SAPIENZA
UNIVERSITÀ DI ROMA

Autonomous Networking

Gaia Maselli
Dept. of Computer Science

*Some slides in this course are readapted from lecture slides from **Prof. Tommaso Melodia** (Northeastern University, Boston)*

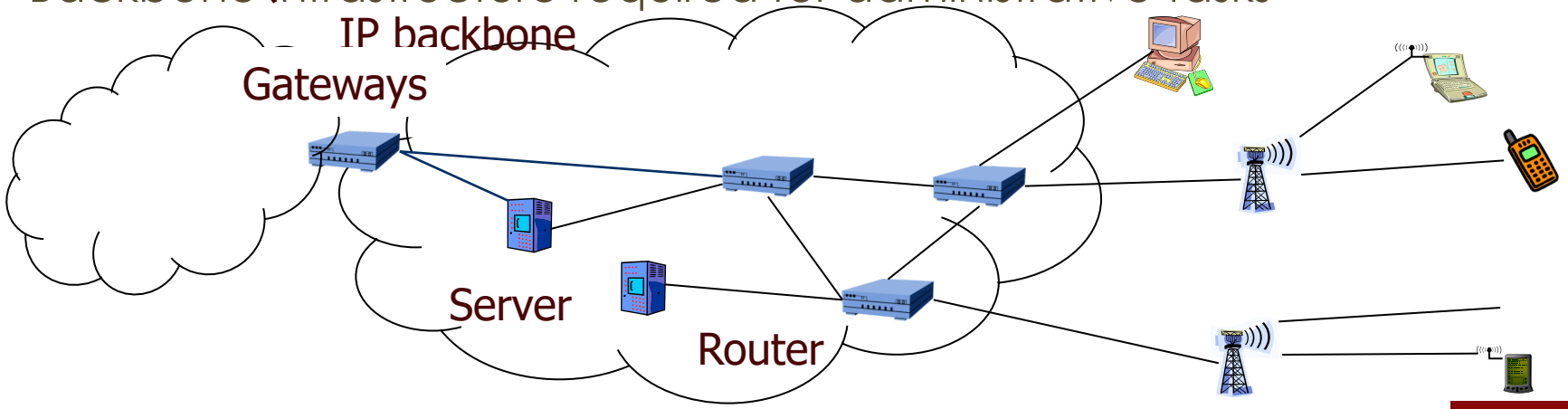
Today's plan

- Infrastructure-less wireless networks?
  - (Mobile) Ad Hoc Networks (MANET)
  - Wireless Sensor Networks (WSN)
  - Comparison
- Applications of Wireless Sensor Networks

Infrastructure-based wireless networks

Infrastructure-based Wireless Networks

- Traditional wireless network: based on infrastructure (GSM, UMTS, …)
- Base stations connected to a wired backbone network
- Mobile devices 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



Limits

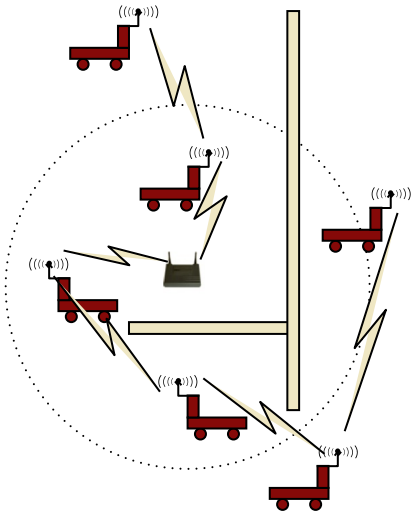
What if…

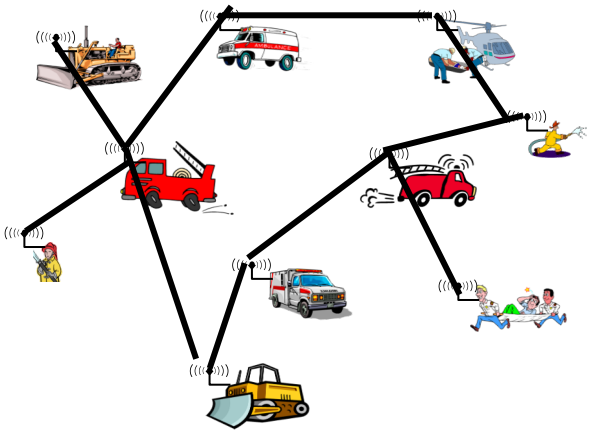
- No infrastructure is available?
  - Disaster areas
- It is too expensive/inconvenient to set up
  - Remote, large constructions sites
  - Houses
- There is no time to set it up
  - Military operations

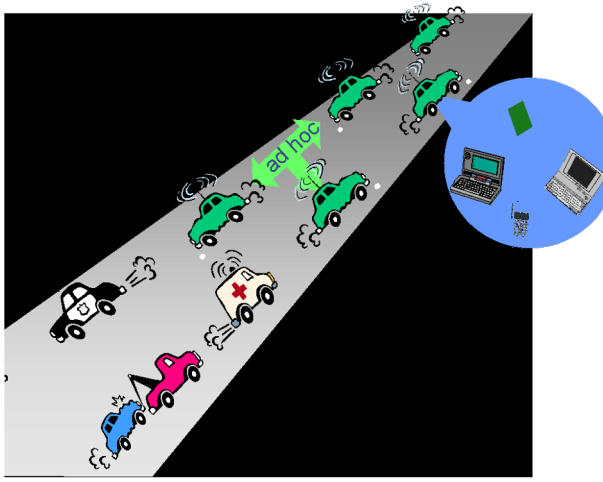
Infrastructureless-based wireless networks

Applications of Infrastructureless networks

- Factory floor automation
- Disaster recovery
- Car-to-car communication







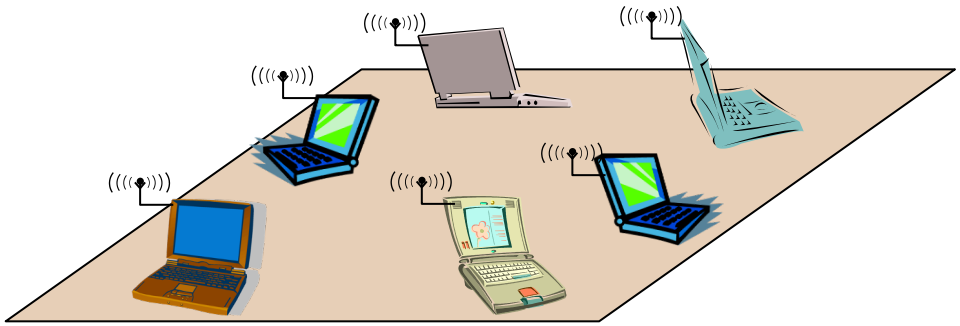
- Military networking: Tanks, soldiers, …
- Finding out empty parking lots in a city, without asking a server
- Search-and-rescue in an avalanche
- Personal area networking (watch, glasses, PDA, medical appliance, …)

Solution: Wireless Ad Hoc Networks

SAPIENZA UNIVERSITÀ DI ROMA

- Build a network without infrastructure, using networking abilities of the participants
  - Ad hoc network – a network constructed "for a special purpose"

- Example: Laptops in a conference room – a single-hop ad hoc network



Challenges in 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** devices

Self-organization

Lack of central entity

Without a central entity, participants must organize themselves into a network (self-organization)

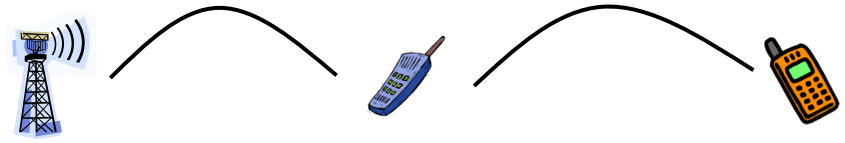
Challenges (among others):

Discovering the presence of neighboring devices	**MAC– no base station can assign transmission resources, must be decided in a distributed fashion**	Finding a route from one participant to another

Limited range of wireless communication

Multi-hop Wireless Networks

- For many scenarios, communication with peers outside immediate communication range is required
  - Direct communication limited because of distance, obstacles
  - Solution: multi-hop network

