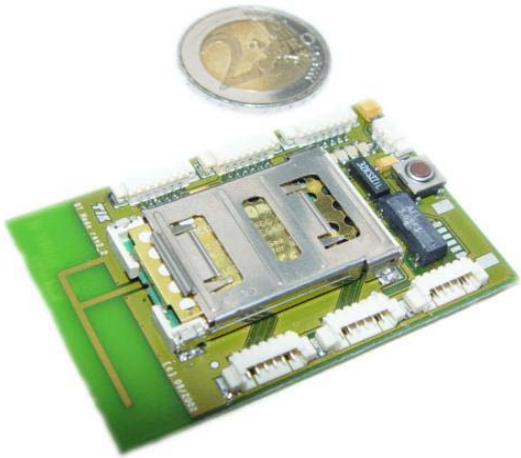


BTnodes

Scaling it up

Networking using the BTnode Platform

Jan Beutel

Computer Engineering
and Networks Laboratory

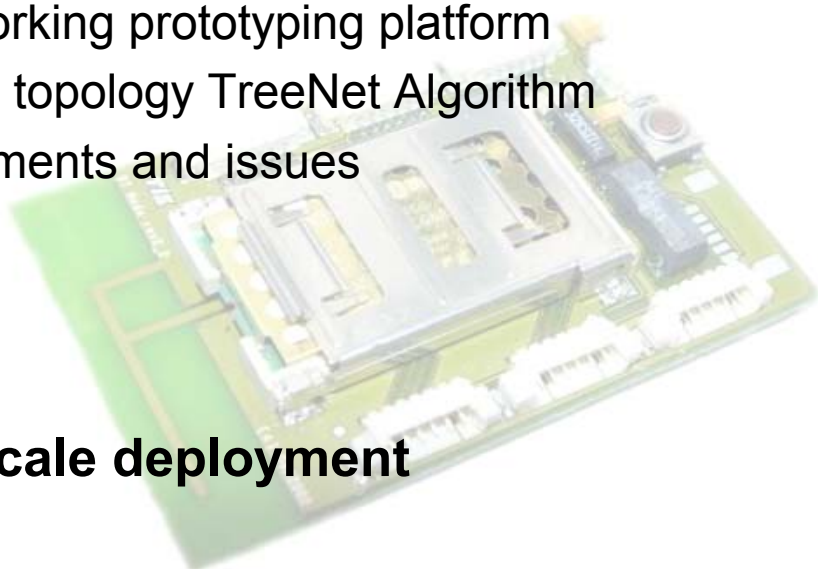
ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Outline

Wireless Sensor Networks – visions and current status

Example: Constructing network topologies using Bluetooth

- BTnode – Ad hoc networking prototyping platform
- robust, self-healing tree topology TreeNet Algorithm
- implementation requirements and issues



