SpiderBat: Augmenting Wireless Sensor Networks with Distance and Angle Information

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Location in Wireless Sensor Networks

- Context of sensor readings

  <location, time, value>

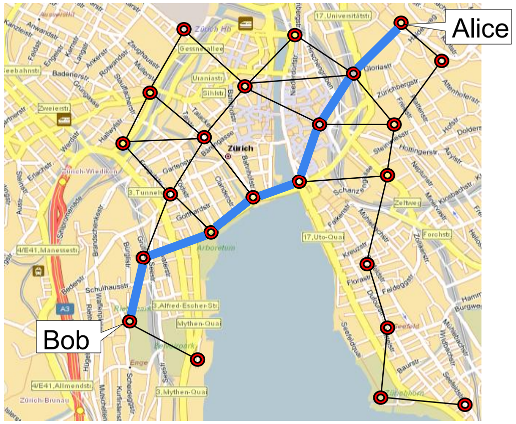
- Leverage location information

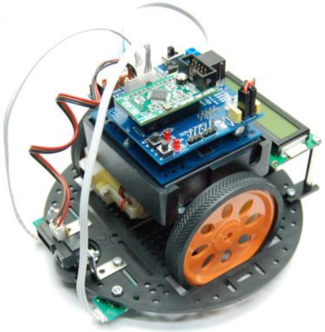
  Network layer: geographic routing

  Physical layer: transmission power control

- Learn about the current node position

  Nodes might be attached to moving objects

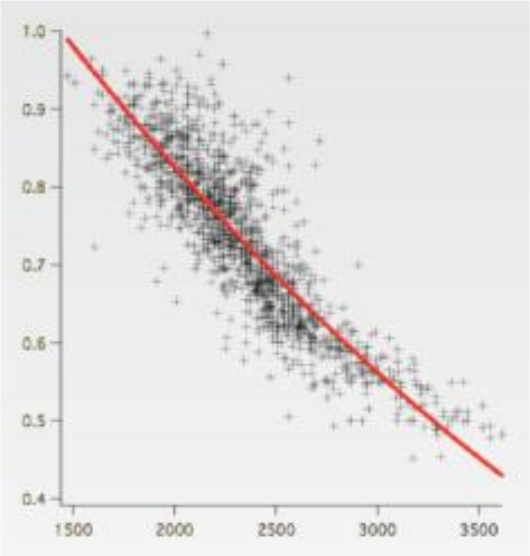




Learning the Position of Sensor Nodes

- Global Positioning System (GPS)
  - Not for indoor applications
  - Special hardware required
  - High power consumption

- Radio-based (connectivity/signal strength)
  - High node density required
  - Limited accuracy (multipath effects)



Positioning with Ultrasound

- Inspired by nature ...

20 – 120,000 Hz

- Human hearing range: 20 – 20,000 Hz

Ultrasound meets Sensor Networks

- High accuracy

  Speed of sound c = 343 m/s

	TelosB/Tmote Sky	MicaZ/IRIS
Clock speed	32 kHz	1 MHz
Resolution	1.04 cm	0.343 mm

- Low complexity

  Simple analog circuits for signal processing and peak detection

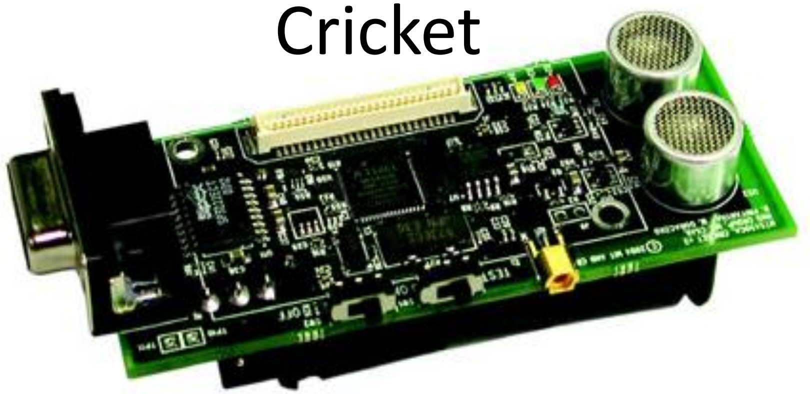
- Energy efficiency

  Short pulses (e.g. 250 microseconds)

