



**« Dual-Mode Real-Time MAC Protocol for
Wireless Sensor Networks:
a Validation/Simulation Approach »**

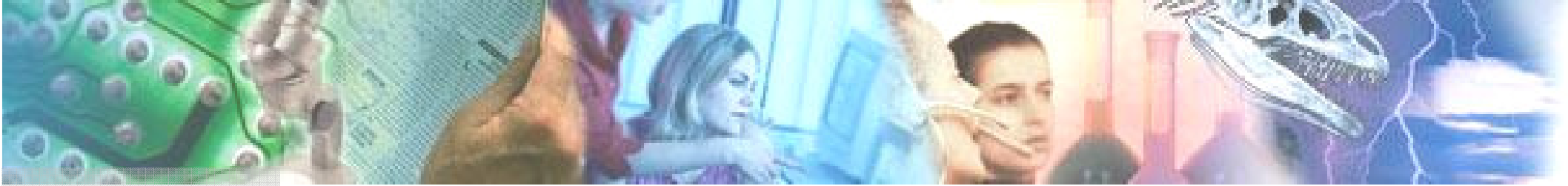
Thomas Watteyne^{†‡}, Isabelle Augé-Blum[‡], Stéphane Ubéda[‡]

[‡]CITI, INSA de Lyon

[†]France Telecom R&D

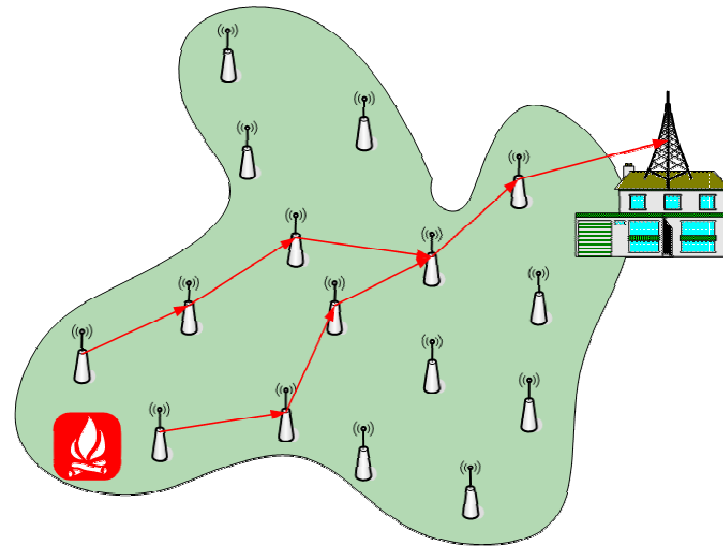
InterSense 2006, May 30th





Wireless Sensor Networks

➔ Numerous applications military, surveillance, health, intelligent homes, ...



- Measuring a physical value
- Processing
- Wireless communication

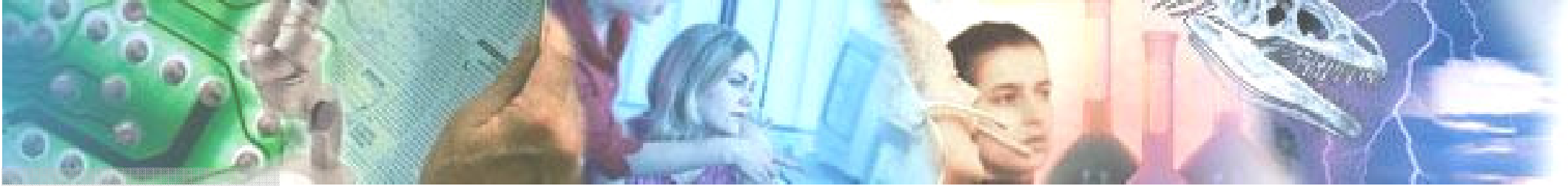
Embedded systems

- computational power
- limited memory
- embedded energy

- inaccessible/dangerous area
- « random » deployment
- impossible human intervention (battery...)

➔ Application domain of Ad-Hoc networks

- no fixed infrastructure
- changing topology
- multi-hop communication



Overview

- Real-time in WSNs, **Related Work**
- Our **proposition**: Hard Real-Time MAC protocol for WSN
- Formal **validation** of our protocol
- **Simulation** and Results



Real-Time in Wireless Sensor Networks

Soft Real-Time

Application such that portion of messages can arrive late

⇒ Flow differentiation

layer 2: decrease medium access time for RT flow

layer 3: take message urgency into account

ex: RAP (*Lu, Blum, Abdelzaher, Stankovic, He, 2002*)

SPEED (*He, Stankovic, Lu, Abdelzaher, 2003*)

Hard Real-Time

Always arrive before **deadline**

Worst Case Execution/Transmission times known,
bounded and guaranteed

⇒ Message Scheduling

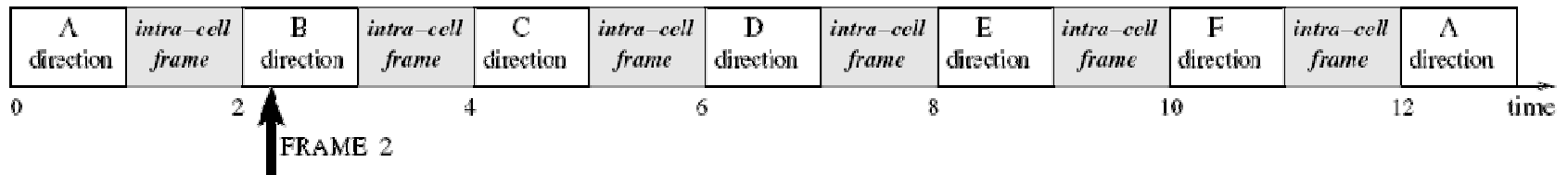
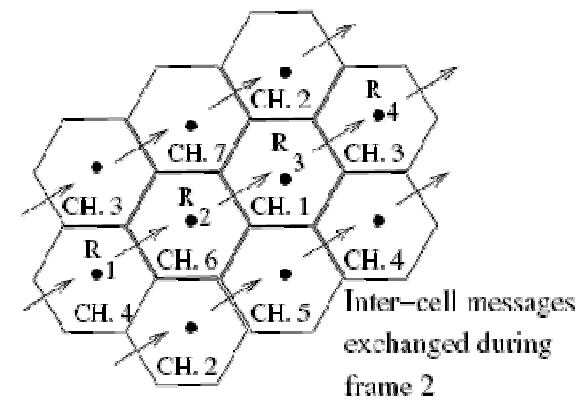
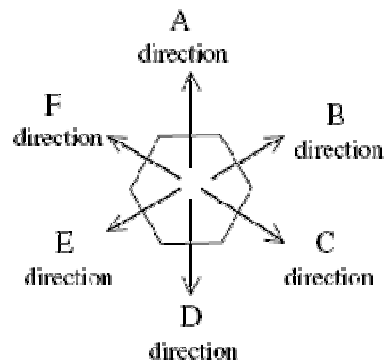
ex: I-EDF (*Caccamo, Zhang, Sha, Buttazzo, 2002*)

