Minimal Transmission Power as Distance Estimation for Precise Localization in Sensor Networks

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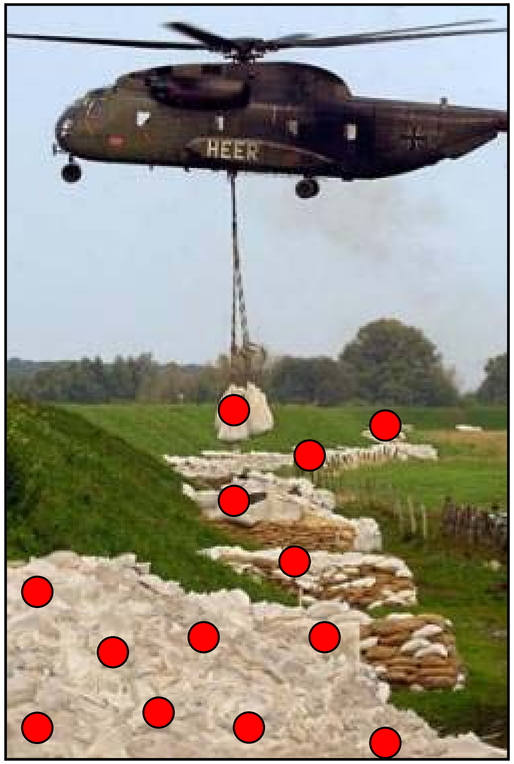
Focus of Presentation

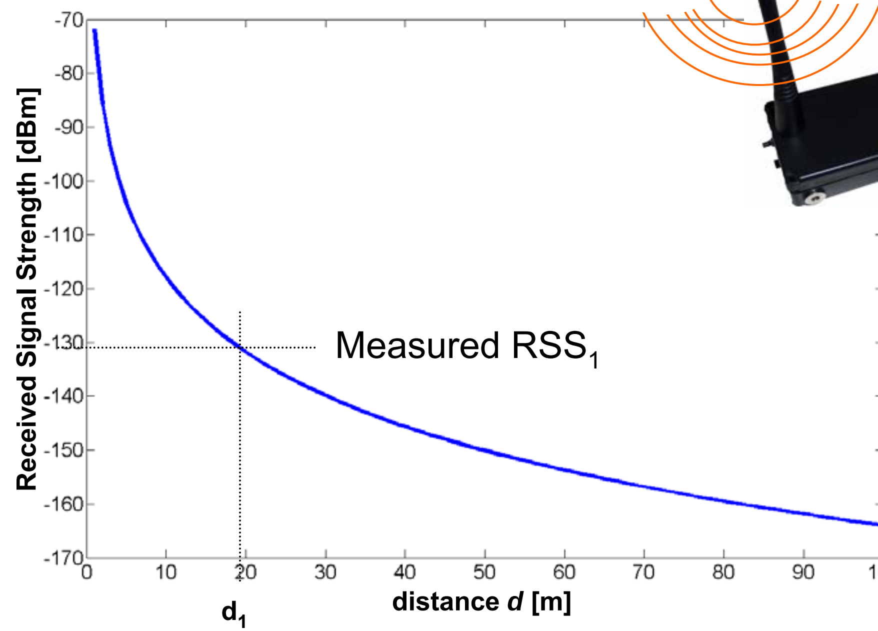
- Preconditions
  - Hundreds of sensor nodes are randomly deployed
  - Position initially unknown
- Why do we need localization?
  - Measurement requires position
  - Example: Self organization, self healing, geographic routing
- Problem Statement
  - Localization needs distance information
  - How to measure distances ?



Flood prevention by dike observation

Distance Estimation with RSSI in Theory

- Energy of signal decreases with distance *d*
- Sensor node measures energy of received signal
- Compared to a reference voltage
- Received Signal Strength supported by hardware
  - Cheap and always available



Power Relations:

$$\frac{P_{RX}}{P_{TX}} = \left(\frac{\lambda_0}{4\pi d}\right)^2 G_{RX} G_{TX}$$

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

P_{TX}	Transmission Power
P_{RX}	Received Power
G_{TX}	Gain at Sender
G_{RX}	Gain at Receiver
d	Distance
λ_0	Wave length

Distance Estimation with RSSI in Theory II

Friis' Equation:

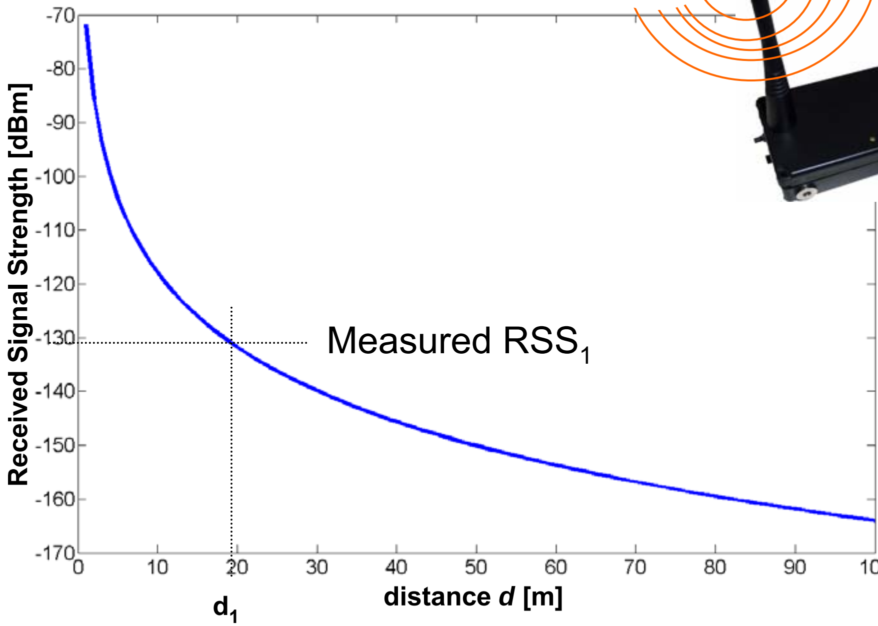
$$\frac{P_{RX}}{P_{TX}} = \left(\frac{\lambda_0}{4\pi d}\right)^2 G_{RX} G_{TX}$$

