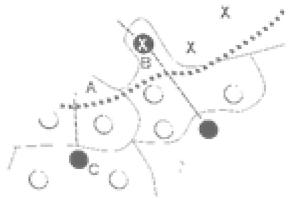
International Workshop on Wireless Ad-hoc and Sensor Networks (IWWAN 2006), New York

"Minimal Transmission Power vs. Signal Strength as Distance Estimation for Localization in Wireless Sensor Networks"



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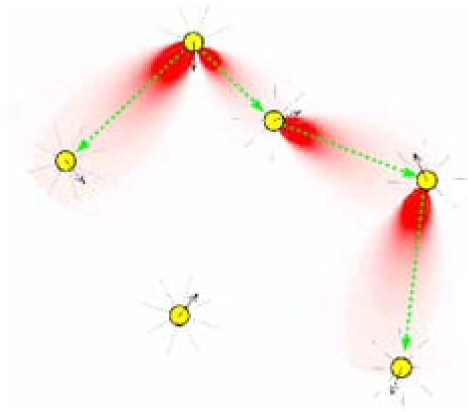
Outline

- Problem Statement
- Classification
- Background
- Distance Estimation Techniques
- New Approach: Minimal Transmitting Power
- Weighted Centroid Localization Algorithm
- Results
- Conclusion



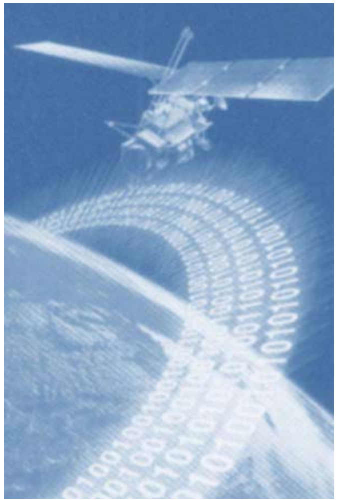
Problem Statement

- Preconditions
  - Hundreds of sensor nodes are randomly deployed
  - Position initially unknown
- Why do we need localization?
  - Position ↔ Measurement
  - Self organization, -healing
  - Geographic Routing
- Considerations
  - Nodes miniaturized
  - Nodes strongly resource limited
  - Changing dynamic topology
  - Nodes are error-prone

Conceivable Solution

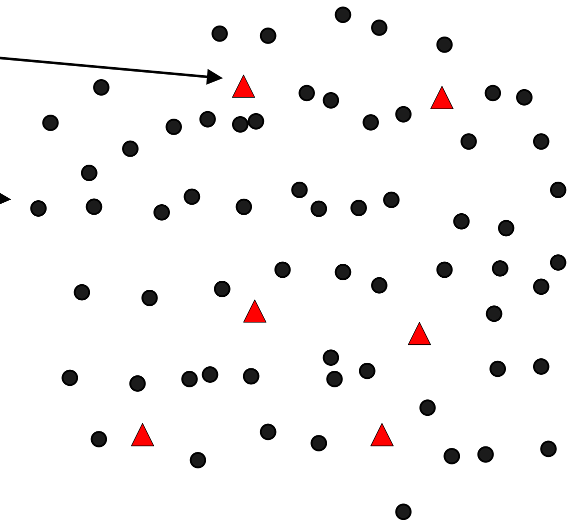
- Integrating existing localization system on every node
  - GPS, GSM, Galileo

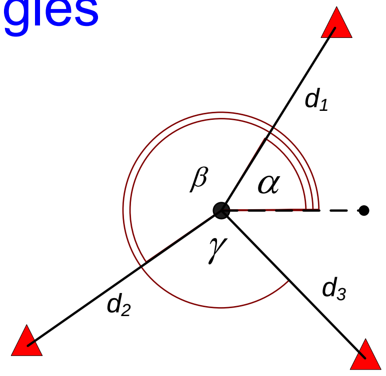
- But:
  - Sensor nodes are strongly resource limited
    - GPS has a relatively high power consumption
  - Sensor nodes have to be tiny
    - GPS modules are comparatively large
  - Localization availability
    - GPS does not work everywhere
  - Nodes must be cheap
    - GPS costs additionally



Problem Solution

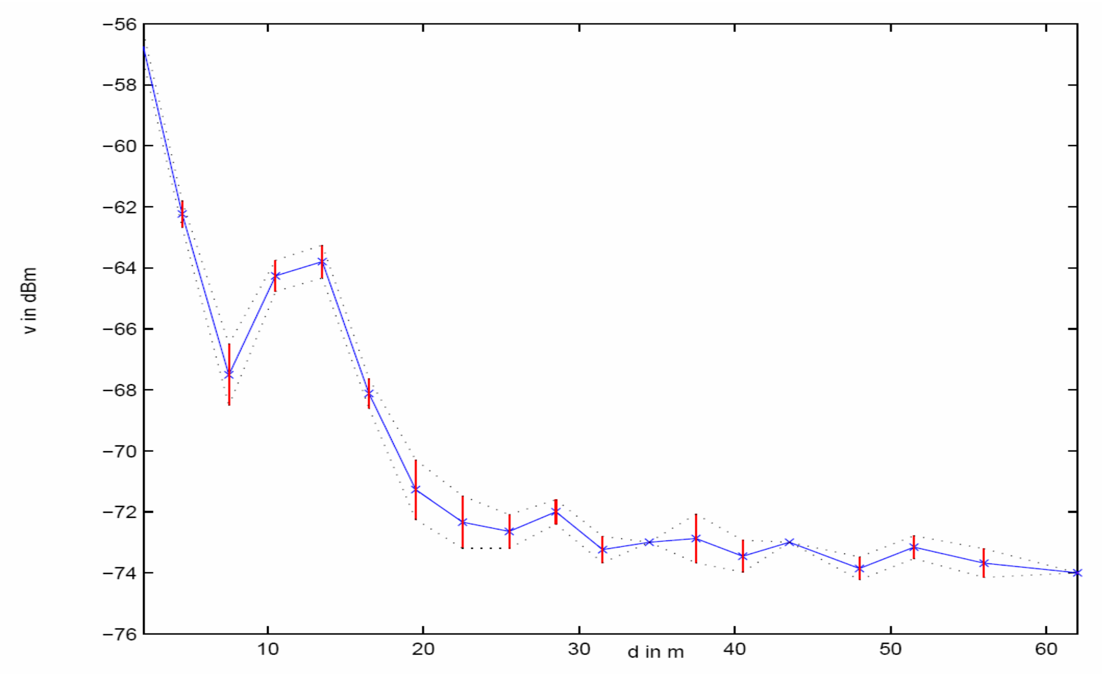
- Equip only some nodes with e.g. GPS
  - Beacons
- Rest of the nodes
  - Unknowns
- Estimation of the position with
  - Distances
  - Angles





Why not just using Trilateration?