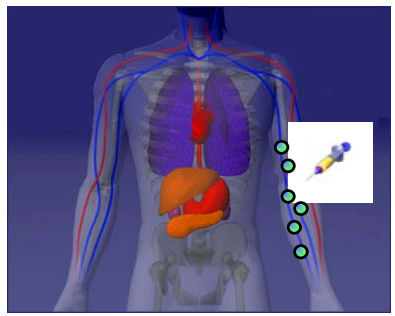
Lessons learned

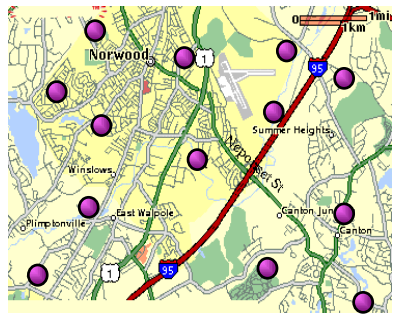
Open issues for large scale deployment

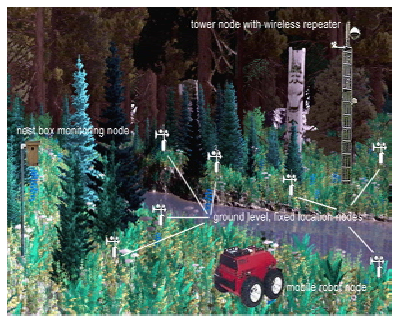
Wireless Sensor Networks visions

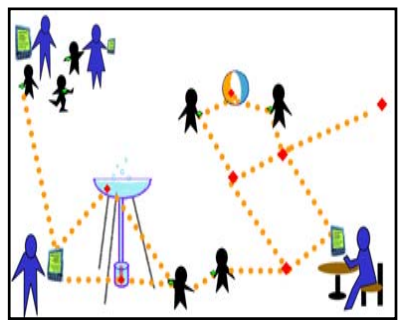
Large scale of proposed systems

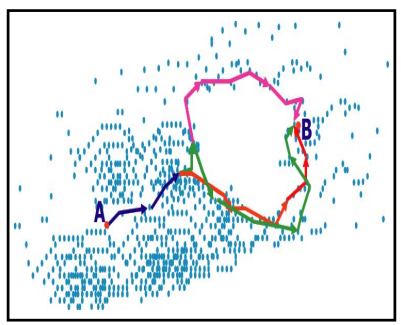
- centralized, decentralized, clustered
- very few, many, massive amounts
- functionally rich, constrained
- homo-, heterogeneous
- self-configuring, managed
- failure tolerant, QoS











Smart Dust *[Kahn1999]*
Paintable Computing *[Butera1999]*
Picoradio *[Rabaey1999]*
Terminodes *[Hubaux1999]*
Amorphous Computing *[Abelson2001]*
Specnet *[Arvind2003]*
Diffusion *[Estrin2000]*
WINS *[Pottie2000]*

Wireless Sensor Network systems today

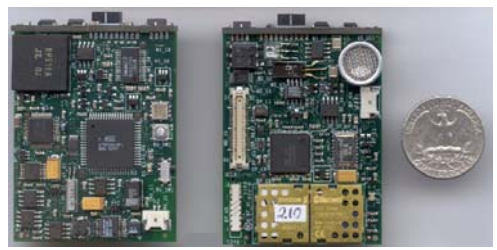
Sub mm scale, super high density all the way to layered, semi infrastructure dependant iPAQ/PC architecture nodes.

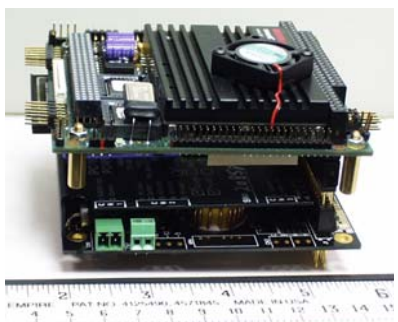
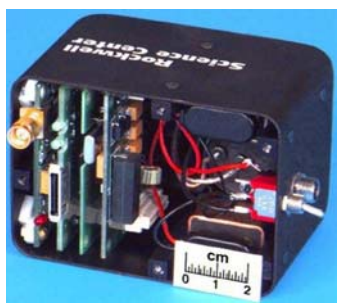






