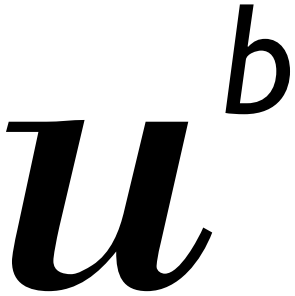

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Internet of Things

I. Introduction and Applications

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Bern, 22.02.2021

Internet of Things: Introduction and Applications

Table of Contents

1. Introduction

1. Ubiquitous Computing

- Vision for the 21st century defined by Mark Weiser in 1991
- Seamless integration of computers into the world at large
- PCs will disappear, become invisible, and will be replaced by intelligent things.
- Many computers per person
- Development enabled by Moore's law
- Sensors and actuators are a key technology for ubiquitous computing.

1. Introduction

2. Definition Sensor Network

A sensor network is a deployment of massive numbers of

- small,
- inexpensive,
- self-powered

devices that can

- sense,
- compute, and
- communicate with other devices

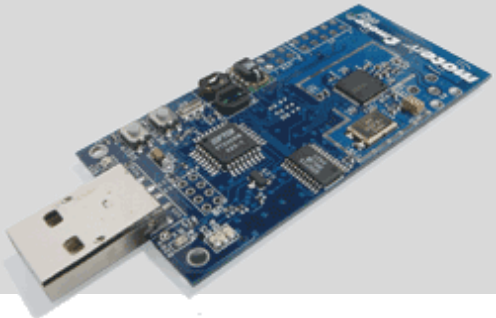
for the purpose of gathering local information to make global decisions about a physical environment.

Source: SmartDust program sponsored by DARPA

2. Sensor Node Hardware

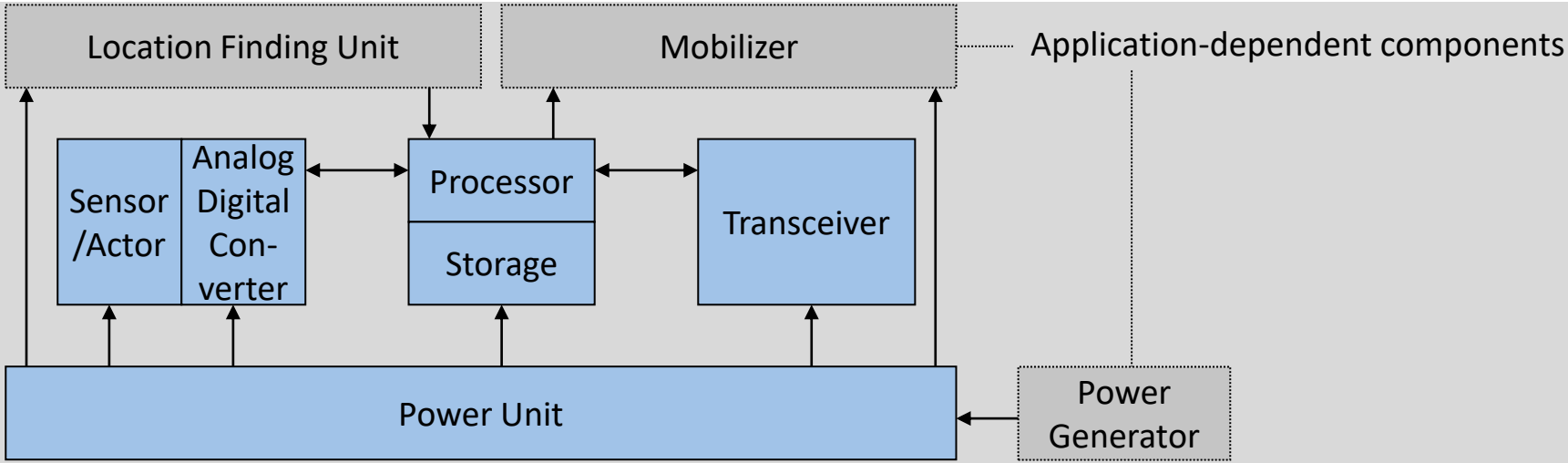
1. Sensor Technology

- Advancements in Micro-Electro-Mechanical System (MEMS) technology allows integration of sensors, transmission units, and CMOS building blocks on a chip.
- Current size of sensors is determined by battery size.



2. Sensor Node Hardware

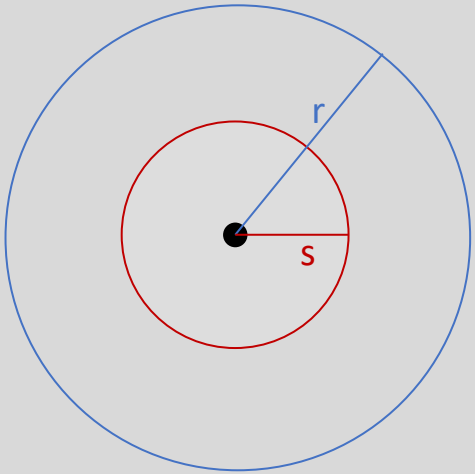
2. Sensor / Actor Node Architecture



2. Sensor Node Hardware

3. Sensing and Transmission Ranges

- Typically: modeling sensing and transmission ranges as circles
- In most cases: transmission radius r > sensing radius s.



