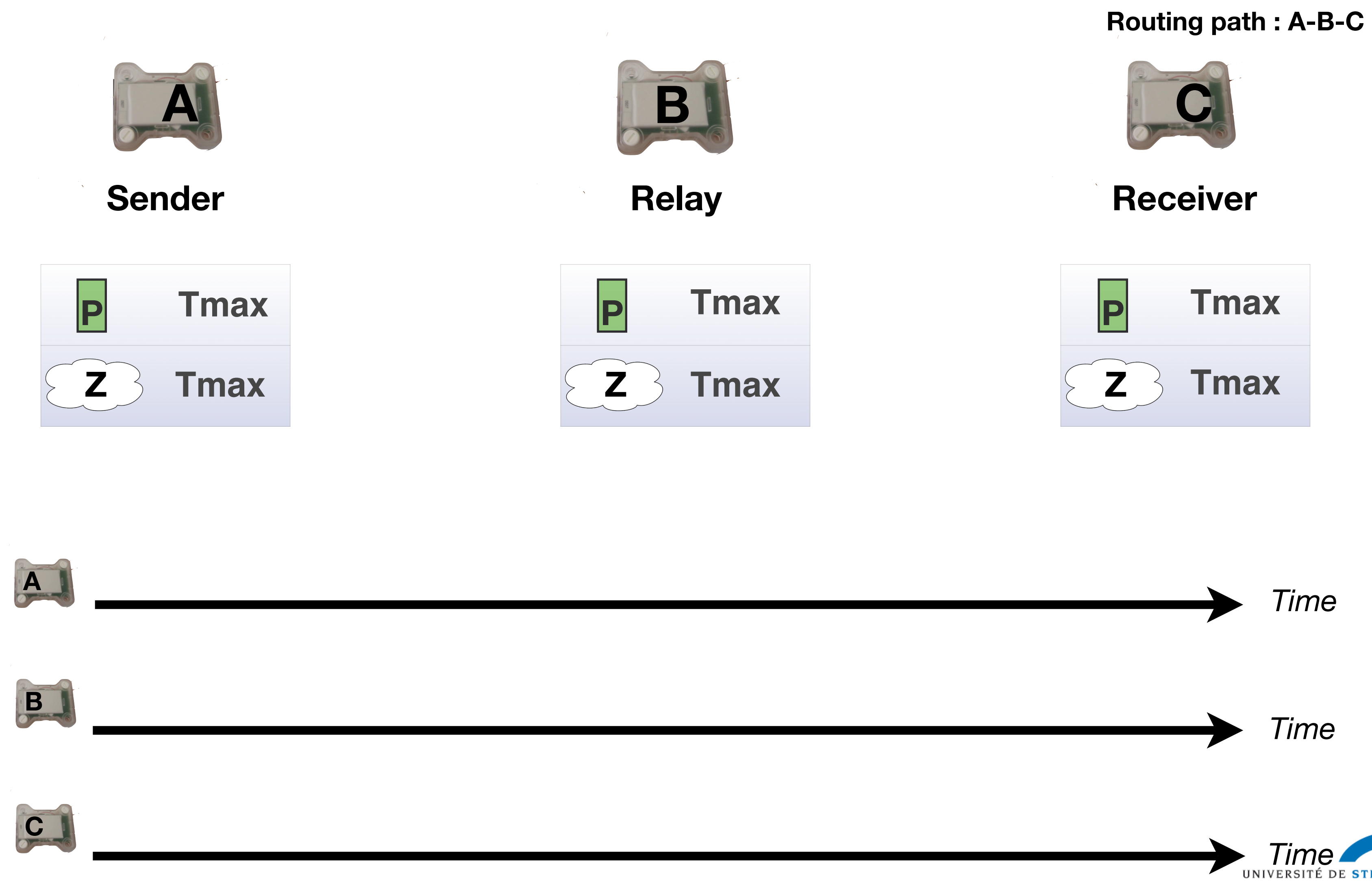


Avoid

LPL 1 < LPL 2

Reactive approach

BOX-MAC: Burst-Oriented X-MAC enhancement



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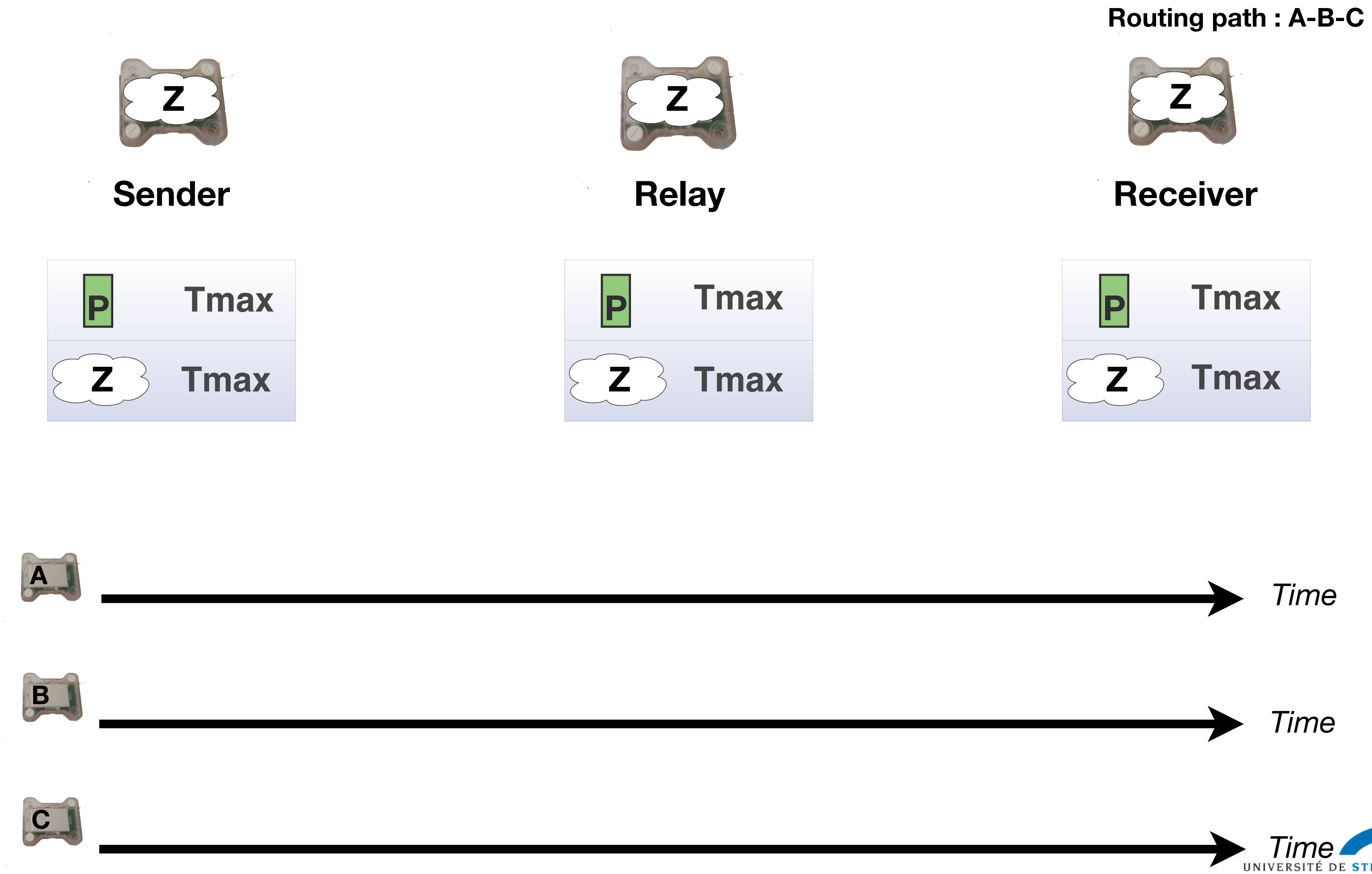

Reactive approach
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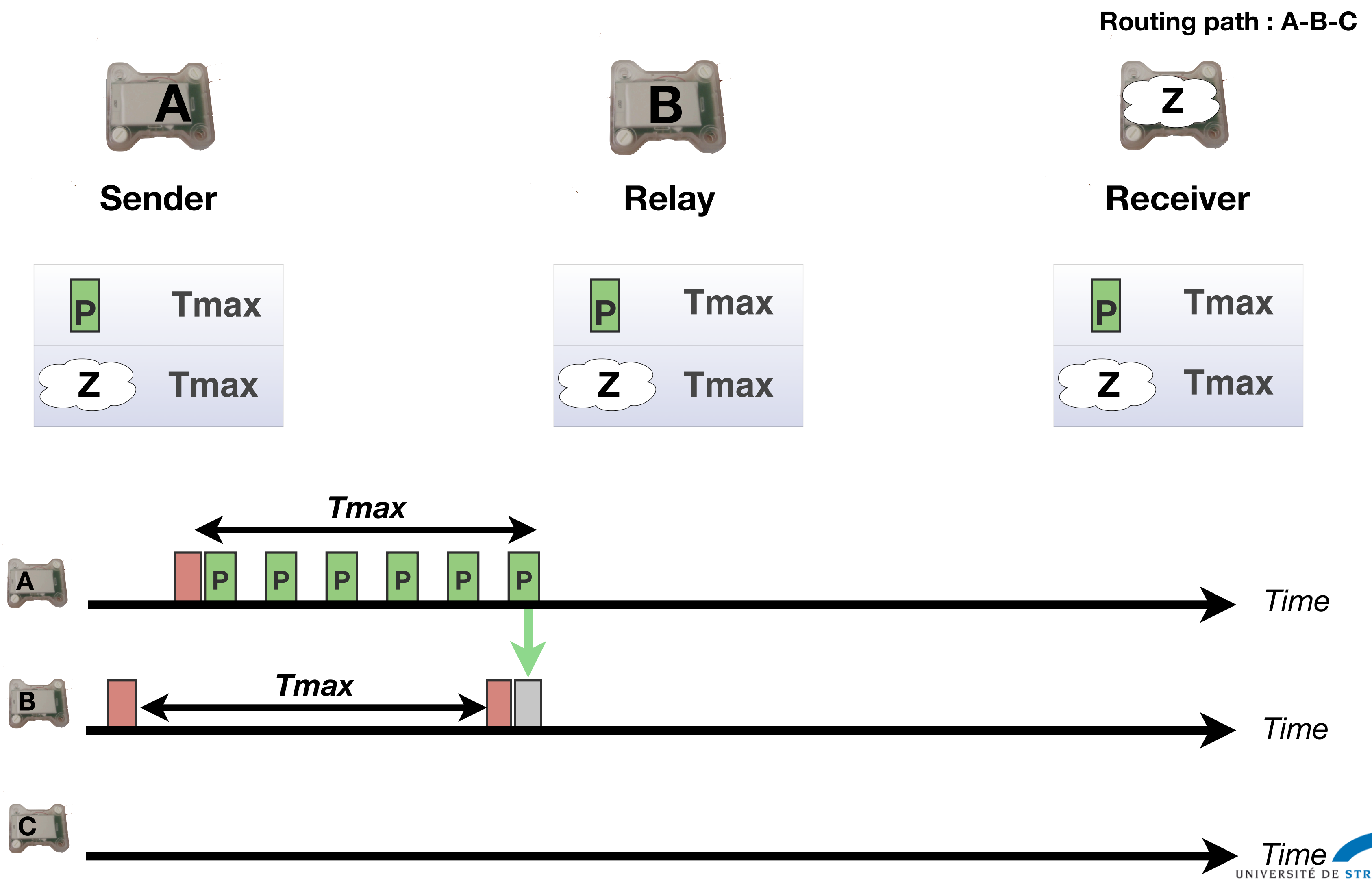
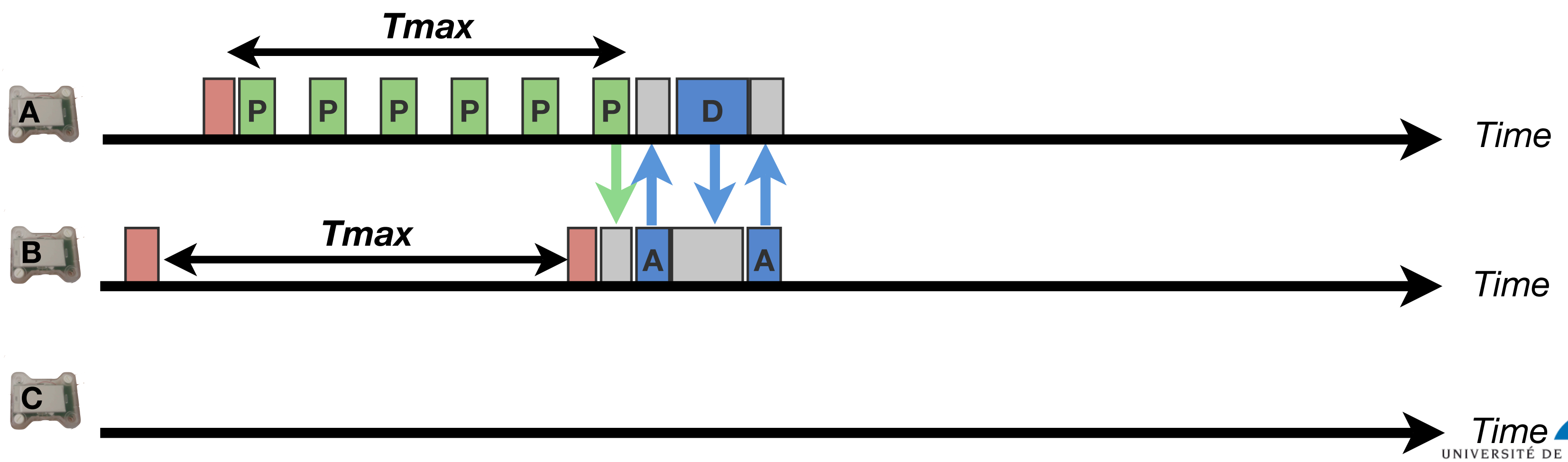


Reactive approach

BOX-MAC: Burst-Oriented X-MAC enhancement

Routing path : A-B-C



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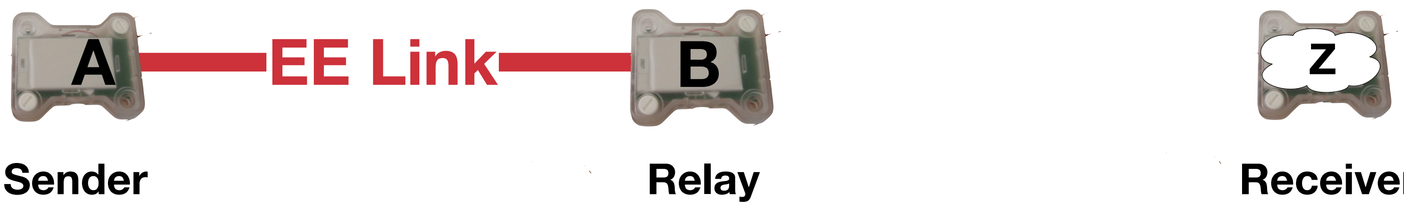
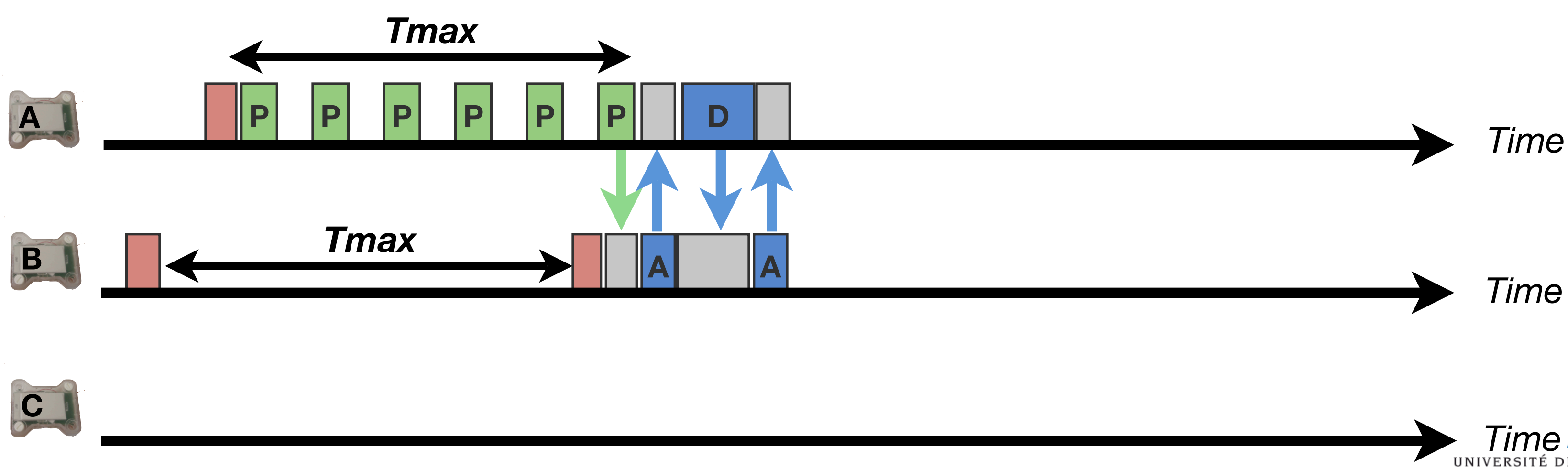


