KNOM 2011 Tutorials

Sensor networks for real-time services

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Future networks

Cyber-World interacts with Real-World in Everyplace

Goals of this talk

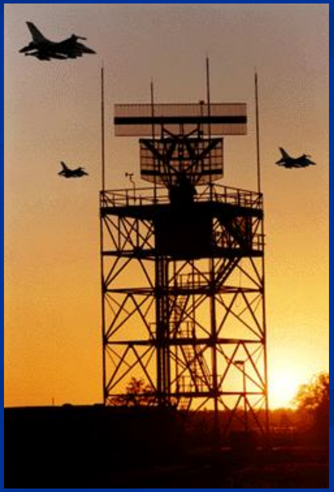
- Give an understanding what embedded, ad hoc, sensor networks are good for, what their intended application areas are
- Discuss about main challenges in wireless sensor network applications
  - real-time constraints
- Propose possible approaches
  - Beacon scheduling algorithm
  - Sensor planning scheme

What are embedded systems?

- Computing system embedded in a larger system
  - Provide computing for a system with special purpose (cf. general purpose computing)
  - Computing itself is hidden from the user
    - computing is not the ultimate goal
    - computing serves for real mission (ECU of cars)
  - Usually perform static tasks - predetermined
  - Usually small to be embedded
  - Battery operated sometimes
  - Usually have “real-time” constraints

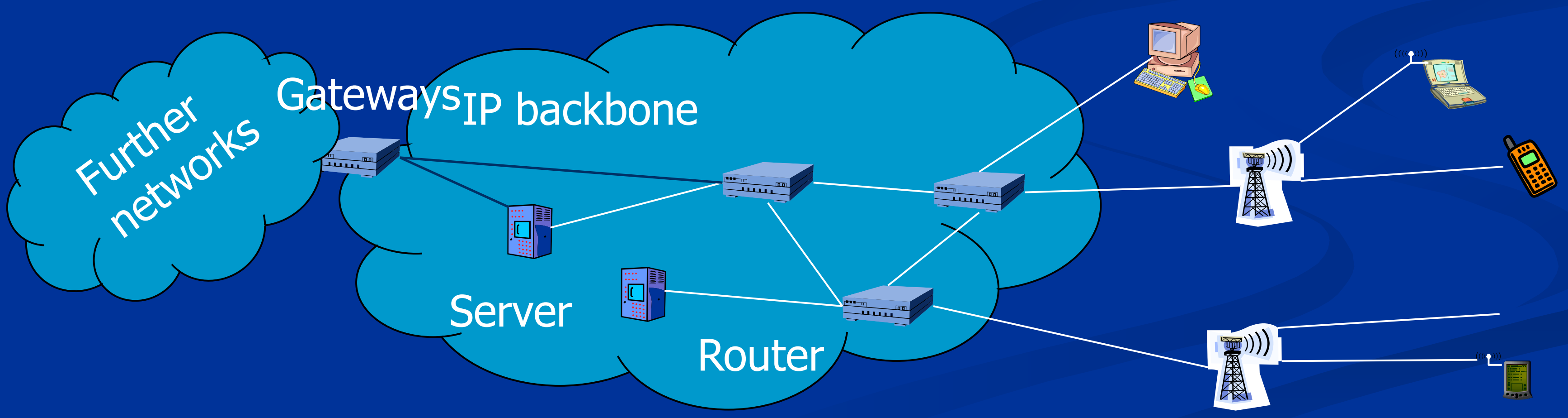
Possible applications for embedded systems

- Let's take a look at "examples"
  - Cell phones, PDAs
  - Digital cameras
  - Microwave ovens
  - Factory process control
  - Radar systems
  - Avionics



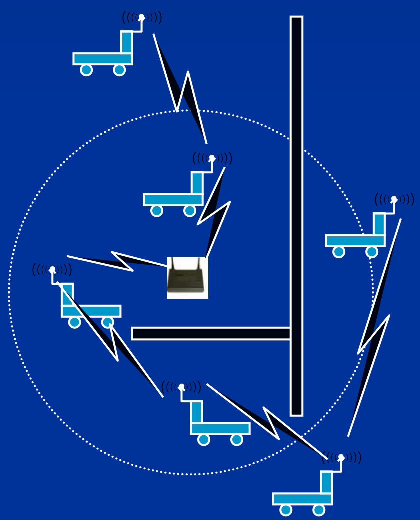
Infrastructure-based wireless networks

- Typical wireless network: Based on infrastructure
  - E.g., GSM, UMTS, …
  - Base stations connected to a wired backbone network
  - Mobile entities communicate wirelessly to these base stations
  - Traffic between different mobile entities is relayed by base stations and wired backbone
  - Mobility is supported by switching from one base station to another
  - Backbone infrastructure required for administrative tasks