Rearrange

$$d = \frac{\lambda_0}{4\pi}\sqrt{\frac{G_{RX} G_{TX} P_{TX}}{P_{RX}}}$$

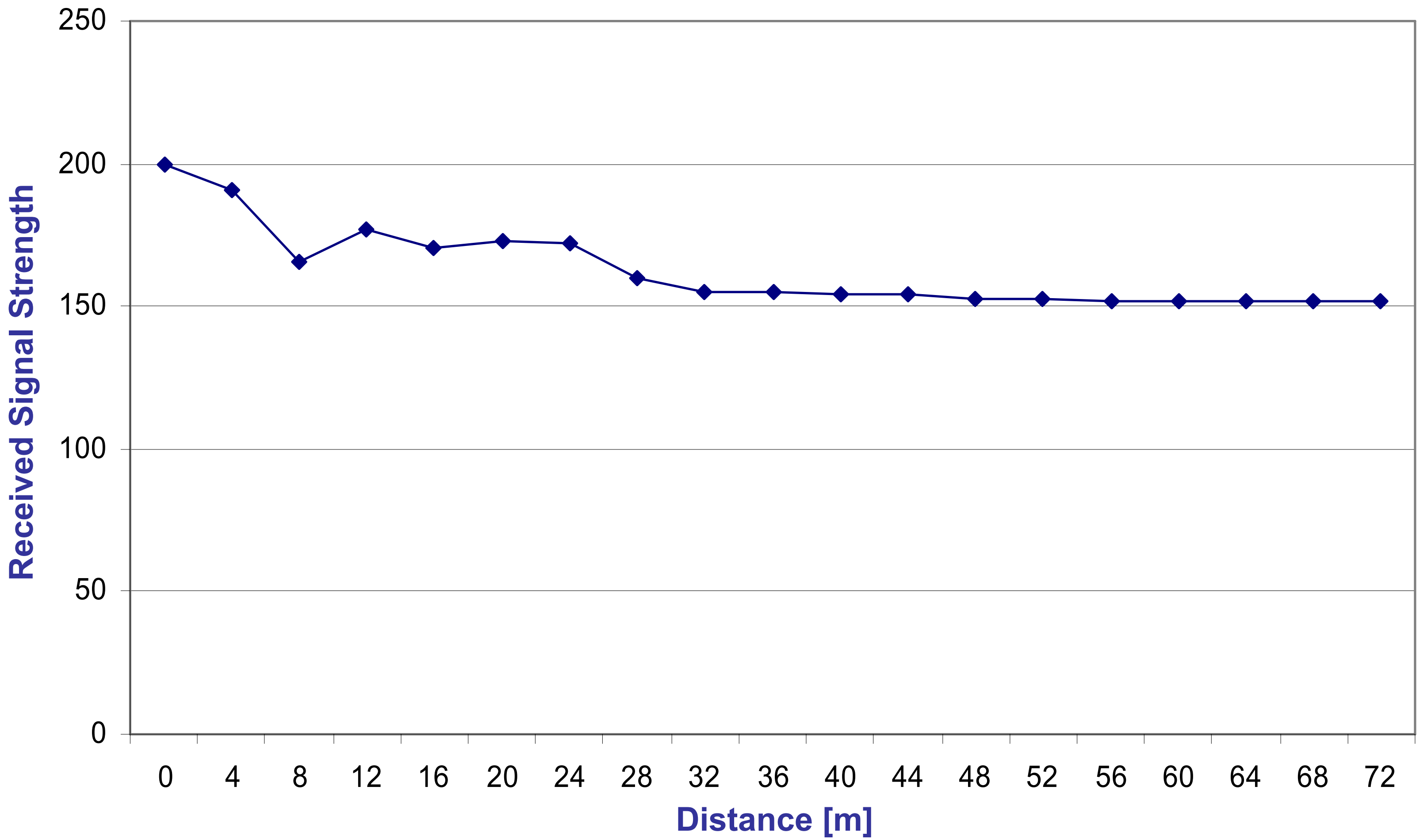
$$= k\sqrt{\frac{P_{TX}}{P_{RX}}}$$

$$d_{\max} \sim \sqrt{P_{TX}}$$



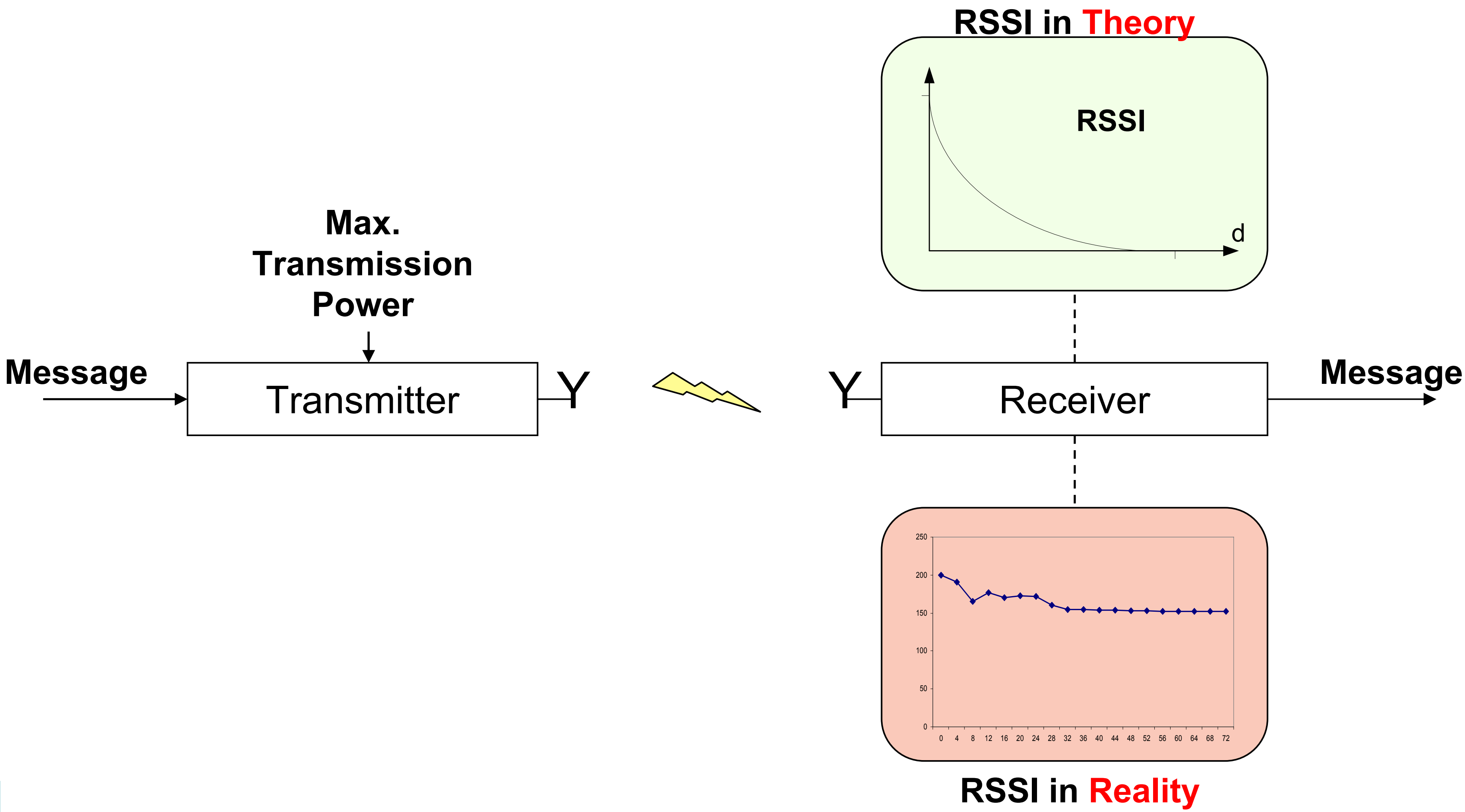
P_{TX} Transmission Power
P_{RX} Received Power
G_{TX} Gain at Sender
G_{RX} Gain at Receiver
d Distance
λ_0 Wave length

RSSI on Chipcon CC1010



- graph not stable
- high variance

RSSI in Theory and in Reality



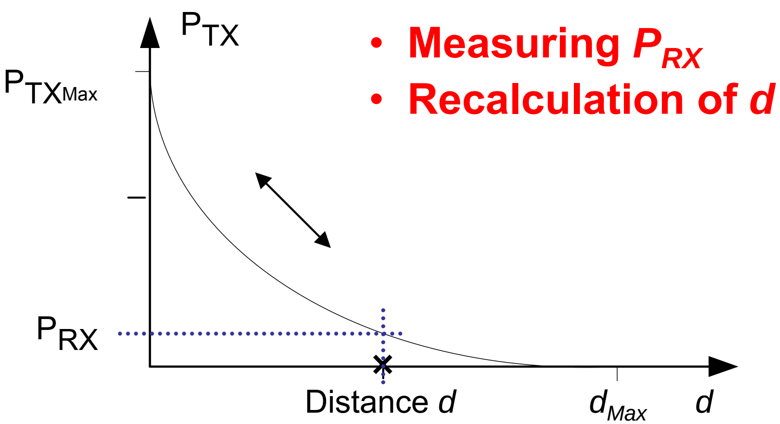
Result: In Reality, distances based on RSSI are inaccurate.

