Sensornetze

wie viele kleine Computer Großes leisten

ALPEN-ADRIA UNIVERSITÄT KLAGENFURT | WIEN GRAZ

FAKULTÄT FÜR TECHNISCHE WISSENSCHAFTEN

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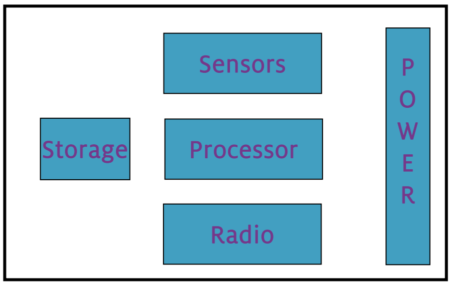
Agenda

- Introduction to Sensor Networks
  - Enabling Technologies
  - Applications
- Selected Challenges
  - Topology
  - Networking
  - Synchronization
- Visual Sensor Networks
  - Research at PCG
- Relevance for Own Research

Introduction to Sensor Networks

Wireless Sensor Networks (WSNs)

- Networks of typically small, battery-powered, wireless devices, ("sensor nodes", "motes")
  - On-board processing,
  - Communication, and
  - Sensing capabilities.



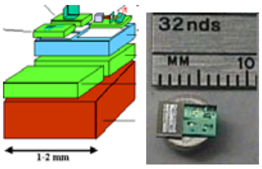
Sensor node schematics

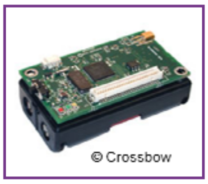
Anatomy of a Sun SPOT

[© Oracle Labs]

Sensor Node Platforms

- From research prototypes to commercial products





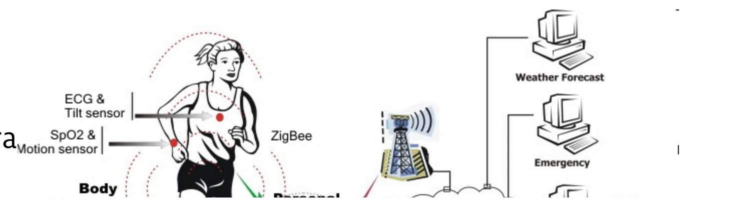
The Vision
„Smart Dust" UC Berkeley
late 1990's

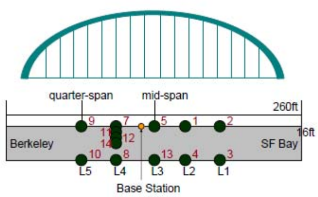
Research Prototypes
„Mica-2"
Crossbow 2004

Commercial Products
„Mote-on-a Chip"
Dust Networks, 2010

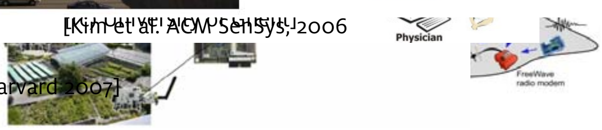
Some Applications of Sensor Networks

- Health
- Structura
- Agricultu
- Environm





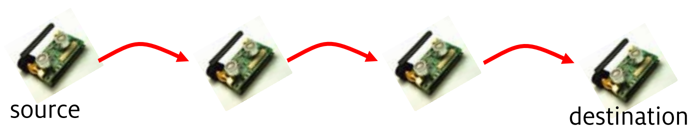
[Kim et al. ACM SenSys, 2006



[AgriNet]
[M. Welsh, Harvard 2007]

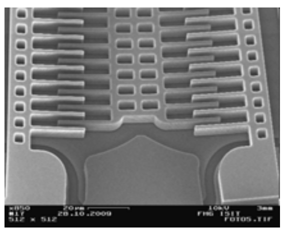
Communication is Key

- Wireless communication is an enabling technology
  - Eases deployment
  - Enables mobility
  - Increases flexibility
  - Reduces costs
- Communicate on demand (ad hoc, spontaneous) with dynamic infrastructure
  - Nodes organize themselves into network
  - Data is transferred via multiple hops



But also …

- Advances in sensor technology
  - Micro electro-mechanical system (MEMS) revolutionized sensing
  - Integration of mechanical and electrical components on single chip
  - Example: 3D accelerometer (in your cell phone)



[© SensorDynamics]

- Embedded processors and integration
  - Moore's Law still valid
  - Trade-off between processing performance and power consumption