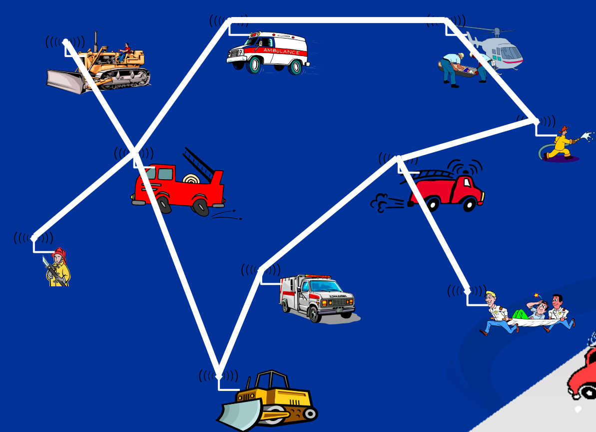


Possible applications for infrastructure-free networks

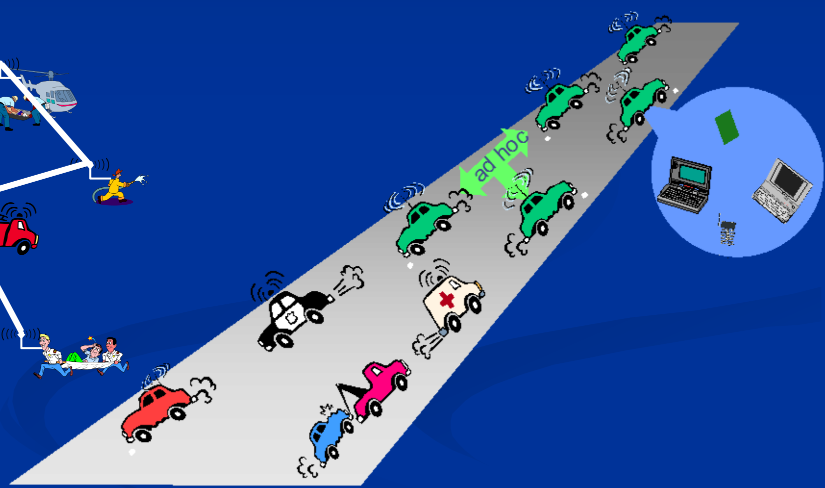
- Factory floor automation



- Disaster recovery



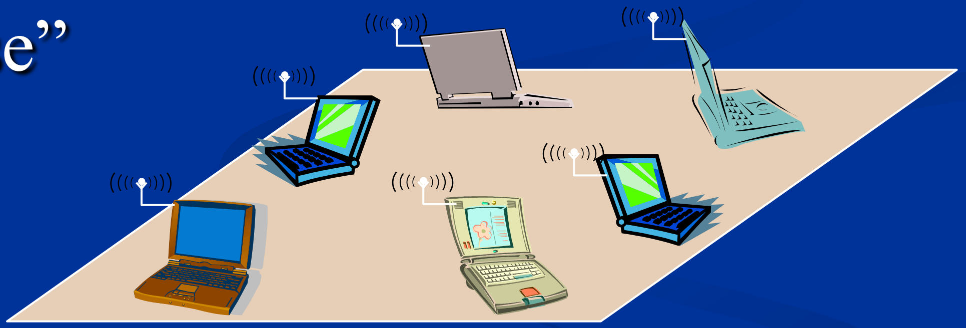
- Car-to-car communication



- Military networking: Tanks, soldiers, …
- Finding out empty parking lots in a city, without asking a server
- Search-and-rescue in an avalanche
- Personal area networking (watch, glasses, PDA, medical appliance, …)
- …

Solution: (Wireless) ad hoc networks

- Try to construct a network without infrastructure, using networking abilities of the participants
  - This is an ***ad hoc network*** – a network constructed "for a special purpose"

