

# Protocols and Architectures for Wireless Sensor Networks

by

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# Grade

- Midterm Exam. 25%
- Exercises 35% (5 ~ 7 times)
- Term Project 30%
- Class Attitude 10%

# Ad hoc and Sensor Networks

## Chapter 1: Motivation & Applications

# Goals of this chapter

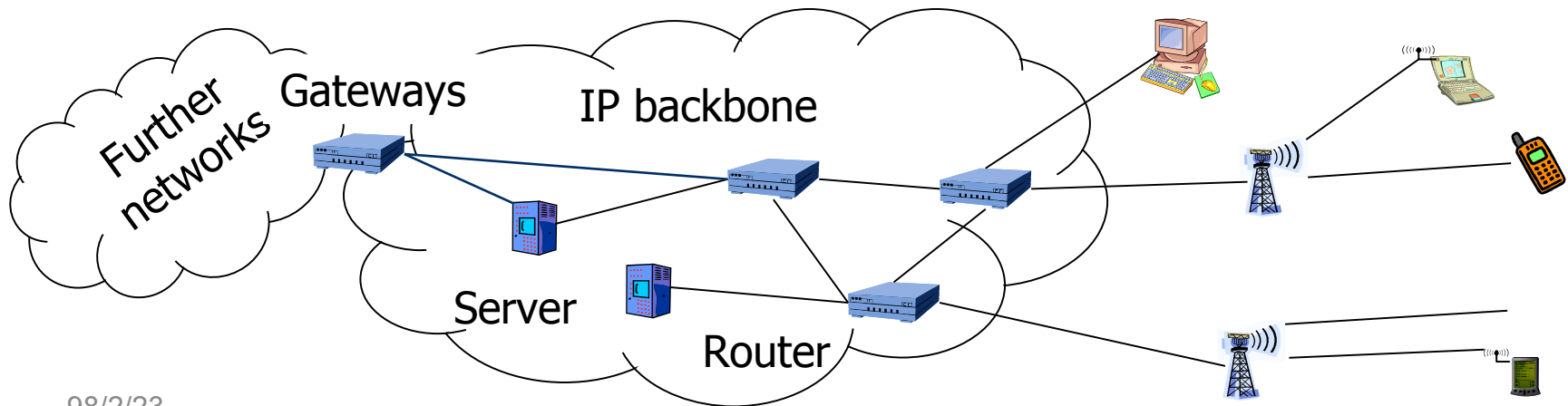
- Give an understanding what ad hoc & sensor networks are good for, what their intended application areas are
- Commonalities and differences
  - Differences to related network types
- Limitations of these concepts

# Outline

- *Infrastructure for wireless?*
- (Mobile) ad hoc networks
- Wireless sensor networks
- Comparison

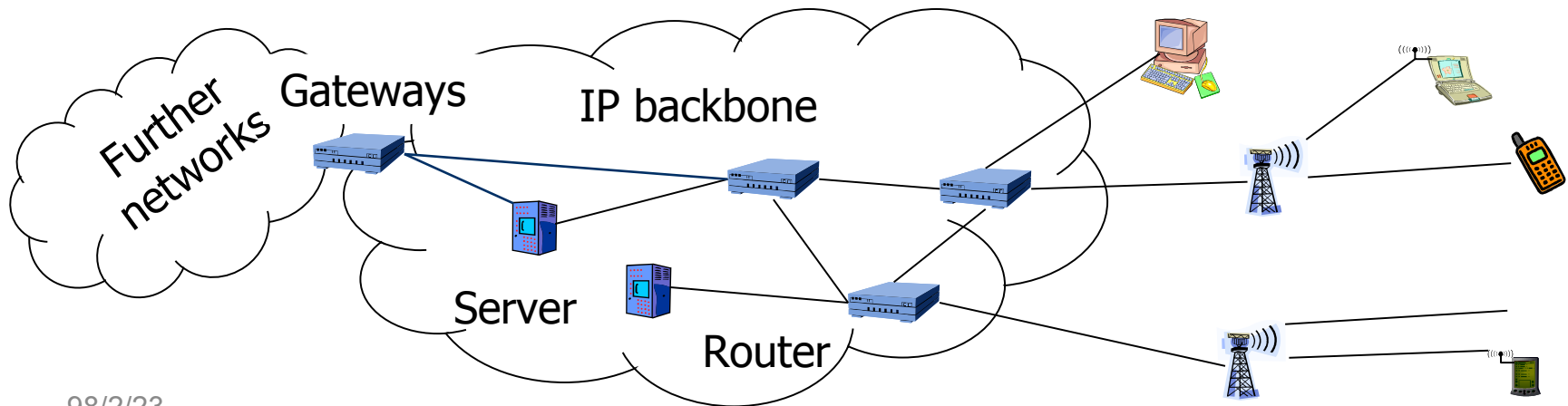
# Infrastructure-based wireless networks

