Principles of Wireless Sensor Networks

https://www.kth.se/social/course/EL2745/

Lecture 1

Introduction to WSNs

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KTH Royal Institute of Technology
Stockholm, Sweden

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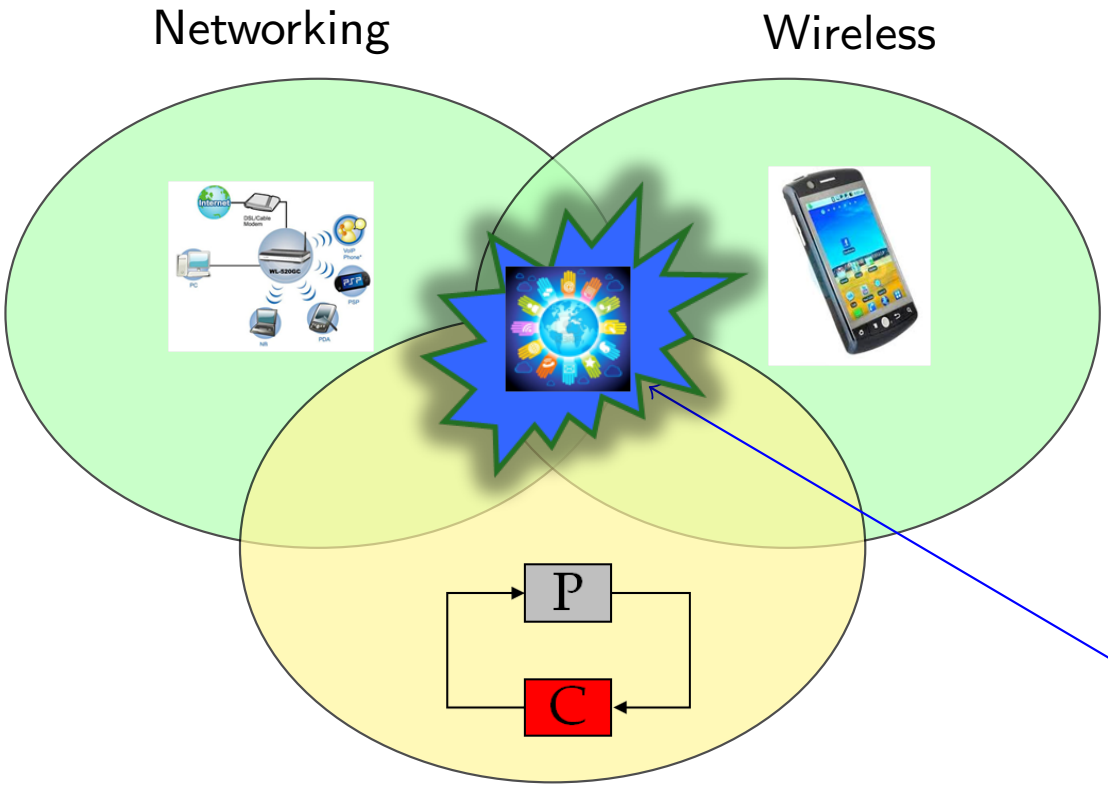
Course goal

After finishing the course, you will know the essential control, networking, programming, and signal processing tools to cope with Wireless Sensor Networks (WSNs)

You will understand the design issues of WSNs and will be able to develop WSNs applications

Wireless Sensor Networks



Outline

- Course overview
- Introduction to WSNs

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- Course overview
- Introduction to WSNs
  - Definition
  - Applications
  - Components
  - Protocols

EL2745 Principles of Wireless Sensor Networks

- Disposition
  - 7.5 credits
  - 14 lectures, 26 exercises, 3 homework, 1 project
- Instructors
  - Carlo Fischione, lecturer, carlofi@kth.se
  - Antònio Gonga, teaching assistant, gonga@kth.se
  - Hossein Shokri-Ghadikolaei, teaching assistant, hshokri@kth.se
  - Yuzhe Xu, teaching assistant, yuzhe@kth.se
  - Hanna Holmqvist, administration, hanna.holmqvist@ee.kth.se