  Duty-cycling ultrasound transmitter/receivers

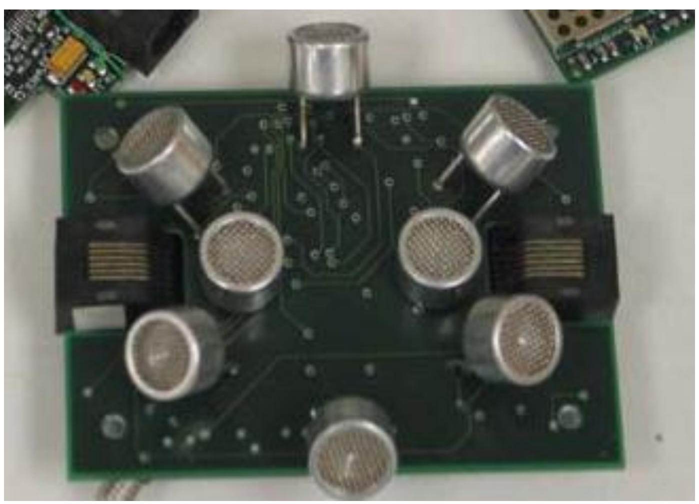
Related Work

Cricket



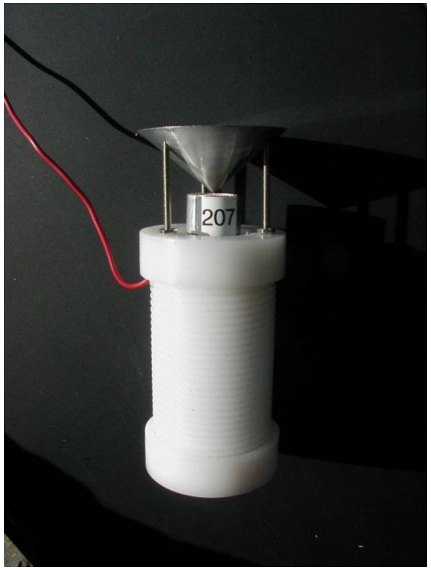
[Priyantha et al., 2000]

Medusa



[Savvides et al., 2001]

Calamari

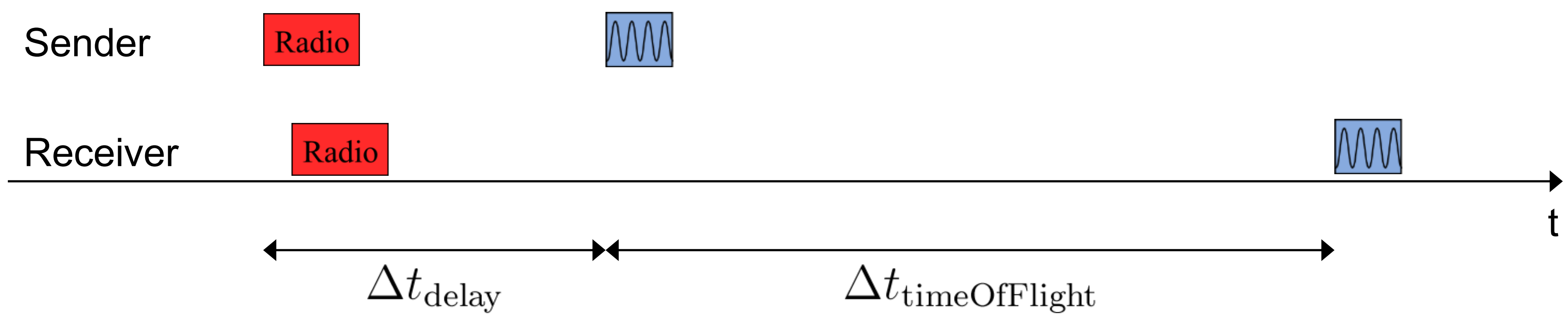


[Whitehouse et al., 2004]

Ultrasound Ranging

- Time difference of arrival (TDoA) between radio and ultrasound:
  1. Radio packet wakes up ultrasound receivers
  2. Ultrasound pulse is sent after a constant delay