related work

proposition
validation
simulation



Hard real-time, Implicit Earliest Deadline First



Hard-to meet Hypothesis:

- hexagonal cells, same size
- 7 frequencies
- synchronization

related work

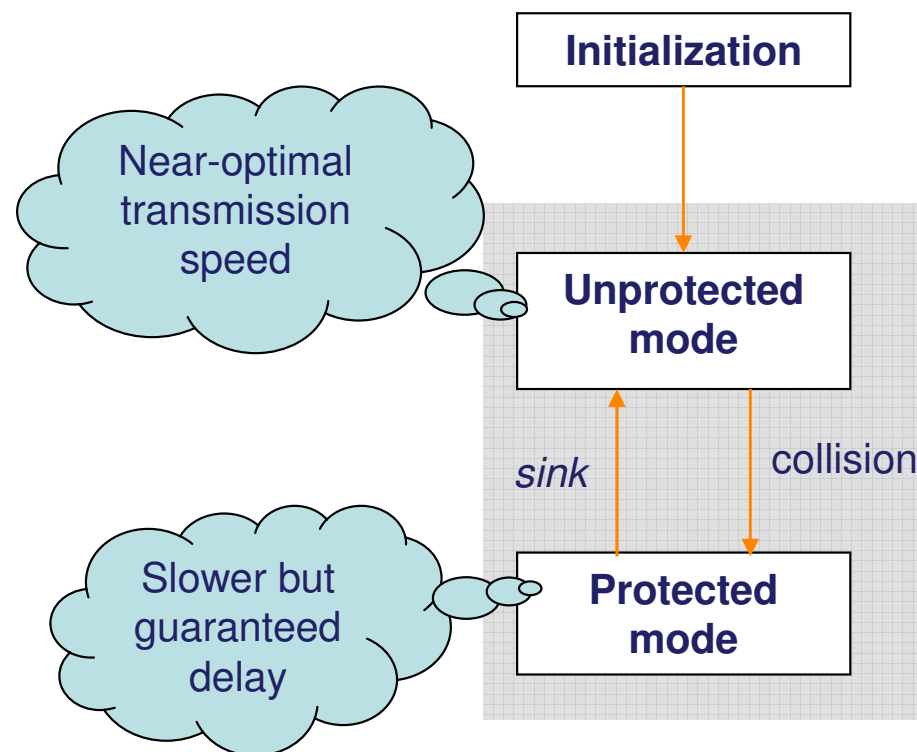
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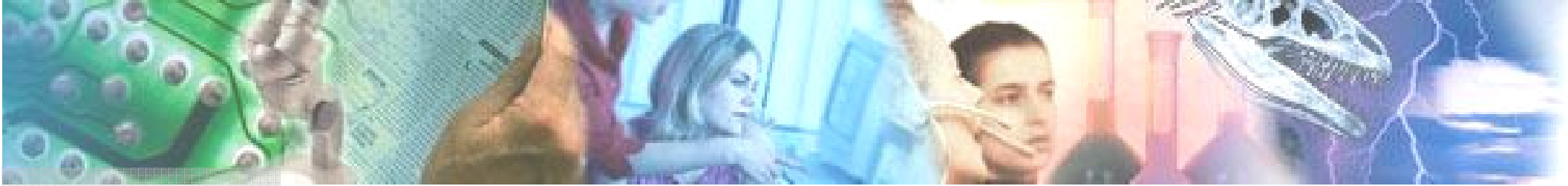


“Propose and validate a MAC protocol for WSN which offers hard-real time guarantees”

No routing, application domain: **linear networks**:

- highway car accident monitoring
- railway train tracking
- production chain surveillance





Hypothesis

Nodes

- all nodes are the same
- one frequency, one transmission power
- no GPS (*positioning, synchronization*)
- each node knows its position

Monitored area

- linear
- sink node at one end
- $dist_{min} \leq \text{distance between neighbors} \leq max_{range}$

Radio link

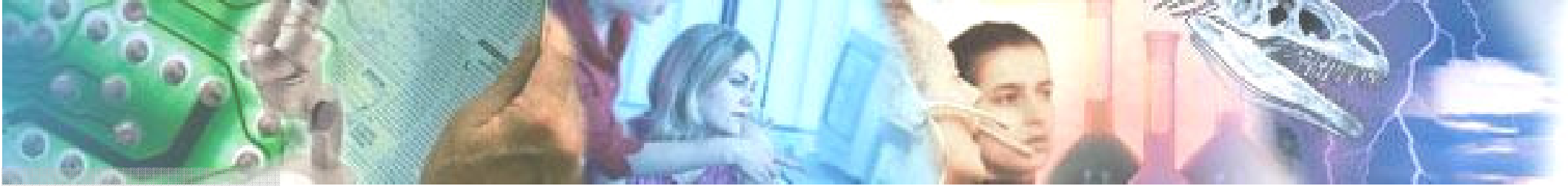
- bidirectional
- no transmission errors