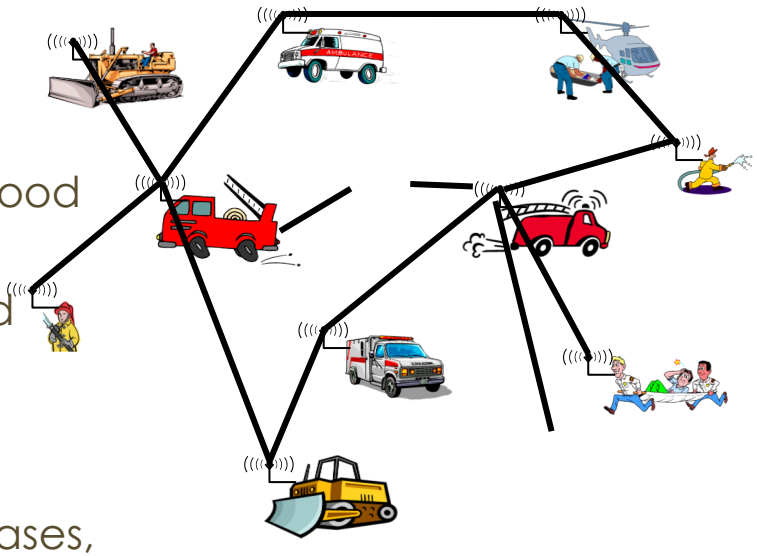


  - Under some circumstances, multi-hopping may help save energy

Adaptive Protocols

Mobility

- In several 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
  - Routes must be reconfigured adaptively
- Complicated by scale
  - When the network size increases, reconfiguration becomes more difficult



Energy-efficient operation

Battery operated devices

Participants in an ad hoc network often draw energy from batteries

Desirable: long lifetime for

- Individual devices
- Network as a whole

Energy-efficient networking protocols

- E.g., use multi-hop routes with low energy consumption (energy/bit)
- How to resolve conflicts between different optimizations?

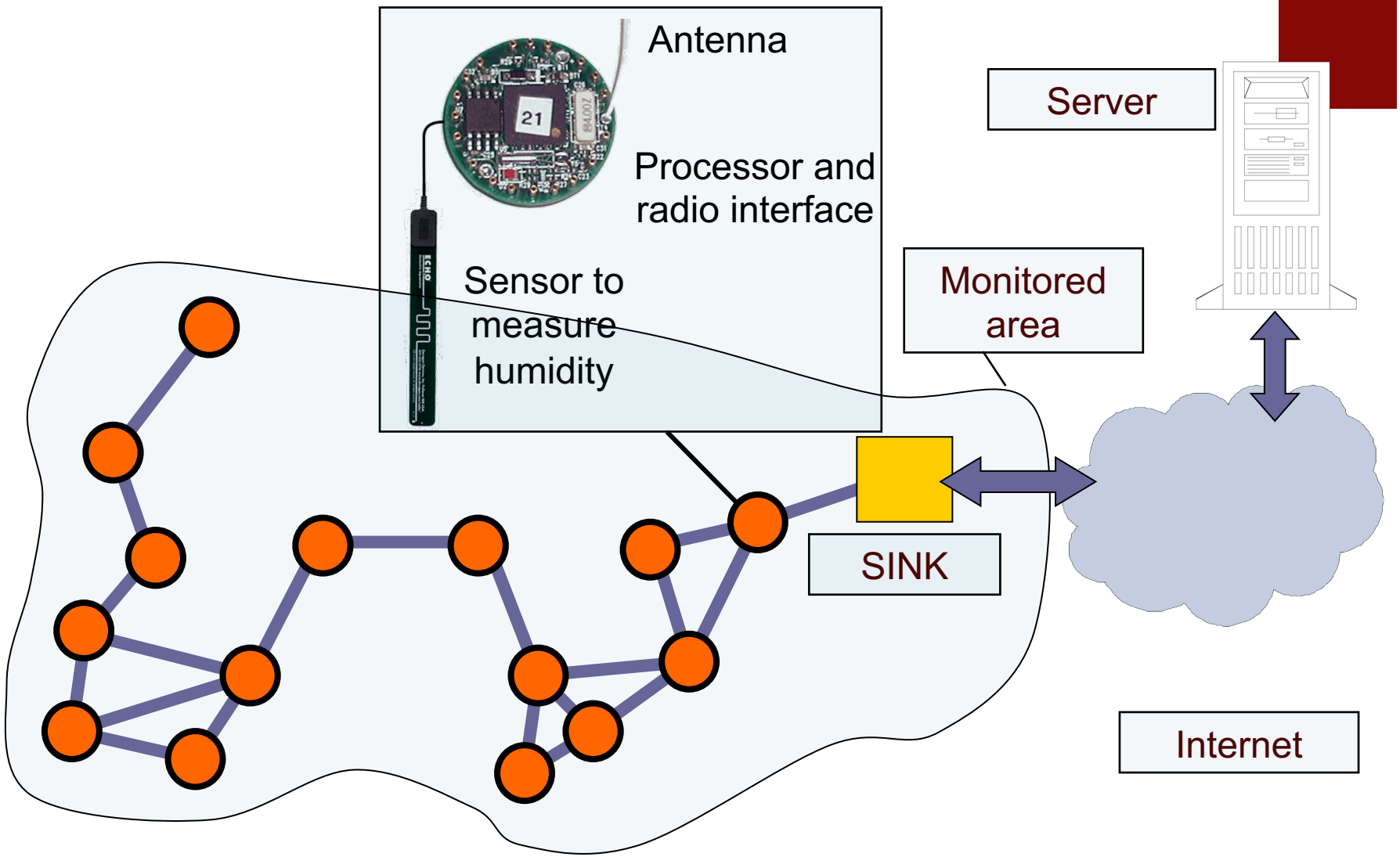
Mobile ad hoc networks

- A lot of research has been done to address all these challenges
- However a **killer application** for ad hoc networks has never been found
- **Sensor networks** (a special case of ad hoc networks), have had much wider success

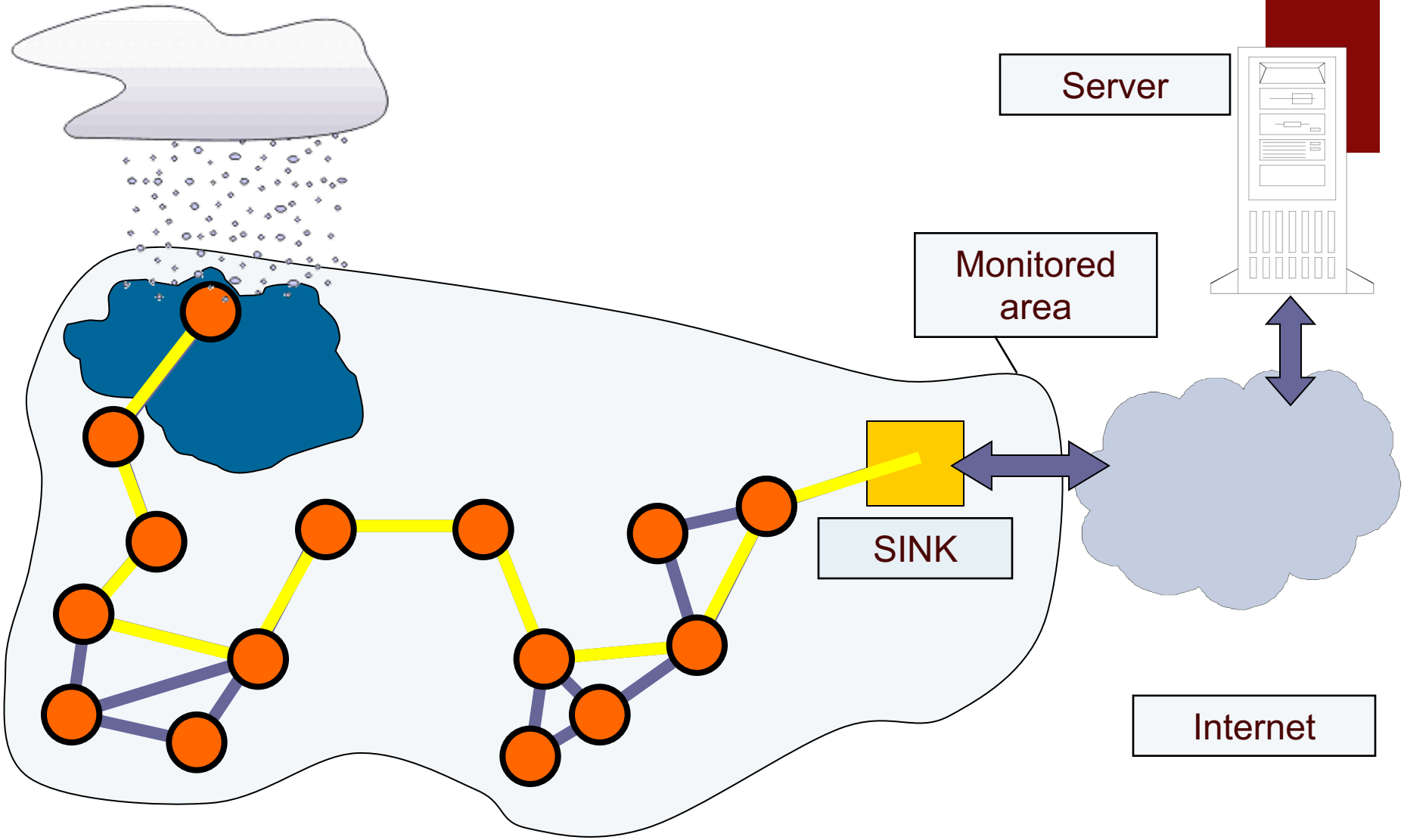
Wireless sensor networks

- Devices are much smaller than laptops
- Devices are limited in resource and computation capabilities
- Many devices can be deployed in an evironment
- Device main goal is sensing one or more phenomena

Wireless Sensor Network: architecture



Wireless Sensor Networks: data gathering



WSN: applications

Application Areas: **Everywhere** there is a need for monitoring a physical space OR using sensors for controlling a procedure.

