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Sensor Networks

13.10.2010 13:45 – 15:30 HIL D53

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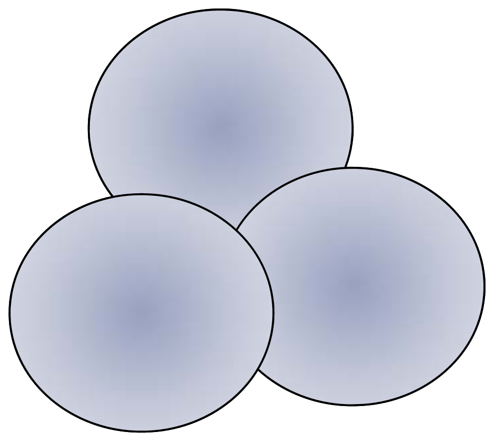
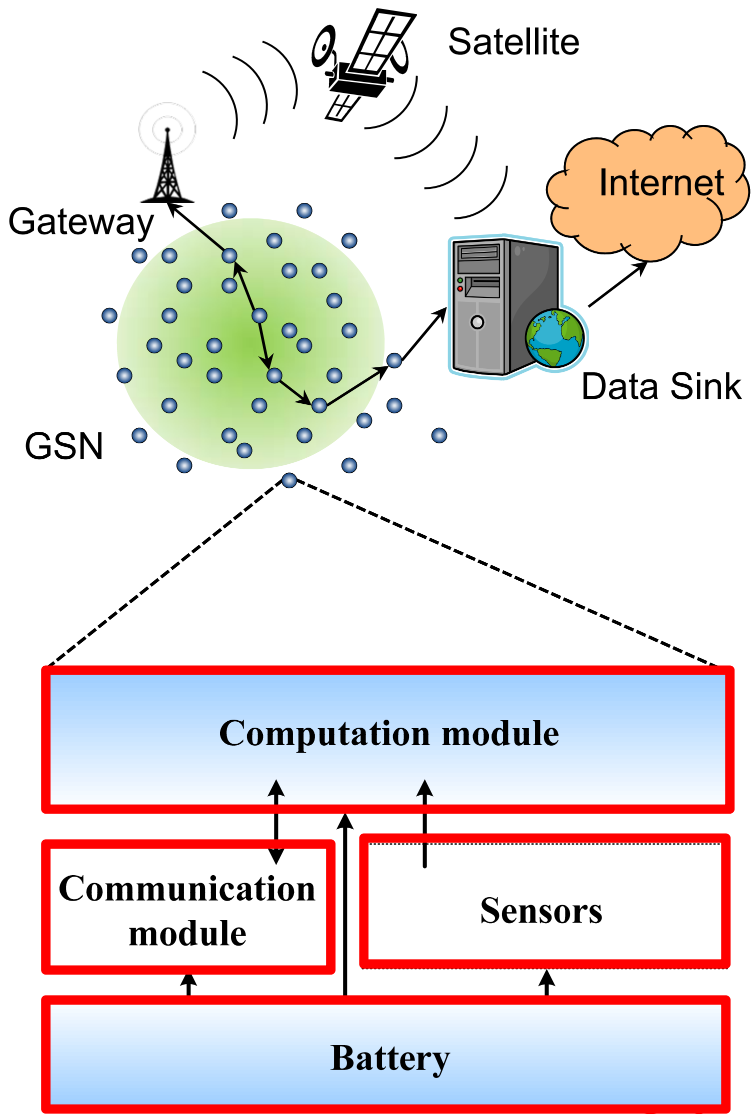
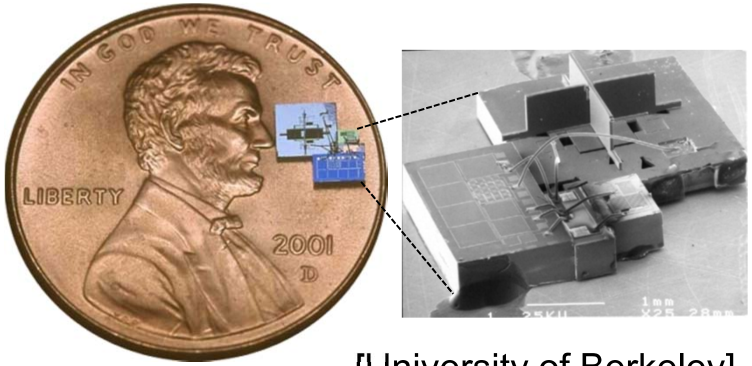


1. Introduction

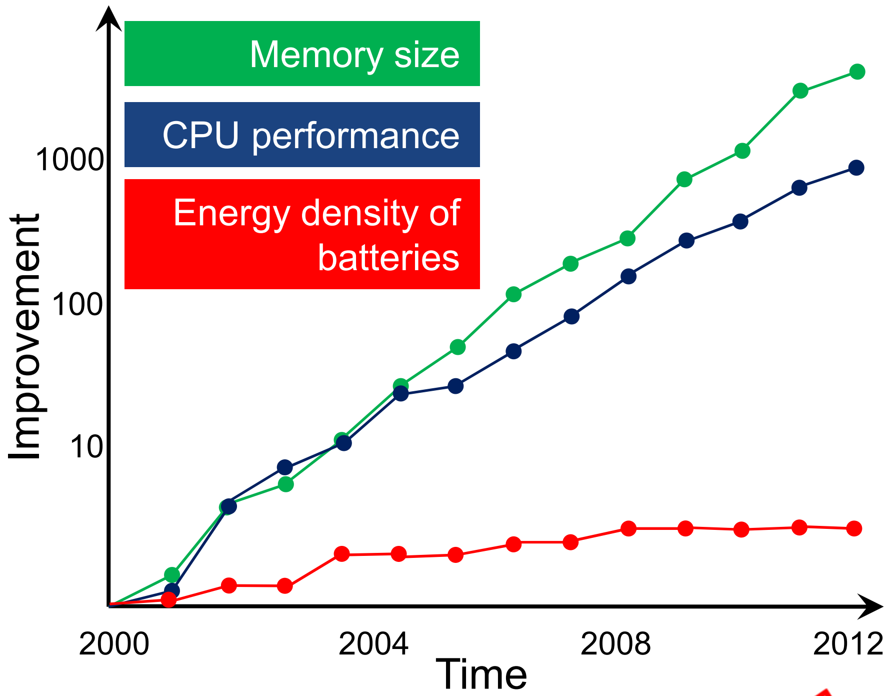
- Basic idea:
  - Random deployment of thousands of nodes over a phenomenon of interest
  - Ad hoc networking
  - Measurement of physical parameters
  - Forwarding of data to a sink
- Tasks / Components of a node:
  - Measuring sensor values
  - Preprocessing information
  - Routing of information
  - Saving energy
- Characteristics:
  - Self configuration
  - High node density



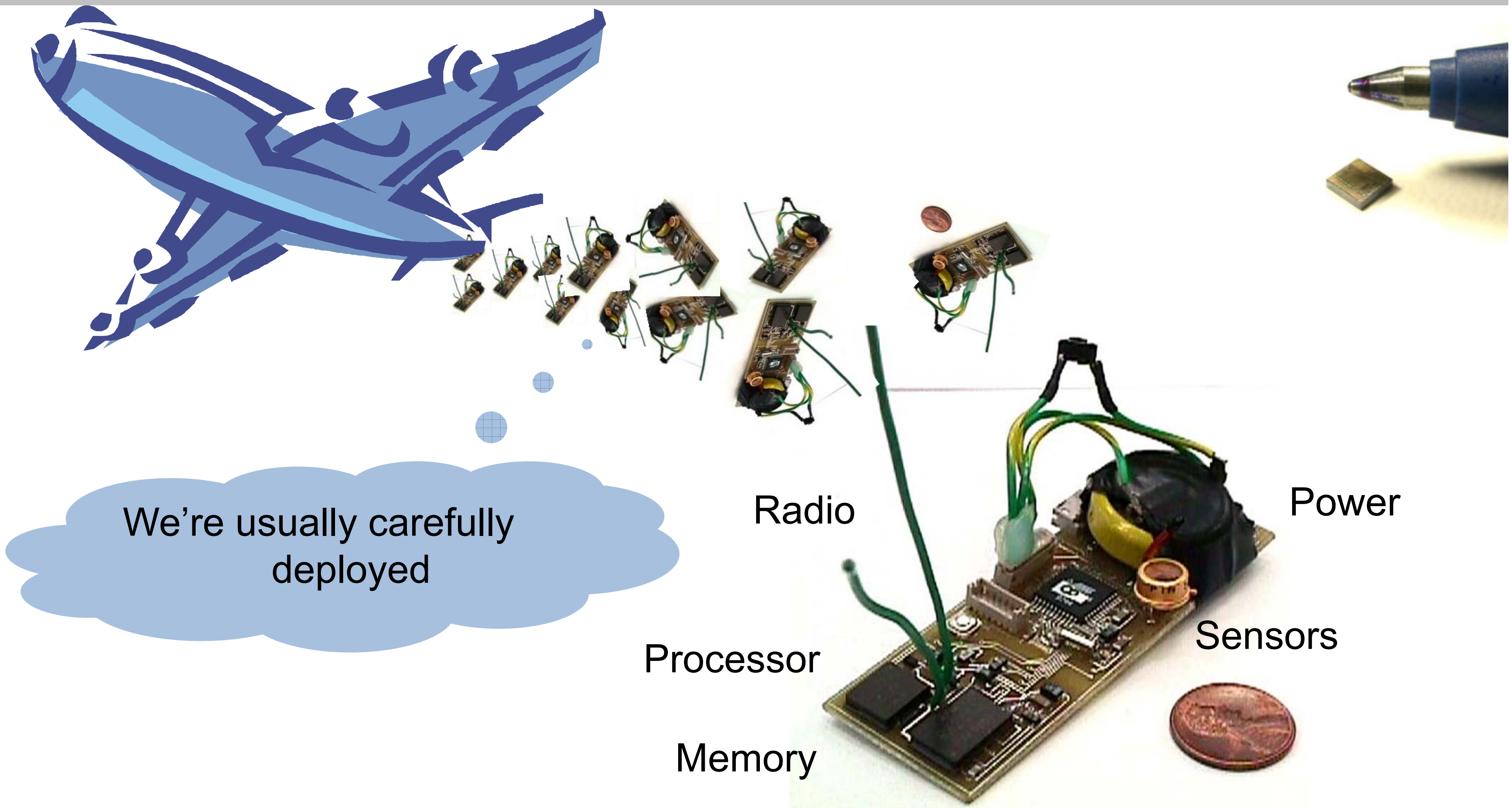
- Long-term objectives:
  - Extremely small nodes (<mm^3)
  - Cheap (<1$)
  - Long lifetime (>years)
- Resource problem:
  - Limited amount of energy
  - Low performance
- Complex tasks must be executed:
  - Data (de)compression
  - Data (de)encryption
  - Localization

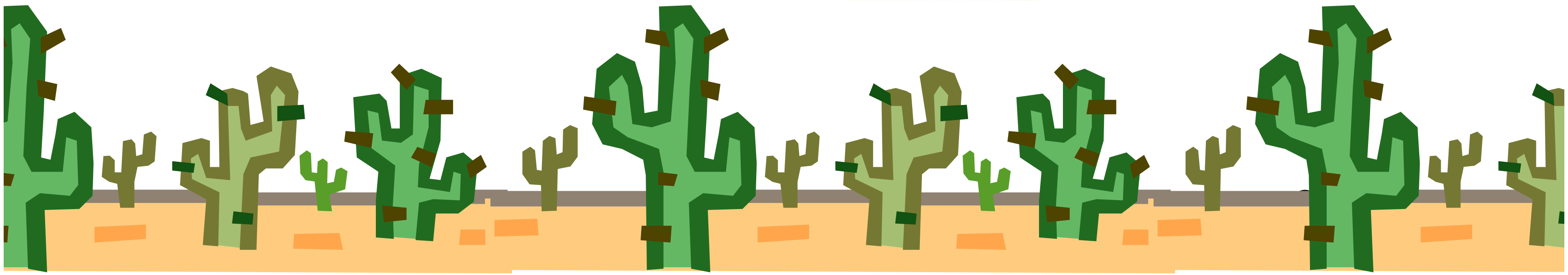


[University of Berkeley]



Deployment by Airplanes?

