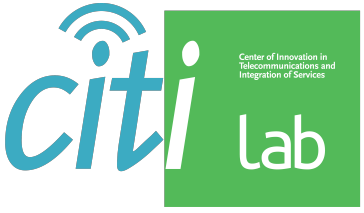
Formal Verification of Real-Time Wireless Sensor Networks Protocols: Scaling Up

Alexandre Mouradian
Isabelle Augé-Blum

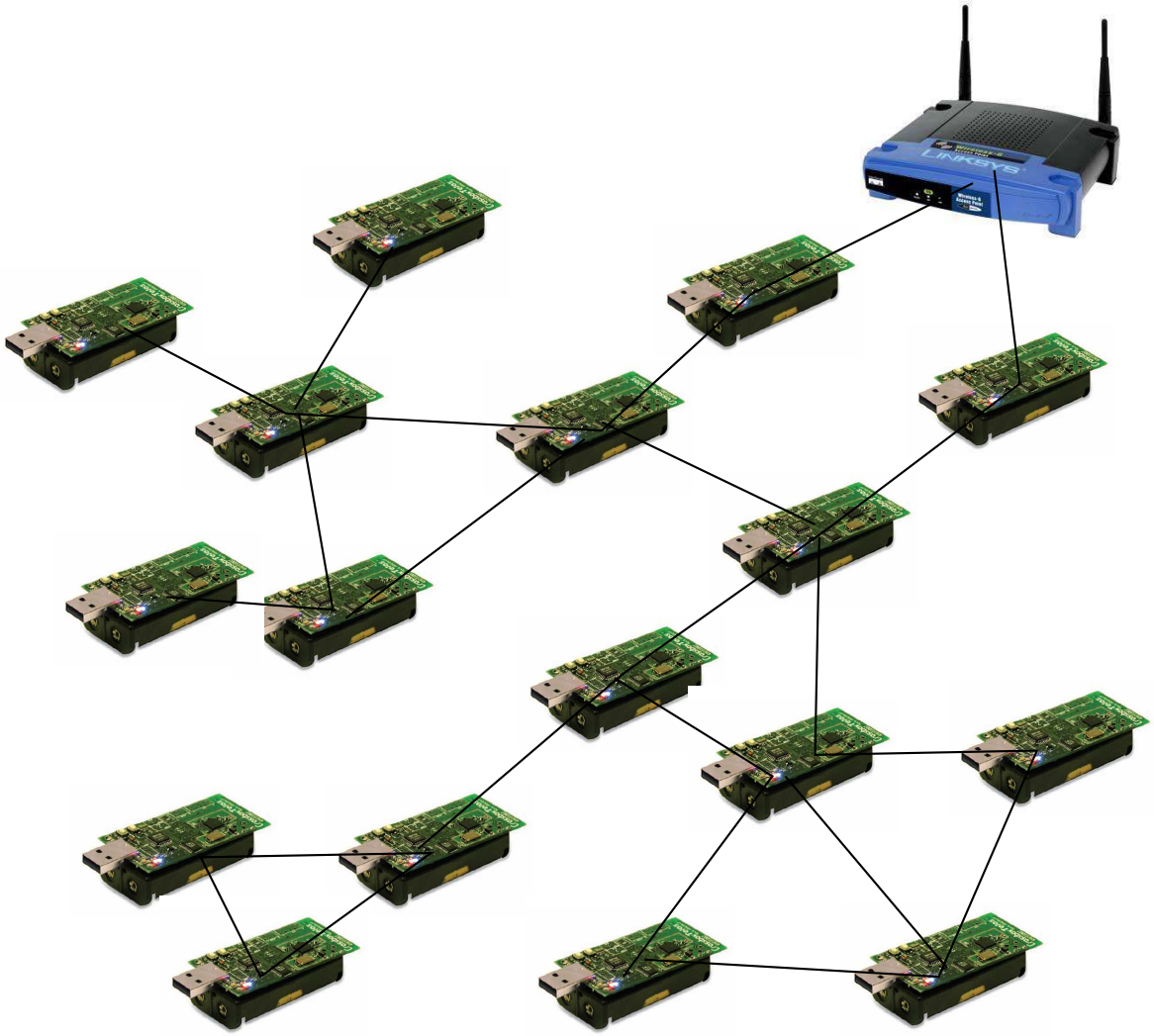


ECRTS

9th July 2014

Context

Wireless Sensor Networks



Constraints :

