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Wireless Sensor Networks

Constraints:
- Limited hardware capabilities
- No fixed infrastructure
- Unreliable Links

Goals:
- Energy efficiency
- Self-organization
- Reliability
- Scalability
- Constrained delays
Context

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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

\[ R(t) - R(s) \leq \alpha(t - s) \]

\[ \alpha^* = \tilde{\alpha} \odot \beta \]

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

\[
\bar{\alpha}_i = \alpha_i + \sum_{j \in Ch(i)} \alpha^*_j
\]

\[
\alpha^*_i = \bar{\alpha}_i \otimes \beta_i = (\alpha_i + \sum_{j \in Ch(i)} \alpha^*_j) \otimes \beta_i
\]

\(\beta_i\) is the service provided by the protocol.
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\( \beta_i \) is the service provided by the protocol

Adding medium access competitors:

\[ \alpha_i^c = \sum_{j \in Cp(i)} \alpha_j^* \]
From curves to automata


\[
\gamma_N(\Delta) = N + \left\lfloor \frac{\Delta}{\delta} \right\rfloor
\]

Global declarations:
- broadcast chan event;

Local declarations:
- clock x;
- const int BMAX=N;
- int[0,BMAX] b=0;
- const int delta=\delta;
Proposed verification algorithm

- Sensor Network Calculus + MAC Competitors
- Protocol
- Properties
- Hypothesis on $\beta_i$
- Input traffic
- MAC Competitors
- UPPAAL
- Yes
- No + traces
Application of the method

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

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.
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?