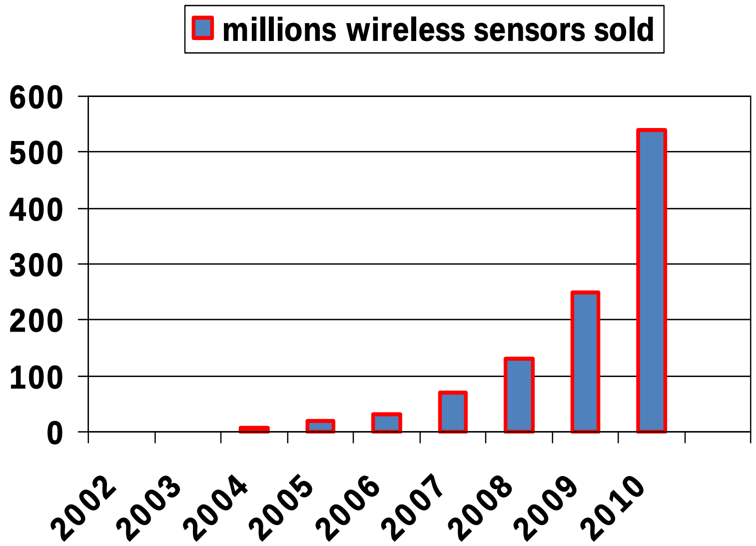




2. Sensor Network Applications

Motivation: Economic Growth

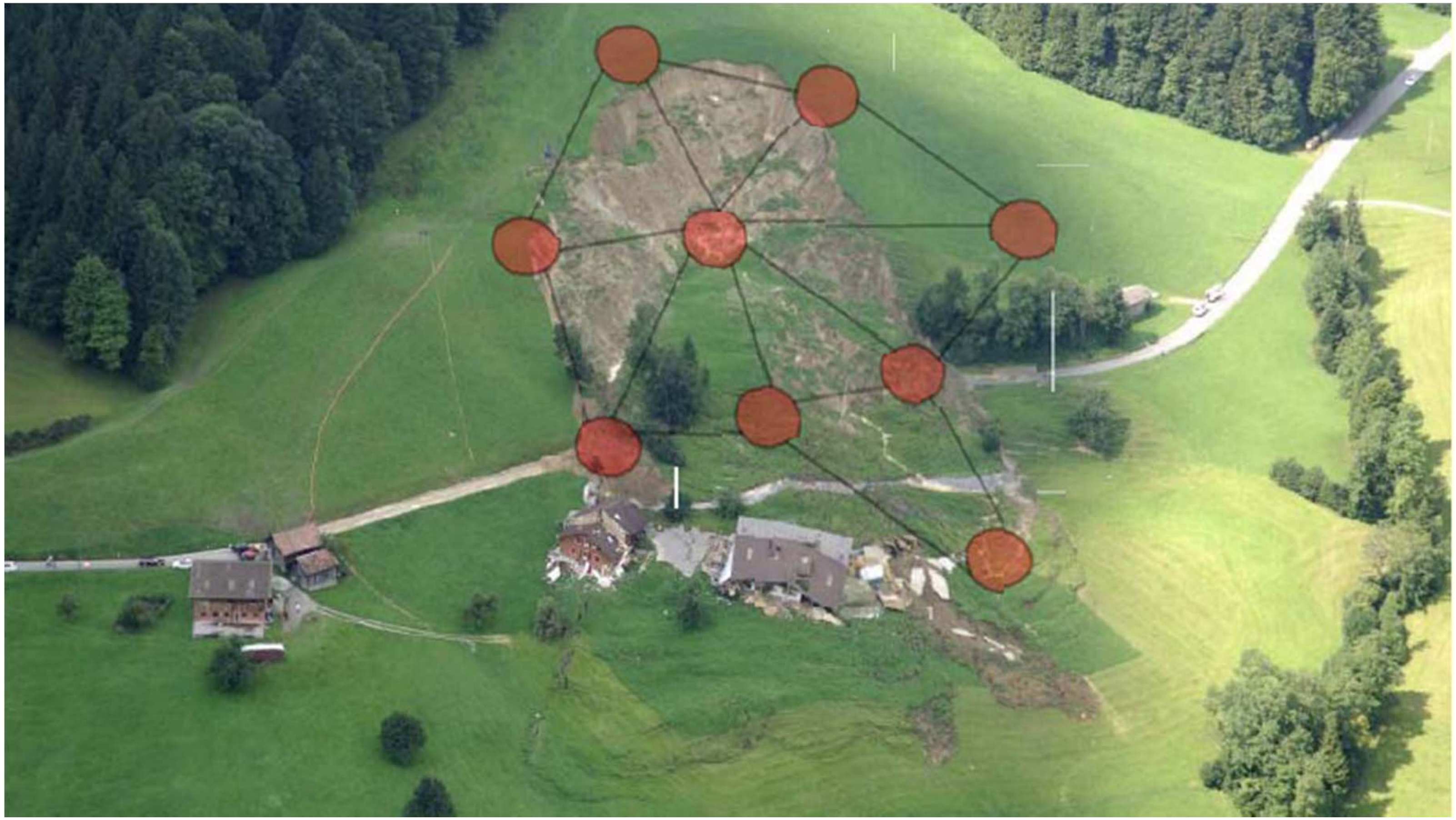
- Industrial Monitoring (35% – 45%)
  - Monitor and control production chain
  - Storage management
  - Monitor and control distribution
- Building Monitoring and Control (20 – 30%)
  - Alarms (fire, intrusion etc.)
  - Access control
- Home Automation (15 – 25%)
  - Energy management (light, heating, AC etc.)
  - Remote control of appliances
- Automated Meter Reading (10-20%)
  - Water meter, electricity meter, etc.
- Environmental Monitoring (5%)
  - Agriculture
  - Wildlife monitoring



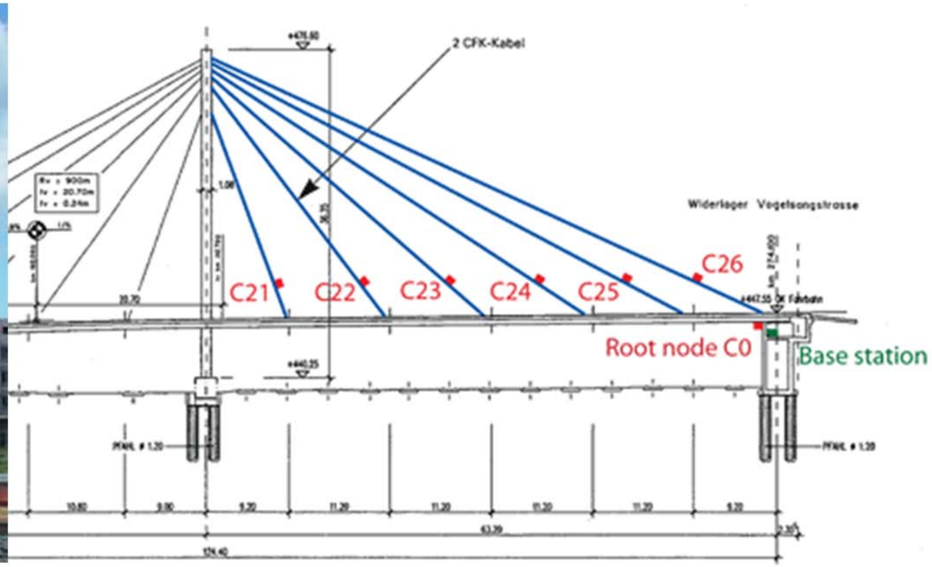
[Jean-Pierre Hubaux, EPFL]

Application: Sessor based Landslide Early Warning System

Geoservice infrastructure by integration of real-time sensors

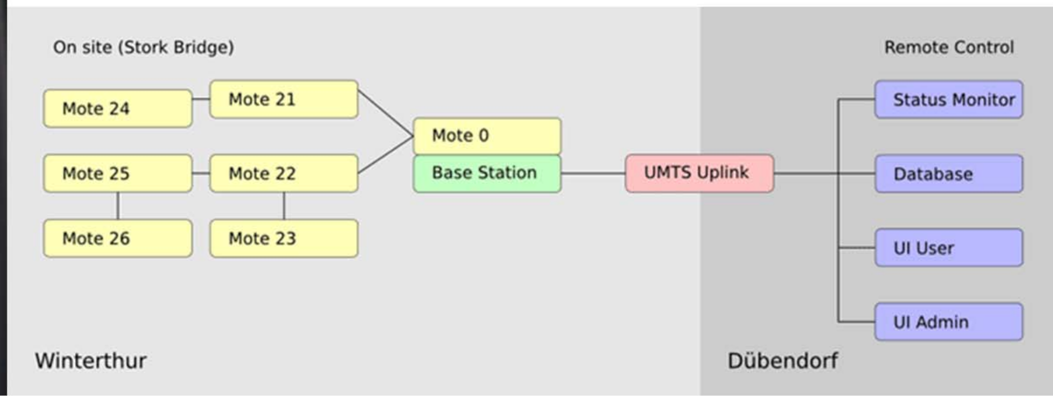


Application: Structural Health Monitoring (e.g. Bridges)

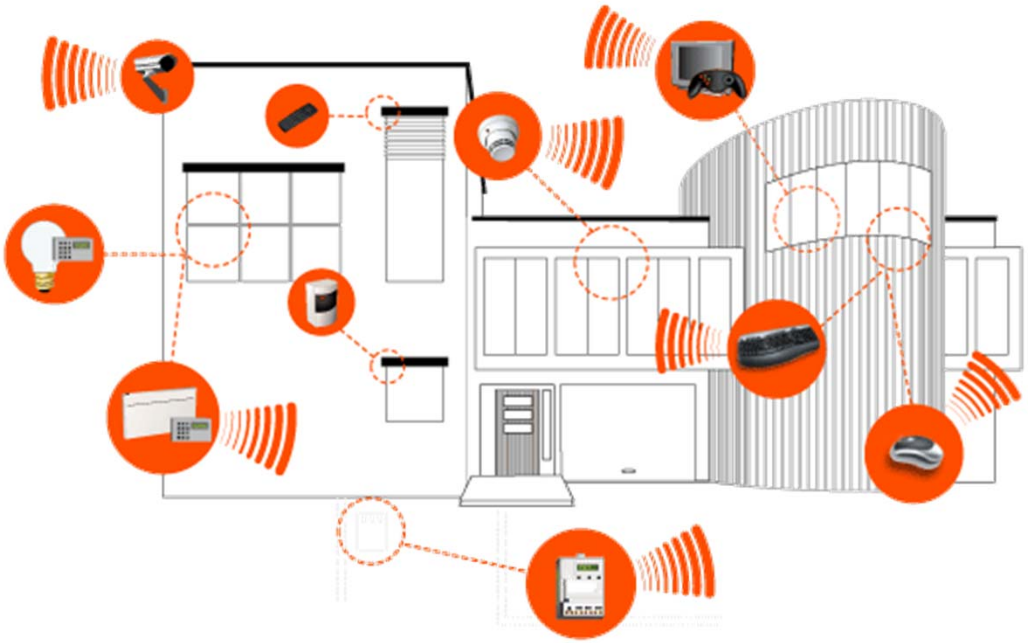


Swiss Made
[EMPA]

Detect structural defects, measuring temperature, humidity, vibration, etc. using geotechnical and geodetic sensors



- Smart House
- Cold chains



Application: Natural Hazards Monitoring (e.g. Volcanos)

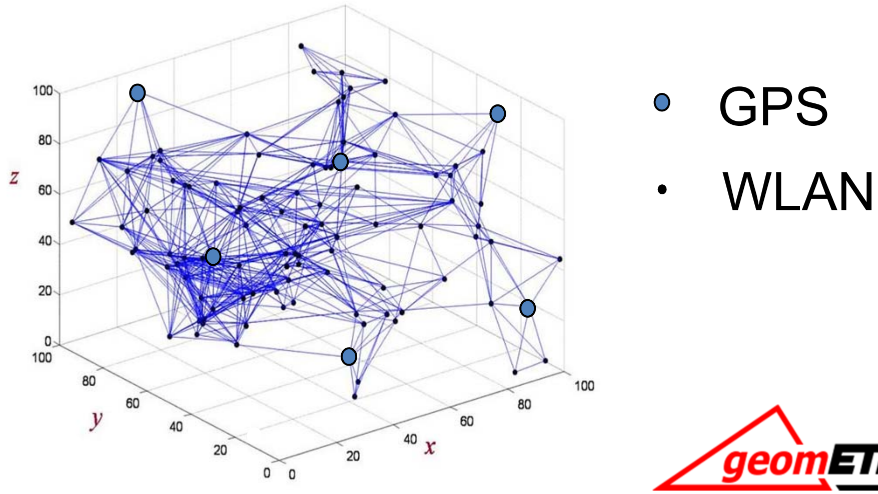
Example: Sakurajima
Stratovolcano, island with 77 km^2, 1117 m height
Extremely active, densely populated
Monitored with levelling, EDM, GPS

Landsat image, created by NASA

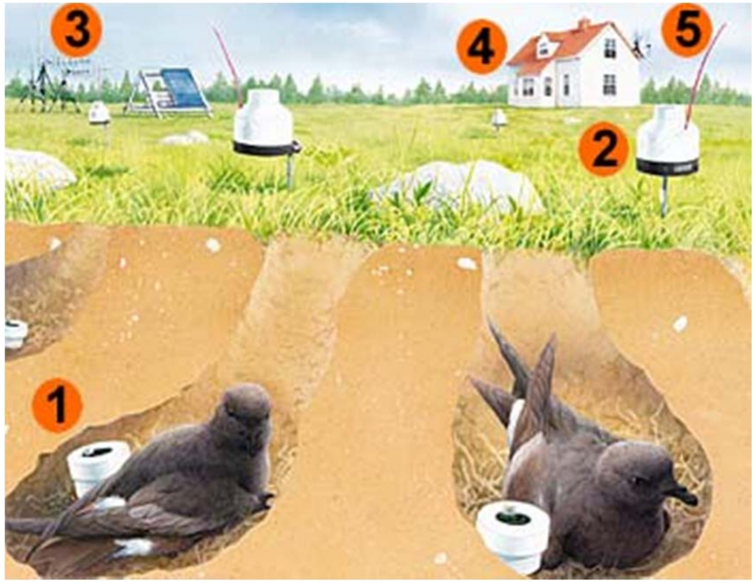
Volcanoes experience pre-eruption surface deformation
cm – dm over 10 km^2
Spatially distributed monitoring for early warning system

- SAR interferometry: update rate 35 days
- Geodetic GNSS: expensive, energy

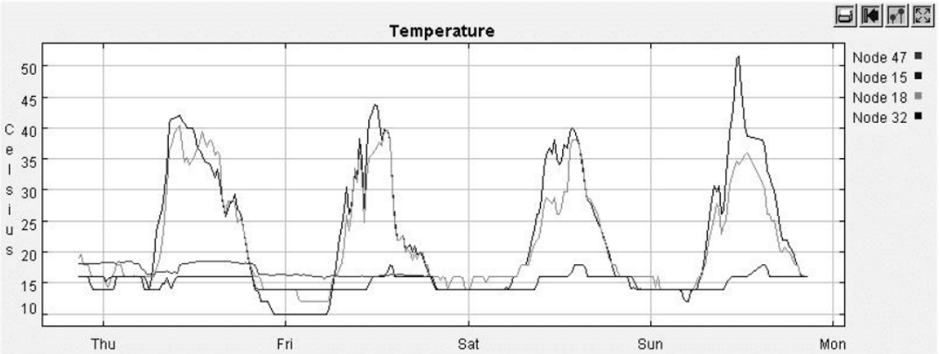
WLAN positioning system with densely deployed location aware nodes

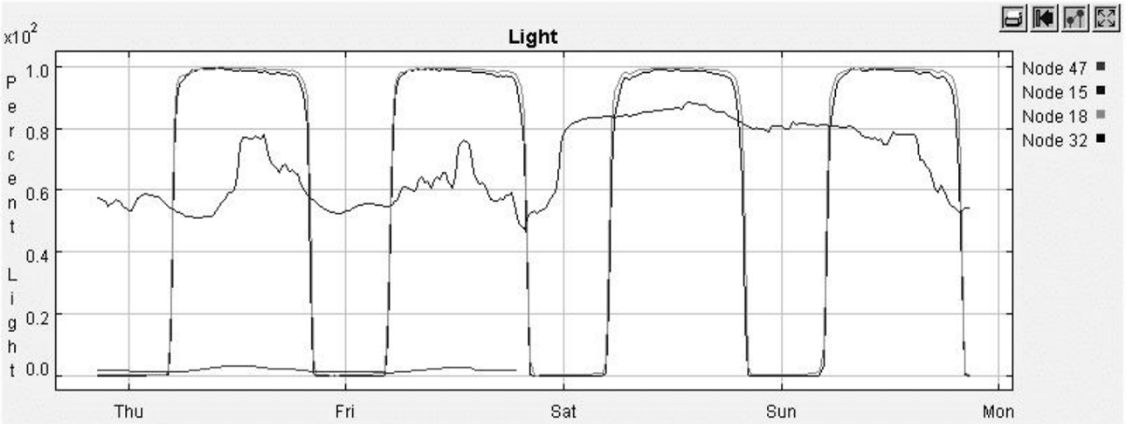


Application: Animal Monitoring (Great Duck Island)

