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Information and Communication Technologies Institute

Wireless Sensor Networks
Chapter 1: Motivation & Applications

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Courtesy: Holger Karl, UPB

Goals of this chapter

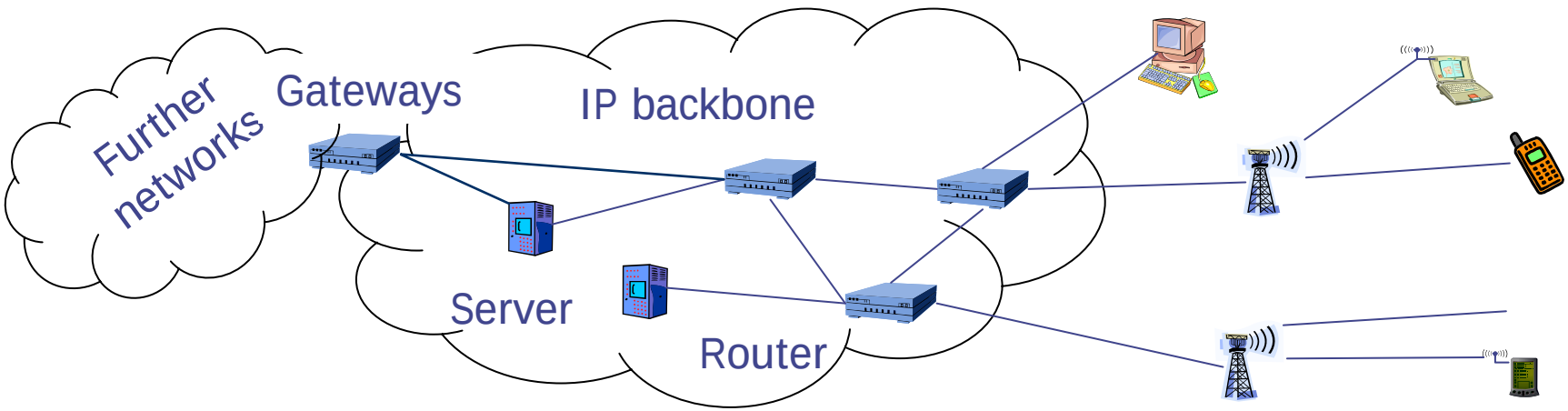
- Give an understanding what ad hoc & sensor networks are good for, what their intended application areas are
- Commonalities and differences
  - Differences to related network types
- Limitations of these concepts

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, 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

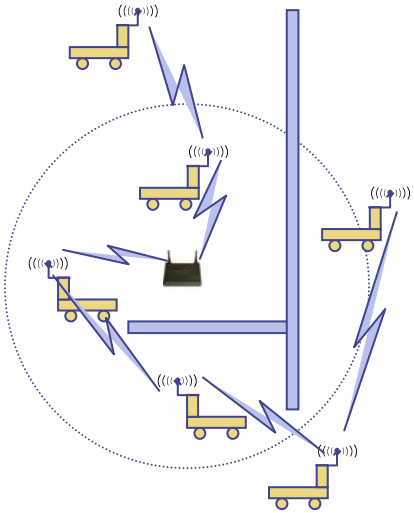


Infrastructure-based wireless networks – Limits?

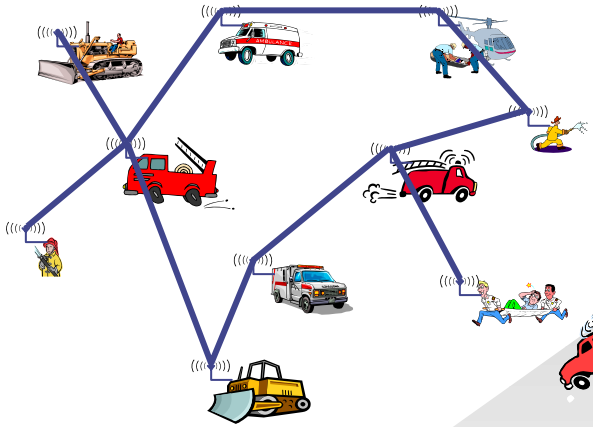
- What if …
  - No infrastructure is available? – E.g., in disaster areas, underwater
  - It is too expensive/inconvenient to set up? – E.g., in remote, large construction sites
  - It is too expensive to use? – E.g., SATCOM
  - There is no time to set it up? – E.g., in military operations