- Industrial Control: Networked Control Systems – closing the industrial loop over WSN
- Environmental Monitoring & Agriculture: Wild Life Monitoring, Vineyards, Forest Fire Detection
- Structural Health Monitoring
- Marine monitoring: Ocean life & ecosystem
- Health Care: rehabilitation, prosthetics, chronic conditions management, emergency response
- Smart Homes – Smart Buildings – Smart Cities: Energy consumption monitoring and optimization, transportations & traffic management, etc

Environmental monitoring

- Sensing (in a distributed and self-managing fashion) of natural phenomena and processes allows to access environmental data in real-time over large-scale area
  - temperature, humidity, light
  - wind, rainfall,
  - river height
  - Vibrations
- Monitoring of critical areas

(volcanic areas, remote areas)

- Fire detection alarms
- Agriculture monitoring

Structural health monitoring (SHM)

- SHM allows to detect deteriorations and potential damages of a structural system by observing the changes of its material and geometric properties over long periods of time.

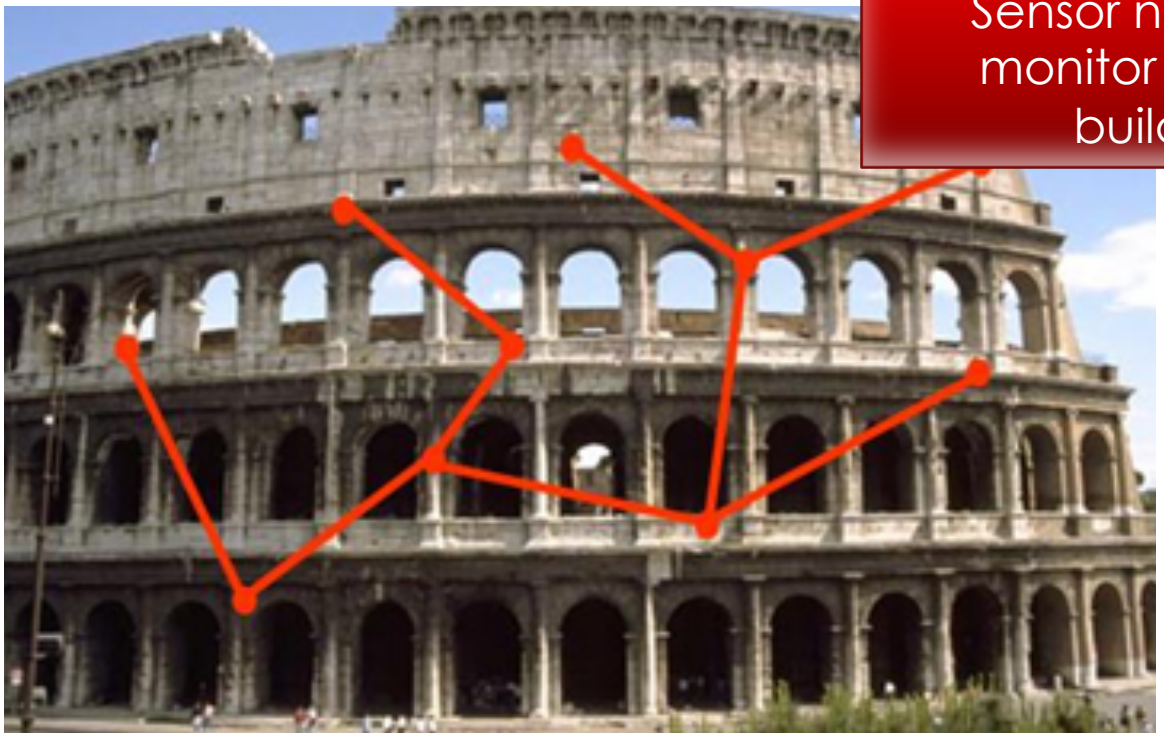
- Usually there are 3 main risks in a lifetime of a structure:

1. During or directly after the construction or reconstruction (design failures, quality problems, uncertain or unknown outer parameters, e.g. geology)

2. Due to or after an outer impact (possibly repeated)

3. When the structure gets old and maintenance is inadequate

Structural health monitoring

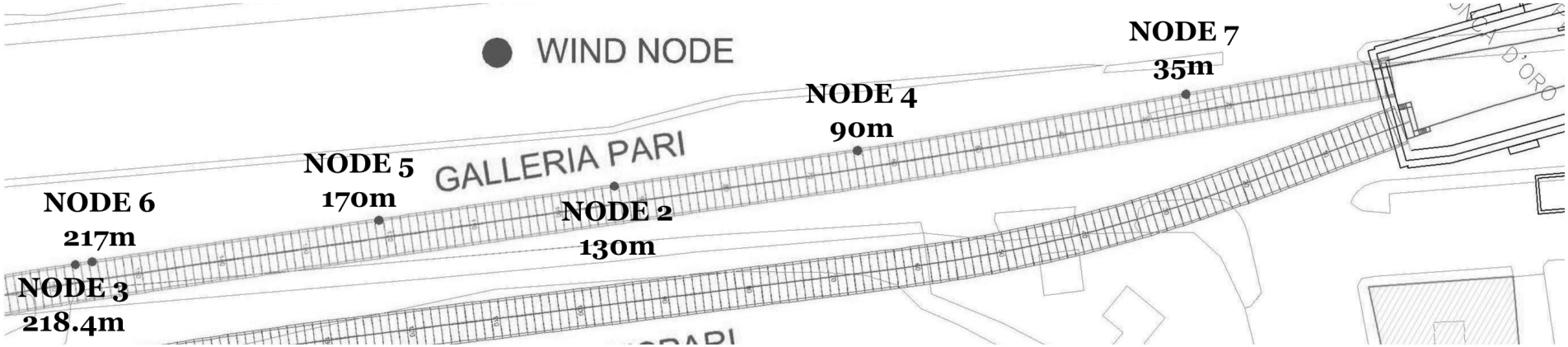


Sensor network to monitor historical buildings

Structural health monitoring

SAPIENZA UNIVERSITÀ DI ROMA

- SHM is a vital tool to help engineers improving the safety of critical structures, avoiding the risks of catastrophic failures.
- Wireless sensor networks can provide a quality of monitoring similar to conventional (wired) SHM systems with lower cost.
- WSNs are both non-intrusive and non-disruptive and can be employed from the very early stages of construction.