Approach: Minimal Transmission Power

Approach

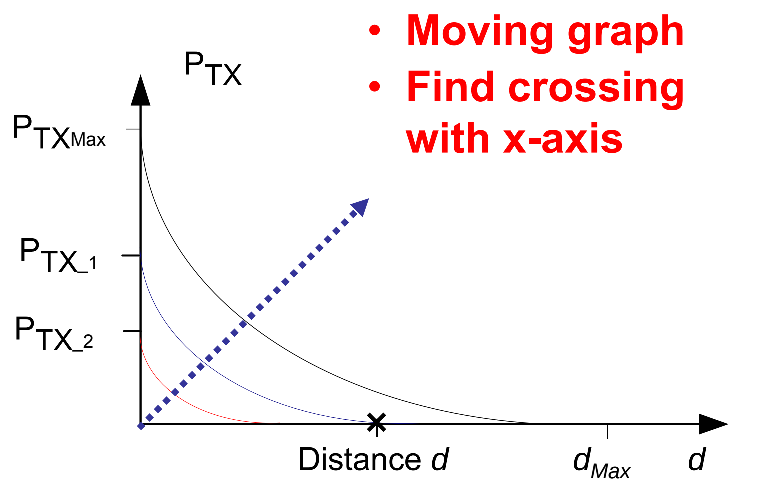
Assumption:

- Max. transmission power
- Measuring RSSI is inaccurate caused by
  - Measuring principle
  - Hardware effort



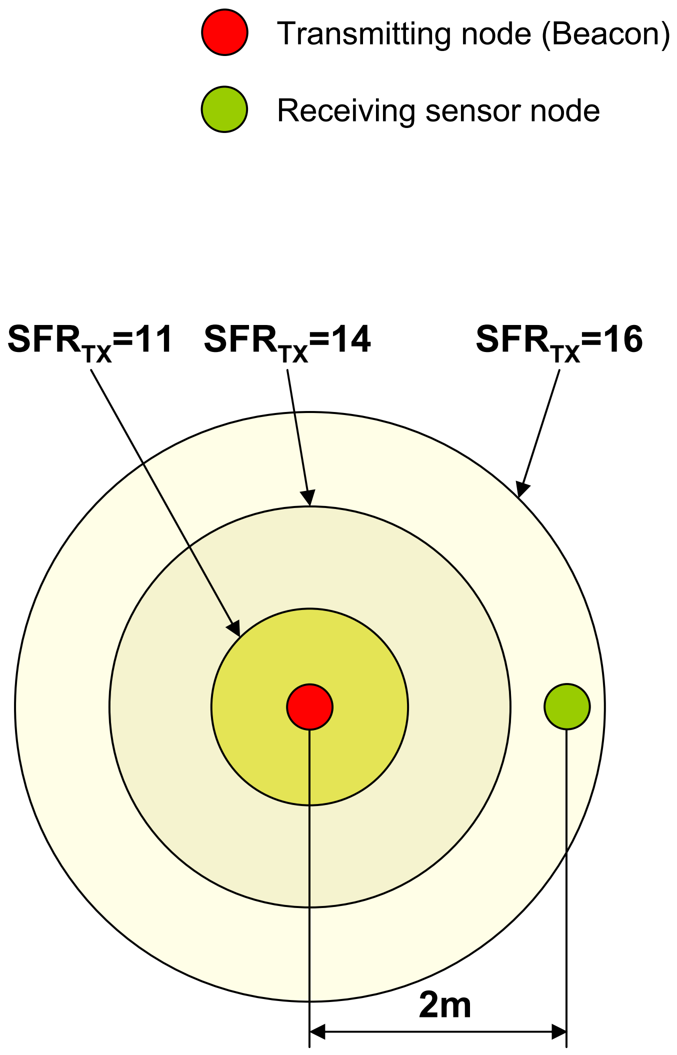
Approach:

- Stepwise increasing transmission power P_{TX}
- In case of reception of a message the transmission power P_{TX} specifies a distance d
- Utilize only smallest transmission power



Finding the Distance

- **Transmission power** P_{TX} is controlled via **Special Function Register** SFR_{TX}
- SFR_{TX} of tranceiver is transmitted with every message
- Distance d is calculated out of smallest SFR_{TX}

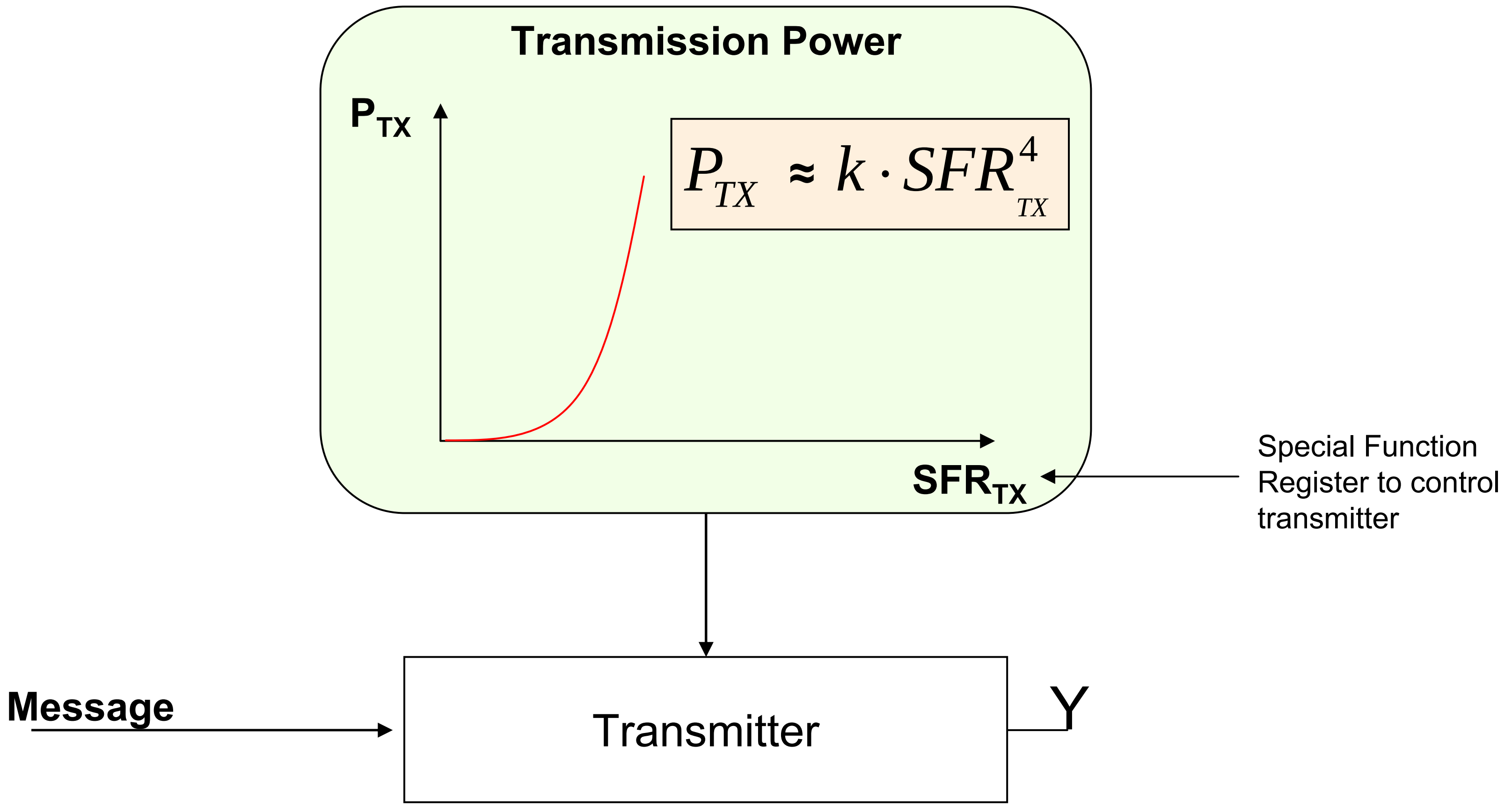


Example (Scatterweb)

- SFR_{TX} tunable in range $0..100$ (300m)
- $SFR_{TX}(16\pm4) \rightarrow d=2m$

Relation between Transceiver and SFR_{TX}

Approximated transfer function *H(x)* of tranceiver (npn transistor)



Relation between Distance and SFR_{TX}

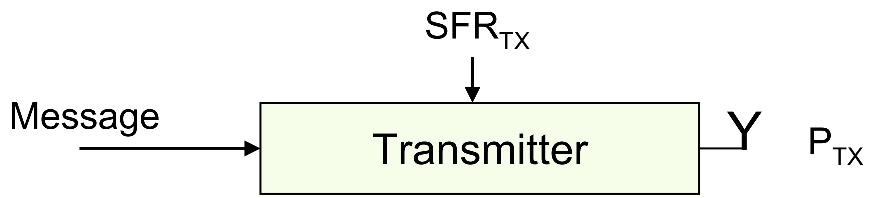
Already known:

$$d_{max} \sim \sqrt{P_{TX}}$$

P_{TX} = Transmission Power
SFR_{TX} = Transmission Register
P_{RX} = Received Power
d = distance