- **Typical wireless network: Based on infrastructure**
  - E.g., GSM (Global System for Mobile Communications), UMTS (Universal Mobile Terrestrial Telecommunication Systems), ...
  - Base stations connected to a wired backbone network



# Infrastructure-based wireless networks

- 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



# Infrastructure-based wireless networks

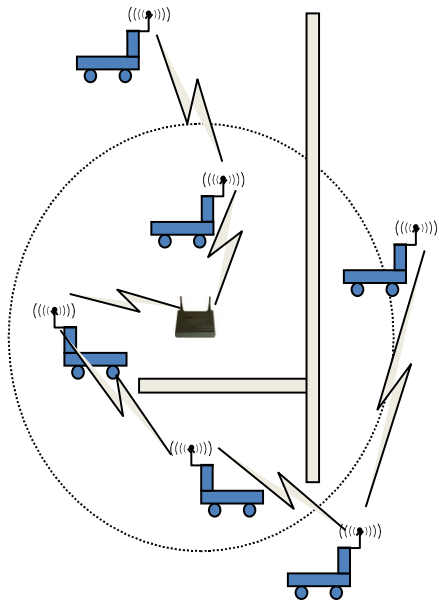
## – Limits?

- What if ...
  - No infrastructure is available? – E.g., in disaster areas
  - It is too expensive/inconvenient to set up? – E.g., in remote, large construction sites
  - There is no time to set it up? – E.g., in military operations

