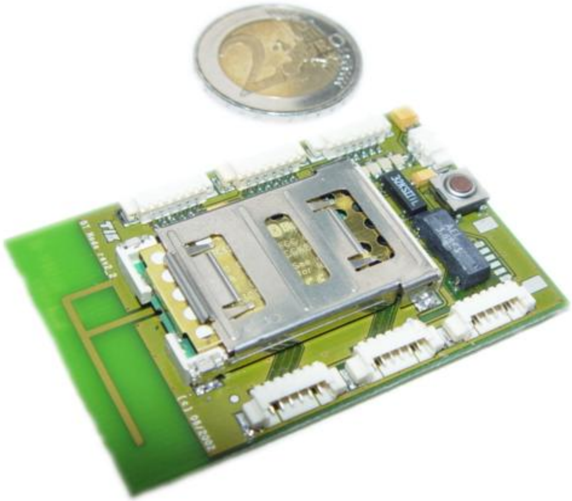


# BTnodes

Computer Engineering and Networks Laboratory

## Topology Discovery and Multihop Networking

Jan Beutel

IP9 - Communicating Embedded Systems

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

# Outline

**Highlight the idiosyncrasies of multihop ad hoc networking on real devices**

**BTnode - Ad hoc networking prototyping platform**

**Constructing network topologies using Bluetooth**

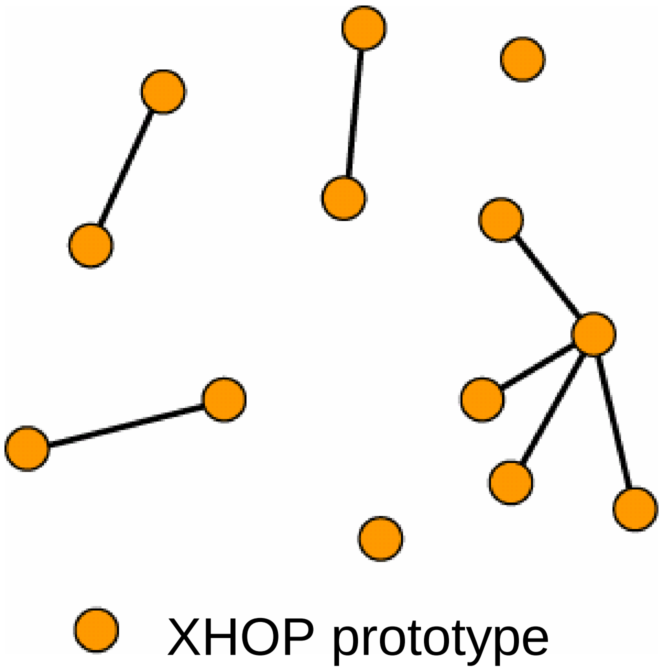
**First implementation of a robust, self-healing tree topology**

# Large ad hoc network topologies

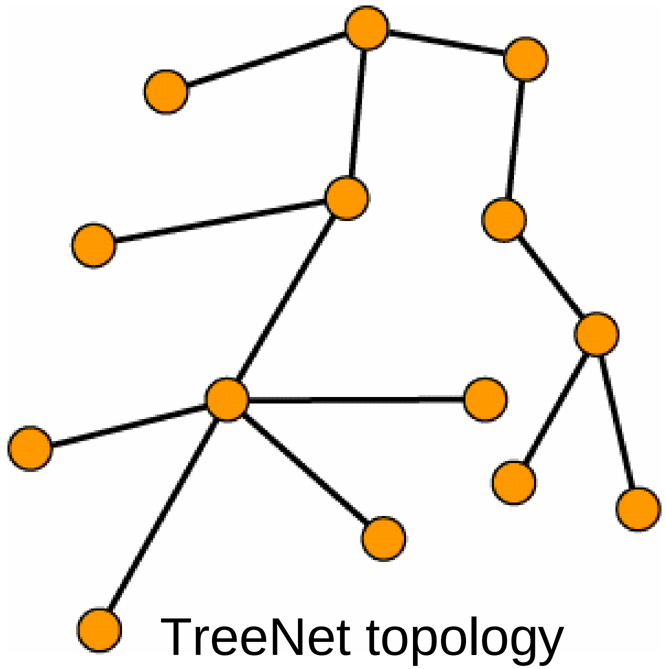
**How to construct an ad hoc network topology with Bluetooth**