- Only 3 beacons needed (2D)
- Simple to calculate
- But:
  - Distance estimations are highly defective!



RSSI over distance indoor (868MHz)

Classification

Approximate Localization (coarse-grained)

- Geometric
- Proximity
- Scene analysis

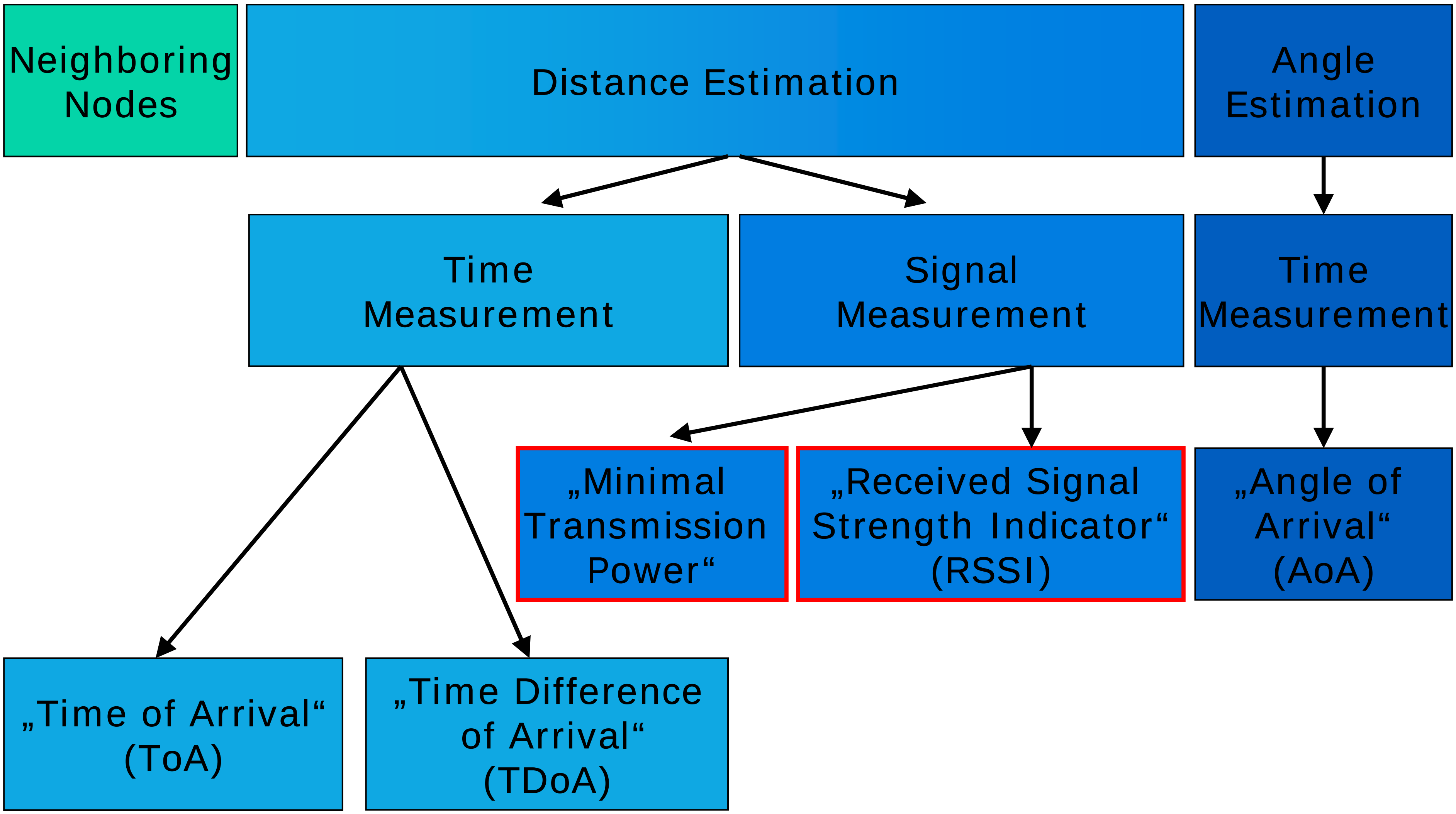
Examples:
- Coarse Grained Localization (Bulusu)
- APIT (He et al.)
- Weighted Centroid Localization (Blumenthal et al.)
- Convex Position Estimation (Doherty et al.)

Exact Localization (fine-grained)

- Angulation
- Trilateration
- Least Squares
- Kalman Filter

Examples:
- Dynamic Fine Grained Multilateration (Savvides et al.)
- Acoustic with Least Squares (Kwon et al.)