Alarm messages

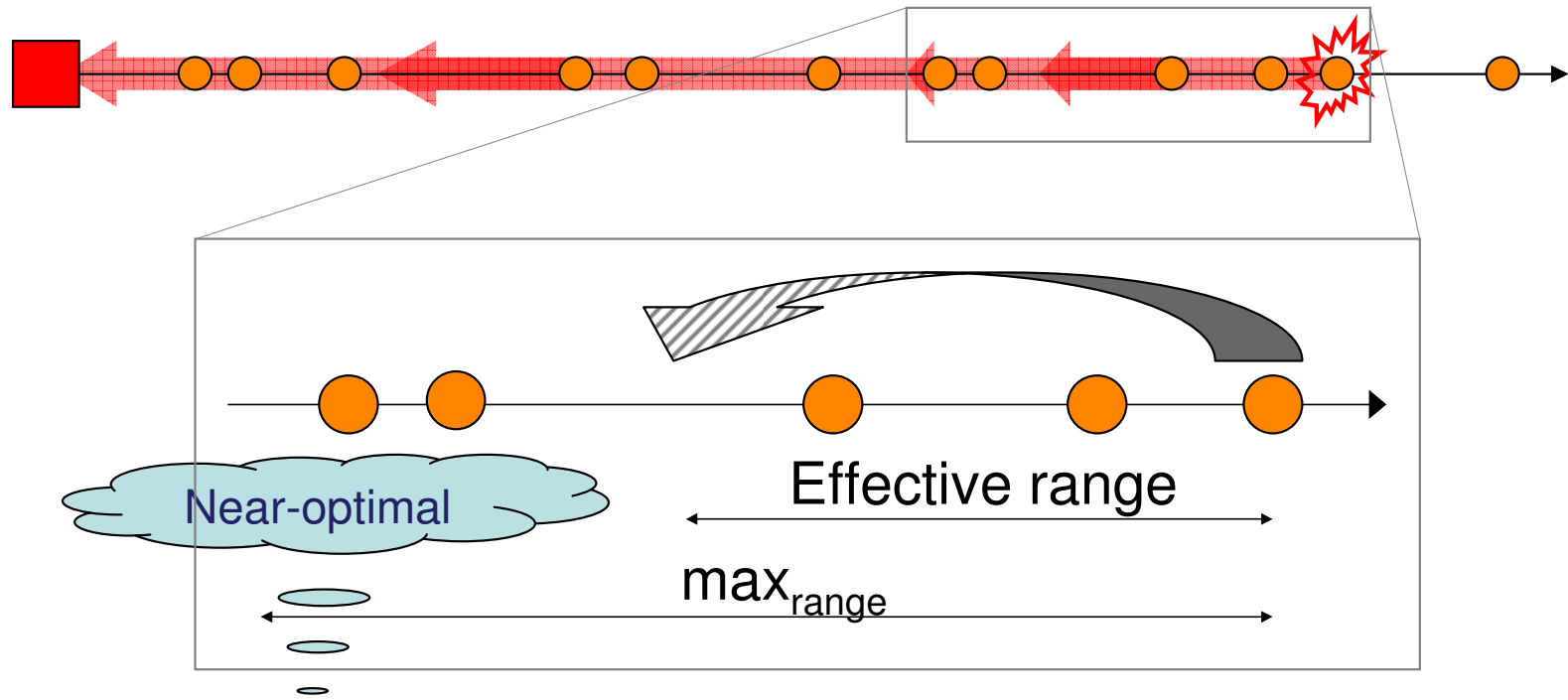
- possibly generated by all nodes
- no priorities



related work
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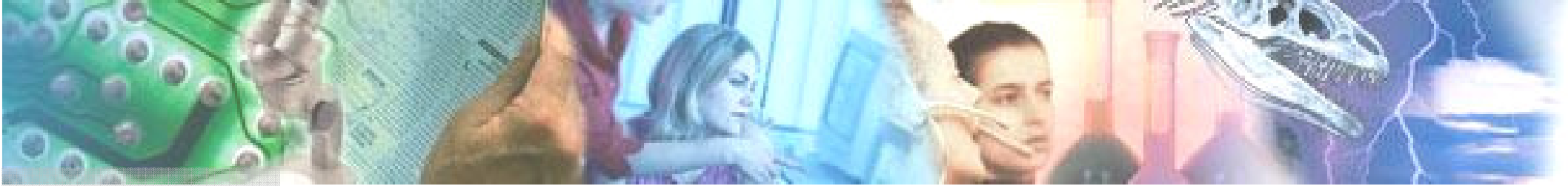