Sender	
P	Tmin
Z	Tmax

Relay	
P	Tmax
Z	Tmin

Receiver	
P	Tmax
Z	Tmax



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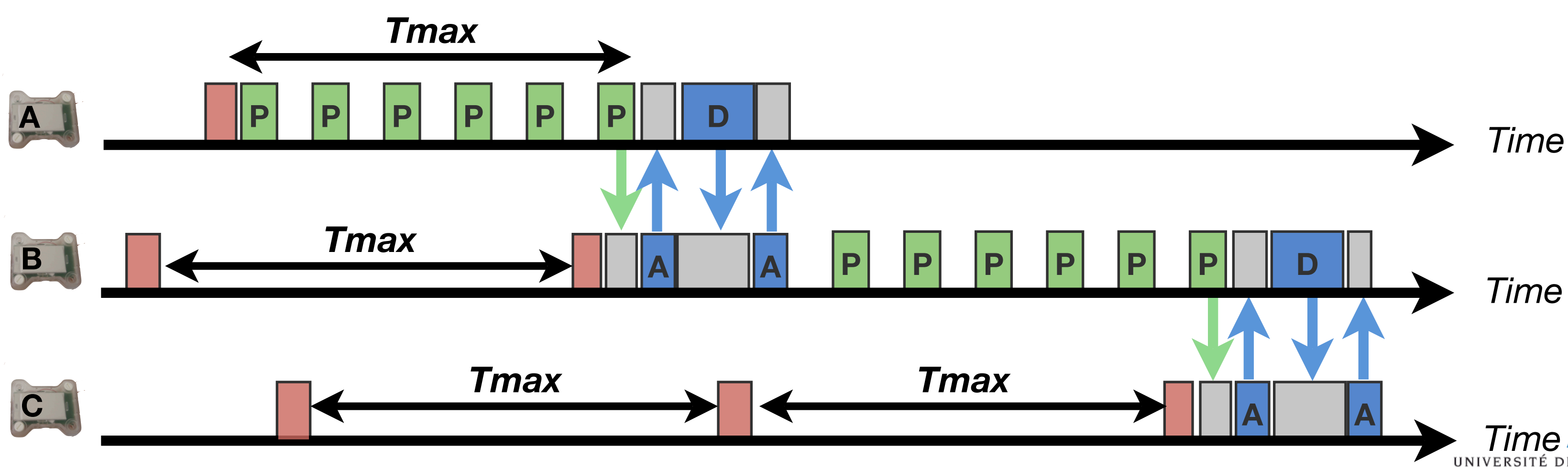
Routing path : A-B-C

	Sender	Relay	Receiver
P	Tmin	Tmin	Tmax
Z	Tmax	Tmin	Tmin



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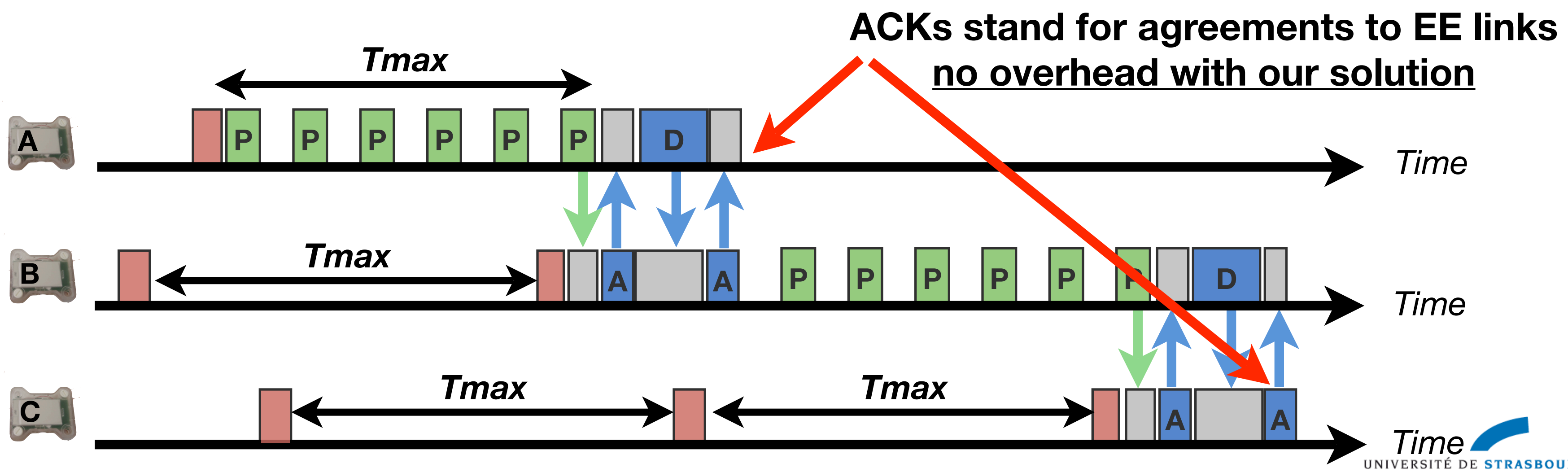

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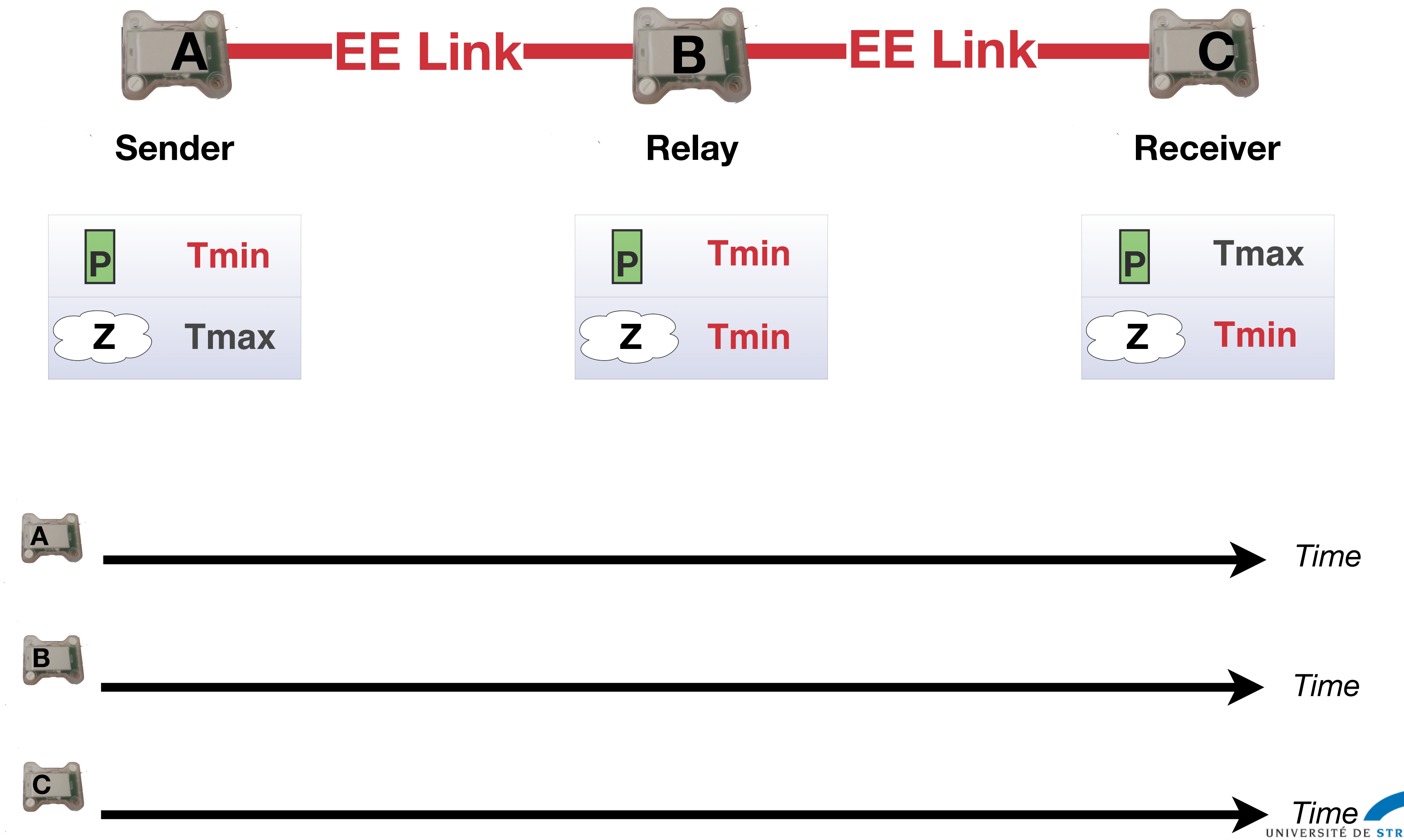

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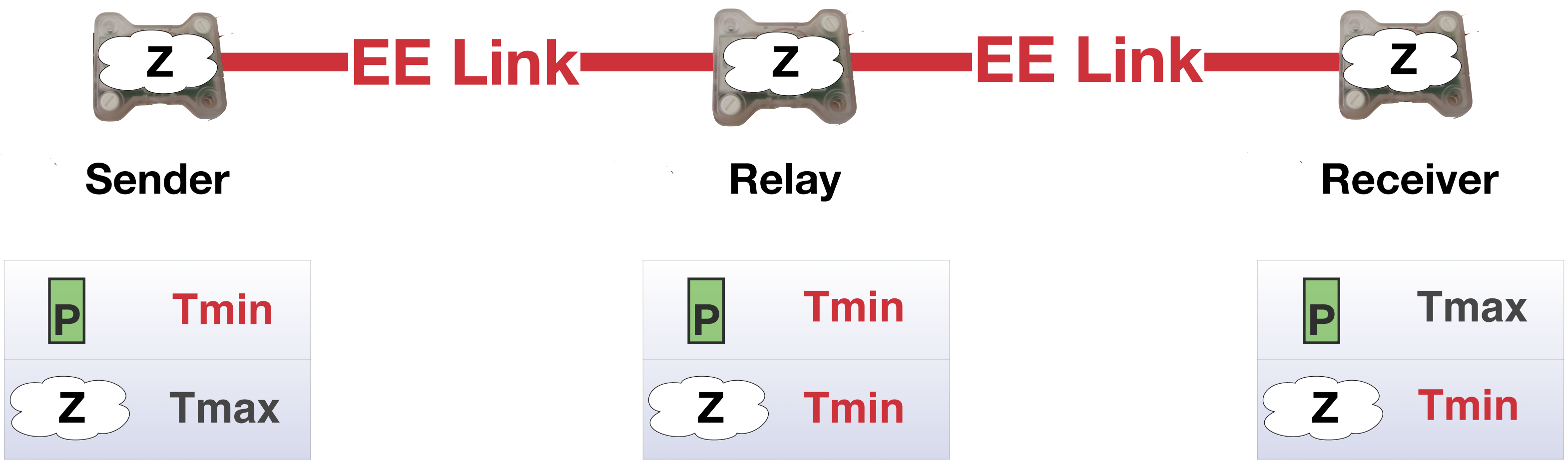

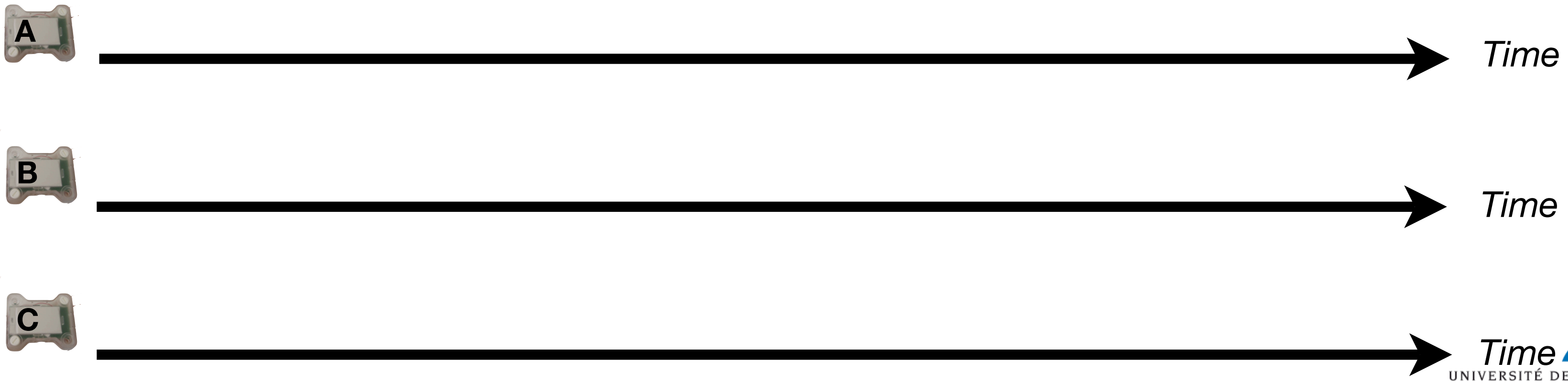

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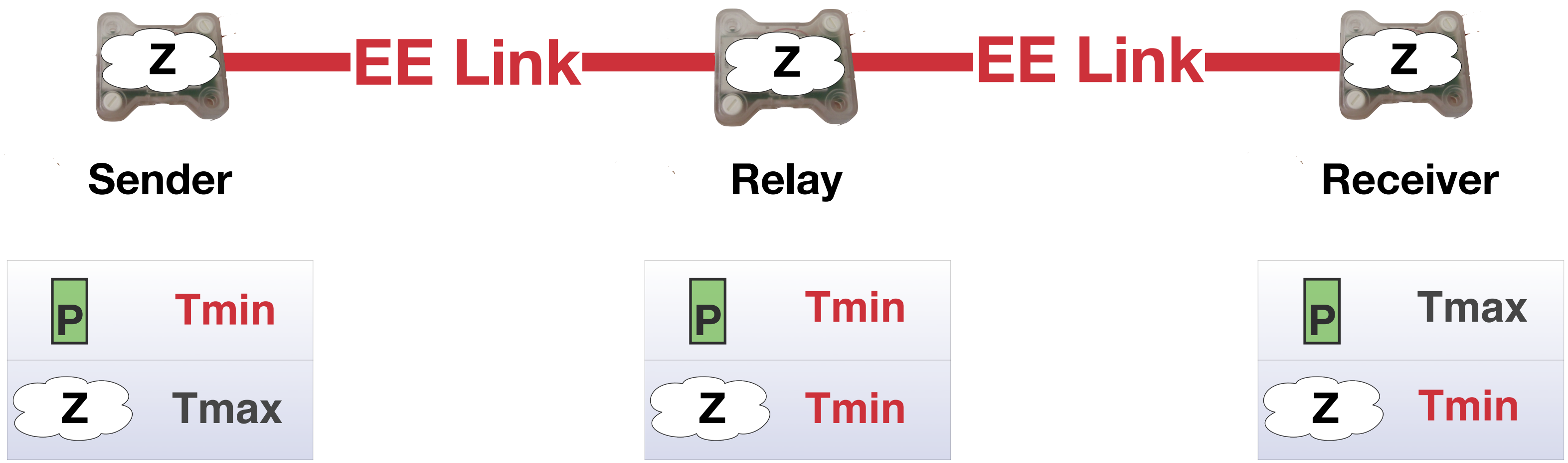