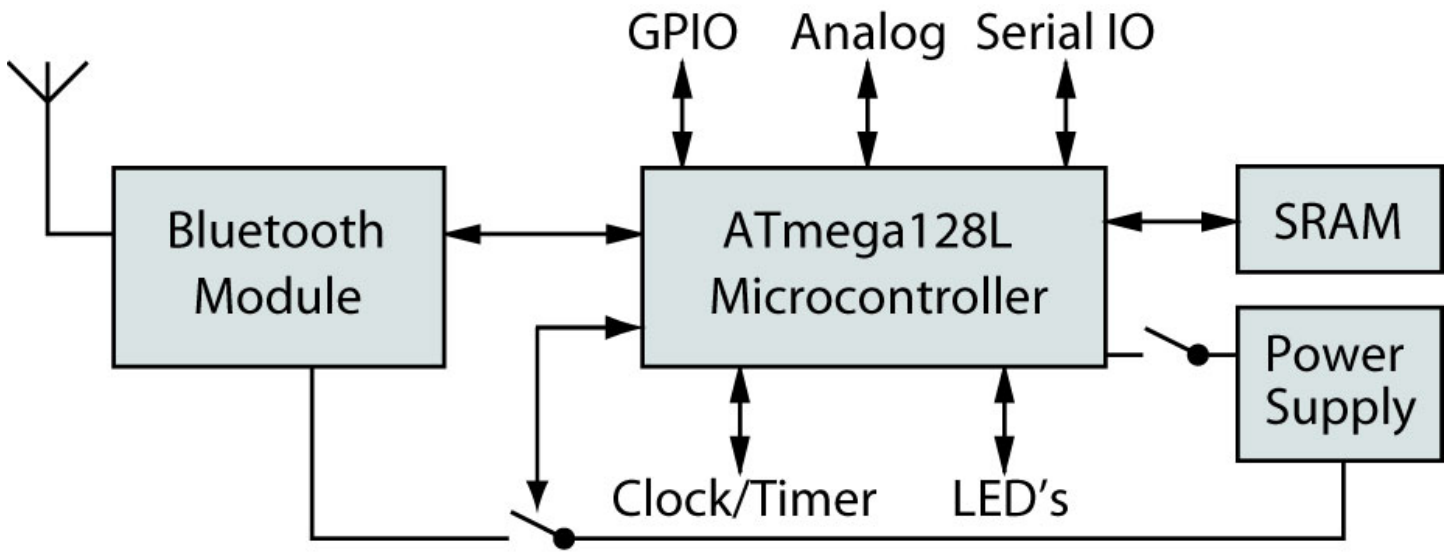




BTnode prototyping platform

Lightweight wireless communication and computing platform based on a Bluetooth radio module and a microcontroller.



Bluetooth has the advantage of

- availability today for experimentation
- compatibility to interface to consumer appliances
- an abstract, standardized high level digital interface

Bluetooth architecture details

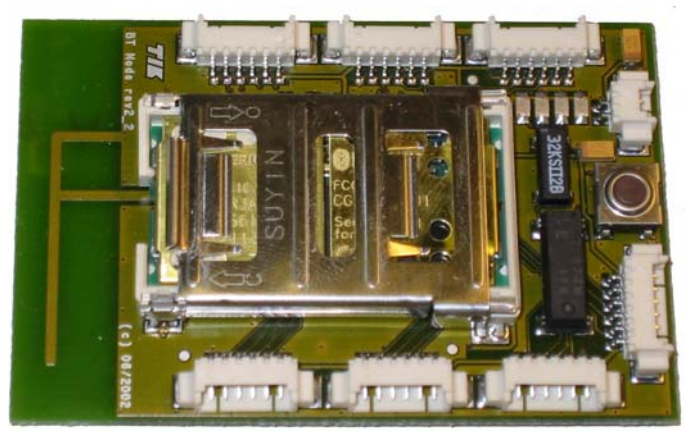
Integrated hardware features

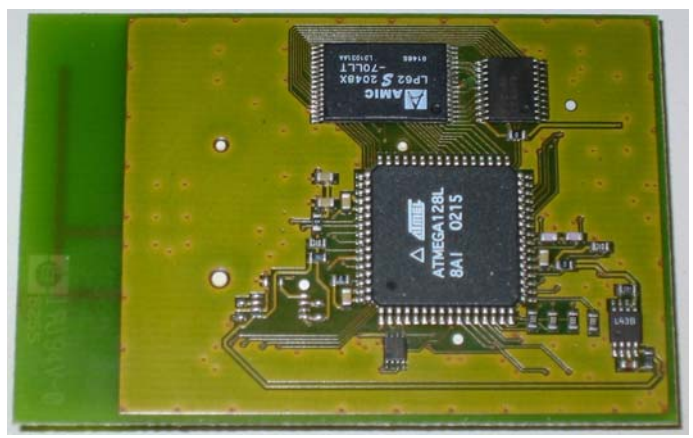
- 8-Bit RISC, max. 8 MIPS, 128 kB Flash, 64 kB SRAM, 180 kB data cache
- operating from 3 cell batteries
- generic sensor interfaces

