# Chapter 1: Motivation & Applications

For use in conjunction with *Protocols and Architectures for Wireless Sensor Networks*, by Holger Karl, Andreas Willig (http://www.wiley.com)

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# Goals of this chapter

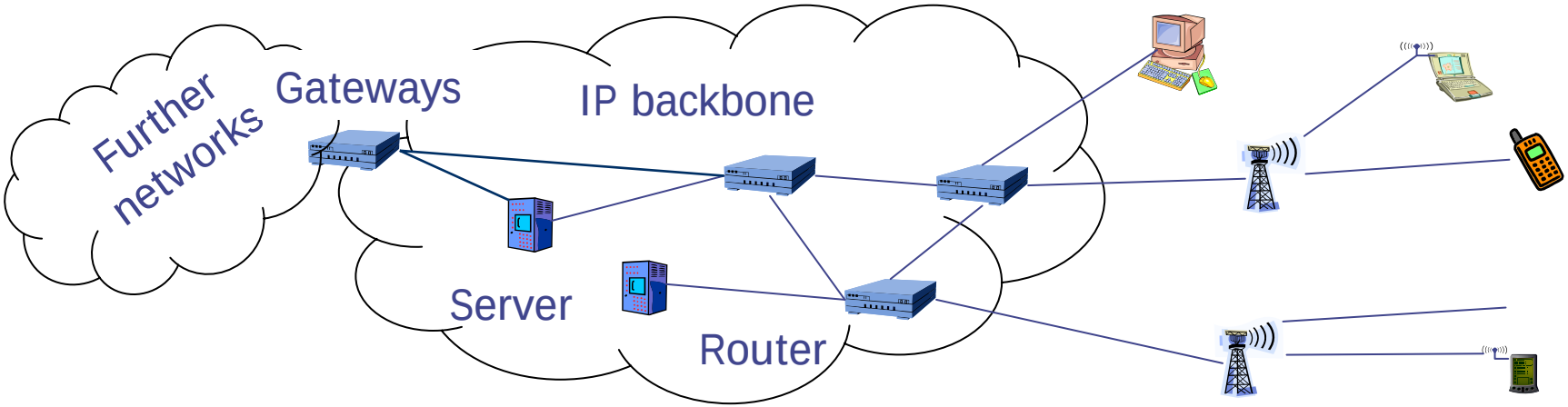
- Give an understanding what ad hoc & sensor networks are good for, what their intended application areas are
- Commonalities and differences
  - Differences to related network types
- Limitations of these concepts

# 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

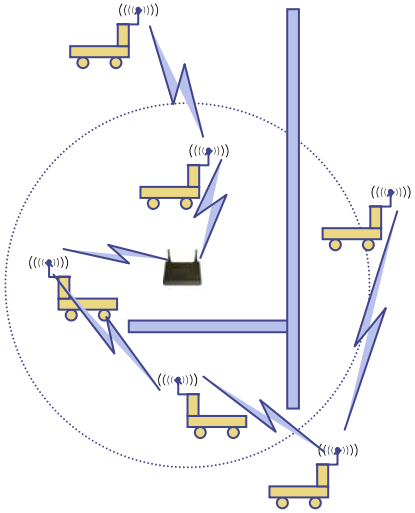


# Infrastructure-based wireless networks – Limits?

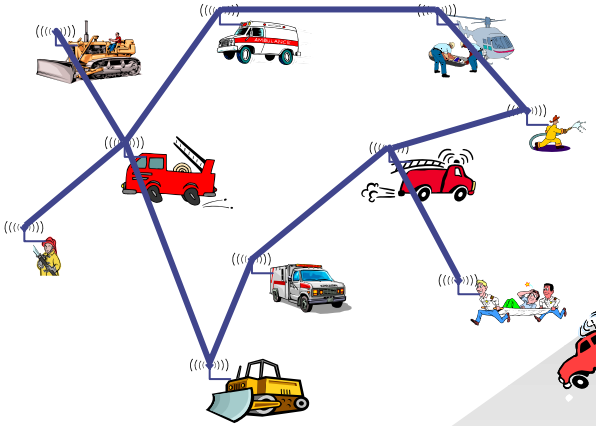
- What if …
  - No infrastructure is available? – E.g., in disaster areas
  - It is too expensive/inconvenient to set up? – E.g., in remote, large construction sites
  - There is no time to set it up? – E.g., in military operations