Unprotected mode



$$backoff_{unprotected} \propto A - (A_{emitting} - \max_{range})$$

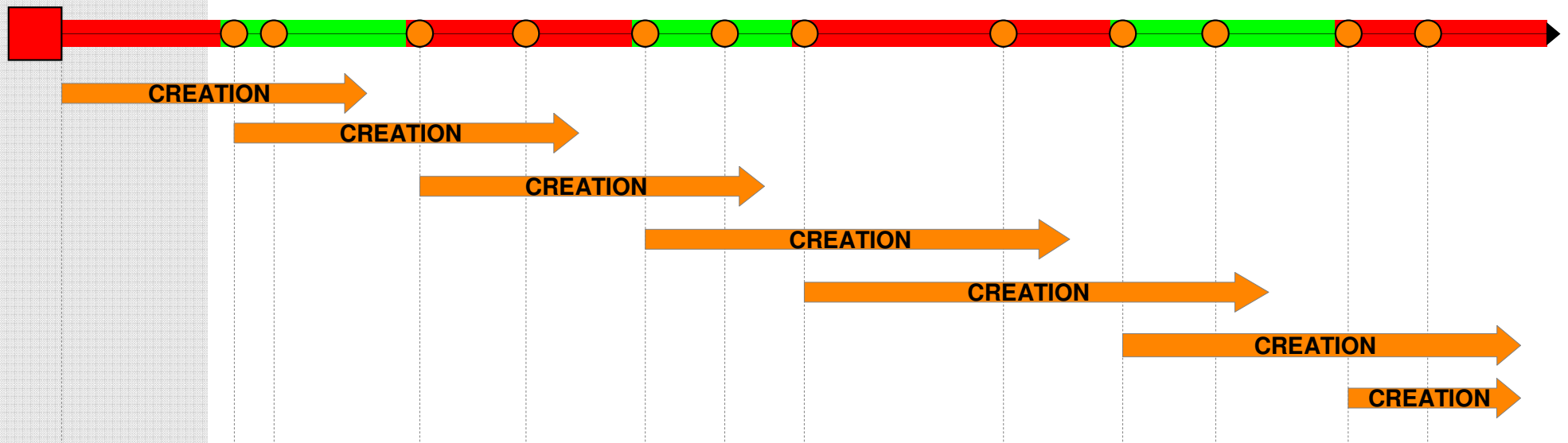
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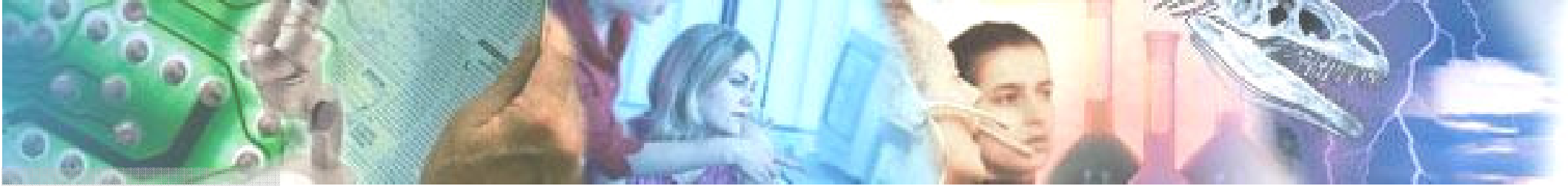
Protected mode

Goal: Separate simultaneously emitting nodes by enough distance

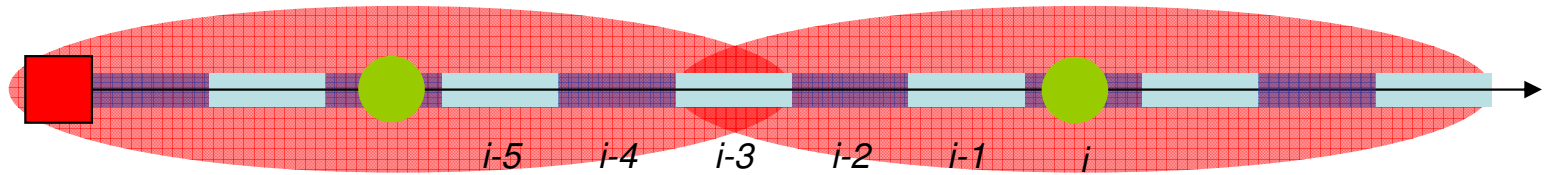
➔ Construct cells of length proportional to one radio range



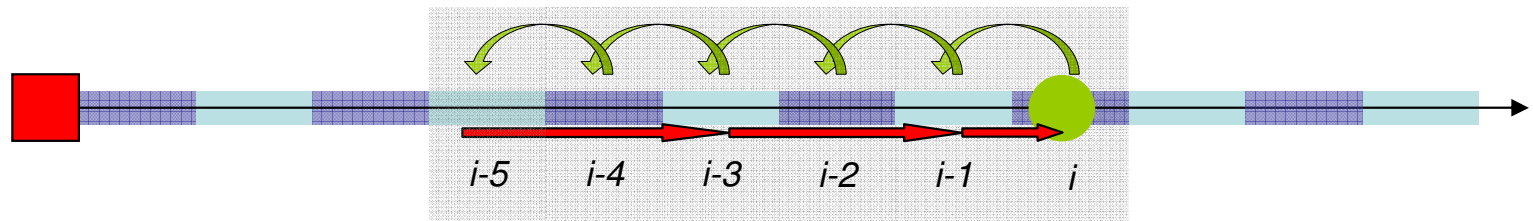
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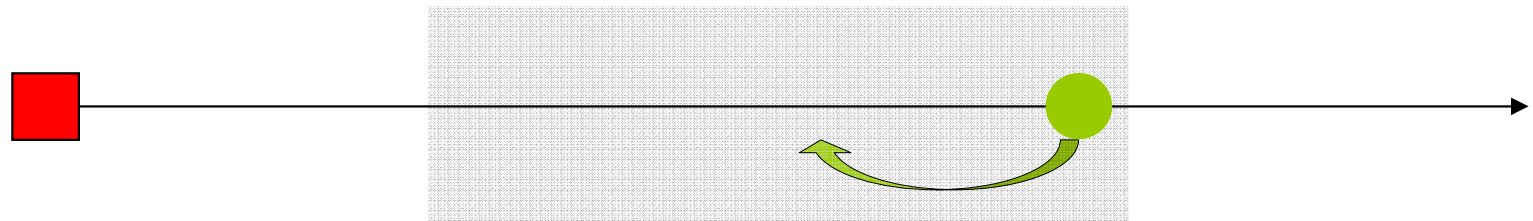
Protected mode



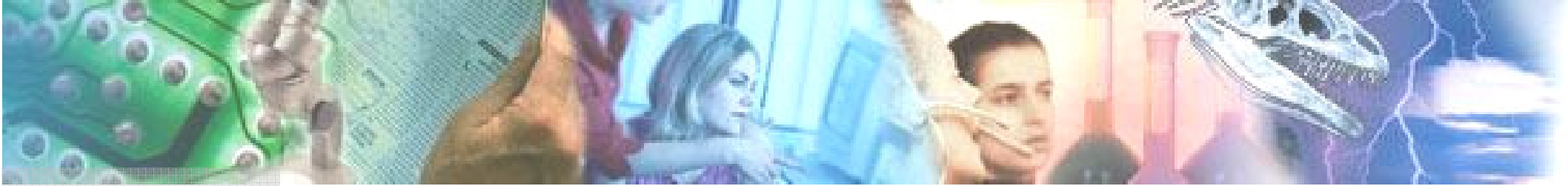
Protection of a network portion...