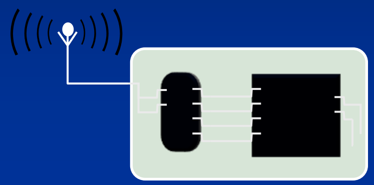


- Simplest example:

  Laptops in a conference room – a ***single-hop ad hoc network***

Wireless sensor networks

- Participants in the previous examples were devices close to a human user, interacting with humans



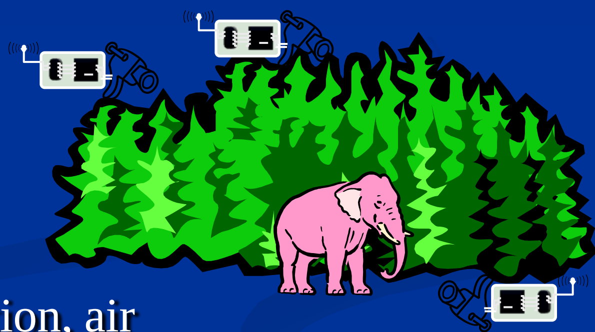
- Alternative concept:

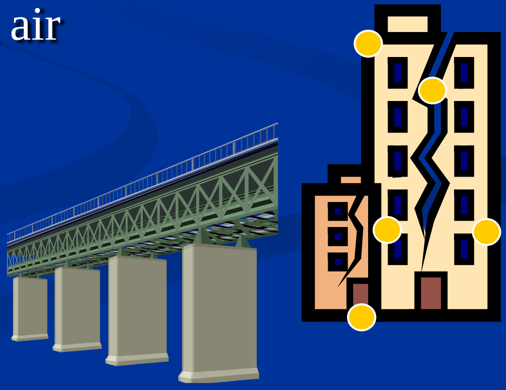
  Instead of focusing interaction on humans, focus on interacting with ***environment***

  - Network is ***embedded*** in environment
  - Nodes in the network are equipped with ***sensing*** and ***actuation*** to measure/influence environment
  - Nodes process information and communicate it wirelessly

WSN application examples

- Disaster relief operations
  - Drop sensor nodes from an aircraft over a wildfire
  - Each node measures temperature
  - Derive a "temperature map"
- Biodiversity mapping
  - Use sensor nodes to observe wildlife
- Intelligent buildings (or bridges)
  - Reduce energy wastage by proper humidity, ventilation, air conditioning (HVAC) control
  - Needs measurements about room occupancy, temperature, air flow, …
  - Monitor mechanical stress after earthquakes





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Problems/challenges for embedded wireless sensor networks

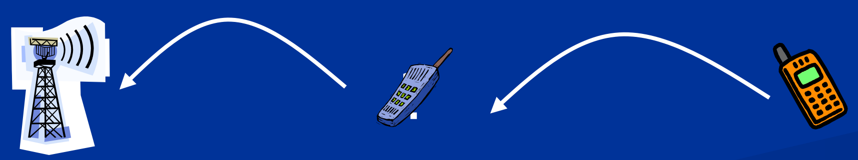
- Without a central infrastructure, things become much more difficult
- Problems are due to
  - Lack of central entity for organization available
  - Limited range of wireless communication
  - Mobility of participants
  - Battery-operated entities
  - “Quality of service”

No central entity → self-organization

- Without a central entity (like a base station), participants must organize themselves into a network (***self-organization***)
- Pertains to (among others):
  - Medium access control – no base station can assign transmission resources, must be decided in a distributed fashion
  - Finding a route from one participant to another

Limited range → multi-hopping

- For many scenarios, communication with peers outside immediate communication range is required
  - Direct communication limited because of distance, obstacles, …
  - Solution: ***multi-hop network***