# Possible applications for infrastructure-free networks

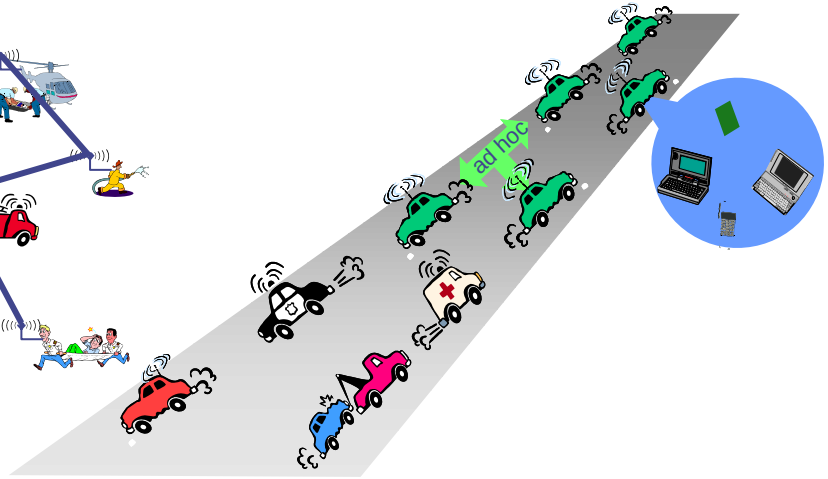
- Factory floor automation



- Disaster recovery

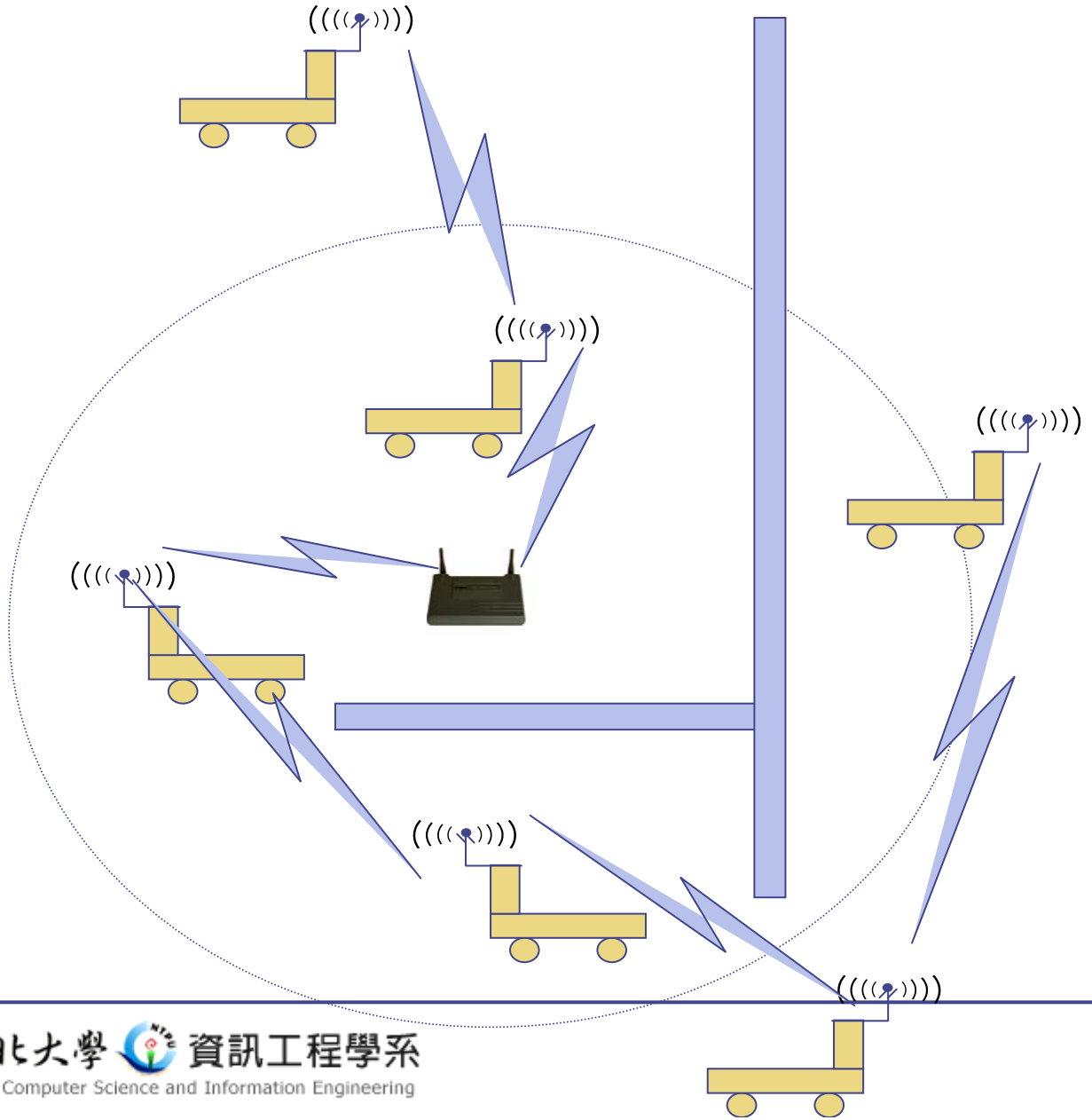


- Car-to-car communication

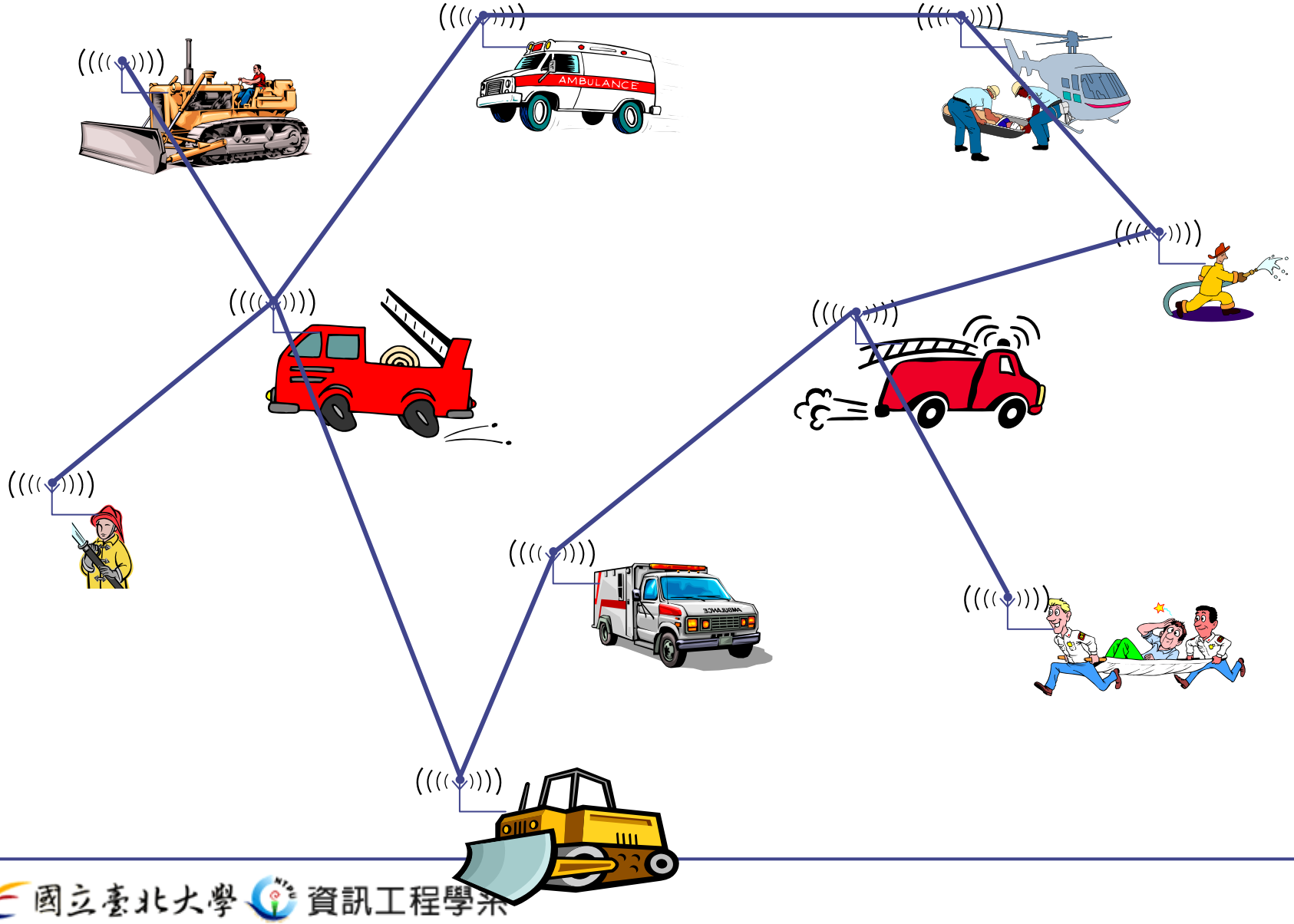



- Military networking: Tanks, soldiers, …
- Finding out empty parking lots in a city, without asking a server
- Search-and-rescue in an avalanche
- Personal area networking (watch, glasses, PDA, medical appliance, …)
- …