Course content

- Part 1
  - Lec 1: Introduction to WSNs
  - Lec 2: Introduction to Programming WSNs
- Part 2
  - Lec 3: Wireless Channel
  - Lec 4: Physical Layer
  - Lec 5: Medium Access Control Layer
  - Lec 6: Routing
- Part 3
  - Lec 7: Distributed Detection
  - Lec 8: Static Distributed Estimation
  - Lec 9: Dynamic Distributed Estimation
  - Lec 10: Positioning and Localization
  - Lec 11: Time Synchronization
- Part 4
  - Lec 12: Wireless Sensor Network Control Systems 1
  - Lec 13: Wireless Sensor Network Control Systems 2
  - Lec 14: Summary and Project Presentations

Course material

- **Solution manual:** exercise solutions available online
- **Book:** lectures will be based on various chapters from
  - C. Fischione, "An Introduction to Wireless Sensor Networks", 2014, draft book.
- **Additional useful books:** some chapters of these books might be useful:
  - G.J. Pottie and W.J. Kaiser, "Principles of Embedded Networked Systems Design", Cambridge, 2005
  - W. Dargie and C. Poellabauer, "Fundamentals of Wireless Sensor Network", Wiley, 2010
- **Lecture slides:** available online before the lecture
- **Homework:** 3 exercises to hand in. First deadline, September 22
- **Software:** Matlab and TinyOS

Practical Information

Office: Osquldas väg 10, floor 6

Office Timings: Whenever you like, by appointment, send an e-mail to carlofi@kth.se to book the time. Welcome!

Prerequisites: The course is self-contained, familiarity with linear algebra and analysis

Grades: A,B,C,D,E based on

1. Homework admits to exam: pass/fail
2. Project admits to the exam: up to 10 points
3. Exam: up to 50 points
   Example: you get A by 10 credits of the project + 40 credits of the exam

Project

- Form groups of 2 (preferred) or 3 students each
- Every group gives first and second preference for two topics below:
  - The wireless channel: how the wireless channel behaves (Lec 3)?
  - Physical layer: how to shape signals to transmit information (Lec 4)?
  - Mac layer: how to access the wireless channel to transmit messages (Lec 5)?
  - Routing: how to route messages over the network (Lec 6)?
  - Distributed detection: how to detect phenomena (Lec 7)?
  - Distributed estimation: how to estimate signals corrupted by noises (Lec 8)?
  - Positioning and localization: how to estimate the position of nodes (Lec 9)?
  - Time synchronization: how to synchronize nodes (Lec 10)?
  - WSN control systems: sampling continuous time systems, PID controller (Lec 11-12)?

Project

- The project is a 10-15 pages double column written report. 5 pages per student. 2 students group = 10 pages
- Must contain experimental results of your proposal
- Time line:
  1. Sept 5: Every group communicates to carlofi@kth.se the preferences on the topic
  2. Sept 8: Carlo sends out the study material with detailed instructions
  3. Sept 9: The groups start working on the writing and experiments
  4. Sept 15: Every group e-mails to carlofi@kth.se the proposal for report table of content
  5. Sept 16: Carlo sends feedback on the table of content of the proposal
  6. Sept 9 - Oct 14: Groups work and ask feedback if needed to the teaching assistants and Carlo
  7. Oct 15: Every group gives a presentation on the project and submits the final project report

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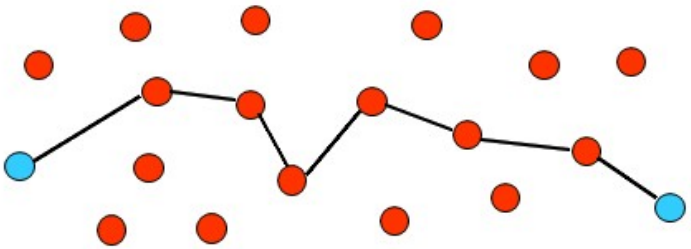
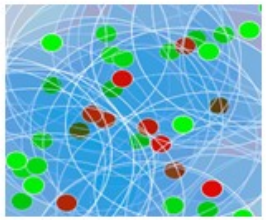
  - Applications
  - Components
  - Protocols

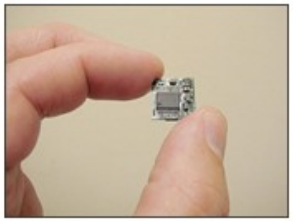
Today's learning outcome

- What are typical applications of a WSN?
- What are the components of a WSN?
- What is a networking protocol?