Structural health monitoring

The **Golden Gate Bridge Case Study** (Stanford Univ. - 2005) Objectives:

- determine the response of the structure to both ambient and extreme conditions
- compare actual performance to design predictions
- measure ambient structural accelerations from wind load
- measure strong shaking from a potential earthquake
- the installation and the monitoring was conducted without the disruption of the bridge's operation

http://sukunkim.com/research/ggb/

WSN

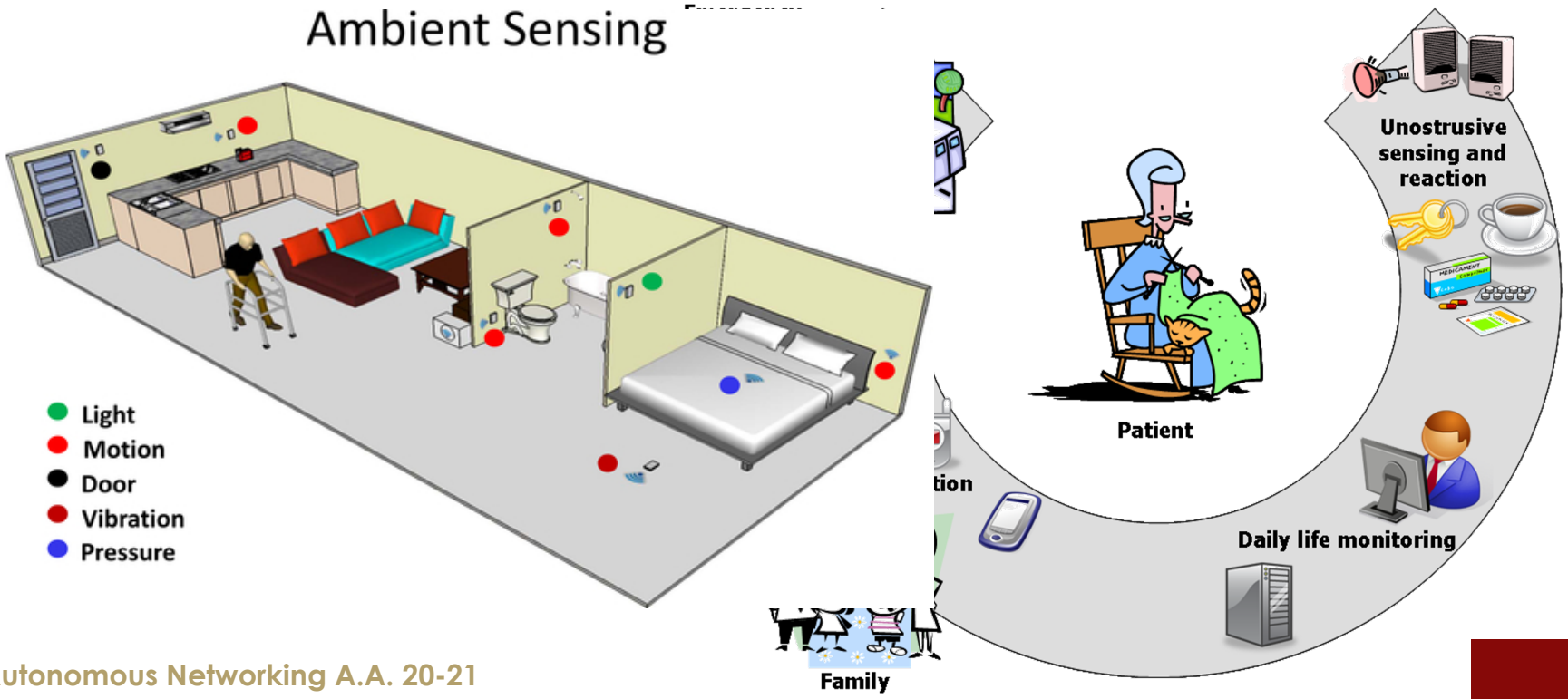
- 64 wireless sensor nodes
- Synchronous monitoring of ambient vibrations
- 46-hop network

Health-care

- In hospital – patients carry **medical sensors** to monitor parameters such as **body temperature, blood pressure, breathing activity** but also **location** and **activity** sensors to monitor patient activities

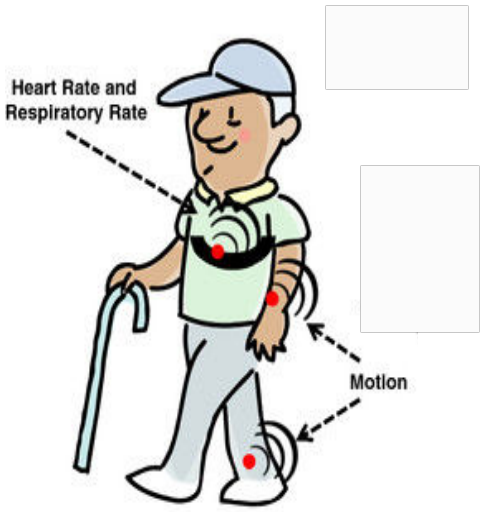
Health-care

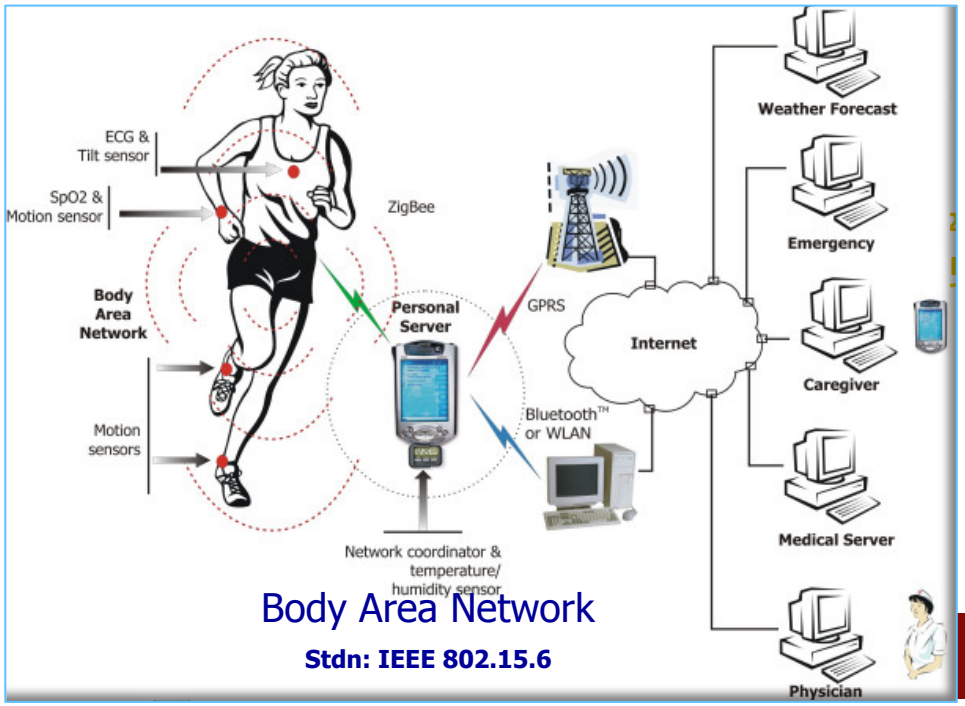
- At home – besides body sensors, wearable (accelerometers, gyroscopes) or fixed (proximity) **sensors can be used to infer user's activities and state in his/her living environment**. This is particularly useful for the elderly who live alone (detection of falls or illness)



Health-care: well being

- Personalized health-care and well-being solutions
- The use of wearable sensors, together with suitable applications running on personal computing devices enables people to **track their daily activities (step walked, calories burned, exercises performed**, etc.) providing suggestions for enhancing their lifestyle and prevent the onset of health problems