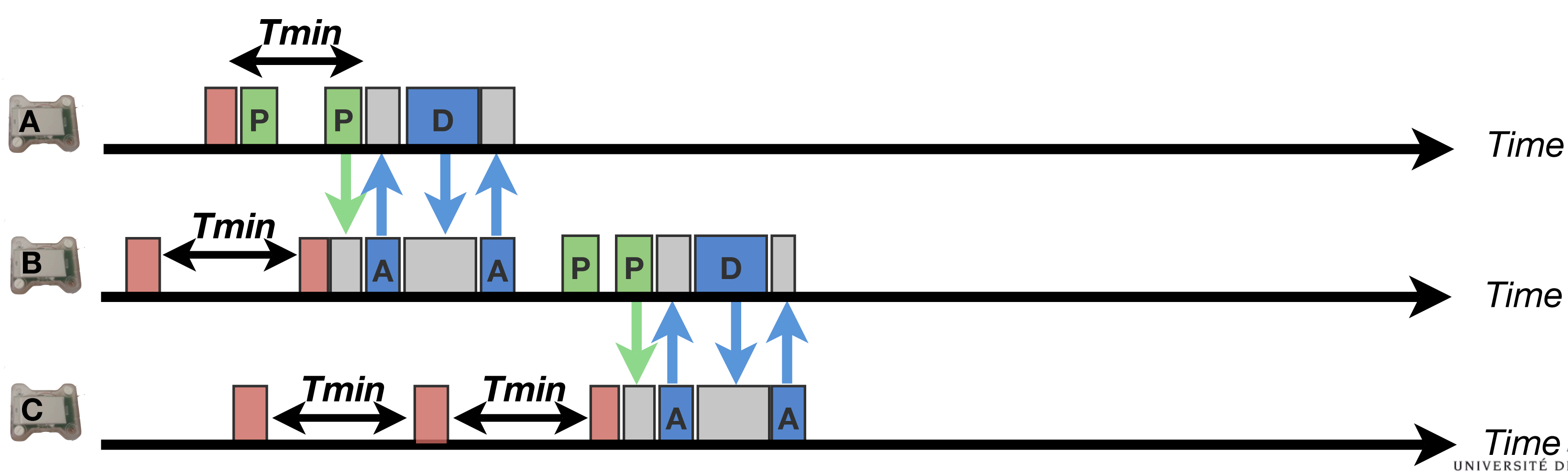

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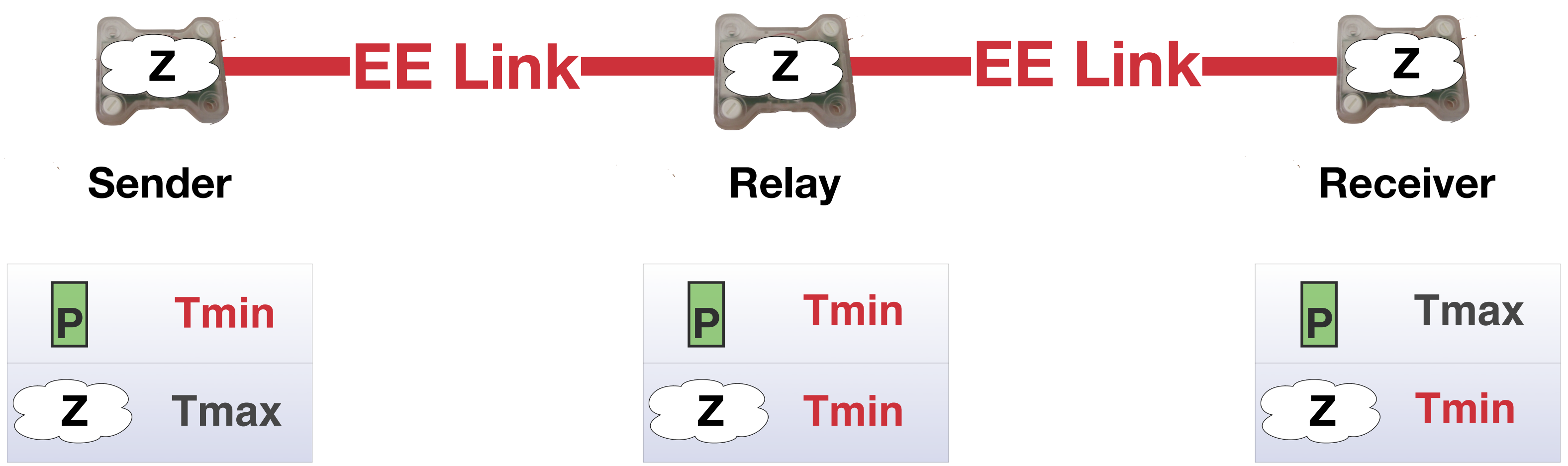

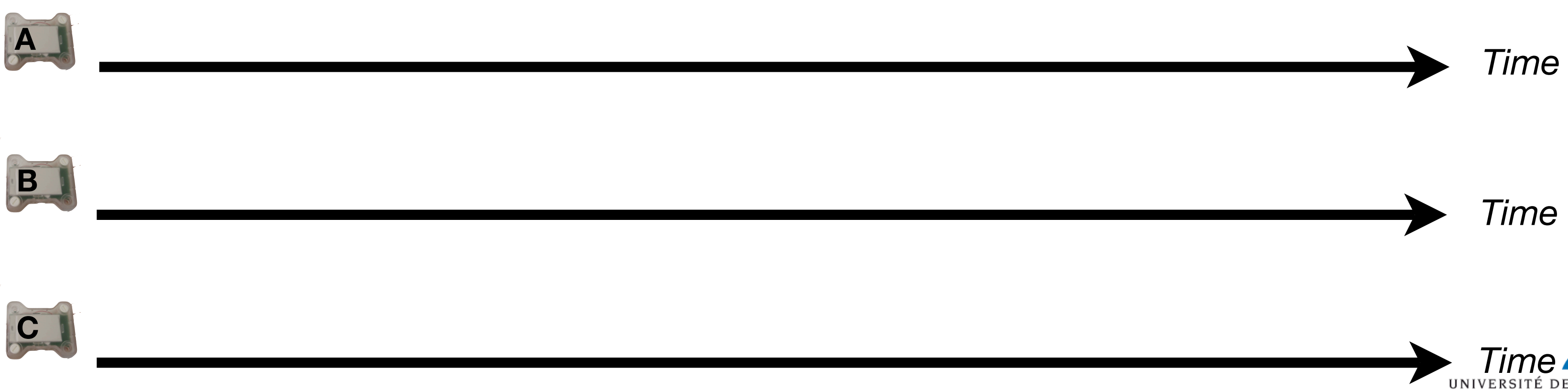

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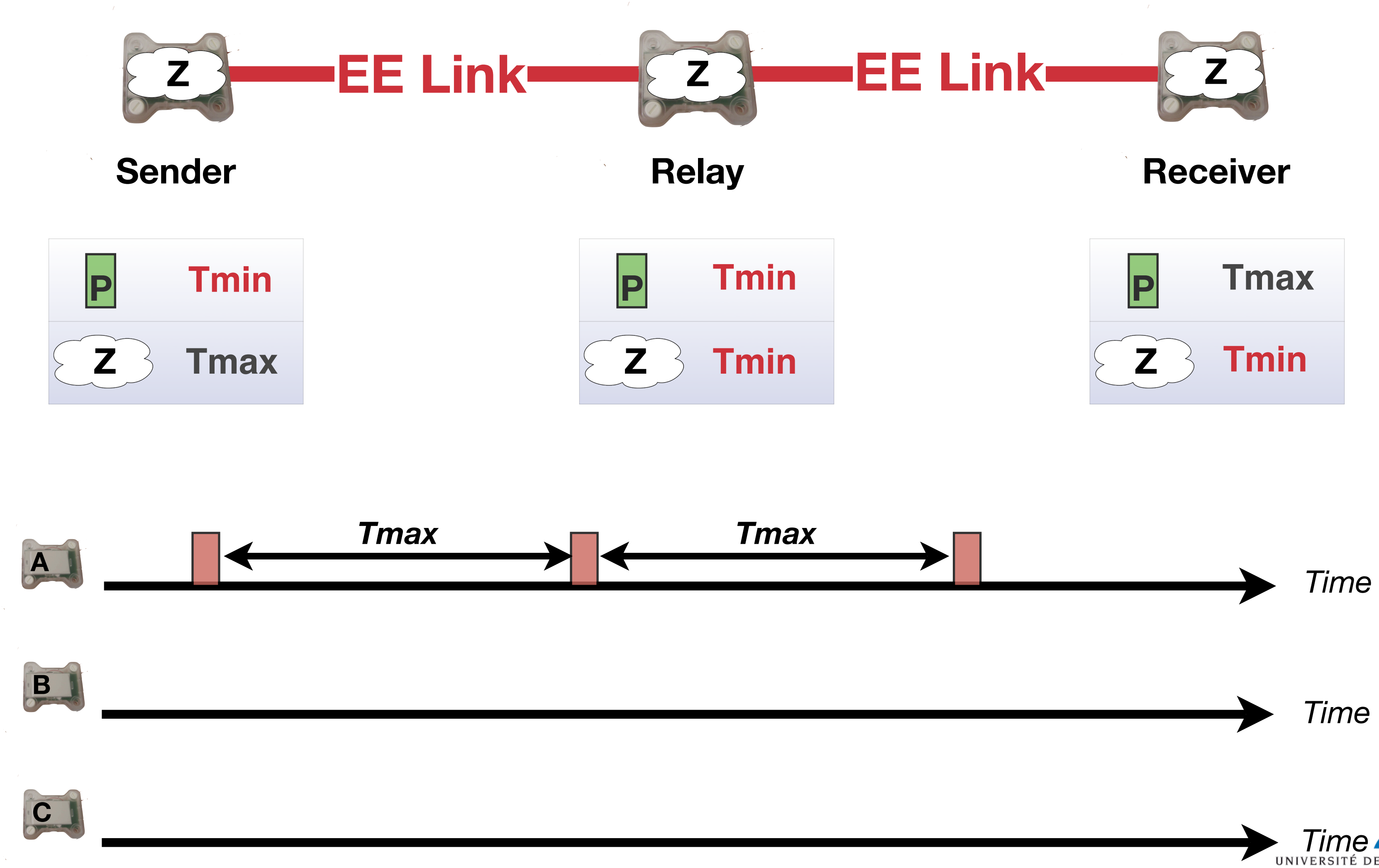

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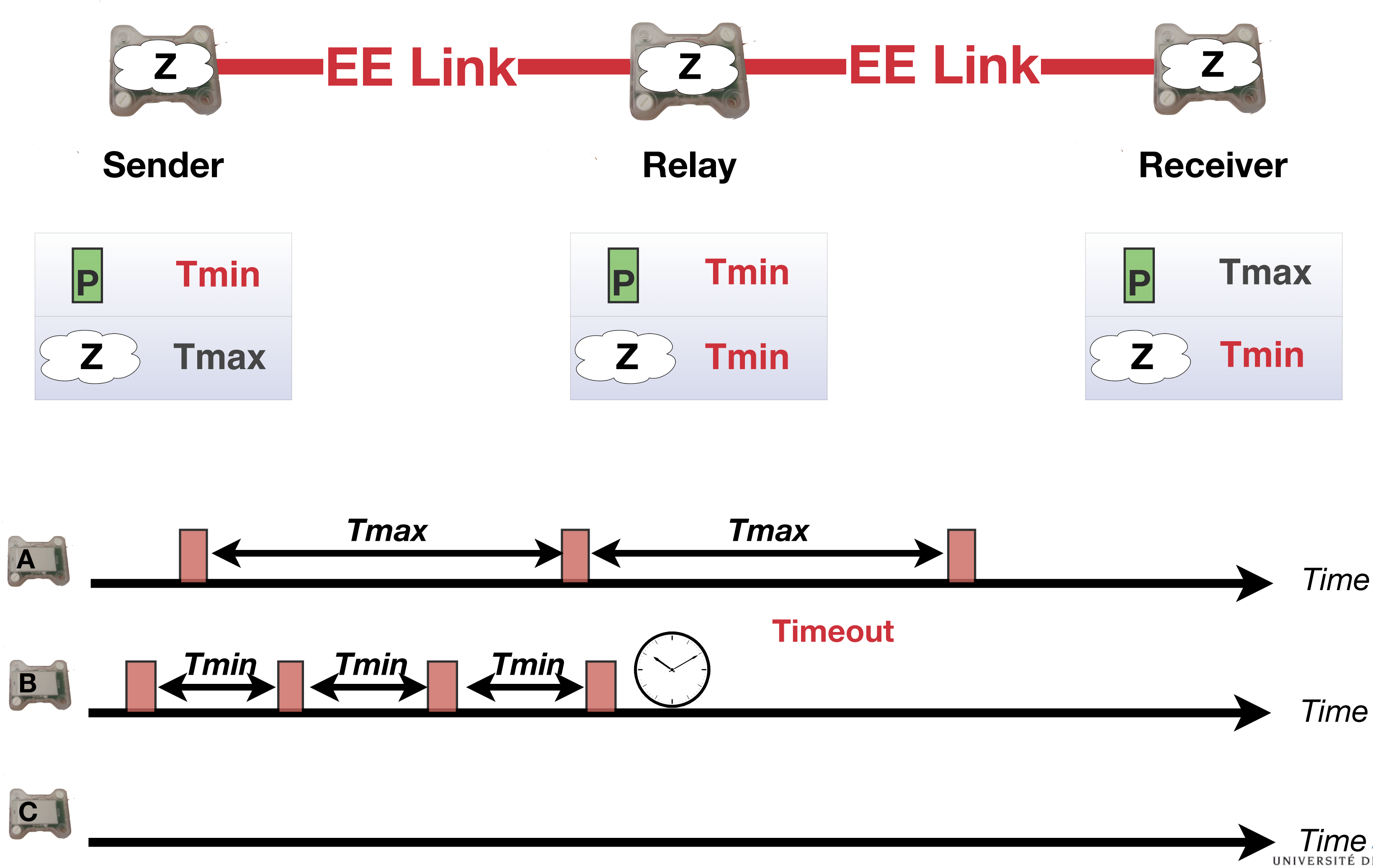

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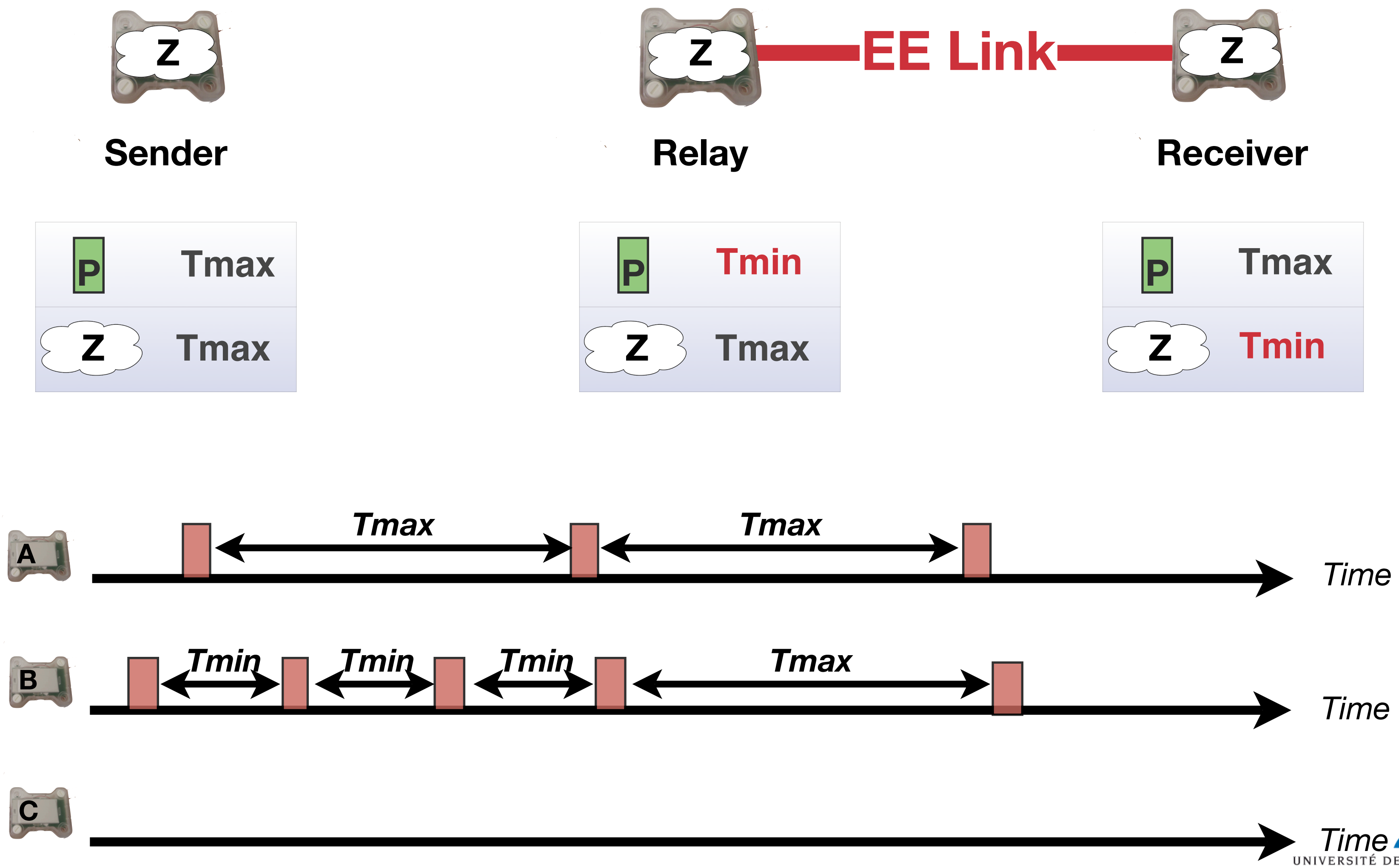