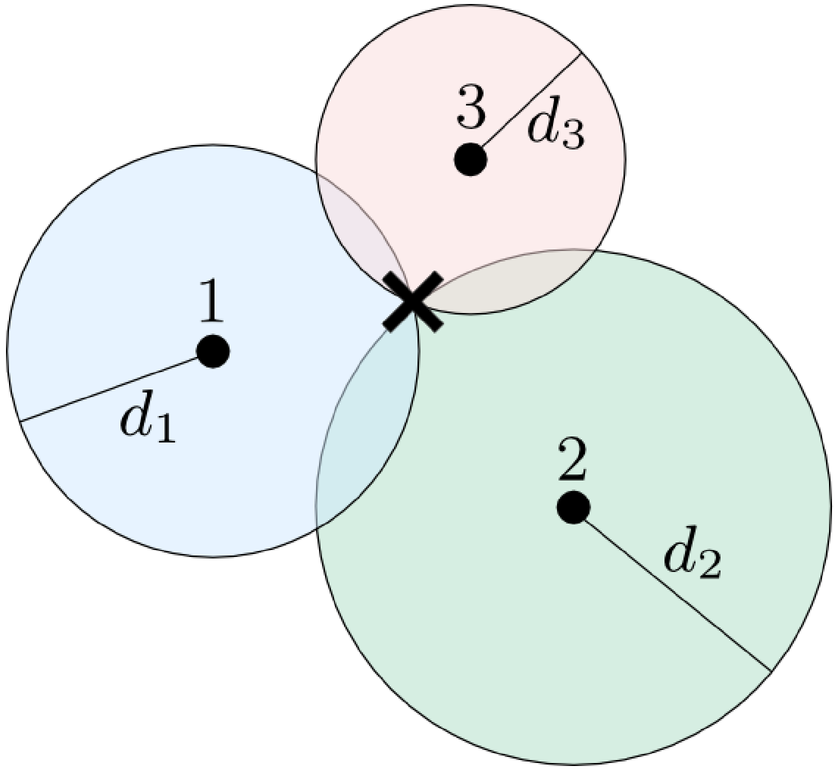
$c_{\mathrm{radio}} \approx 2.99 \cdot 10^8 \ \frac{\mathrm{m}}{\mathrm{s}}$ $\qquad$ $c_{\mathrm{sound}} \approx 343.2 \ \frac{\mathrm{m}}{\mathrm{s}}$



$$d = c_{sound} \cdot \Delta t_{\mathrm{timeOfFlight}}$$

Distance based Positioning in Sensor Networks

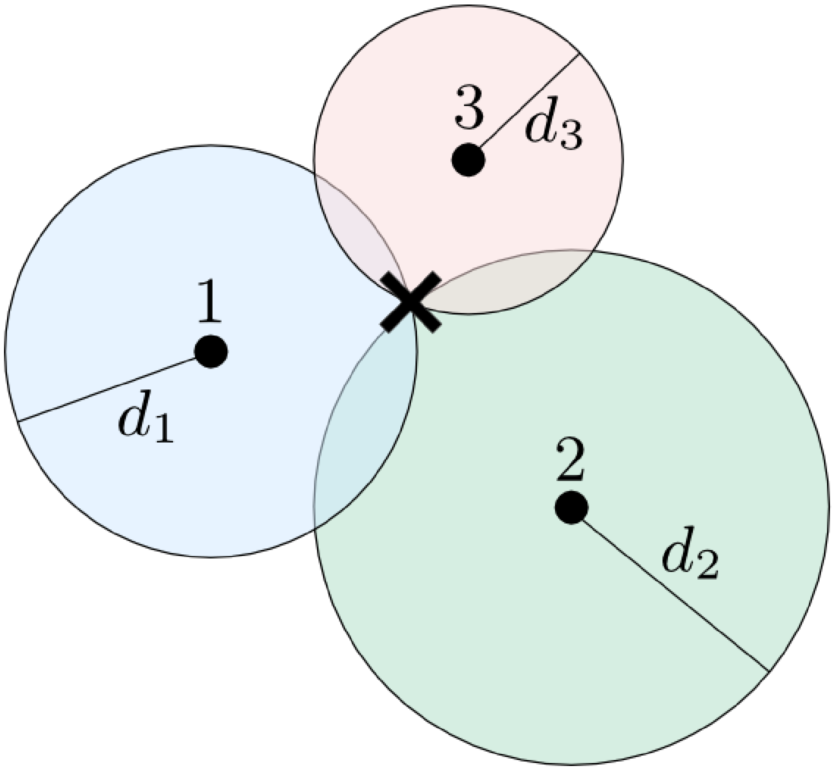
- Determine position based on distances to anchor nodes (trilateration)