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

**Understanding the limits and benefits of Bluetooth**



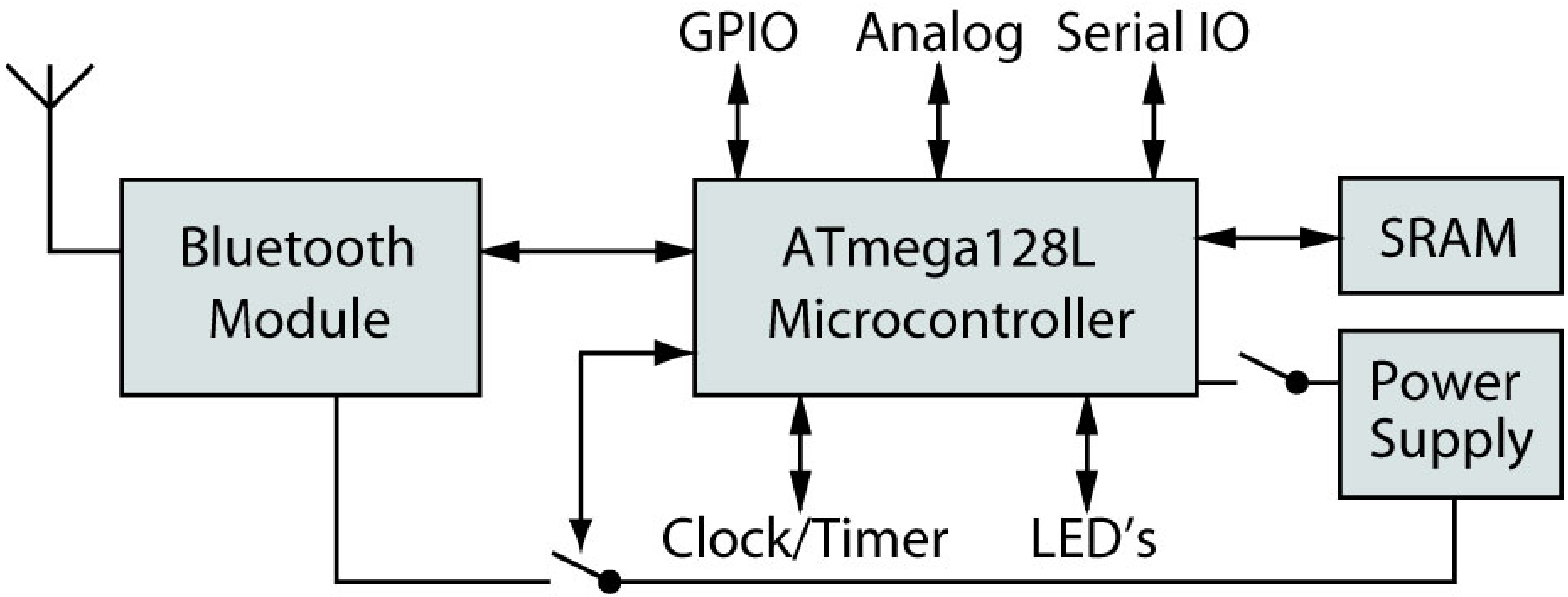
XHOP prototype



TreeNet topology

# BTnode architecture

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



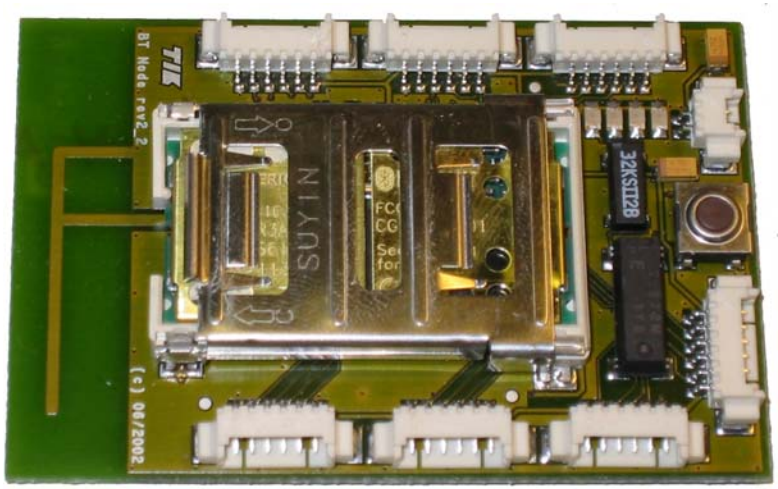

**Bluetooth has the advantage of**

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

# Bluetooth prototyping platforms

## Integrated hardware features

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



## Event-driven lightweight OS

## Dual Bluetooth stack for TinyOS

- developed on the BTnodes
- scalability to multiple frontends
- good energy-per-bit ratio due to high throughput of Bluetooth

  DistLab, U Copenhagen [Leopold2003]

## imote – the Intel research mote

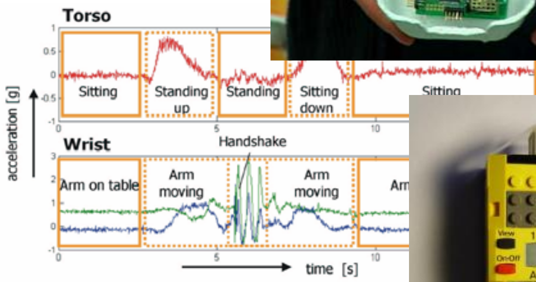