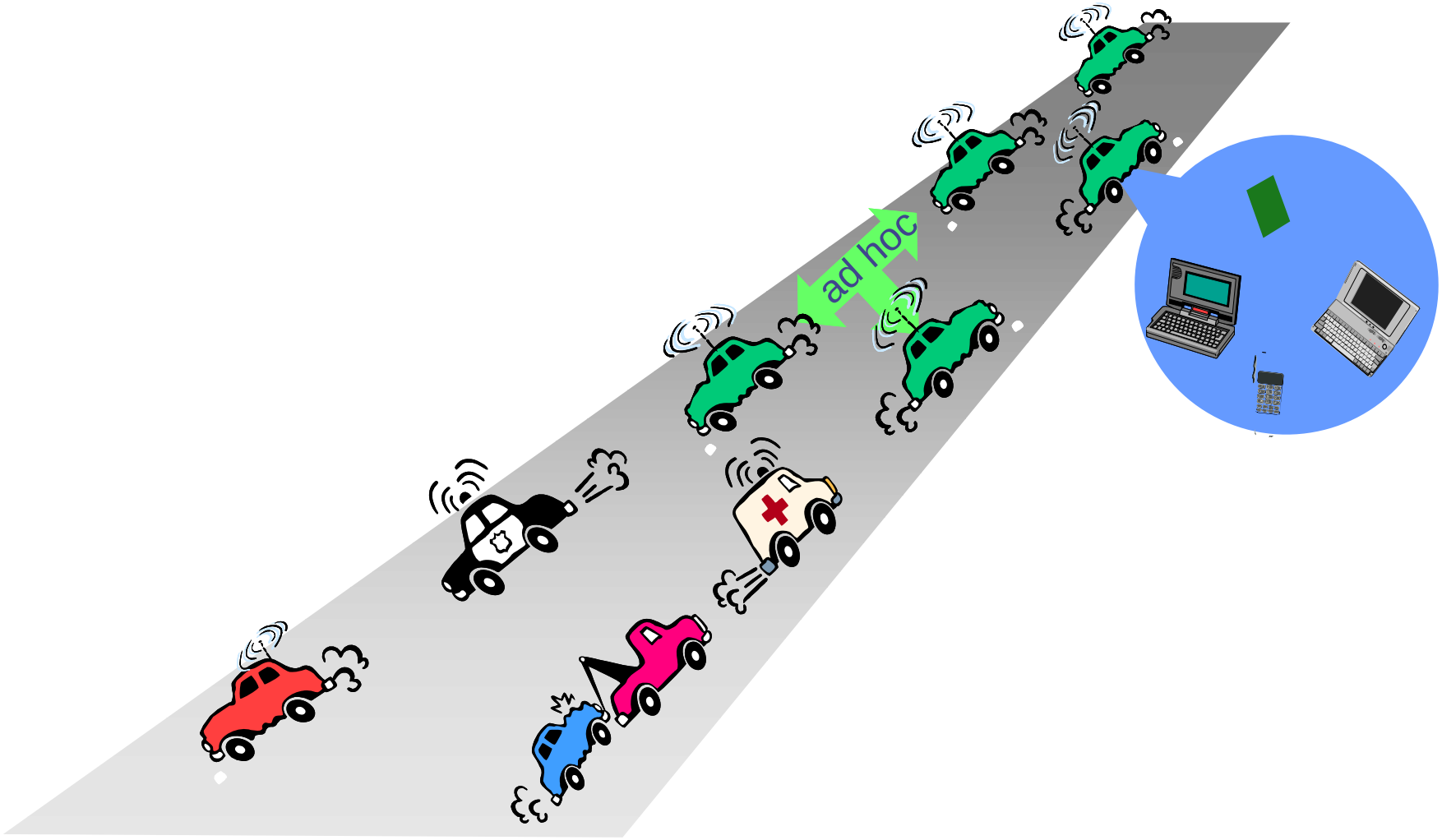
# Factory floor automation



# Disaster recovery



# Car-to-car communication



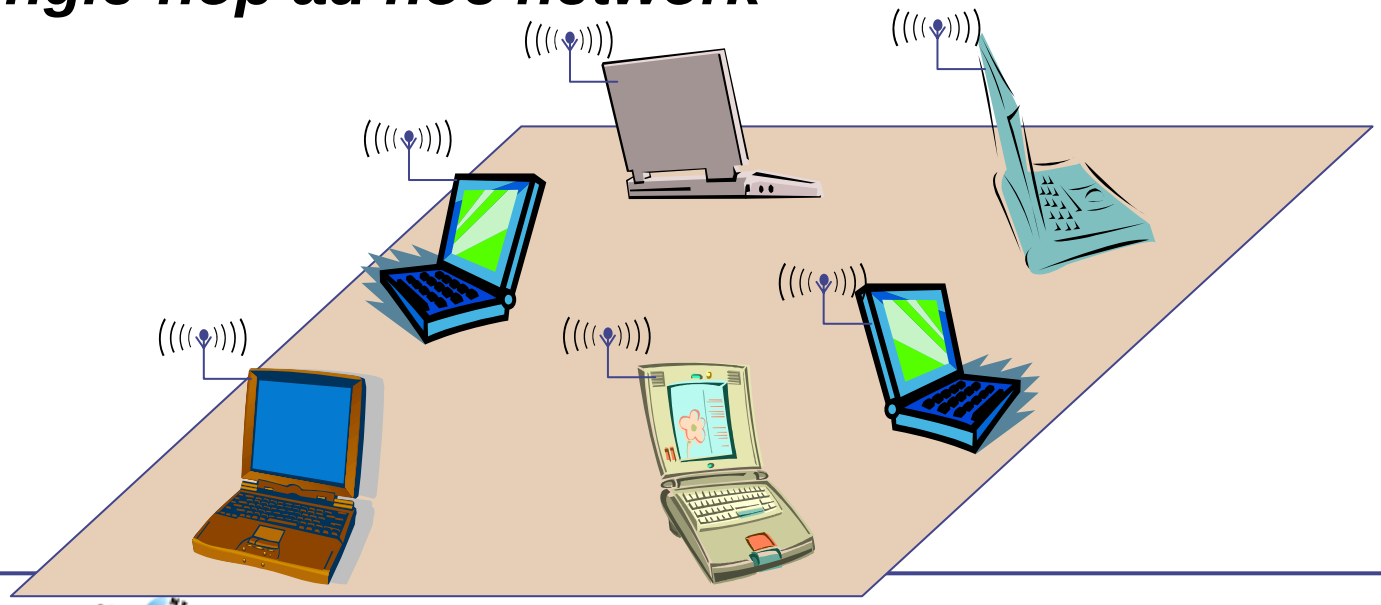
# Outline

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

# **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

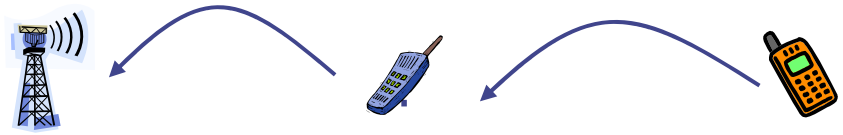
- Without a central infrastructure, things become much more difficult
- Problems are due to
  - Lack of central entity for organization available
  - Limited range of wireless communication
  - Mobility of participants
  - Battery-operated entities

