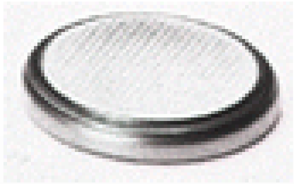
Sensor networks and applications

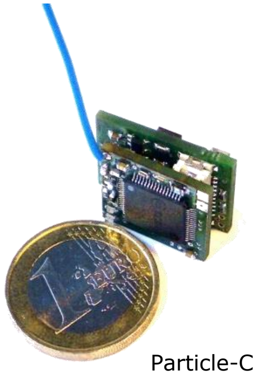
Physical layer

Features of sensors

- Small devices with sensing, processing and (radio) transmitting capabilities..
- Limited resources
  - CPU: (< 10 MIPS);
  - memory: (~ 4 kbyte)
  - limited energy
    - (e.g., AAA batteries)

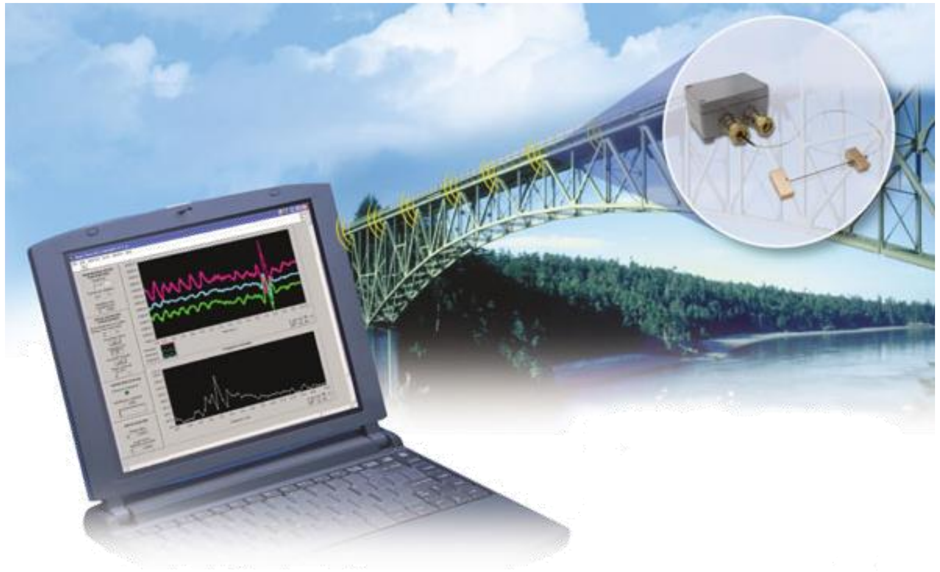



MICA


Particle-C

- Task: Collecting and forwarding data from a given territory towards the “sink” (base station)

Features of sensor nets



- Many, small, cheap sensors.
- Wireless communication
  - ad-hoc network formation, communication with slow bitrate (~10–100 kbps)
- Other requirements:
  - long lifetime
  - unattended operation
  - robustness

Physical layer

Existing solutions, design constraints

Content

- Physical layer
  - existing solutions & special WSN solutions
  - energy efficiency
- Data link layer
  - MAC solutions

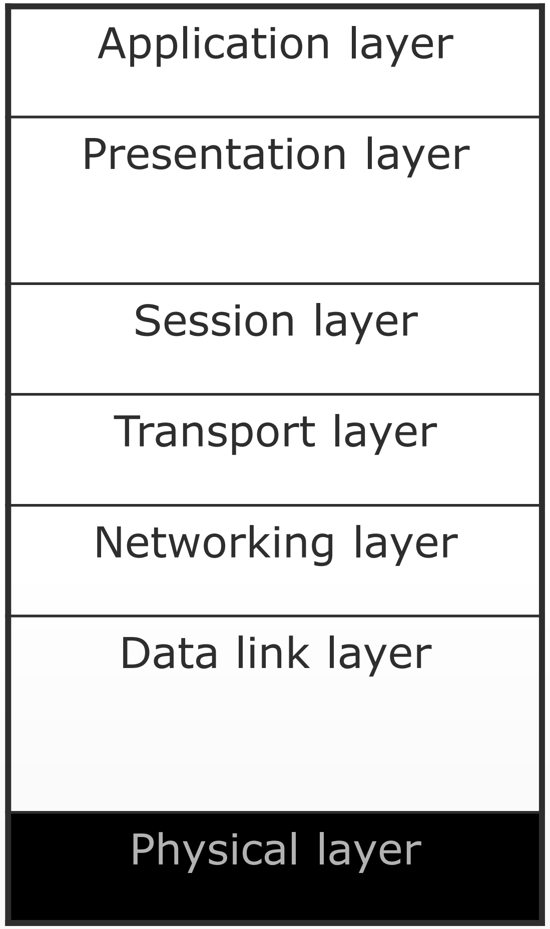
Physical layer

Physical layer:

„The physical layer consists of the basic networking **hardware transmission technologies** of a network. ... this is perhaps the most complex layer in the OSI architecture.”