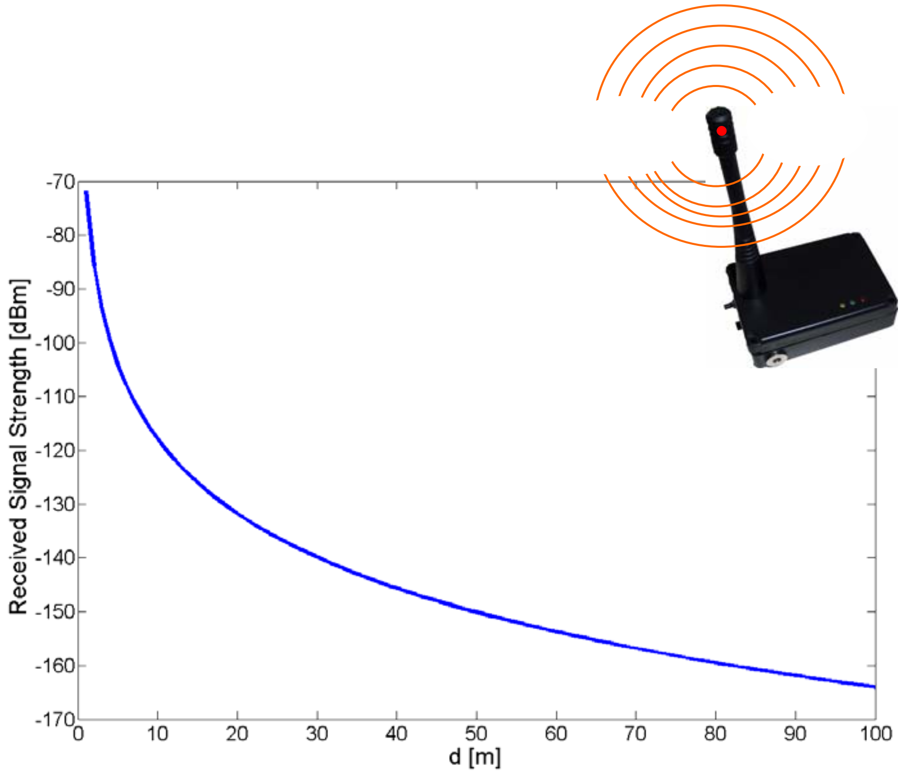
Observation Techniques



Distance Estimation with RSSI in Theory

- Received Signal Strength Indicator supported by hardware
  - Cheap and always available
- Circuit measures the received energy of a signal
- Compared to a reference voltage
- Received Power:

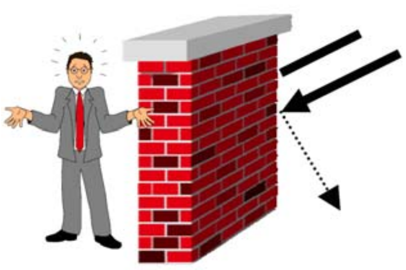
$$\frac{P_R}{P_S} = \left(\frac{\lambda_0}{4\pi d}\right)^2 G_R G_S$$



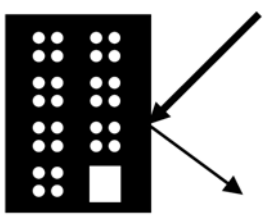
- Logarithm: $P_R(d)[dBm] = P_S[dBm] + 10 \cdot \log\left[\left(\frac{\lambda_0}{4\pi}\right)^2 G_R G_S\right] - 20 \cdot \log(d)$

Problems with RSSI in Practice

- Transceiver sensitivity
- Signals in real world are strongly influenced
- Attenuation when passing objects
  - 876MHz → 8-20dB by a tree
  - 2.4 GHz → bricks 3dB, tinted glass walls 19dB
- Signal propagation characteristics can change frequently
- Received Signal Strength depends on battery level