Body Area Network

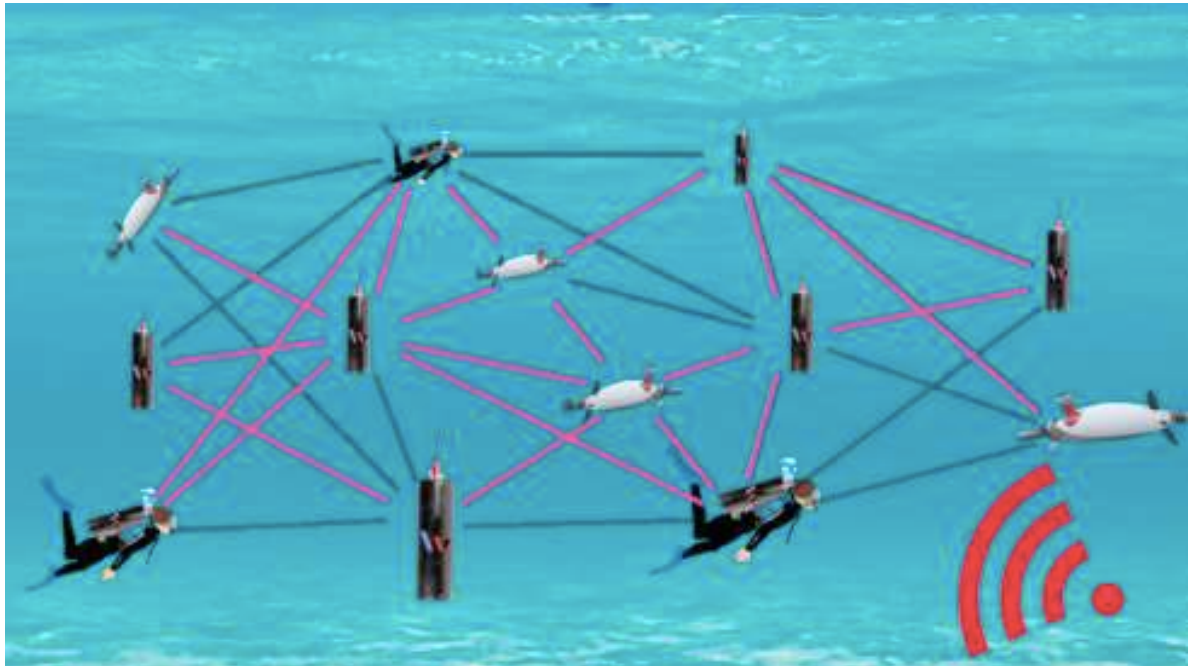
Stdn: IEEE 802.15.6

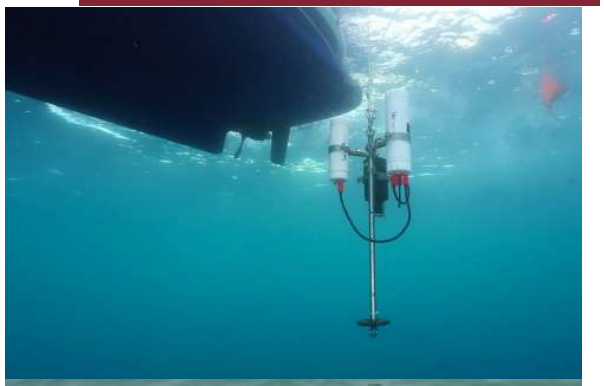
Security and surveillance

- There are many public places where it is useful to improve surveillance
- Sensor networks can improve surveillance in enterprise buildings, shopping malls, factory floors, car parks and many other public places.
- ***Ambient sensors*** can be used to monitor the ***presence of dangerous chemicals***
- Sensors monitoring the ***behavior of people*** may be used to assess the presence of people acting in a suspicious way
- Efficient early warning systems can therefore be built

Underwater WSN

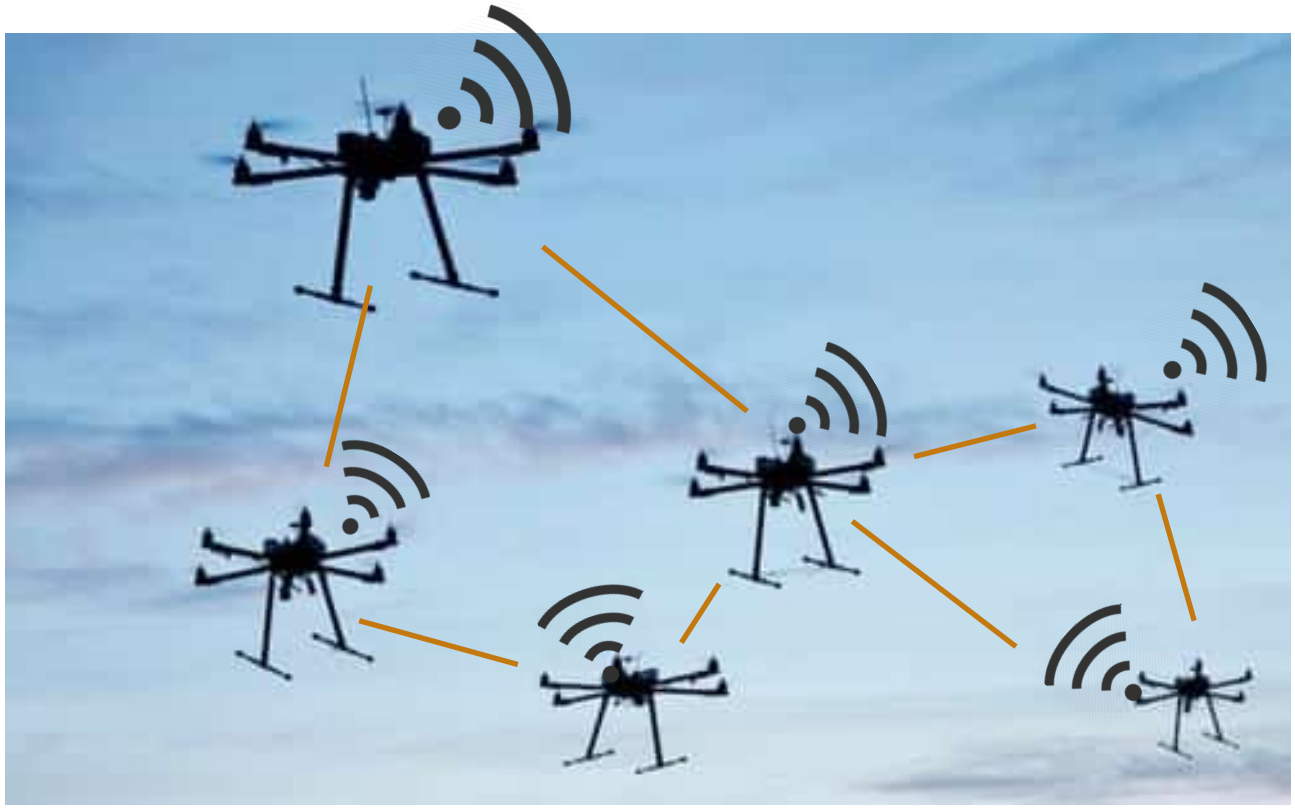
- Allows to interconnect underwater sensors, underwater robotics technologies, enabling **real-time data, reliable, secure information exchange**, providing an unprecedented opportunity to map, know, understand, sustainably exploit the marine environments





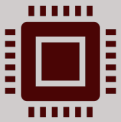
Aerial WSN: dronet

- Drones can be equipped with different types of sensors to monitor an environment and report information on large areas



Roles of participants in WSN

Sources of data: measure data, report them "somewhere"



Sinks of data: interested in receiving data from WSN

Actors/actuators: control some devices based on data

Deployment Options

Random deployment

- Dropped from aircraft
- Usually uniform random distribution for nodes over finite area is assumed

Regular deployment

- Well planned, fixed
- 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

Characteristics of WSN

Scalability

- Support large number of nodes
- Performance should not degrade with increasing number of nodes

Wide range of densities

- Vast or small number of nodes per unit area, very application-dependent

Limited resources for each device

- Low amount of energy
- Low cost, size, and weight per node
- Nodes may not have a global ID such as an IP address

Mostly static topology

Characteristics of WSN

Service in WSN

- Not simply moving bits like traditional networks
- In-network processing
  - Provide answers (not just numbers)
- **Communication is triggered by queries or events**
- **Asymmetric flow of information** (sensors to sink)

Quality of service

- Traditional QoS metrics do not apply

Fault tolerance

- Be robust against node failure
  - Running out of energy, physical destruct

Characteristics of WSN

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

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

Typical Adopted Mechanisms

Multi-hop wireless communication	
Energy-efficient operation	Both for communication and computation, sensing, actuating
Self-configuration	
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

Mechanisms to Meet Requirements

Data centric networking	Focusing network design on data, not on node identifiers (id-centric networking)
Locality	Do things locally (on node or among nearby neighbors) as far as possible
Exploit tradeoffs	For example between invested energy and accuracy

MANET vs. WSN

Applications, equipment:	MANETs more powerful equipment assumed, often "human in the loop"-type applications, higher data rates, more resources
Application-specific:	WSNs depend much stronger on application specifics
Scale:	WSN likely to be much larger
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	

WSN: reasoning of existence

Collect	Collect information from the physical environment – regardless of how easily accessible that is;
Couple	Couple the end-users directly to the sensor measurements (cyber to physical space);
Provide	Provide information that is precisely localized (in spatio-temporal terms) according to the application demands;
Establish	Establish a bi-directional link with the physical space (remote & adaptable actuation based on the sensing stimulus)