... and sending a message.

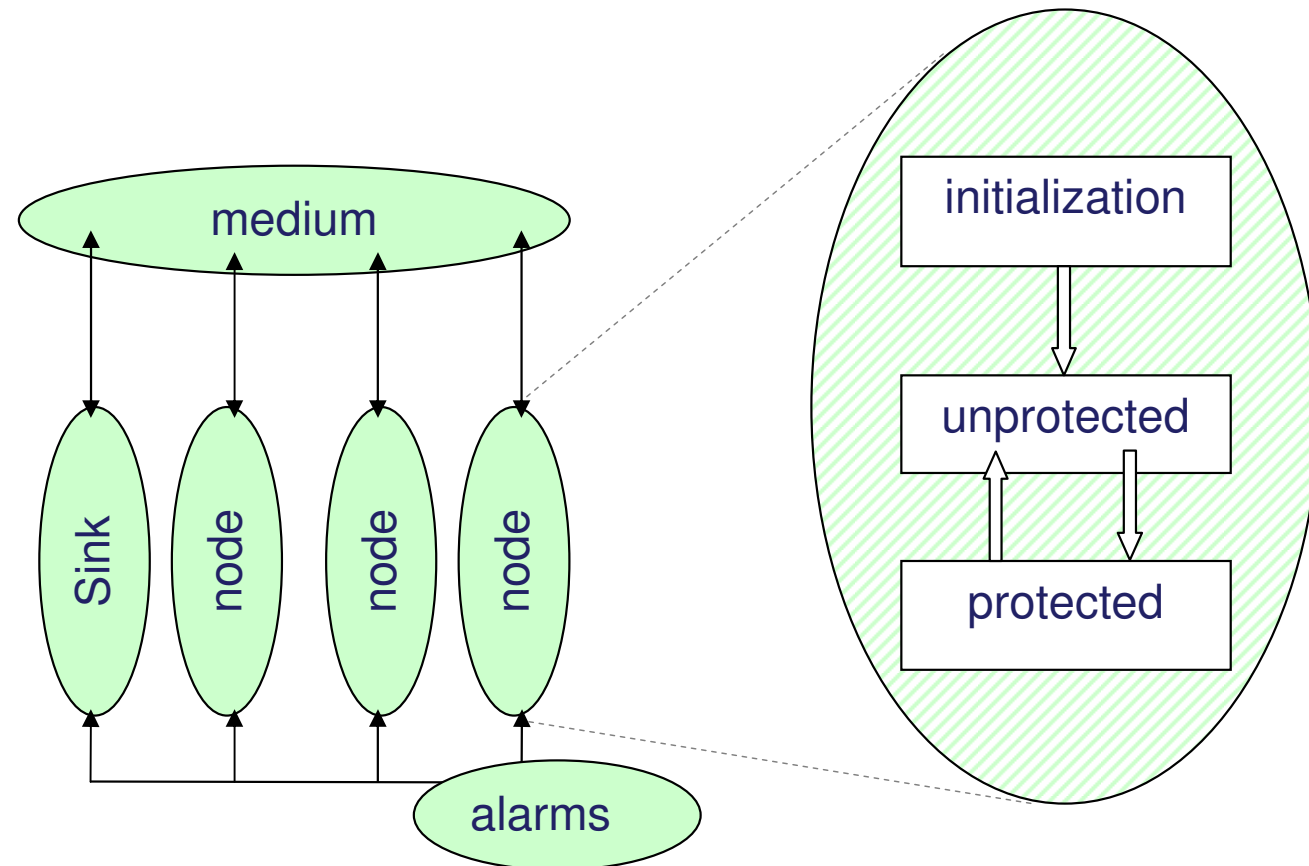


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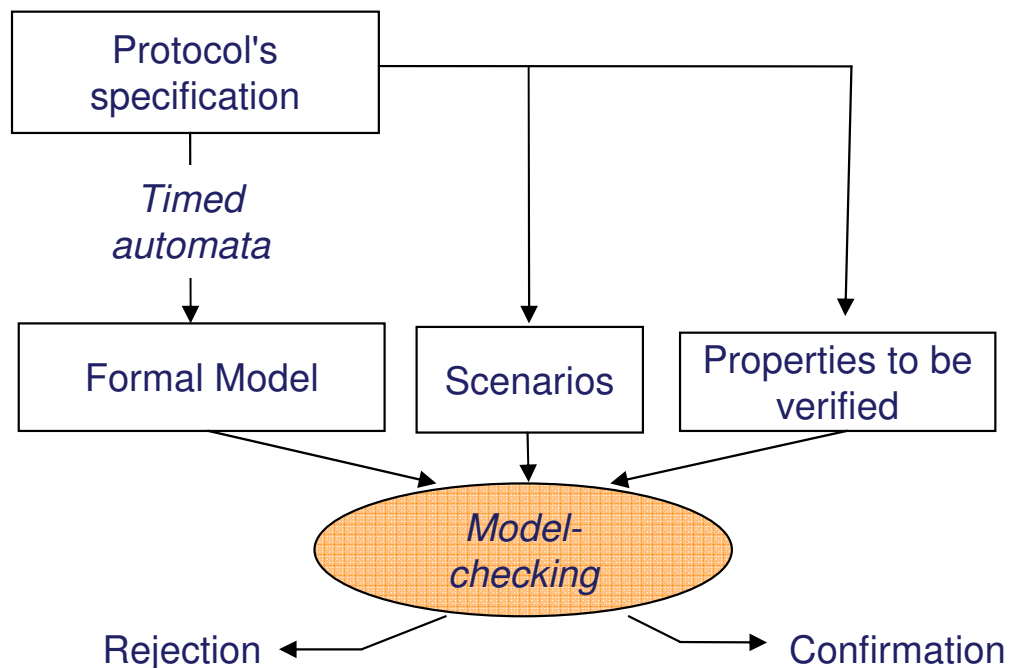
Formal Validation

- Analytically determine worst case times (*initialization, unprotected, protected*)
- Validation using a formal model: *Timed Automata (UPPAAL)*