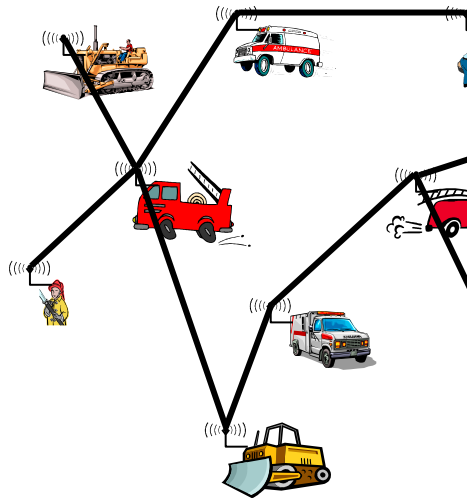


# Possible applications for infrastructure-free networks

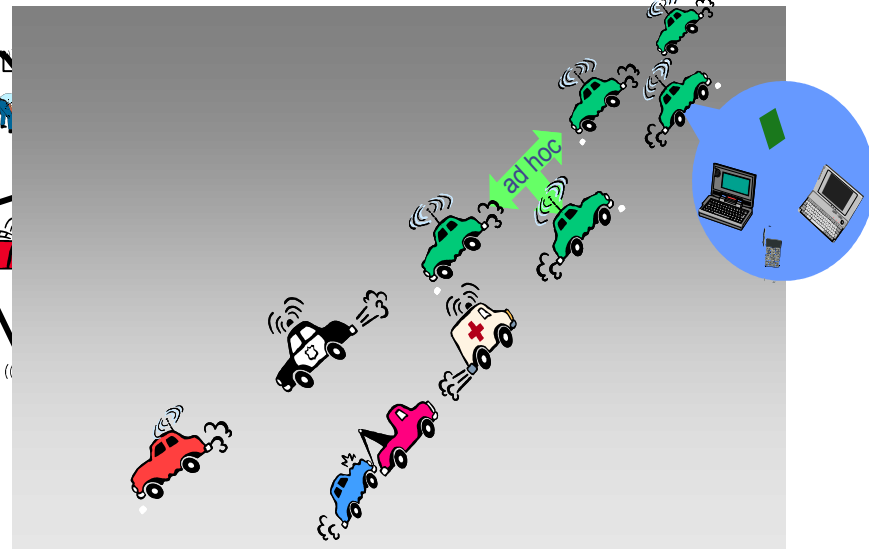
- Factory floor automation



- Disaster recovery



- Car-to-car communication



# Possible applications for infrastructure-free networks

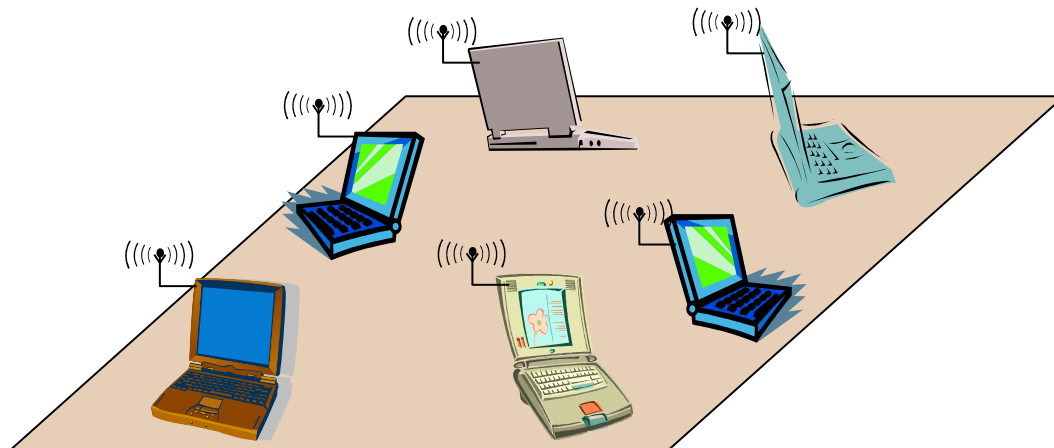
- Military networking: Tanks, soldiers, ...
- Finding out empty parking lots in a city, without asking a server
- Search-and-rescue in an avalanche
- Personal area networking (watch, glasses, PDA, medical appliance, ...)
- ...

# Outline

- Infrastructure for wireless?
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# 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***



# Problems/challenges for ad hoc networks

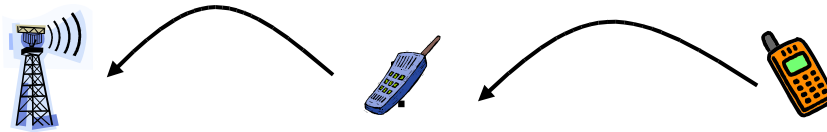
- Without a central infrastructure, things become much more difficult
- Problems are due to
  - Lack of central entity for organization available
  - Limited range of wireless communication
  - Mobility of participants
  - Battery-operated entities

# 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):
  - No base station can assign transmission resources, must be decided in a distributed fashion
  - Finding a route from one participant to another

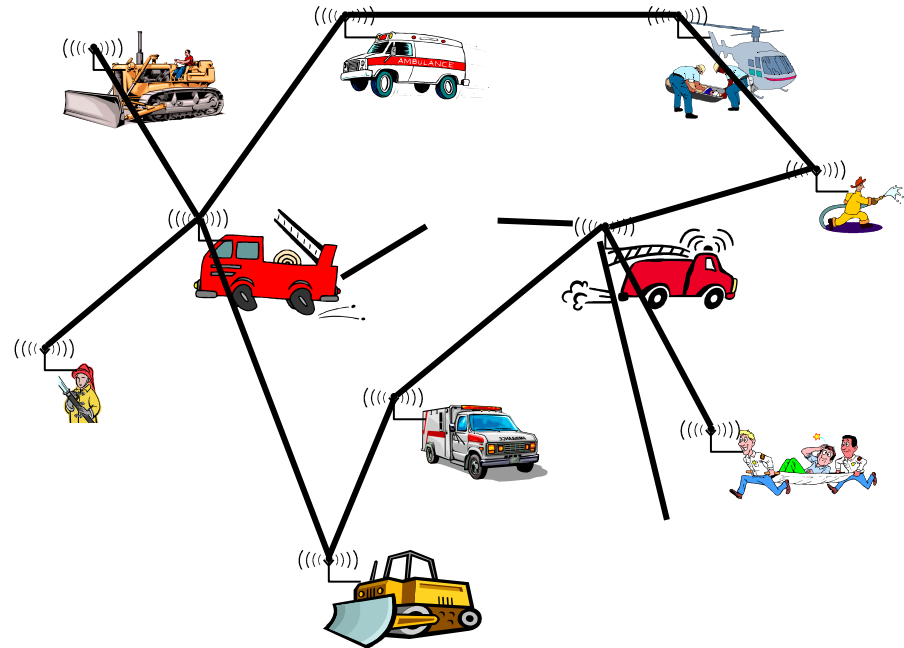
# Limited range ! multi-hopping

- Communication outside immediate communication range
  - 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