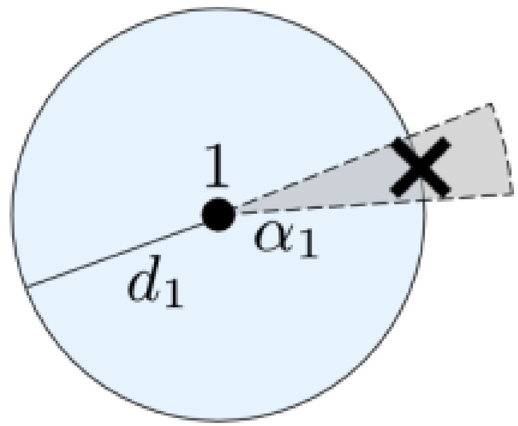


3 anchor nodes

Positioning in Sparse Networks

- How does angle information help to position nodes?





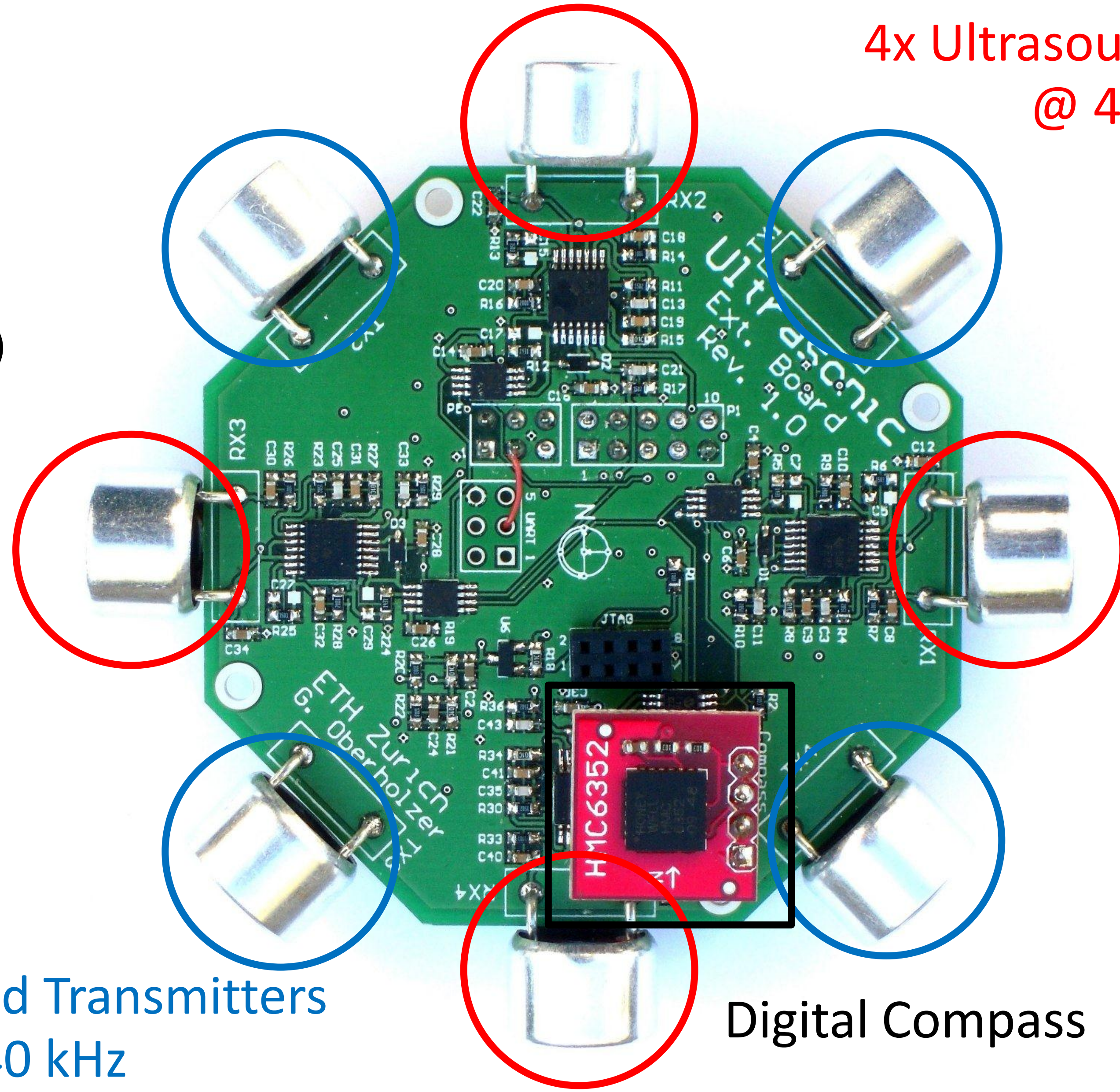
3 anchor nodes

1 anchor node

The SpiderBat Ultrasound Platform

4x Ultrasound Receivers
@ 40 kHz

6.5 cm
(2.56 inches)