- 1G prototype based on Zeevo Bluetooth module, integrated arm host

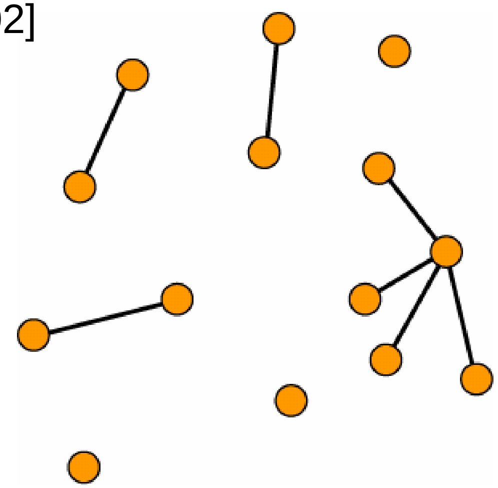
  [Kling2003]

# 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 network topologies

**Scatternet formation algorithms**

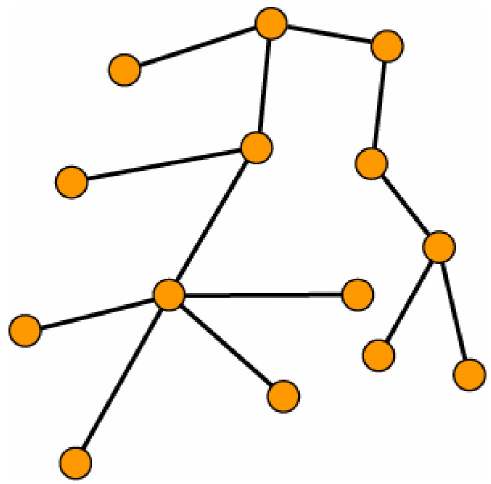
- many theoretical studies and simulations often far away from reality
- improvements in the current Bluetooth voting draft specification v1.2

**BlueStars** [Basagni2002/3]**, BlueRing** [Lin2003] **…**

- make assumptions on physical prerequisites not available today
- assume “perfect” connection performance
- assume symmetric data availability on nodes

**Ad hoc network topologies only in simulations**

- usually all using the same underlying physical models
- often lacking realistic distributed system models for large networks
- limited access to appropriate hardware devices