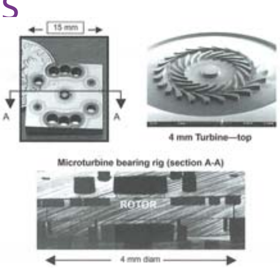
[© ARM]

The “Energy Problem”

- Major sources of energy consumption
  - Sensing, computing, communication
  - High temporal variation
- Energy is the scarce resource for WSN. Several challenges
  - What energy reservoirs to exploit?
    Constraints: availability, max. power, size, …
  - How to distribute power over the network?
    Energy provider and consumer might be dislocated.
  - How to control the distribution?
    “The proper amount of energy in the right place at the right time”
- Sensor networks have always been a “green” technology!

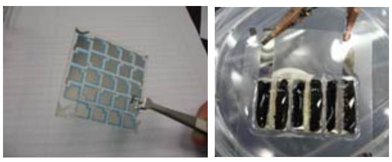
Alternative Energy Reservoirs

- Maybe micro-heat engines
  - Exploit MEMS technology
    to build „internal combustion engines“
  - Expected power: 10-20 W
  - Still in early research/development phase



[Handbook of Sensor Networks, Wiley]

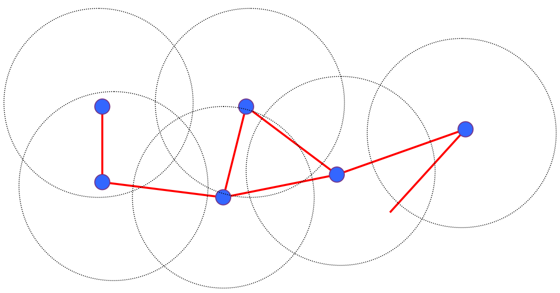
- Or harvest energy from environment
  - Organic semiconductors for exploiting indoor ambient light
  - Thin film batteries for storing energy
  - EnHANTs : energy harvesting networked active tags


[Columbia University, CLUE]

(Selected) Challenges for Ad-hoc Networking

Topology Control

- Determine (bidirectional) communication topology
  - Which nodes are my neighbors ?
  - Is the network connected ?
- Sending power determines radio coverage



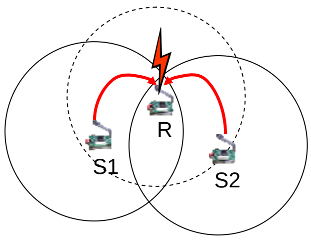
Topology Control (2)

- Critical Transmitting Range (CTR)
  - Compute the minimum (common) transmitting range such that the network is connected.
  - If node locations are known -> CTR is the length of the longest edge of the minimum spanning tree (MST)

- Setting individual transmission rates
  - Objective: Minimize $\sum_{1}^{n} r_i^{\alpha}$
  - "range assignment problem" (NP-complete)

Power-aware Media Access

- Contention-based vs. contention-free media access
- In wireless communication energy is "wasted" by
  - Collisions
  - Overhearing
  - Idle listening
  - Protocol overhead

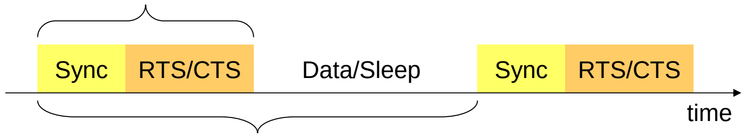


Hidden terminal

Carrier sense multiple access (CSMA)
„listens before transmits“ a message, but collision can still occur.

Sensor-MAC (S-MAC) Protocol

- Use SYNC, RTS, CTS phases



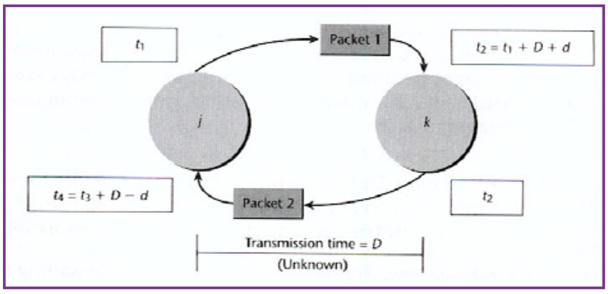
- Schedule active and passive periods for the radio
  - Low-duty-cycle operation (1-10%)
  - Synchronization of listen/sleep schedules required
  - At startup all nodes choose their own listen/sleep schedules
  - These schedules are shared with their neighbors to make communication possible between all nodes
  - Each node periodically broadcasts its schedule in a SYNC packet, which provides simple time synchronization

