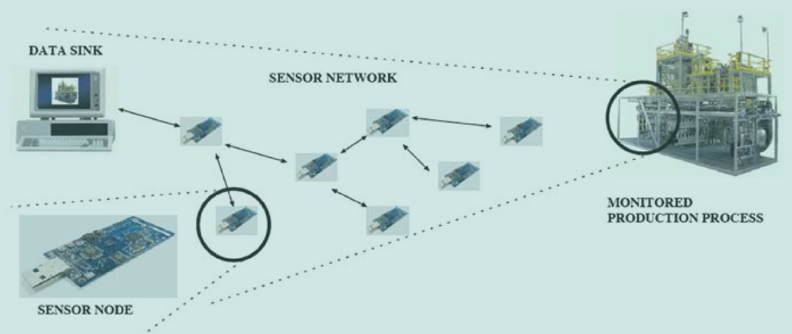
Sensor Networks For Time Critical Applications

Abstract

Existing sensor network installations have in common that they are not considered time critical. No immediate action has to be undertaken as a response to the received data. However, many future application areas of wireless sensor networks such as plant automation and control, traffic management or medical applications require this feature. In such environments, data has to be transported in time through the sensor network. Due to the lack of appropriate models, components and protocols it is currently very difficult to construct and operate a wireless sensor network with a controlled performance. Thus, the commercial success of wireless sensor networks in many application areas is unsure unless this particular problem is understood and solved.

Overview



Current Use Of Sensor Networks

- Example: environmental monitoring
- Network performance in terms of data delivery times is not considered critical
- The sensor network fulfills its intended function if data is delivered late
- Time is available for retransmission and/or data loss can be compensated

Intended Use of Sensor Networks for Time Critical Applications

- Example: production process automation
- Network performance in terms of data delivery times is absolutely critical
- The application can only function if sensor data arrives timely
- Strict time limits for data delivery to the sink exist

Open Research Questions

How can we plan, manage and operate a sensor network for time critical applications?

Which network components should be used ot build a sensor network for time critical applications?

Research Goals

WSNs are not used in applications that require timely reaction to sensor data as

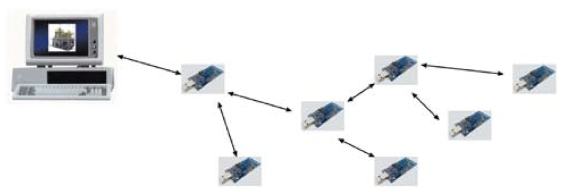
- the performance capabilities of WSNs are unpredictable
- available WSNs do not provide necessary features

The goal of our research is to:

→devise methods that allow us to control and predict sensor network performance

→design network components that allow us to build a performance controlled sensor network

Sensor Network Dimensioning



Sensor networks are currently deployed without exact dimensioning. However, an exact dimensioning - especially regarding data transmission delays - of a sensor network before its deployment is required to a) ensure network functionality in all circumstances b) avoid costly overprovisioning.

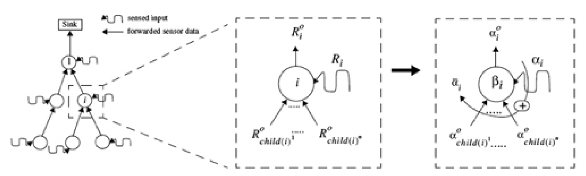
Problem

- Analytical tools to dimension a sensor network do not exist

SNC: Sensor Network Claculus [SR05]

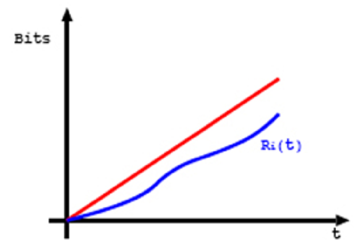
The sensor network calculus (SNC) provides the following features:

- The SNC allows us to determine worst-case bounds for the data transfer delay
- The SNC allows us to relate the data transfer delay with buffer and power needs

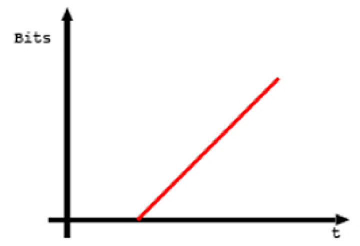


Input function: $\bar{R}_i = R_i + \sum_{j=1}^{n_i} R^{\circ}_{child(i,j)}$

- Maximum expected arrival
- Arrival curves: $\bar{\alpha}_i = \alpha_i + \sum_{j=1}^{n_i} \alpha^{\circ}_{child(i,j)}$