Formal Validation



What has been validated:

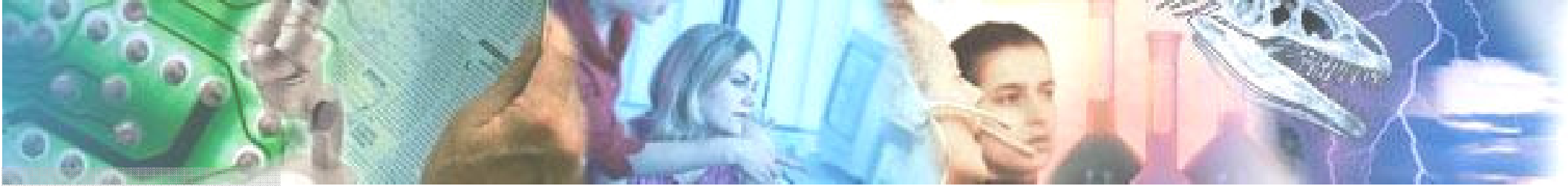
- correct **behavior** of *initialization, protected and unprotected modes*
→ all alarms **always reach the sink** node
- correct **timeliness behavior** of *initialization, protected and unprotected modes*
→ all alarms always reach the sink node **on time**



Simulation

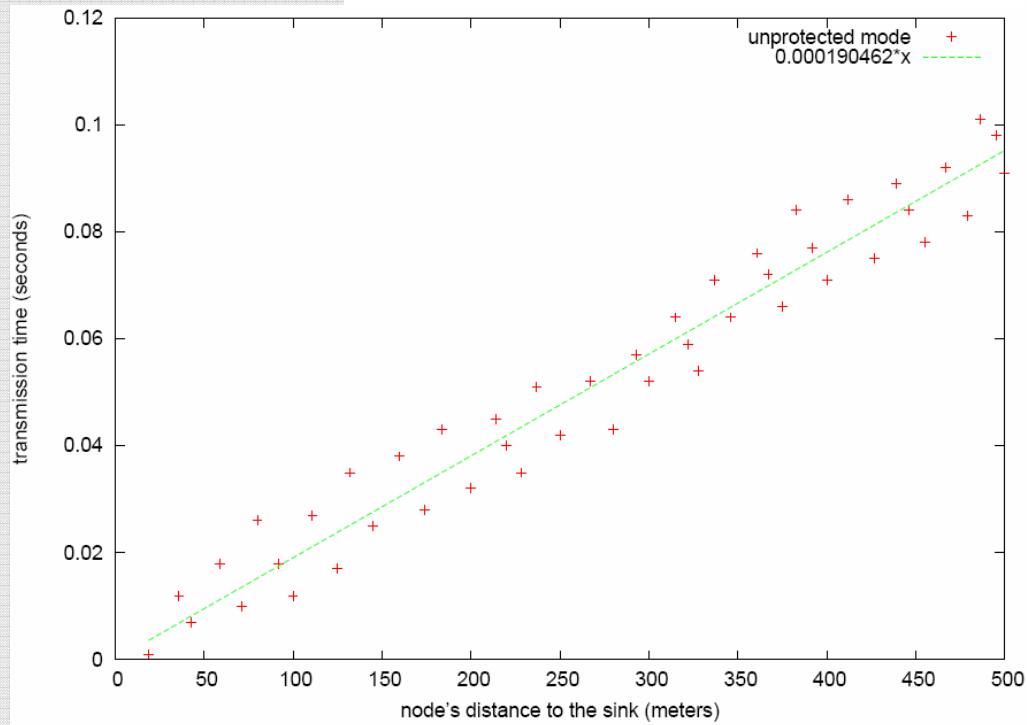
Initialization times

Topology	Initialization time
10 nodes, 100m	10.160 sec.
46 nodes, 500m	10.923 sec.

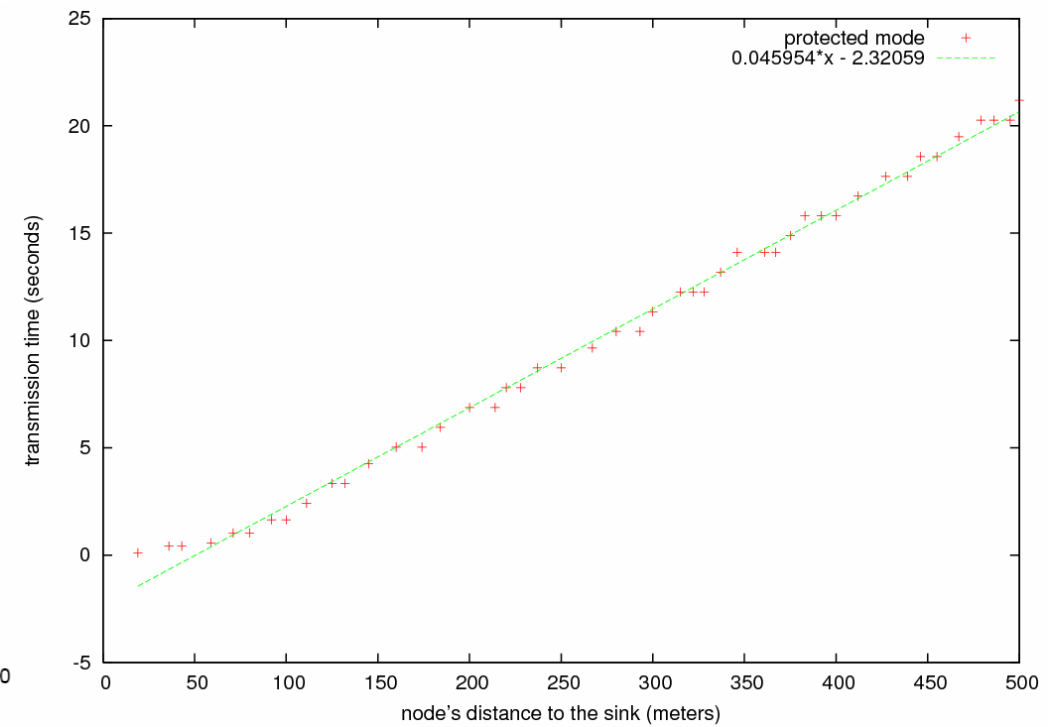


Simulation

Time for reaching the sink in unprotected and protected modes



Transmission times in unprotected mode.