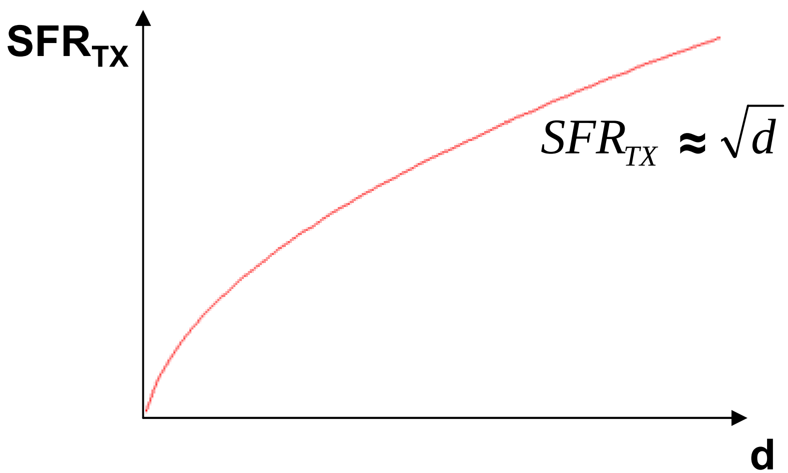
Adjust Transmission Power via Special Function Register SFR_{TX}

$$P_{TX} \approx k \cdot SFR_{TX}^4$$

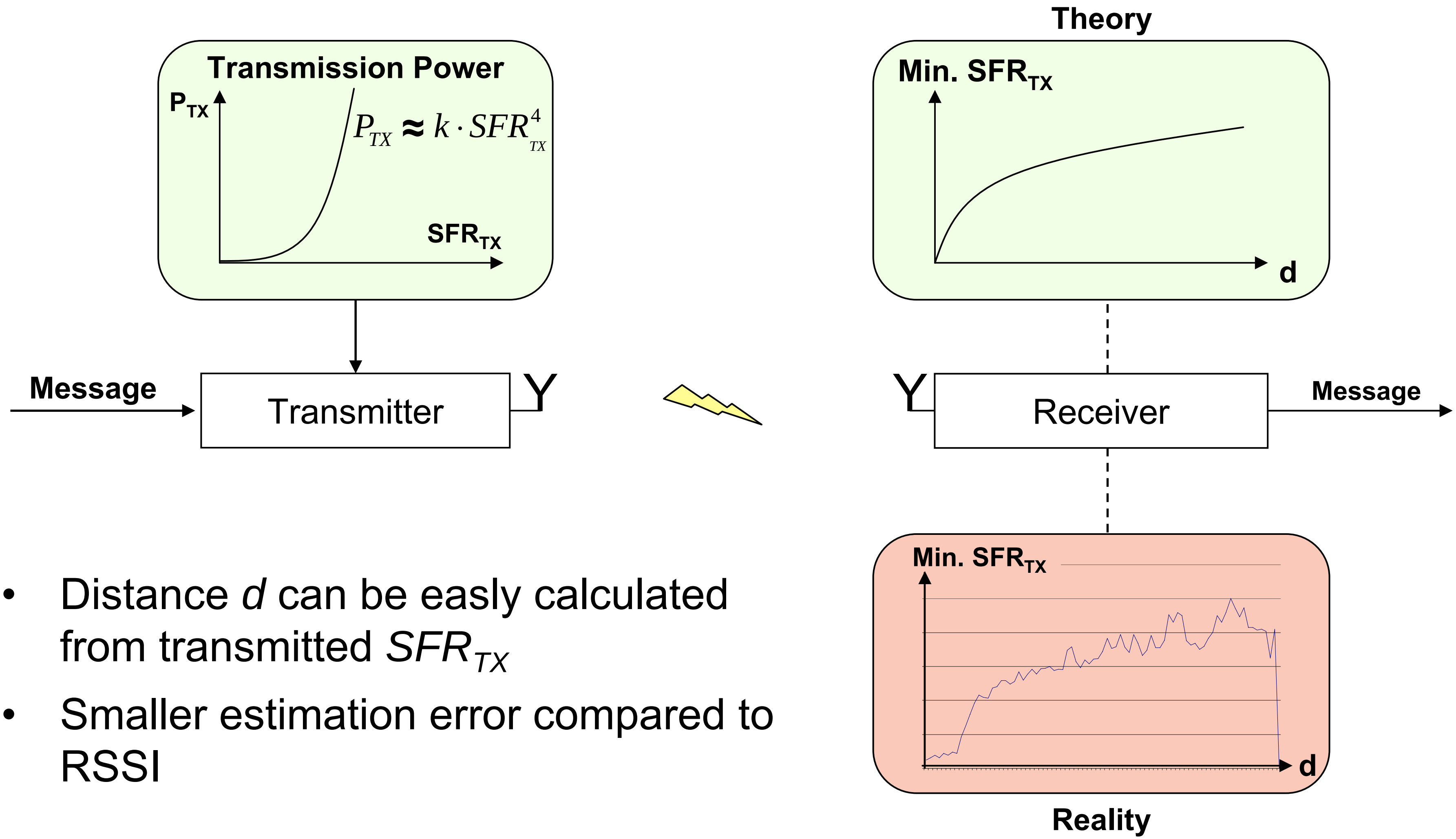


$$d = SFR_{TX}^2 \left(\frac{\lambda}{4\pi}\right)\sqrt{\frac{k}{P_{RX}}}$$

$$d \approx SFR_{TX}^2$$



Min. Transmission Power

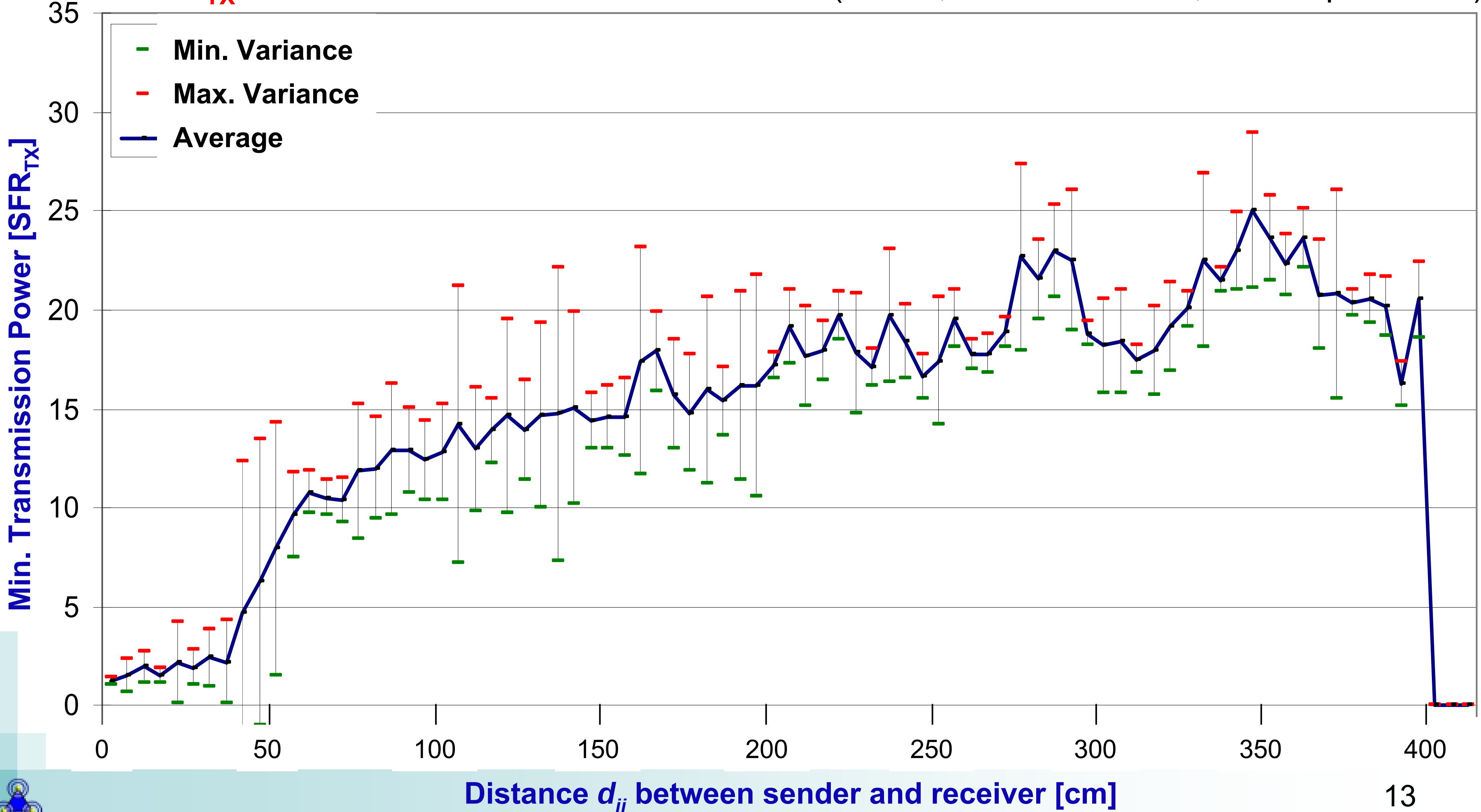


- Distance *d* can be easly calculated from transmitted SFR_{TX}
- Smaller estimation error compared to RSSI