# 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

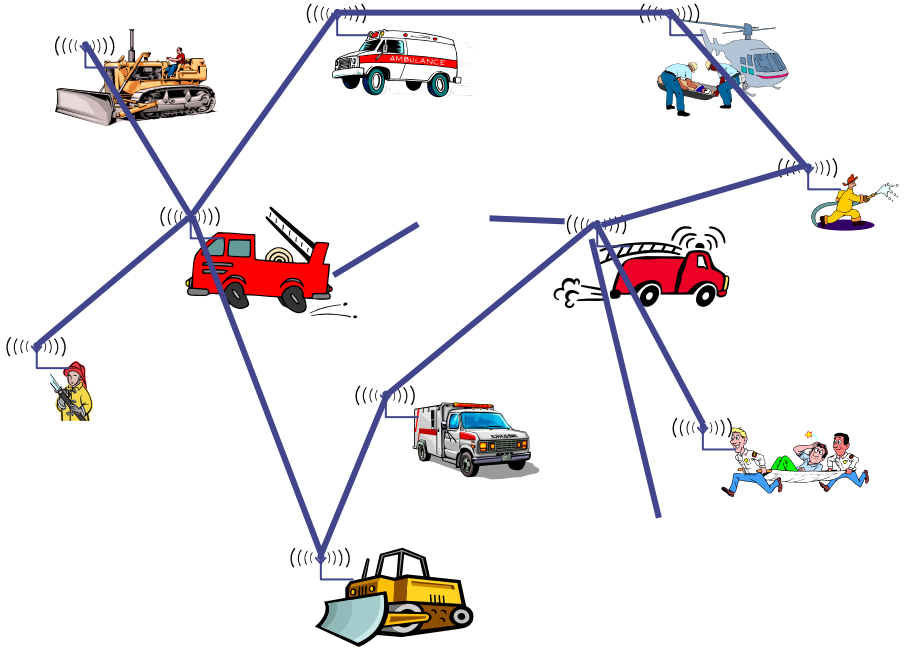
# Limited range → multi-hopping

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

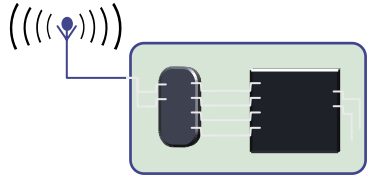
  - E.g., use multi-hop routes with low energy consumption (energy/bit)
  - E.g., take available battery capacity of devices into account
  - How to resolve conflicts between different optimizations?

# Outline

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

# Wireless sensor networks

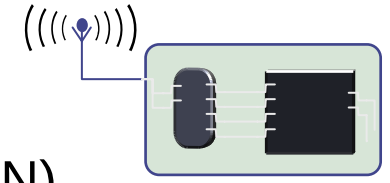
- Participants in the previous examples were devices close to a human user, interacting with humans



- 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

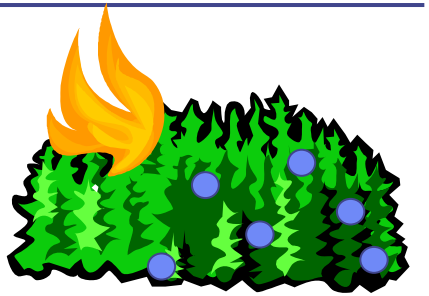
→ ***Wireless sensor networks*** (WSN)



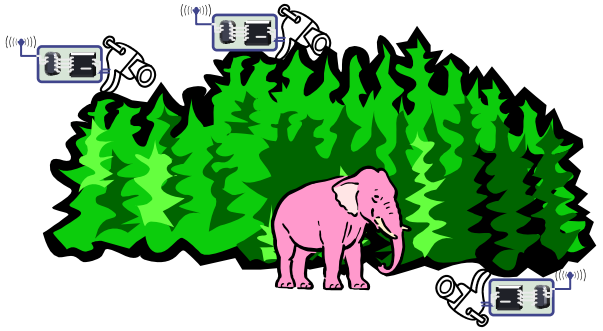
  - Or: ***Wireless sensor & actuator networks*** (WSAN)

# WSN application examples

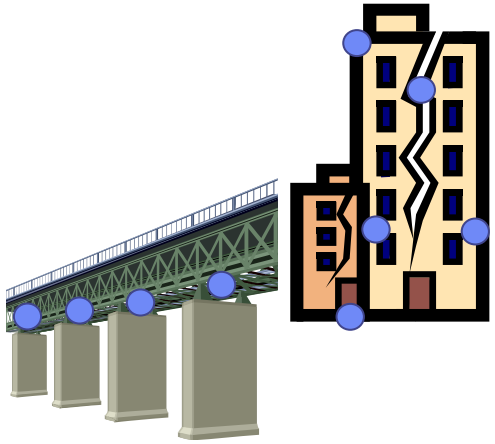
- Disaster relief operations
  - Drop sensor nodes from an aircraft over a wildfire
  - Each node measures temperature
  - Derive a “temperature map”