- Minimum expected Service
- Service Curves: β_i



The output of sensor node i is constrained by the following arrival curve:

- $\alpha_i^{\circ} = \bar{\alpha}_i \oslash \beta_i = (\alpha_i + \sum_{j=1}^{n_i} \alpha^{\circ}_{child(i,j)}) \oslash \beta_i$

The delay bounds D_i can be calculated as:

- $D_i = h(\bar{\alpha}_i, \beta_i) = \sup_{s \geq 0}\{\inf\{\tau \geq 0 : \bar{\alpha}_i(s) \leq \beta_i(s+\tau)\}\}$

RESULT: Worst-case delay bounds in the network can be calculated before deployment

References

[DRHS07a] Cormac Duffy, Utz Roedig, John Herbert, and Cormac J. Sreenan. Adding Preemption to TinyOS. In Proceedings of the 4th IEEE Workshop on Embedded Networked Sensors (EMNETS2007), Cork, Ireland, 2007.

[DRHS07b] Cormac Duffy, Utz Roedig, John Herbert, and Cormac J. Sreenan. Improving theEnergy Efficiency of the MANTIS Kernel. In Proceedings of the 4th IEEE European Workshop on Wireless Sensor Networks (EWSN2007), Delft, Netherlands, January 2007.

[RBS06] Utz Roedig, Andre Barroso, and Cormac J. Sreenan. f-MAC: A Deterministic Media Access Control Protocol Without Time Synchronization. In Proceedings of the third IEEE European Workshop on Wireless Sensor Networks (EWSN2006), Zurich, Switzerland, February 2006.

[SR05] Jens Schmitt and Utz Roedig. Sensor Network Calculus - A Framework forWorst Case Analysis. In Proceedings of the International Conference on Distributed Computing in Sensor Systems (DCOSS05), Marina del Rey, USA, June 2005.

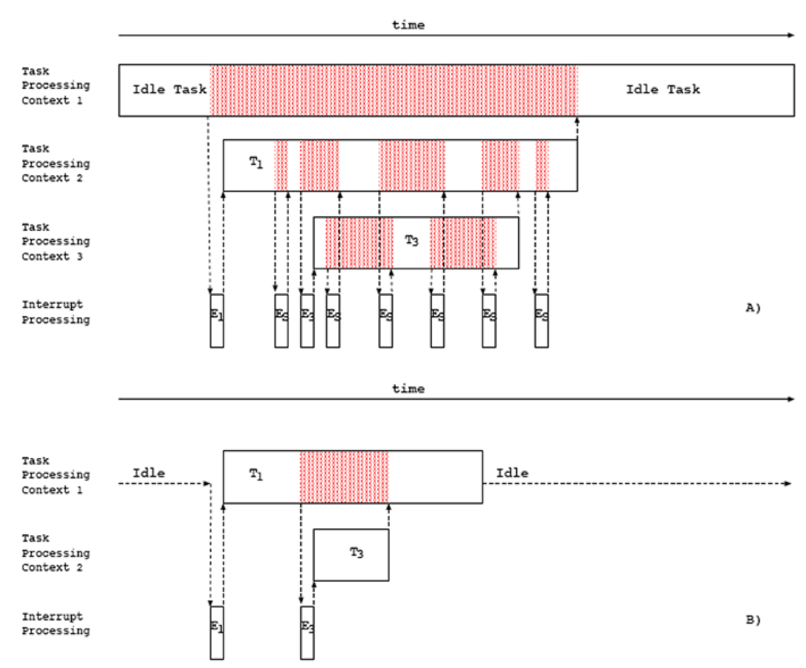
Operating Systems

Sensor nodes must be designed to be energy efficient in order to allow long periods of unattended network operation. In addition, timely processing and reporting of sensing information is often required as well.