Measurement Results: Scatterweb

We know, in theory: $SFR_{TX} \approx \sqrt{d}$

Min. SFR_{TX} of sensor nodes based on Scatterweb (indoor, ideal conditions, 40 samples each)



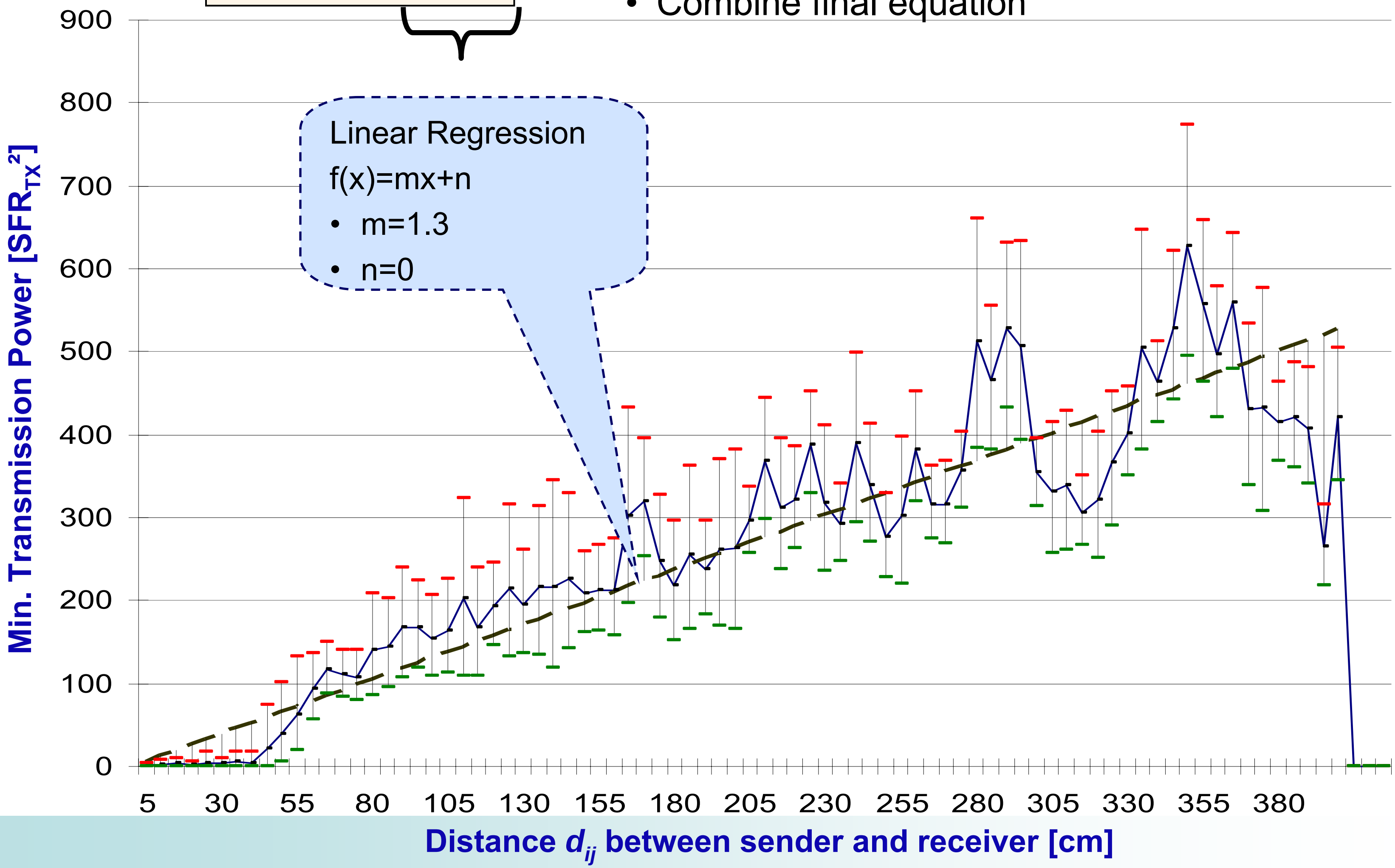
Linearized Measurements

Theory:

$$SFR_{TX} \approx \sqrt{d}$$

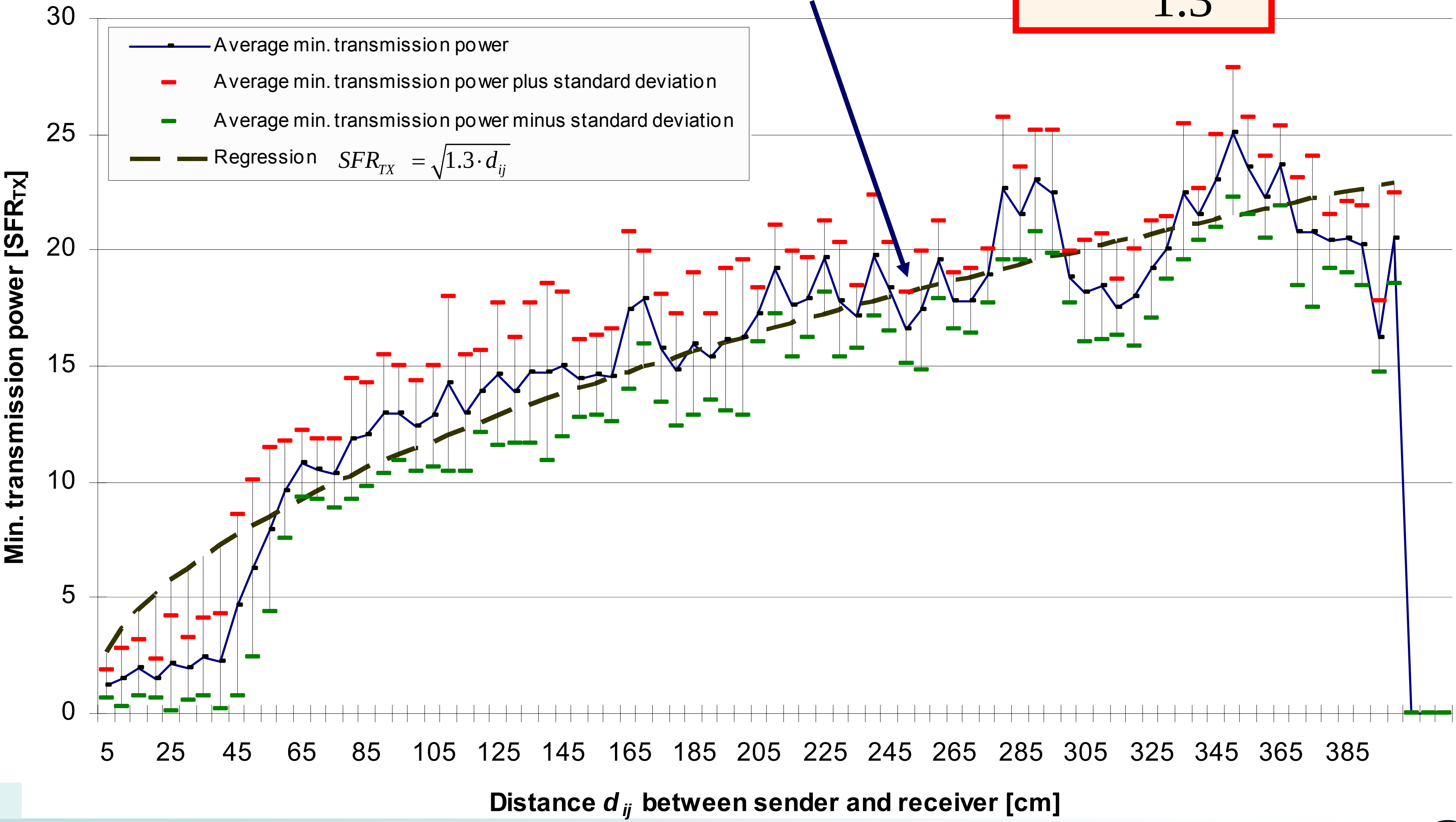
$$SFR_{TX}^2 = m \cdot d$$

- Create linear equation
- Linearize graph by squaring *d*
- Determine raising of graph
- Combine final equation