Possible applications for infrastructure-free networks

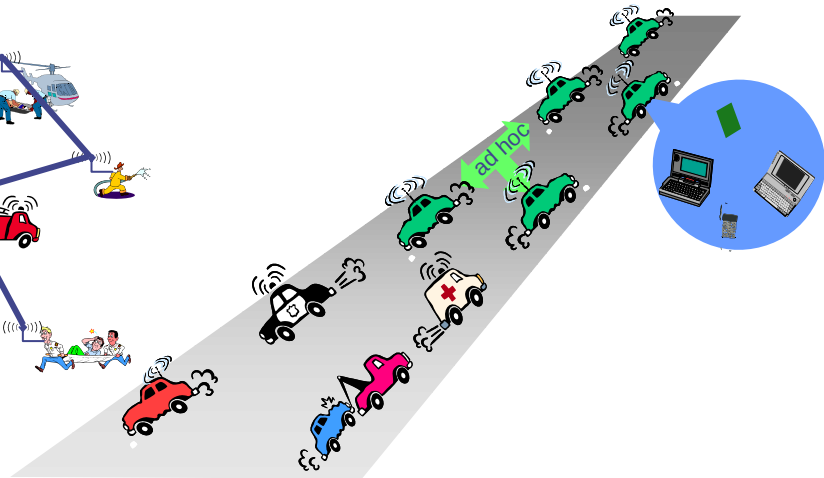
- Factory floor automation



- Disaster recovery



- Car-to-car communication



- Survivable communications infrastructure: Mesh Vegas, IEEE 802.16
- Military networking: Tanks, soldiers, unmanned platforms …
- 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, …)
- …

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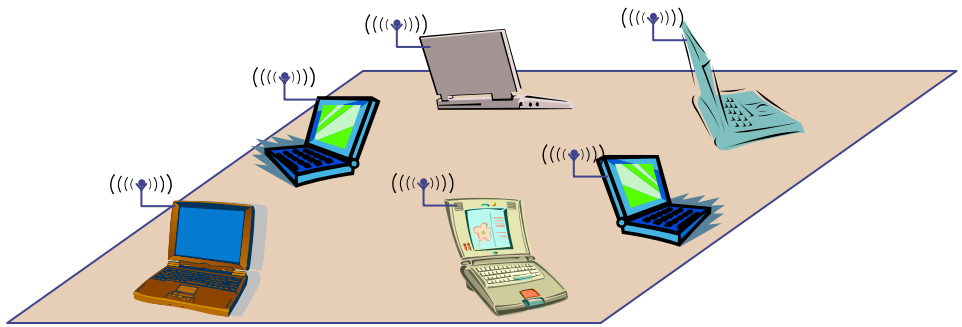
Solution: (Wireless) ad hoc networks

- 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

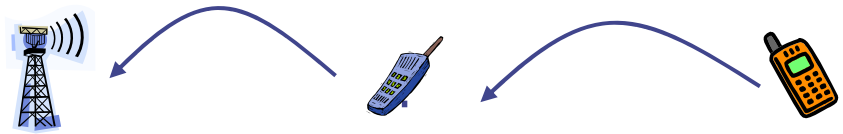
- Without a central infrastructure, things become much more difficult
- Problems are due to
  - Lack of central entity for organization available
  - Limited range of wireless communication
  - Mobility of participants
  - Battery-operated entities

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):
  - 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

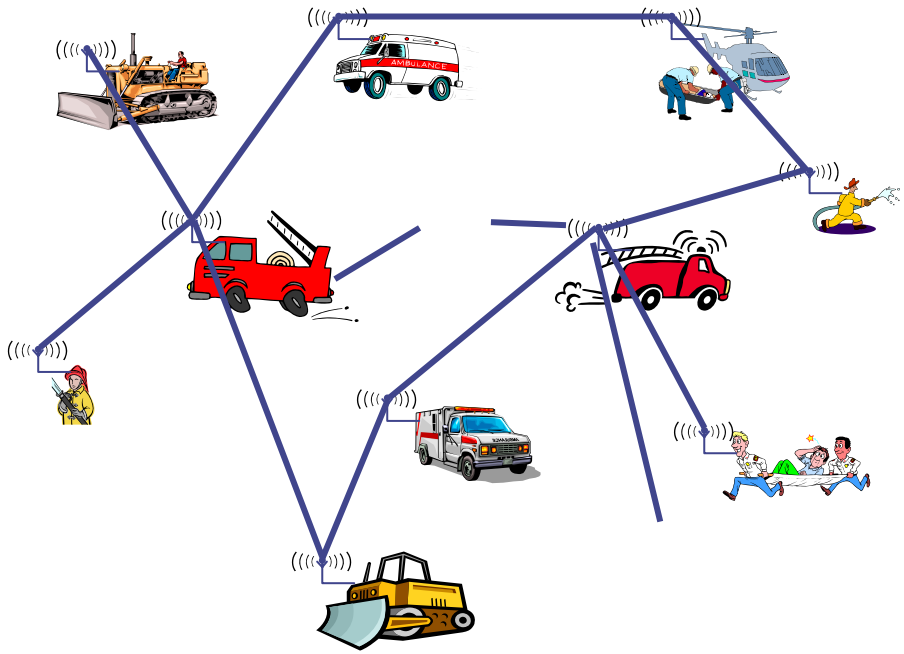
Limited range ! multi-hopping

- For many scenarios, communication with peers outside immediate communication range is required
  - Direct communication limited because of distance, obstacles, energy consumption…
  - 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 accordingly
- 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