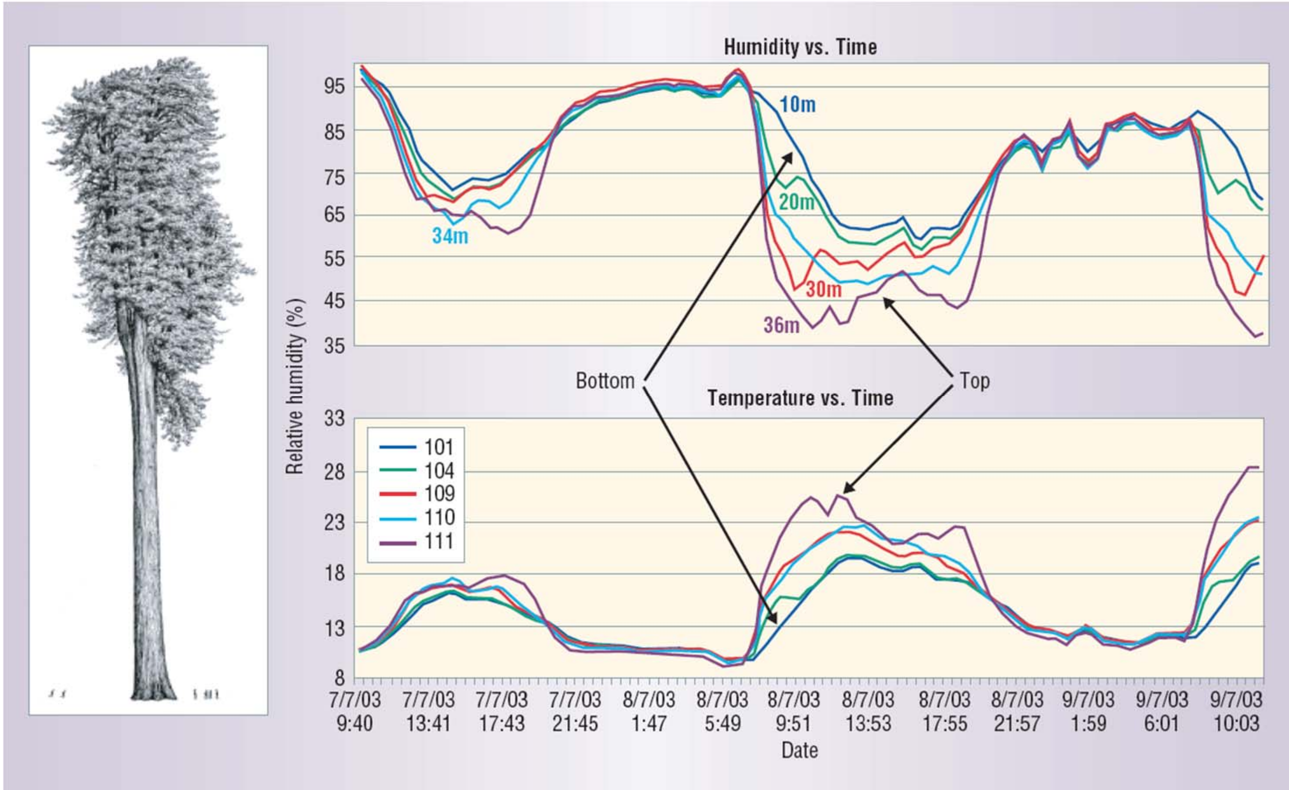


1. Biologists put sensors in underground nests of storm petrel (Sturmschwalbe)
2. Devices record data about birds
3. Transmit to research station via Com. devices on 10 cm stilts
4. Com. via satellite to lab





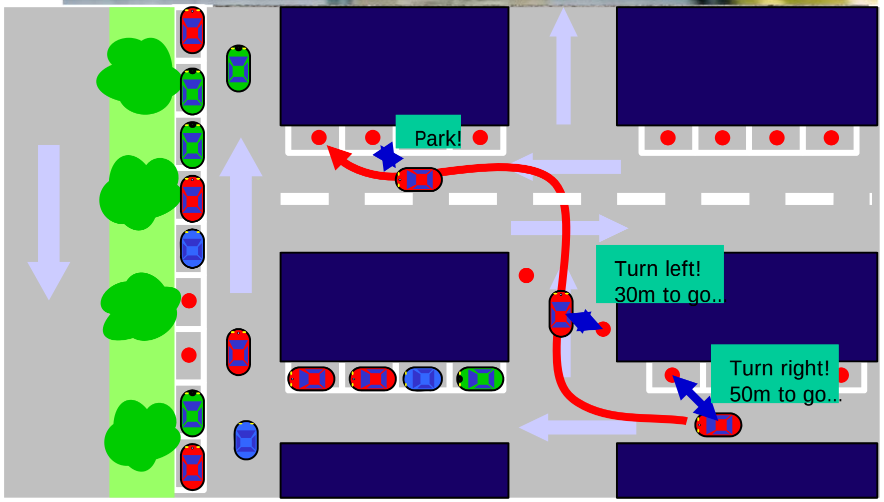
Application: Environmental Monitoring (Redwood Tree)



- Microclimate in a tree
- 10 km less cables on a tree; easier to set up
- Sensor Network = The New Microscope?

Application: Smart Spaces (Car Parking)

- The good: Guide cars towards empty spots
- The bad: Check which cars do not have any time remaining
- The ugly: Meter running out: take picture and send fine



[Matthias Grossglauser, EPFL & Nokia Research]

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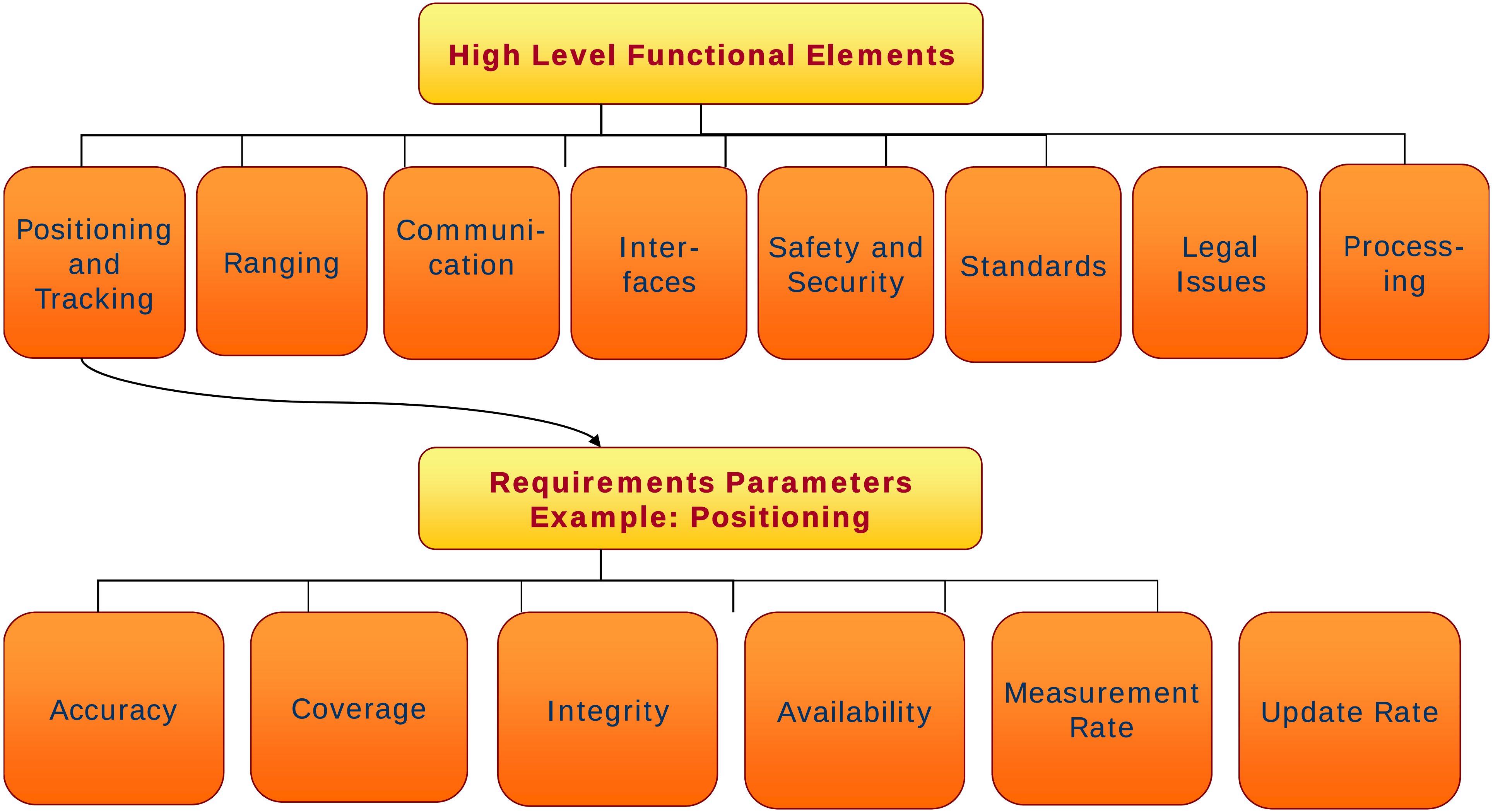
Application: Virtual Fence (CSIRO Australia)

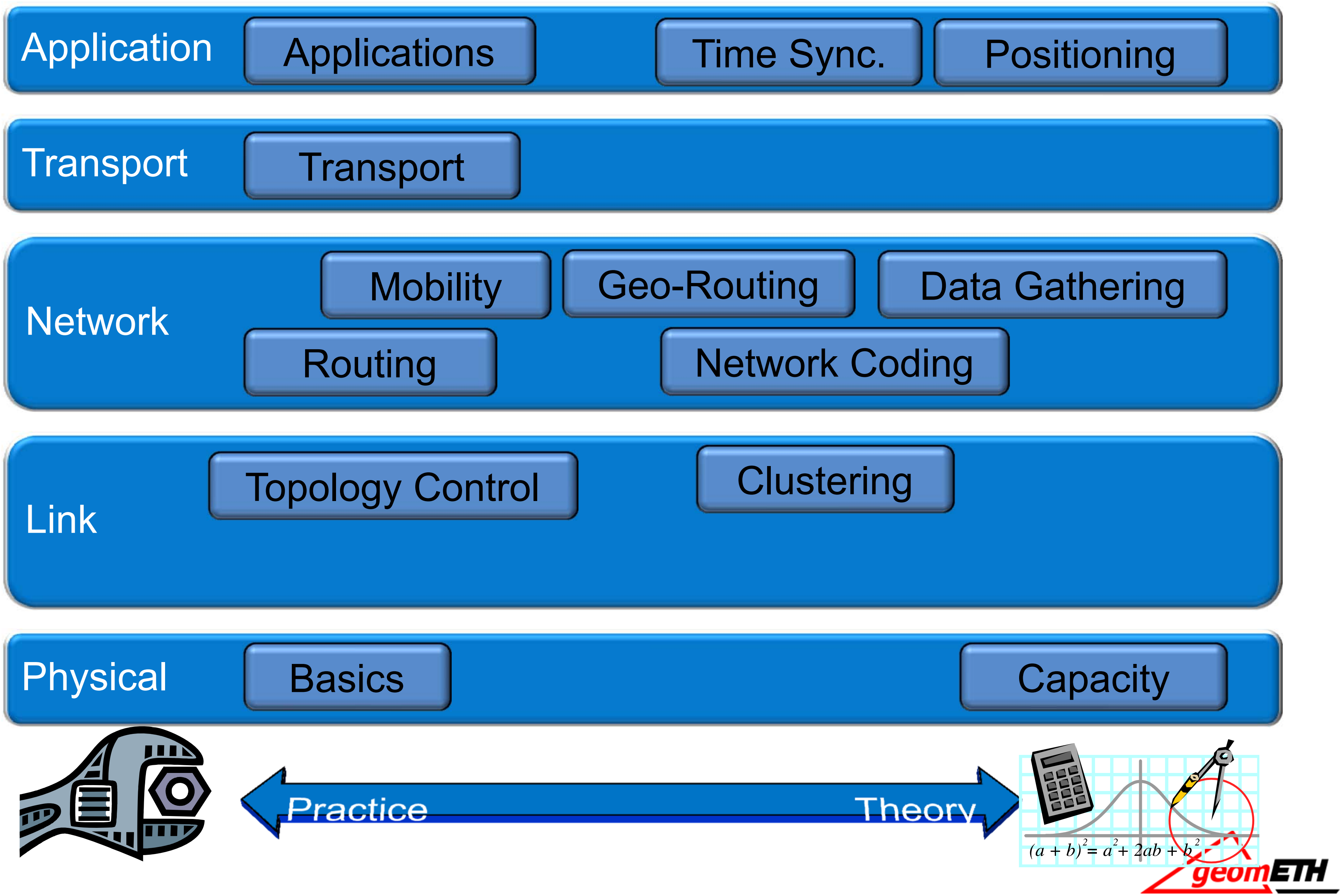
- Download the fence to the cows.
- software running on the collar triggers a stimulus chosen to scare the cow away

Virtual-livestock fence:
replacing wire with wire-less

Elements of a Sensor Network and User Requirements



Sensor Network Layers



3. Sensor Networks in Engineering Geodesy

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Swipos and Totalstations part of Sensor Networks?

swipos **AGNES** GNSS network: sensor density small, coverage huge
automatic **total station**: a 1-node network
relation to Geodesy: Positioning / Monitoring / Sensor Technology / Data Transfer / Adjustments

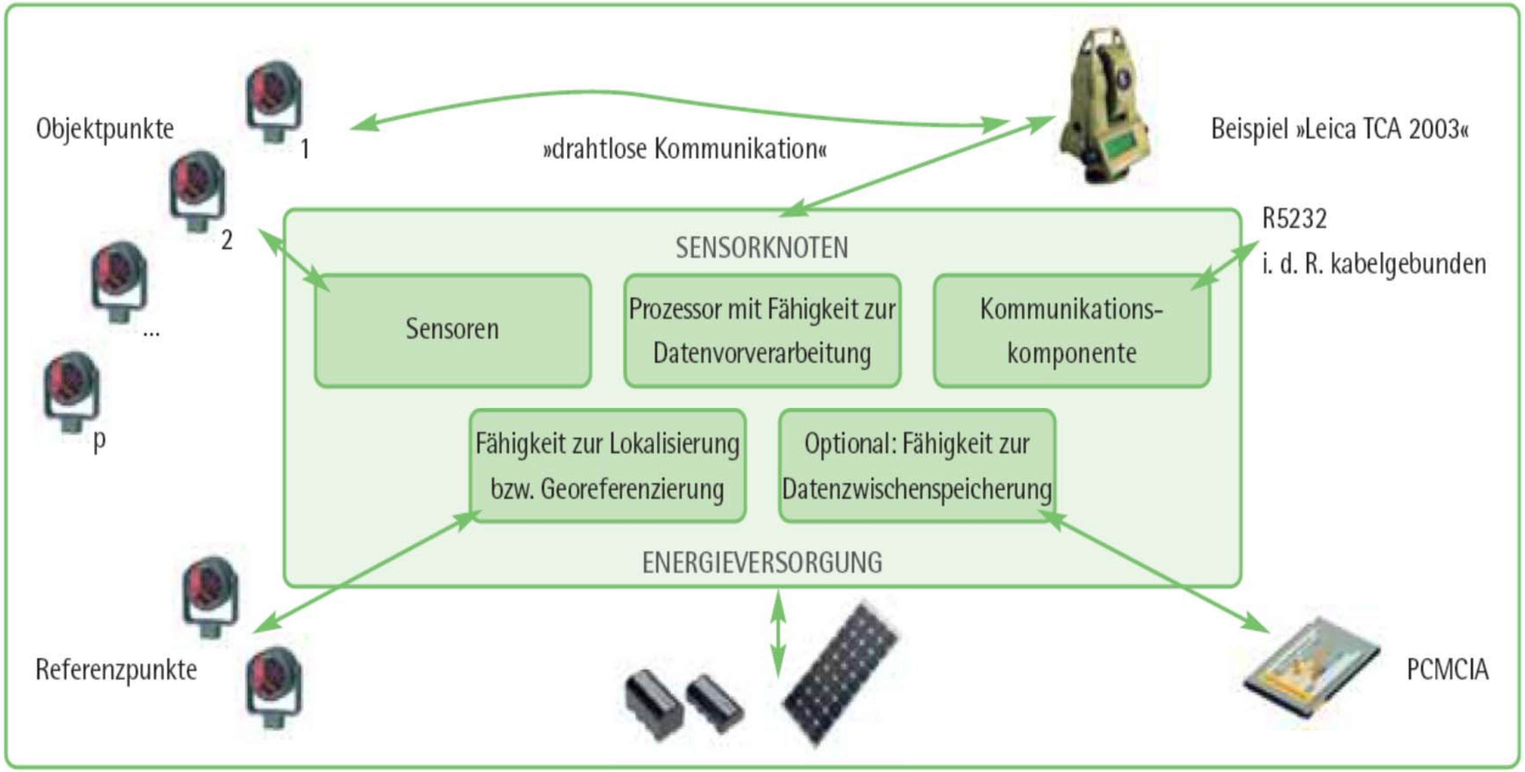

Abb. 3: Motorisiertes Tachymeter als Sensorknoten bei Überwachungsaufgaben

from: Heunecke, Geosensornetze im Umfeld der Ingenieurvermessung

Commercial Systems for Geodetic Monitoring

Software & Hardware Systems:

GeoMOS (Leica Geosystems)
GPSNet (Trimble)
DANA2000 (Furuno Electric)

– mostly tailored to sensors built by the company itself

+ good concept that includes:
  - data collection
  - data management
  - data analyses

Pure Software Systems:

GeoMonitor (Solexperts, www.solexperts.com, geomonitor.solexperts.com)
GNPOM (Geo++, www.geopp.de)
Monitor/GOCA (Trimble GeoNav GmbH)

Difference between general Sensor Networks and those used in Engineering Geodesy: application and technical solution. Concept remains the same.