2. Sensor Node Hardware

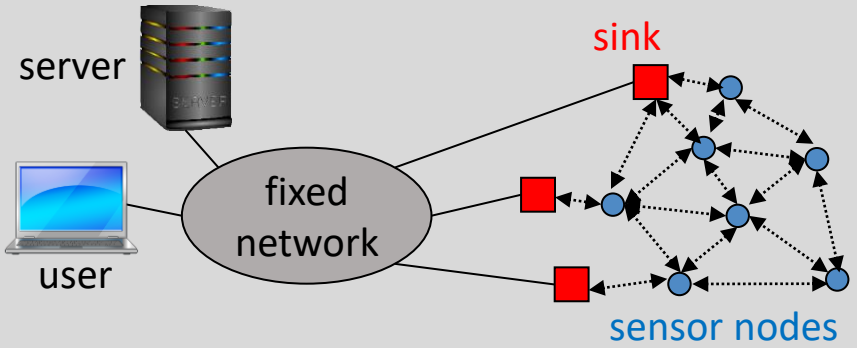
4. Sensing Parameters

- Pressure
- Humidity
- Temperature
- Light
- Sound
- Strain and tilt
- Speed and acceleration
- Magnetic fields
- Vibrations
- Motion
- Metal detection
- Chemicals

3. Wireless Sensor Networks

1. Structure

- Sink
  - gateway between fixed network and wireless sensor network
  - controls and manages sensor nodes on behalf of a user
- Sensor data flow from sensor nodes to sink via several intermediate nodes → *multi-hop communication*
  - Aggregation and fusion of sensor data
  - Broadcast / multicast commu-nication from sink to sensors



3. Wireless Sensor Networks

2. Requirements

- Long network lifetime
- Low costs
- Wide area availability
- Fault tolerance
- Scalability
- Security
- Quality-of-Service (delay and data throughput)
- Programmability and maintainability

3. Wireless Sensor Networks

3. Challenges

- Finite energy resources
  → *energy-efficient operation*
- Limited processing, communication, and storage capabilities
  → *in-network processing and data-centric communications*
- High degree of uncertainty
  → *redundancy*
- Importance of time and location of events
  → *synchronization and localization*
- Unattended operation of sensors and dynamic structures due to
  - sleep cycles
  - node failures and unreliable nodes
  - energy depletion
  - varying workload, e.g., by simultaneous related events
  - mobility of sensors, targets, and observers
  - changing environmental conditions

  → *self-configuration capabilities*

3. Wireless Sensor Networks

4. Energy Issues

- Energy is the main concern in wireless sensor networks.
- Battery-driven sensors can not be recharged and become useless after depletion.
- Energy sources
  - Batteries
    - Capacity: << 1 J / mm^3
  - Fuel Cells
    - Oxidation of a chemical element generates flow of electrons
  - Scavenging, i.e., extracting energy from environment
    - Solar cells: 1 mW / mm^2
    - Mechanical or thermal energy
- Communication
  - Tradeoff between processing and communication:
    Transmission of 1 bit costs the same energy as 100 – 1000 instructions.
    - 1 nJ per instruction / sample
    - Bluetooth: 100 nJ per bit for a distance of 10 – 100 m
  - Transmission and reception costs are nearly the same.
  - Overhearing is rather expensive.
  - Startup costs must be considered.