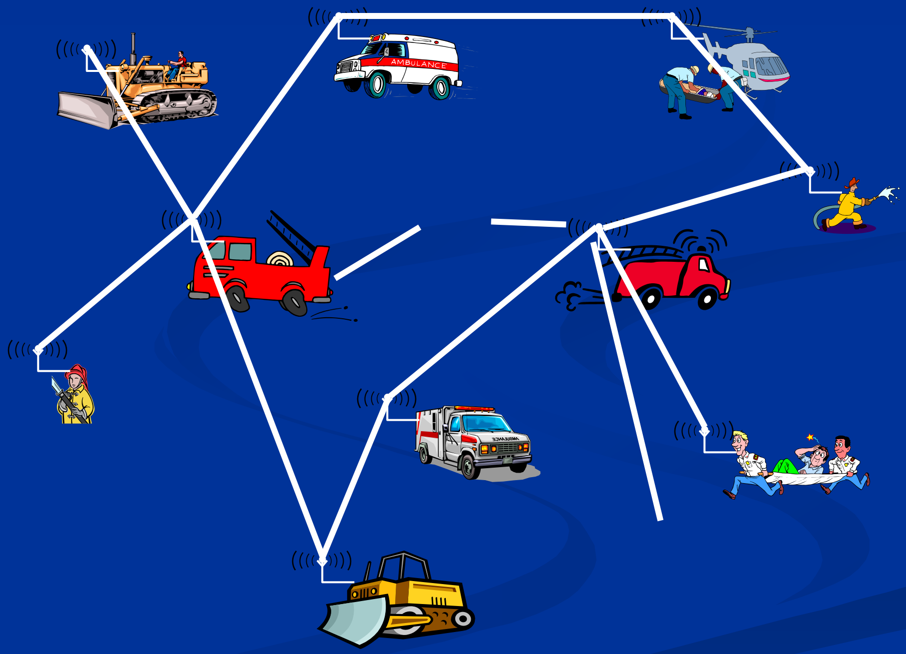


Mobility
→ Suitable, adaptive protocols

- In many (not all!) ad hoc network applications, participants move around
  - In cellular network: simply hand over to another base station

- In *mobile ad hoc networks (MANET)*:
  - Mobility changes neighborhood relationship
  - Must be compensated for
  - E.g., routes in the network have to be changed

- Complicated by scale
  - Large number of such nodes difficult to support



Battery-operated devices → energy-efficient operation

- Often (not always!), participants in an ad hoc network draw energy from batteries
- Desirable: long run time for
  - Individual devices
  - **Network as a whole**

! Energy-efficient networking protocols

  - E.g., use multi-hop routes with low energy consumption (energy/bit)
  - E.g., take available battery capacity of devices into account
  - How to resolve conflicts between different optimizations?

Quality of service → real-time supporting operation

- Traditional QoS metrics do not apply
- Still, service of WSN must be "good"
  - Right answers at the right time

! Sensor network protocols with time-constraints supported

  - E.g., Consider time constraints of applications when scheduling and planning of systems
  - E.g., Try to reduce communication delay
  - How to resolve conflicts between different optimizations?

What are real-time systems?

- Computing system whose specification includes both logical and temporal correctness requirements
  - *Logical Correctness*: produces correct outputs
  - *Temporal Correctness*: produces outputs at the right time

Real-Time Embedded Systems

	Real-time Embedded sensor networks	General Purpose Computing
User's perspective	Special purpose computing	General purpose
	Non-programmable (Static Tasks)	Programmable (Dynamic Tasks)
Environmental perspective	Interaction with physical world	Less Interaction with physical world
	Real-time requirements	As fast as possible
Designer's perspective	Restricted resource – small size, battery, CPU, memory	Plenty of resource
	Close to HW- low level programming	Far from HW- high level programming