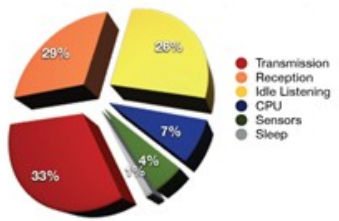
WSNs







- Wireless sensor networks (WSNs) make Internet of Things possible
- Computing, transmitting and receiving nodes, wirelessly networked together for communication, control, sensing and actuation purposes
- Characteristics of WSNs
  - Battery-operated nodes
  - Limited wireless communication
  - Mobility of nodes
  - No/limited central manager



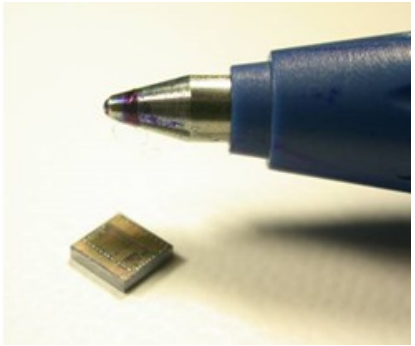
Typical power consumption of a node

Applications of WSNs

- Let us now see some applications of WSNs

History of WSNs

DARPA DSN node, 1960



Tmote-sky, 2003

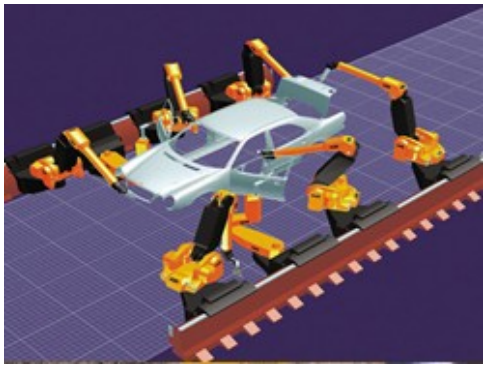
Mica2 mote, 2002

Smart Dust

Applications of WSNs

Environmental Monitoring

Industrial Control



Transportation

Healthcare

Smart Buildings

WSNs for controlling temperature, light, air and humidity, doors, alarms

Smart Buildings

- By 2020, one of the most technological urban districts in the world
- Thousands of Smart Buildings will be built

Structural Monitoring

- Sensors used to measure response to traffic, tidal and seismic activity
- Deployed on Golden Gate Bridge