3. Wireless Sensor Networks

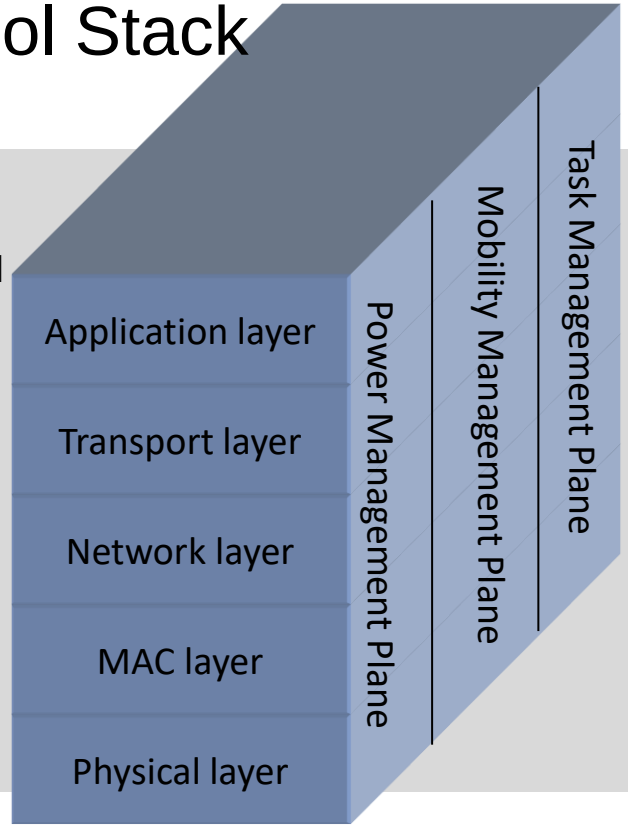
5. System Issues

- Operating System (OS)
  - may only use few resources (few kB code space, restricted RAM)
  - Emphasis on event processing besides usual OS functionality
- Positioning and Localization
  - Position (absolute/relative) of events or acquired data is usually needed for further processing.
  - Automatic positioning due to uncontrolled deployment is favorable.
  - Localization either with GPS or local positioning schemes
- Time Synchronization: Similar time on sensor nodes in a network needed for
  - association with data samples and events to derive network state
  - scheduling of transmissions and energy saving states

3. Wireless Sensor Networks

6. Communication System and Protocol Stack

- Layers
  - Application: application software
  - Transport: maintain data flow, reliability and congestion control
  - Network: routing and topology control
  - Medium Access Control (MAC): fixed and random channel allocation, power awareness, collision avoidance
  - Physical: robust modulation, transmission, and reception techniques
- Management Planes
  - Power: management of power usage by a node
  - Mobility: detection / registration of sensor movements and neighbors
  - Task: balancing and scheduling of sensing tasks in a region



3. Wireless Sensor Networks

7. Information Processing

Data dissemination modes

- observer-initiated (user)
- event-driven (in-network storage after advertisement by sensors)
- continuous (pre-specified rate)

Issues: Reliability and Accuracy

- Huge amount of data may be generated by several sensor nodes.
- Interest of users may be very specific.
- Filtering and aggregation of sensor data is mandatory to prevent overhead.
- Management and deployment of sensor nodes have to be facilitated.

4. Advanced WSN Structures

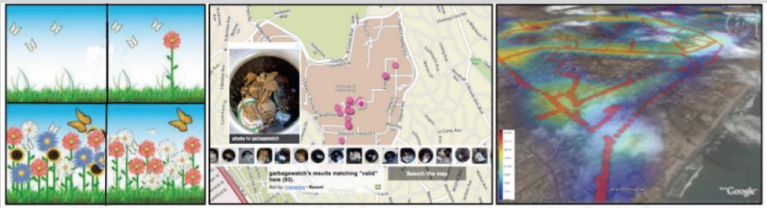
1. Mobile Wireless Sensor Networks

- Static WSNs
  - Examples
    - Environmental monitoring
    - Surveillance of building
  - Problem
    - Static sensor networks require dense deployment of sensors to cover an area.
- Fully mobile WSNs
  - Examples
    - Mobility of sensors by robots, aerial vehicles, or swimming sensors
  - Challenges
    - Localization
    - Low weight
    - Robust communication
- Hybrid WSNs with
  - Fixed base stations / sensors
  - Mobile base stations / sensors carried by humans, animals, vehicles
  - Examples
    - Health applications
    - Participatory sensing
- Alternative to fully connected networks in case of mobility: delay tolerant networking / message ferrying
  - Examples
    - Animal tracking
    - Sports

4. Advanced WSN Structures

2. Participatory Sensing

- Idea: Exploitation of
  - sensors, storage and processing capabilities of mobile end systems
  - mobility of users for sensing instead of deploying a huge amount of static sensors.
- Components of participatory sensing scenario
  - Sensors
  - Sensor carriers (mobile node, smart phone) providing location / time
  - Mobile network (cellular, WiFi)
  - Service providers collecting and processing sensor data using, e.g., cloud infrastructures, social networks
- Applications
  - Environmental and traffic/transport monitoring
  - Urban sensing



4. Advanced WSN Structures

3. Actuation

- Extension of WSNs to Wireless Sensor and Actuator Networks
- Processing of sensor data and feedback to actors

- Examples
  - Climate and temperature control in buildings
  - Virtual fences
  - Control of water flow