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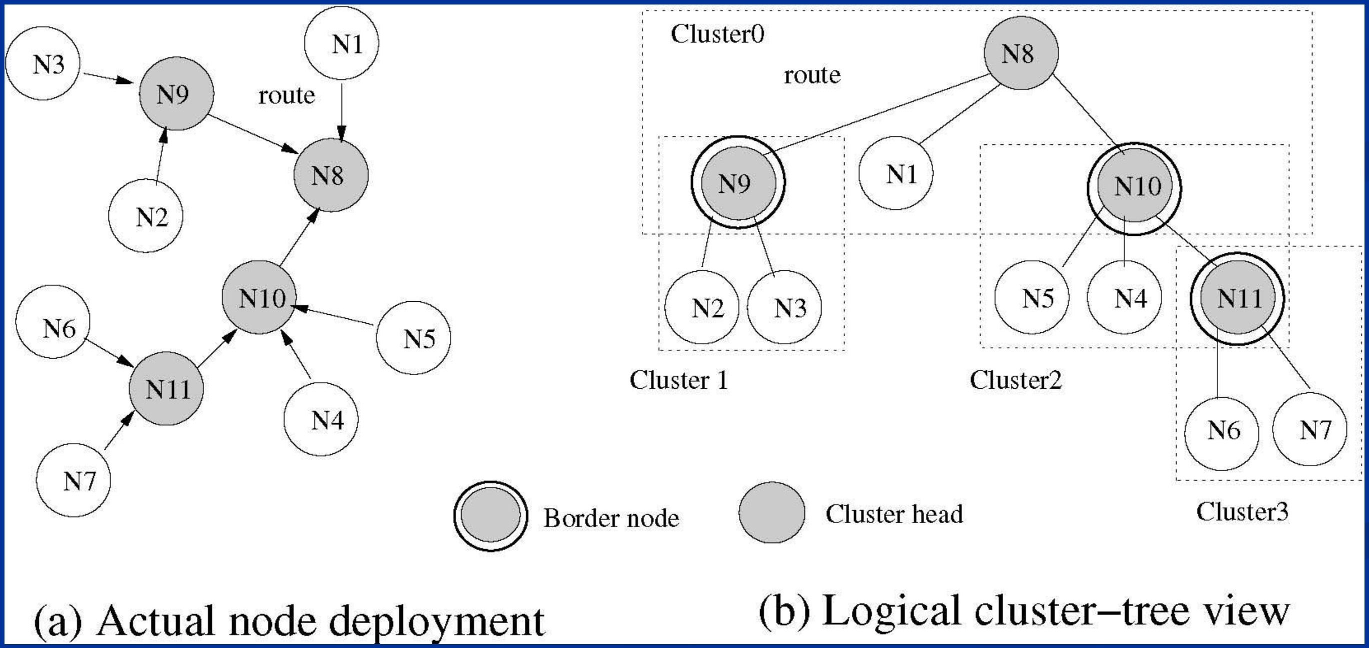
Assumptions

- Tasks are static and periodic
- Tasks have time constraints
- Sensors are power-limited
- Target platform: cluster-tree ZigBee networks

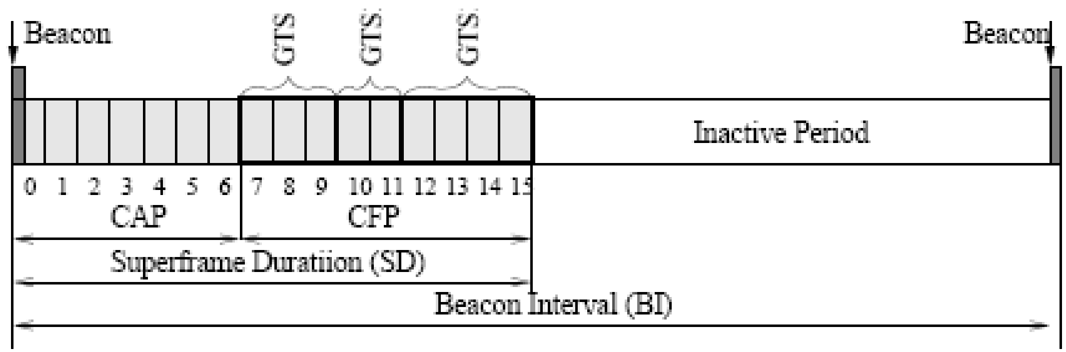
Cluster-tree ZigBee networks

- A ZigBee cluster-tree network is a cost effective choice for sensing and control applications in home and factory environments.
- Consists of multiple clusters
  - Each cluster has a pan coordinator (cluster head), router (border nodes), and ordinary nodes.



Beacon-enabled ZigBee networks

- **For power efficiency…**
  - Head node broadcasts beacon frames at every *beacon interval* (BI).
  - Nodes in a cluster become active only for a portion of each beacon interval, called a *superframe duration* (SD)



Challenges

- BUT…..Two nodes in different clusters may interfere with each other.
  - To avoid this, *BI*s and *SD*s of multiple clusters need to be carefully configured and scheduled.