Smart Energy Grids

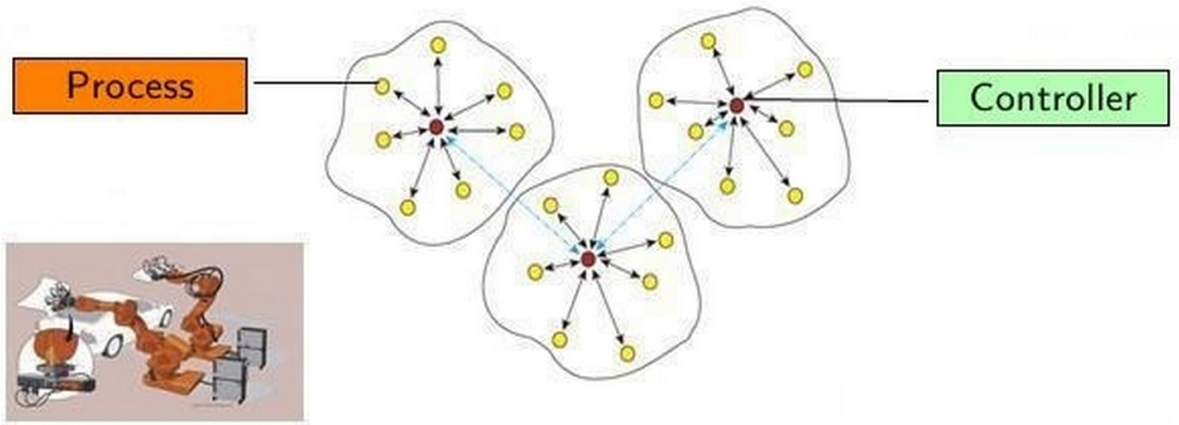
source: http://deviceace.com/

- Smart grids: Smart Grids: It's All About Wireless Sensor Networks (http://stanford.wellsphere.com)

Water Pollution

- The pollution level can be estimated by sensors on the water pipes
- The estimates are reported centrally only when needed

WSNs in Industrial Automation



- Added flexibility
  - Sensor and actuator nodes can be placed more appropriately
  - Less restrictive maneuvers and control actions
  - More powerful control through distributed computations
- Reduced installation and maintenance costs
  - Less cabling
  - More efficient monitoring and diagnosis

Distributed positioning

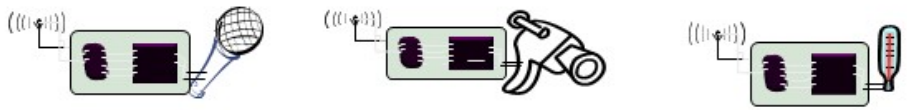
- WSN allows to perform distributed camera calibration, positioning and tracking
- Application: massive graphic effects in film production

Components of a WSN

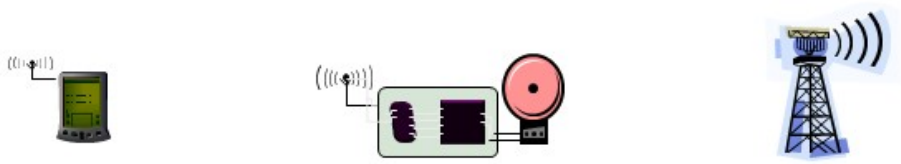
- What are the participants and how is a node of a WSN?

Participants in a WSN

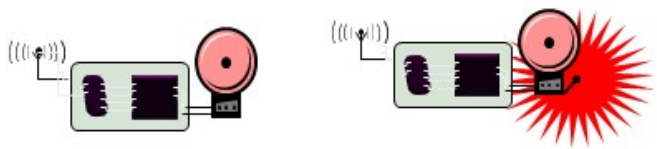
- **Sources** of data: Measure data, report them "somewhere"
  - Typically equip with different kind of actual sensors



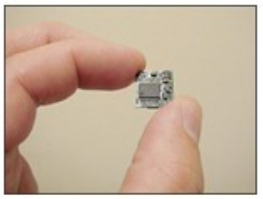
- **Sinks** of data: Interested in receiving data from WSN
  - May be part of the WSN or external entity, PDA, gateway,...