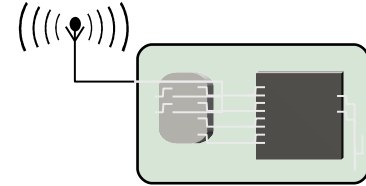
- E.g., use multi-hop routes with low energy consumption (energy/bit)
- E.g., take available battery capacity of devices into account
- How to resolve conflicts between different optimizations?

# Outline

- Infrastructure for wireless?
- (Mobile) ad hoc networks
- ***Wireless sensor networks***
  - ***Applications***
  - Requirements & mechanisms
- Comparison

# Wireless sensor networks

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



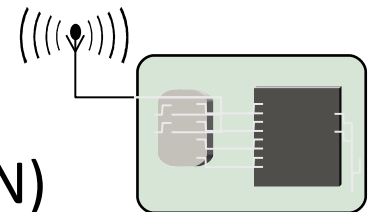
- Alternative concept:

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

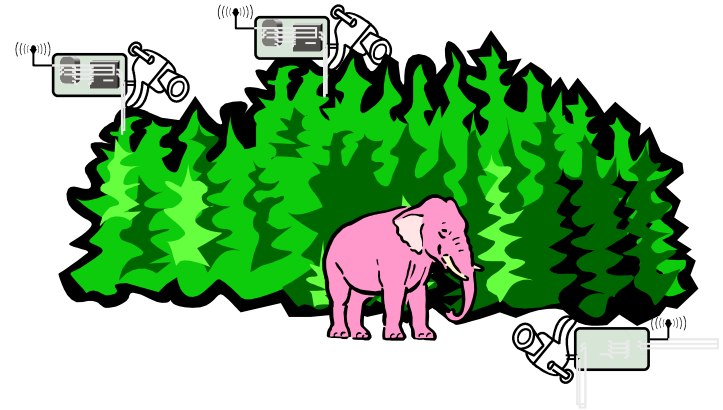
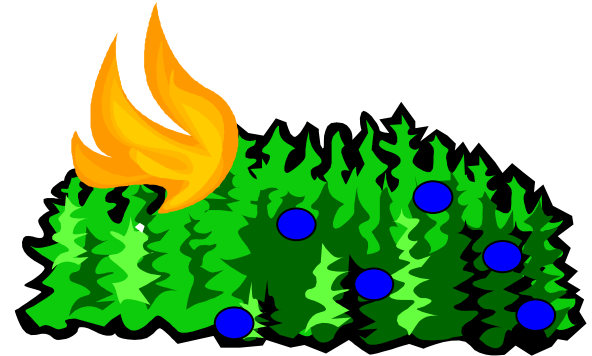
! ***Wireless sensor networks*** (WSN)

- Or: ***Wireless sensor & actuator networks*** (WSAN)