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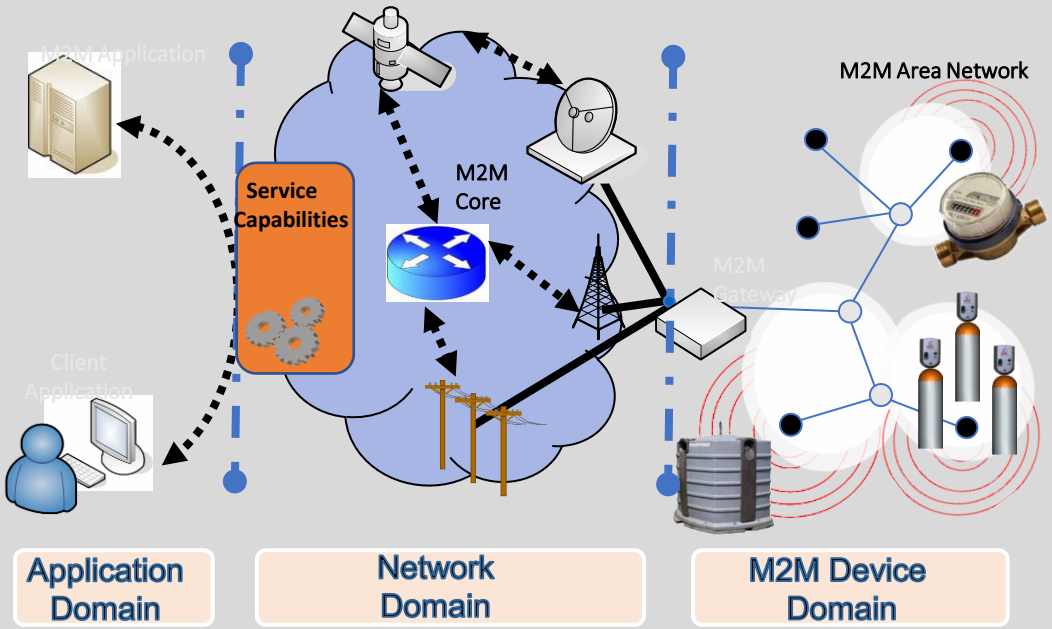
4. Advanced WSN Structures

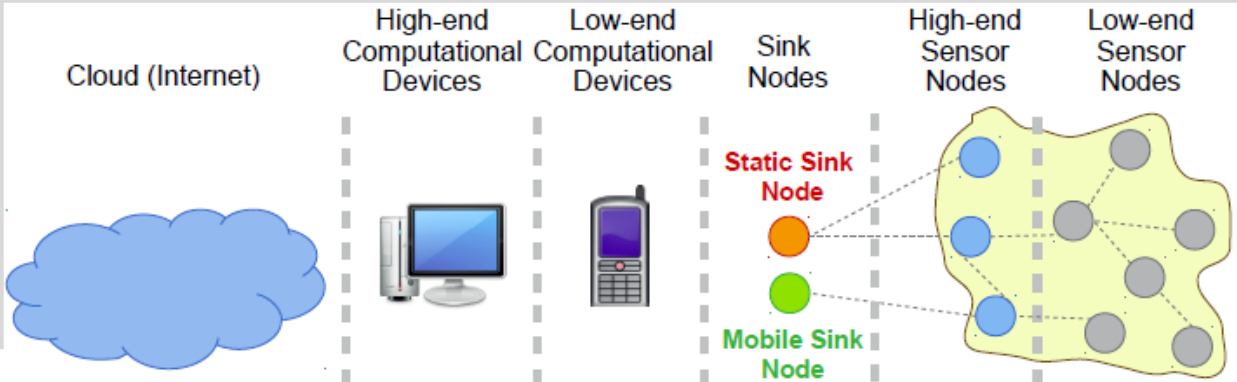
4. Machine-to-Machine (M2M) Communications



4. Advanced WSN Structures

5. Internet of Things

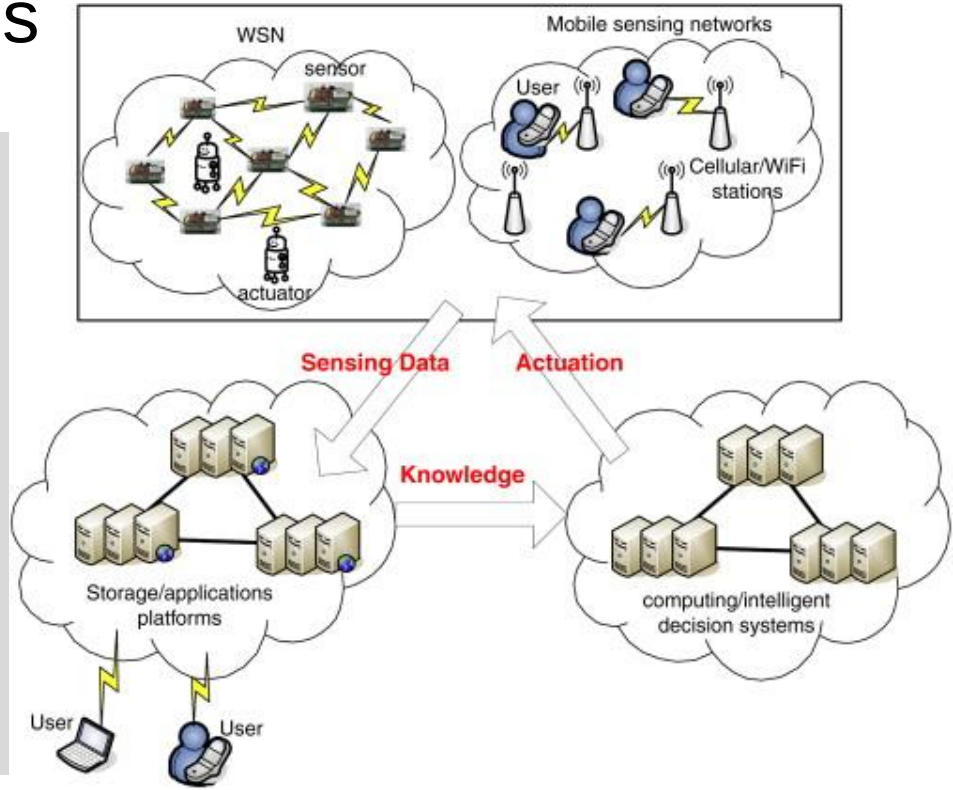
- Things = objects of physical world (*physical things*) or information world (*virtual things*), which can be identified and integrated into information and communication networks.
- Physical things exist in physical world and can be sensed, actuated, and/or connected.
  - Examples: sensors of surrounding environments, industrial robots, goods, electrical equipment
- Virtual things exist in the information world and can be stored, processed, and accessed.
  - Examples: multimedia contents, application software, and service representations of physical things, e.g., avatars or virtual objects