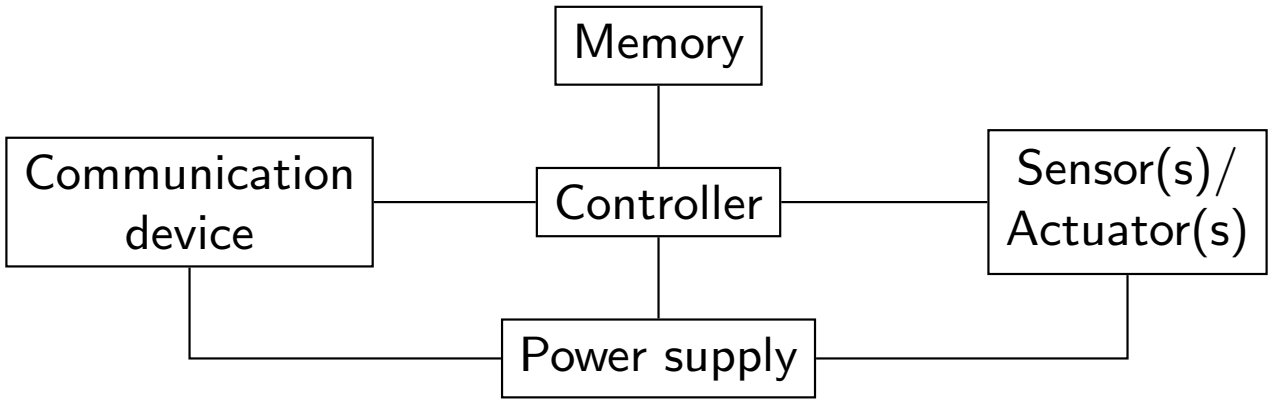


- **Actuators**: Control some device based on data, usually also a sink



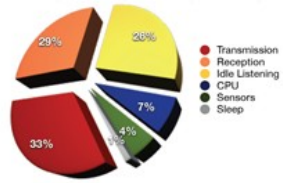
WSN node components





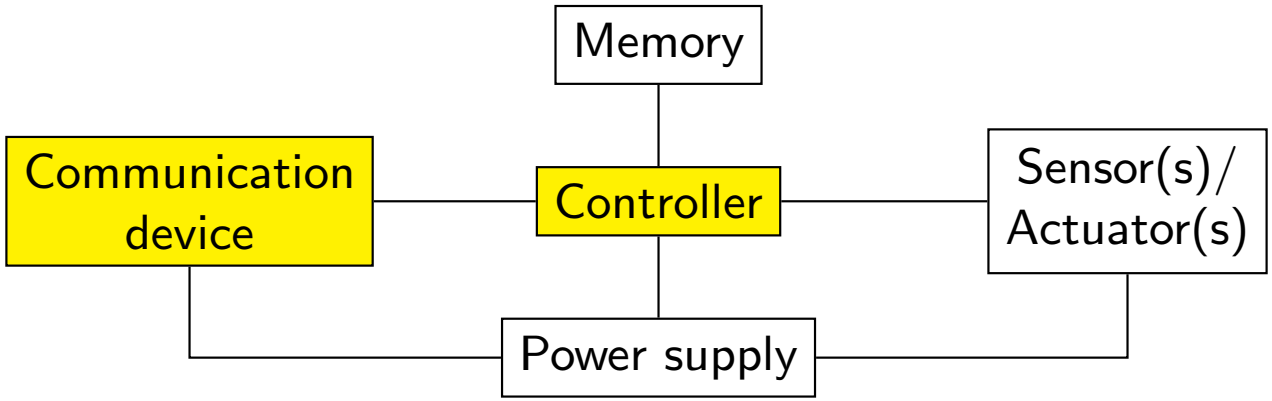
1. Controller
2. Communication device(s)
3. Sensors/actuators
4. Memory
5. Power supply

Transceiver states



- Transceivers can be put into different operational **states** typically:
  - **Transmit**
  - **Receive**
  - **Idle**: ready to receive, but not doing so
    - Some functions in hardware can be switched off, reducing energy consumption a little
  - **Sleep**: significant parts of the transceiver are switched off
    - Not able to immediately receive something
    - **Recovery time** and **startup energy** to leave sleep state can be significant