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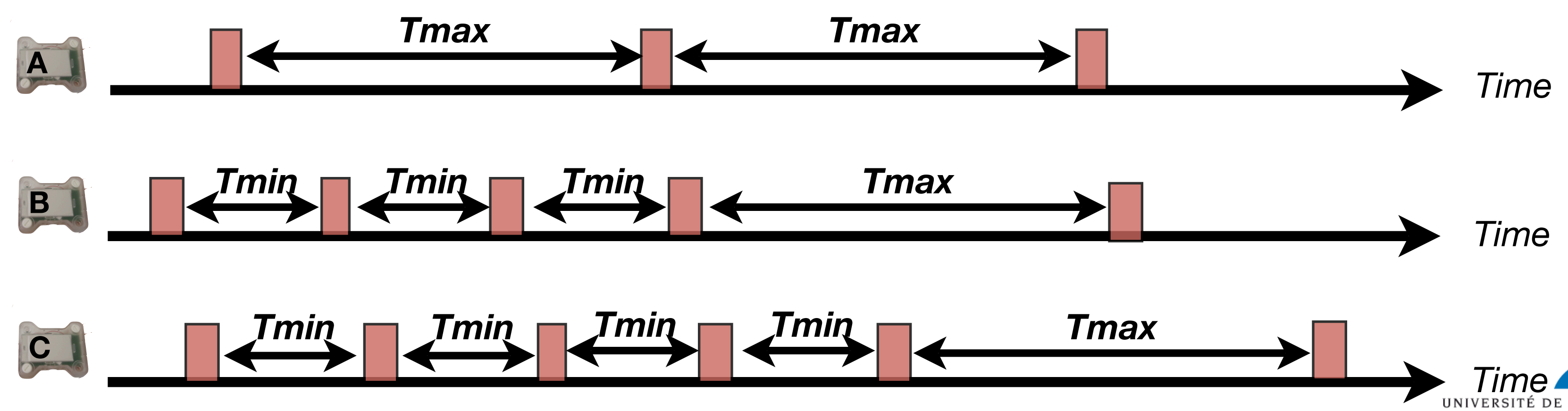
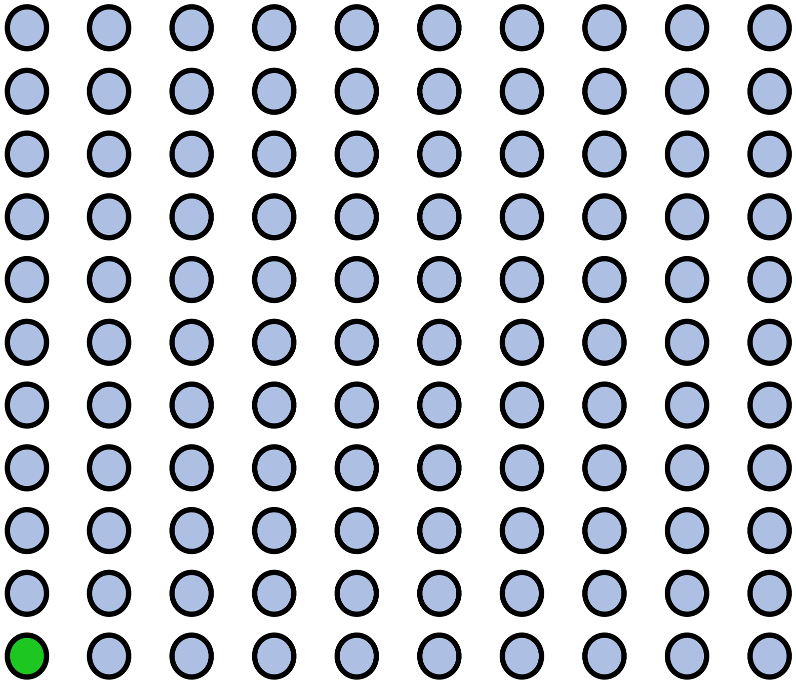


Reactive approach
Performance Evaluation

- Grid topology consisting of **100 sensors**
- Simulations performed with **WSNet**



Sink

Parameter	***Value***
MAC	**X-MAC** LPL 100, 250 and 500 ms
	BOX-MAC Tmin = 100 ms, Tmax = 500 ms Timeout = 10 s.
Data	**Event / time-driven** (1 s. during 10 s.)
Routing	**Random geographic**
Radio model	Friis, throughput 15 ko/s
Energy model	**CC1100** (TX, RX, idle, init)

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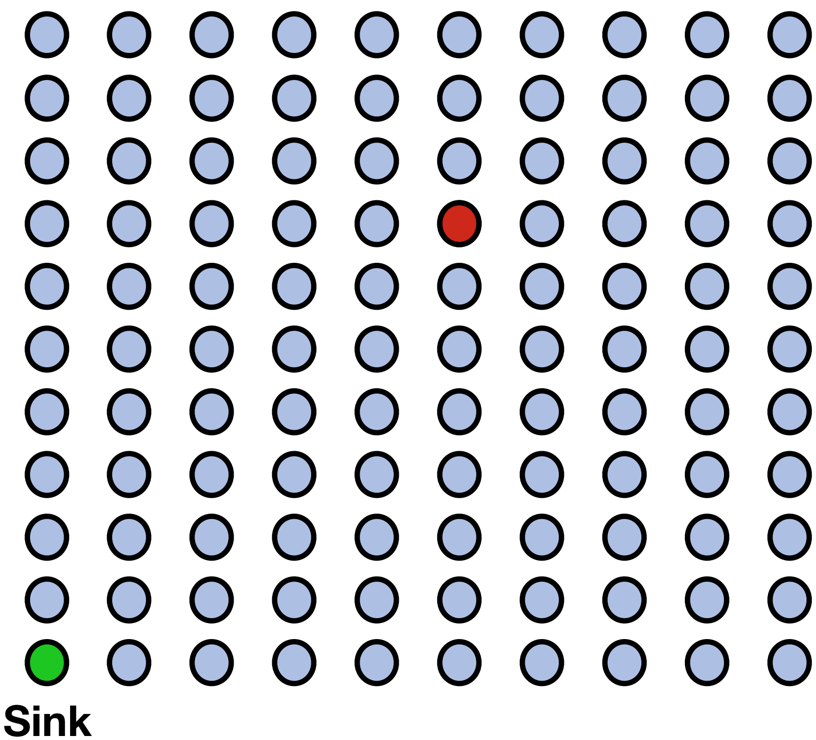

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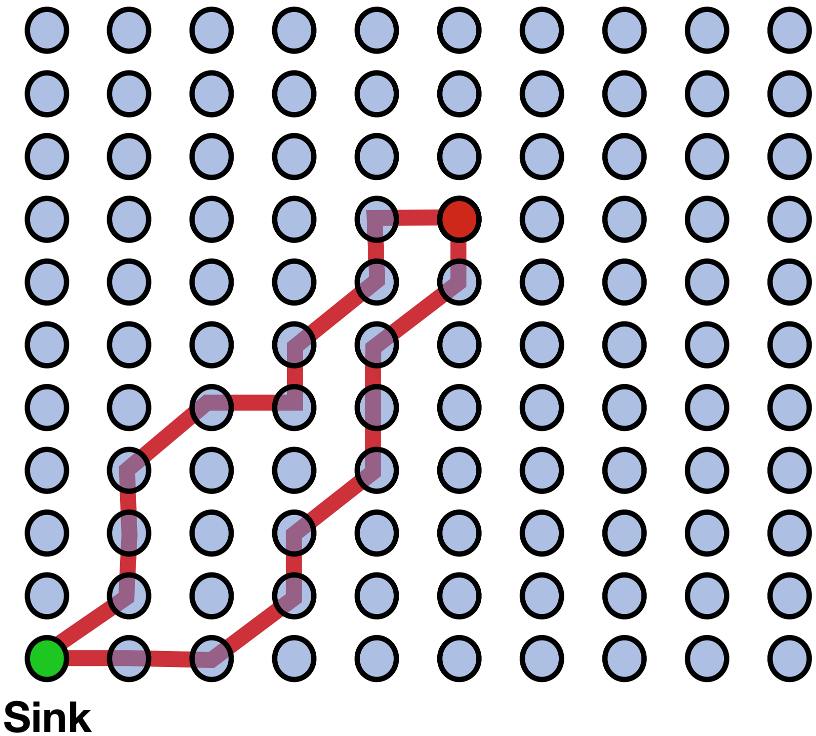

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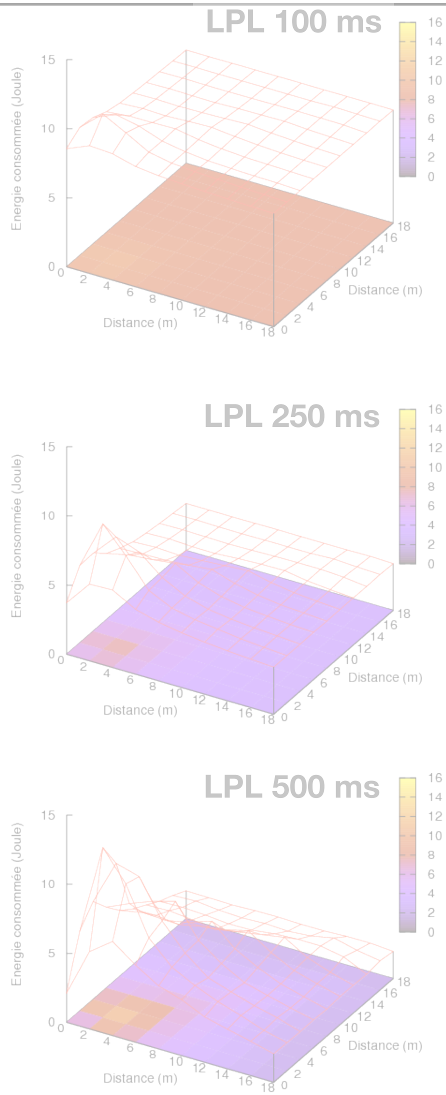
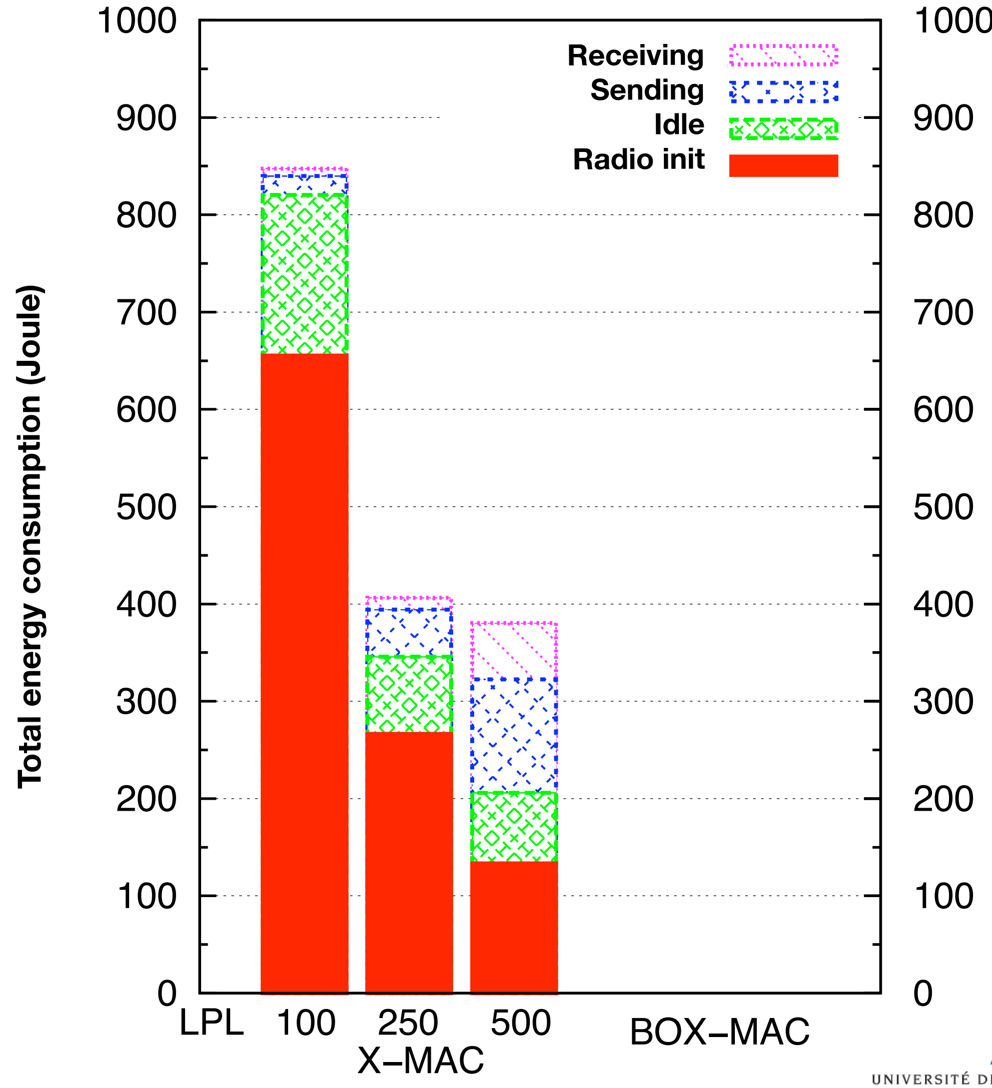
Performance Evaluation: Overall energy consumption





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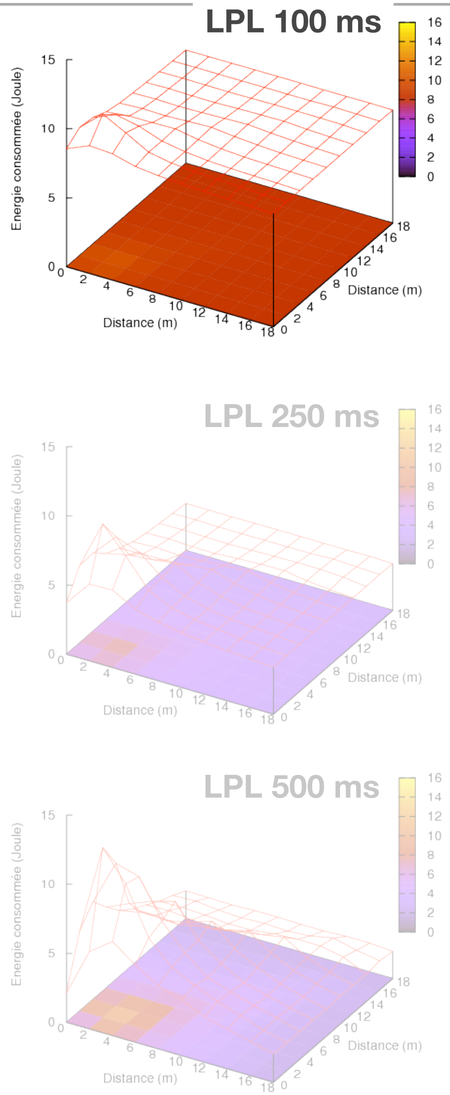