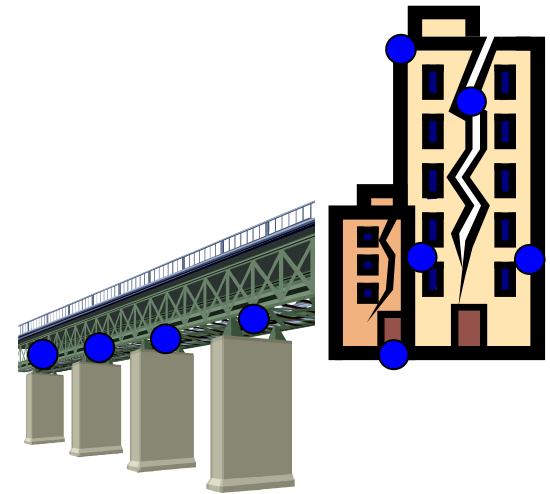
# WSN application examples

- 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



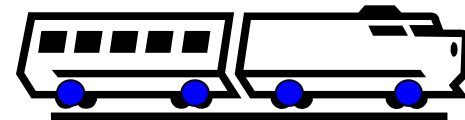
# WSN application examples

- 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



# WSN application scenarios

- Facility management
  - Intrusion detection into industrial sites
  - Control of leakages in chemical plants, ...
- Machine surveillance and preventive maintenance
  - Embed sensing/control functions into places no cable has gone before
  - E.g., tire pressure monitoring
- Precision agriculture
  - Bring out fertilizer/pesticides/irrigation only where needed
- Medicine and health care
  - Post-operative or intensive care
  - Long-term surveillance of chronically ill patients or the elderly



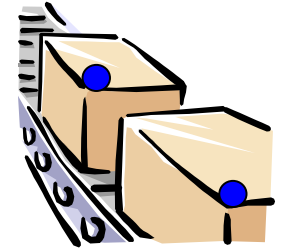
# WSN application scenarios

- Logistics

- Equip goods (parcels, containers) with a sensor node

- Track their whereabouts – ***total asset management***

- Note: passive readout might suffice – compare RF IDs



- Telematics

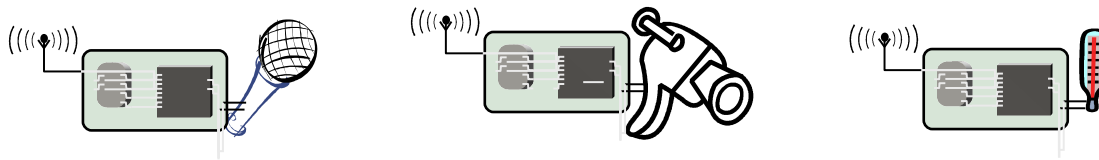
- Provide better traffic control by obtaining finer-grained information about traffic conditions

- ***Intelligent roadside***

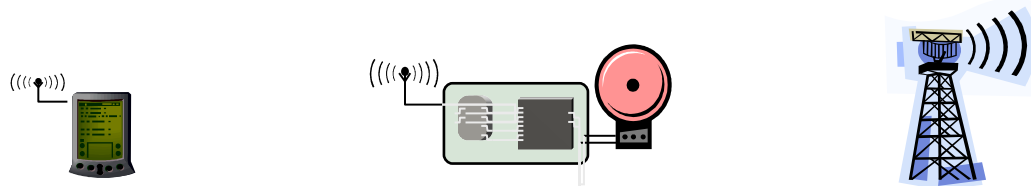
- Cars as the sensor nodes

# Roles of participants in WSN

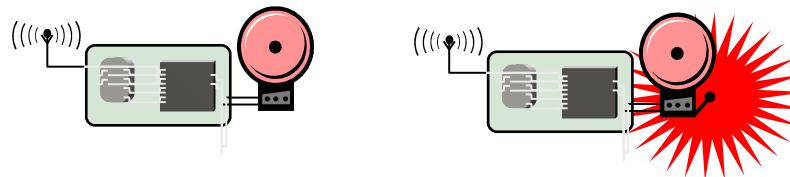
- **Sources** of data: Measure data, report them “somewhere”
  - Typically equip with different kinds of actual sensors



- **Sinks** of data: Interested in receiving data from WSN
  - May be part of the WSN or external entity, PDA, gateway, ...



- **Actuators**: Control some device based on data, usually also a sink





# Structuring WSN application types

- ***Interaction patterns*** between sources and sinks classify application types
  - ***Event detection***: Nodes locally detect events (maybe jointly with nearby neighbors), report these events to interested sinks
    - ***Event classification*** additional option
  - ***Periodic measurement***

# Structuring WSN application types

- ***Function approximation***: Use sensor network to approximate a function of space and/or time (e.g., temperature map)
- ***Edge detection***: Find edges (or other structures) in such a function (e.g., where is the zero degree border line?)
- ***Tracking***: Report (or at least, know) position of an observed intruder (“pink elephant”)