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Sensors used in Engineering Geodesy Networks

1. optical sensors (motorised total station, digital level)
2. GNSS sensors (that allow phase measurements)
3. geotechnical sensors (relative measurements using extensometer, inclinometer, plumbing, DMS, hydrostatic levelling)
4. meteo sensors (thermometer, pressure sensor, air moisture sensor)

key aspects & issues:

- physical dimensions of the sensor (size, weight)
- additional devices for data collection
- format of generated data
- measurement rate
- connection to computer network
- electrical power consumption and voltage
- price

1. optical sensors – motorised total stations

Leica TPS1200	Leica TM 30	Leica TPS2000	Trimble S6/8
			

not yet specialised for that purpose (still can be used manually)
problems: sensitive electronic, optical sight (fog), price, need for prisms

1. optical sensors – motorised total stations

Mt.Terri Felslabor - Messeinsatz – Stephan Schütz

Sensors used in Engineering Geodesy Networks

1. optical sensors – digital levels

Leica DNA03	Leica NA3000	Trimble DiNi12	Zeiss DiNi10 in Sonderausführung der Firma SOLEXPERTS
			

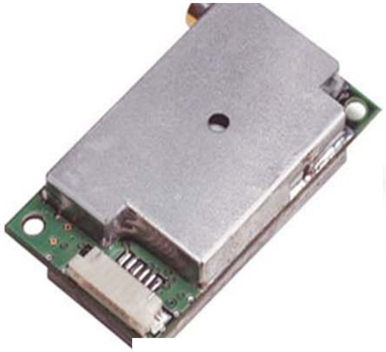
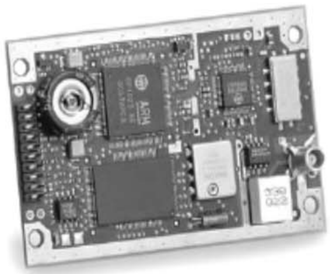
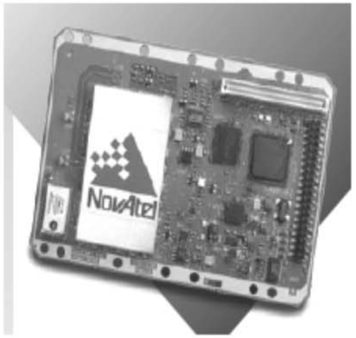
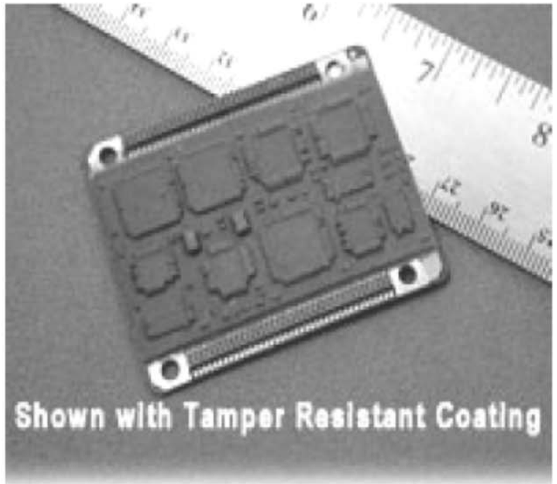
- restricted to 40 m and horizontal views
- restricted to monitor a single staff

2. GNSS sensors – handheld & geodetic receivers

Garmin etrex	Magellan Triton 2000	Leica System 1200	Trimble 5600
			

- for use in geo sensor networks: L1& L2, phase measurements, DGPS
- GPS used for time synchronisation

2. GNSS sensors – OEM-Boards (Original Equipment Manufacturer)

Garmin GPS 15^{TM}	NovAtel Superstar II	NovAtel OEM4	Trimble SAASM Mod 21
 43.50 $ US			

- receivers better suited for monitoring: low power 6 - 30V, 0.2 watts
- like a PC card, without antenna, data and power interfaces
- cheap "GPS chips" not sufficient for precise DGPS & phase measurements
  → requirement for high computing power

3. Geotechnical Sensors

Gloetzl Loggingeinheit MFF2-12	Gloetzl Schlauchwaage GHD	Gloetzl Stangenextensometer GWW 30/40
		

- only one-dimensional, mostly local, relative measurements
- high effort for installation (cables, adaption to the object, e.g. plumbing shafts, inclinometer pipes)
- analogue signals → A/D converter, logging unit

4. Meteorological Sensors

Meteo-Station WS-2308:

T, p, wind direction, wind speed, participation,
time reference: DCF-77 Mainflingen

important for correction of other sensors

5. Digital Cameras

IP-Camera NC 1000-W10:

- detection of movements,
- usable in the night
- WLAN capability
- detection of sounds

IP-camera has its own IP-address. It can be used as a webcam that does not require a direct connection to a computer

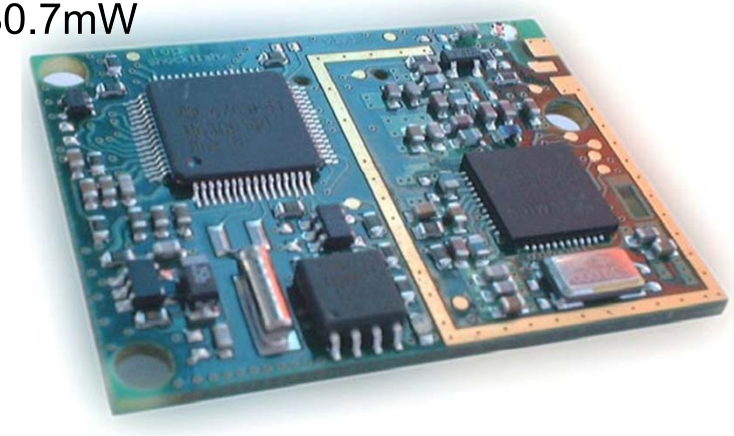
Cameras will play a more important role!

4. Sensor Networks Communication

A Typical Sensor Node: TinyNode 584

- TI MSP430F1611 microcontroller @ 8 MHz
- 10k SRAM, 48k flash (code), 512k serial storage
- 868 MHz Xemics XE1205 multi channel radio
- Up to 115 kbps data rate, 200m outdoor range

	Current Draw	Power Consumption
sleep mode with timer on	6.5 µA	0.0195 mW
active, radio off	2.1 mA	6.3 mW
active, radio idle listening	16 mA	48 mW
active, radio TX/RX at +12dBm	62 mA	186 mW
Max. Power (uC active, radio TX/RX at +12dBm + flash write)	76.9 mA	230.7mW



Hardware Future Trends

- Hitachi μ-Chip
- No sensors
- Only passive transponder (RFID)
- Size: 0.4 · 0.4 mm

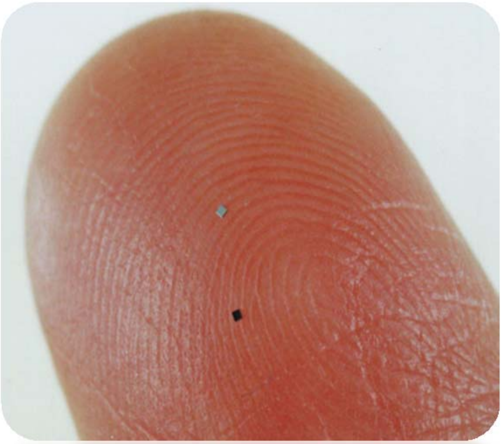


Photo: Hitachi

- SPEC
- Active Node
- μC, 3K RAM, 8 bit ADC
- Proper communication
- Size: 2.0 · 2.5 mm

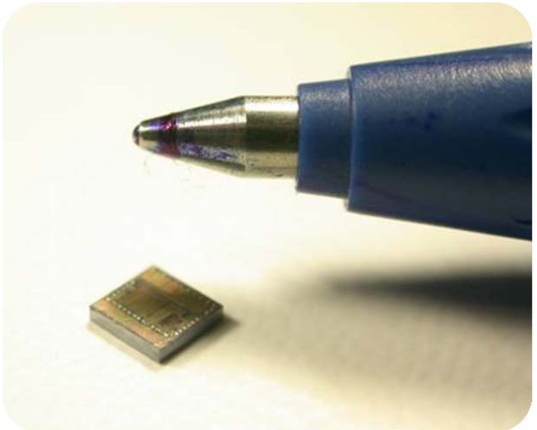
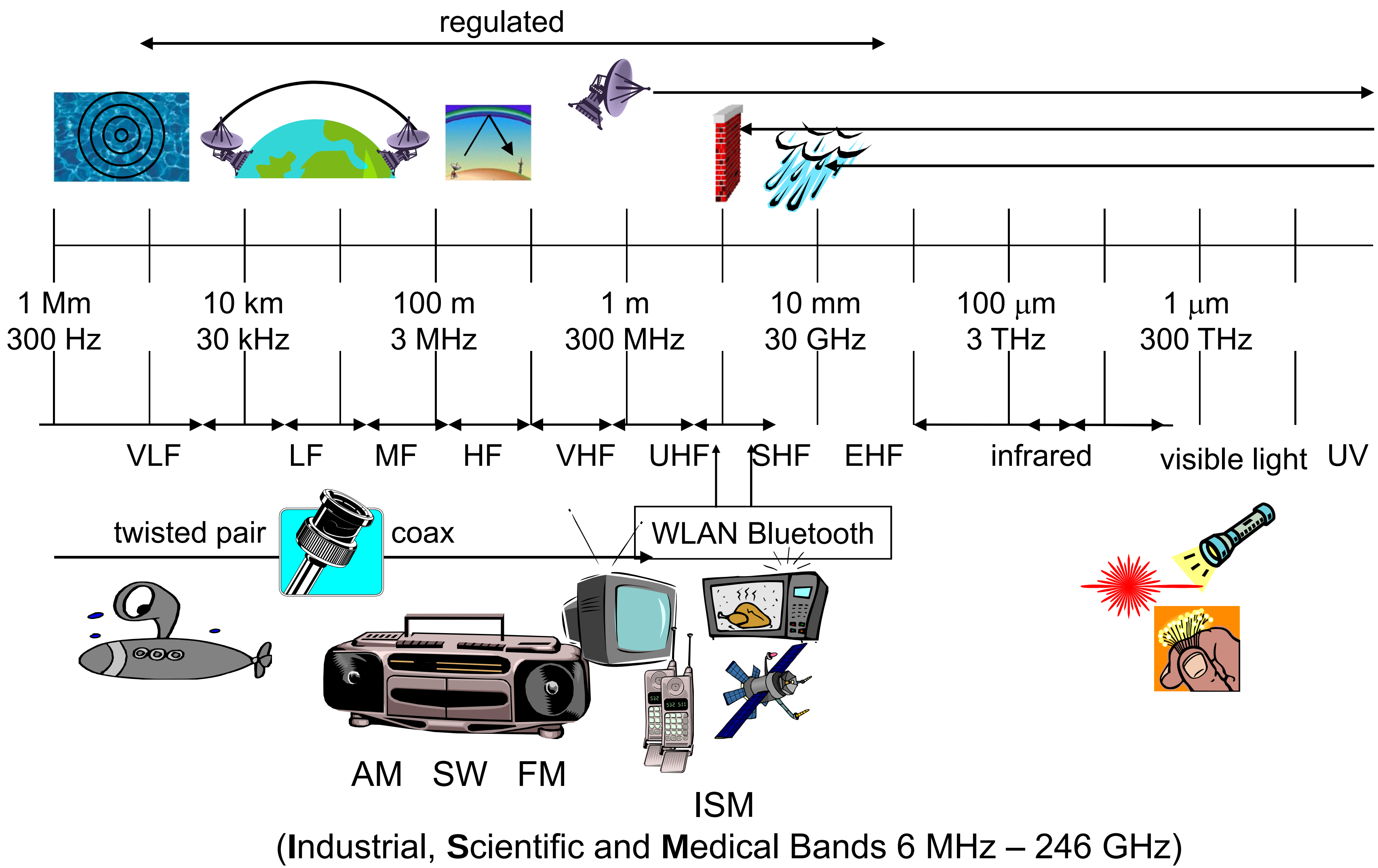


Photo: Jason Hill, UCB

- Golem Dust
- Bidirectional communication
- Solar powered
- Size: 11.7 mm^3

Photo: UCB

Physical Layer: Wireless Frequencies



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Data Transmission by Cables

- Wires

  + simple, cheap, allows power supply via wire

  – not protected against lightning, inductive influences

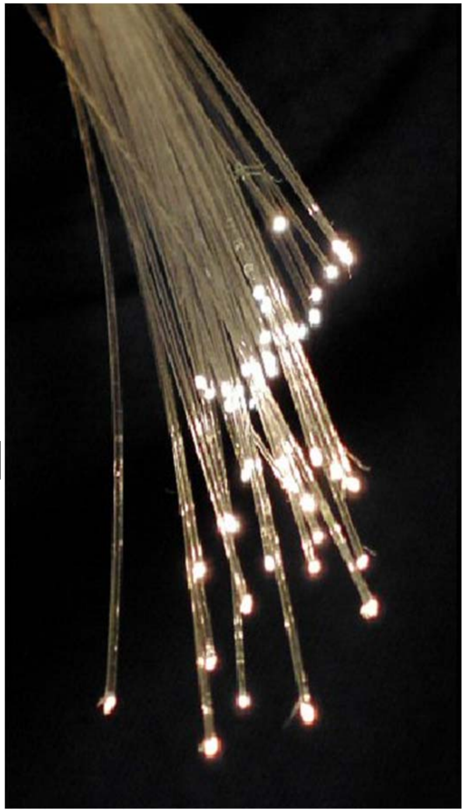
- Optical Fibre

  + transformation of electrical signals into electro optical

  + protected against electrical influences

  + attenuation smaller than electrical cables

  – costs



Principle:

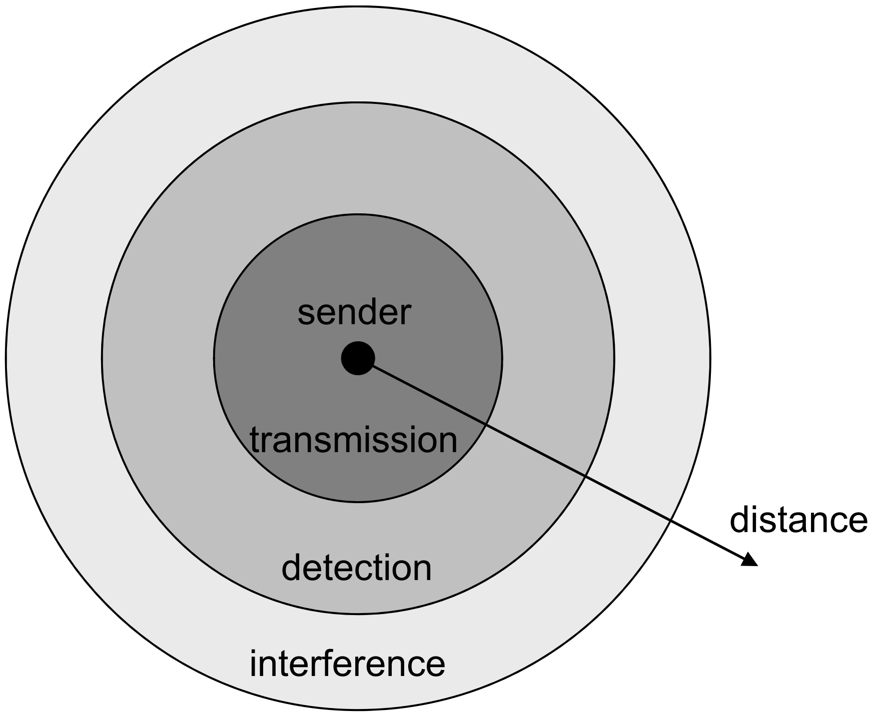
total internal reflection

Application:

optic sensors,
illumination,
communication

Signal propagation ranges, a simplified model

- Propagation in free space always in straight lines
- Transmission range
  - communication possible
  - low error rate
- Detection range
  - detection of the signal possible
  - no communication possible
- Interference range
  - signal may not be detected
  - signal adds to the background noise



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Signal propagation, more accurate models

- Free space propagation $$P_r = \frac{P_s G_s G_r \lambda^2}{(4\text{¼})^2 d^2 L}$$

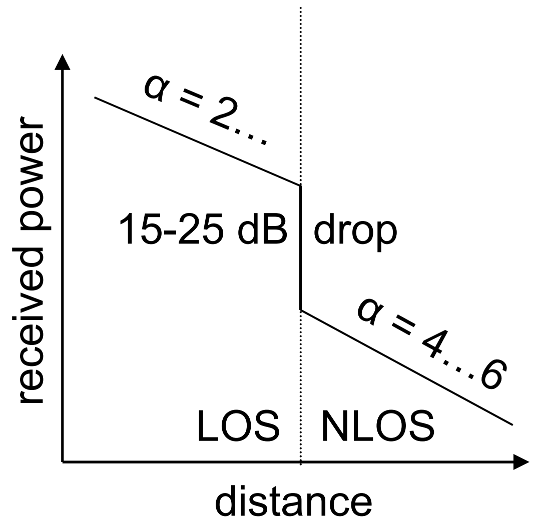
- P_s, P_r: Power of radio signal of sender resp. receiver
- G_s, G_r: Antenna gain of sender resp. receiver (how sensitive is antenna)
- d: Distance between sender and receiver
- L: System loss factor ($L > 1$)
- λ: Wavelength of signal in meters

- Plus, in practice, received power is not constant („fading“)

Attenuation by distance

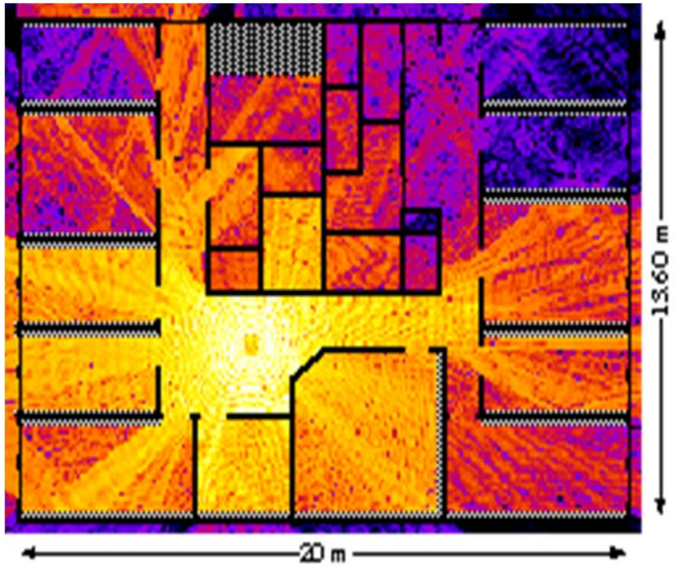
- Attenuation [dB] = 10 log10 (transmitted power / received power)
- Example: factor 2 loss = 10 log10 2 ≈ 3 dB

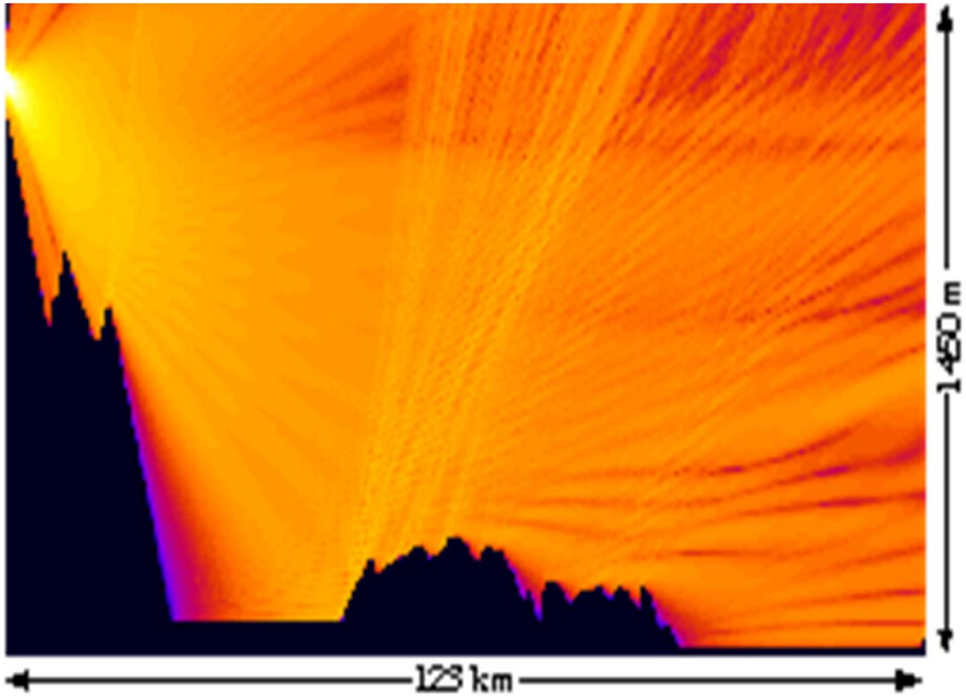
- In theory/vacuum (and for short distances), receiving power is proportional to 1/d2, where d is the distance.
- In practice (for long distances), receiving power is proportional to 1/dα, α = 4…6. We call α the path loss exponent.

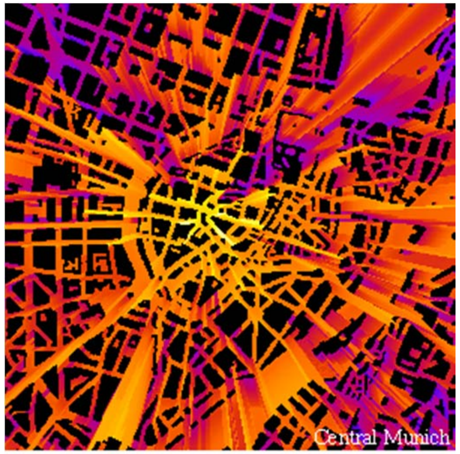


- Example: Short distance, what is the attenuation between 10 and 100 meters distance?
  Factor 100 (=1002/102) loss = 20 dB

Real World Examples

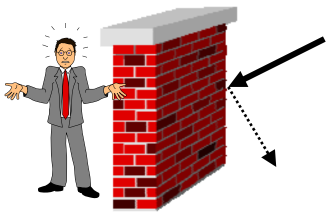




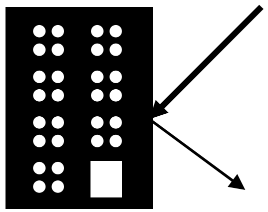


Attenuation by objects

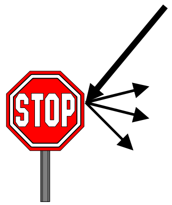
- Shadowing (3-30 dB):
  - textile (3 dB)
  - concrete walls (13-20 dB)
  - floors (20-30 dB)
- reflection at large obstacles
- scattering at small obstacles
- diffraction at edges
- fading (frequency dependent)



shadowing



reflection

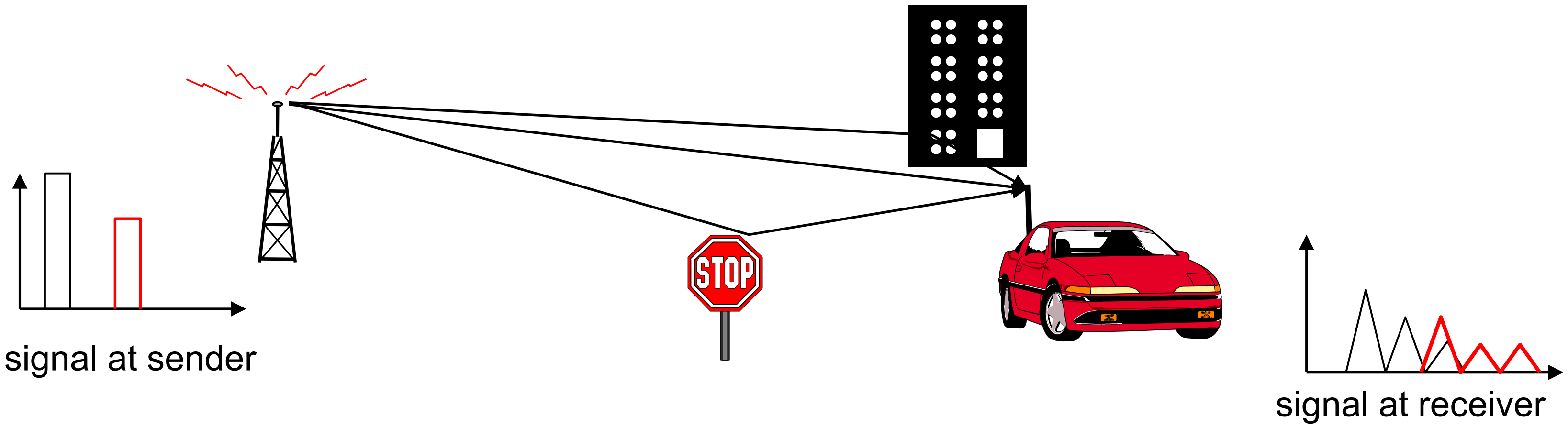


scattering

diffraction

Multipath propagation

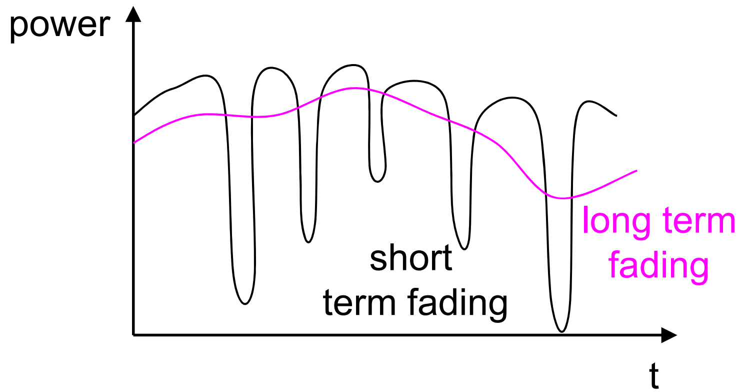
- Signal can take many different paths between sender and receiver due to reflection, scattering, diffraction



- Time dispersion: signal is dispersed over time
- Interference with “neighbor” symbols
- The signal reaches a receiver directly and phase shifted
- Distorted signal depending on the phases of the different parts

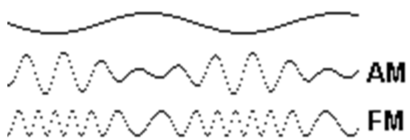
- Channel characteristics change over time and location
  - signal paths change
  - different delay variations of different signal parts
  - different phases of signal parts
- quick changes in power received (short term fading)

- Additional changes by
  - distance to sender
  - obstacles further away
- slow changes in average power received (long term fading)



- Doppler shift: Random frequency modulation

- Modulation in action:



Time Synchronization

- Time synchronization is essential
  - Coordination of wake-up and sleeping times (energy efficiency)
  - TDMA (time division multiple access) schedules
  - Ordering of collected sensor data/events
  - Co-operation of multiple sensor nodes
  - Estimation of range / position information

- Goal of clock synchronization
  - Compensate *offset* between clocks
  - Compensate *drift* between clocks

- External versus internal synchronization

External sync: Nodes synchronize with an external clock source (UTC)
Internal sync: Nodes synchronize to a common time to a leader, to an averaged time, or to anything else

Clock Sources

Radio Clock Signal:

- Clock signal from a reference source (atomic clock) is transmitted over a longwave radio signal
- DCF77 station near Frankfurt, Germany transmits at 77.5 kHz with a transmission range of up to 2000 km
- Accuracy limited by the distance to the sender, Frankfurt-Zurich is about 1ms.