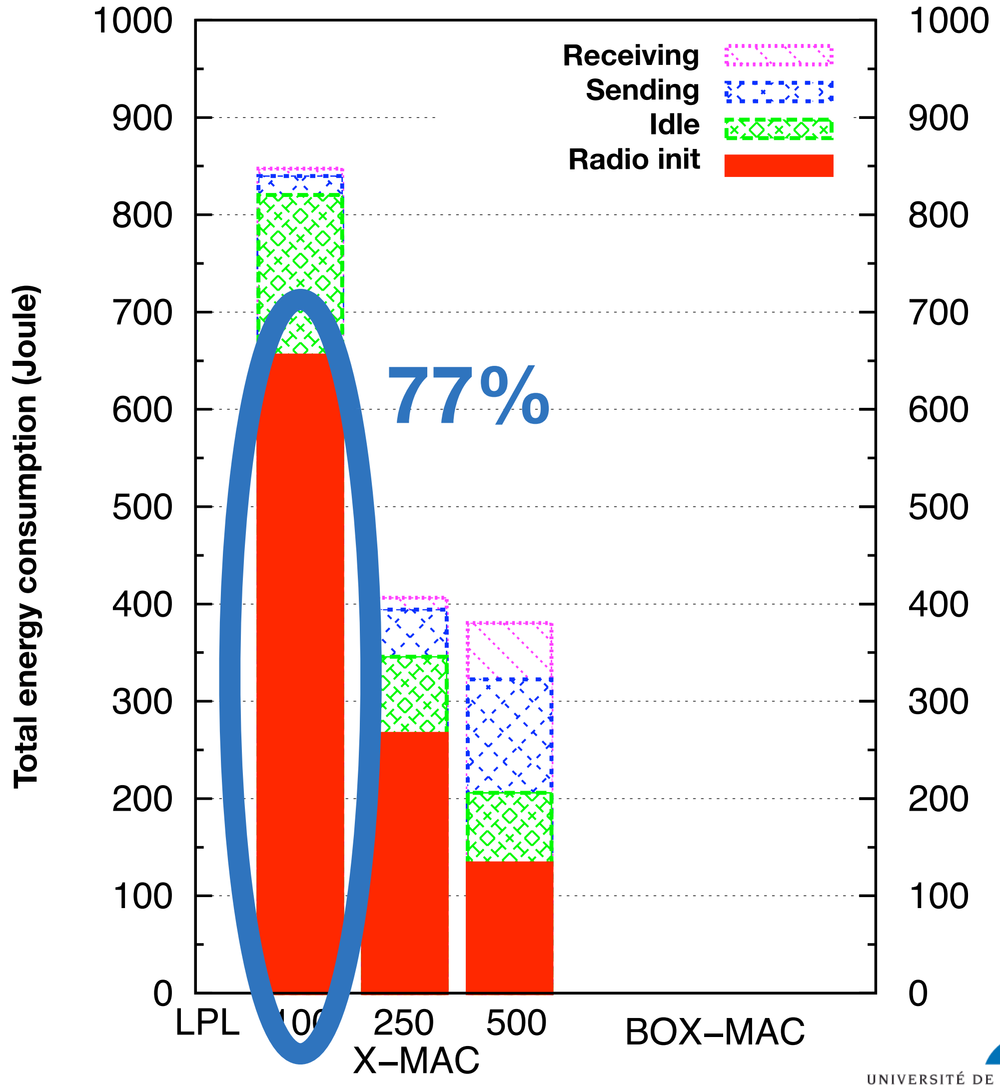

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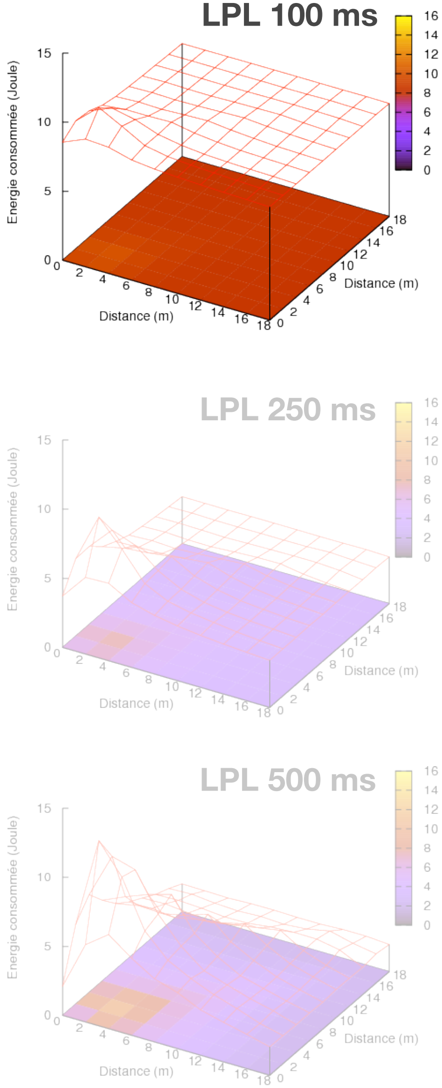

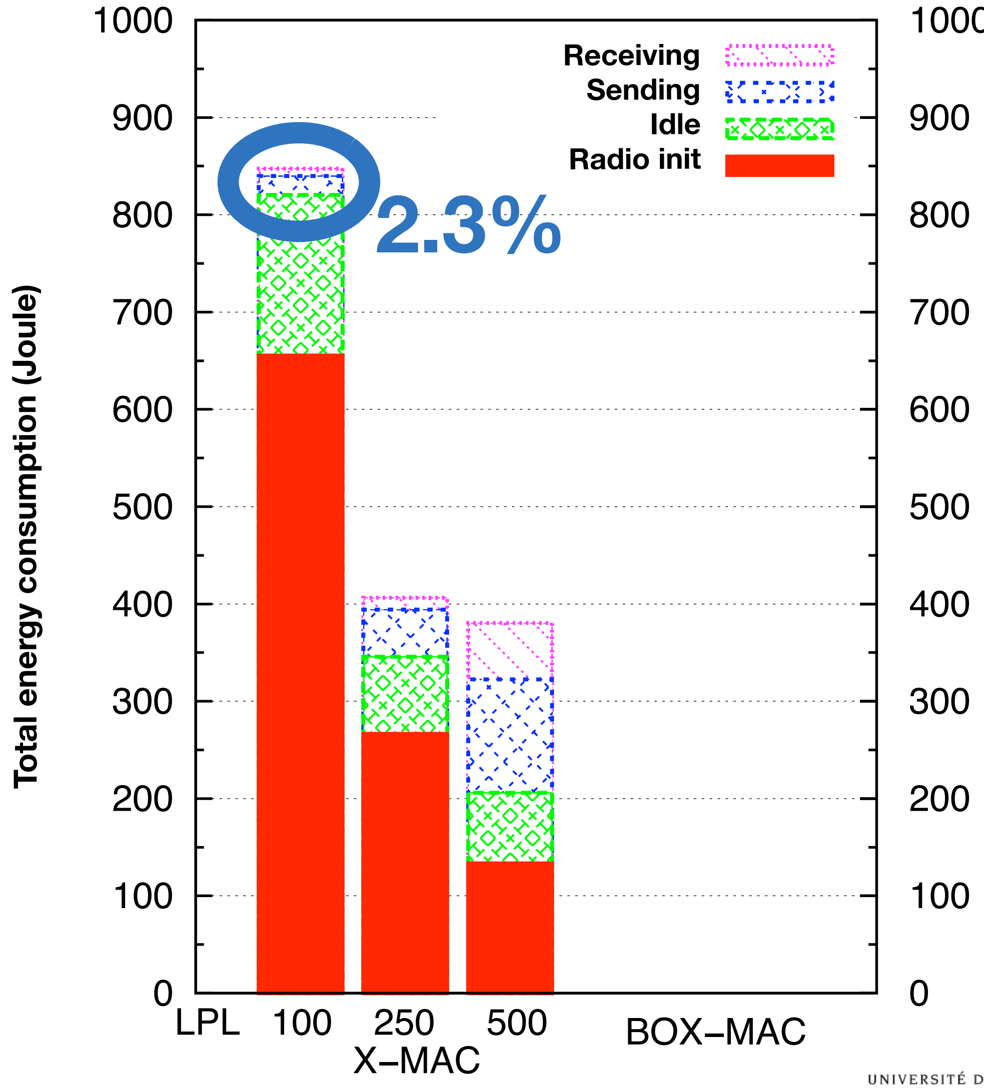

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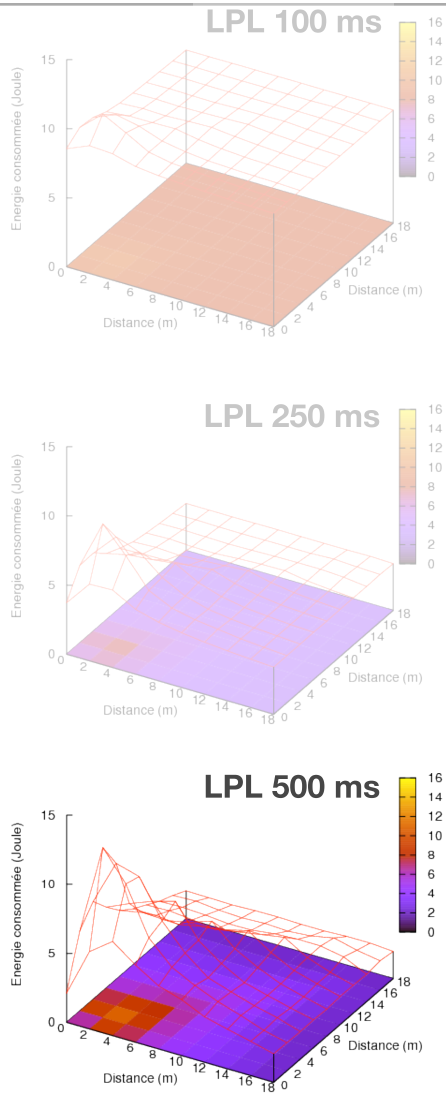

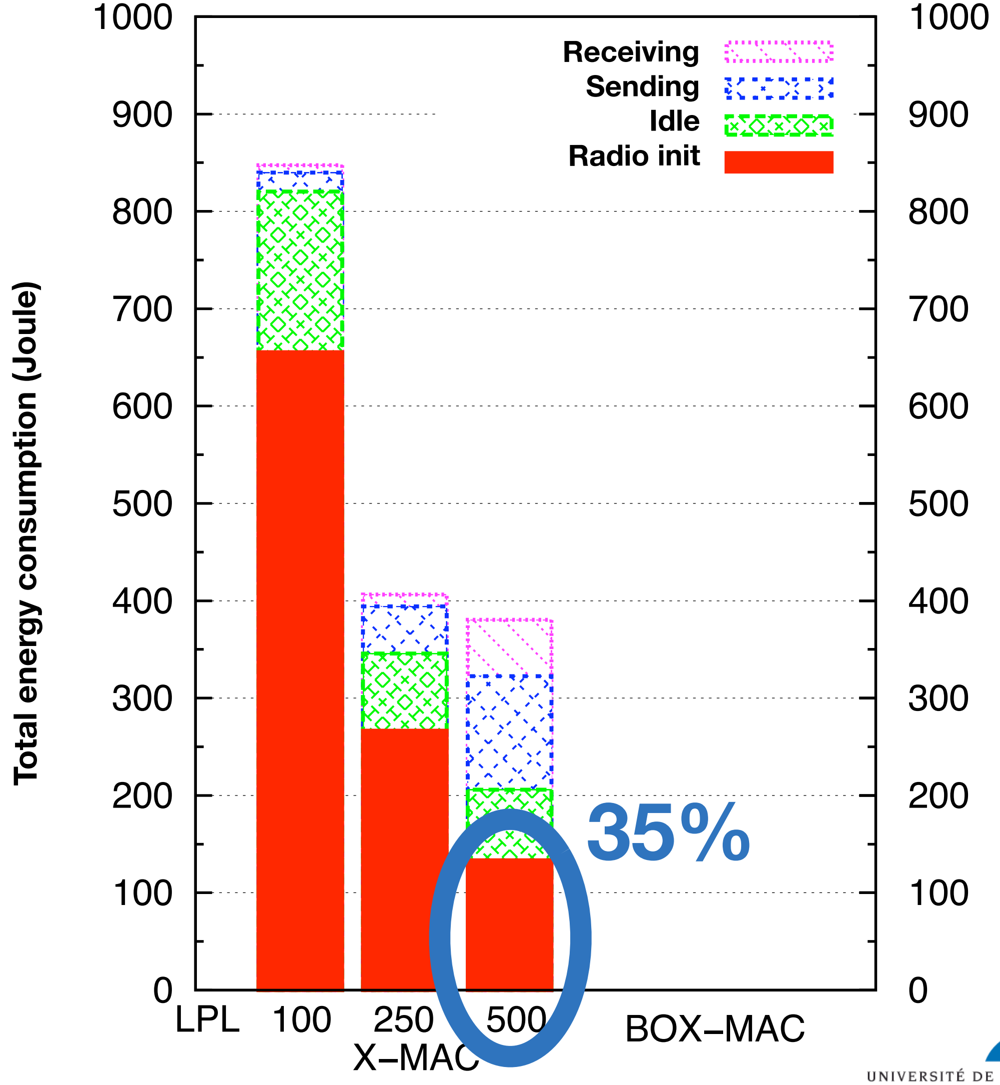

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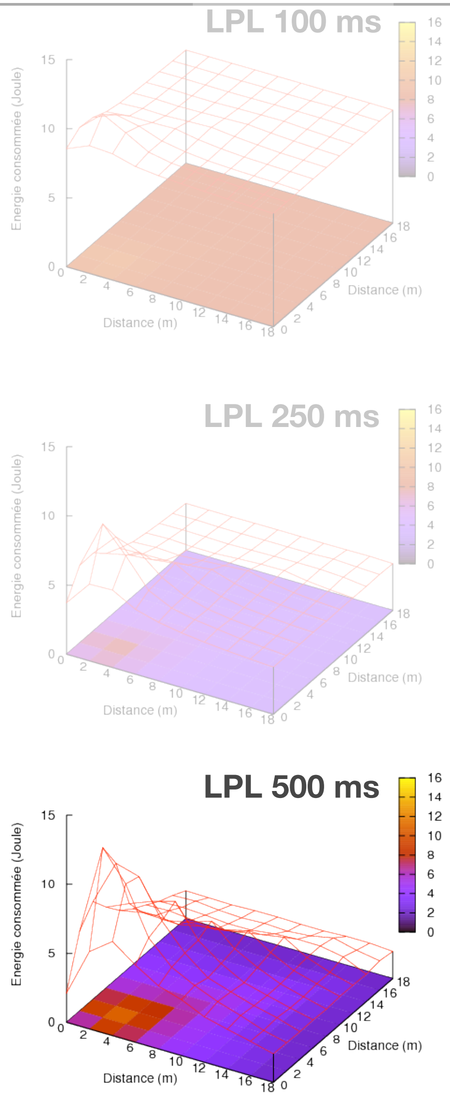