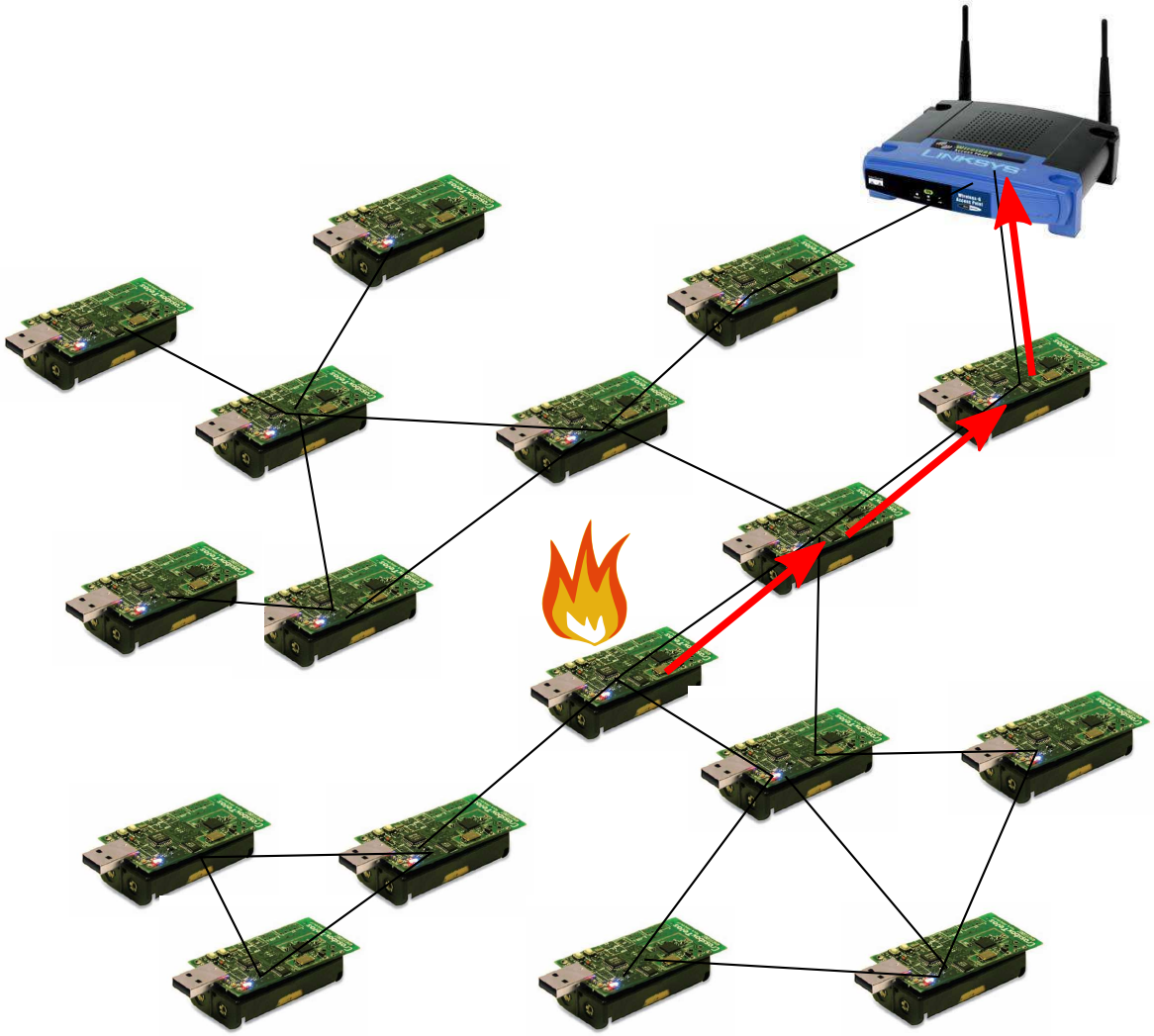
- Limited hardware capabilities
- No fixed infrastructure
- Unreliable Links

Goals :

- Energy efficiency
- Self-organization
- Reliability
- Scalability
- Constrained delays

Context

Wireless Sensor Networks



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Problematic

Critical WSN applications

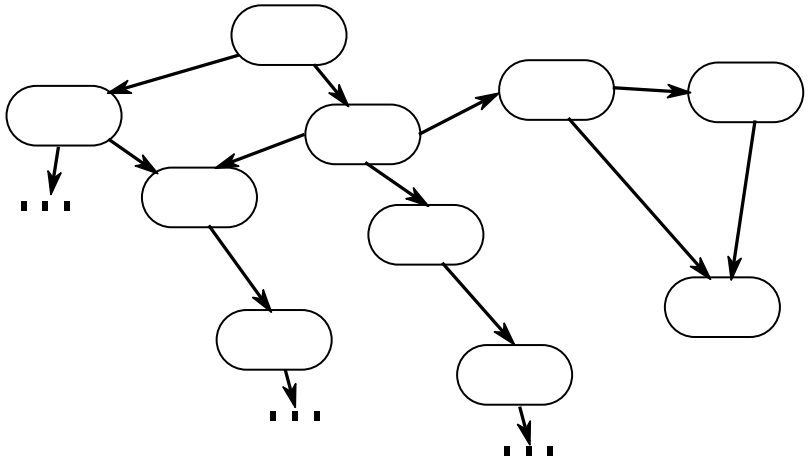
How to guarantee end-to-end delays in WSNs ?

↳ Formal Methods

The goal of this work is to adapt timed formal verification to WSNs

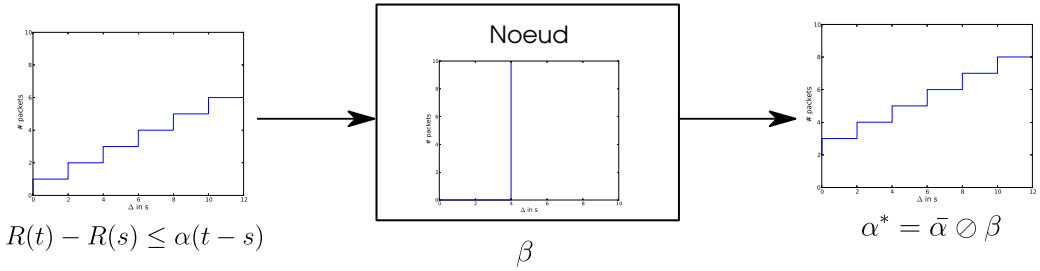
Formal verification of real-time properties

Model Checking



Explores all the possible behaviors of a model of the system, BUT combinatorial explosion