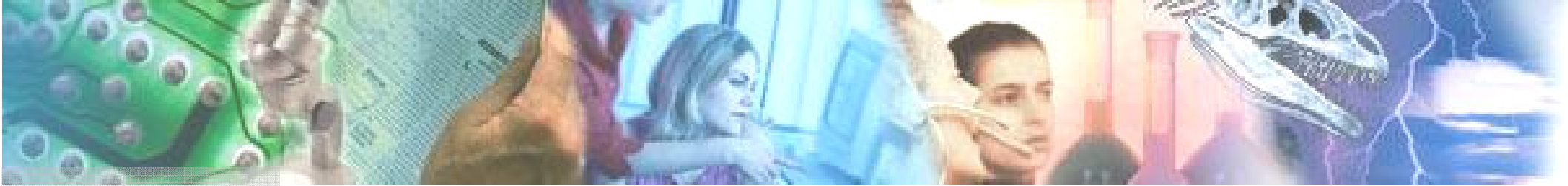


$\approx 5250 \text{ m.s}^{-1}$

200x, too much ?
Backoff like 802.11 ?

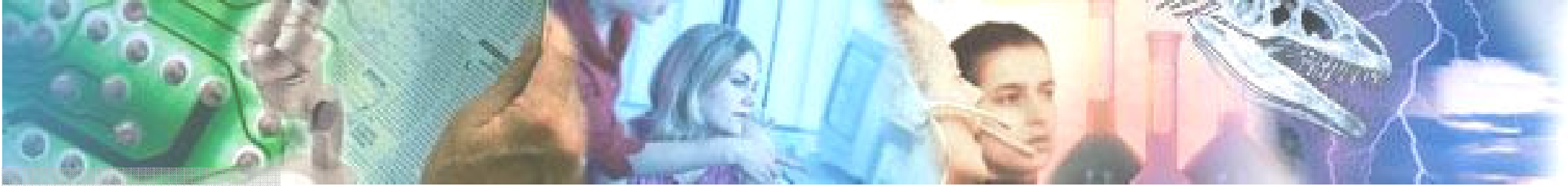
$\approx 22 \text{ m.s}^{-1}$

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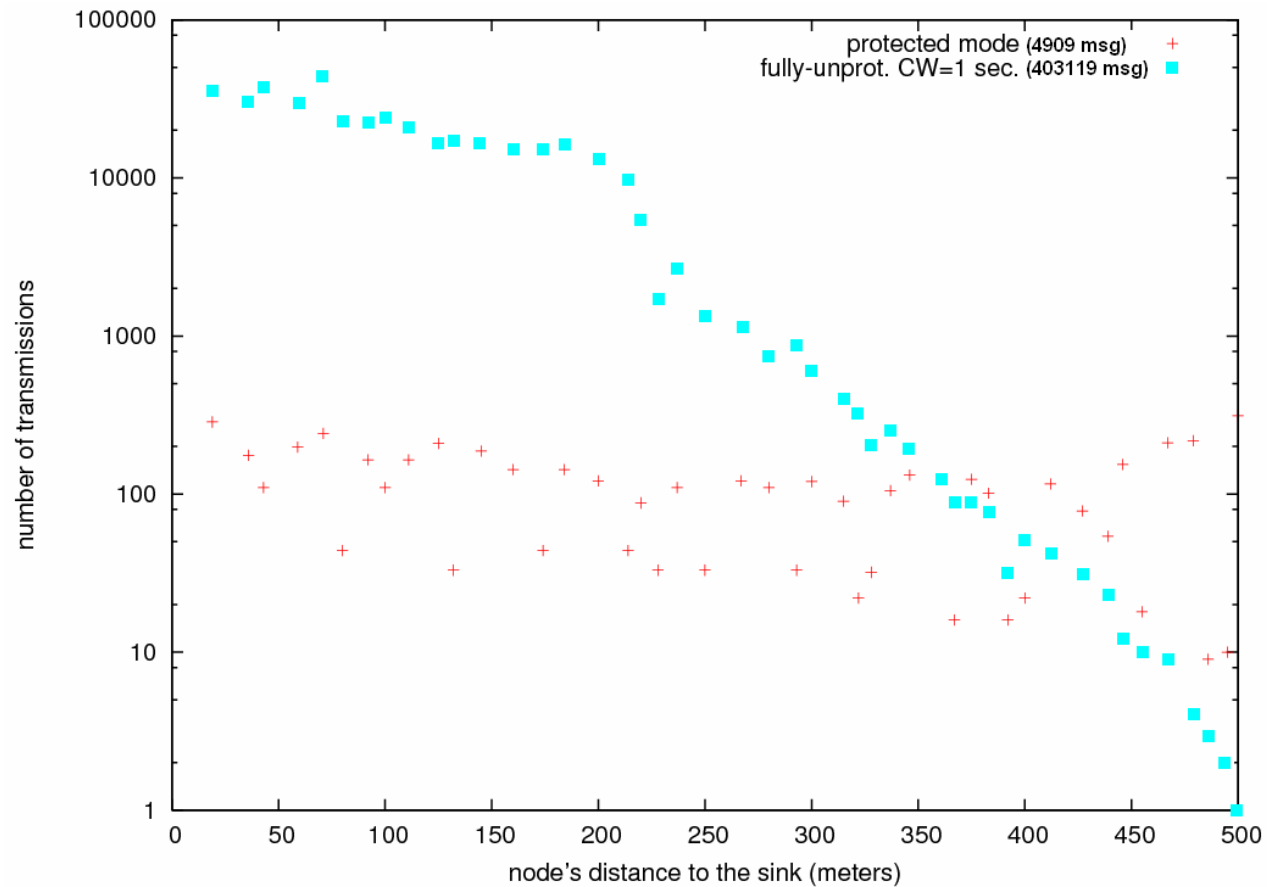
Simulation