Event-driven lightweight OS

- standard C language
- system software available as library

Current bill of material	**50 parts**
Parts	60 USD
Assembly	5 USD
Bluetooth	45 USD
Unit cost @ 200 units	110 USD





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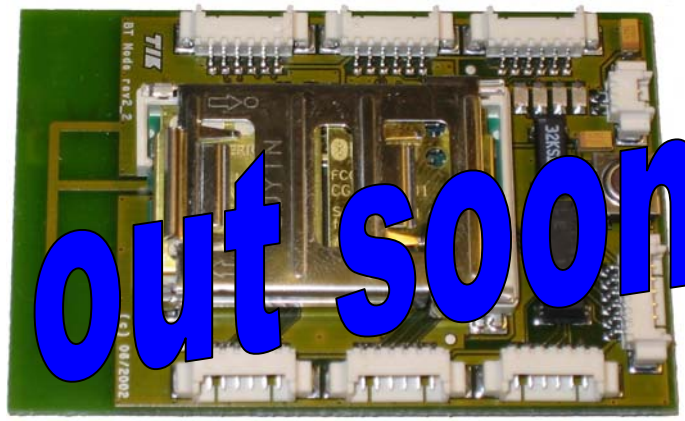
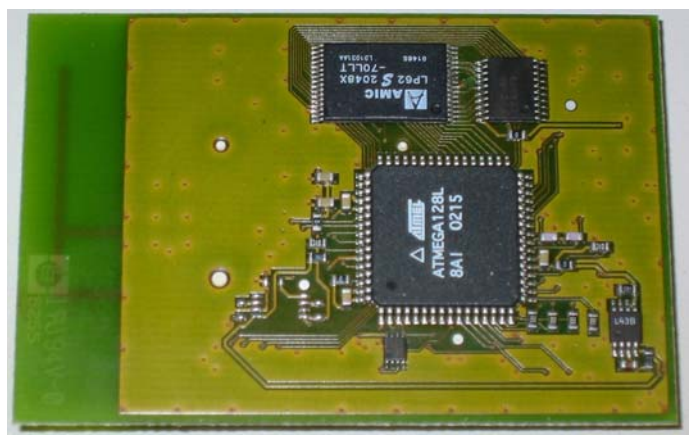
BTnode rev3 out soon





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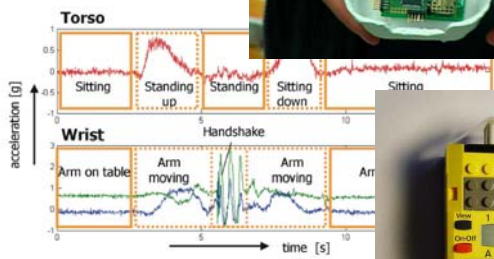
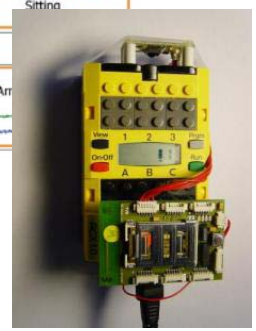
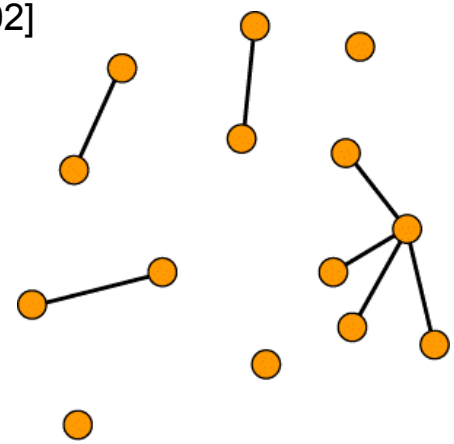
Other BTnode applications