Network Calculus



Abstraction of the behavior with composable functions

Allows to work on large scale systems, BUT abstraction not proven

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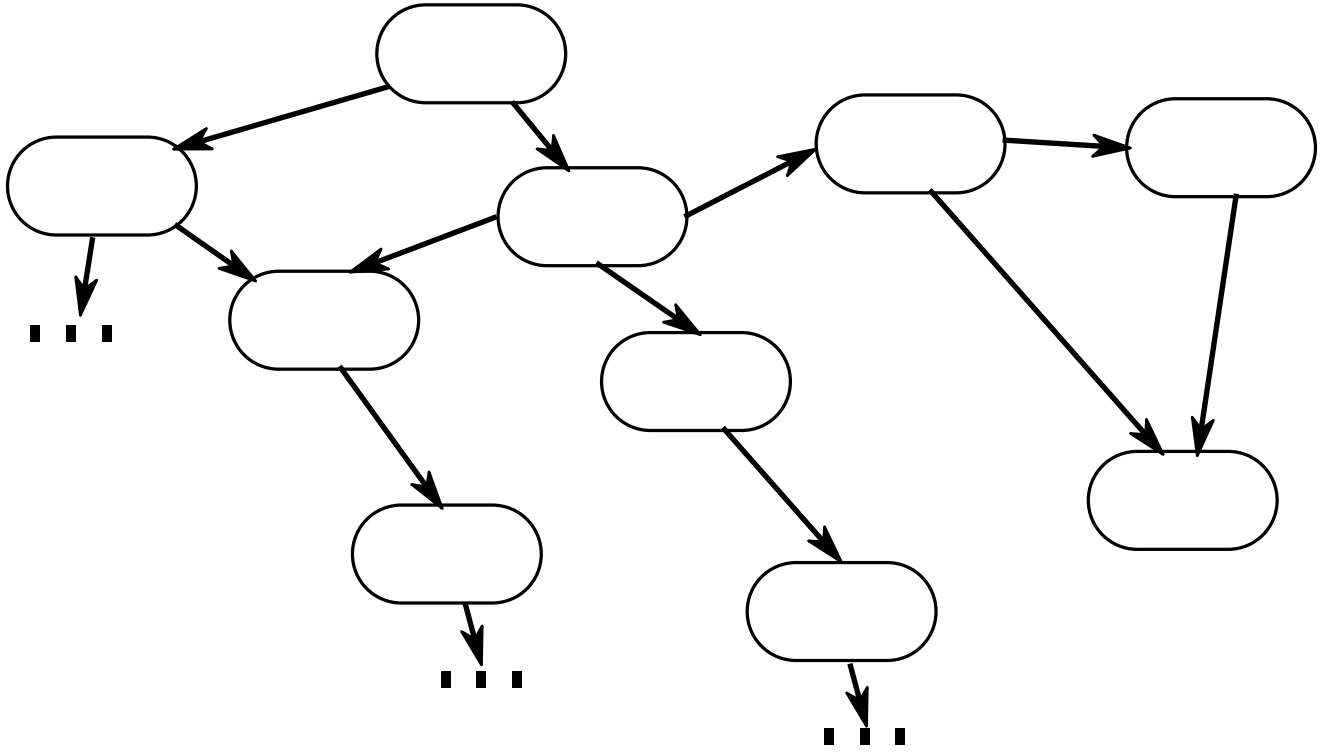

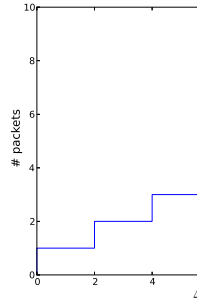

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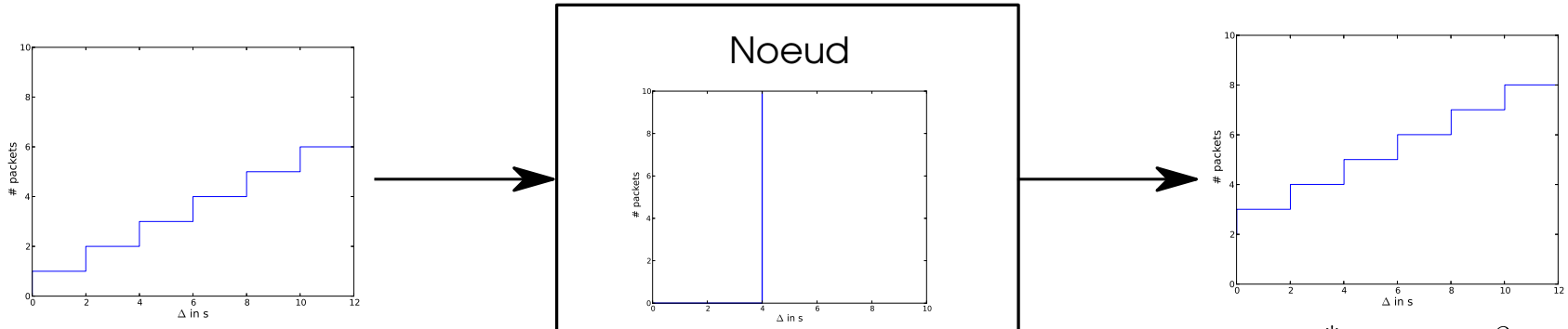

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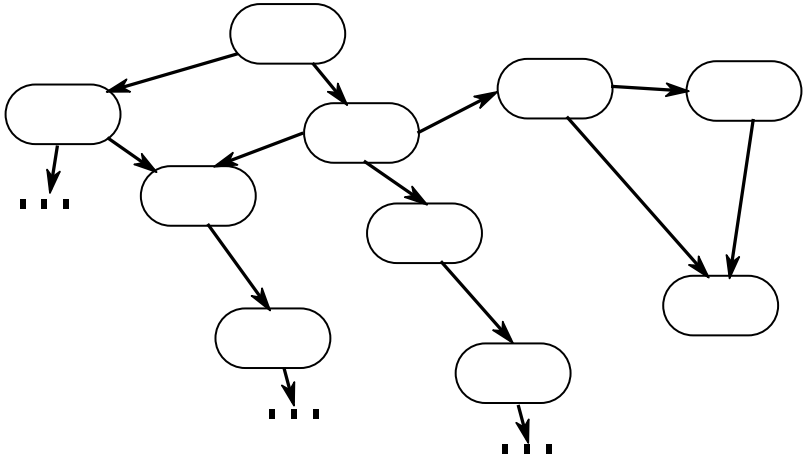

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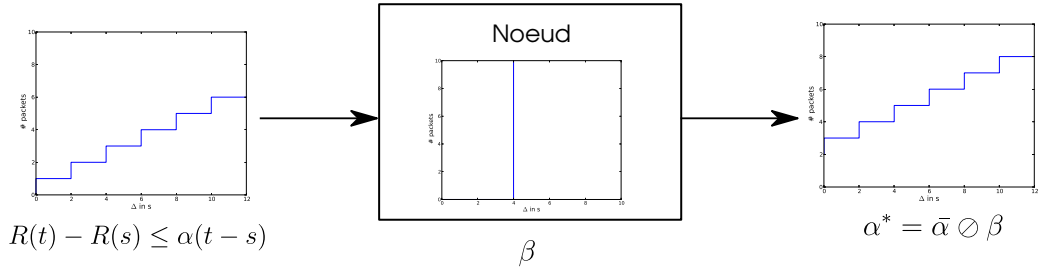