Measurement Results: Scatterweb

$$SFR_{TX}^2 = 1.3 \cdot d \rightarrow SFR_{TX} = \sqrt{1.3 \cdot d} \rightarrow d = \frac{SFR_{TX}^{\ 2}}{1.3}$$



Example Application

Example Application with Scatterweb

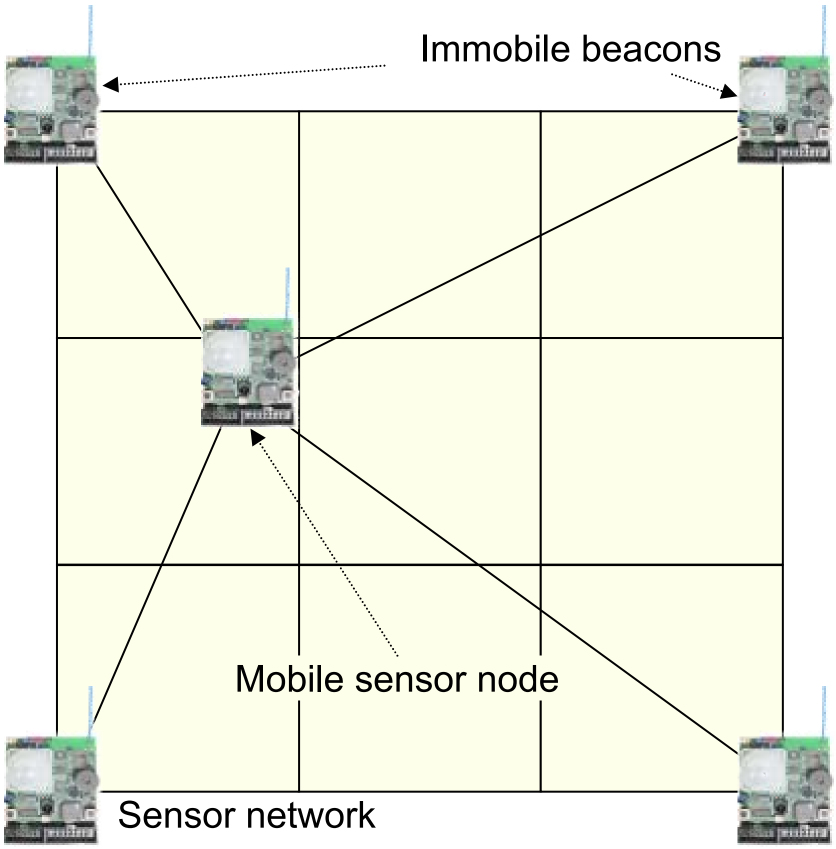
Task:

Determine position of moving sensor node

Localization Algorithm:

Weighted Centroid Localization (WCL)

- simple and fast calculation
- small memory footprint
- acceptable positioning error



References:

Jan Blumenthal, Frank Reichenbach, Dirk Timmermann: Precise Positioning with a Low Complexity Algorithm in Ad hoc Wireless Sensor Networks, PIK - Praxis der Informationsverarbeitung und Kommunikation, Vol.28 (2005), Journal-Edition No. 2, S.80-85, ISBN: 3-598-01252-7, Saur Verlag, Deutschland, June 2005

Jan Blumenthal, Frank Reichenbach, Dirk Timmermann: Position Estimation in Ad hoc Wireless Sensor Networks with Low Complexity (Slides), Joint 2nd Workshop on Positioning, Navigation and Communication 2005 (WPNC 05) & 1st Ultra-Wideband Expert Talk 2005 (05), S.41-49, ISBN: 3-8322-3746-1, Hannover, Deutschland, March 2005

Weighted Centroid Localization (WCL)

Approach:

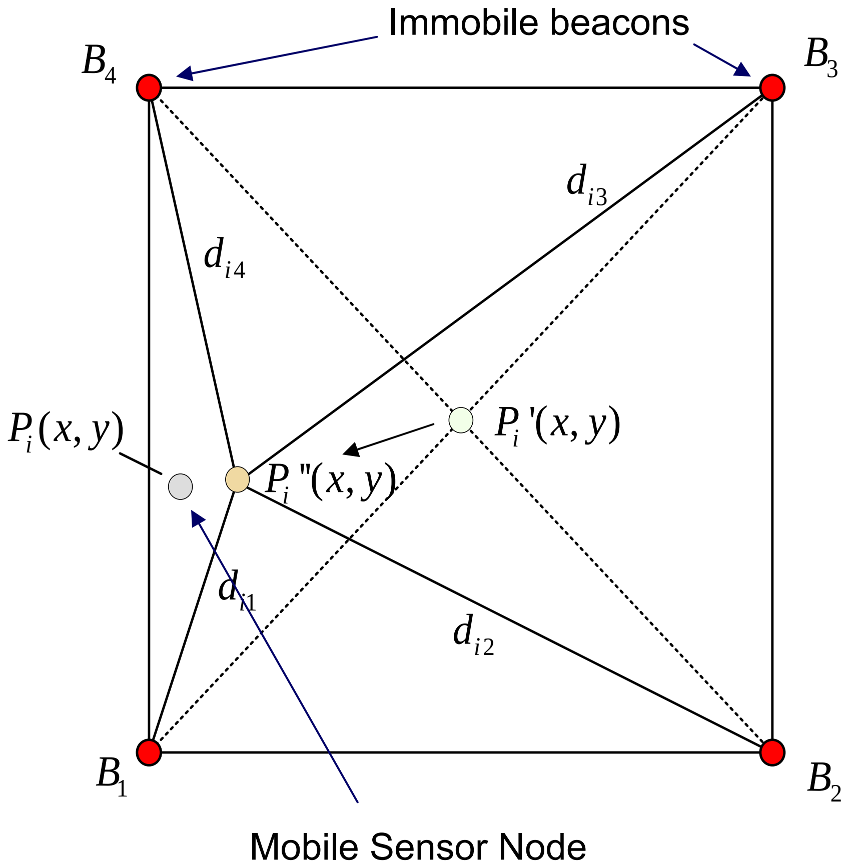
- Positioning by centroid determination P_i' (CGLCD)
- Improved precision by weighting measured distance d_{ix} *using* $w_{ij}()$

CGLCD

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

WCL

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



w_{ij} = Weight of distance B_j and node i
b = Number of beacons
$B_j(x,y)$ = Position of beacons j