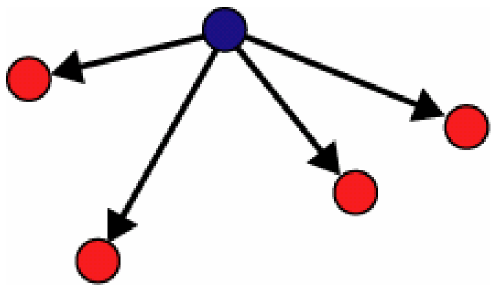
# BTnode networking – definitions

**Four states**

- IDLE
- MASTER
- SLAVE
- MASTERSLAVE

**Useful operations**

- *inquiry()* – find other nodes
- *connect()* – open connection
- *roleSwitch()* – change MS relation
- *sendData()* – data transport



**Hardware limitations on the BTnodes/Bluetooth**

- max. 7 active slaves in one Piconet
- while in *inquiry()* and *connect()* a node is not visible
- while in SLAVE or MASTERSLAVE a node is not visible
- while in SLAVE or MS a node cannot do *inquiry()* or *connect()*
- *inquiry()* and *connect()* have long delays and no a priori guarantee

**Bluetooth only defines single hop Master-Slave data transport**

# Distributed Bluetooth Piconets

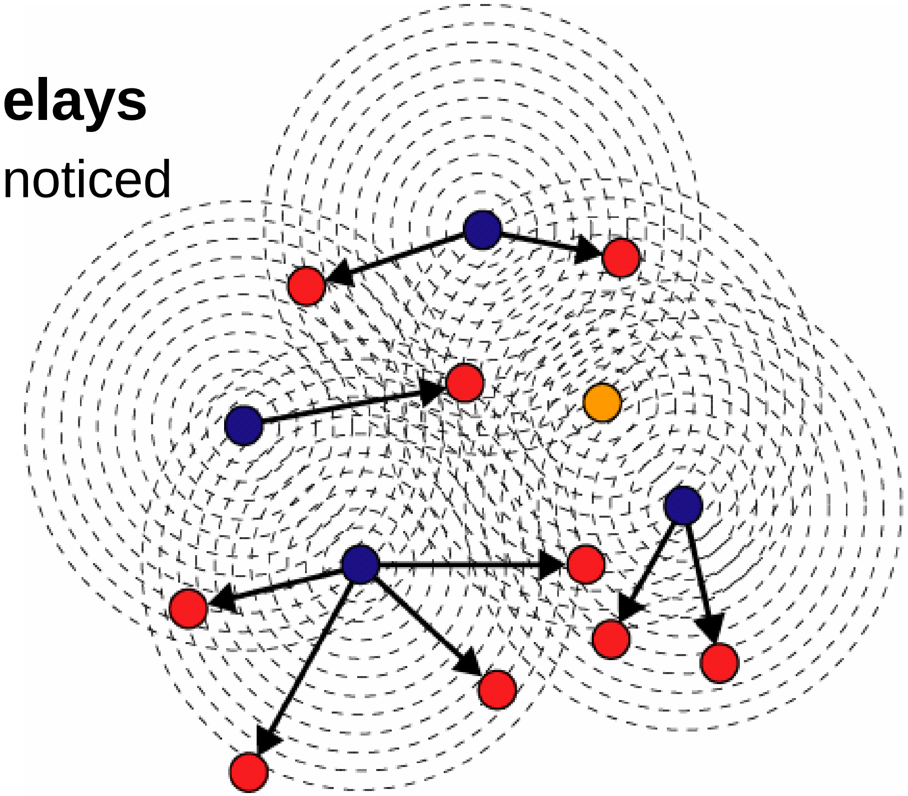
**Distributed *inquiry()* and *connect()* is a problem**

- nodes are uncoordinated
- limited visibility
- asymmetry: inquired node doesn't notice

***Inquiry()* and *connect()* have long delays**

- state change in remote node goes unnoticed
- average delay in seconds [Kasten2001]
- no a priori guarantee for success