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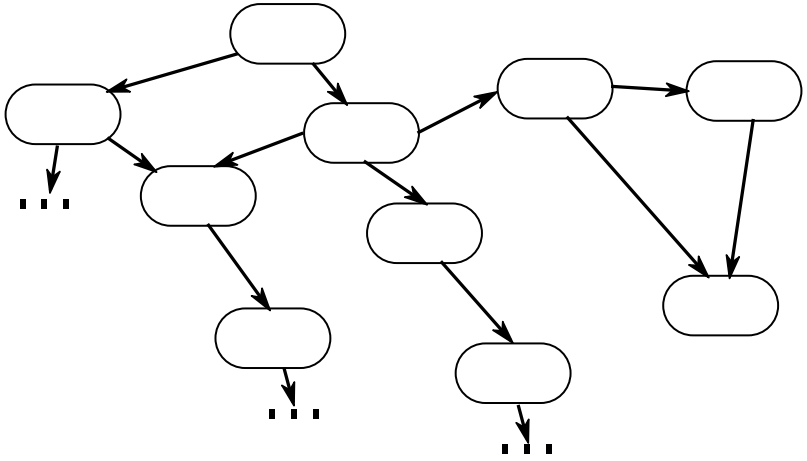

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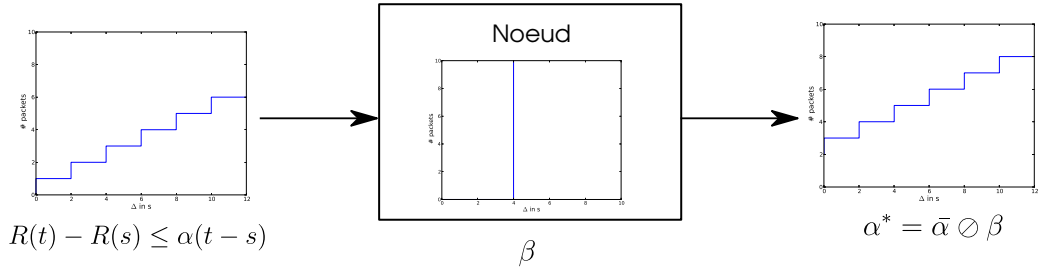

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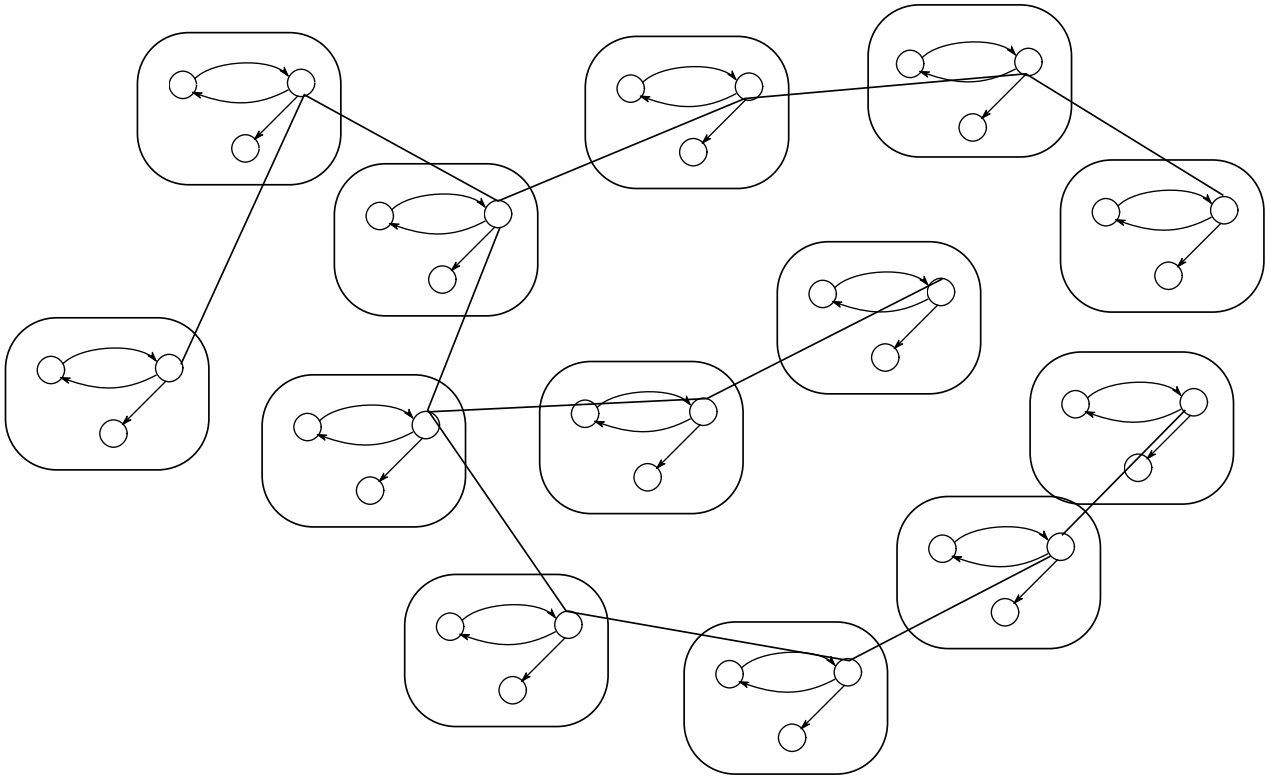
Model Checking seems more convincing at first glance but less applicable to realistic WSNs

Timed Model Checking

The issue:

- A node is represented with a Timed Automaton (with clocks and variables representing its internal state)
- The network is a composition of such automata
- The tree of executions of the network is exponential in the number of clocks and variables