Blocking

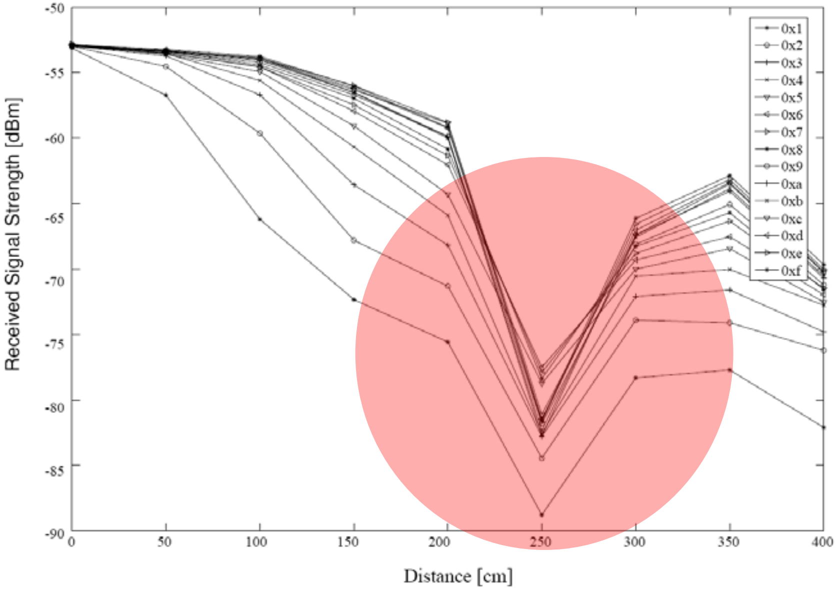


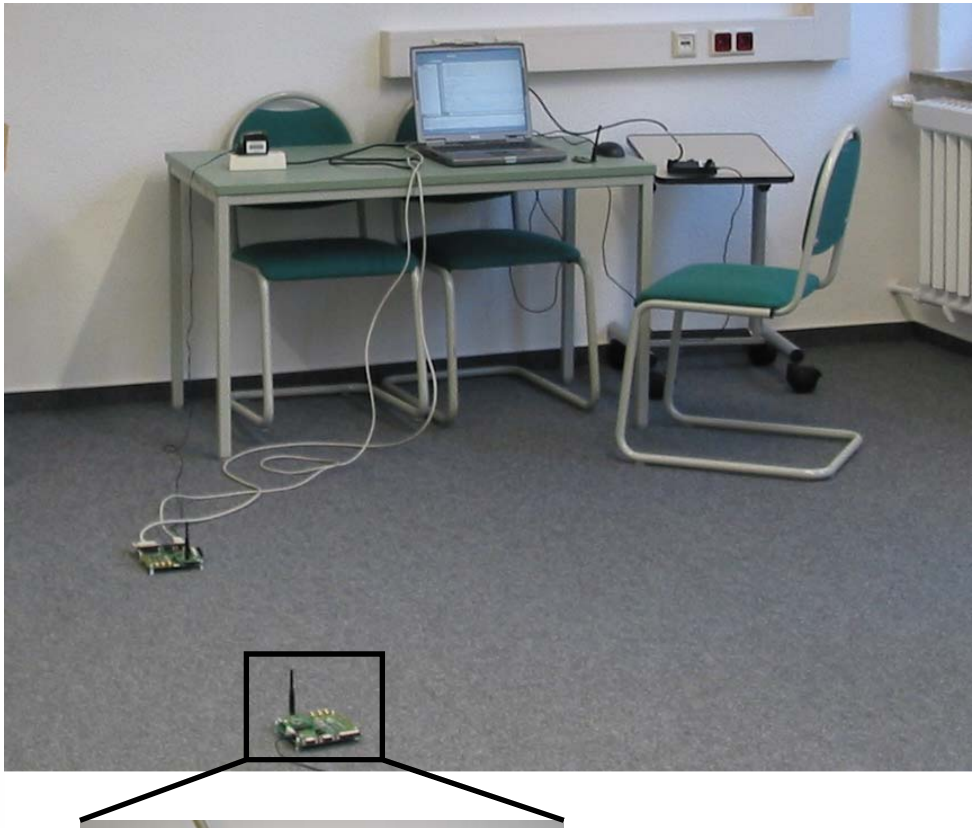
Reflection

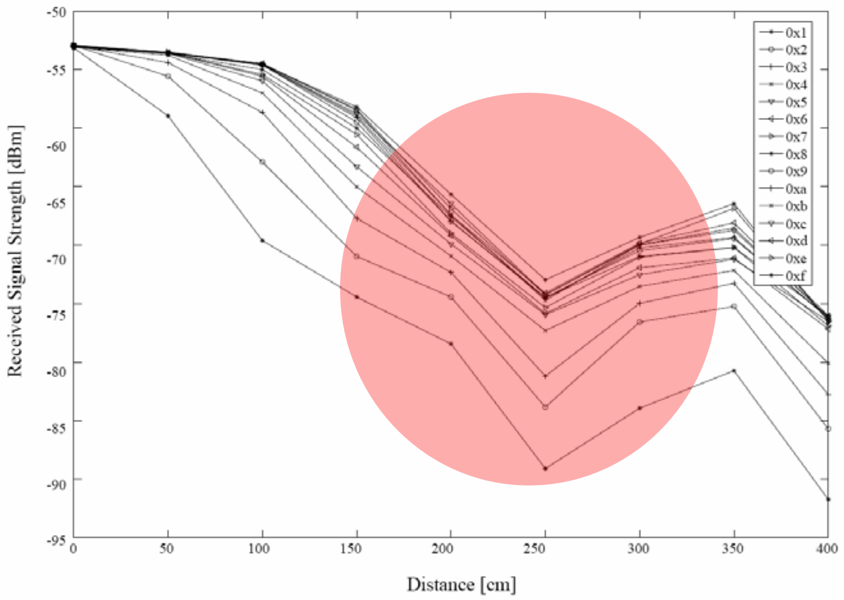
Scattering

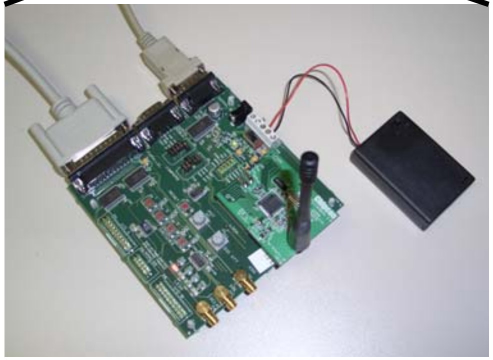
Diffraction

Result Measurements: Indoor (Chipcon)