4. Advanced WSN Structures

6. Cyber-Physical Systems

- Control / computing co-design
- Actor/sensor networks & robots integrated into physical world
  - have typically real-time requirements.
  - might use distributed / high-performance / cloud computing infrastructures.



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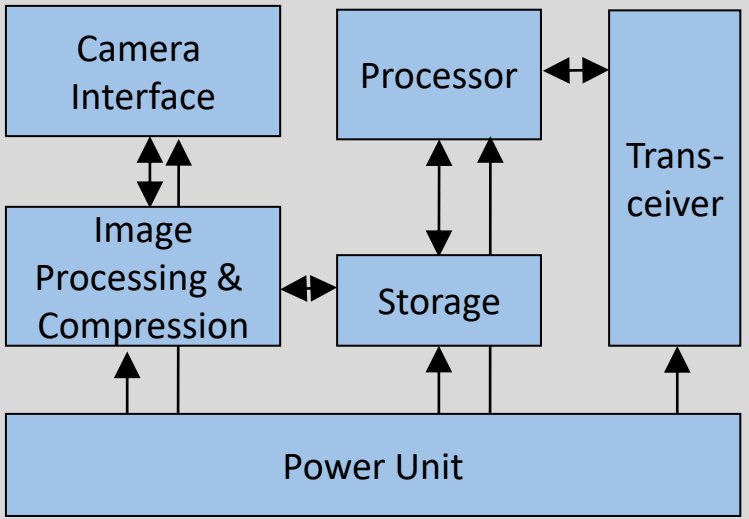
4. Advanced WSN Structures