- Biodiversity mapping
  - Use sensor nodes to observe wildlife

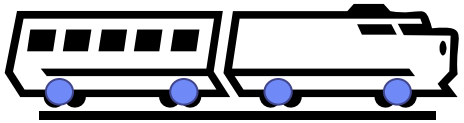


- Intelligent buildings (or bridges)
  - Reduce energy wastage by proper humidity, ventilation, air conditioning (HVAC) control
  - Needs measurements about room occupancy, temperature, air flow, …
  - Monitor mechanical stress after earthquakes



# WSN application scenarios

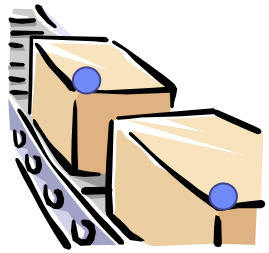
- Facility management
  - Intrusion detection into industrial sites
  - Control of leakages in chemical plants, …
- Machine surveillance and preventive maintenance
  - Embed sensing/control functions into places no cable has gone before
  - E.g., tire pressure monitoring



- 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

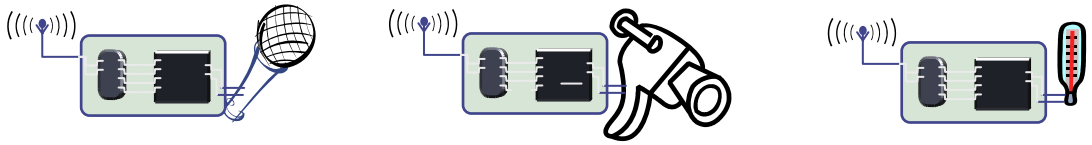
- Logistics
  - Equip goods (parcels, containers) with a sensor node
  - Track their whereabouts – ***total asset management***
  - Note: passive readout might suffice – compare RF IDs



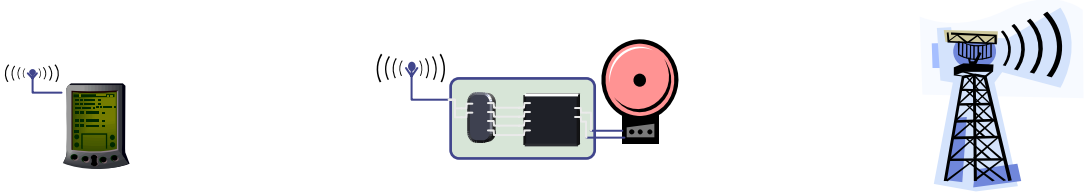
- Telematics
  - Provide better traffic control by obtaining finer-grained information about traffic conditions
  - ***Intelligent roadside***
  - Cars as the sensor nodes

# Roles of participants in WSN

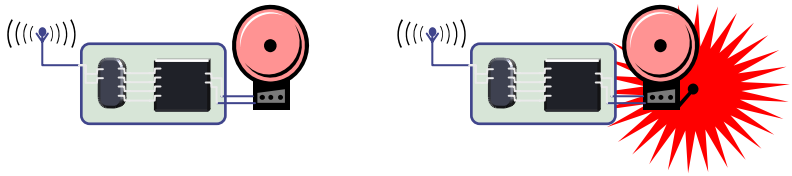
- ***Sources*** of data: Measure data, report them “somewhere”
  - Typically equip with different kinds of actual sensors



- ***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***
  - ***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

# Outline

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

# 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
  - ***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-specificness is a new issue

For use in conjunction with *AD HOC & SENSOR NETWORK: Theory and Applications*, by C. d. M. Cordeiro and D. P. Agrawal