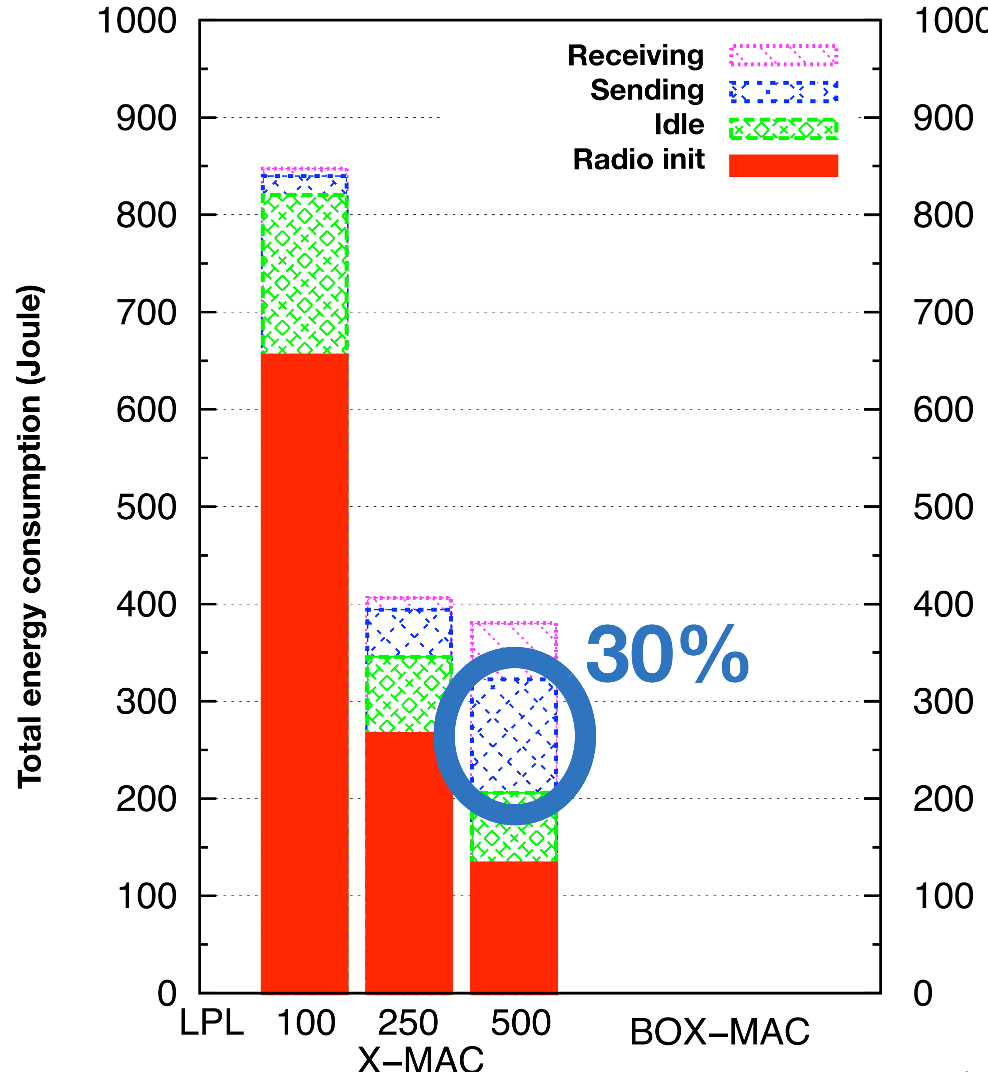

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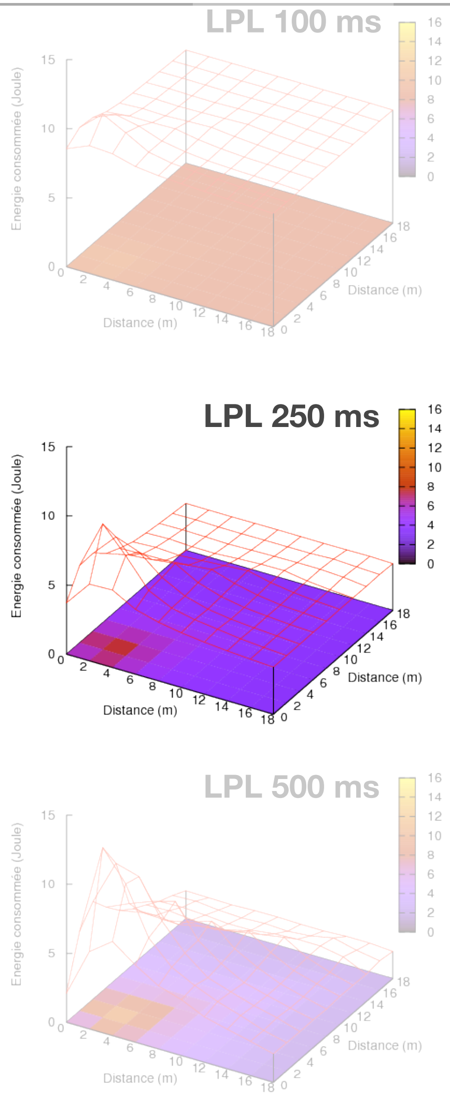
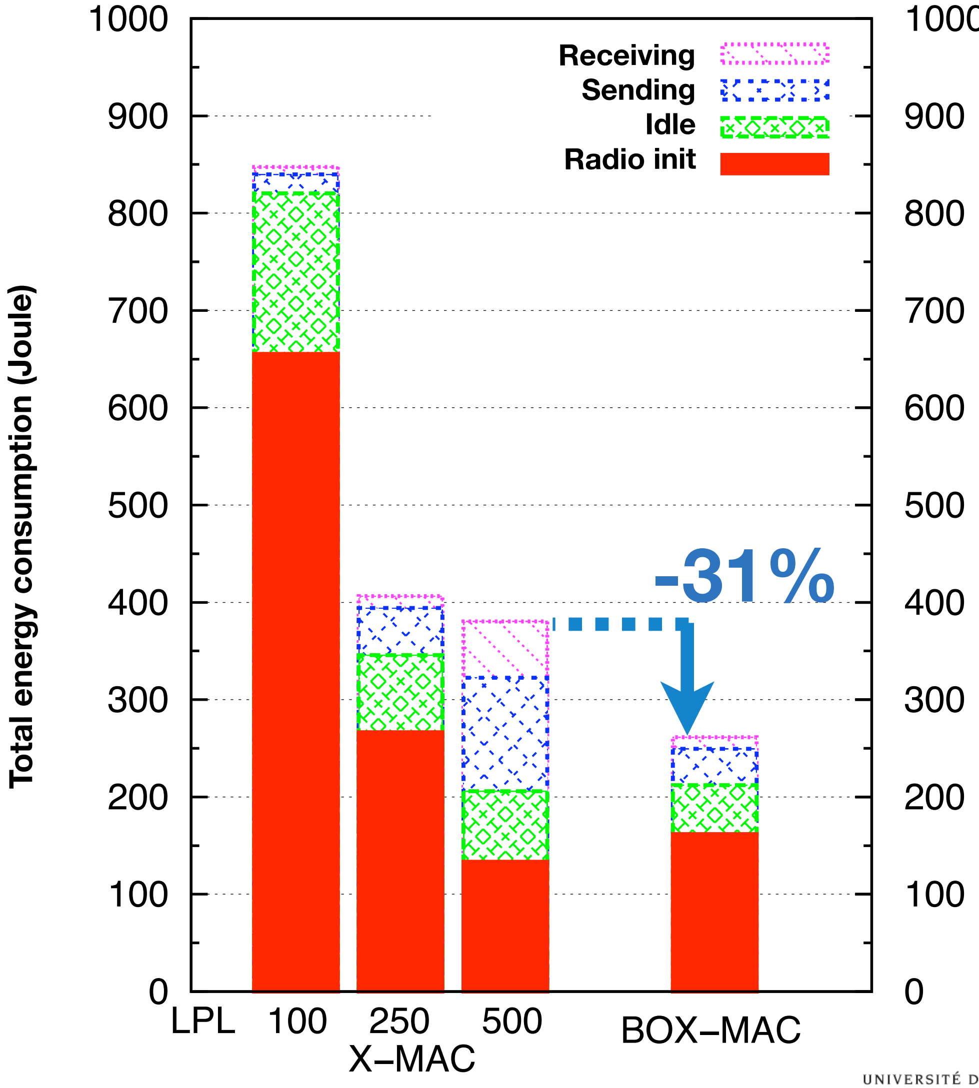
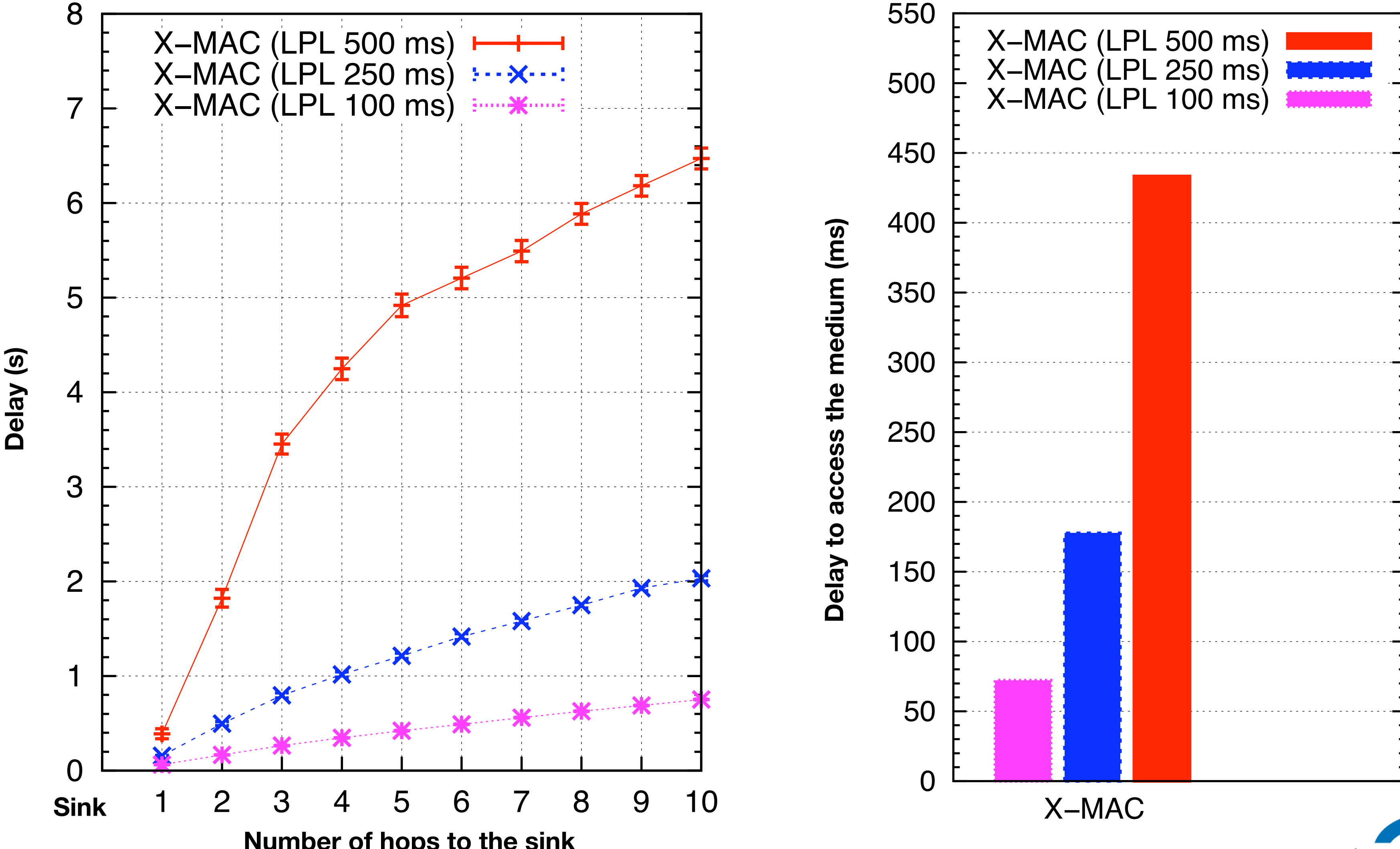




Reactive approach

Performance Evaluation: Delay to access the medium



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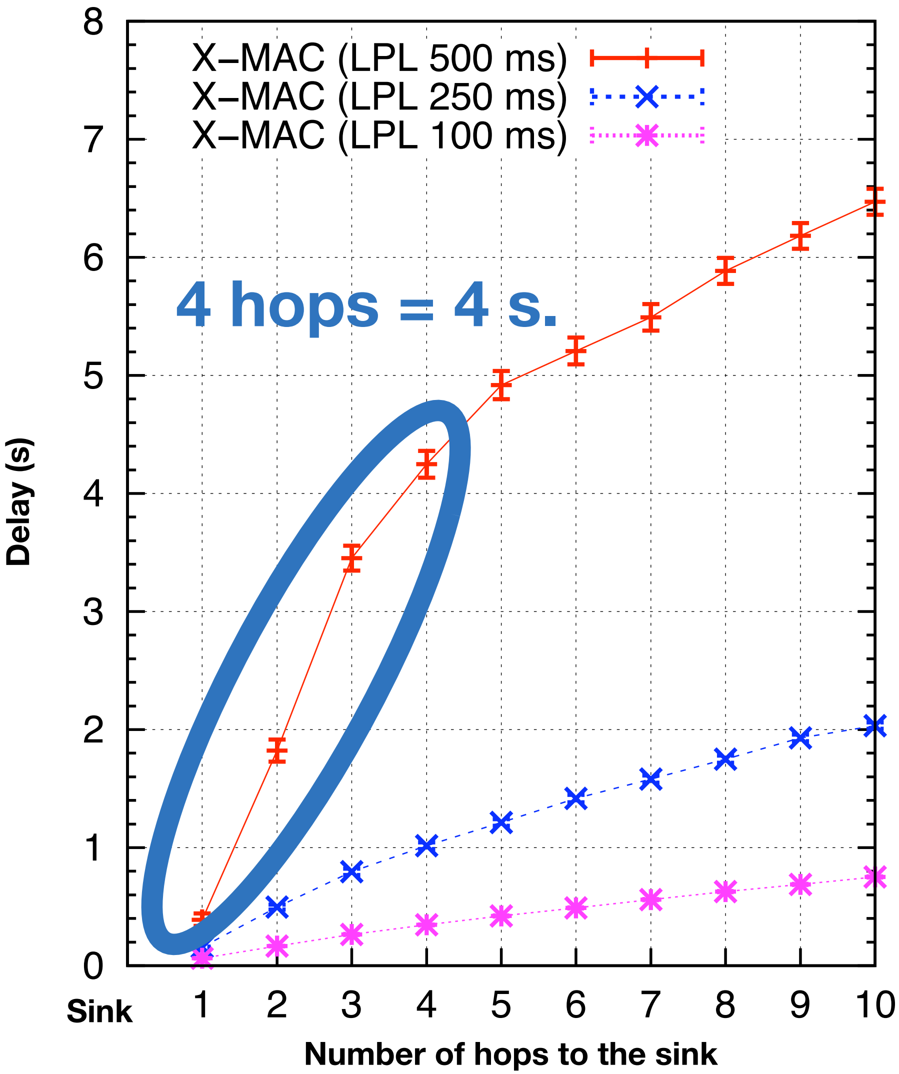