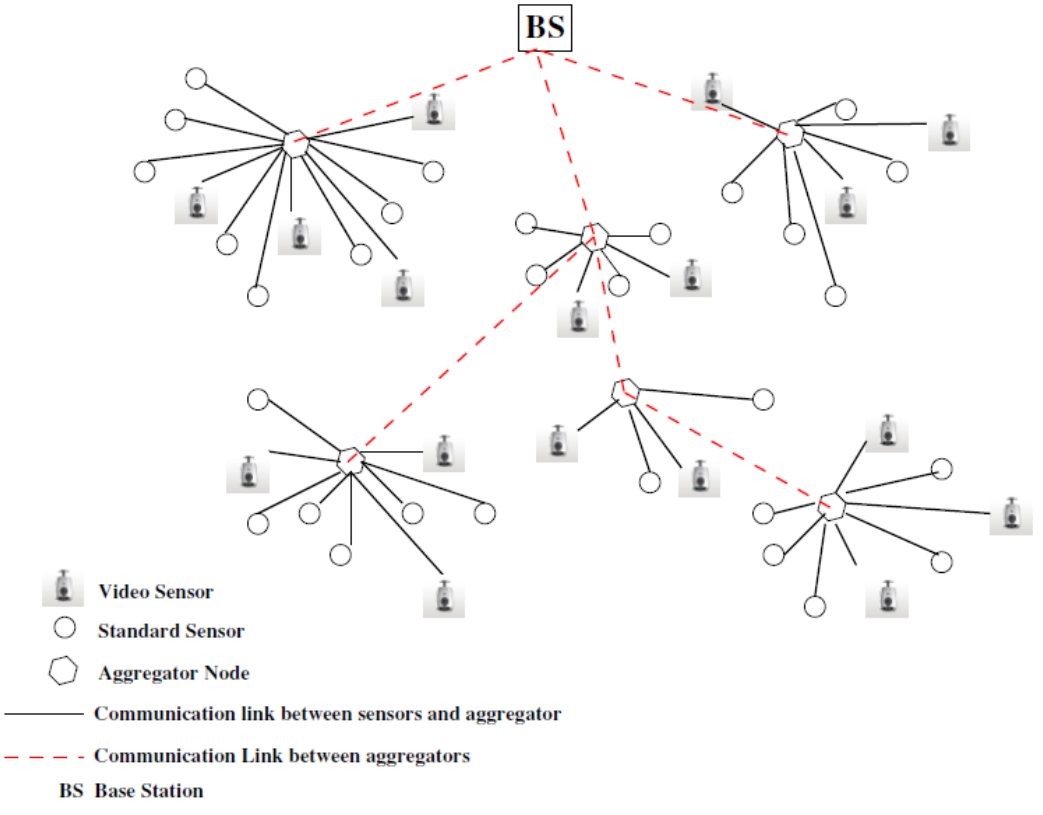
7.1 Multimedia WSN

- Communication technologies
  - WiFi
  - Bluetooth
- Example applications
  - Surveillance
  - Traffic and environmental monitoring
- Different requirements on
  - Real-time support / delay-tolerant networking
  - Bandwidth
  - Storage / off-line processing
- Encoding requirements
  - Low complexity
  - High compression efficiency
  - Error resilience



4. Advanced WSN Structures

7.2 MWSN Scenario



5. Application Issues

1. Application Requirements to WSNs

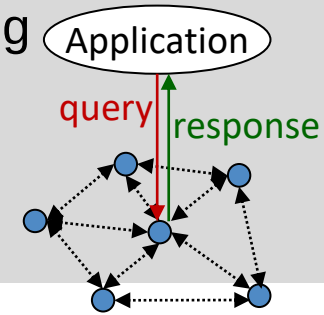
- Small and lightweight sensors
- Low costs
- Robustness to environmental conditions
- Accuracy and fidelity
- Energy-efficient operation to ensure long network lifetime
- Quality-of-Service (delay and data throughput)
- Security and privacy
- Mobility support
- Wide area availability
- Self-configuration and adaptation
- Synchronization
- Localization

5. Application Issues

2. Operation Characteristics

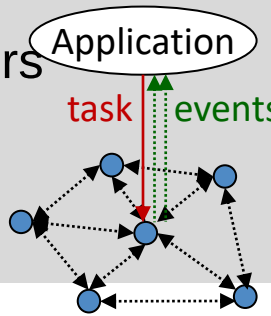
Querying Applications

- Sensors are programmed to collect sensor (measurement) data.
- Applications issue queries to obtain raw sensor data from each sensor.
- Intelligent filtering and aggregation within WSN



Tasking Applications

- Programming of sensors to perform specific actions upon certain events,
  e.g. exceeding thresholds or detecting unusual events (fire, movements etc.)
- Combination with actuators (e.g. building control)



5. Application Issues

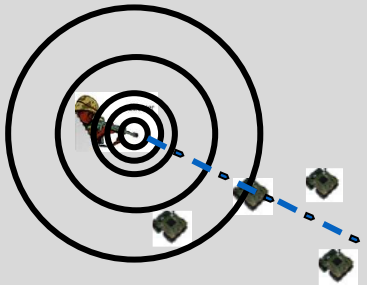
3. WSN Application Taxonomy

- *Goal*: sense-only, sense-and-react
- *Sampling*: periodic, event-triggered
- *Sensed phenomenon*: single, multiple independent phenomena
- *Location*: discrete (located at specific place, event to be detected by single sensor) or distributed
- *Data rate*: low, high
- *Heterogeneity*: homogeneous, heterogeneous sensors
- *Mobility*: static, mobile sensor nodes / base stations
- *Connectivity*: connected, intermittent, sporadic
- *In-network processing*: filtering, compression, aggregation, tracking, event detection, classification, interpretation, decision making
- *Storage*: caching, persistent storage at different nodes / base stations / servers
- *Services*: localization, time synchronization, authentication, encryption, reprogramming, reconfiguration
- *Communication primitives*: single/multi-hop communication, unicast/multicast, broadcast

6. Example Applications

6.1 Security and Military

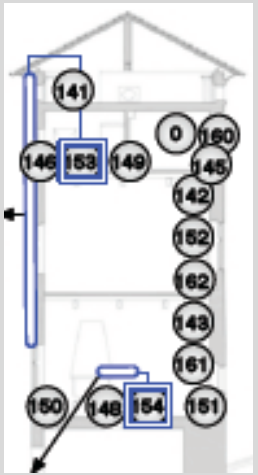
- Security monitoring of homes, public places and infrastructures, e.g. stations, airports, subways, nuclear power plants
- Examples
  - Virtual fences
  - Sniper detection
- Application requirements
  - Robustness
  - Security
  - Localization
  - Energy efficiency
  - Synchronization
  - Size and weight