    → BI(SD) scheduling algorithm

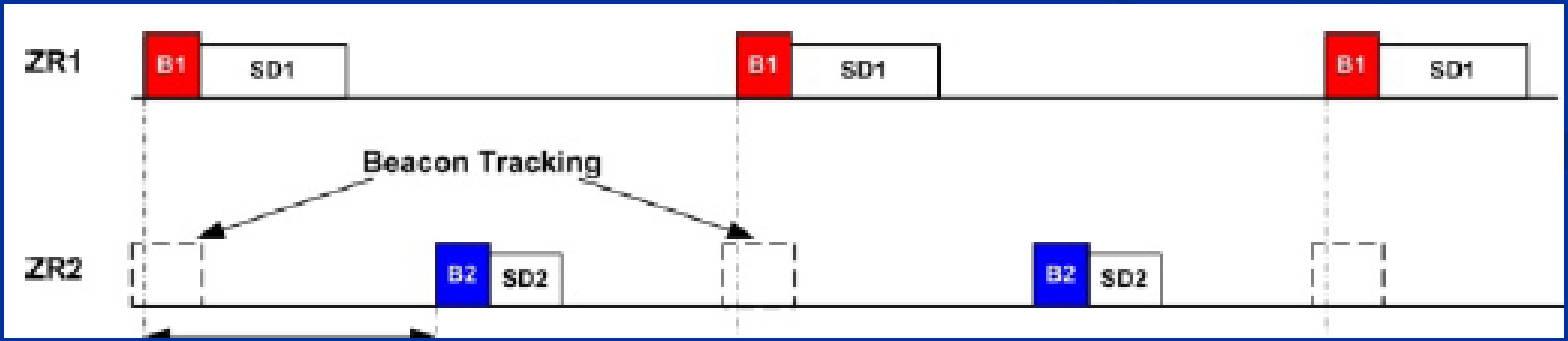
- Tasks may have time constraints
  - To support this, BI value should be carefully determined

    → BI/SD parameter optimization algorithm
  - To consider this, sensor nodes should be carefully deployed

    → Sensor node deployment algorithm

Challenge 1: Beacon Scheduling Algorithms

- Goal
  - Beacon frames of the different coordinators SHOUD avoid collisions with **any other** beacon and data frames
- Solution
  - Organize beacon frame transmissions in a serial way
- Ref
  - *A. Koubaa, M. Alves, and M. Attia, "Collision-Free Beacon Scheduling Mechanisms for IEEE 802.15.4/Zigbee Cluster-Tree Wireless Sensor Networks," 7th International Workshop on Applications and Services in Wireless Networks (ASWN), 2007.*



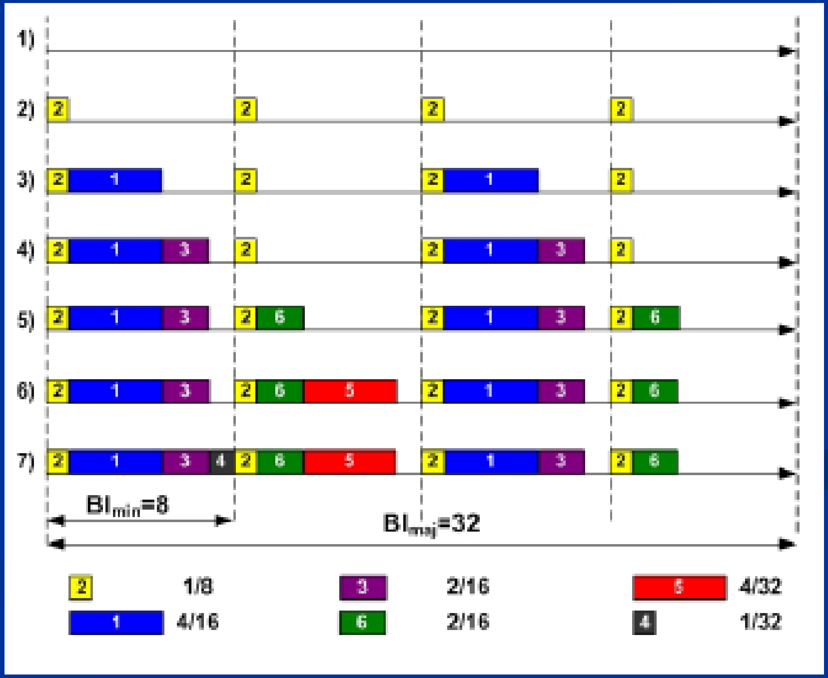
Challenge 1
Beacon Scheduling Algorithms