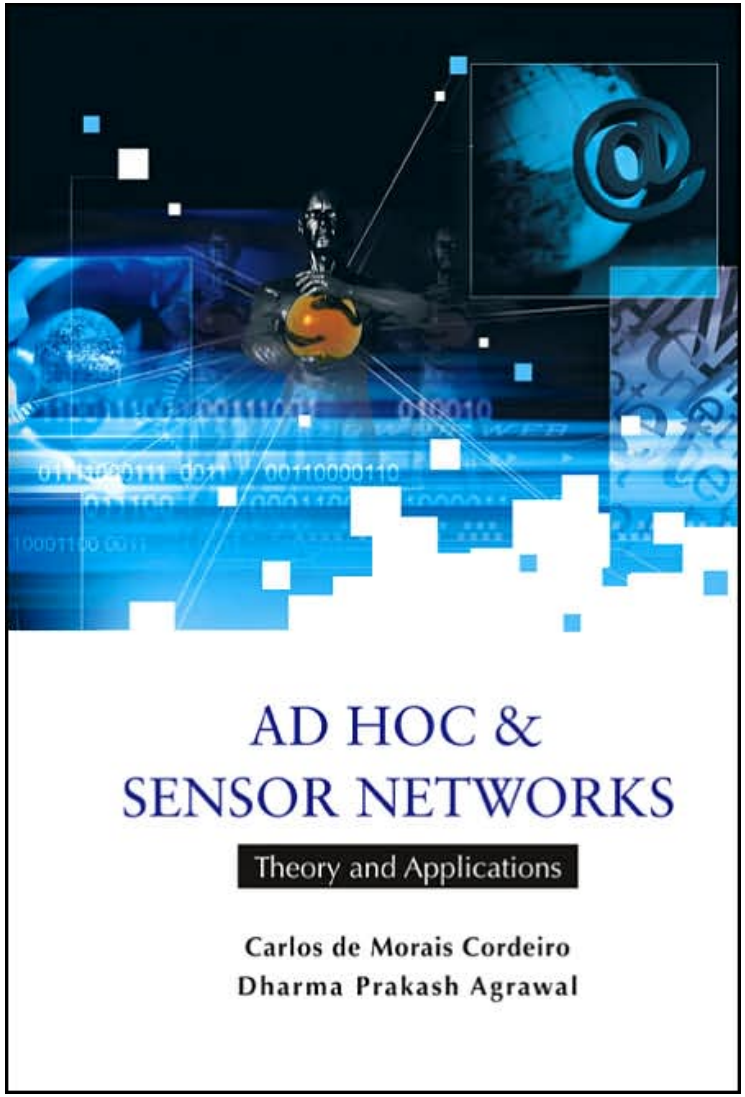


Table 1.1 – Important characteristics of a MANET

| Characteristic | Description |
|---|---|
| Dynamic Topologies | Nodes are free to move arbitrarily with different speeds; thus, the network topology may change randomly and at unpredictable times. |
| Energy-constrained Operation | Some or all of the nodes in an ad hoc network may rely on batteries or other exhaustible means for their energy. For these nodes, the most important system design optimization criteria may be energy conservation. |
| Limited Bandwidth | Wireless links continue to have significantly lower capacity than infrastructured networks. In addition, the realized throughput of wireless communications – after accounting for the effects of multiple access, fading, noise, and interference conditions, etc., is often much less than a radio's maximum transmission rate. |
| Security Threats | Mobile wireless networks are generally more prone to physical security threats than fixed-cable nets. The increased possibility of eavesdropping, spoofing, and minimization of denial-of-service type attacks should be carefully considered. |