Many successful BTnode applications

- The Lighthouse location system [Roemer2003]
- Smart product monitoring [Siegemund2002]
- Bluetooth enabled appliances [Siegemund2003]
- Smart It's friends [Siegemund2003]
- XHOP/R-DSR multihop prototype [Beutel2002]
- Distributed positioning – TERRAIN implementation [Frey2003]
- Physical activity detection network [Junker2003]
- Better avalanche rescue through sensors [Michahelles2002]
- Wearable unit with reconfigurable modules [Plessl2003]
- Undergrad projects with Lego Mindstorms [Blum2003]
- …





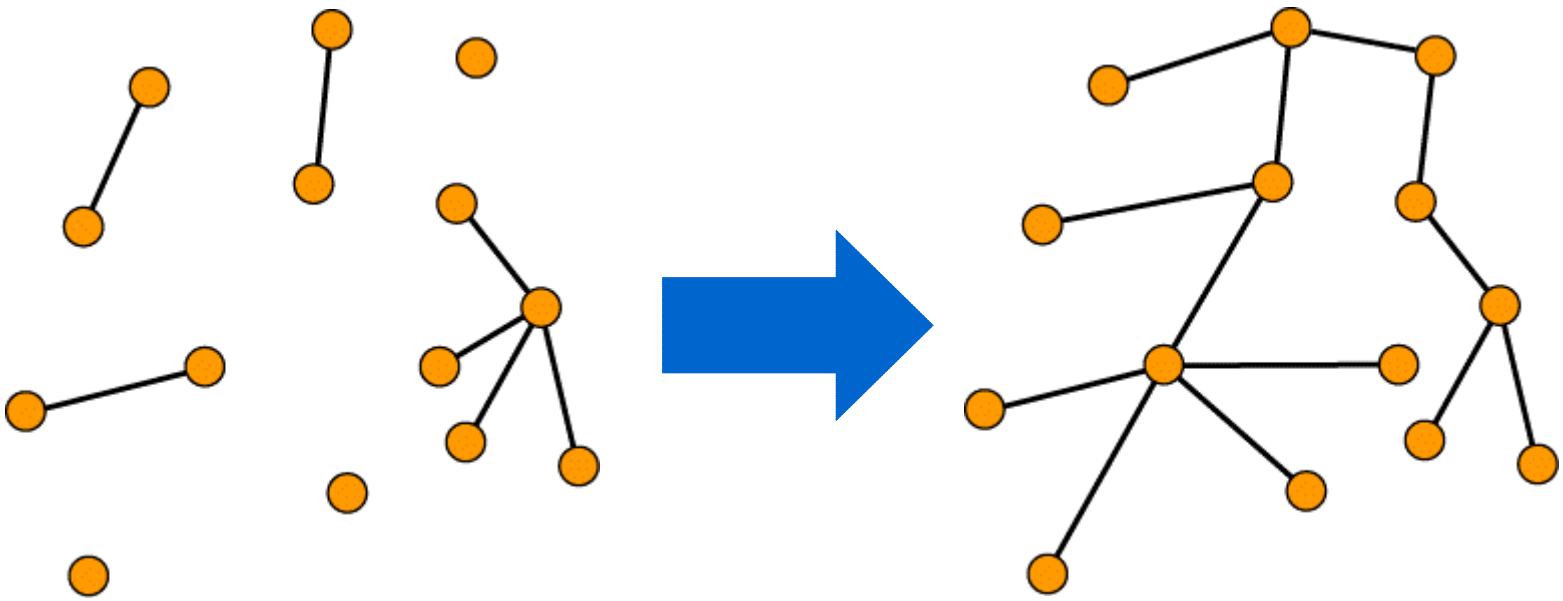


Mostly relying on simple point to point data links

Constructing large network topologies

How to construct an ad hoc network topology with Bluetooth

- large network, many devices
- all devices connected, supporting transparent multihop transport