- Examples

Coordinator	SD	BI
C1	4	16
C2	1	8
C3	2	16
C4	1	32
C5	4	32
C6	2	16

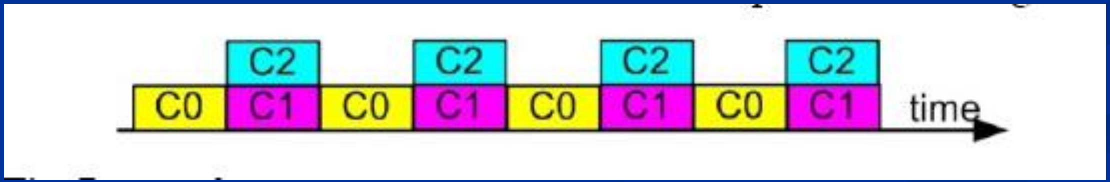
<Table: PAN configuration>

<Scheduled BI and SD>



Challenge 1:
Grouped Beacon Scheduling

- Extension
  - Original algorithm + beacon overlapping
  - → Increase utilization and feasibility
- Issues
  - Which cluster can be grouped with which?
  - How to assign BI and SD for each grouped clusters
  - → We have worked on this issue

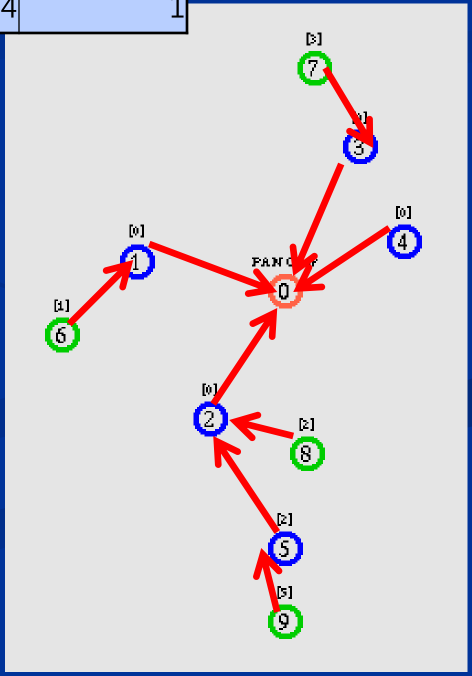


Challenge 1: Grouped Beacon Scheduling

- NS2 Simulation results
  - 1 PAN coordinator
  - 5 router (cluster heads)
  - 4 leaf nodes
  - Using NOAH protocol

	BO	SO
PAN	4	2
ZR1	5	2
ZR2	4	1
ZR3	4	1
ZR4	5	0
ZR5	4	1

	Non schedule	Serial SDS	Group SDS
Packet drop rate	16.5%	1.1%	1.2%
Utilization	N/A	71.8%	59%



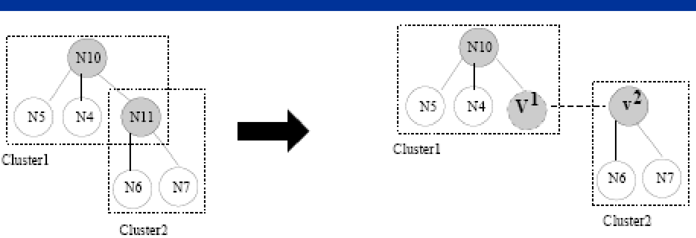
Challenge 2-1: GTS-based BI assignment

- Goal
  - guarantee end-to-end deadlines of real-time flows
  - maximize the lifetime of the entire system
- Proposed solution
  - *a heuristic algorithm*
  - *to optimally configure* ZigBee parameters with low complexity by decomposing the global optimization problem into a set of cluster-based local problems.

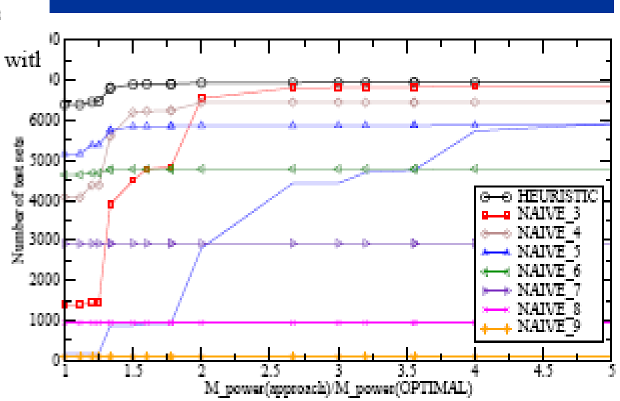
- *Ref*
  - *Junghee Han, Suhan Choi, and Taejoon Park "Maximizing Lifetime of Cluster-Tree ZigBee Networks Under End-to-End Deadline Constraints", IEEE Communication Letters, vol14, No3, 2010*