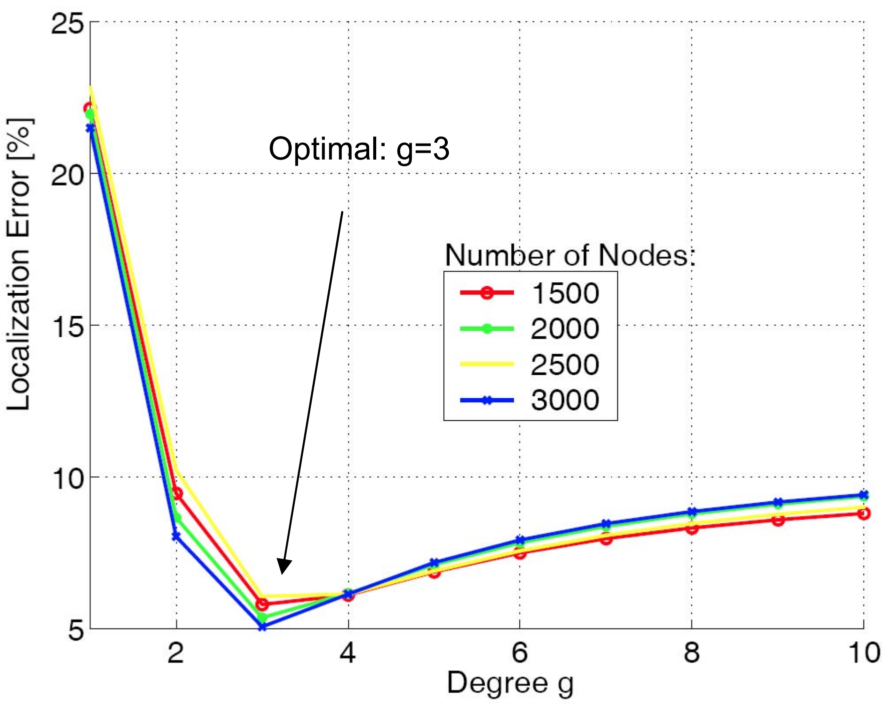
Weight-based on Distances

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

Definition of Weight:

Weight $w_{ij}()$ depends on measured distance between beacon and sensor node.

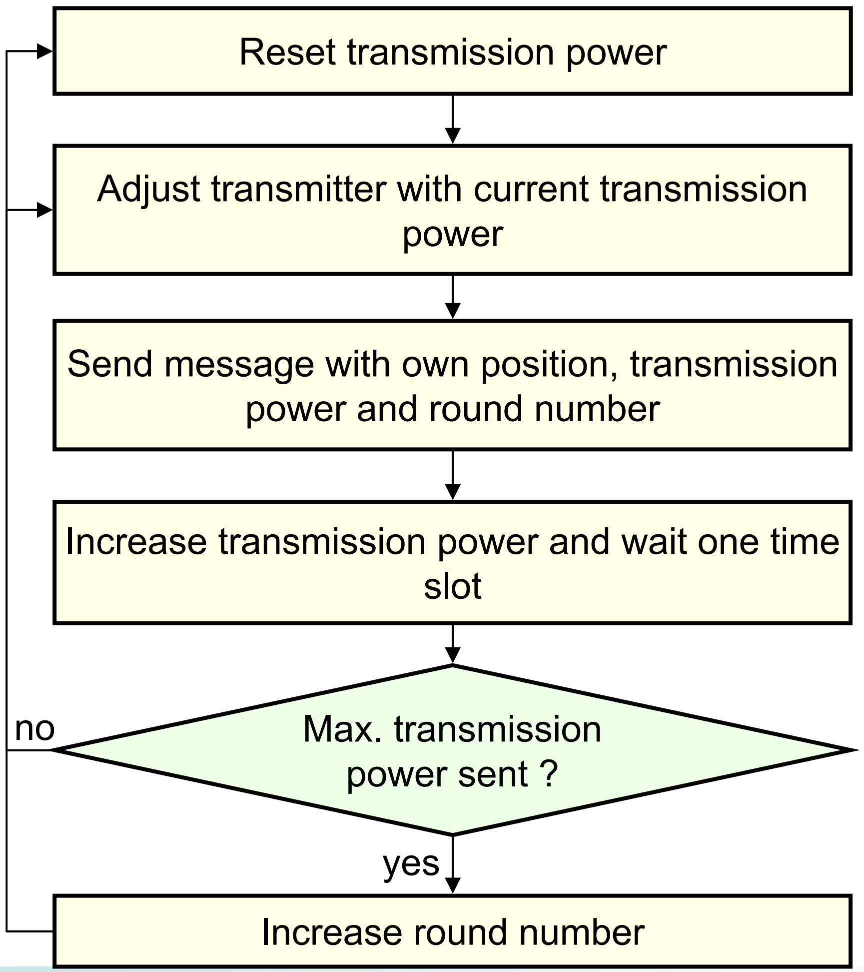
$$w_{ij} = \frac{1}{\left(d_{ij}\right)^g}$$



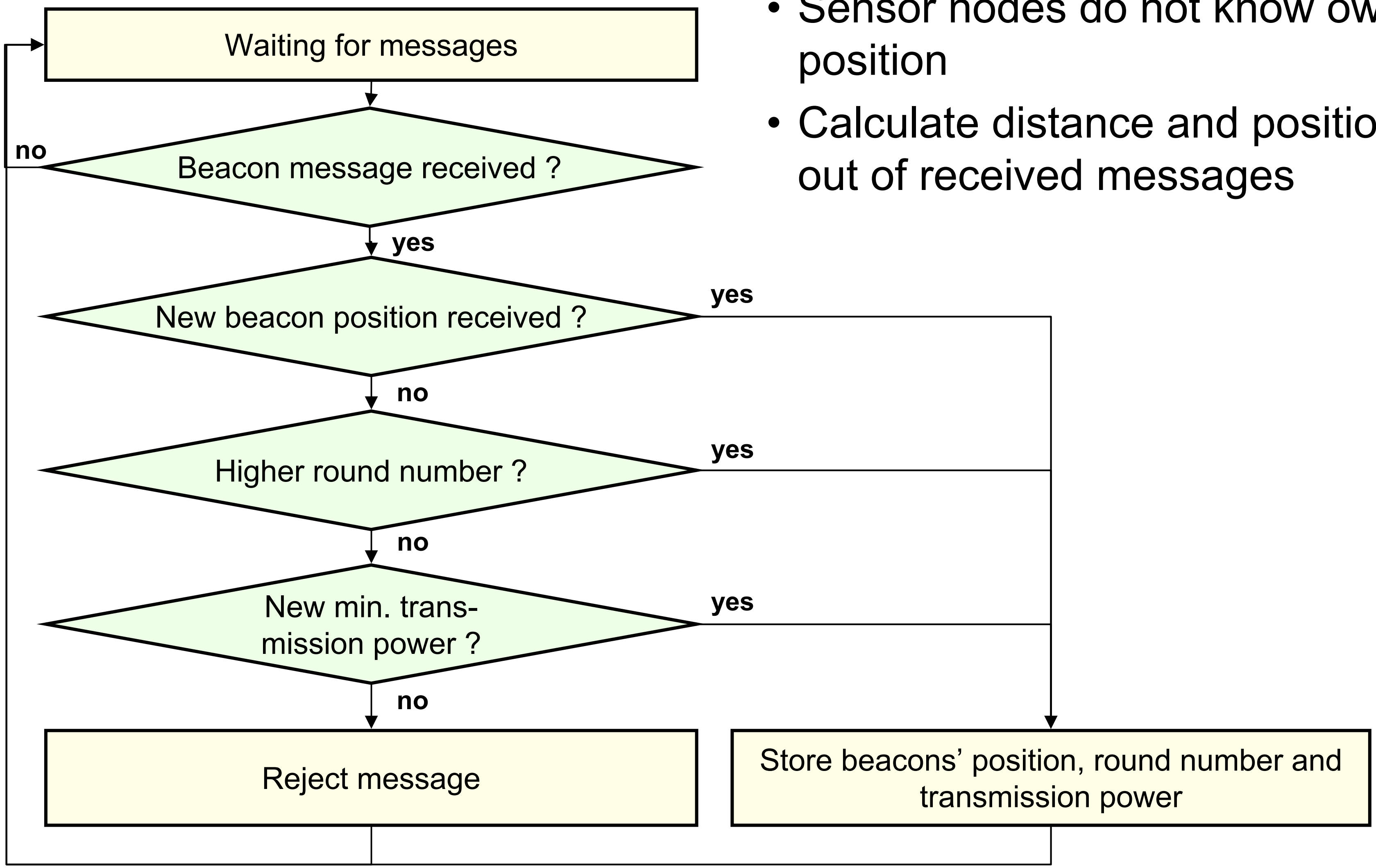
How to determine d_{ij}?