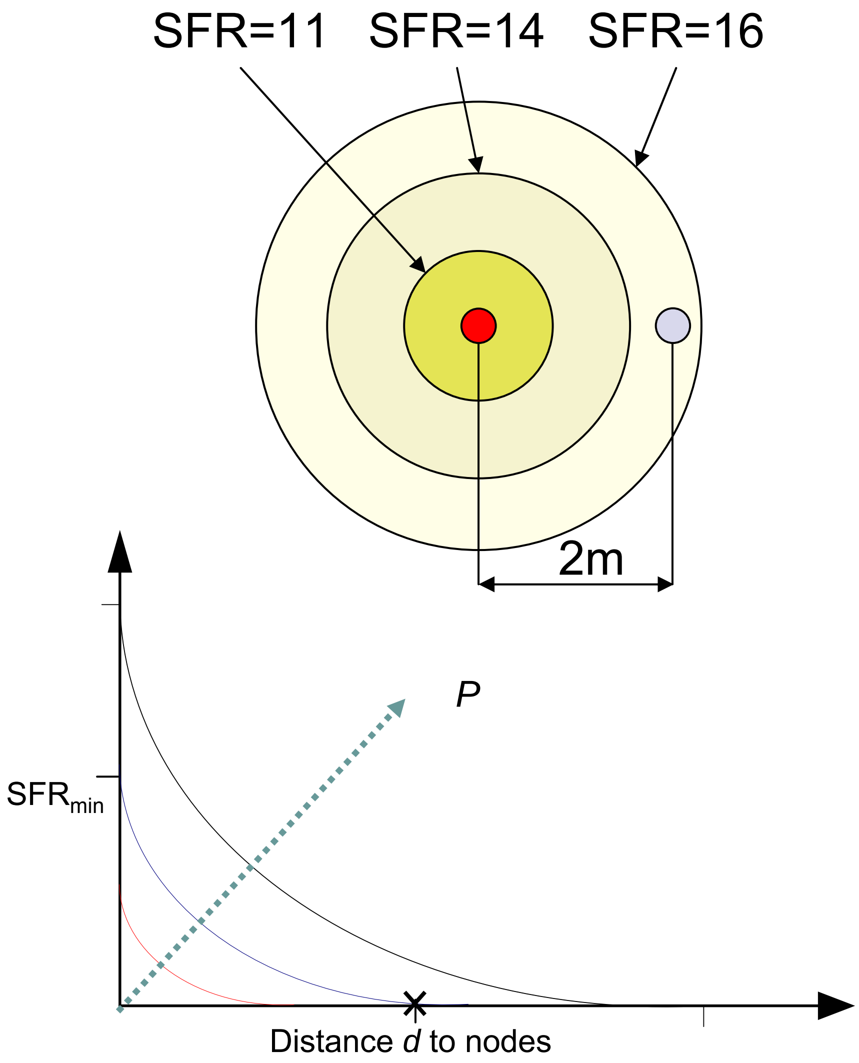




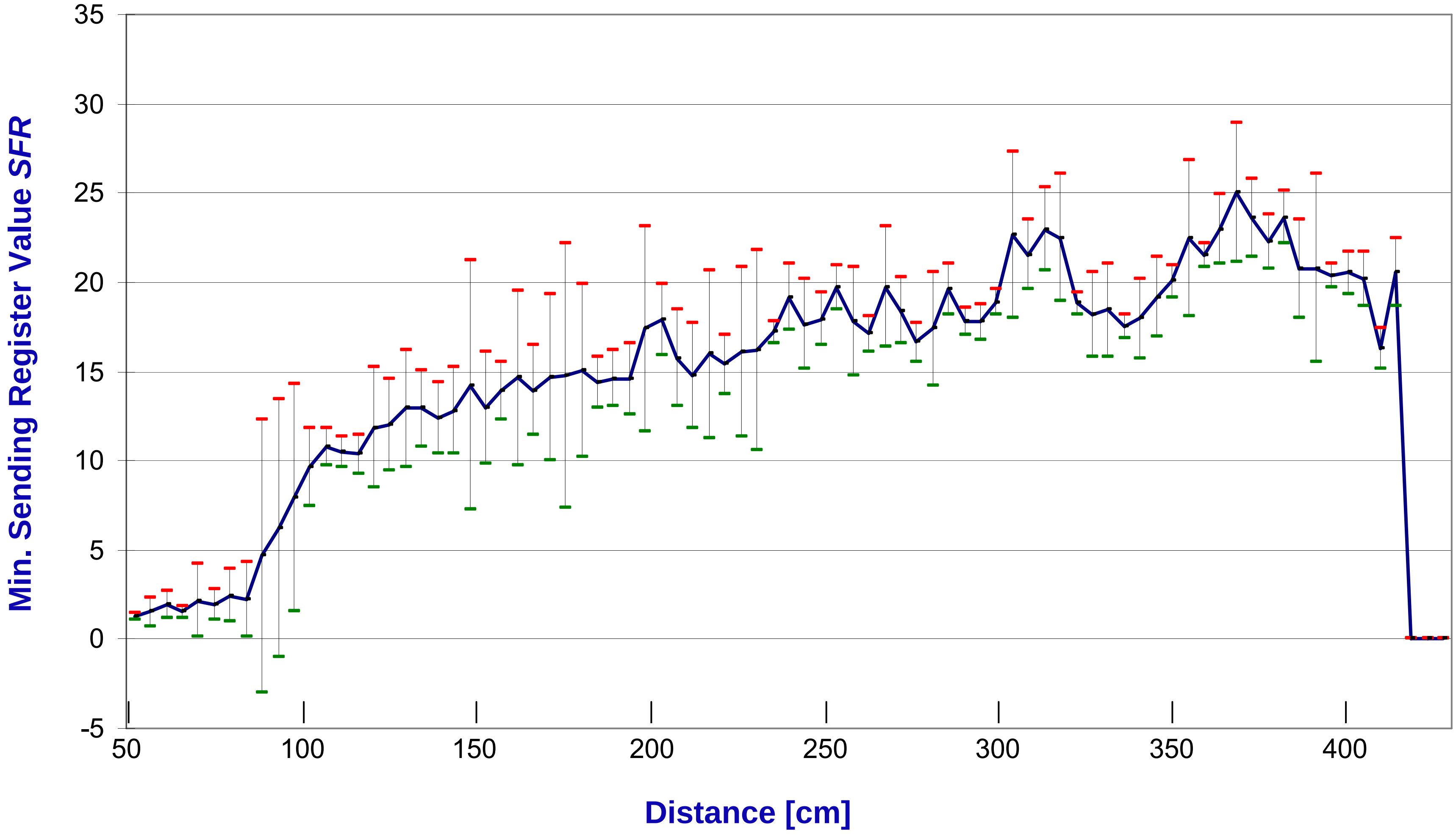
Chipcon CC1010

Distance Estimation with Power Adjustment

- Estimation of the minimal transmitting power of a beacon
- Transmitting power corresponds to the distance
- Transmitting power *P* is a register *SFR* in the hardware
- Transmitting power *SFR* adjustable in the interval *SFR*=0..100 (*d*=1-300m)