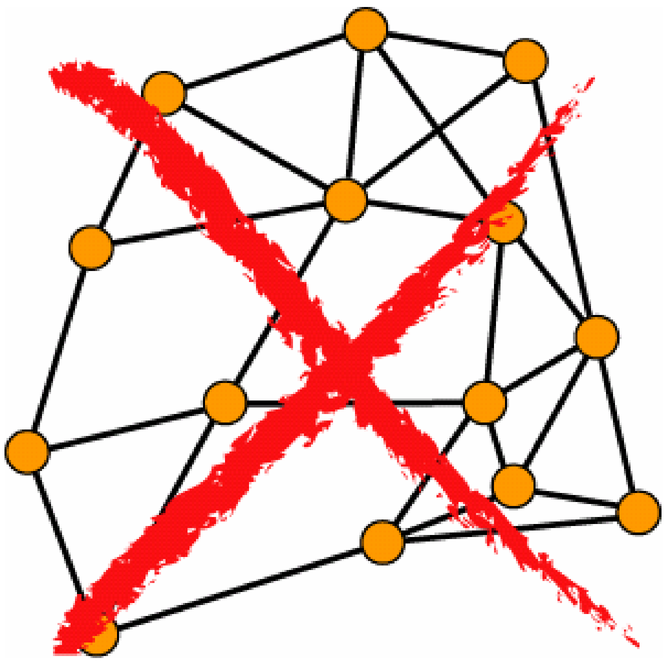
***Inquiry()* and *connect()* are highly nondeterministic (both in timing and function)**

