Sensor networks for real-time services

Han, Junghee
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 \( \rightarrow \) 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

User’s perspective
- Real-time Embedded sensor networks
- Special purpose computing
- Non-programmable (Static Tasks)
- Interaction with physical world
- Real-time requirements
- Restricted resource – small size, battery, CPU, memory
- Close to HW – low level programming

Environmental perspective
- General purpose Computing
- General purpose
- Programmable (Dynamic Tasks)
- Less Interaction with physical world
- As fast as possible
- Plenty of resource
- Far from HW – high level programming

Designer’s perspective
- Environment perspective
- User’s perspective

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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 SHOULD avoid collisions with any other beacon and data frames

- **Solution**
  - Organize beacon frame transmissions in a serial way

- **Ref**
Challenge 1
Beacon Scheduling Algorithms

Examples

<table>
<thead>
<tr>
<th>Coordinator</th>
<th>SD</th>
<th>BI</th>
</tr>
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<tbody>
<tr>
<td>C1</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>C2</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>C3</td>
<td>2</td>
<td>16</td>
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<tr>
<td>C4</td>
<td>1</td>
<td>32</td>
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<tr>
<td>C5</td>
<td>4</td>
<td>32</td>
</tr>
<tr>
<td>C6</td>
<td>2</td>
<td>16</td>
</tr>
</tbody>
</table>

<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

<table>
<thead>
<tr>
<th></th>
<th>BO</th>
<th>SO</th>
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<tbody>
<tr>
<td>PAN</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>ZR1</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>ZR2</td>
<td>4</td>
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<tr>
<td>ZR5</td>
<td>4</td>
<td>1</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Non schedule</th>
<th>Serial SDS</th>
<th>Group SDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Packet drop rate</td>
<td>16.5%</td>
<td>1.1%</td>
<td>1.2%</td>
</tr>
<tr>
<td>Utilization</td>
<td>N/A</td>
<td>71.8%</td>
<td>59%</td>
</tr>
</tbody>
</table>
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
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 !!!