# Fourth-generation wireless technologies

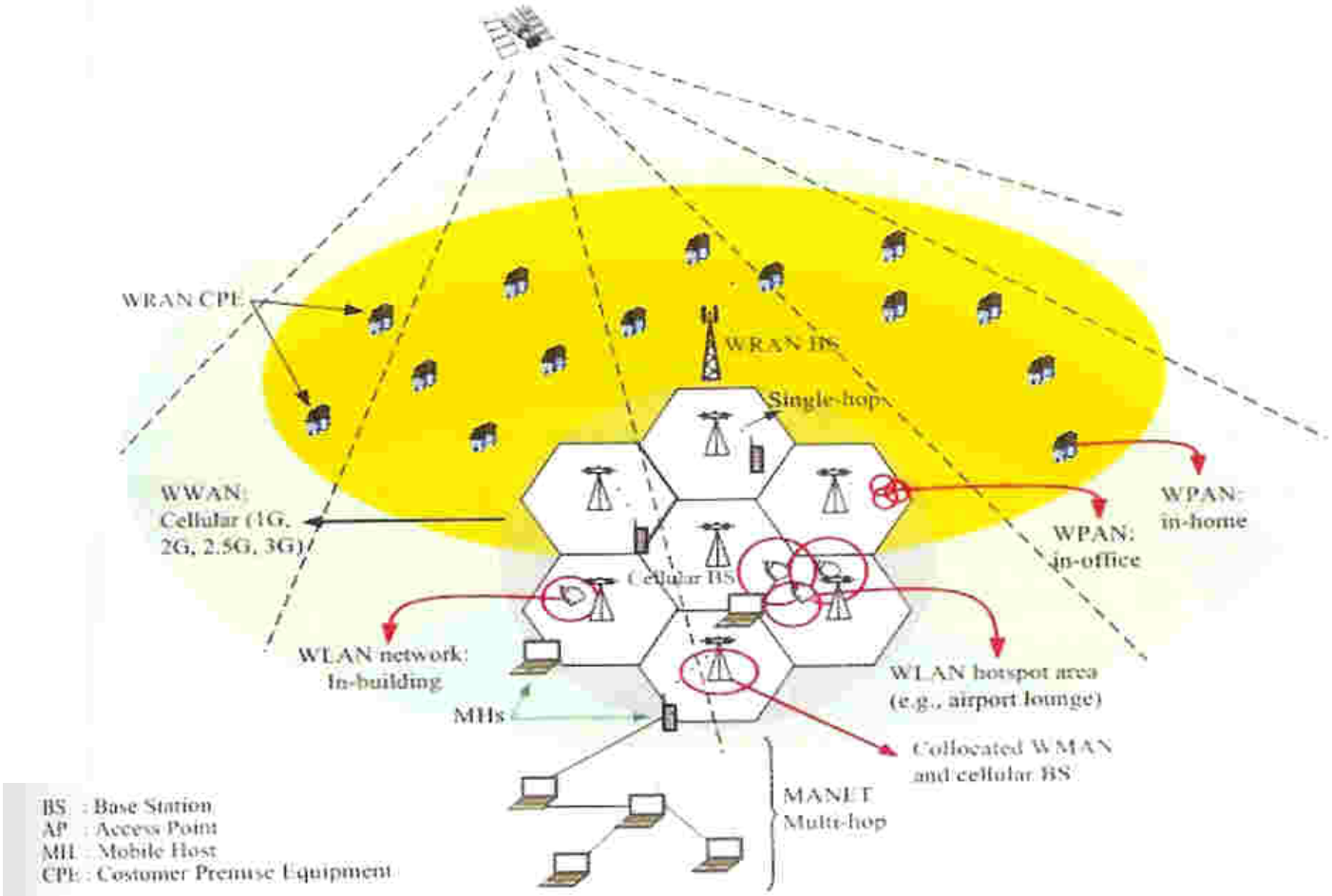



Figure 1.2 – The envisioned communication puzzle of 4G and beyond

# The Communication Puzzle

- Fourth-generation wireless technologies include
  - Wireless Personal Area Networks
    - Wireless PANs or WPANs
  - Wireless Local Area Networks
    - Wireless LANs or WLANs
  - Wireless Metropolitan Area Networks
    - Wireless MANs or WMANs
  - Wireless Regional Area Networks
    - Wireless RANs or WRAN
  - Cellular wide area network
  - Satellite network

# The scope of various wireless technologies

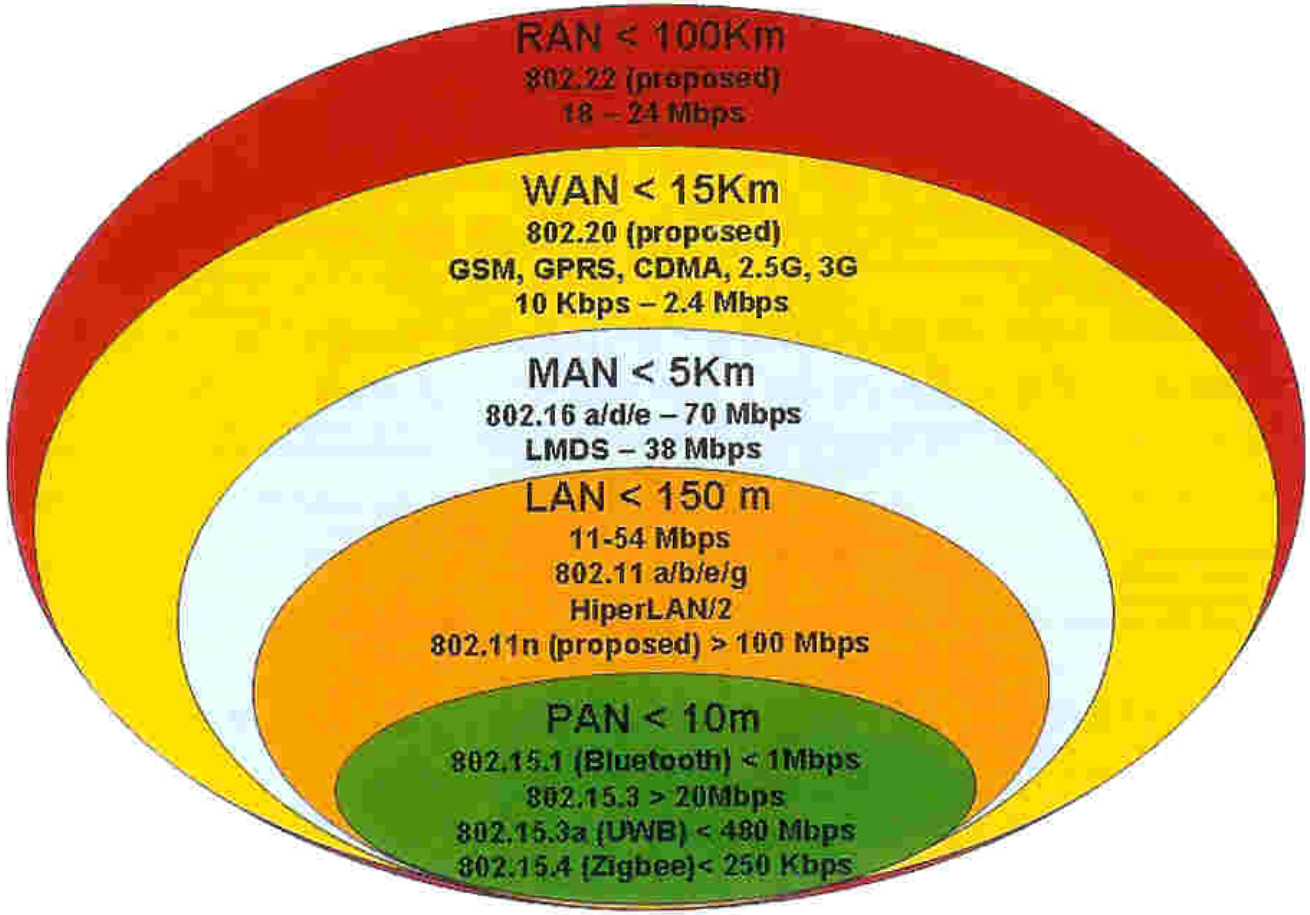



Figure 1.3 – The scope of various wireless technologies

# Homework:

1. Describe what's the difference and mobile ad hoc network (MANET) and wireless sensor network (WSN) ?
2. Think more possible applications of wireless sensor network.
3. What's the difference of WPAN, WLAN, WMAN, WRAN, cellular area network, and satellite network.