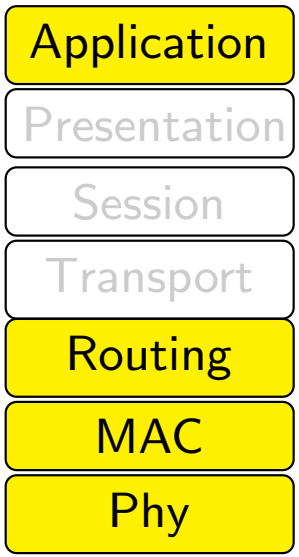
Components in a wireless node



Let's now focus on the protocols that are followed at the communication device

WSN Protocols, the ISO-OSI stack

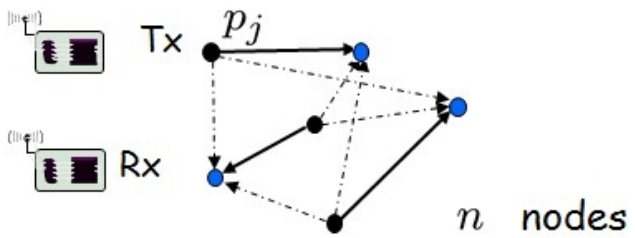
- The behavior of a node is specified by a set of protocols, or set of rules with which the node operate

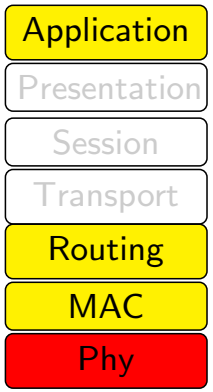


The radio power control problem

- Let $\mathbf{p} = (p_1, p_2, ..., p_n) \in \mathbb{R}^n, \mathbf{p} \succeq 0$, be a vector of radio powers
  - Each element of the vector is the radio power used for transmission by a node
- Let $I_j(\mathbf{p}) : \mathbb{R}^n \rightarrow \mathbb{R}$ be the interference that the radio power has to overcome so that the receiver can receiver successfully the transmitted information
- $I(\mathbf{p}) = (I_1(\mathbf{p}), I_2(\mathbf{p}), ..., I_n(\mathbf{p}))$ Interference Function
- The radio powers of every sensor must be minimized subject to quality of communication constraints:

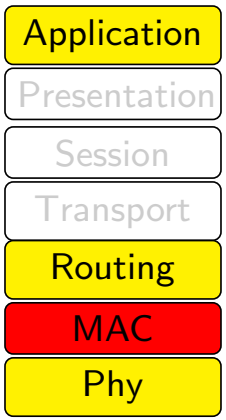
$$\begin{aligned} \underset{p}{\text{minimize}} \quad & \mathbf{p} \\ \text{s.t.} \quad & \mathbf{p} \geq I(\mathbf{p}) \end{aligned}$$





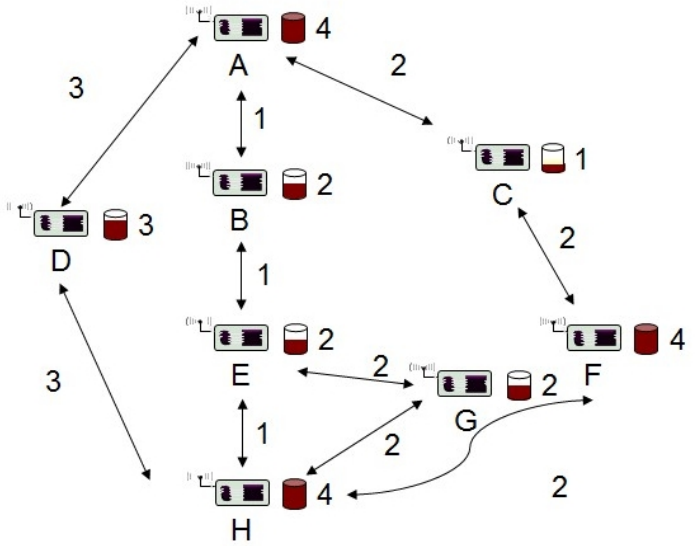
Medium Access Control (MAC)

- MAC: mechanism for controlling when to send a packet and when to listen for a packet
  - MAC is one of the major component for energy expenditure
  - Especially, idly waiting to receive packets wastes huge amounts of energy
- MAC is influenced by the transmit radio power