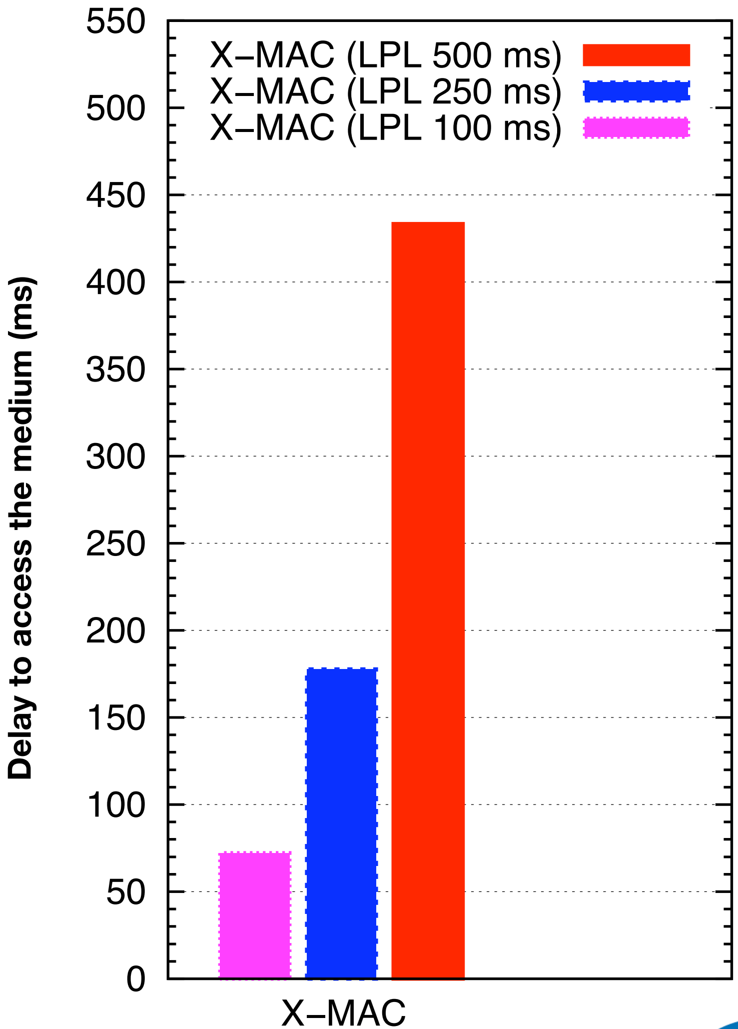

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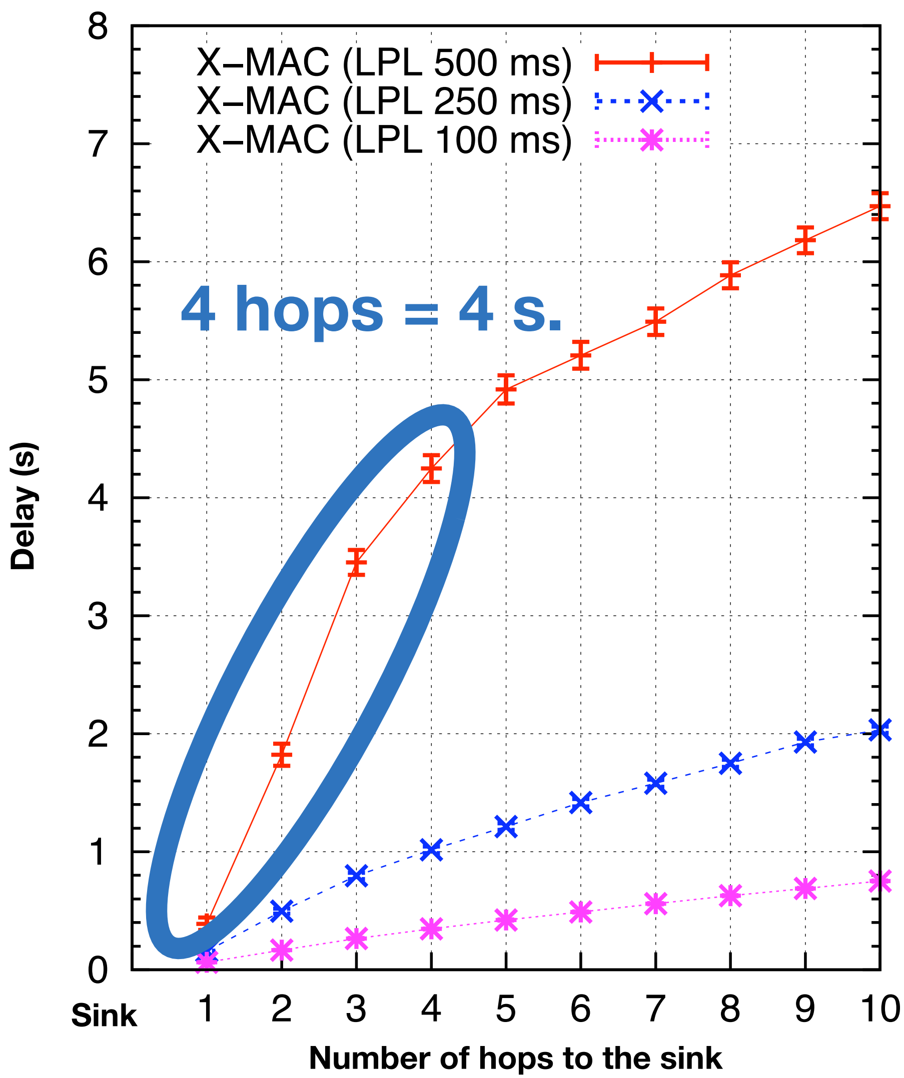

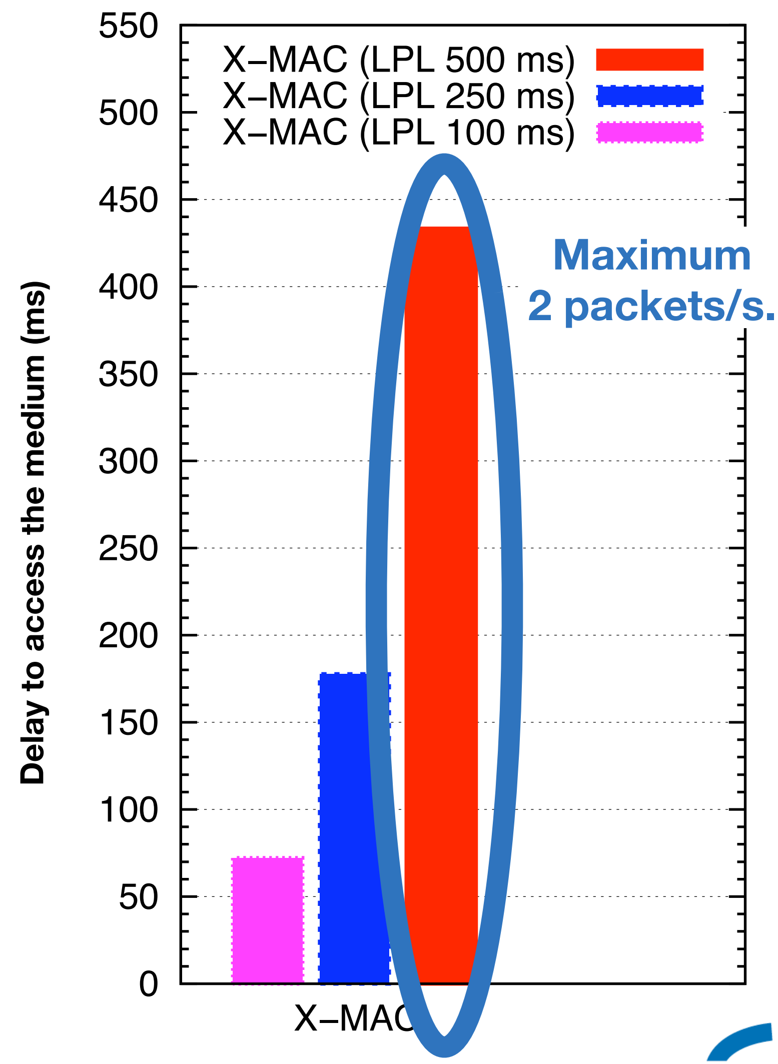

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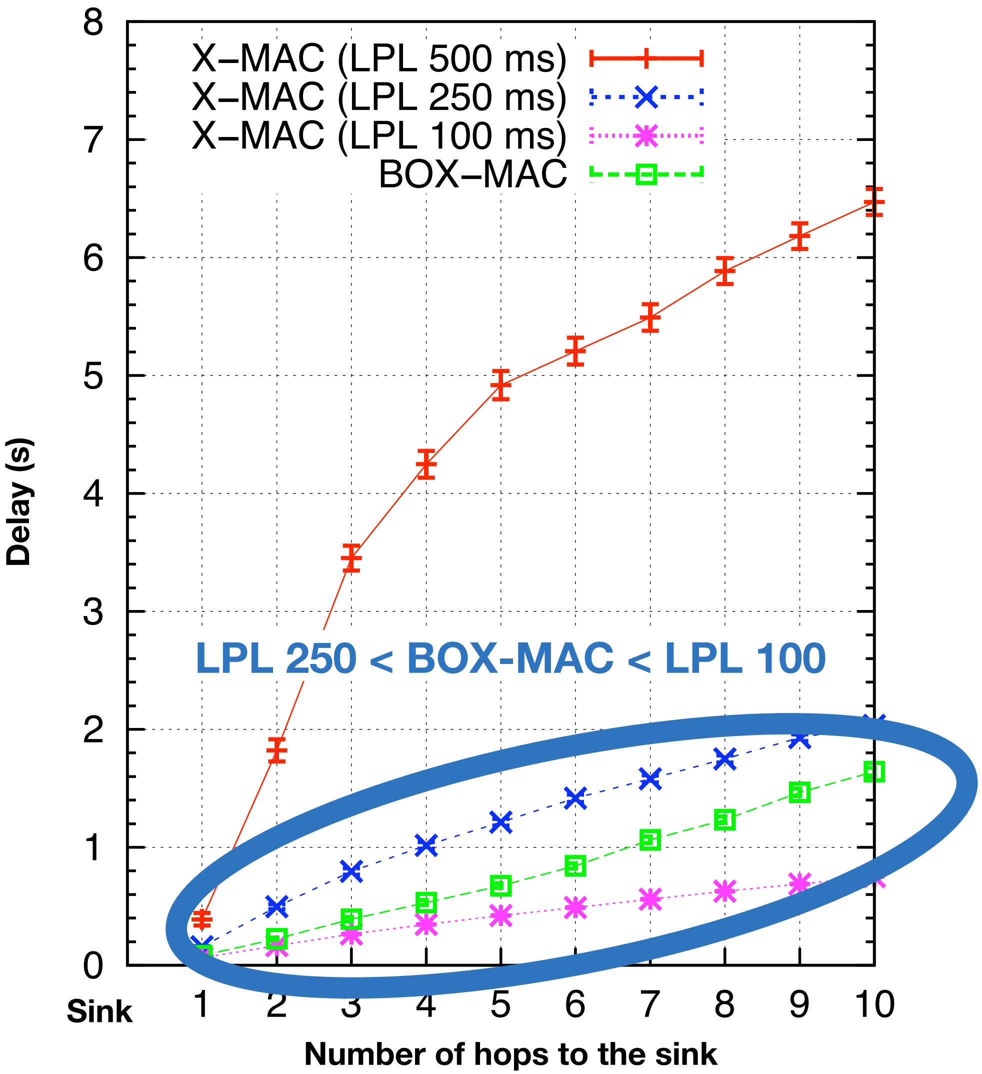
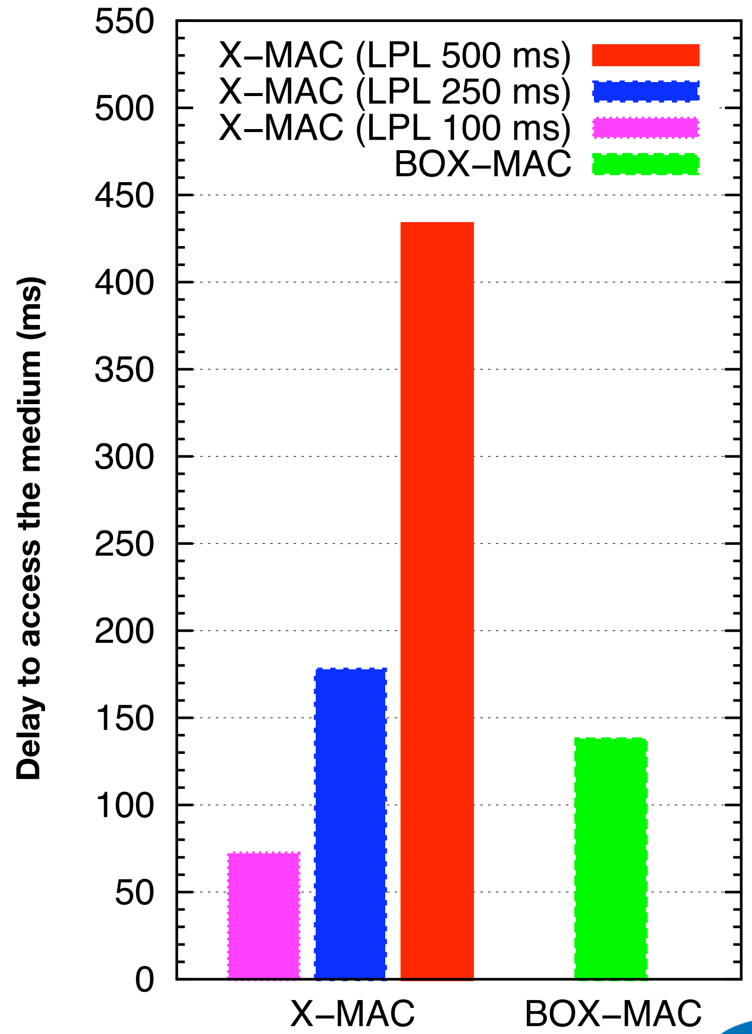




Reactive approach: Conclusion

- **Configuring LPL** prior to deployments poorly efficient against dynamic situations
  ➡ **Auto-adaptation** is required

- **BOX-MAC** skips LPL in **2 values:** Preamble length and sampling period
  - **EE links:** Connectivity ensured between sensors
  - **Bonus:** No control message overhead

  ➡ Energy-efficient

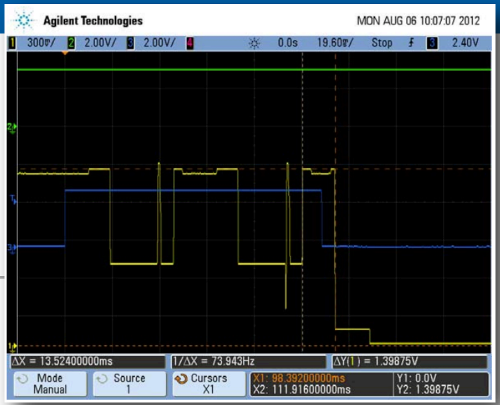
  ➡ Shortened delays and less losses due to **improved resource utilization**

R. Kuntz, A. Gallais and T. Noel.
From Versatility to Auto-Adaptation of the Medium Access Control in Wireless Sensor Networks.
In Elsevier Journal of Parallel and Distributed Computing (JPDC). 2010.

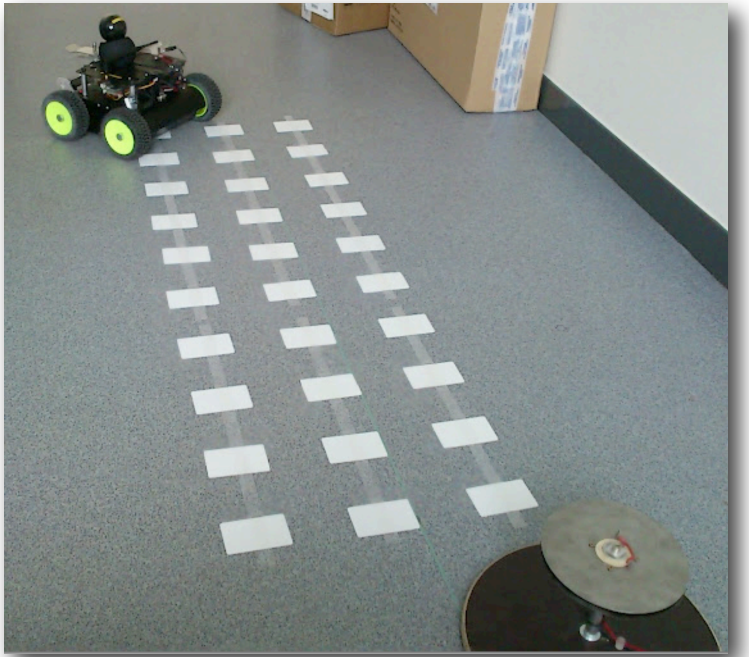
Conclusion

- **Communicating biologgers require finer energy-efficient mechanisms**
- **Energy-efficiency: Radio usage -> MAC layer, LPL configuration**
  - Reactive and proactive approaches
    - Induced traffic, routing information, application criteria
  - Strong needs for prior detailed information (e.g. expected traffic)
- **Mobility**
  - Several solutions already investigated
    - e.g. medium stealing, dynamic time slot allocation
  - Very much remains to be done

Future works



- **Experimentations before real deployment**
  - Multi-chip boards -> select the best on-the-shelf hardware components
  - Mobile robots and FIT equipex project -> emulating expected situations



- **Communication protocols**
  - Other L2 solutions
    - Receiver-Initiated MACs ?
    - Standards (IEEE 802.15.4)
  - MAC/Routing interactions
    - Increased energy-efficiency
    - Fault tolerance (using passive nodes)

Long-term deployments of communicating mobile sensors for wildlife monitoring*

*Works extracted from : PhD thesis of R. Kuntz, ongoing PhD preparation of J. Beaudaux