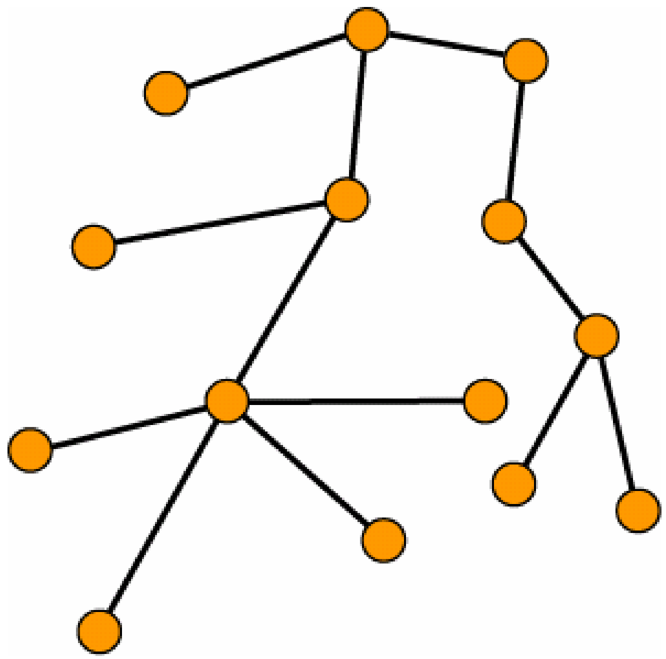


# Bluetooth applied

**Purpose of this study:**

**How can we construct ‘arbitrarily’ large trees in a robust and distributed way?**





# TreeNet simple tree construction

**Every node executes algorithm**

- until single tree is reached

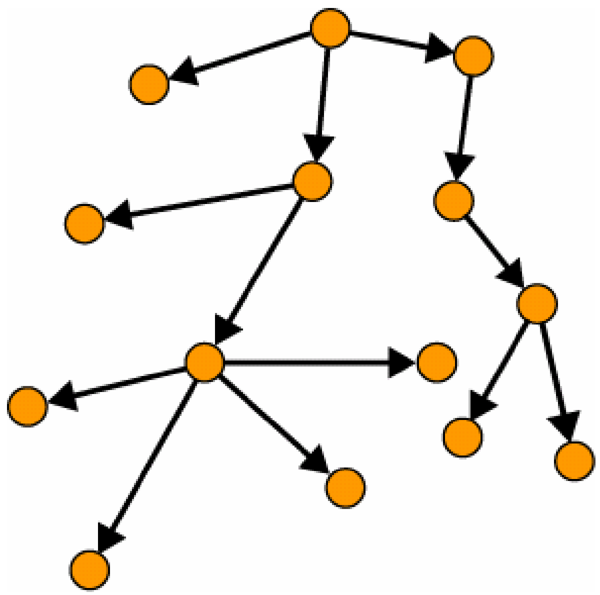
**Formation of large topologies**

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

**Services and applications can break up trees later**

- forming other topologies
- optimizing topology

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



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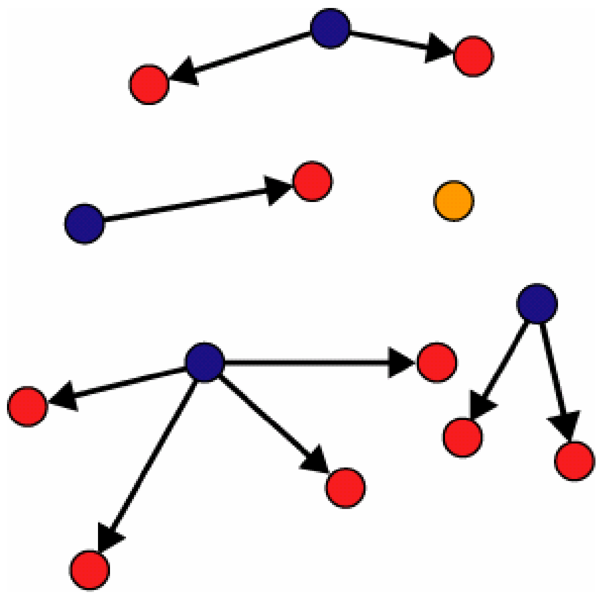

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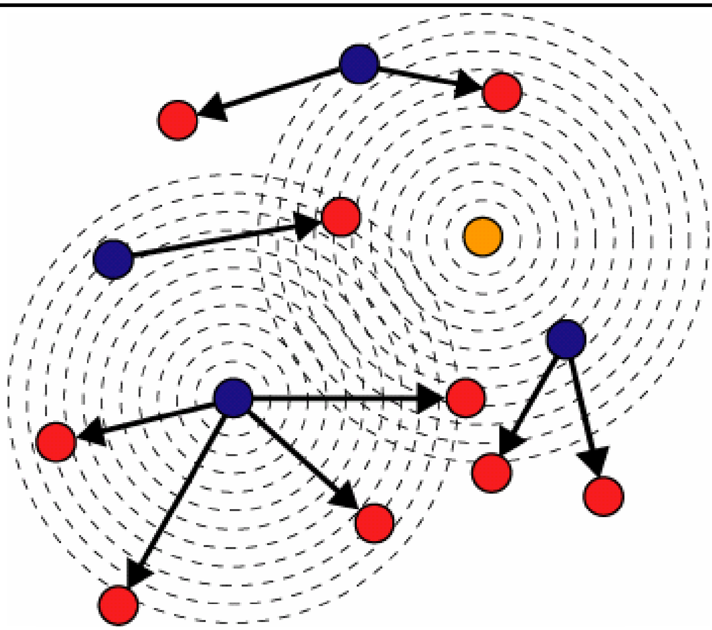

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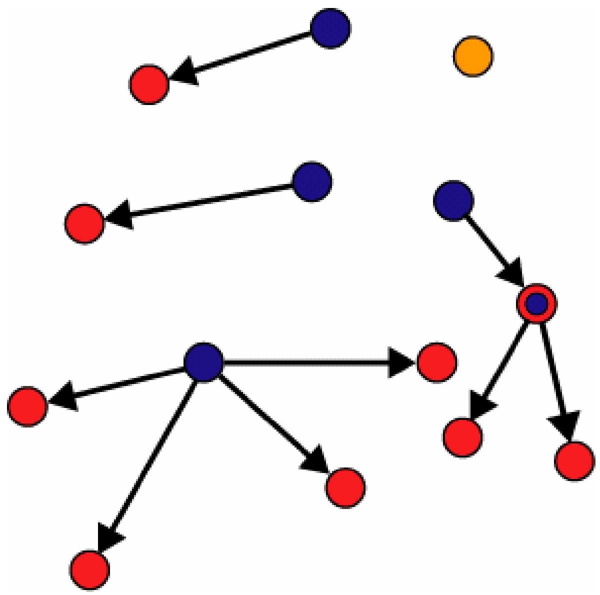