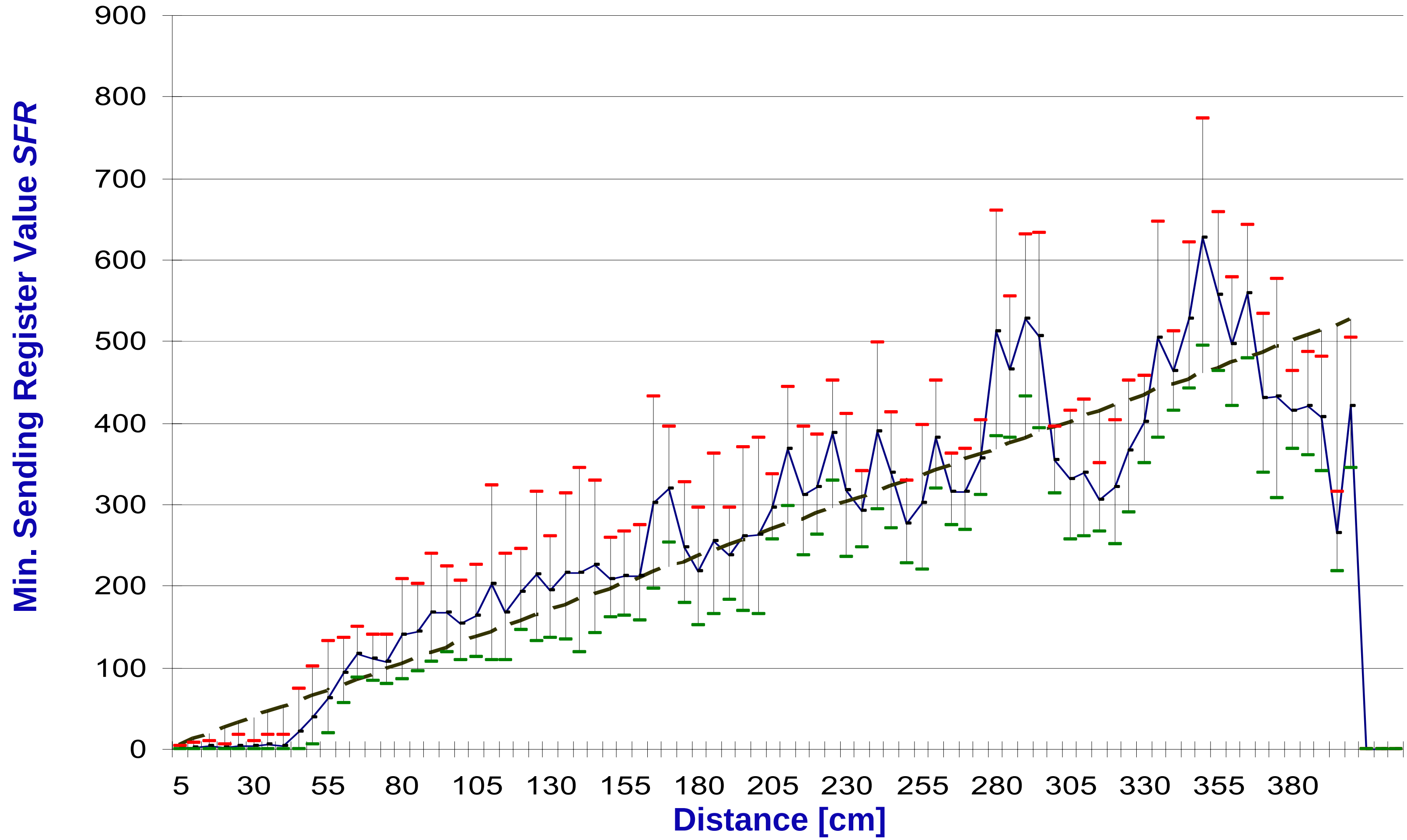


Result Measurements: Indoor (Scatterweb)



Result Measurements: Linearized

- What is *d*? → $SFR(d)^2 = m \cdot d + n \rightarrow d = \frac{SFR(d)^2}{1.3} \quad with\ m = 1.3, n = 0$



Weighted Centroid Localization (WCL)

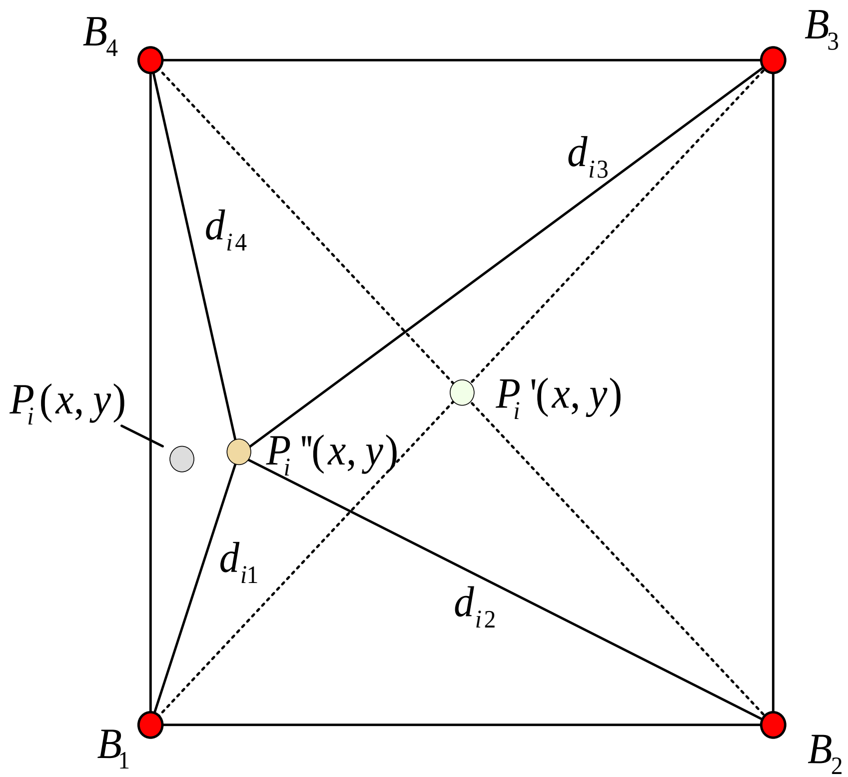
- Approach:
  - Including distances in localization
  - Define a function for the weight $w_{ij}(d)$

CGLCD

$$P_i'(x,y) = \frac{1}{n}\sum_{j=1}^{n} B_j(x,y)$$

WCL

$$P_i''(x,y) = \frac{\left(\sum_{j=1}^{b}\left(w_{ij}\cdot B_j(x,y)\right)\right)}{\left(\sum_{j=1}^{b} w_{ij}\right)}$$



Determination of the Weight

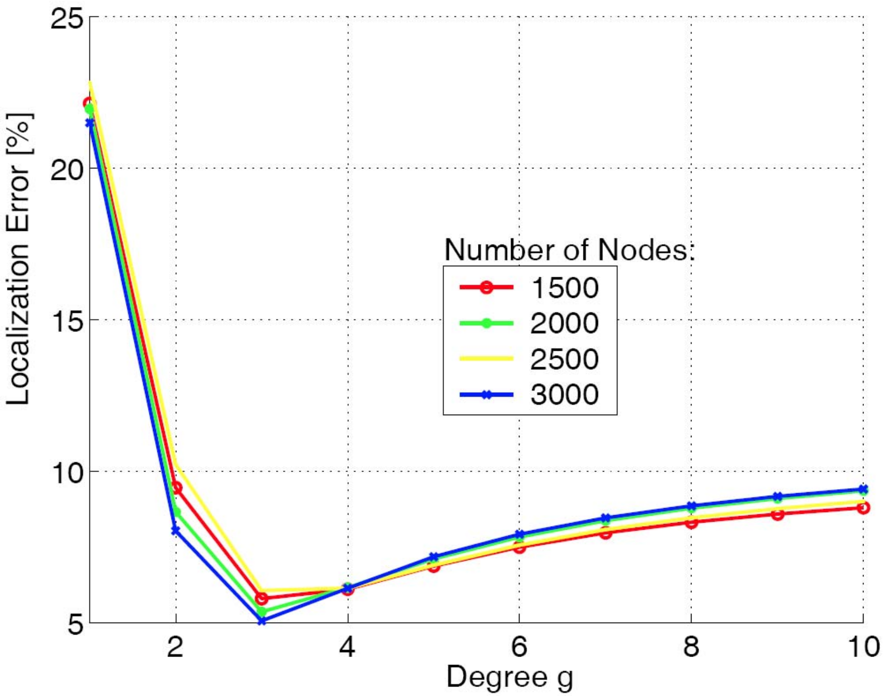
- Free parameter is the weight
- Substituting the weight:

$$P_i''(x,y) = \frac{\left(\sum_{j=1}^{b} \left(w_{ij} B_j(x,y)\right)\right)}{\left(\sum_{j=1}^{b} w_{ij}\right)}$$

$$w_{ij} = \frac{1}{\left(d_{ij}\left(SFR\right)\right)^{g}}$$

- Optimal degree *g*?
  - Density
  - Placement

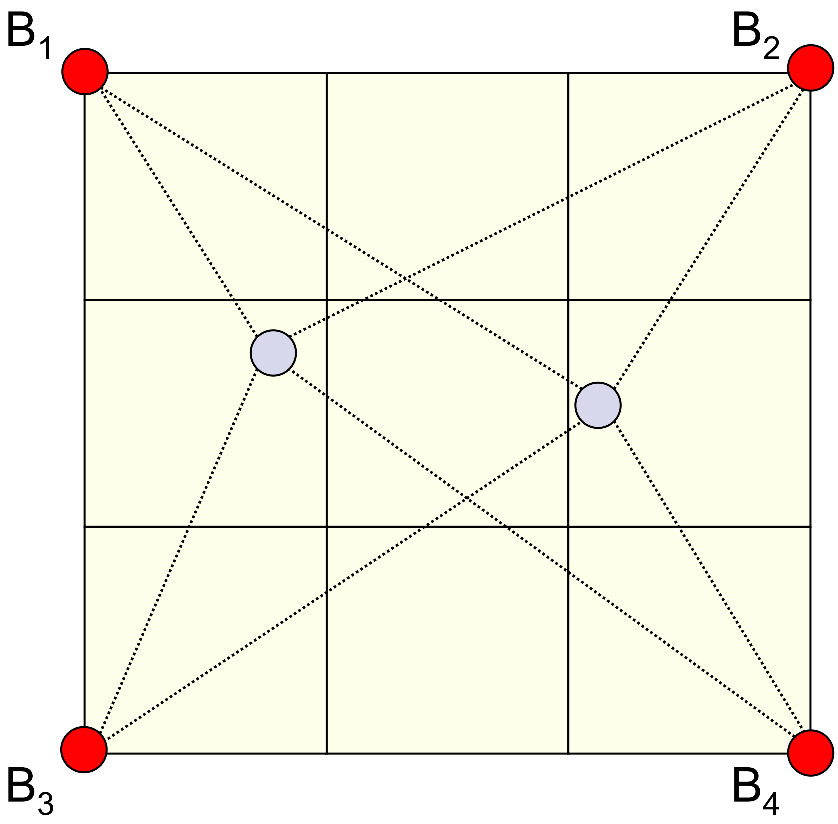
- Simulations → *g = 3* is optimal
- Real → *g* = 2



Realization of a Localization

- Beacons transmit position with increasing transmitting power
- Node saves minimal transmitting power
- Beacon reached max. transmitting power

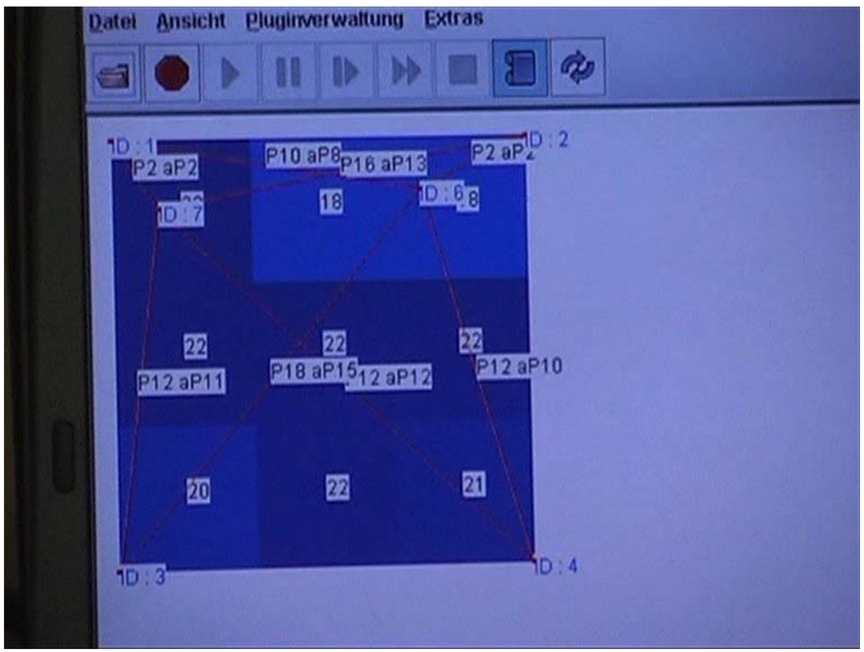
  → counter for the round is incremented
- Round based system via “Token Ring”-mechanism