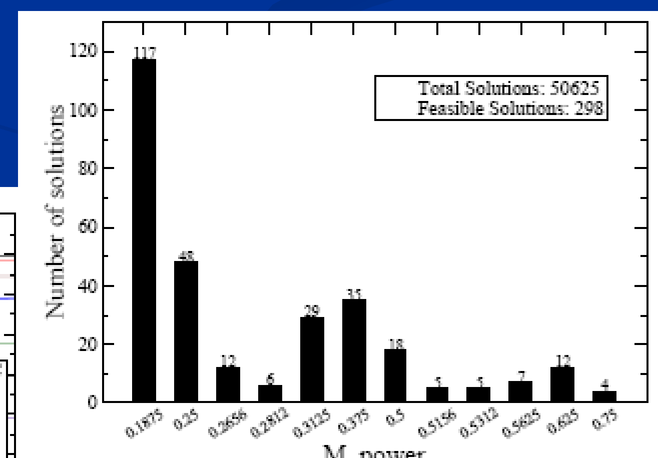
Challenge 2-1:
GTS-based BI assignment

- Algorithm
  1. split a inter-cluster border node belonging to multiple clusters into a set of intra-cluster virtual nodes
  2. split end-to-end deadline into a set of cluster-based onehop deadlines
  3. estimate a per-cluster worst-case one-hop delay
  4. select BI and SD for each cluster based on the above steps



(a) Original ZigBee network (b) Localized ZigBee network wit

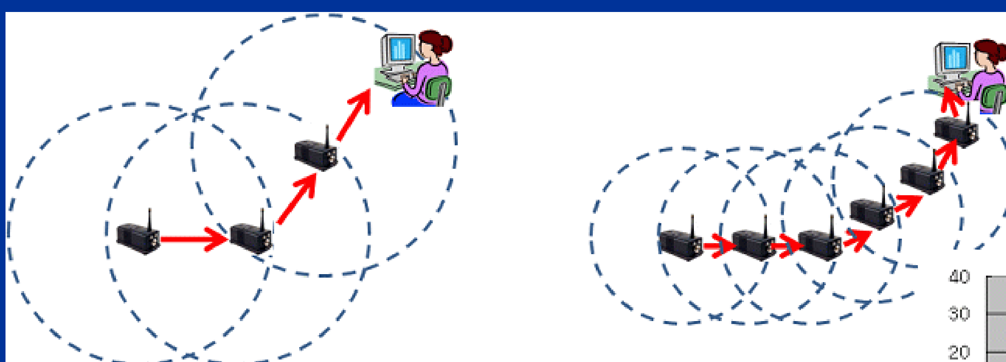


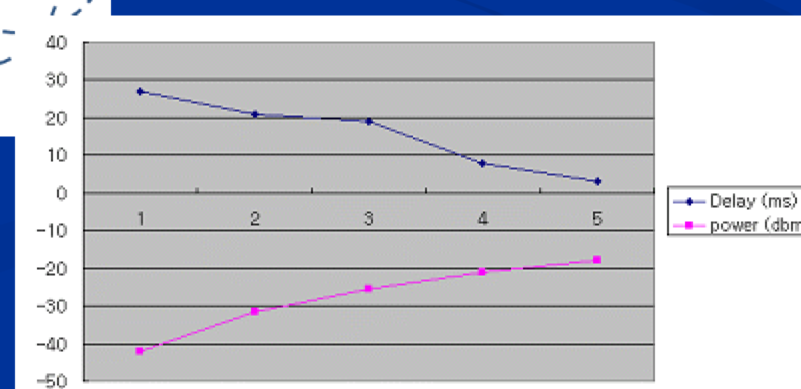


Challenge 2-2: Sensor node deployment

- How to deploy sensor nodes?
- Goals
  - consider sensor transmission and sensing range
  - guarantee end-to-end deadlines of real-time flows

  → Conflicting objectives !!!





Conclusion

- They are just preliminary steps for building scientific foundation of future networks design
- We still have an awful lot of work to do !!!