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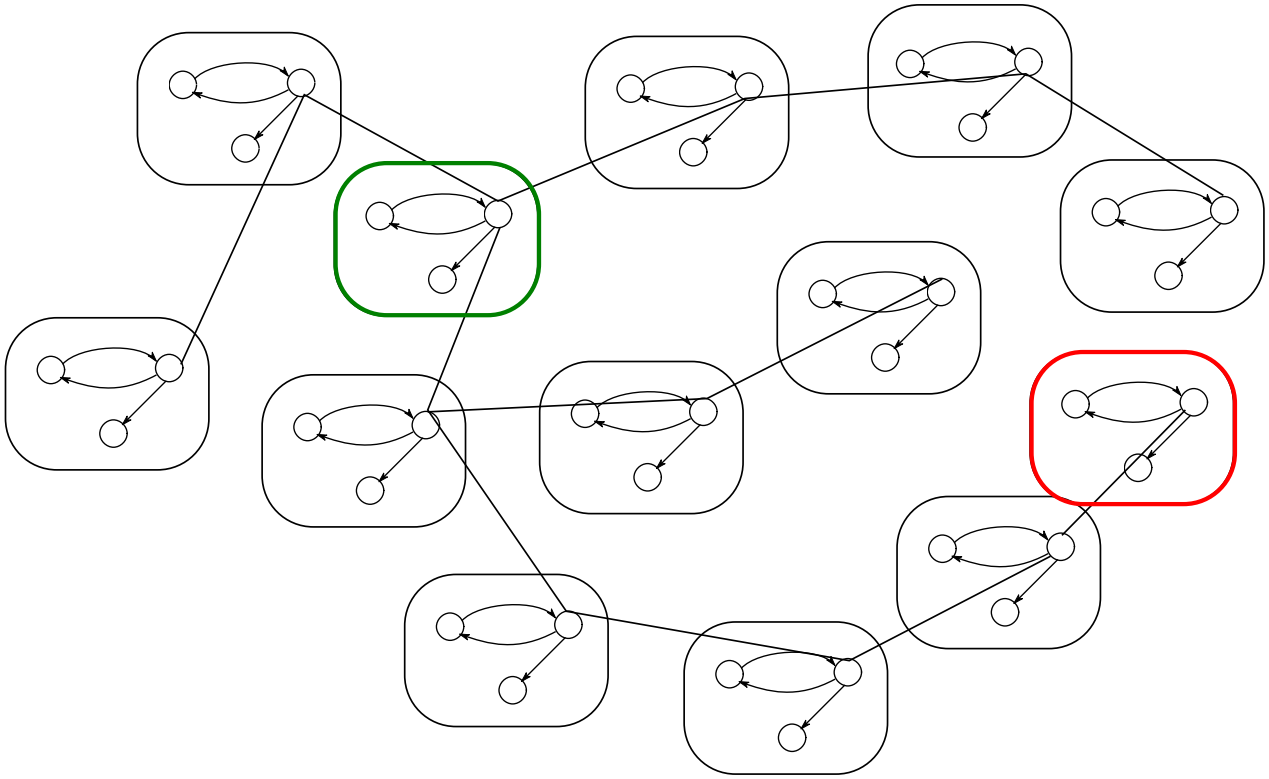

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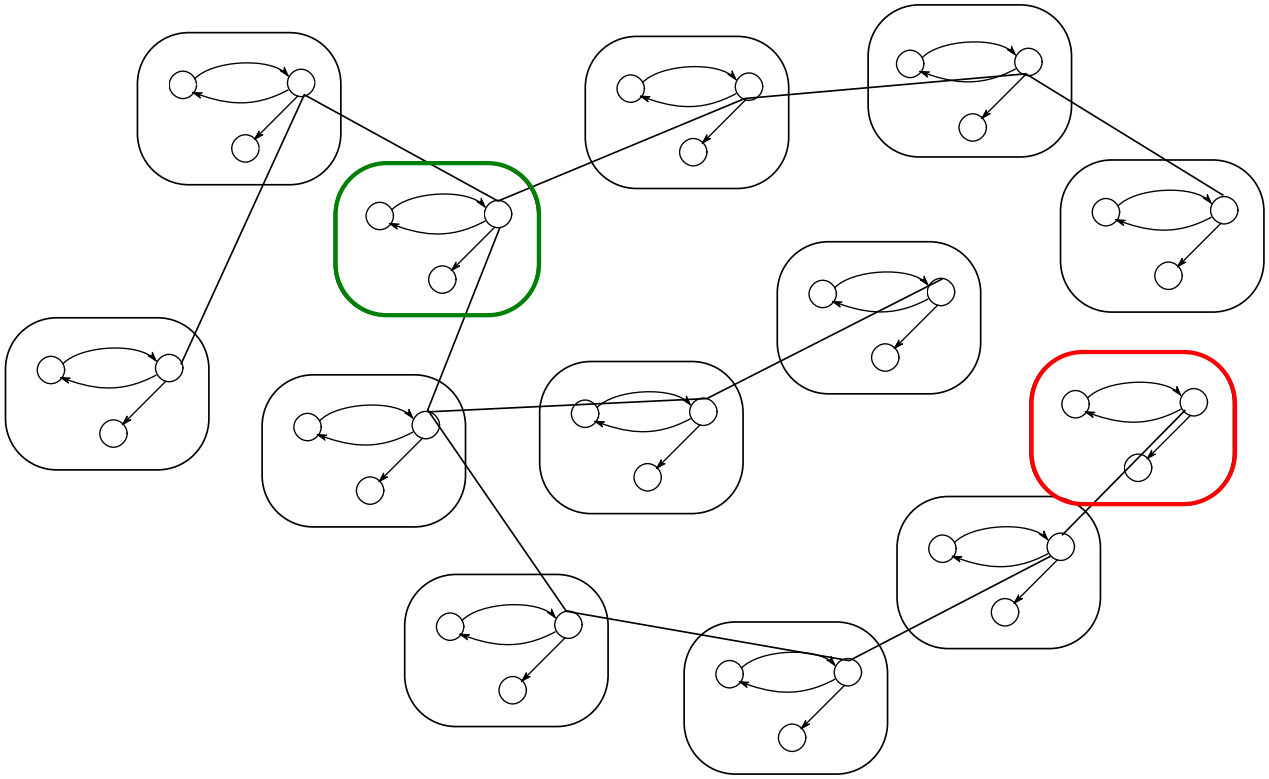