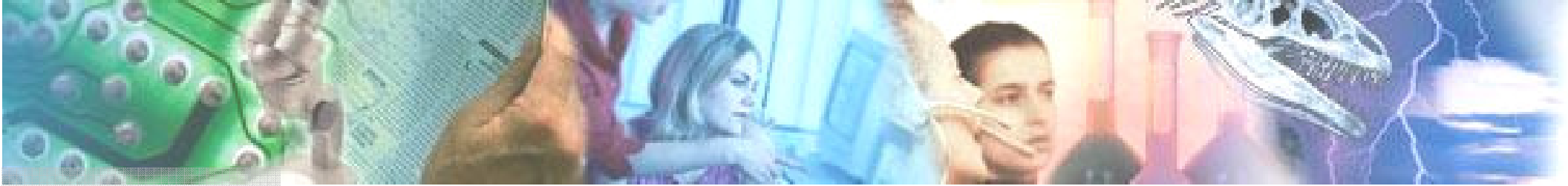




Simulation : importance of the protected mode

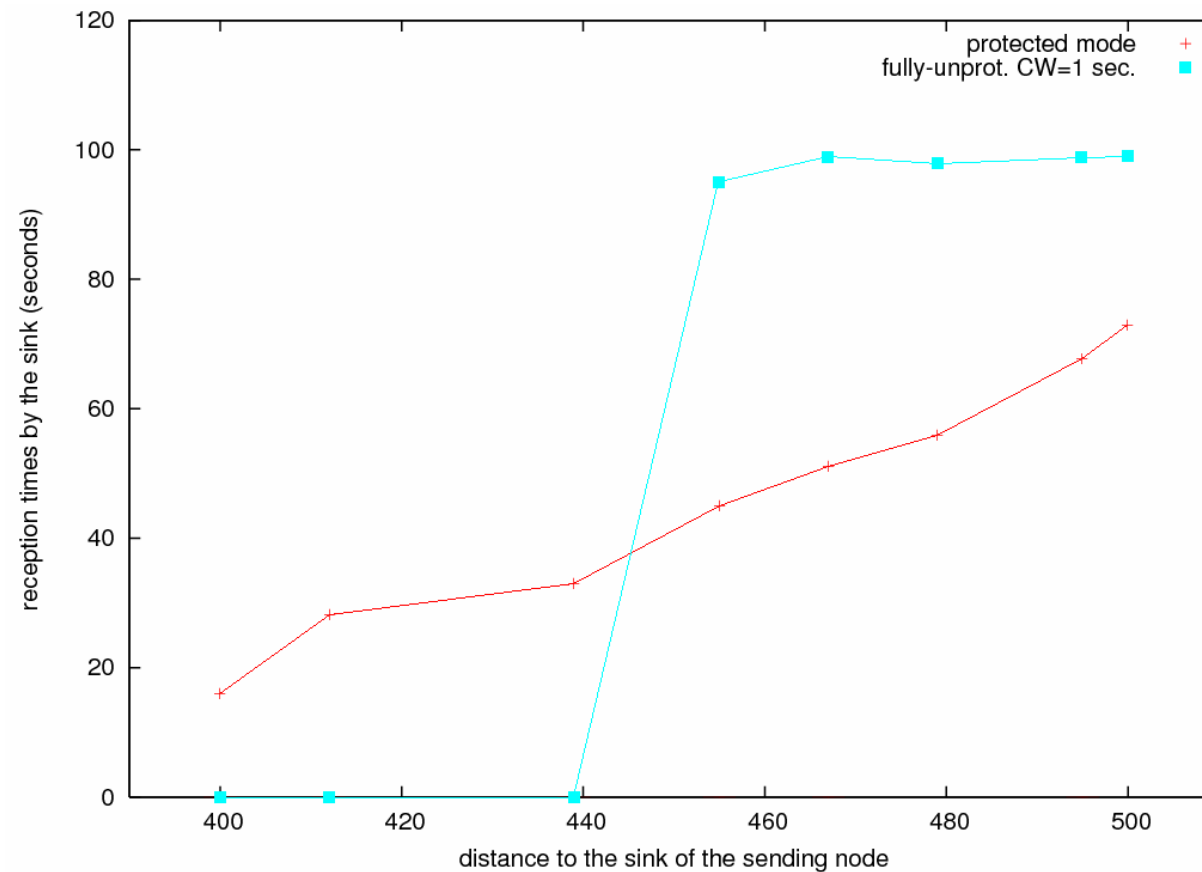
- infinite transmission times in worst case
- many transmissions → smaller lifetime

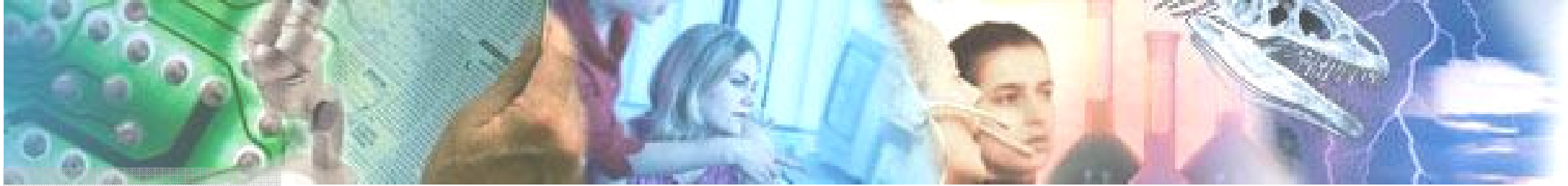




Simulation : importance of the protected mode

- infinite transmission times in worst case
- many transmissions → smaller lifetime
- **higher achievable load using protected mode**





Conclusion

- Hard-Real Time MAC for WSN
- Formal Validation
- Importance of having two modes shown by simulation

Future Work

- Energy consumption optimization
- Detailed study of switching mechanisms
- Compare performances with other MAC protocols (*802.11*)
- 2-D extension: hard real-time routing layer
- Add fault tolerance mechanisms
- Implementation on a real platform