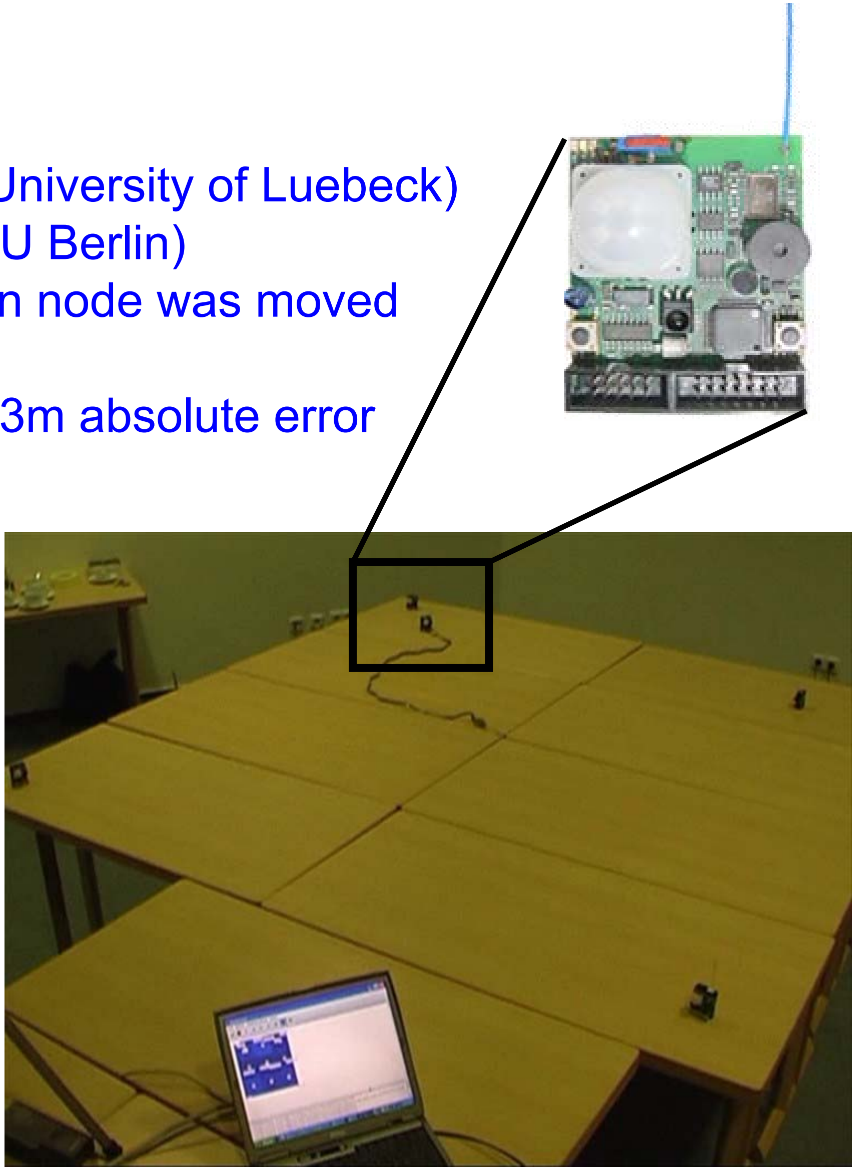


- Beacon (known position)
- Sensor node (unknown position)

Demonstrator Show

- Graphical User Interface: SpyGlass (University of Luebeck)
- Transceiver Hardware: Scatterweb (FU Berlin)
- 4 beacons at all corners, one unknown node was moved
- Field size = 2x2 m
- Yields in a running localization with 0,3m absolute error

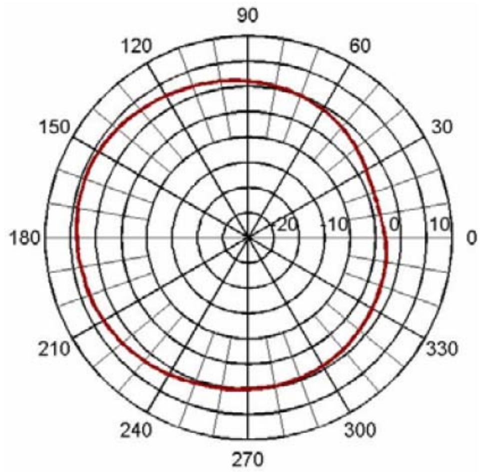




http://rtl.e-technik.uni-rostock.de/~bj/movies/PositionEstimationUsingMinimalTransmissionPower.mpg

Discussion

- Pros
  - Incomplex Calculation (WCL) → O(*n*)
  - Fully distributed on every sensor node autonomously
  - Transmission activity only on beacons
  - Relatively robust against defective inputs



- Cons
  - Errors arise by non-circular borders
  - Round-based transmission stresses the channel
  - Latency
  - Limited precision
  - Strongly hardware dependent (Chipcon not possible)
  - Transmission range depends on battery level

Conclusions and Future Work

- Localization in WSN is strongly demanded
- Most classical observation techniques are defective (ecsp. indoor)

- New Approach: Minimal transmitting power

- Verification:
  - High resolution and smaller variances than RSSI
  - Combining localization algorithm WCL with MTP showed good practical results
  - 2x2m field with 9 areas → max. localization error = 0.3m

Thank You!

Substituting the Parameters

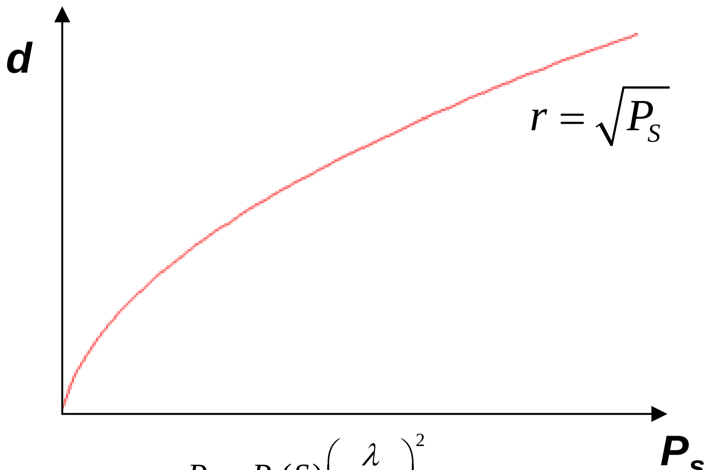
- V

$$P_E = P_S(S)\left(\frac{\lambda}{4\pi d}\right)^2$$

$$d = P_S(S)^2$$

$$S = ?\,P_S$$

$$P_E = P_S(S)\left(\frac{\lambda}{4\pi r}\right)^2$$



$$P_E = P_S(S)\left(\frac{\lambda}{4\pi r}\right)^2$$

Empfangsprofile von Antennen