6. Example Applications

2. Building Monitoring and Control

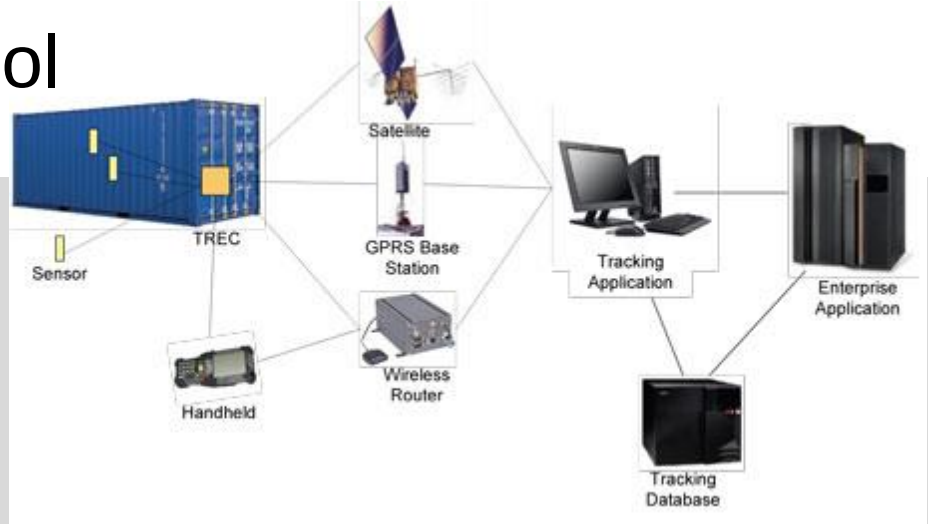
- Building automation
  - Temperature measurements and heating control
  - Control of lights and computers based on human presence
- Monitoring of buildings
  - Deployment of sensors at bridges or old buildings, e.g., Torre Aquila
  - Sensors monitor load, vibration, and micro-movements
- Application requirements
  - Energy efficiency
  - Robustness and accuracy

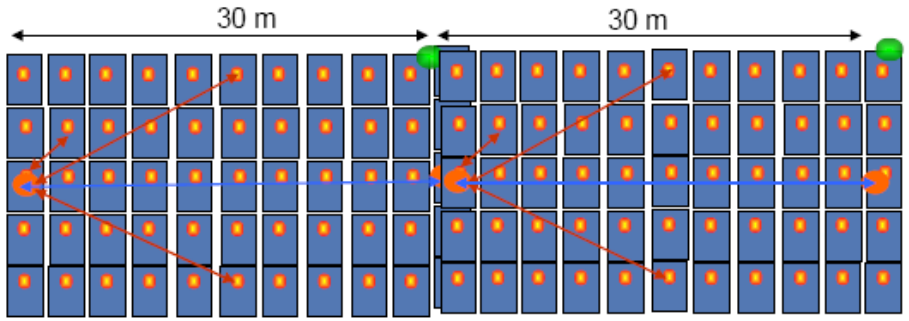


6. Example Applications

3. Industrial Process Control

- Monitoring of manufacturing processes or equipment and products
- Control actions based on monitoring results
- Other Examples
  - Supply Chain Management
  - Secure / Intelligent Trade Lane
- Application requirements
  - Cost efficiency
  - Security
  - Robustness
  - Quality-of-Service

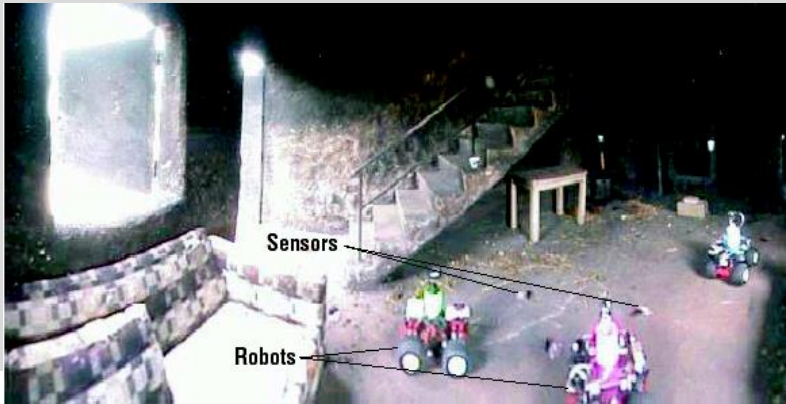




6. Example Applications

4. Disaster Recovery and Emergency Response

- Application of sensors in case of disasters such as fires, earthquakes, accidents in coal mines, etc.
- Rescue persons or robots carry sensors and equip patients with sensors.
- Control center can coordinate distribution of rescue personnel, e.g., to identify most urgent cases and send doctors to severe cases.
- Application requirements
  - Robust routing
  - Prioritization of critical data
  - Security and privacy
  - Location tracking