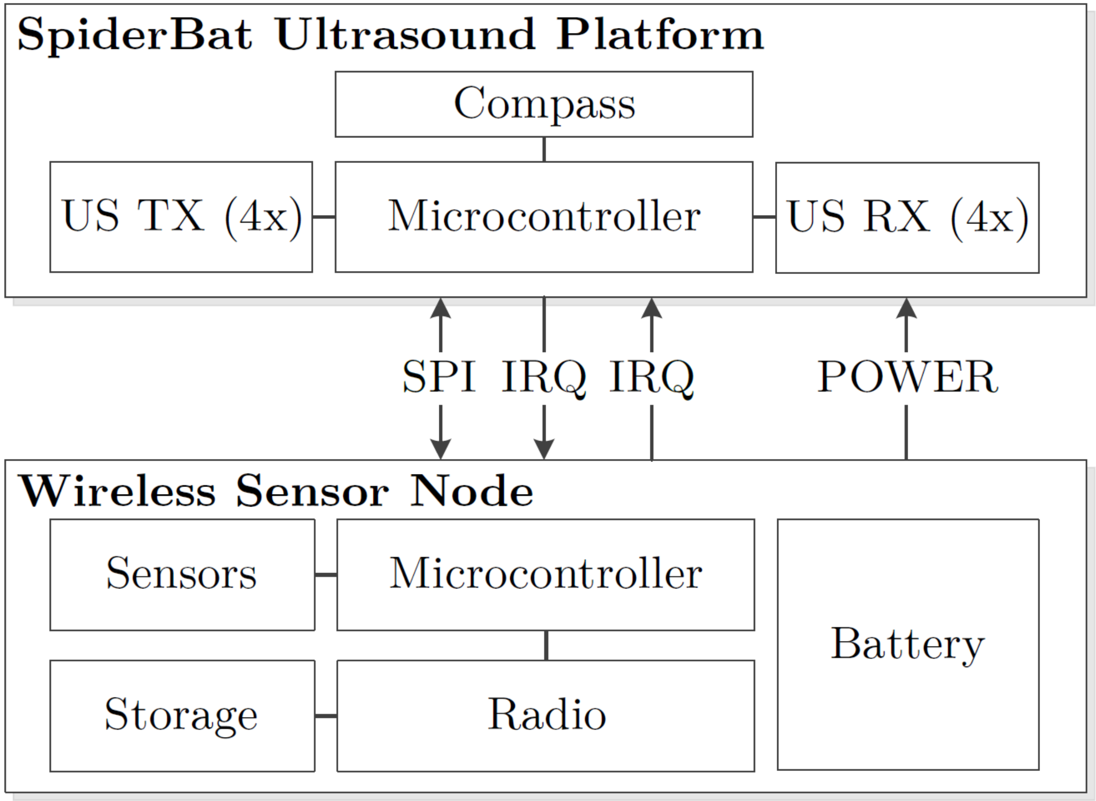


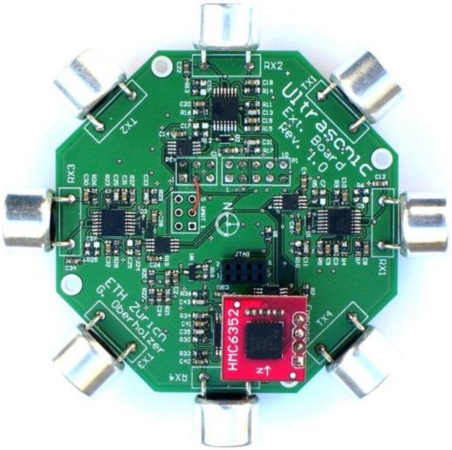
4x Ultrasound Transmitters
@ 40 kHz

Digital Compass

System Architecture

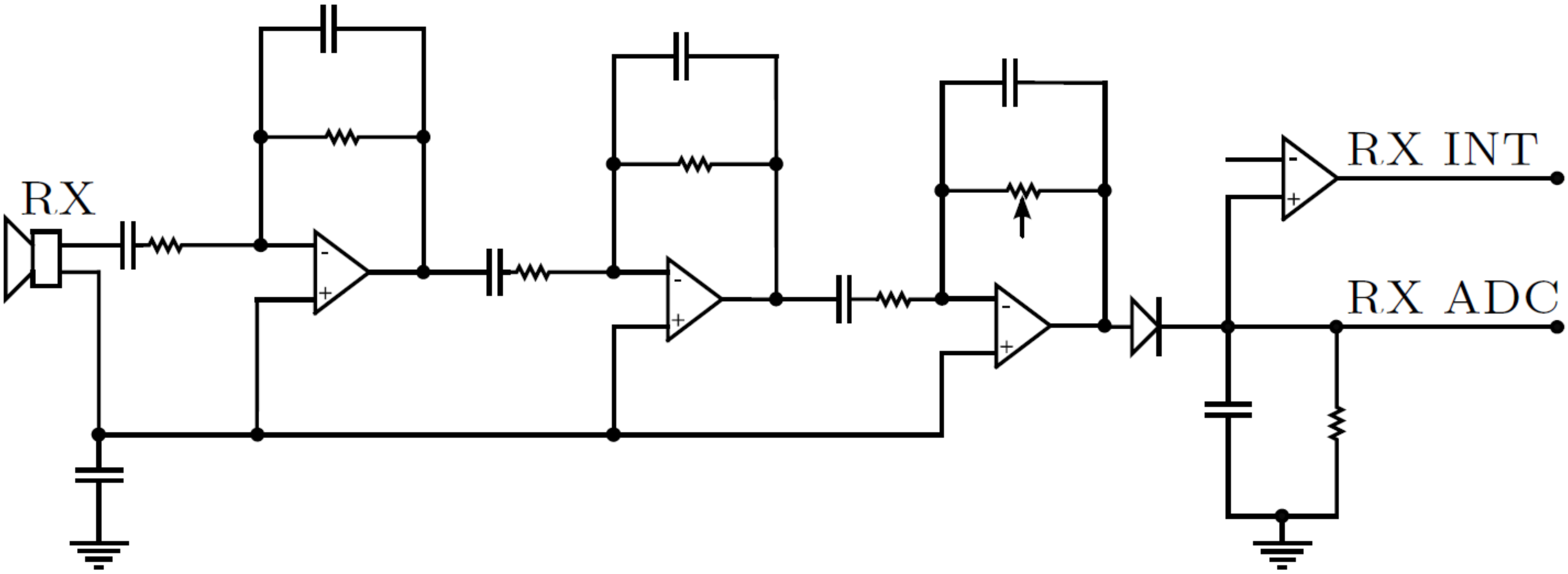
- SpiderBat is an extension board for wireless sensor nodes