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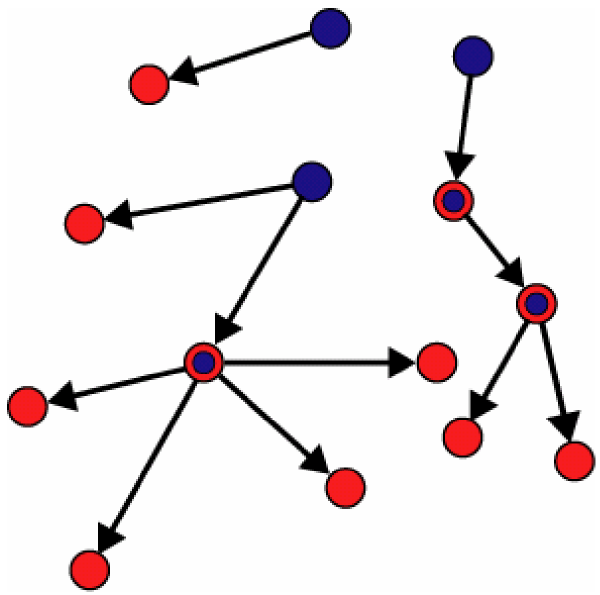

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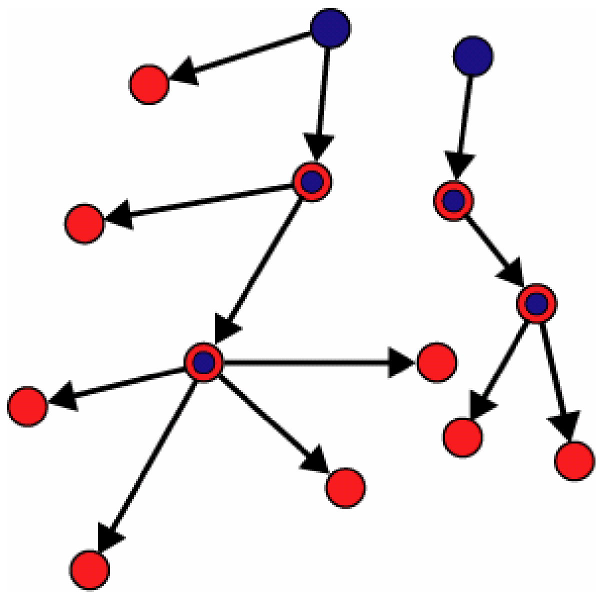

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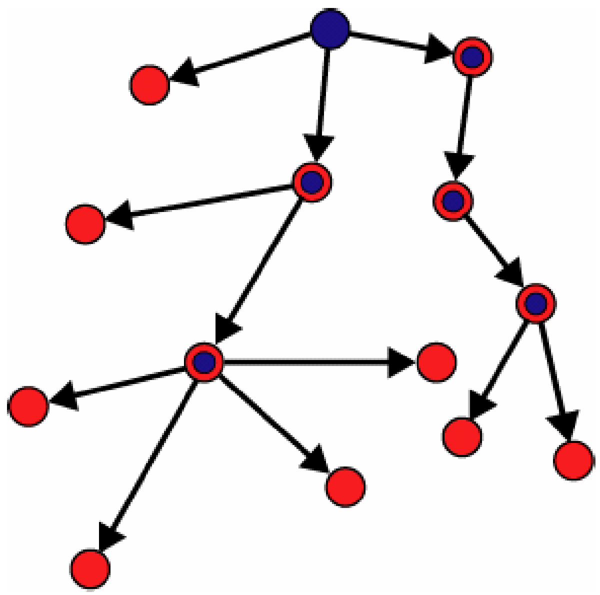
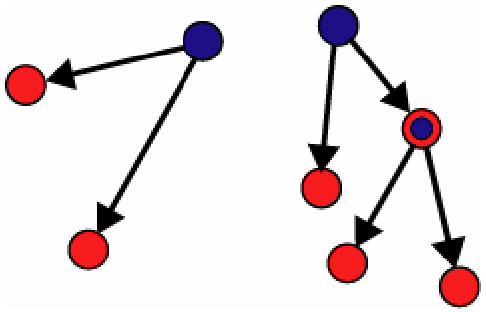