Time Synchronization

- Nodes operate independently
  - Local clocks may not be, or stay, synchronized
  - Clocks are inaccurate (eg., bias and drift)
- Synchronized clocks important for many applications
  - Sensor data interpretation
  - (Many) localization techniques require synchronization
  - Communication!
- Time synchronization in the "wired world"
  - (often) more accurate clocks are available
  - assume constant communication delays

Time Synchronization (2)

- Computing the clock phase difference d
  - Assumption: no clock skew, symmetric, constant delay D



[Zhao, Guibas. Wireless Sensor Networks, 2004]

  - d = (t2 – t1 – t4 + t3)/2
  - Even such simple setting requires to exchange 3 messages

Visual Sensor Networks

Smart Cameras as Sensor Nodes

- Differences to traditional sensor nodes
  - Process (much) more sensor data
  - Apply advanced analysis algorithms onboard
  - Avoid transferring raw image data
  - Energy!
- Various Prototypes

Rinner et al. (multi-DSP)
10 GOPS @ 10Watt

WiCa/NXP (Xetal SIMD)
50 GOPS @ 600mWatt

CMUcam3 (ARM7)
60 MIPS @ 650mW

CITRIC (PXA270)
660 MIPS @ 970mW

[Rinner et al. The Evolution from Single to Pervasive Smart Cameras. Proc. ICDSC 2008]

Resource-awareness in VSN

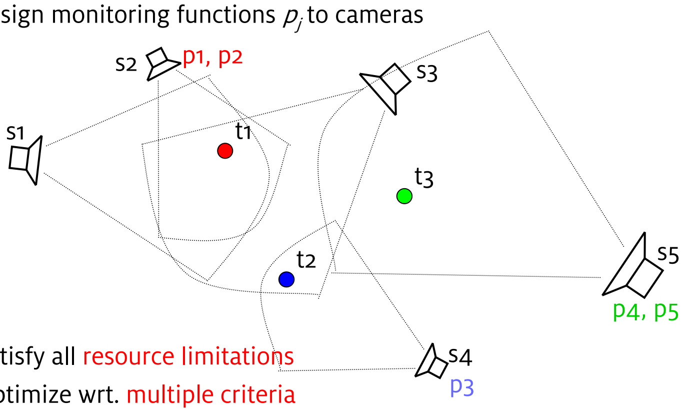
Lakeside Labs

- SRSnet Project: Smart Resource-Aware Multi-Sensor Network
  - Goal: deploy audio/video sensor network in biologically sensitive environments to autonomously detect complex events
  - Resource-awareness to run long from batteries
  - Partners: Lakeside Labs, NES, IST, Udine

- Configure the network such that detection task requires minimal energy

Resource-aware VSN Configuration

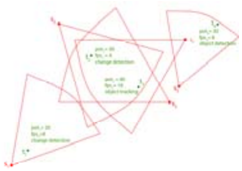
- VSN configuration as complex coverage problem
  - Select a set of cameras to cover all observation points t_i
  - Set the sensor (frame rate, resolution, PTZ) to achieve QoS
  - Assign monitoring functions p_j to cameras



  - Satisfy all resource limitations
  - Optimize wrt. multiple criteria

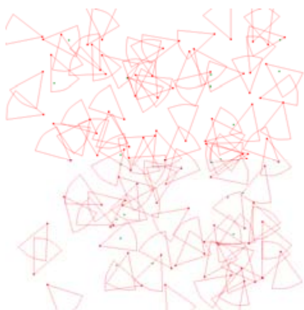
Experimental Evaluation

- Different scenarios with different activities
  - Various configurations, activities, observation points …
  - Nodes execute real monitoring tasks (CV algorithms)



small

medium (campus@Udine)

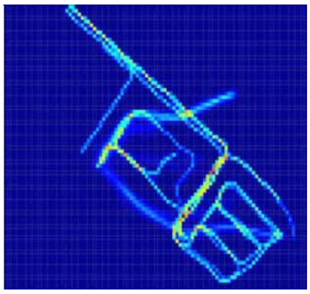


large (randomly generated)

Experimental Evaluation (2)