„Cross-layer design”

ISO OSI



Features and requirements

- Typically very small amount of data to transmit.
  - few bits/day

- Better lower transmission rates and higher delays for lower prices and longer lifetime.
  - Pl: One (or more) year(s) lifetime with 750 mAh AAA battery

- Universal (globális), unlicenced operation.
  - Limits the available frequency bands and modulation techniques.

Examples for physical layer

- The communication can be of electromagnetic (RF, IR) or acoustic solutions.
- Existing radiofrequency (RF) solutions:
  - Bluetooth
  - IEEE 802.11b (WLAN)
  - (IEEE 802.15.4)
- Special WSN solutions
  - PicoRadio
  - WINS, µAMPS
  - nrf24, NBIoT, LoRa, ...

Design issues for PHY

Design issues for physical layer

- The two most important requirements:

low cost

and

long lifetime.

Price as design constraint...

- The cost of the physical layer is primarily the price of hardware
  - price of chips + additional external components
- Goal: single chip + antenna + batteries
  - (Integrating the antenna and the batteries are hard, altough not impossible.)

Price as design constraint...

- One of the most difficult task is the integration of quartz oscillator for reference frequency.
  - An alternative: MEMS (micro-electromechanical) rezonator
  - The technology is not yet mature enough, there can be problems with accuracy and stability.

- Consequence: Design the physical layer where the requirements for the frequency are not too strict.

Price: analogous vs. digital

- The price of the chip depends on the ratio of analogous and digital components.
  - The size of the digital elements are going down as lithography advances.
  - The size of the analogous elements typically does not go down with advances of technology. (E.g., physical size of passive electric components, like area of capacitors)

Price: analogous vs. digital

- Possible two options:
  - Analogous elements using „large” and „old” (and thus cheap) technology.
  - Only digital components, new technology, thus small (thus cheap) circuits.

- In the long run, the trend favours „all-digital” technology.
  - The energy consumption of RF circuits is also proportional with their size.

Price: large quantity...

- Unit price goes down with large quantity.
- Consequence: Design of physical layer that is in harmony with most countries' regulations.
- Solution: ISM band
  - (But which one? 2.4 GHz, 5.8 GHz or 24 GHz?)

Price: available technologies...

- The technology of circuits operating at high (e.g., 60 GHz) frequency range (e.g., SoC silicone CMOS) is costly at the moment and sub-optimal regarding energy consumption..
- Low (e.g., 1 GHz) frequencies the size of the node is problematic because of the small antenna.
- The selection of optimal ISM band is a trade-off between price and energy efficiency, and antenna-efficiency.
- Optimal today: 2.4 GHz ISM band

2.4 GHz ISM band

- The 2.4 GHz-es ISM band is far from being „empty” :
  - E.g., IEEE 802.11b (Wi-Fi) WLAN, Bluetooth WPAN
  - Different technologies use different channel access strategies -> they can be highly unfair!
- The co-eistence and compatibility of different services is of primary importance for physical layer design!
  - E.g., spread spectrum solutions for robustness

2.4 GHz ISM band

- Possible alternative: 3.1-10.6 GHz UWB (ultra-wideband)
  - Positioning capabilities are very good (few centimetres).
  - High node density is possible.
  - Standardized only in the US.

Energy consumption (lifetime)

- The two components of the energy-problem:
  1. Energy source (battery)
  2. Energy consumption of the system.

Energy sources

- The low energy consumption of sensors makes it possible to use novel energy sources
  - E.g.: solar cells, RF, mechanical vibration
- The use of „traditional” dry batteries are most common
- Effect of charge regeneration: The total capacity of a battery can be much higher if drained with a series of impulses, instead of a constant drain.
- In WSNs, the bursty nature of data transfer together with low energy consumption on the average fits ideally with this: the high-power requirement of some components (e.g., radio) are only for short period of time, with inactive periods in between.