- Global Positioning System (GPS):
  - Satellites continuously transmit own position and time code
  - Line of sight between satellite and receiver required
  - Special antenna/receiver hardware required

Clock Devices in Sensor Nodes

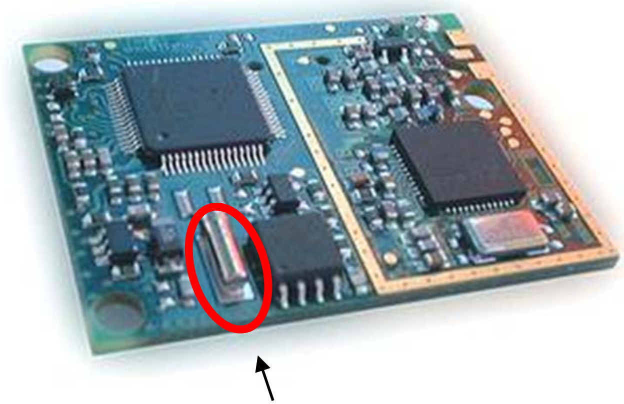
Structure

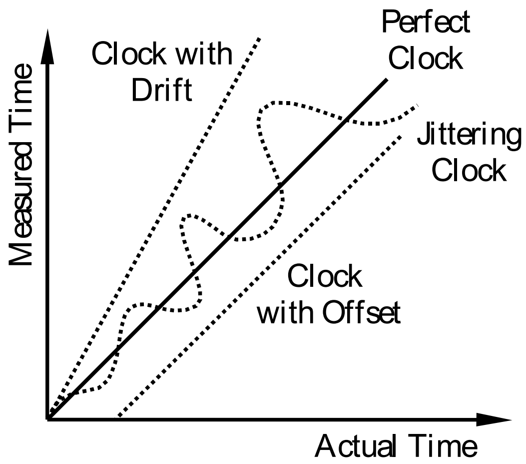
- External oscillator with a nominal frequency (e.g. 32 kHz)
- Counter register which is incremented with oscillator pulses
- Works also when CPU is in sleep state

Accuracy

- Clock drift: random deviation from the nominal rate dependent on power supply, temperature, etc.
- E.g. TinyNodes have a maximum drift of 30-50 ppm at room temperature

This causes a drift of up to 50 µs per second or 0.18s per hour





5. Sensor Networks Routing

- What is Routing?
- „Routing is the act of moving information across a network from a source to a destination.“ (CISCO)

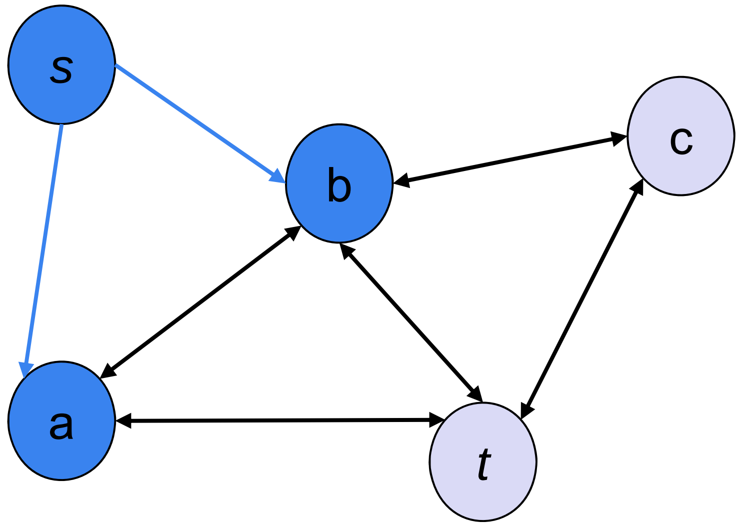
- The simplest form of routing is “flooding”: a source *s* sends the message to all its neighbors; when a node other than destination *t* receives the message the first time it re-sends it to all its neighbors.

\+ simple (sequence numbers)

– a node might see the same message more than once. (How often?)

– what if the network is huge but the target *t* sits just next to the source *s*?

→ We need a smarter routing algorithm



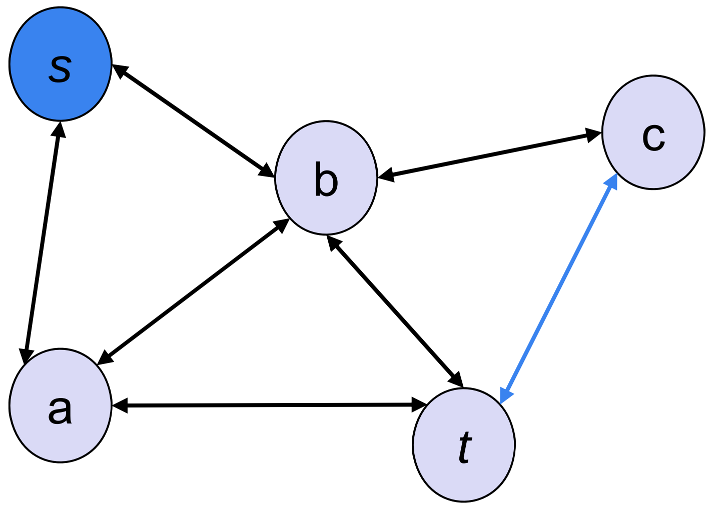
- Link-state routing protocols are used in the Internet

- Idea: periodic notification of all nodes about the complete graph
- Routers then forward a message along (for example) the shortest path in the graph

\+ message follows shortest path

– every node needs to store whole graph,

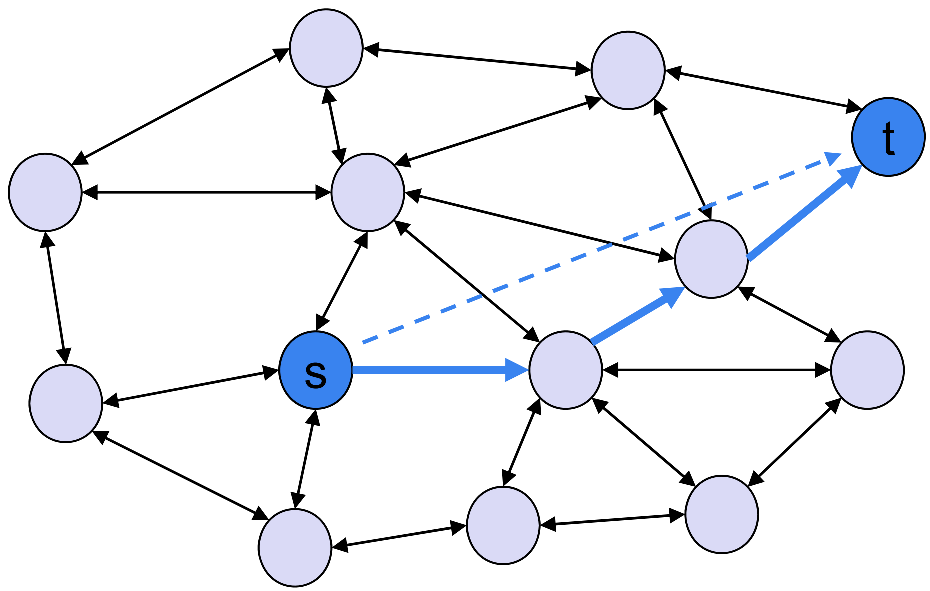
– every node needs to send and receive messages that describe the whole graph regularly



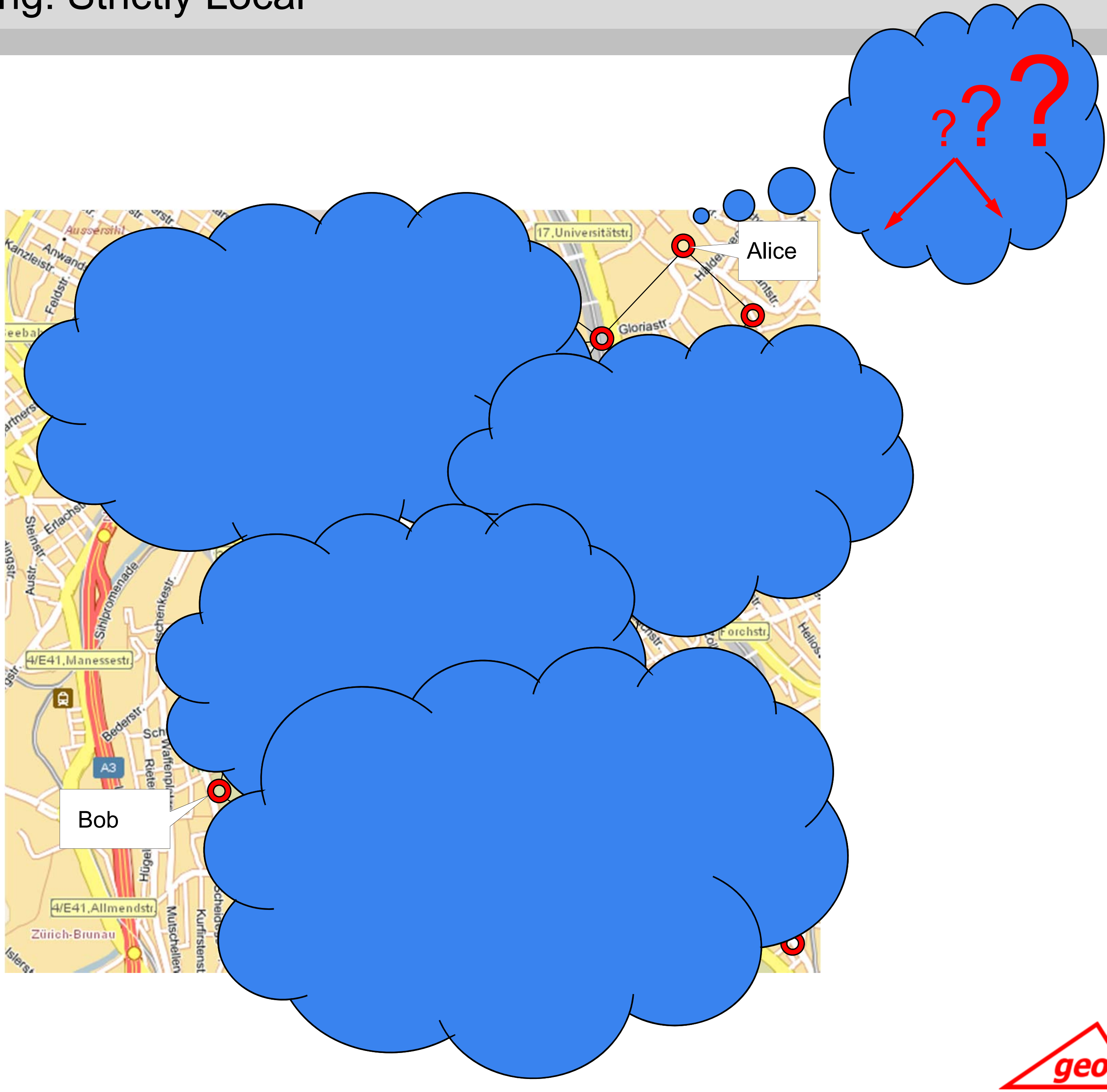
- Assumption that the nodes are location aware (they have GNSS, or an ad-hoc way to figure out their coordinates), and that we know where the destination is.

- Then we simply route towards the destination

➢ Problem: What if there is no path in the right direction?

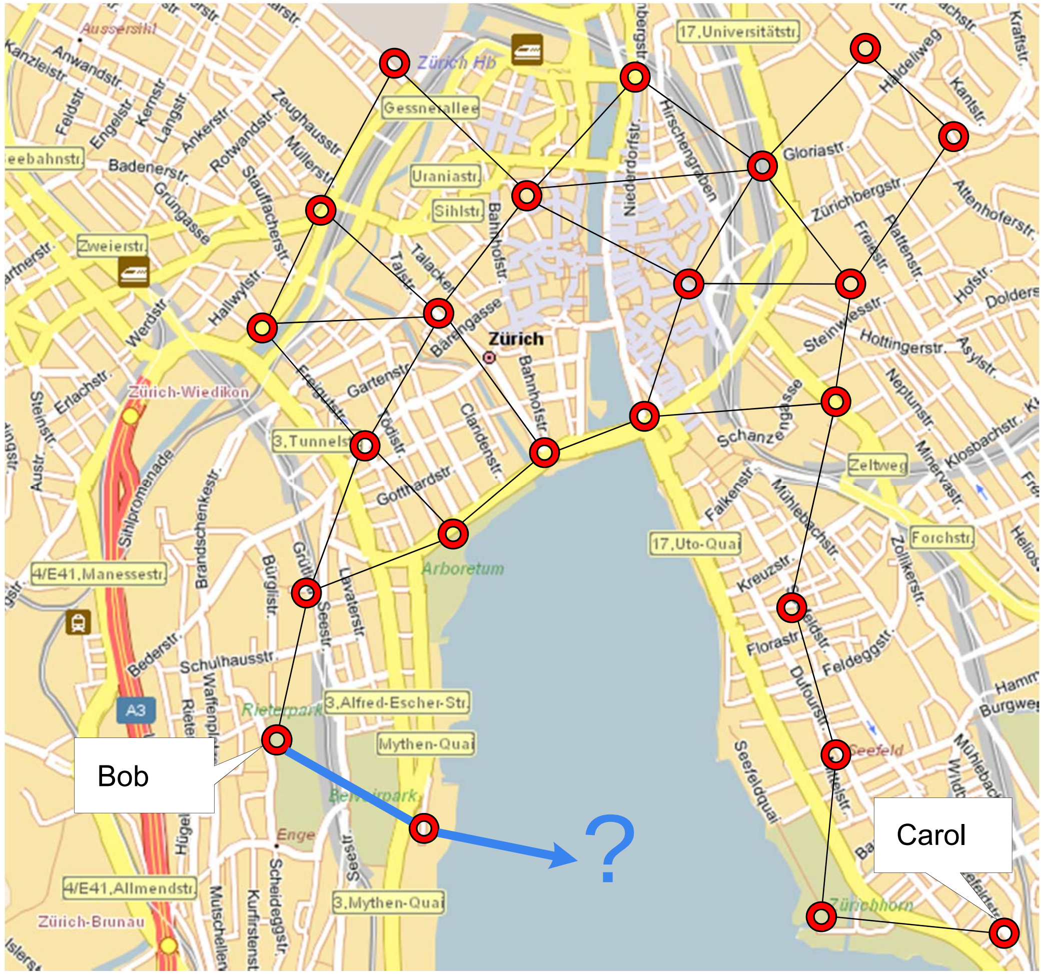


Geo-Routing: Strictly Local



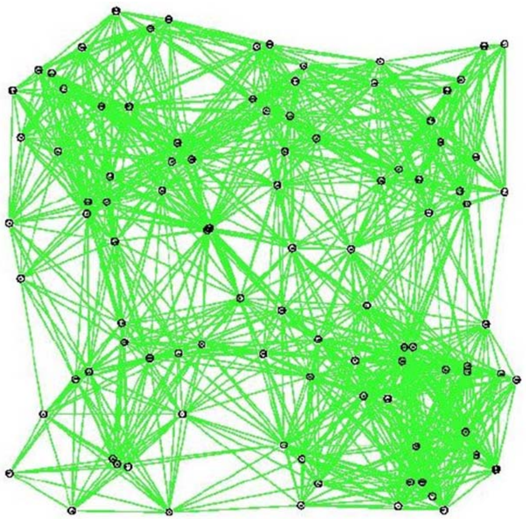
Greedy Geo-Routing?