WSN: devices

Wireless Sensor Networks combine

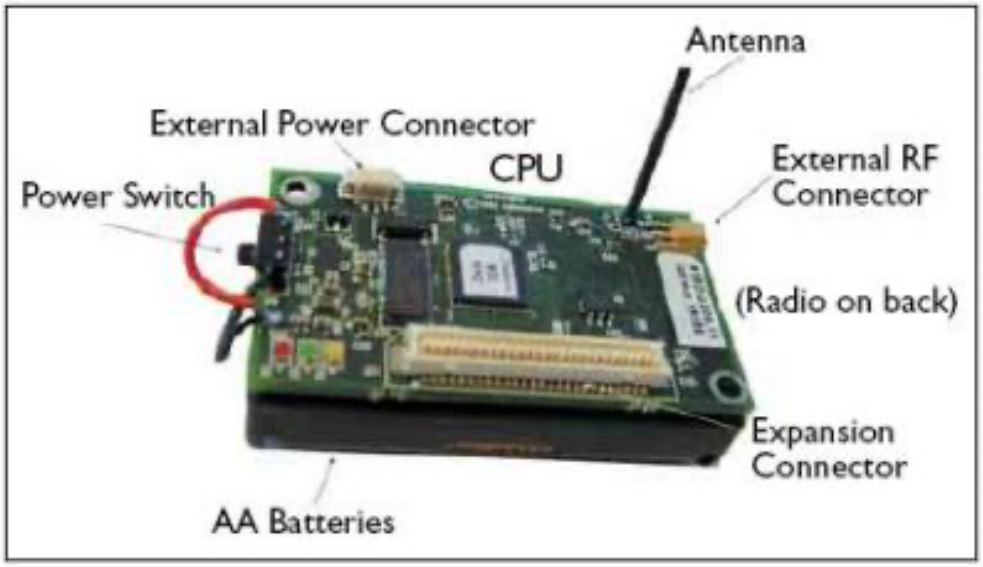
Sensing
Processing
Networking

over miniaturized embedded devices

→ sensor nodes

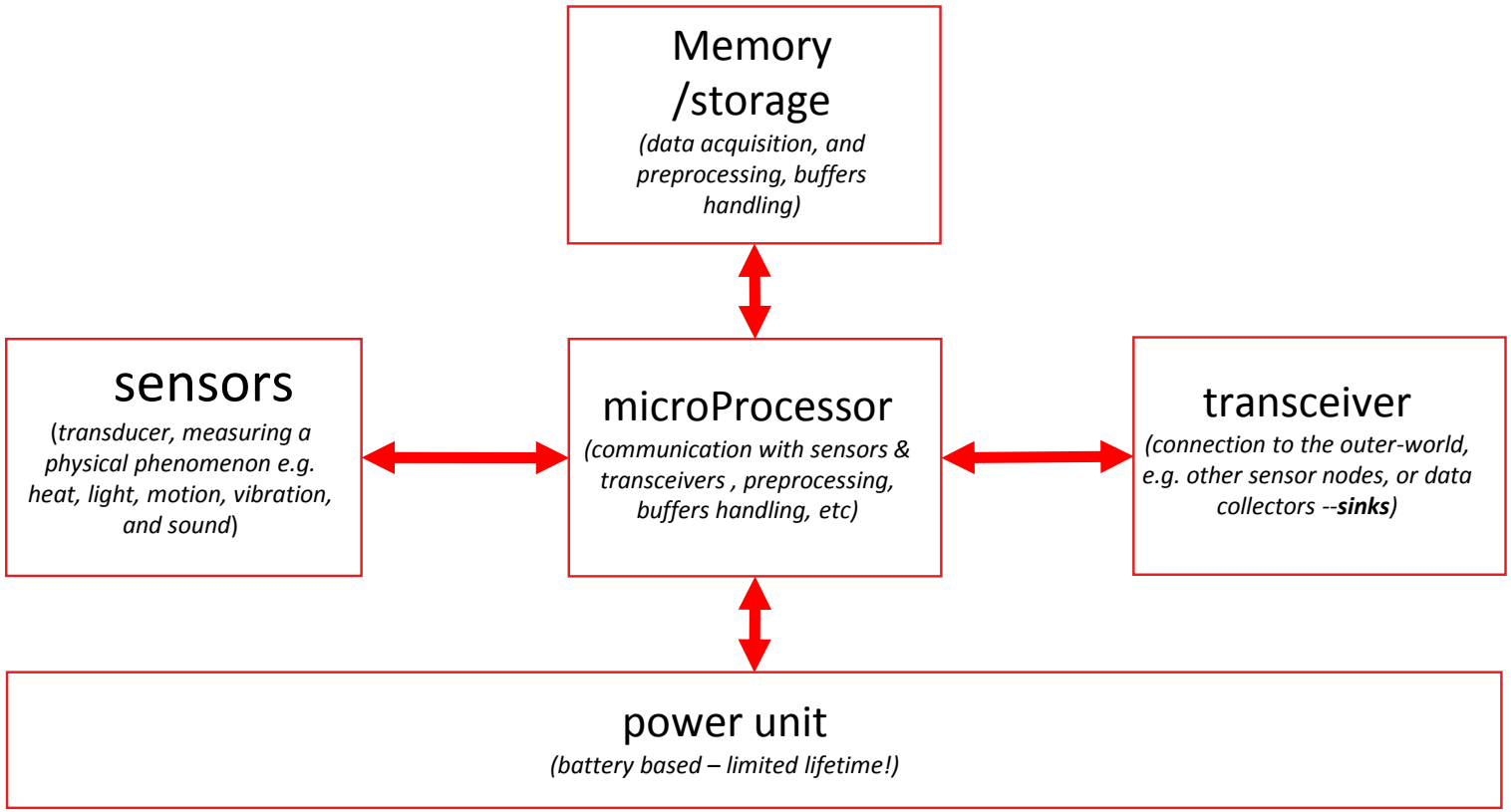
Main sensor node components

- an antenna and a radio frequency (RF) transceiver to allow communication with other nodes,
- a memory unit
- a CPU
- the sensor unit (i.e. thermostat)
- the power source which is usually provided by batteries.



- The operating system running on sensor nodes is called TinyOS and was initially developed at the University of California, Berkeley. TinyOS is designed to run on platforms with limited computational power and memory space. The programming language of TinyOS is stylized C and uses a custom compiler called NesC.

Sensor node


Memory
/storage
(data acquisition, and preprocessing, buffers handling)
sensors
(transducer, measuring a physical phenomenon e.g. heat, light, motion, vibration, and sound)
microProcessor
(communication with sensors & transceivers , preprocessing, buffers handling, etc)
transceiver
(connection to the outer-world, e.g. other sensor nodes, or data collectors --sinks)
power unit
(battery based – limited lifetime!)

Sensing elements

- Sensors: capture a signal corresponding to a physical phenomenon (process, system, plant)
- Signal conditioning prepare captured signals for further use (amplification, attenuation, filtering of unwanted frequencies, etc.)
- Analog-to-digital conversion (ADC) translates analog signal into digital signal
- **Model to translate raw value to measurable unit**

Temperature & Humidity

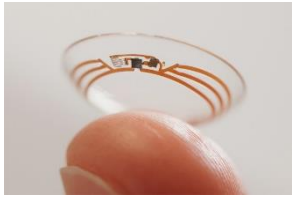
Image

Sound

Pressure

Vibration, Motion

Glucose (&biometrics)

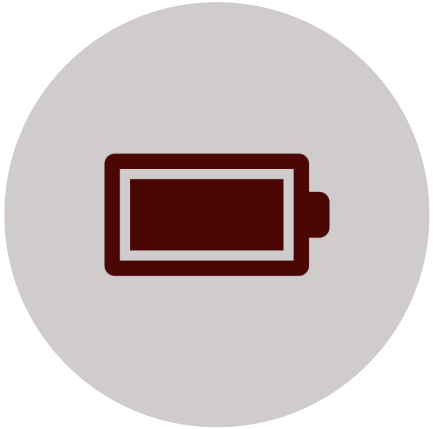


WSN vs. conventional networks

Conventional Networks	WSN
General purpose design (many applications)	Serving a single application or a bouquet of applications
Network Performance and Latency	Energy is the primary challenge
Devices and networks operate in controlled / mild environments (or over an appropriate infrastructure)	Unattended, harsh conditions & hostile environments
Easily accessible	Physical access is difficult / undesirable
Global knowledge is feasible and centralized management is possible	Localized decisions – no support by central entity