- Demonstration for monitoring campus scenario
  - Observation of person traces to compute the activity map (used to identify observation points)

person tracks



activity map

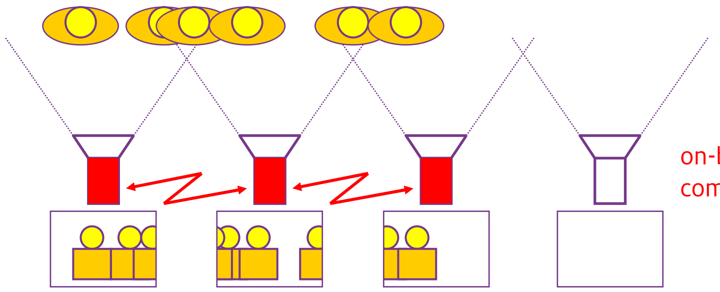
Self-aware smart camera networks

- EPiCS Project: Engineering Proprioception in Computing Systems
  - Goal: develop networks that react autonomously (requires self-awareness and self-expression)
  - Focus on smart camera networks
  - FP7 FET project with 8 European partners: U Paderborn, ETHZ, Imperial, U Oslo, U Birmingham, EADS, AIT,

- Demonstrate autonomous multi-object tracking in camera network

Multi-camera Tracking

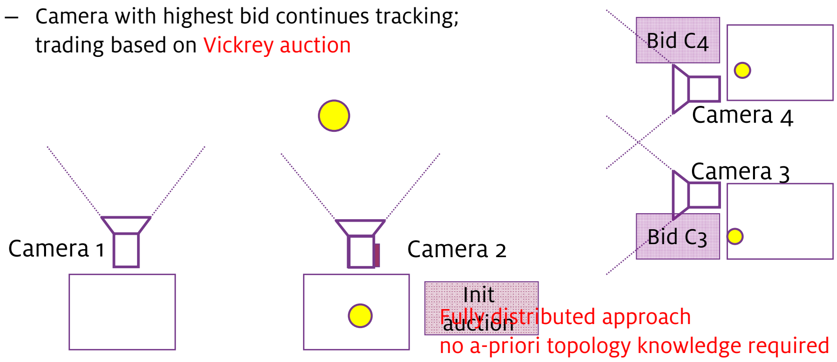
- Track mobile objects autonomously among multiple cameras



- How to select the next camera?
  - Requires knowledge of the topology (overlapping FOVs)

Virtual Market-based Handover

- Initialize auctions for exchanging tracking responsibilities
  - Cameras act as self-interested agents, i.e., maximize their own utility
  - Selling camera (where object is leaving FOV) opens the auction
  - Other cameras return bids with price corresponding to “tracking” confidence
  - Camera with highest bid continues tracking; trading based on Vickrey auction

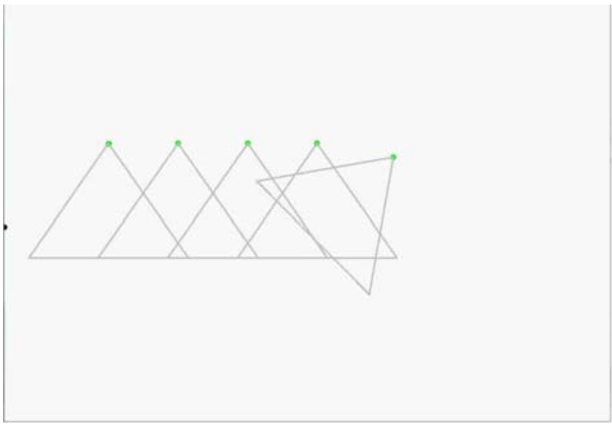


Fully distributed approach
no a-priori topology knowledge required

Market-based Handover

- Utility function (each camera) $U_i(O_i) = \sum_{j \in O_i} u_i(j) = \sum_{j \in O_i} [c_j \cdot v_j \cdot \Phi_i(j)]$

visibility
tracking decision
confidence



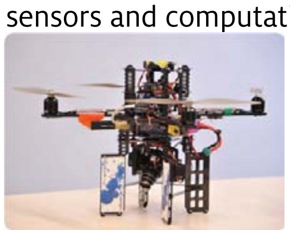
Simulation
green: tracking
yellow: shared FOV
red: trading (handover)