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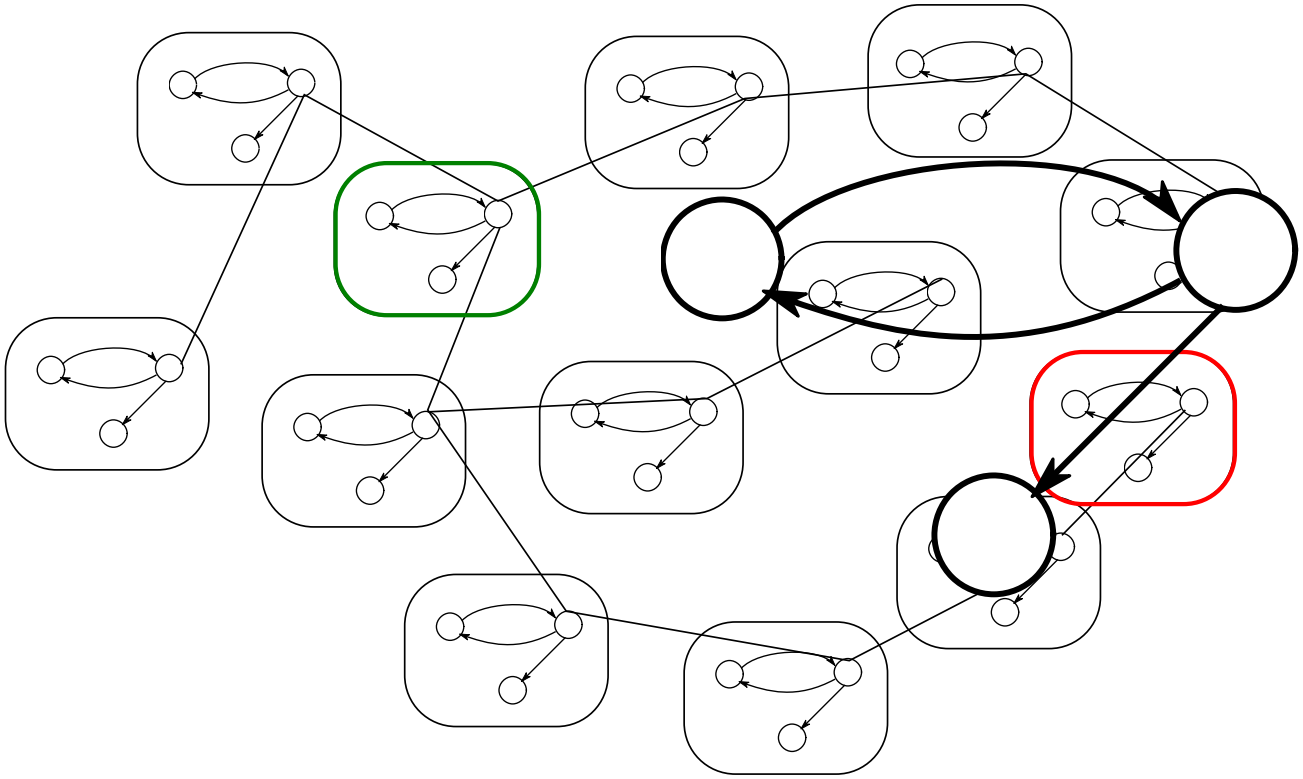
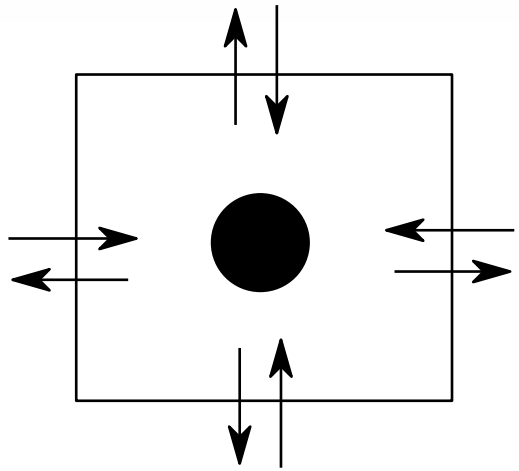


Overview of the scheme



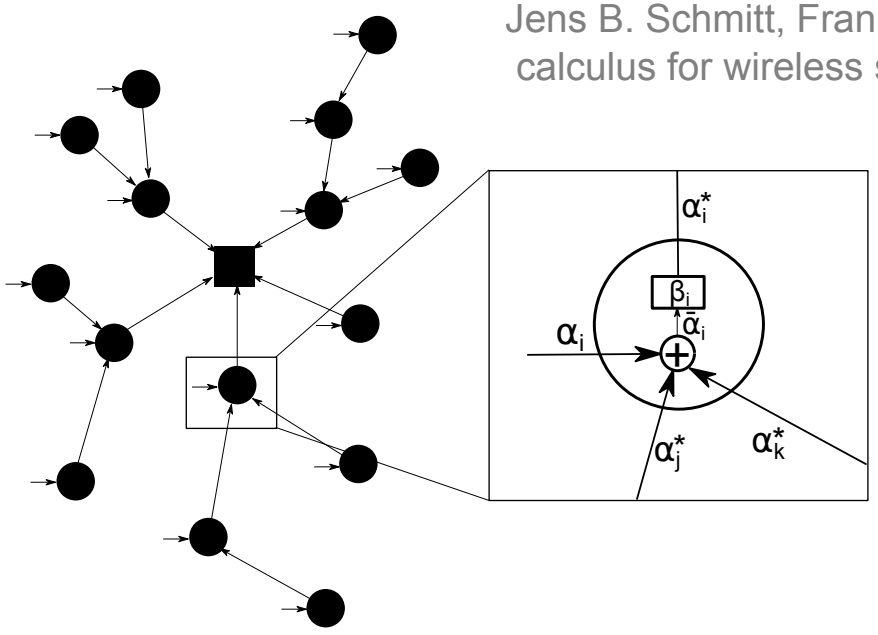
For each node:

1- Express the interactions of each node with the rest of the network: Network Calculus

2- Verify that the node can actually deal with these interactions in bounded time: Model Checking

Sensor Network Calculus

Jens B. Schmitt, Frank A. Zdarsky, and Lothar Thiele. "A comprehensive worst-case calculus for wireless sensor networks with in-network processing." RTSS 2007.



$$\bar{\alpha}_i = \alpha_i + \sum_{j \in Ch(i)} \alpha_j^*$$

$$\alpha_i^* = \bar{\alpha}_i \oslash \beta_i = (\alpha_i + \sum_{j \in Ch(i)} \alpha_j^*) \oslash \beta_i$$