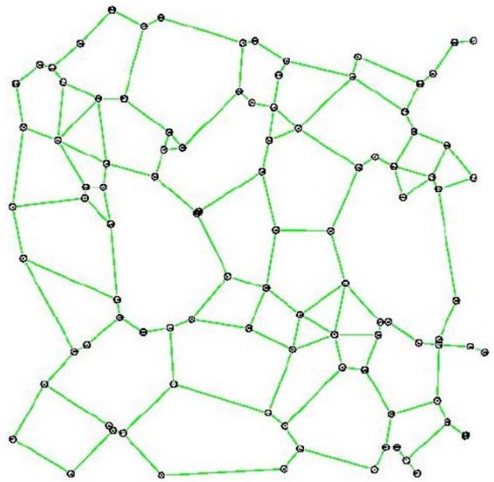
Greedy Geo-Routing?



Idea: Use Euclidean and Planar Graphs

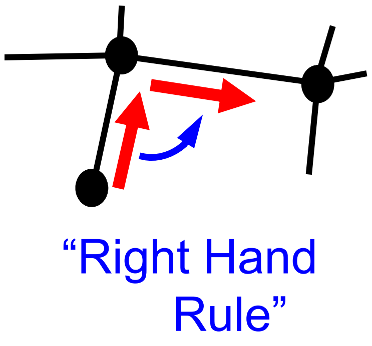
- Planar: can be drawn without “edge crossings” in a plane

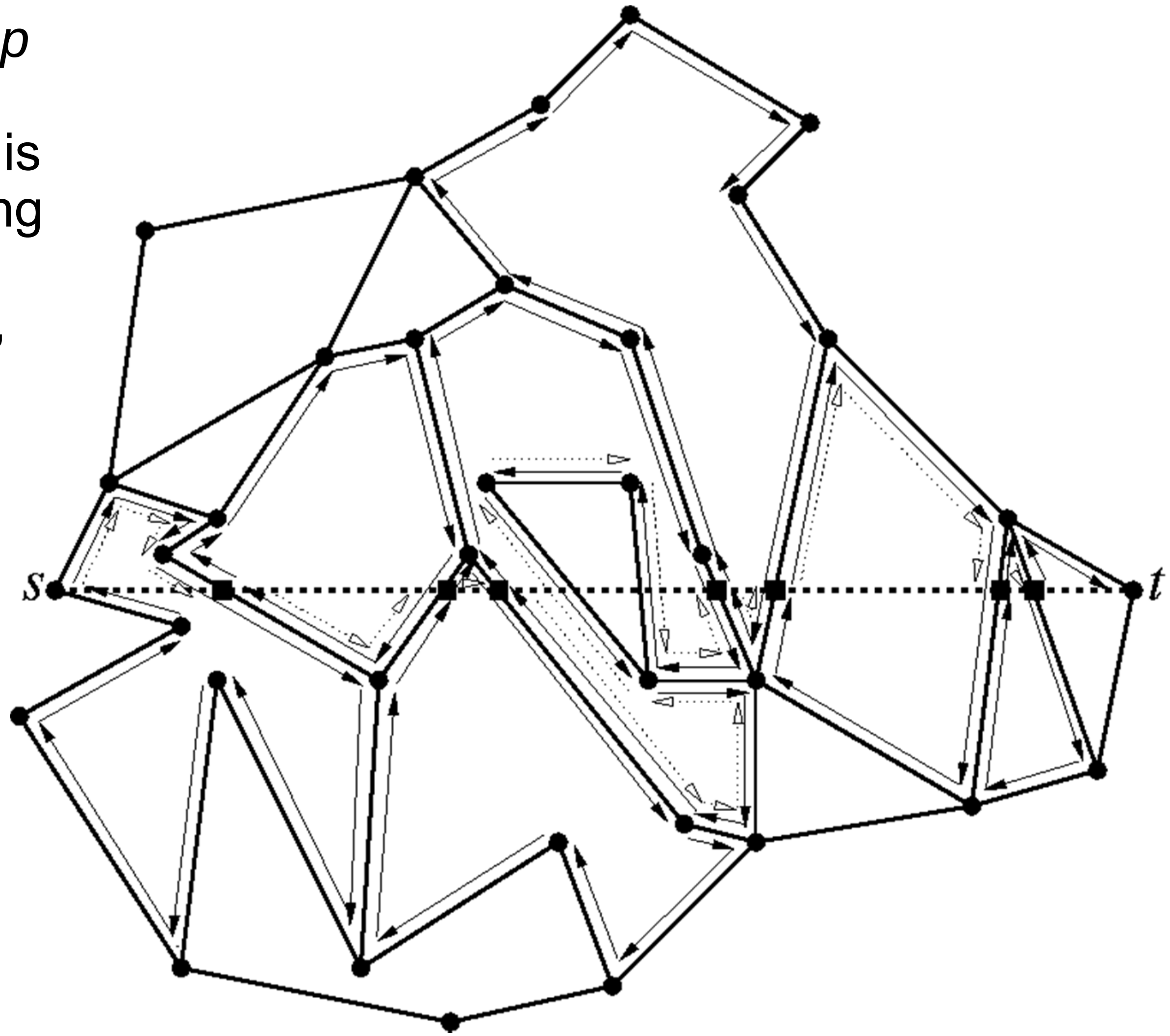




- A planar graph drawn in the plane without edge intersections is called a plane graph.

Explore the boundary of a face; remember the point *p* where the boundary intersects with (*s*,*t*) which is nearest to *t*; after traversing the whole boundary, go back to p, switch the face, and continue until you hit destination *t*.

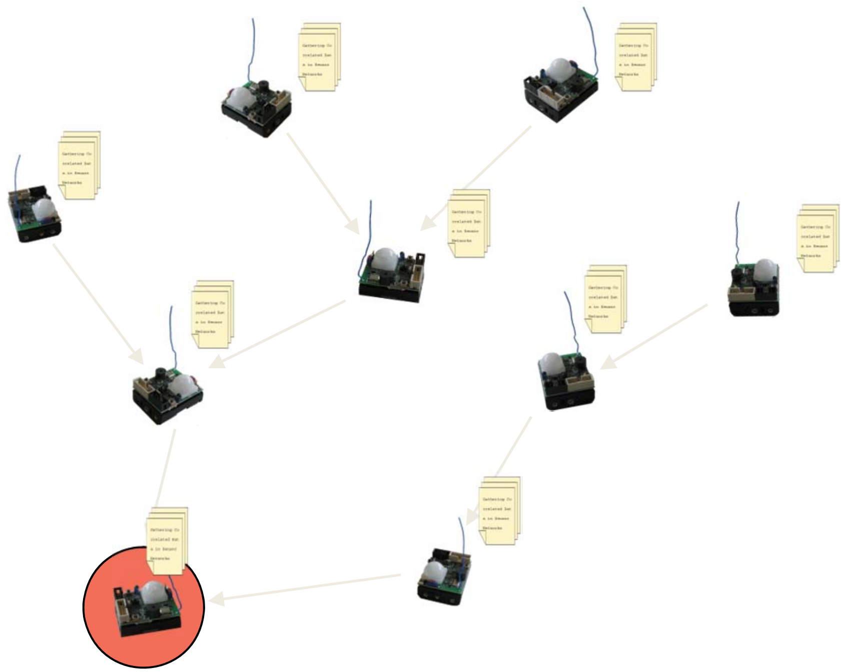




Data Gathering

Sensor Node Requirements:

- Monitoring geodata
- Unattended operation
- Long battery lifetime



All nodes produce relevant information about their vicinity periodically.

Data is conveyed to an information sink for further processing.

- Variants
  - continuous data gathering
  - on request
  - on event

➢ optimization: If the sensed data of a node changes not too often (e.g. temperature), the node only needs to send a new message when its data values (significantly) change.

➢ Improvement: Only send change of data, not actual data (similar to videos)

6. Sensor Networks Positioning

- Sensor nodes without position information is often meaningless
- Why not GPS (or Galileo)?
  - Heavy, large (now solved) and expe
  - Battery drain
  - Not indoors

Example u-blox: 4x4 mm, 50 mW, 4 Hz

- Solution: equip small fraction with GPS (anchors)
- A lot of recent progress, GPS is definitely becoming more attractive

GNSS Attenuation of building materials (L1 = 1500 MHz)

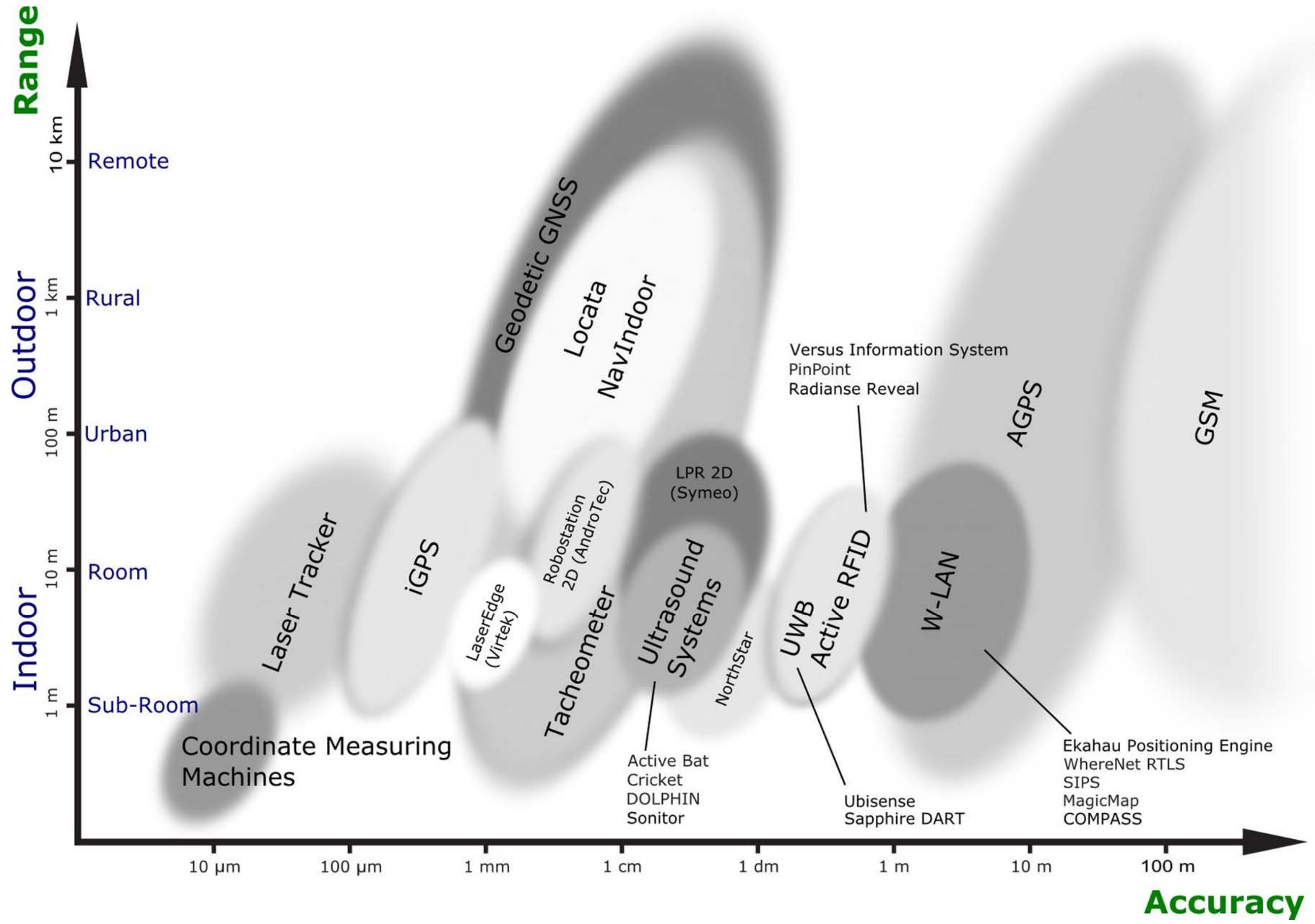
Material	[dB]	Factor [-]
Glass	1 - 4	0.8 – 0.4
Painted Glass	10	0.1
Wood	2 - 9	0.6 – 0.1
Roofing Tiles / Bricks	5 - 31	0.3 – 0.001
Concrete	12 - 43	0.06 – 0.00005
Ferro-Concrete	29 - 33	0.001 – 0.0005

Stone (1997)

Signal Strength in Decibel Watt of GNSS Satellites

Environment	[dBW]	
Satellite	+14	signal strength delivered from satellite
Outdoors	-155	unaided fixes OK for standard receivers
Indoors	-176	decode limit for high sensitive receivers
Underground	-191	decode limit for aided, ultra-high sensitive receivers

Positioning Systems



Positioning (a.k.a. Localization)

- Task: Given distance or angle measurements or mere connectivity information, find the locations of the sensors

- Anchor-based
  - Some nodes know their locations, either by a GPS or as pre-specified.
- Anchor-free
  - Relative location only. Sometimes called virtual coordinates.
  - Theoretically cleaner model (less parameters, such as anchor density)

- Range-based
  - Use range information (distance or angle estimation).
- Range-free
  - No distance estimation, use connectivity information such as hop count.
  - It was shown that bad measurements don't help a lot anyway.

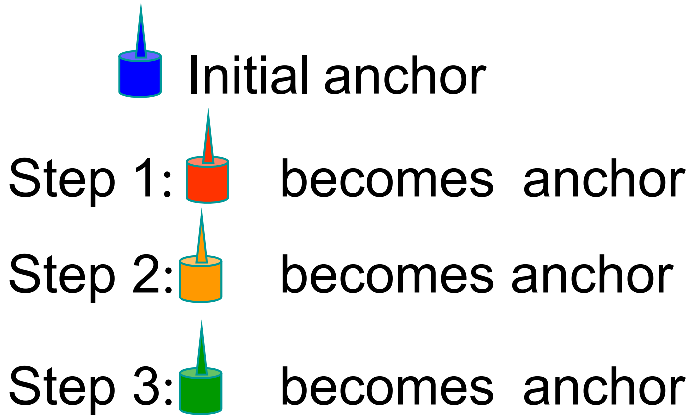
Angle estimation

- Angle of Arrival (AoA)
  - Determining the direction of propagation of a radio-frequency wave incident on an antenna array.

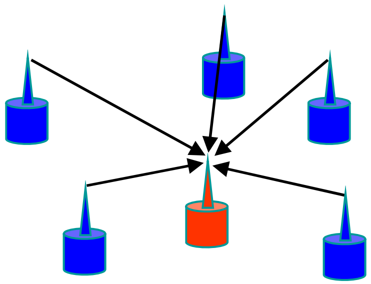
Distance estimation

- Received Signal Strength Indicator (RSSI)
  - The further away, the weaker the received signal.
  - Mainly used for RF signals.
- Time of Arrival (ToA) or Time Difference of Arrival (TDoA)
  - Signal propagation time translates to distance.
  - RF, acoustic, infrared and ultrasound.