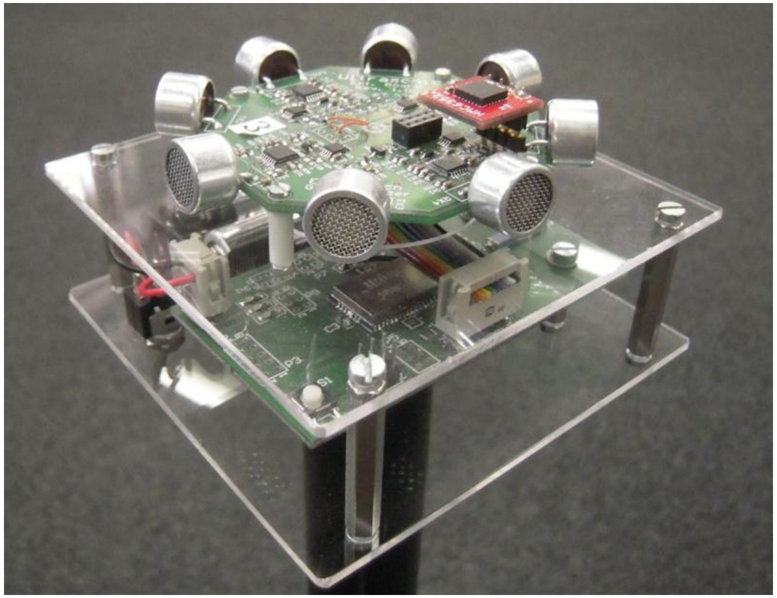
Ultrasound Receiver Circuits

- Three amplification stages with a total gain of 58-75 dB
- Each receiver provides two output signals:
  1. Digital comparator output generates an interrupt signal (RX_INT)
  2. Analog signal output (RX_ADC)