β_i is the service provided by the protocol

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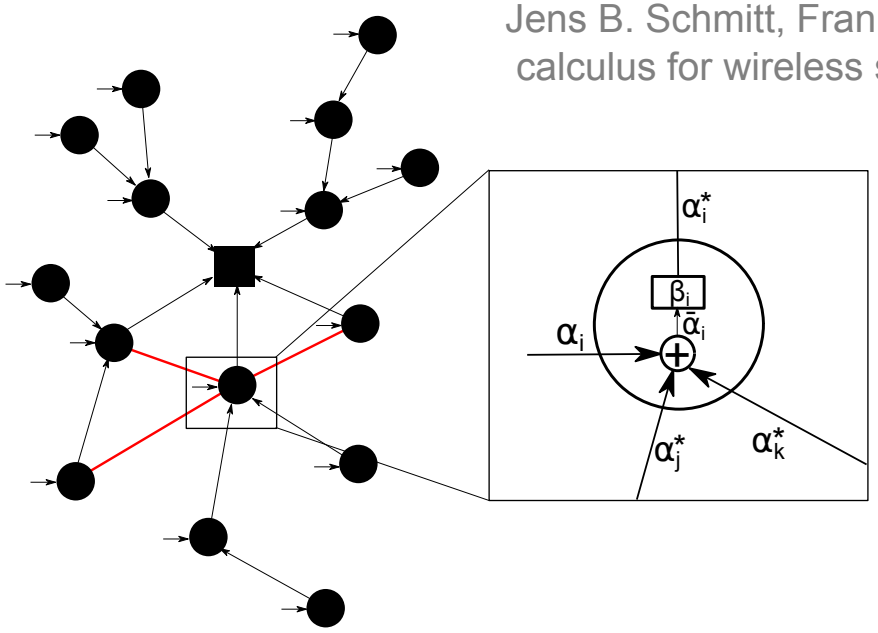

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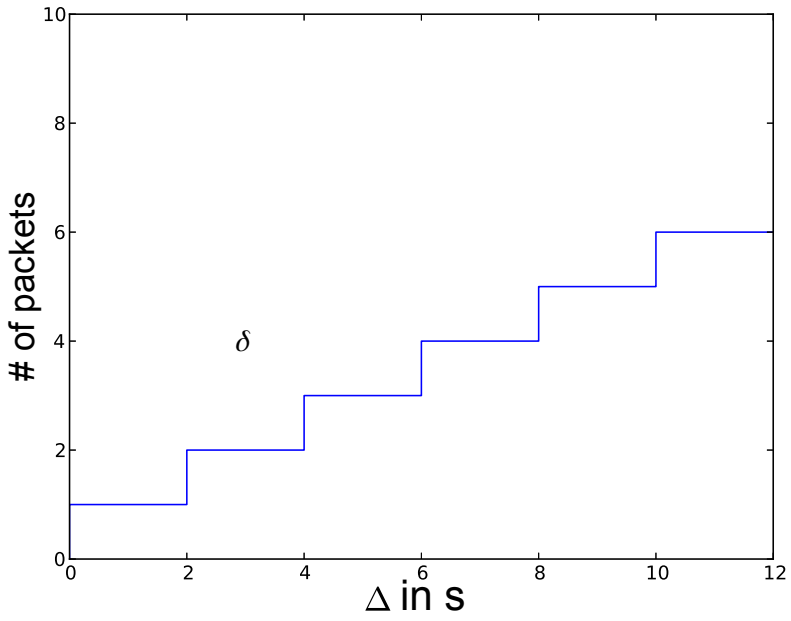
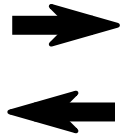
Adding medium access competitors :

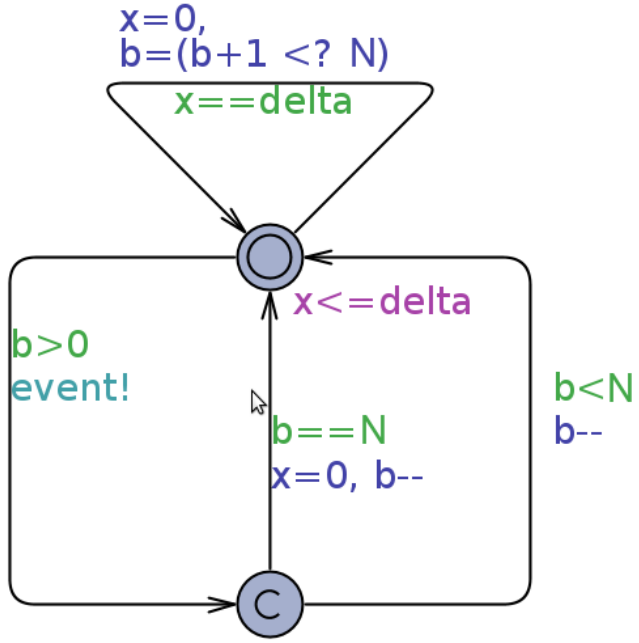
$$\alpha_i^c = \sum_{j \in Cp(i)} \alpha_j^*$$

From curves to automata

Kai Lampka, Simon Perathoner, and Lothar Thiele. "Analytic real-time analysis and timed automata: a hybrid method for analyzing embedded real-time systems." EMSOFT 2009.