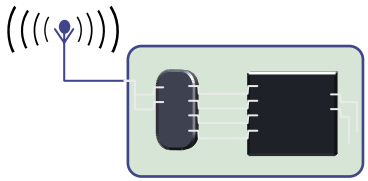
- E.g., use multi-hop routes with low energy consumption (energy/bit)
- E.g., take available battery capacity of devices into account when setting-up routes
- How to resolve conflicts between different optimizations? E.g. latency vs energy

Outline

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

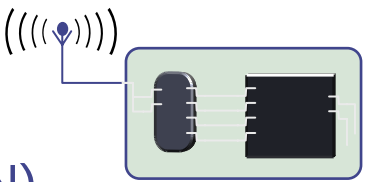
Wireless sensor networks

- 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)

WSNs: May not be the best solution when...

- It is more efficient to do the job locally:
  - Friendly environment
  - Very restricted Area
  - Very smooth temporal variability of target measures

- It is more efficient to do the job remotely
  - Very large area
  - Very large-scale variability of target measures
  - Very long sensor range

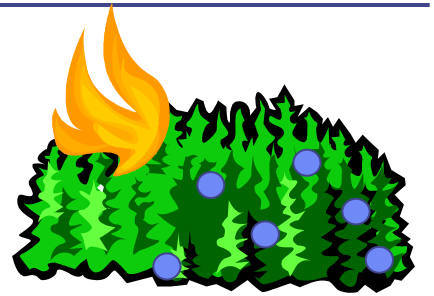
WSNs: May be advantageous in scenarios that combine...

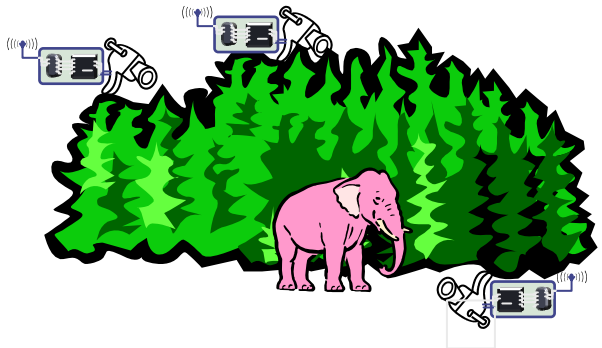
- Harsh environment: E.g., battlefield, nuclear plant
- Short sensor range: E.g., temperature, smoke detection
- Large area: E.g., forest, agricultural field, building
- High temporal/spatial variability: E.g., temperature in wildfire
- Event detection: E.g., intrusion detection in restricted areas

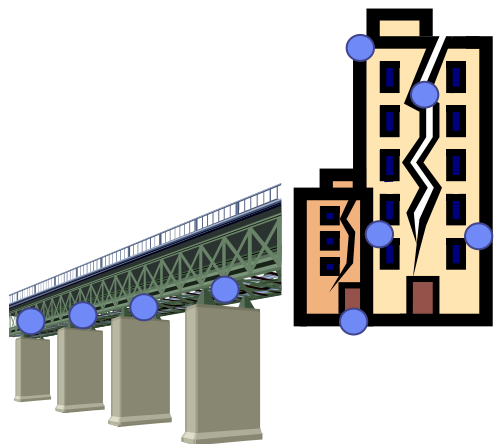


WSN application examples

- 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

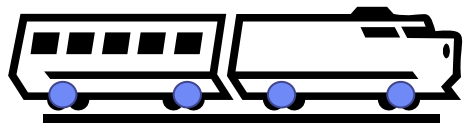






WSN application scenarios

- Facility management
  - Intrusion detection into industrial sites and other restricted areas
  - 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