XHOP prototype

TreeNet topology

TreeNet simple tree construction

Every node executes algorithm

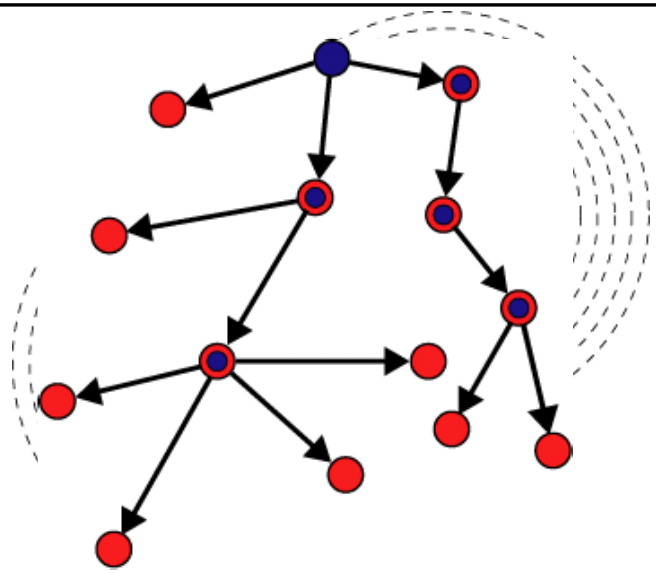
- until a single tree is reached

Formation of large topologies

- robustness
- simplicity
- redundancy
- distribution
- self-healing

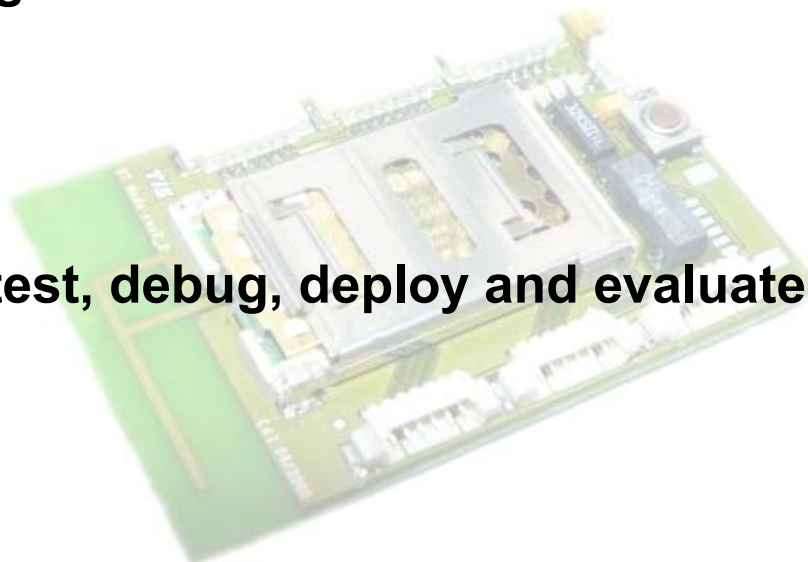
Demonstrated with 40 nodes at NCCR-MICS annual review

```
loop {
  inquiry();
  forall (nodes_found) do {
    while (not_max_degree)
      connect();
  }
}
```



Lessons Learned

A. A 7 line high level algorithm leads to about 2000 lines of code.

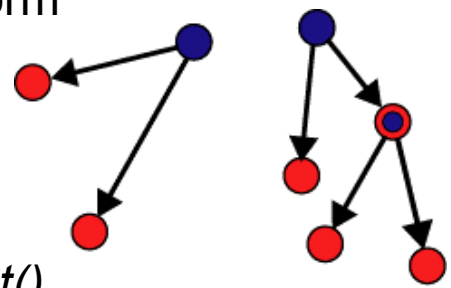


B. It is very difficult to test, debug, deploy and evaluate a large amount of devices.

A. Code size and complexity

Lockup issues

- might not fully connect if multiple max_degree roots form
- distributed *inquiry()* and *connect()* problem



