Localization in Wireless Sensor Networks

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Outline

- Introduction
  - What are wireless sensor networks (WSNs)?
  - Hardware platforms
  - Application examples
- Challenges for localization in WSNs
- Classification of localization mechanisms
  - Active localization
  - Passive localization
- Two localization systems: GPS, MSR RADAR
- Comparison of techniques
- Conclusion

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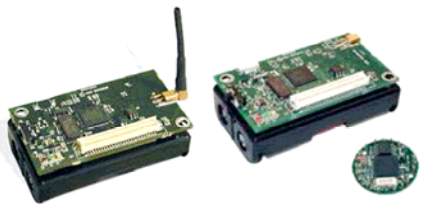
What are Wireless Sensor Networks?

- **Definition:** Collections of small devices that:
  - Are equipped with *sensors*
  - Communicate *Ad-Hoc* with each other
  - Exchange and process *data*
  - Have *limited resources*
  - Are mostly *static*

Source: UC Berkeley

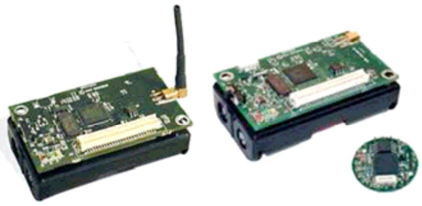


Source: Crossbow Technologies Inc.

How does the Future Look Like?

- **Definition:** Collections of small devices that:
  - Are equipped with *sensors* and *actuators*
  - Communicate *Ad-Hoc* and using *infrastructure*
  - Process *data* and interact with *services*
  - Have *limited resources*
  - Are *static* and *mobile*

Source: UC Berkeley



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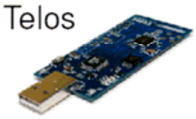
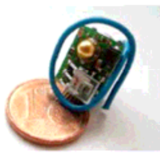
Hardware Platforms

Moteiv Telos



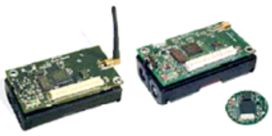
Smartdust

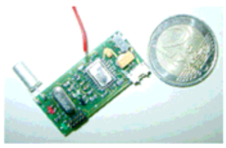
BTNode



Teco Particle

Crossbow MICAs





Teco Node

Sensor Network Applications

- Habitat Monitoring Applications
  - Great Duck Island (GDI) System
  - Hogthorb – Sow heat period monitoring
- Environment Observation and Forecasting Systems
  - ALERT – National Weather Service
  - Floodnet – River monitoring in UK
- Health Applications
  - Care in the Community – UK
  - UbiCare – UK
- Military Applications
  - WINS – Surveillance and exploration
  - Odyssey – Underwater surveillance

Sensor Network Applications

- Intelligent Building Monitoring
  - Structure Health Monitoring System – US, Canada
  - Sustainable Bridges – EU
- Intelligent Traffic Systems
  - Safe Traffic – Sweden
  - Vehicular Networks (CarTalk 2000) – EU
- Smart Room Environments
  - Aware Home – Georgia Institute of Technology
  - Sense-R-Us – University of Stuttgart
- . . . and many more

Sensor Network Applications

- Intelligent Building Monitoring
  - Structure Health Monitoring System – US, Canada
  - Sustainable Bridges – EU
- Intelligent Traffic Systems/Vehicular Networks
  - Safe Traffic – Sweden
  - Vehicular Networks (CarTalk 2000) – EU
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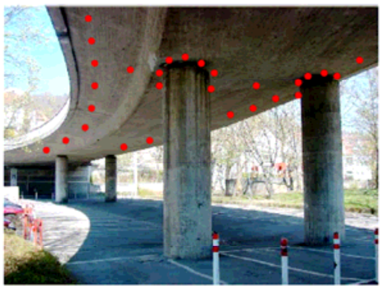
Sustainable Bridges

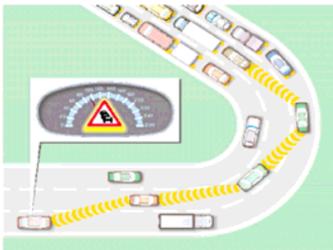
- **Goal:** Cost-effective monitoring of bridges to detect structural defects