Collaborative Aerial Cameras

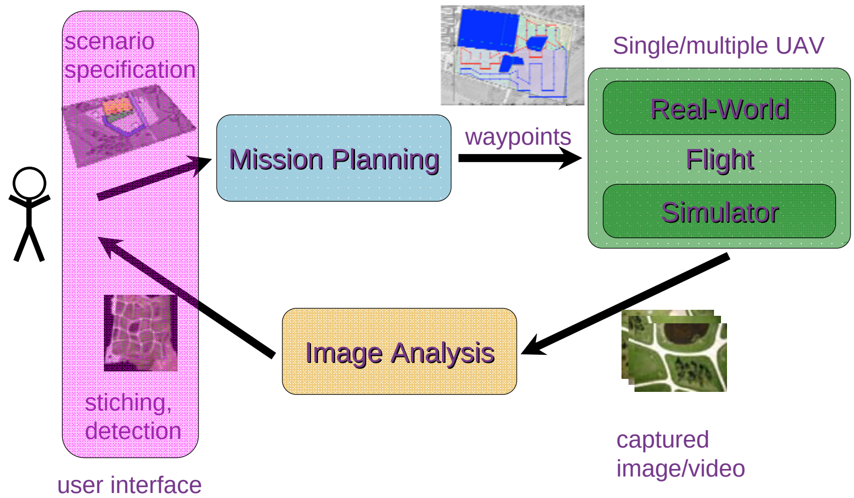
Lakeside Labs

- Develop autonomous multi-UAV system for aerial reconnaissance
- Up-to-date aerial overview images are helpful in many situations:
  "Google Earth with up-to-date images in high resolution"
- cDrones Project (NES, ITEC, AINF)

- Quadcopter platform with onboard sensors and computation
- GPS receiver for autonomous waypoint flights
- Limitations on payloads, flight time, weather conditions



Autonomous UAV Operation



User Interface

Define high-level tasks, i.e., observation area

Real-time overview image and execution status

cDrones Videos

http://pervasive.aau.at/cDrones

Are Sensor Networks relevant for your research?

Arg #1: Many open problems

- Wide field of challenging problems
  - Resource limitations
  - Energy-awareness
  - Embedded systems, integration
  - Sensors
  - Distributed sensing and processing
  - System-level software
- Interdisciplinary approach
  - Mathematics
  - Computer Science
  - Electrical Engineering
  - Material Sciences

Arg #2: Relevance and Impact

- Sensor networks help to solve "real" problems
  - Various applications
  - Standardization effort (ie., for "low power wireless", wirelessHART)
- Manifestations of some fundamental problems, eg.,
  - (Self-)coordination of large networks
  - Coupling of "sensing-processing-networking-actuating"
  - Software engineering large networks

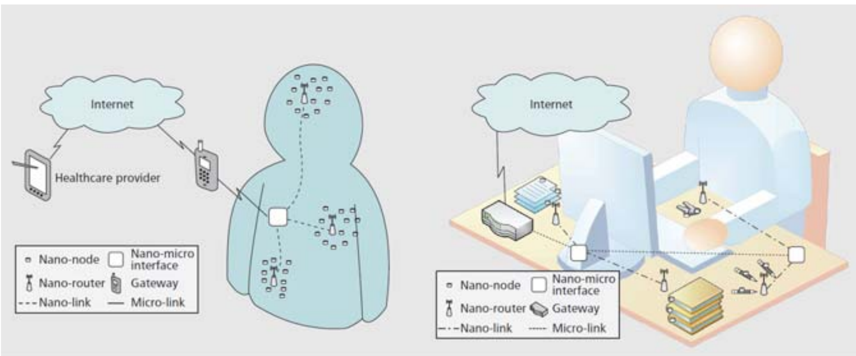
- Build your own network and conduct experiments!

Arg #3: Attractive for CS

- “Distributed systems” revisited, but
  - Strong resource limitations
  - Distributed sensing & processing
- Quality of Service provisioning
- Multimedia processing and distribution
- System-level software & Middleware systems

What next ?

- Nano Networks



[Akyildiz, Jornet. The Internet of Nano-Things. IEEE Wireless Communications. Dec. 2010]

Further Information

Web site: http://pervasive.aau.at

To probe further:

IEEE/ICE Summer School
Networked Embedded Systems
Klagenfurt Sep 3-7, 2011

ice.aau.at/ss-2011

www.avss2011.org

www.icephd.org