# TreeNet discussion

**Nodes must all be in visible range**

**Might not fully connect if multiple max_degree roots form**

- rebuilding of partial trees necessary if nodes cannot connect at root



**Simple greedy algorithm reduces *inquiry()* and *connect()***

- better performance by caching and time-stamping *inquiry()* and *connect()*
- try to *connect()* to node-last-seen first
- exchange of topology data and adaptive *connect()* retries

**In reality a 5 line algorithm ends up to be ~2000 lines of code!**

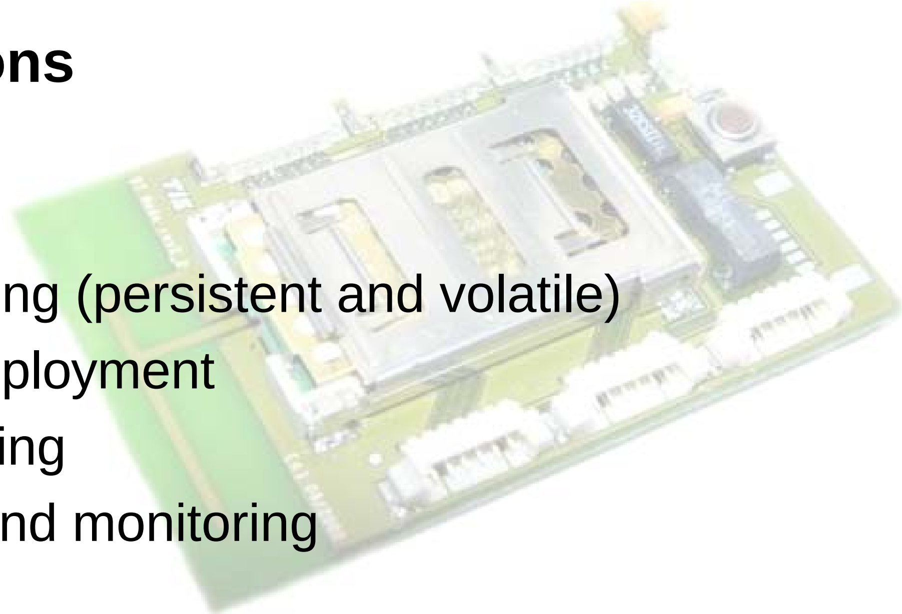
# Large scale distributed deployment

**So why do we actually need ~4000 lines of code?**

- 5 lines -> 2000 lines + system software + debugging and monitoring
- result in an ~87 kB program (un-optimized)

**Necessary node functions**

- data exchange
- timing and time-stamps
- data storage and handling (persistent and volatile)
- stepwise testing and deployment
- distributed reprogramming
- distributed debugging and monitoring



**A backbone infrastructure like TreeNet only enables to deploy and test the 'interesting' distributed ad hoc networking algorithms…**

# Acknowledgements


## TreeNet collaborators in IP9

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


## Related publications:


J. Beutel: *Location Management in Wireless Sensor Networks.* Book Chapter in Handbook on Wireless Sensor Networks, CRC Press, 2004, to be published.

J. Beutel et al.: *Prototyping Wireless Sensor Networks with BTnodes.* 1st European Workshop on Wireless Sensor Networks (EWSN 2004), to be published.

R. Bischoff and R. Wattenhofer: *Analyzing Connectivity-Based Multi-Hop Ad Hoc Positioning*, Technical Report 418, CS Dept. ETH Zurich, 2003.

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

M. Leopold et al.: *Bluetooth and Sensor Networks – A Reality Check.* ACM SenSys 2003, to be published.

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.* Workshop in Ubiquitous Computing and Communications (PACT 2001).

# To probe further…

**Come and play the TreeNet puzzle in the poster session tomorrow**

## Posters

– Prototyping Applications with BTnodes

– The Lighthouse Location System for Smart Dust

## BTnode platform

– online documentation and support

– mailing list

– BTnode rev3 development

**[http://www.btnode.ethz.ch](http://www.btnode.ethz.ch)**