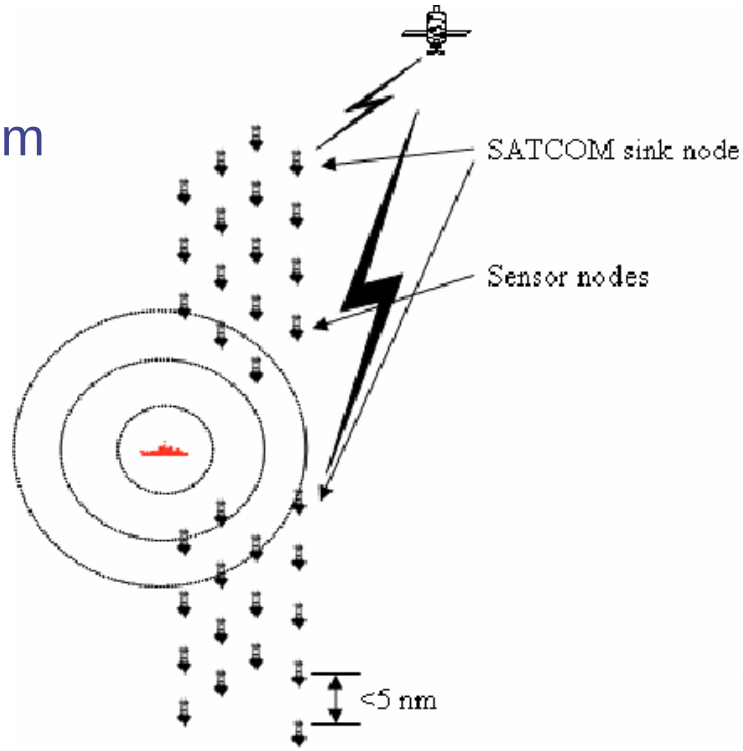
WSN application scenarios

- Logistics
  - Equip goods (parcels, containers) with a sensor node
  - Track their whereabouts – ***total asset management***
  - Note: passive readout might suffice – compare RF IDs

- Vehicle Telematics
  - Provide better traffic control by obtaining finer-grained information about traffic conditions
  - ***Intelligent roadside***
  - Cars as the sensor nodes
- Intruder Detection and Tracking in Military/Security Ops
  - Scatter seismic, noise, movement sensors in sensitive sectors
  - E.g., IST FP6 UbiSec&Sens (Homeland Security scenario)

WSN application scenarios (not only land)

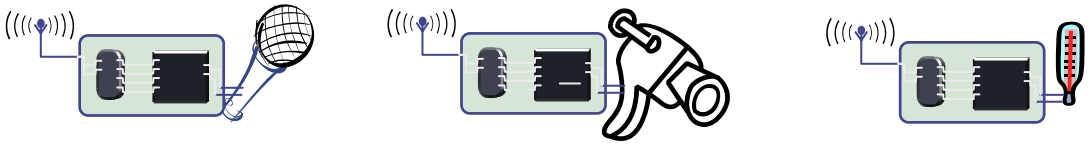
- Oceanographic WSN
  - Deploy oceanographic buoys to perform measurements far from the coastline
  - E.g., EEZ-WSN project



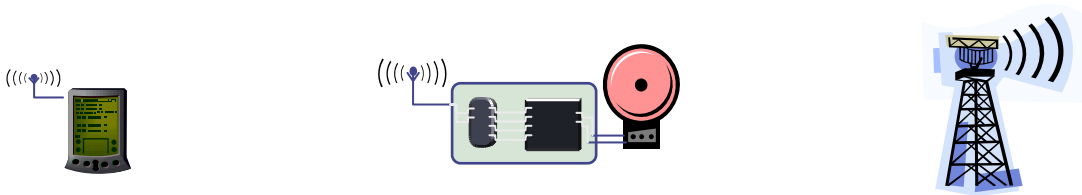
- Underwater WSNs
  - Employ Acoustic communications
  - Pollution detection in shallow waters
  - Measurement seismic activity on the sea bed
  - Anti-submarine warfare

Roles of participants in WSN

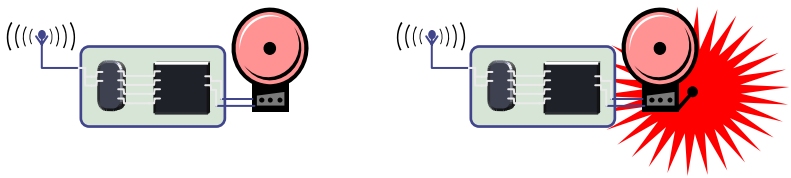
- ***Sources*** of data: Measure data, report them “somewhere”
  - Typically equip with different kinds of actual sensors



- ***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***
  - ***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
    - Is that a likely proposition?
  - Well planned, fixed ! ***Regular deployment***
    - E.g., in preventive maintenance or similar
    - 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

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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
- 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
  - But often treated equivalently

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

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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
  - ***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. (e.g., CAN):
  - 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, …)
- Environment friendly electronics
  - Disposable sensors present environmental issues

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-specificness is a new issue