Operations on Beacons

- Beacons are sensor nodes with already known position
- Send out messages with own position and currently adjusted SFR_{TX}

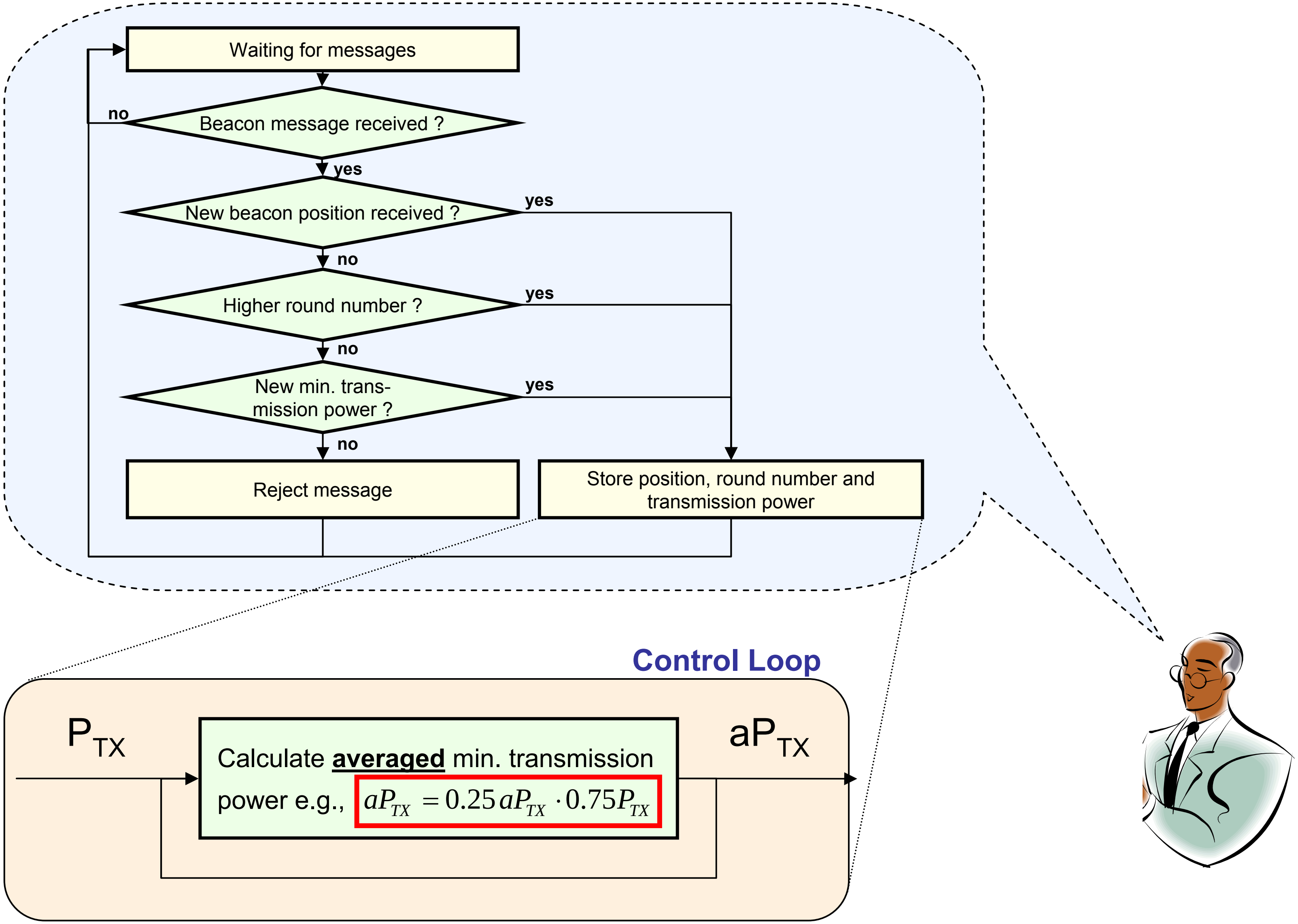


Operations on Sensor Nodes



- Sensor nodes do not know own position
- Calculate distance and positions out of received messages

Reduce high Oscillating Measurements

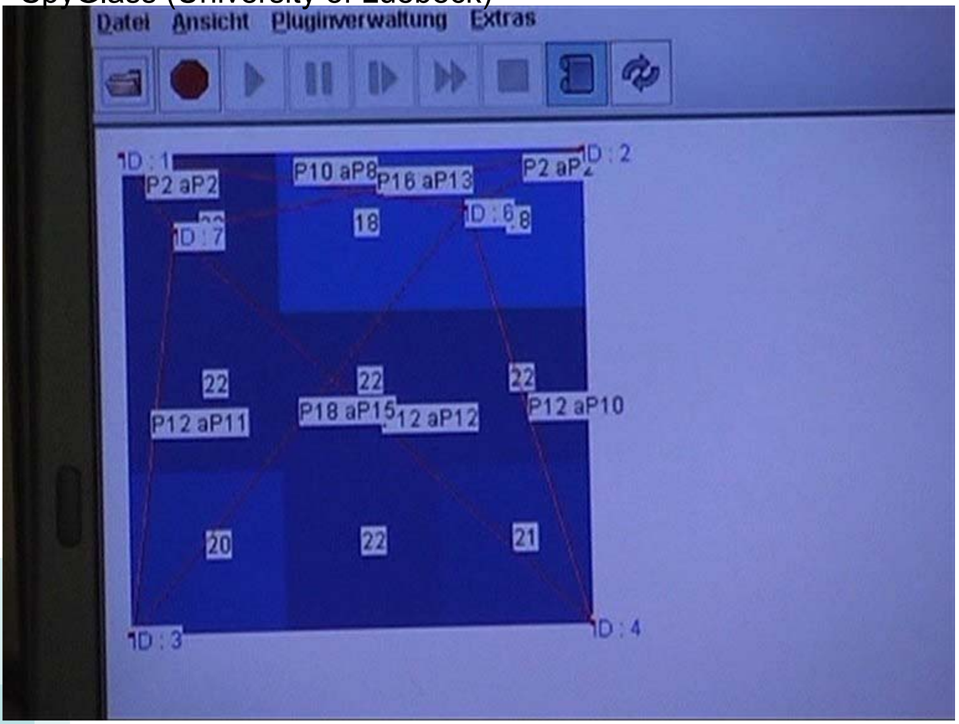


Demonstrator Show

- 4 beacons at all corners, one unknown node was moved
- Localization error: 0.3m
- Notation:
  - P12 : current transmission power is 12
  - aP10: <u>averaged</u> transmission power is 10

Scatterweb

SpyGlass (University of Luebeck)



Field size = 2x2 m

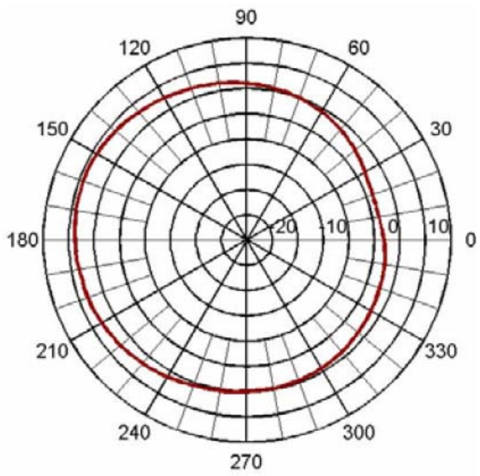
Discussion

Advantages of min. Transmission Power

- simple distance estimation
- easy to implement
- more accurate than RSSI

Remarks

- based on circular transmission range
- concurrent channel access through hidden terminal problem
- numerous sources of interferences (sensor nodes, steel girders, obstacles)
- noticeable delays caused
  - increasing transmission power
  - round counting



Conclusion

Essentials

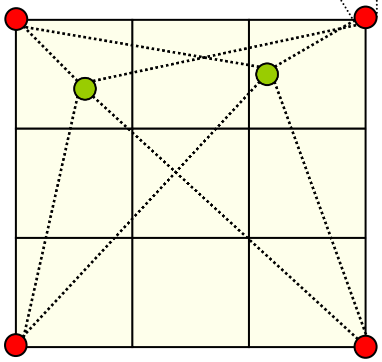
- Wireless sensor networks require localization of sensor nodes
- Most distance estimations are inaccurate especially in indoor use

New approach to estimate a distance

- Minimal transmission power

Proof of concept

- Higher resolution and smaller variances than RSSI
- Example application combined with Weighted Centroid Localization (WCL)



Thank you!

www.sensornetworks.org