# Deployment options for WSN

- How are sensor nodes deployed in their environment?
  - Dropped from aircraft ! **Random deployment**
    - Usually uniform random distribution for nodes over finite area is assumed
  - Well planned, fixed ! **Regular deployment**
    - Not necessarily geometric structure, but that is often a convenient assumption
  - **Mobile** sensor nodes
    - Can move to compensate for deployment shortcomings
    - Can be passively moved around by some external force (wind, water)
    - Can actively seek out “interesting” areas

# Maintenance options

- Feasible and/or practical to maintain sensor nodes?
  - E.g., to replace batteries?
  - Or: unattended operation?
  - Impossible but not relevant? Mission lifetime might be very small
- Energy supply?
  - Limited from point of deployment?
  - Some form of recharging, energy scavenging from environment?
    - E.g., solar cells

# Outline

- Infrastructure for wireless?
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  - Applications
  - ***Requirements & mechanisms***
- Comparison

# Characteristic requirements for WSNs

- Type of service of WSN
  - Not simply moving bits like another network
  - Rather: provide *answers* (not just numbers)
  - Issues like geographic scoping are natural requirements, absent from other networks
- Quality of service
  - Traditional QoS metrics do not apply
  - Still, service of WSN must be “good”: Right answers at the right time

# Characteristic requirements for WSNs

- Fault tolerance
  - Be robust against node failure (running out of energy, physical destruction, ...)
- Lifetime
  - The **network** should fulfill its task as long as possible – definition depends on application
  - Lifetime of individual nodes relatively unimportant

# Characteristic requirements for WSNs

- Scalability
  - Support large number of nodes
- Wide range of densities
  - Vast or small number of nodes per unit area, very application-dependent
- Programmability
  - Re-programming of nodes in the field might be necessary, improve flexibility
- Maintainability
  - WSN has to adapt to changes, self-monitoring, adapt operation
  - Incorporate possible additional resources, e.g., newly deployed nodes



# Required mechanisms to meet requirements

- Multi-hop wireless communication
- Energy-efficient operation
  - Both for communication and computation, sensing, actuating
- Auto-configuration
  - Manual configuration just not an option
- Collaboration & in-network processing
  - Nodes in the network collaborate towards a joint goal
  - Pre-processing data in network (as opposed to at the edge) can greatly improve efficiency

# Required mechanisms to meet requirements

- Data centric networking
  - Focusing network design on ***data***, not on ***node identifies*** (id-centric networking)
  - To improve efficiency
- Locality
  - Do things locally (on node or among nearby neighbors) as far as possible
- Exploit tradeoffs
  - E.g., between invested energy and accuracy

# Outline

- Infrastructure for wireless?
- (Mobile) ad hoc networks
- Wireless sensor networks
- *Comparison*

# MANET vs. WSN

- Many commonalities: Self-organization, energy efficiency, (often) wireless multi-hop
- Many differences
  - ***Applications, equipment***: MANETs more powerful (read: expensive) equipment assumed, often “human in the loop”-type applications, higher data rates, more resources
  - ***Application-specific***: WSNs depend much stronger on application specifics; MANETs comparably uniform

# MANET vs. WSN

- ***Environment interaction***: core of WSN, absent in MANET
- ***Scale***: WSN might be much larger (although contestable)
- ***Energy***: WSN tighter requirements, maintenance issues
- ***Dependability/QoS***: in WSN, individual node may be dispensable (network matters), QoS different because of different applications
- ***Data centric*** vs. id-centric networking
- ***Mobility***: different mobility patterns like (in WSN, sinks might be mobile, usual nodes static)

# Wireless fieldbuses and WSNs

- Fieldbus:
  - Network type invented for real-time communication, e.g., for factory-floor automation
  - Inherent notion of sensing/measuring and controlling
  - Wireless fieldbus: Real-time communication over wireless

! Big similarities

- Differences
  - Scale – WSN often intended for larger scale
  - Real-time – WSN usually not intended to provide (hard) real-time guarantees as attempted by fieldbuses

# Enabling technologies for WSN

- Cost reduction
  - For wireless communication, simple microcontroller, sensing, batteries
- Miniaturization
  - Some applications demand small size
  - “Smart dust” as the most extreme vision
- Energy scavenging
  - Recharge batteries from ambient energy (light, vibration, ...)

# Conclusion

- MANETs and WSNs are challenging and promising system concepts
- Many similarities, many differences
- Both require new types of architectures & protocols compared to “traditional” wired/wireless networks
- In particular, application-specificity is a new issue