6. Example Applications

5. Habitat Monitoring

- Monitoring of animal habits/movement patterns
- Examples
  - Great Duck Island project
  - Autonomous Monitoring of Vulnerable Habits
  - ZebraNet

- Application requirements
  - Localization
  - Calibration, self-configuration and adaptation to changing environmental conditions
  - Fast deployment and deployment assurance
  - Energy efficiency and long lifetimes
  - Robustness and redundancy
  - Environmental challenges (rain, humidity)

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6. Example Applications

6. Environmental Monitoring

- Monitoring of environmental / climate / weather data
- Examples
  - A4-Mesh project
  - River monitoring
- Application requirements
  - Extreme out-door conditions
  - Data storage
  - Heterogeneous delay and bandwidth requirements
  - Energy efficiency

6. Example Applications

7. Health Care and Medical Applications

- Monitoring of patients during surgeries, transport, or scanning
- Monitoring of heart frequency, blood pressure, oxygen level of (elderly) patients
- Storage of data for long-term monitoring and rather infrequent transmission to hospital, immediate transmissions in case of alarms
- Implementation options
  - Network of ambient, statically deployed sensors in hospital or buildings
  - Body Area Network: small set of sensors with gateway for data collection, aggregation, and relay to ambient sensors
- Application requirements
  - Manageable cognitive load for health care professionals
  - Robustness and reliable message delivery
  - Quality-of-Service (bandwidth, delay)
  - Confidentiality and privacy
  - Power efficiency and usability

6. Example Applications

8. Sports

- Measurement of sportsmen data and availability to spectators / medical people or personal training
- Examples
  - BikeNet
    - Bicycle Area Network based on IEEE 802.15.4 with mobile phone as mobile sensor access point.
    - Deployment of static SAPs along routes
    - Data “muling” between bicycles
  - MarathonNet
    - Deployment of < 10 base stations along Marathon course
    - Connectivity provided by clusters of runners
- Application requirements
  - Connectivity of network
  - Storage and disconnected operation

6. Example Applications

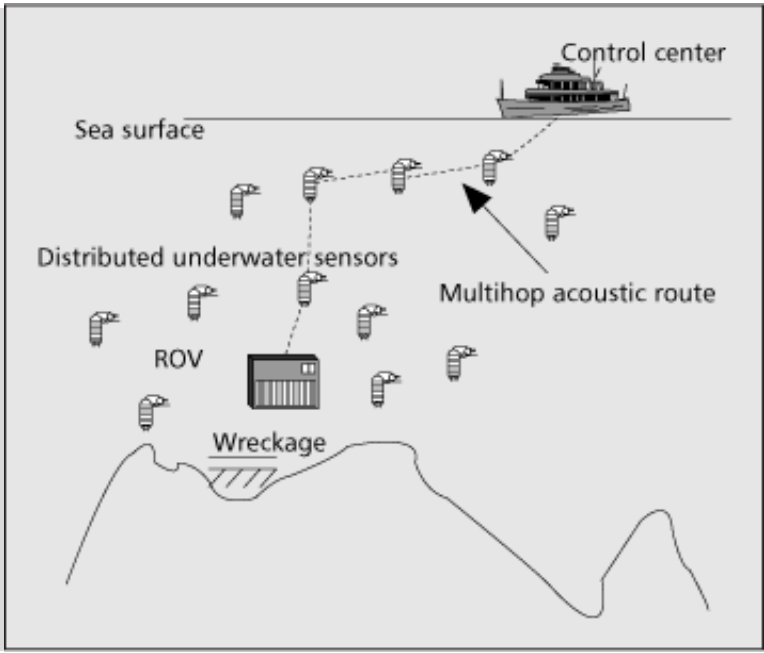
9. Vehicle and Traffic Control

- Monitoring and control of vehicles for maintenance and security
- Vehicle tracking and identification
- Theft protection and detection
- Traffic measurements may impact traffic control signs and traffic lights.
- Car-to-car communication for dynamic warnings to car driver, e.g., alarms from cars driving in opposite direction
- Driving assistance based on sensor information
- Parking space detection
- Application requirements
  - Energy efficiency
  - Cost efficiency
  - Localization and tracking

6. Example Applications

10. Underwater Monitoring

- Application Scenarios
  - Long-term non-time-critical aquatic monitoring
  - Short-term time-critical aquatic exploration, e.g., for submarine detection, remotely operated vehicles
- Technical issues
  - Node mobility (propellers)
  - Underwater acoustic channel (low bit rate, multi-path, long delay)
  - Intermittent connectivity → store and forward mechanisms
- Application requirements
  - Real-time data transfer vs. energy-saving
  - Positioning



Thanks

for Your Attention

Prof. Dr. Torsten Braun, Institut für Informatik

Bern, 22.02.2021