Performance issues

- simple greedy algorithm reduces *inquiry()* and *connect()*
- highly non-deterministic behavior

Basic underlying infrastructure

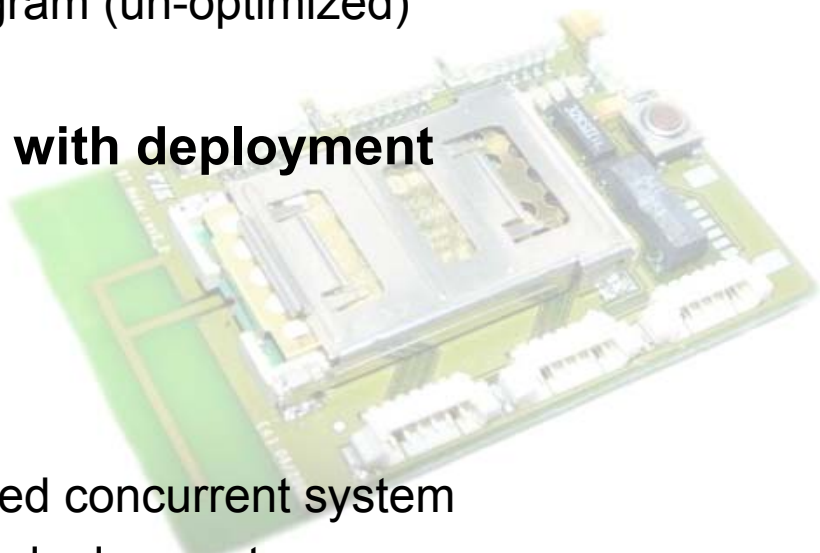
- data storage and exchange
- timing and time-stamping
- connection/link management

Leads to about 2000 lines of additional code!

B. Large scale distributed deployment

So why do we actually need even more lines of code?

- additional system software + debugging + visualization + monitoring
- stepwise testing and deployment
- result in an ~87 kB program (un-optimized)

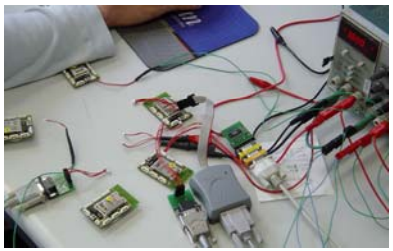


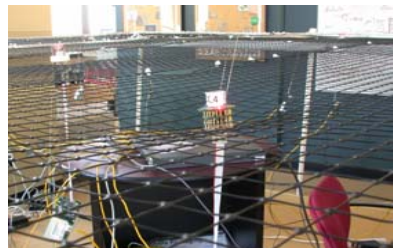
Other problems we had with deployment

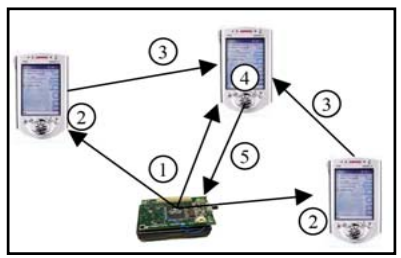
- cables
- batteries
- mounting/casing
- (re-)programming
- debugging of a distributed concurrent system
- developing for stepwise deployment
- visualization/analysis
- online access to nodes
- …

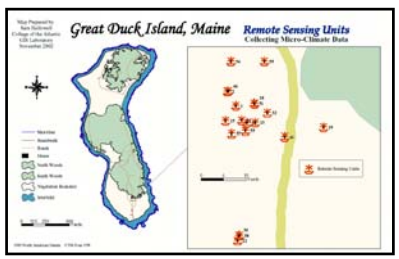
WSN development reality

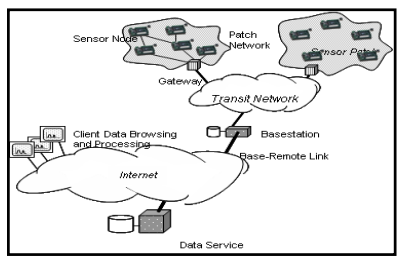
It is hard to deploy anywhere beyond 10-20 nodes today.