- Static sensor nodes
- Simple and complex data: temperature, vibration
- Noise detection and localization
- Data sampling: 40 KHz!
- Time synch.: 60 μs
- Sensor lifetime: 3 years!
- Hybrid network topology

Vehicular Networks – Cartalk

- **Goal:** Development of a cooperative driver assistance system
- Provide an Ad-Hoc warning system for:
  - Traffic jams
  - Accidents
  - Lane/highway merging
- Standard query interface:
  - Avg speed/temperature, road conditions
  - Location, position



Vehicular Networks – Properties

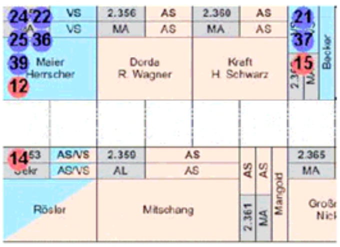
- Wide range of sensor data continuously gathered
  - Speed, position, tire pressure
- Sensor data is highly dynamic
- Sensors located within the car
- Communication plays a crucial role in the system
- Processing of data must be performed in a timely manner
- Energy constraints are not so important
- Sensor nodes are mobile
- Ad-hoc network topology

Sense-R-Us

- **Goal:** Smart environment used to store and query context information
- Types of nodes
  - Red = Rooms
  - Blue = People
  - Yellow = Gateways
- Types of queries
  - Location
  - Meetings
  - Meeting duration

Sense-R-Us – Properties

- Several variations of context data needed
  - Location, temperature, personal data
  - Audible information
- Noise analysis and event generation
- Data sampling rate of 5-10 KHz
- Time synchronization within 1s
- Sensor nodes are static and mobile
- Hybrid network topology (ad-hoc and gateways)



Application Commonalities

Most sensor network applications:

- Are **data-centric** and/or data-driven
  - Provide some form of monitoring
- Are **state-based**
  - Their needs might change depending on the current state of the application
- Must be **fault-tolerant** with respect to failures and/or environmental conditions
- Require **high availability** of sensors and nodes
- Must be either flexible or **reconfigurable**

Application Differences

Property	Sust. Bridges	VANETs	Sense-R-Us
Data Model	Specific	Generic	Generic
Query Model	Push-based	Pull-based	Pull/Push
Topology	hybrid	ad-hoc	hybrid
Localization	passive	GPS	active
Dist. Transparency	○	●	○
Energy	●	◔	◑
Mobility	○	●	◑
Real-time	●	◑	◔
Time Synch.	◕	◔	○
Reconfiguration	◔	◕	◑

○ Not important ◑ Medium ● Very important

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Challenges for Localization

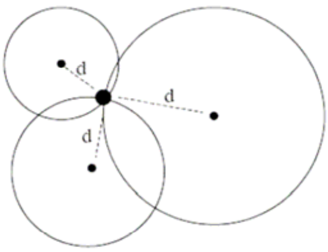
- Physical Layer Challenges
  - Noisy environments
  - Fluctuating measurements
- Algorithm Design Challenges
  - Noisy and/or inconsistent data
  - Computation and communication trade-offs
  - Error behavior and scalability (ad-hoc)
- System integration challenges
  - Customized software and hardware
  - Measurement technology not always applicable

Location Sensing Techniques

- Triangulation
  - Location determined using triangle geometry
  - Possible techniques
    - Lateration: Computation of position based on distance measurements
    - Angulation: Use of angles to determine distance
- Scene analysis
  - Use of environmental features to infer the location of nodes and targets in the system
- Proximity
  - Infer the location of objects based on relative distance to known locations

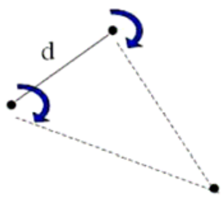
Lateration vs. Angulation

- Lateration:
  - 2D positioning requires three distance measurements
  - 3D positioning requires four distance measurements



Lateration vs. Angulation

- Angulation:
  - 2D position requires two angle + one distance measurement
  - 3D position requires two angle + one distance + one azimuth measurement



Measurement Technologies

- **Time-of-flight:**
  - Ultrasonic time-of-flight
    - Common frequencies: 25–40 KHz, range: few meters, accuracy: ~2–5 cm
  - Acoustic time-of-flight
    - Range: tens of meters, accuracy: 10 cm
  - Laser time-of-flight range measurement
    - Range: ~200 m, Accuracy: ~2 cm
  - Acoustic angle of arrival
    - Accuracy: ~5 degrees
- **Attenuation:**
  - Received Signal Strength Indicator (RSSI)
    - Range: ~10 m, Accuracy: 2–3 m