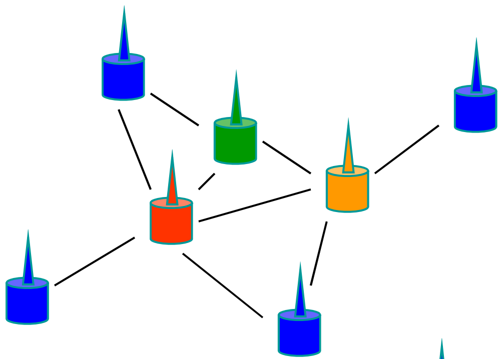
Lateration Methods



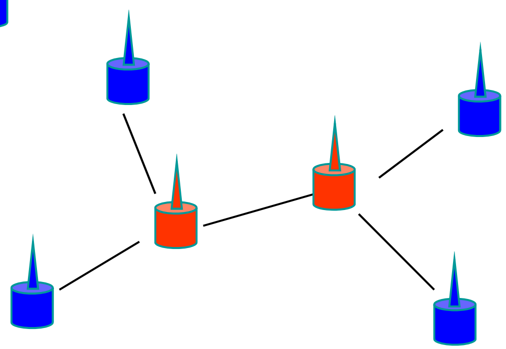
Multilateration:



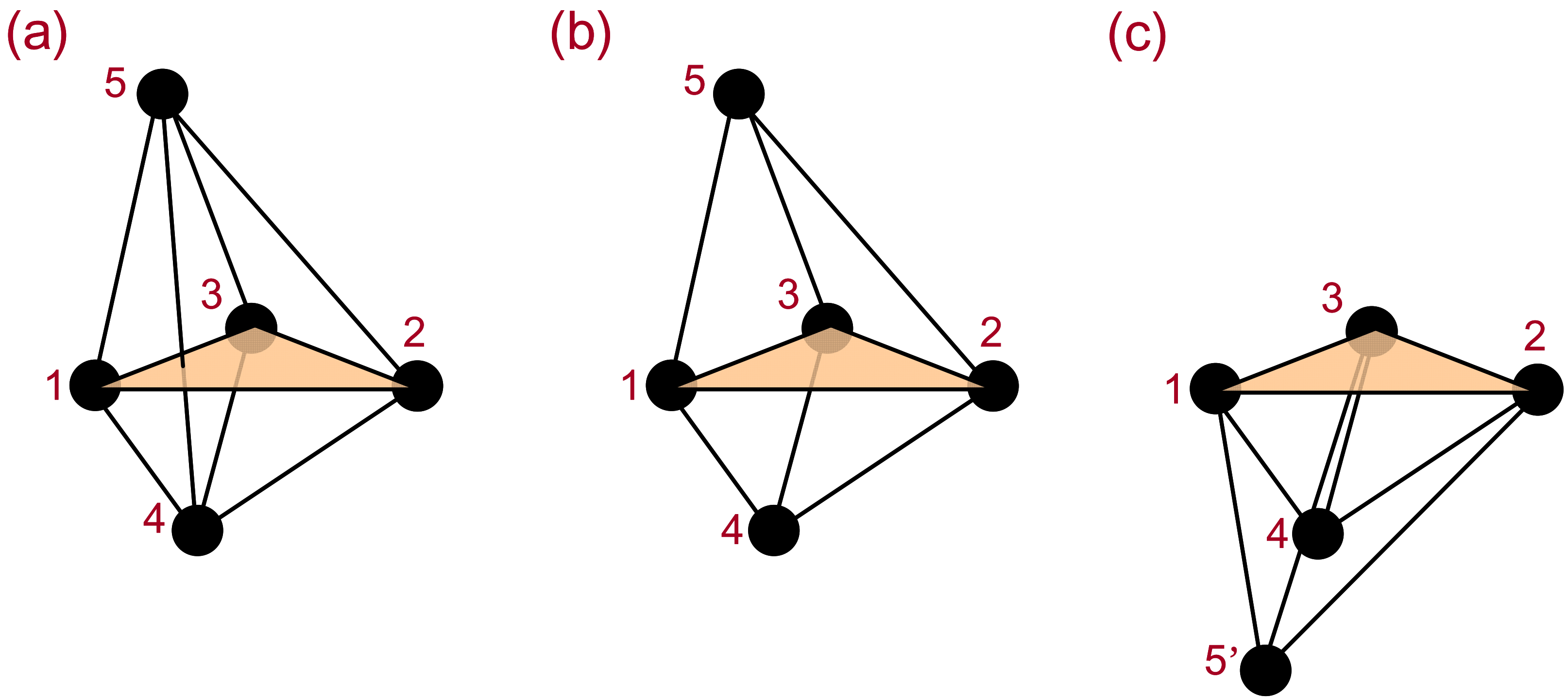
Iterative Multilateration:



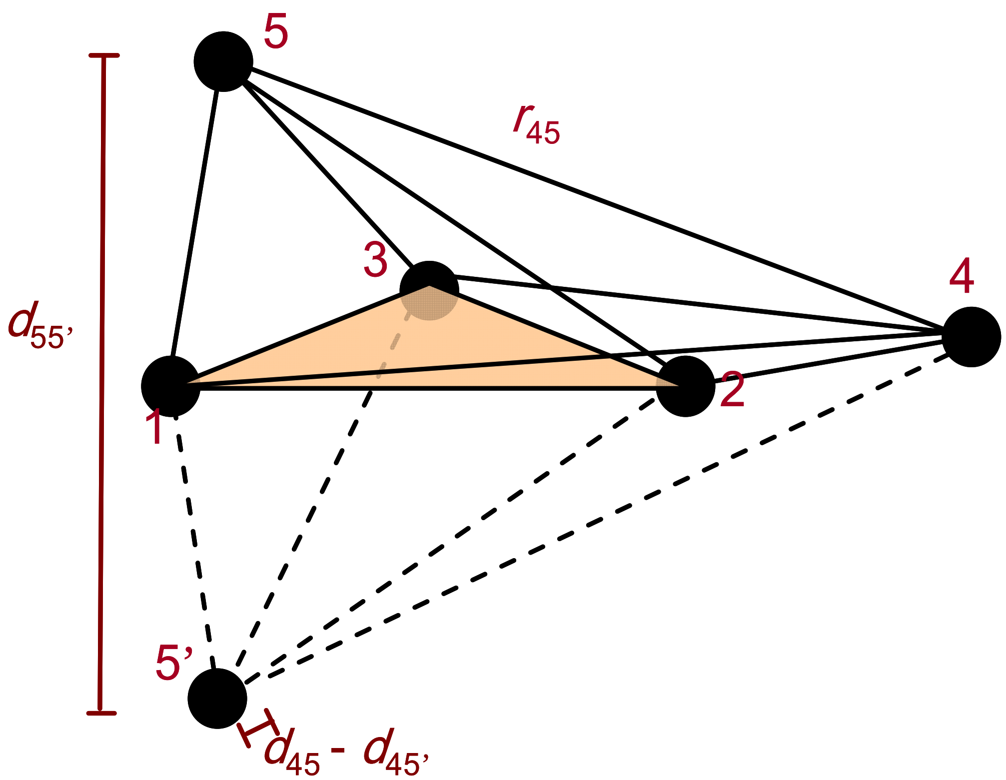
Collaborative (n-hop) Multilateration:



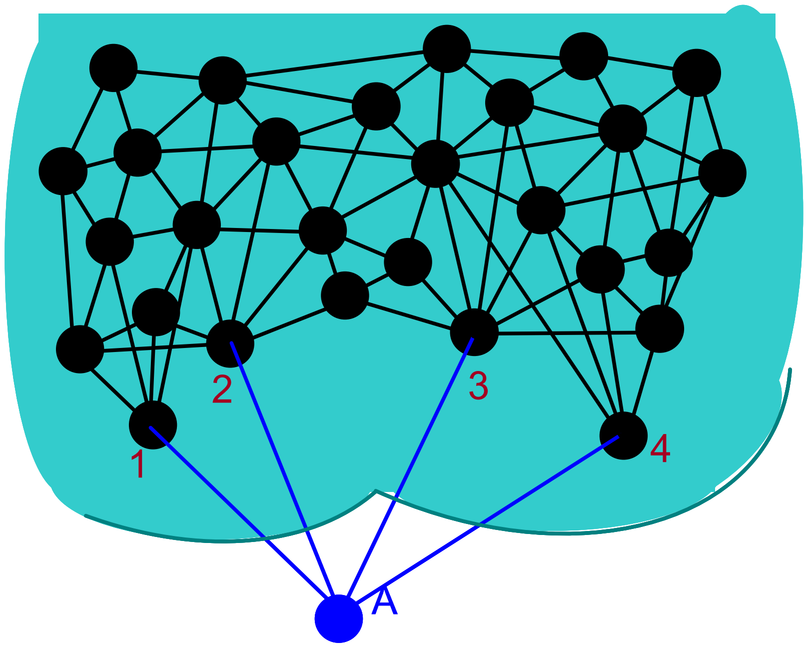
Ambiguity problem when creating the smallest rigid structure

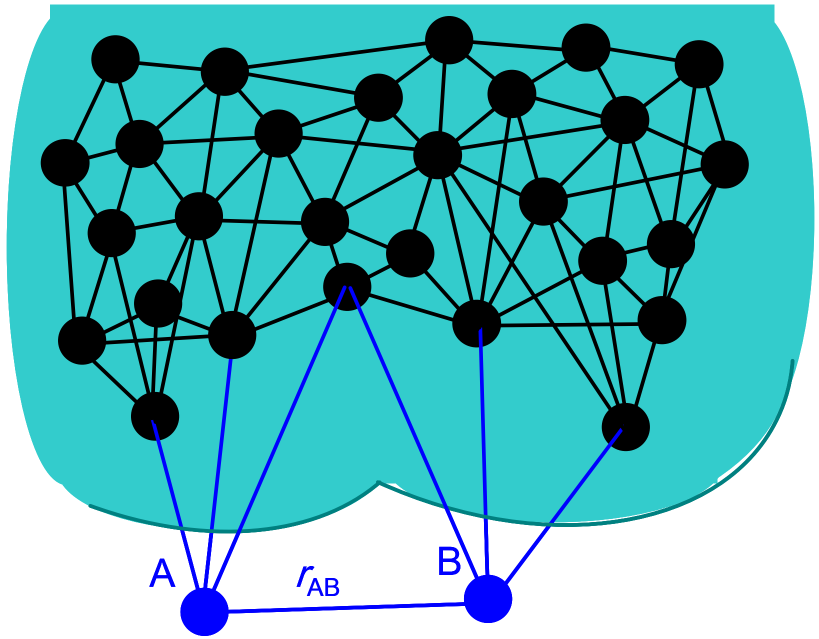


Solving flip ambiguity in the presence of noise



Expansion of a rigid structure by multilateration





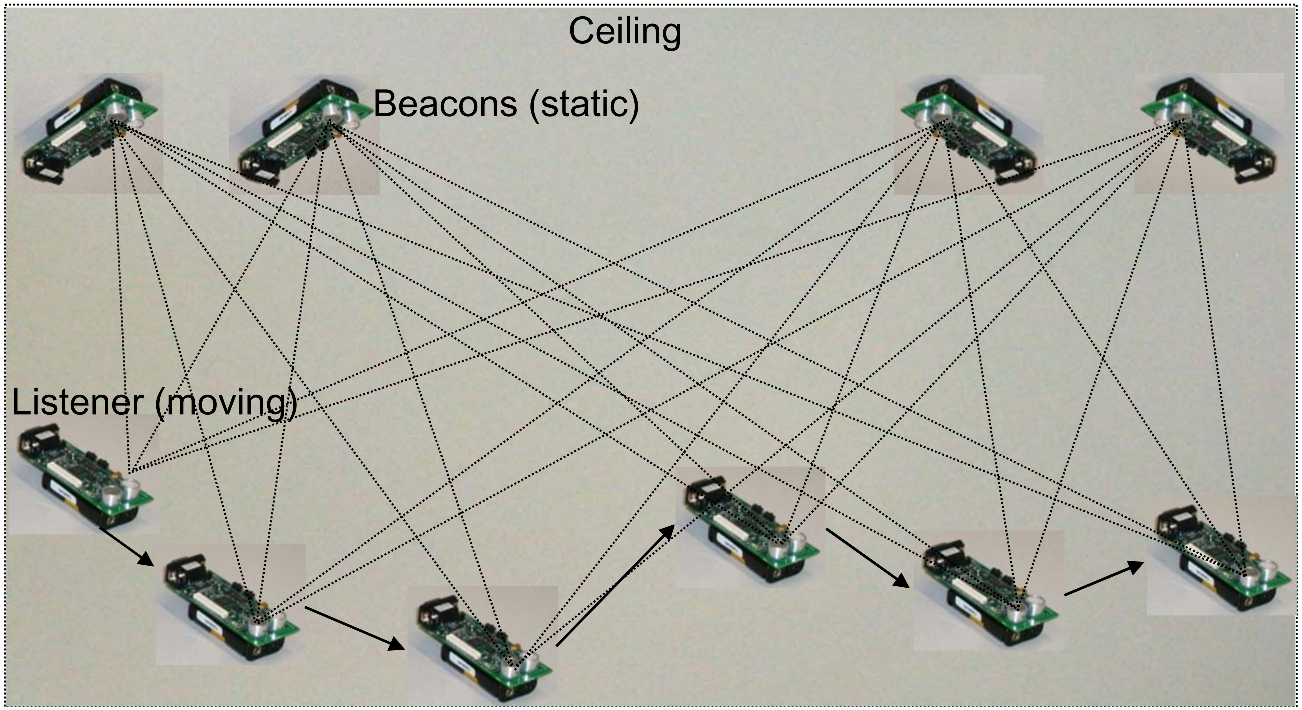
Auto-Positioning Algorithm

Mobile listener collects distance measurements

$$redundancy = R - 3(B + P) + 6,$$

R = observed ranges, B = fixed beacons P = listener positions

Example below: redundancy = 0 (R = 24, B = 4, P = 6)



Auto-Positioning Algorithm

Procedure:

a) collection of range measurements

b) grouping of listener positions

c) detection of gross errors

d) distance matrix

e) completion of approximate distance matrix by MDS or lateration

f) computation of approximate positions in local system

g) refinement by global and local optimisation

	B_1	B_2	B_3	B_4	P_1	P_2	P_3	P_4	P_5	P_6
B_1										
B_2		not observed					observed			
B_3										
B_4										
P_1										
P_2										
P_3		observed					not observed			
P_4										
P_5										
P_6										

Literature

- Dorothea Wagner & Roger Wattenhofer – Algorithms for Sensor and Ad Hoc Networks, Springer (Prof. Wattenhofer at ETH Distributed Systems Group)

- Sönke Pink (2007) : Entwicklung und Erprobung eines multifunktionalen Geo-Sensornetzwerkes für ingenieurgeodätische Überwachungsmessungen, Diss. an Universität der Bundeswehr München, Fakultät für Bauingenieur- und Vermessungswesen

- HEUNECKE, O. (2008): Geosensornetze in der Ingenieurvermessung. Forum, Zeitschrift des Bundes der Öffentlich bestellten Vermessungsingenieure e. V., Heft 2, 34. Jahrgang, 2008, S. 357-364

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