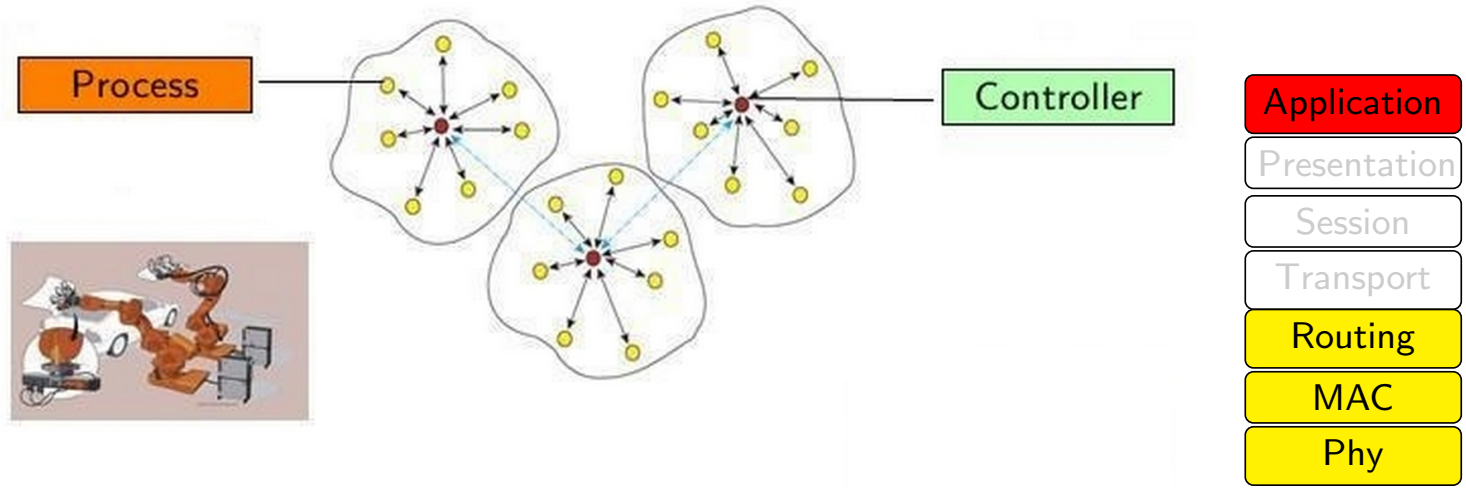


Routing: how to choose paths

- Maximum total available battery capacity
  - Path metric: Sum of battery levels
  - Example: A-C-F-H
- Minimum battery cost routing
  - Path metric: Sum of reciprocal battery levels
  - Example: A-D-H
- Conditional max-min battery capacity routing
  - Only take battery level into account when below a given level
- Minimum total transmission power



Control over WSNs



- The state of a process is sensed by wireless nodes
- State information reaches the controller via multi-hop routing
- How the protocols and the controller interact?

Useful Links

Blogs:
http://www.wsnblog.com/

Industries:
http://www.dustnetworks.com/
http://www.sensinode.com/
http://www.libelium.com/
http://www.xbow.com/
http://www.siemens.com/
http://www.abb.com/

University courses:
http://www.cs.berkeley.edu/~culler/eecs194/
http://bwrc.eecs.berkeley.edu/Research/energy_efficient_systems.htm
http://wsnl.stanford.edu/
http://courses.csail.mit.edu/6.885/spring06/readings.html
http://www.eecs.harvard.edu/~mdw/course/cs263/fa04/
http://www3.cs.stonybrook.edu/~jgao/CSE590-spring11/

Useful Links

WSNs Standard:

http://www.hartcomm.org/
http://www.ieee802.org/15/pub/TG4.html
http://www.ietf.org/dyn/wg/charter/roll-charter.html
http://www.ipso-alliance.org/Pages/Front.php
http://www.isa.org/
http://www.tinyos.net/
http://www.sics.se/contiki/
http://www.zigbee.org/

Summary

- We have seen the key aspects of WSNs
  - Applications
  - Protocols
- Reading material: Chapter 1 of "Introduction to WSNs"
- Next Lecture, Monday 8: Introduction to WSN Programming
  - You have to install TinyOS on your laptop before the lecture
  - Download instructions on Week 37 of Schedule in `https://www.kth.se/social/course/EL2745/`