Problem

- Event-based operating systems: no timely processing, energy efficient operation
- Multi-threaded systems: timely processing, energy in-efficient operation

Option1: Improve Energy Efficiency of Multi-threaded Systems [DRHS07b]



Existing MANTIS limitations:

- Idle thread for power management
- Time slicing for multitasking

→ Many energy consuming context switches

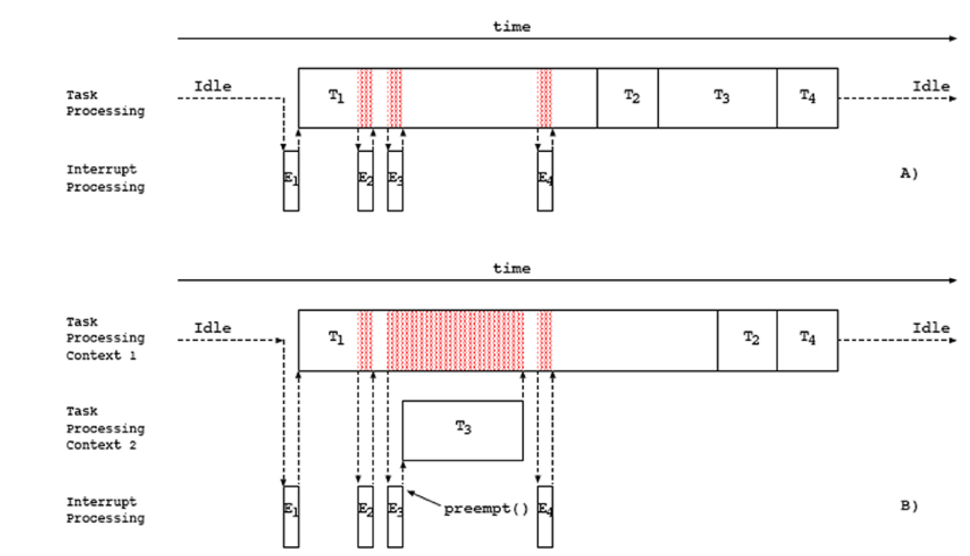
Introduced MANTIS modifications:

- Idle thread removed
- Time slicing as optional library
- Simplified kernel queue structure

→ MANTIS can be modified to be as power efficient as TinyOS

→ Multi-threaded operating systems can be suitable for resource constrained sensor networks

Option2: Improve Energy Efficiency of Multi-threaded Systems [DRHS07b]



Existing TinyOS limitations:

- Sequential task processing

→ Task prioritization is not supported

Introduced TinyOS modifications:

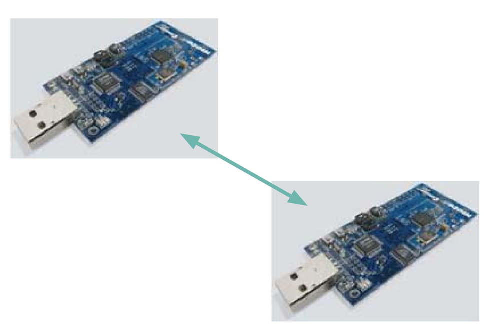
- Introduction of a priority scheduler
- Support of task preemption mechanisms

→ Task prioritization and preemption in TinyOS

→ Existing TinyOS programming conventions are retained

RESULT: Energy efficient AND responsive operating systems for sensor networks

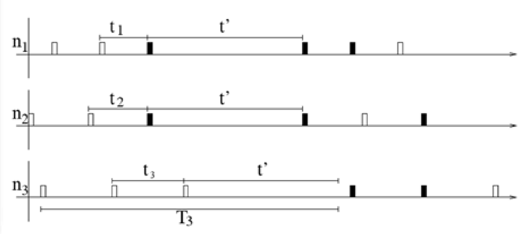
Medium Access Control



Media Access Control (MAC) protocols for sensor networks are designed to be as energy efficient as possible. However, for many application areas hard guarantees regarding transmission delay are considered to be the most important design goal.

Problem

- Contention based MAC protocols: simple design, no delay guarantees
- Schedule based MAC protocols: complex (e.g. time sync), delay guarantees can be given F-MAC: A Deterministic MAC Protocols Without Time Sync [RBS06]



Protocol principle

- Messages are repeated several times (framelets)
- Each node sends framelets with a different frequency

→ At least one framelet of each transmission is received

RESULT: A simple AND deterministic MAC protocol for sensor networks

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Project Part-Financed by the European Regional Development Fund
NW Objective 2 Programme 2000-06 NW Knowledge-Based Action Plan www.nwua.ac.uk