Classification of Loc. Mechanisms

- Active Localization
  - System sends signals to localize the target
    - Non-cooperative: The target does not help in determining its position, e.g. radar
    - Cooperative Target: The target cooperates with the system, e.g. Active Bat
    - Cooperative Infrastructure, e.g. GPS
- Passive Localization
  - System deduces location from signal observation
    - Passive Target Localization, e.g. birdcall
    - Passive Self-Localization, e.g. RADAR
    - Blind Localization: System deduces location without *a priori* knowledge of its characteristics, e.g. blindbeamforming

System Solution Space

- **Computational model**
  - Centralized, where only one node computes locations
  - Locally centralized, where some nodes compute locations
  - Fully distributed, where every node participates
- **Frame of reference**
  - Absolute vs. relative
  - Beacons vs. no beacons, relates to active vs. passive techniques

System Solution Space (cont.)

- **Topology**
  - Infrastructure vs. ad-hoc
  - Single hop vs. multihop
- **Range-based techniques**
  - Triangulation, where geometry is applied
  - Scene Analysis, where environmental features are used to infer location
  - Proximity, where positions are detected by measuring changes from a known location
- **Limitations:**
  - Types of situations where technology cannot be applied

Location System Properties

System	Model	Reference	Topology	Technique	Limitations
GPS	Distributed	Absolute, beacons	Infrastruc., single hop	radio ToF lateration	Not indoors
Active Badges	Locally centralized	Relative, beacons	Infrastruc., single hop	Infrared proximity	sunlight interference
Active Bats	Centralized	Relative, beacons	Infrastruc., multi-hop	Ultrasound ToF lateration	Ceiling sensor grids
MSR RADAR	Locally centralized	Absolute, beacons	Infrastruct., single hop	Scene analysis	Wireless NICs
Smart Floor	Centralized	Relative	Infrastruc., single hop	Physical contact proximity	Not really scalable
Easy Living	Centralized	Relative	Infrastruc., single hop	Vision, triangulation	Ubiquitous cameras

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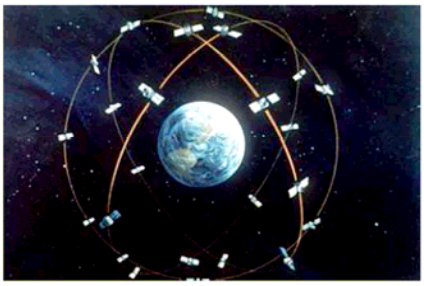
GPS System



- GPS provides physical, absolute positions
- 24 satellites available configured so that at least 4 are always “visible”
- 3D lateration with accuracy up to several meters
- Not available in-door

MSR RADAR

- Two available systems from Microsoft, one using scene analysis and another using lateration
- Accuracy to within 3 meters with 50% probability
- Technique:
  - Uses RSSI to perform signal strength matching
  - Extract RSSI from base stations
  - Find table matching best entry
- Offline calibration is needed
  - Compute map of RSSI signals within an area
    - Empirical method
    - Mathematical method: use propagation model

MSR RADAR (cont.)

- Location determined by finding the nearest neighbor signal space (NNSS)
- Using Euclidean distance: $\sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$
- Use nearest neighbor (NN) as location
- Posible refinement using k neighbors (k-NNSS)

N_1

T

G

N_2

N_3

N_1,N_2,N_3: neighbors

T: true location

G: guess based on avg.

Comparison of Techniques

- Active techniques tend to work best
  - Signal is well characterized
  - Cooperative systems can synchronize with the target to enable accurate estimation
- Passive techniques
  - Detection quality depends on signal
  - Time difference of arrivals only
  - Time difference of arrivals requires precise knowledge of sensor positions
- Blind techniques
  - May increase communication cost
  - May not be inmune to noise

Conclusions

- Localization in sensor network environments remains a challenge
  - Characteristics of the environment
  - Available techniques
  - Increasing system requirements
- Current systems use active and/or passive techniques
- There is no one-fits all solution
  - All current systems have limitations regarding accuracy, applicability, etc.
- There is still a lot of work to do

In other words...

The journey has just started

Thank You for Your Attention

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