Energy consumption - example

- 1 pc of AAA batteries (750 mAh), 1 year lifetime (8760 hours)

$$I_{avg} = 750mAh/8760h = 86\mu A$$

- Average power consumption (1.8 V with voltage regulator)

$$P_{avg} = 1.8V \cdot 86\mu A = 154.8\mu W$$

- Typically 2.4 GHz CMOS transciever with 32 mW power consumption when transmitting, and 38 mW when receiving. (average of ~35 mW)

$$I_{on} = 19.5mA \qquad I_{stby} = 30\mu A$$

- Then from

$$I_{avg} = T_{on} \cdot I_{on} + (1 - T_{on}) \cdot I_{stby}$$

- it results:

$$\boxed{T_{on} = 0.0029}$$

Energy consumption

- T_{on}=0.0029 is practically 4 minutes per day.
- In spite of low information bit rate, high bitrate is required during the (short) active periods.
- T_{on} includes the „warm-up” period as well.
  - Assuming many but short communication periods, the draining energy for the „warm-up” periods can be significant!
- The DSSS solutions with 250 kbps (raw) transfer rate are preferable.

Data link layer

MAC

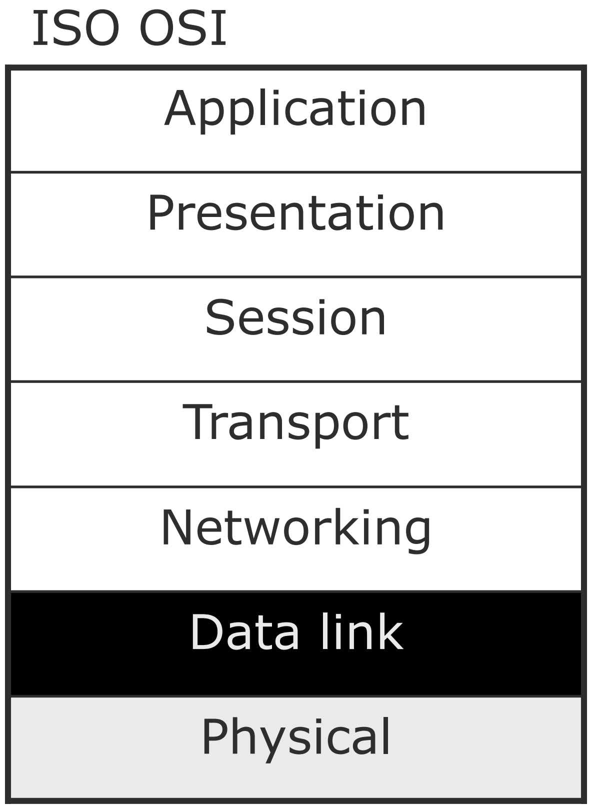
Content

- Data link layer
- Wireless MAC techniques
  - ALOHA
  - CSMA – Carrier Sense Multiple Access
  - Polling
  - MD (Mediation Device) protocol
- Sensor network solutions
  - WINS
  - PicoRadio
  - S-MAC

Data link layer

- Main tasks:
  - framing
  - error detection and correction
    - E.g., Hamming code, CRC, Go-Back-n
  - traffic control
    (flow control)
    - E.g.: ACK, Stop&Wait

  - **MAC – Medium Access Control**



Medium Access Control (MAC)

- Two types of networks:
  1. **point-to-point** communication between any two nodes
  2. **broadcast** channel for all nodes
- The channel is dedicated in point-to-point communication, so there is no need for MAC.
- The main question in using broadcast channel:
  „Who is the winner to have the right to use the channel?"
- *Alternative naming:*
  - *Multiple Access*
  - *Random Access*

Medium Access Control (MAC)

- The channel allocation can be **static** or **dynamic**
- **Static** allocation solutions:
  - frequency division (FDM – Frequency Division Multiplexing)
  - time division (TDM – Time Division Multiplexing)
  - code division (CDM – Code Division Multiplexing)

  Disadvantage: For high number of nodes and/or uneven traffic load the utilization drops dramatically.
- By **Dynamic** channel allocation, channel access can be controlled to take into account the varying needs.

MAC – Assumptions, requirements

- **Assumptions** for channel allocation:
  - *N* independent nodes communicate
  - Single channel, all nodes transmit and receive on this same channel
  - Collision: If two frames overlap in time, the signals are mixed, collision occurs.
  - Collision can be detected by all nodes.
  - Time can be continuous or sliced.
  - Channel monitoring: Are the nodes able to sense if someone else already uses the channel?