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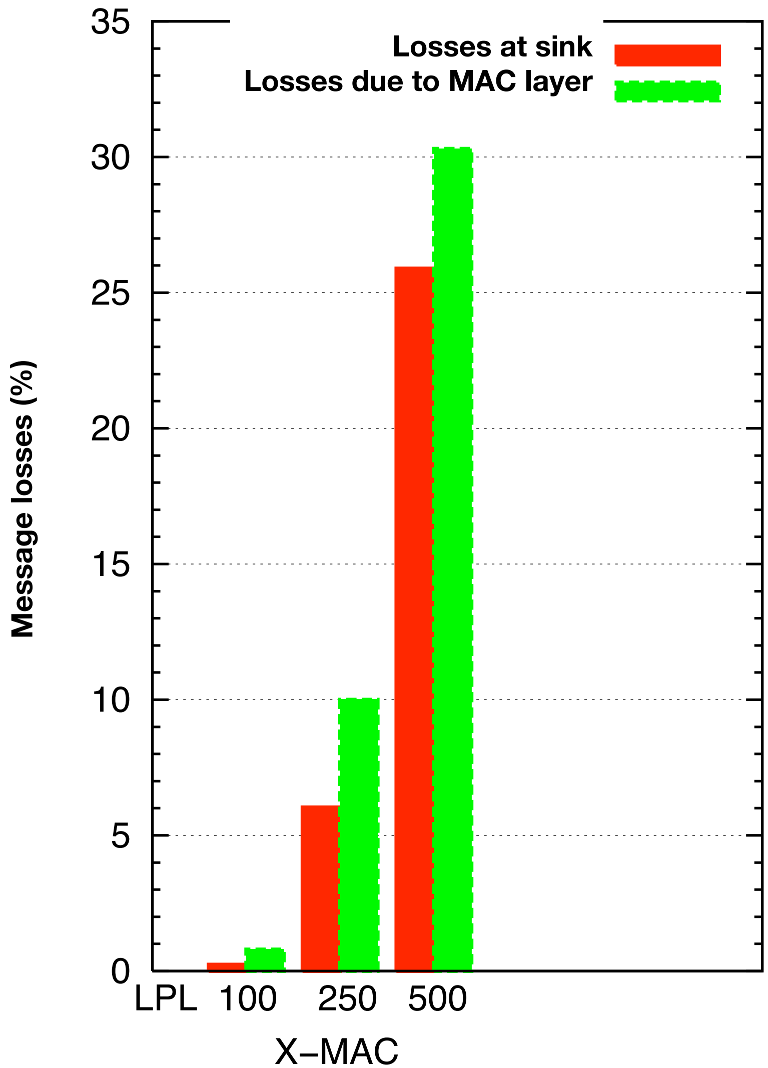
Research and Development of Ad-hoc- and Wireless Sensor Networks for Environmental and Animal Behavioural Monitoring
Crossed Seasons France / South Africa

Turtle tracking

- **For some climate change models**
  - More and more jellyfishes while less and less fish and fishers
  - Problem: Hard to study jellyfishes
- **MIRETTE project (2008-*): Study impact of global change on jellyfish ?**
  - Through the monitoring of its main predator: the luth turtle

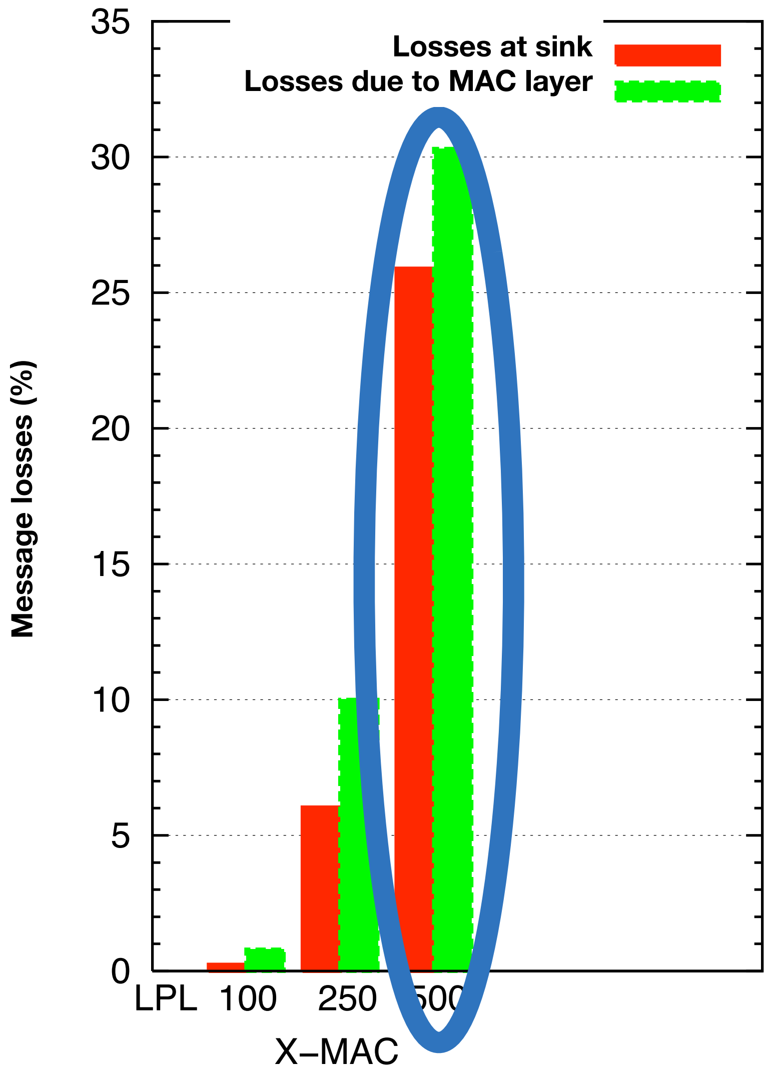
Reactive approach

Performance Evaluation: Overall energy consumption



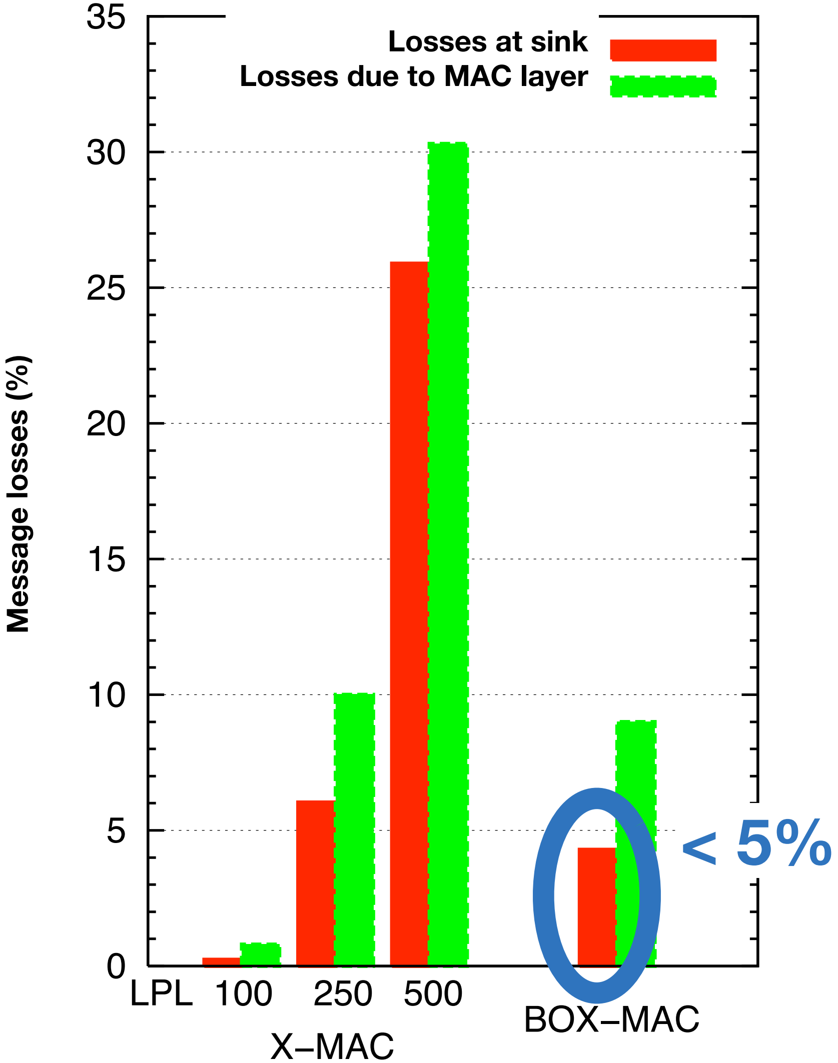
Reactive approach

Performance Evaluation: Overall energy consumption



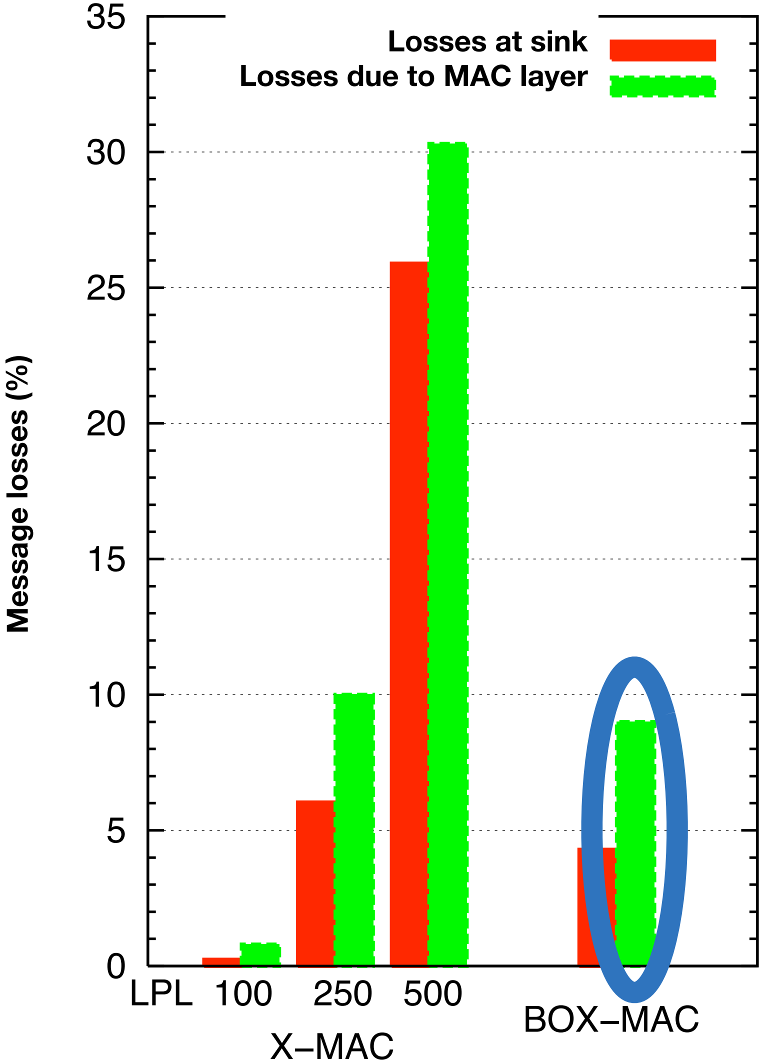
Reactive approach

Performance Evaluation: Overall energy consumption



Reactive approach

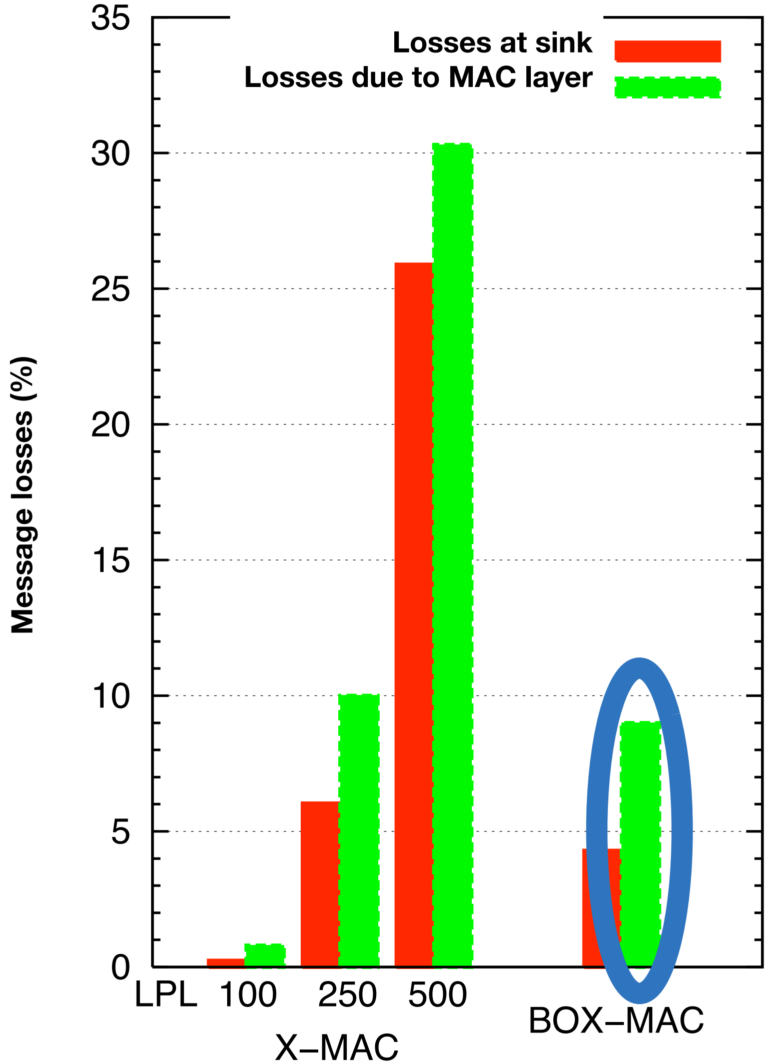
Performance Evaluation: Overall energy consumption



- **BOX-MAC** more sensitive to **hidden node problem**:
  - Several short preambles may collide with a long one.

Reactive approach

Performance Evaluation: Overall energy consumption



- **BOX-MAC** more sensitive to **hidden node problem**:
    - Several short preambles may collide with a long one.

➡ Need to reduce the **number of long preambles** that are used **(51%)**

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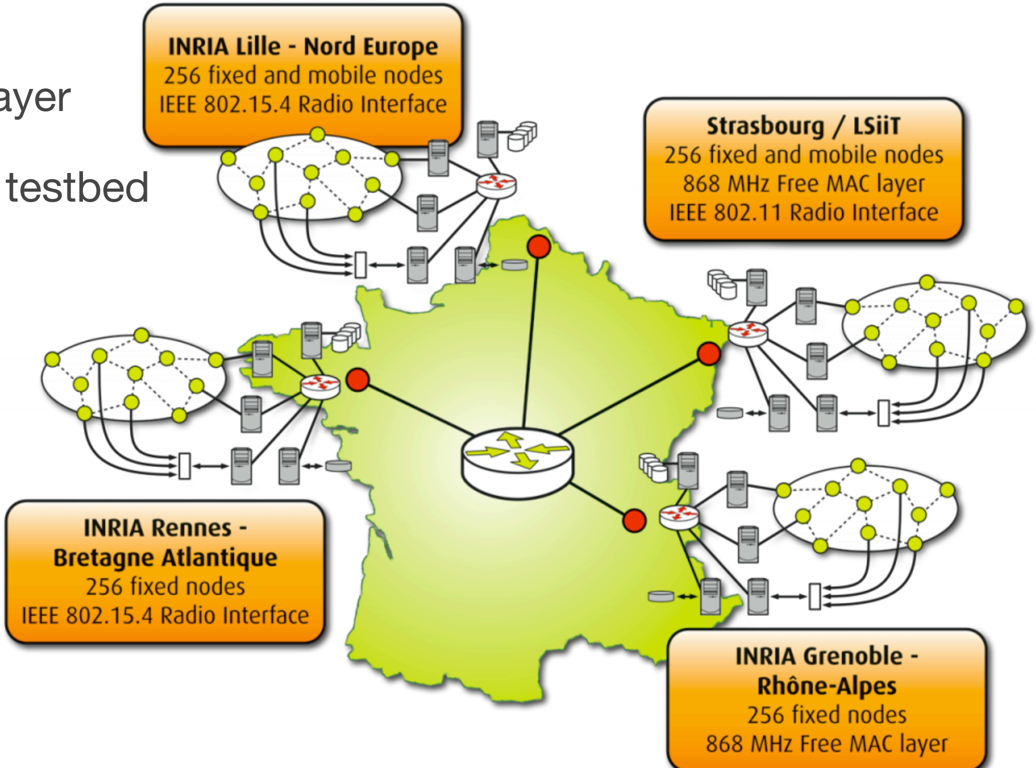
Future Work

- **Several optimizations**
  - e.g. suggesting next hops to routing layer
- **Large-scale experiment** with **SensLAB** testbed



More information
www.senslab.info

C. Burin des Rosiers, G. Chelius, E. Fleury, A. Fraboulet, A. Gallais, N. Mitton and T. Noel.
SensLAB: Very Large Scale Open Wireless Sensor Network Testbed.
ICST TRIDENTCOM'11 - Shanghai, China, April 2011.

C. Burin des Rosiers, G. Chelius, T. Ducrocq, E. Fleury, A. Fraboulet, A. Gallais, N. Mitton, T. Noel and J. Vandaele.
Using SensLAB as a First Class Scientific Tool for Large Scale Wireless Sensor Network Experiments.
IFIP Networking'11 - Valencia, Spain, May 2011.