WSN: characteristics

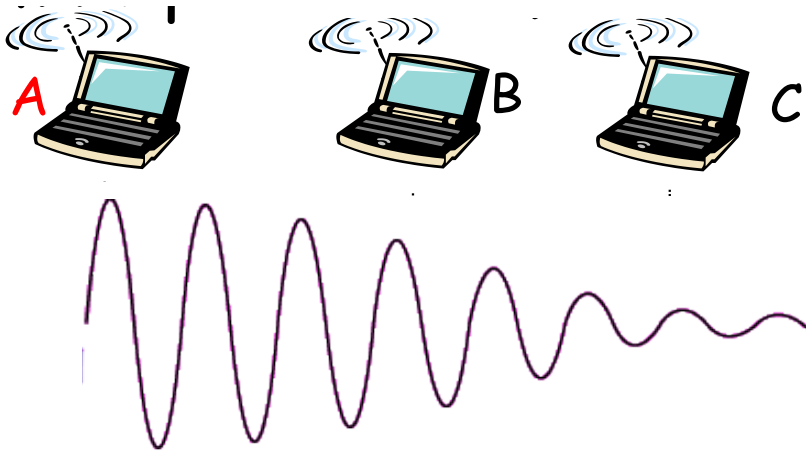
WIRELESS SIGNAL

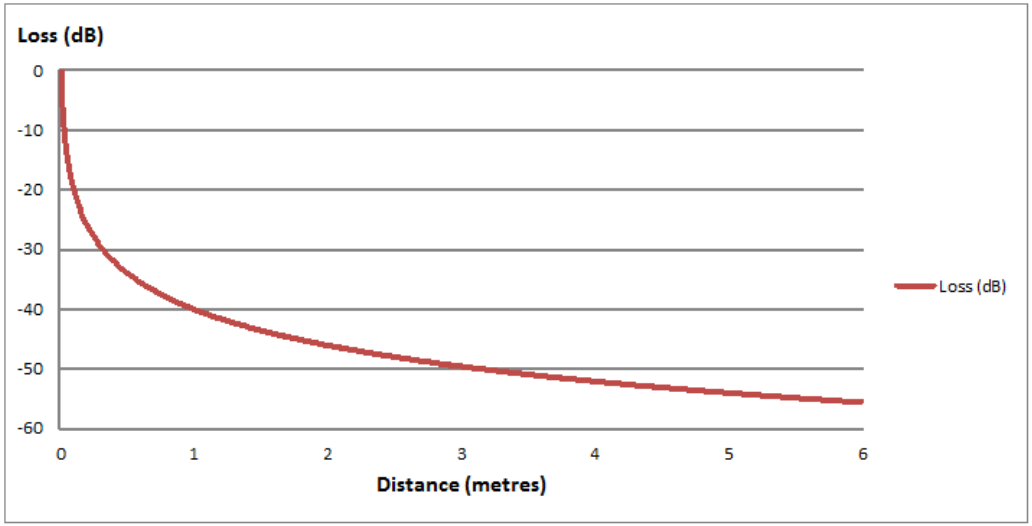


BATTERY POWERED

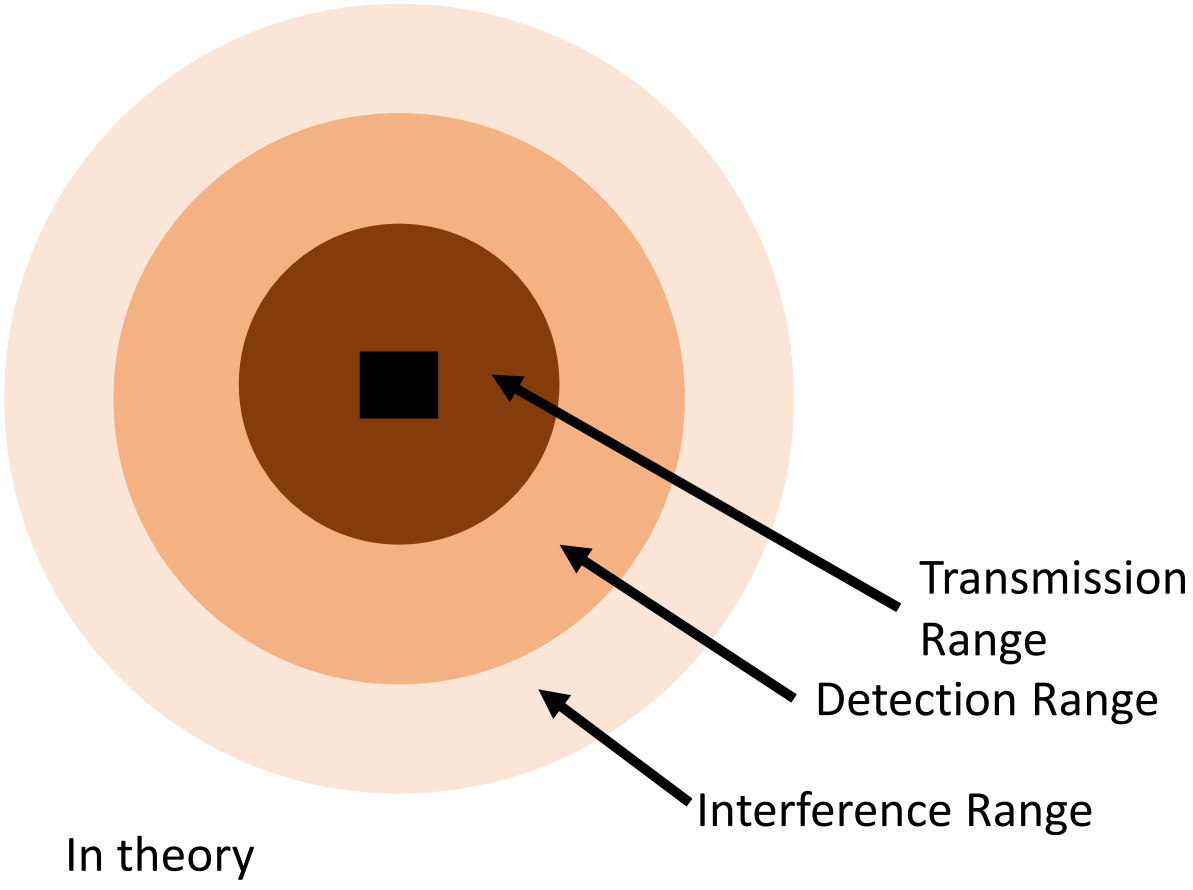
Wireless signal

- Attenuation
  - The strength of the electromagnetic signals decreases rapidly as the distance from the transmitter increases (the signal is dispersed in all directions)



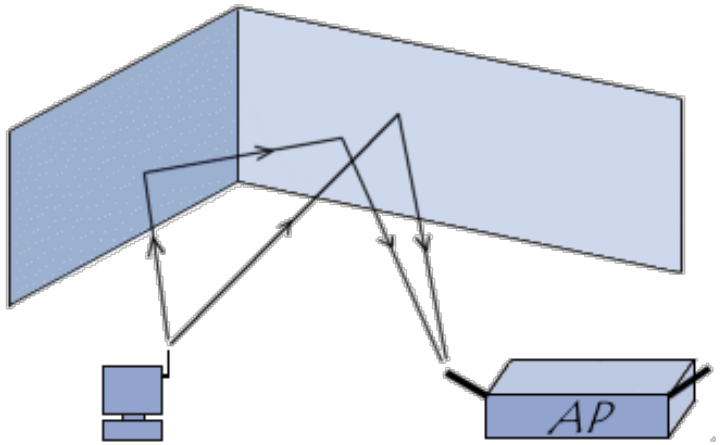


Wireless signal



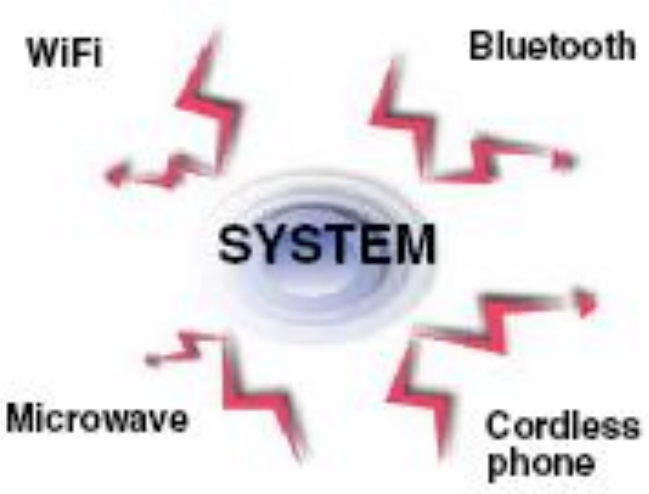
Wireless signal

- Multi-path propagation
  - When a radio wave encounters an obstacle, all or part of the wave is reflected, with a loss of power
  - A source signal can arrive, through successive reflections (on walls, ground, objects), to reach a station or an access point through multiple paths