Coordinated methods and tools are missing today.

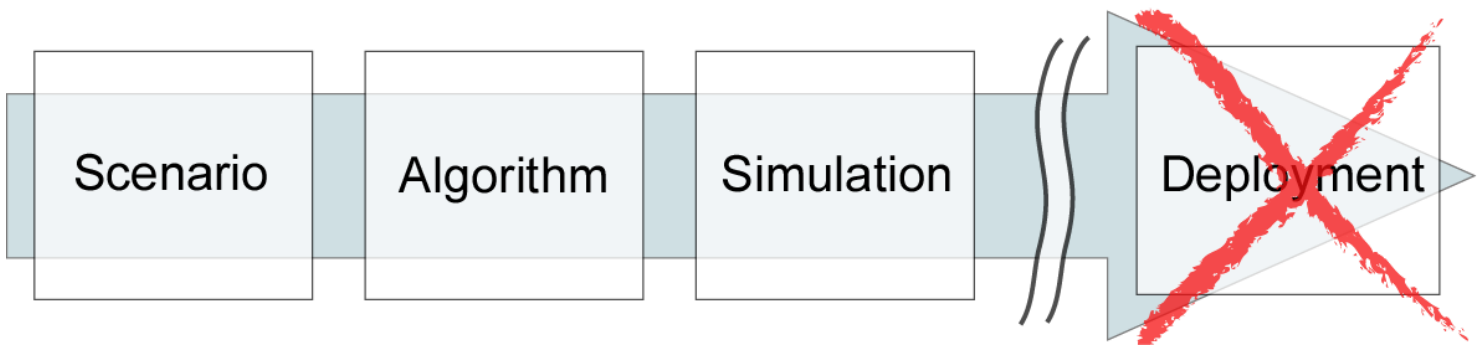
Motivation for future work

A. Models and methods for the design.

- How do we deal with unreliable links?
- Do we need a model that enables formal verification and optimization of parameters (e.g. time outs)?
- How do we integrate this into OS and deployment concepts?

B. Deployment.

- Is there a methodology for a stepwise refinement?
- How do we debug and quantify?
- Situation today:



Acknowledgements

BTnode/TreeNet collaborators

- Oliver Kasten, Friedemann Mattern, Matthias Ringwald, Kay Römer, Frank Siegemund
- Regina Bischoff, Roger Wattenhofer, Aaron Zollinger
- Jan Beutel, Matthias Dyer, Lennart Meier, Martin Hinz, Lothar Thiele

Related publications

J. Beutel et al.: *Prototyping Wireless Sensor Networks with BTnodes.* EWSN 2004.

R. Bischoff and R. Wattenhofer: *Analyzing Connectivity-Based Multi-Hop Ad Hoc Positioning*, PerCom 2004.

J. Beutel, O. Kasten and M. Ringwald: *BTnodes - A Distributed Platform for Sensor Nodes.* ACM SenSys 2003.

K. Römer: *The Lighthouse Location System for Smart Dust.* ACM MobiSys 2003.

O. Kasten, M. Langheinrich: *First Experiences with Bluetooth in the Smart-Its Distributed Sensor Network.* PACT 2001.

Thanx for material to

- Deborah Estrin, Jeremy Elson, Ivo Locher, Mani Srivastava, UCLA
- David Culler, Rob Szewczyk, Paul Lewis, Jan Rabaey, Brian Boser, UC Berkeley
- Ralph Kling, Intel Research