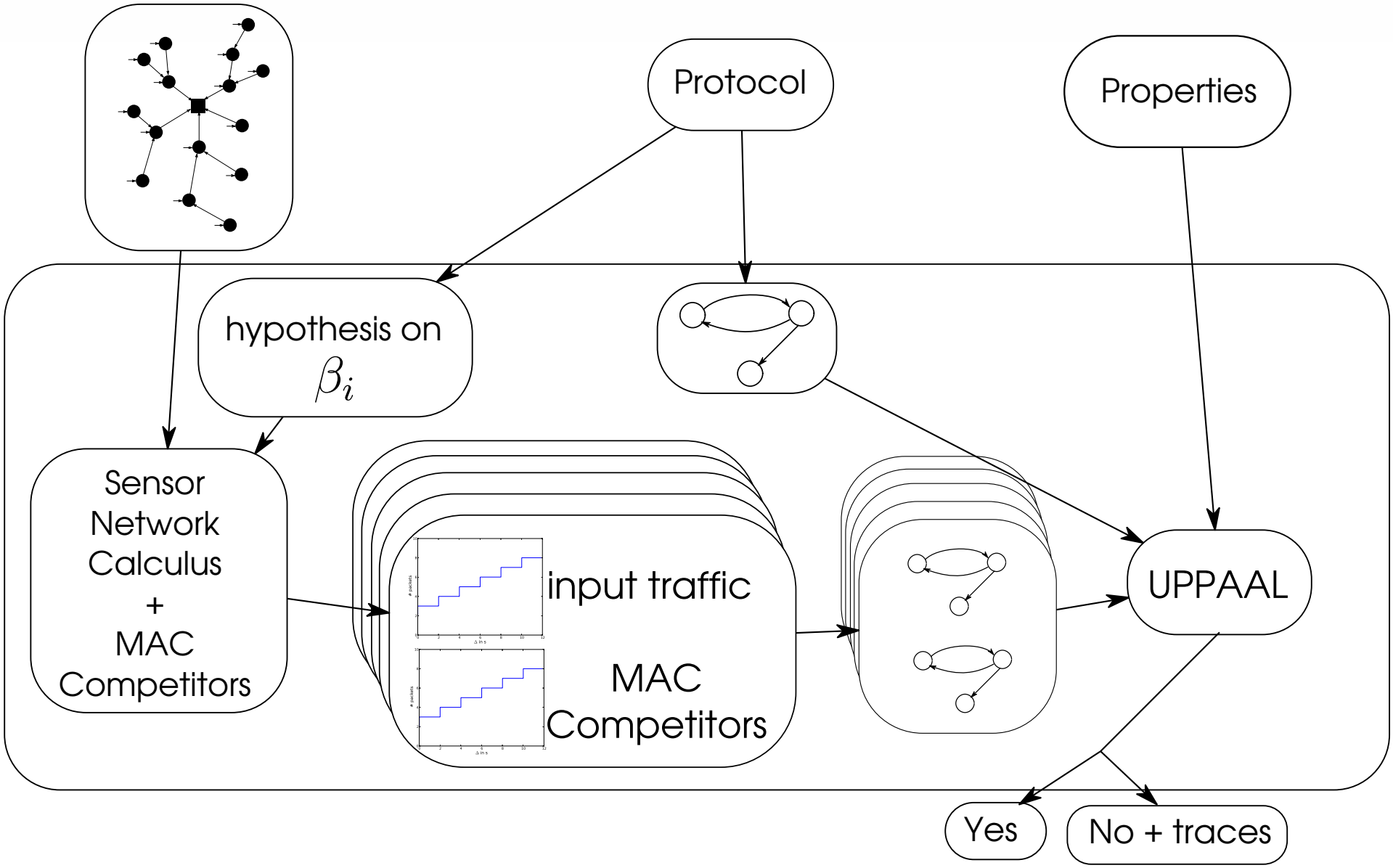


Global declarations:
broadcast chan event;

Local declarations:
clock x;
const int BMAX=N;
int[0,BMAX] b=0;
const int delta=δ;

$$\gamma_N(\Delta) = N + \lceil \frac{\Delta}{\delta} \rceil$$

Proposed verification algorithm



Application of the method

Application to RTXP, a distributed real-time protocol for WSNs

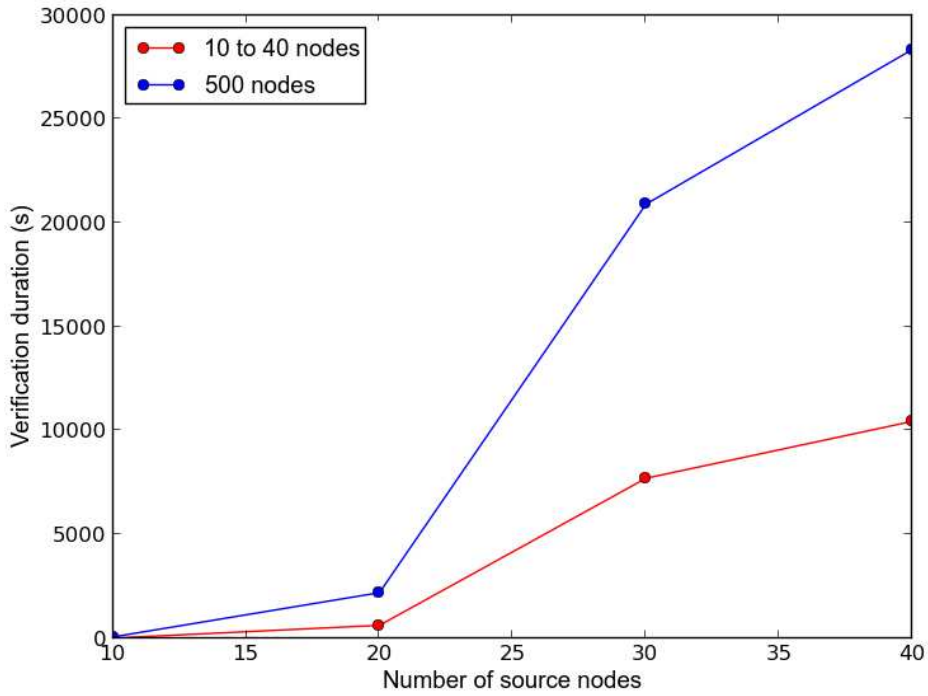
Alexandre Mouradian, Isabelle Augé-Blum, and Fabrice Valois. "RTXP: A localized real-time MAC-routing protocol for wireless sensor networks." Computer Networks 67 (2014): 43-59.

UPPAAL TA model for one node : ~ 30 states, ~ 40 transitions, 3 clocks

Random network graphs :

- 10 to 40 nodes topologies
- 500 nodes topologies
- Number of sources : 10 to 40

We observe that the real-time capacity of RTXP is exceeded with 40 sources.



Conclusion and perspectives

Conclusions

- Novel approach useful for large scale distributed wireless networks
- Take advantage of both Network Calculus and Model Checking
- Scales up to hundreds of nodes

Future works

- Increase the tightness of the bound
- How to represent the network dynamic in Network Calculus ?