Wireless signal

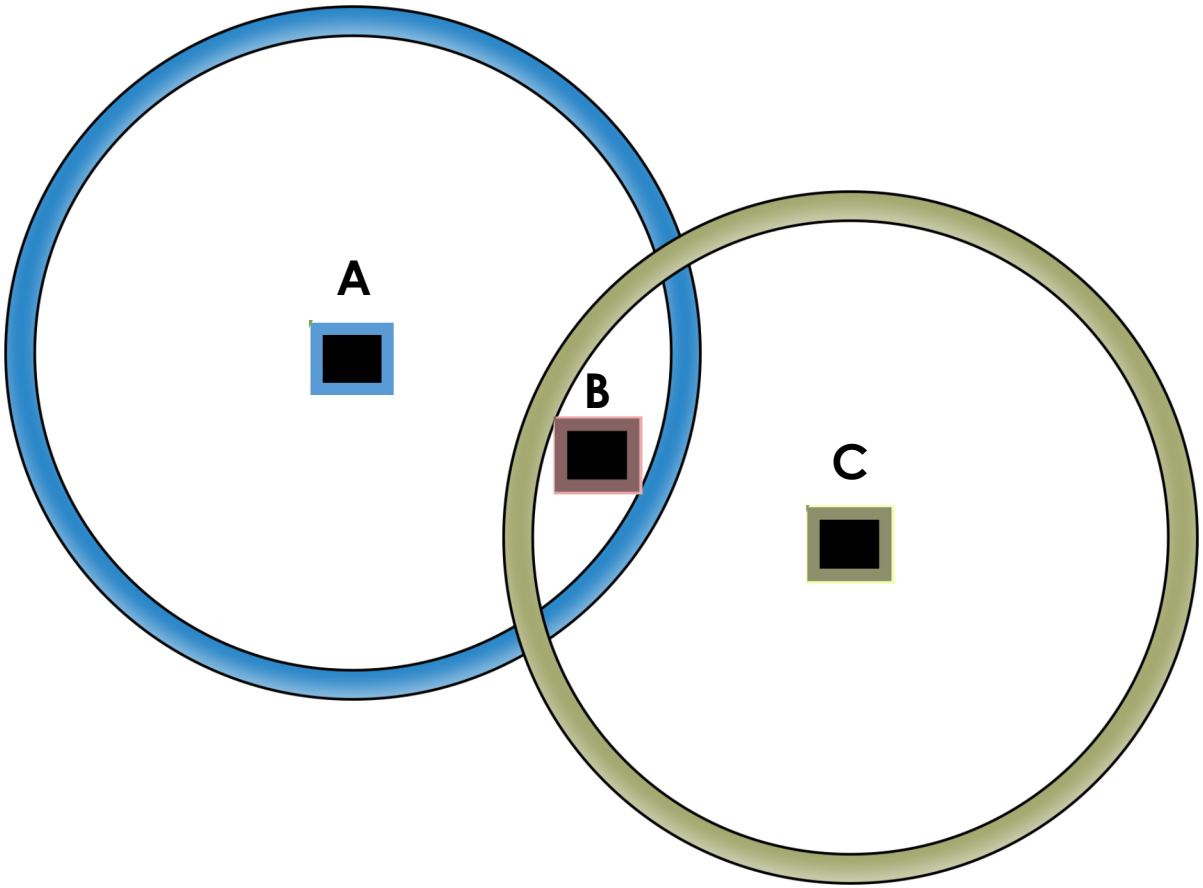
- Interference
  - From the same source: A recipient can receive multiple signals from the desired sender due to multipath
  - From multiple sources: other transmitters are using the same frequency band to communicate with other recipients



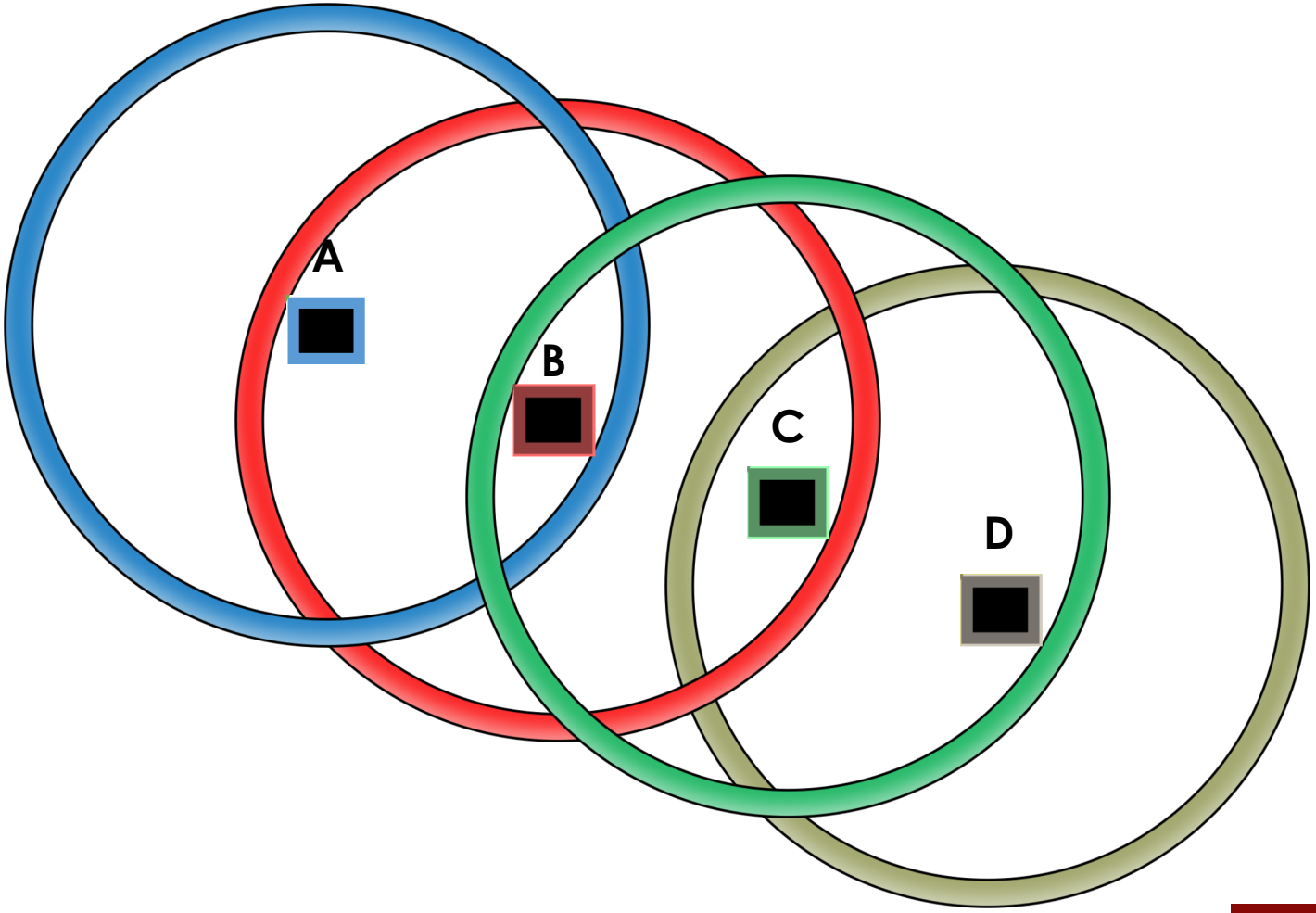
Errors

- The characteristics of wireless links cause errors
- **Signal to Noise Ratio (SNR)** measures the ratio of good to bad signal (signal to noise)
  - High: the signal is stronger than the noise, so it can be converted to real data
  - Low: the signal has been damaged by noise and the data cannot be recovered

Hidden terminal problem



Exposed terminal problem



Objectives of MAC

- Controls how the shared medium (transmission channel) is used by different devices
- Controls when to send a packet, and when to listen for a packet
- Perhaps the two most important operations in a wireless network
  - Especially, idle waiting wastes huge amounts of energy
- We need schemes for medium access control that are
  - Suitable to mobile and wireless networks
  - Emphasize energy-efficient operation

Objectives of MAC

- Collision Avoidance
  - Reduce Retransmissions
- Energy Efficiency
  - Avoid Idle Listening
- Scalability
- Latency
- Fairness
- Throughput
- Bandwidth Utilization

Techniques for WSN MAC

Contention based

- On-demand allocation for those that have frames for transmission
- Sensing the carrier before attempting a transmission
- **Scalable / no need for central authority**
- **Idle listening / Interference / Collisions / Traffic fluctuations -> Energy consumption**
- **Multi-hop topologies (hidden / exposed terminal problem)**

Scheduled based: Fixed assignment or on demand

- Schedule that specifies when, and for how long, each node may transmit over the shared medium
- **Energy efficient**
- **Interference, collisions are not a problem**
- **Synchronization**
- **Central authority**