Experimental Evaluation

- Prototype Hardware
  - SpiderBat extension board
  - Atmel ZigBit900 (Atmega1281 MCU + RF212 radio)

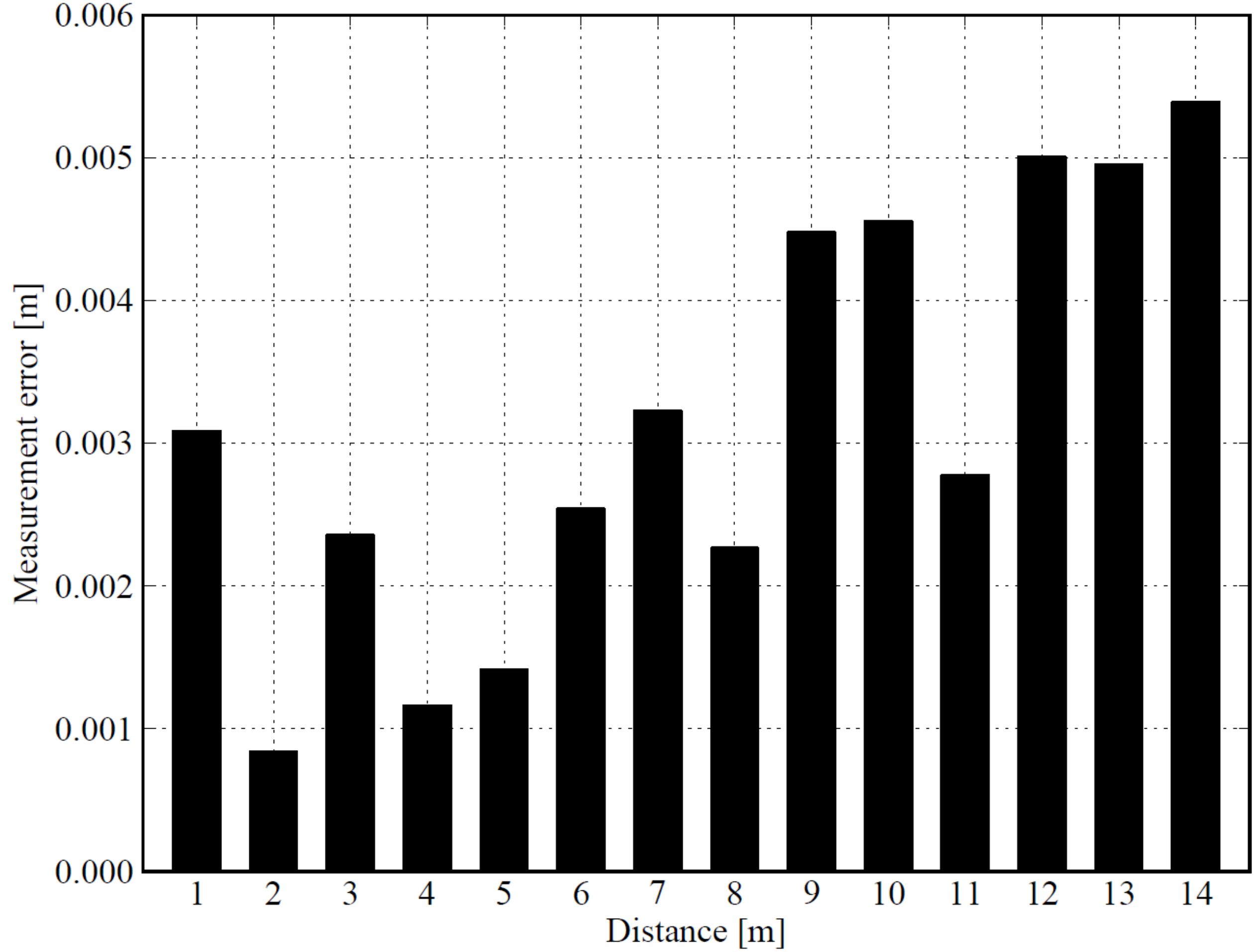


- Software
  - Ultrasound ranging application implemented in TinyOS 2.1
  - Distance/angle/compass information forwarded to a base station

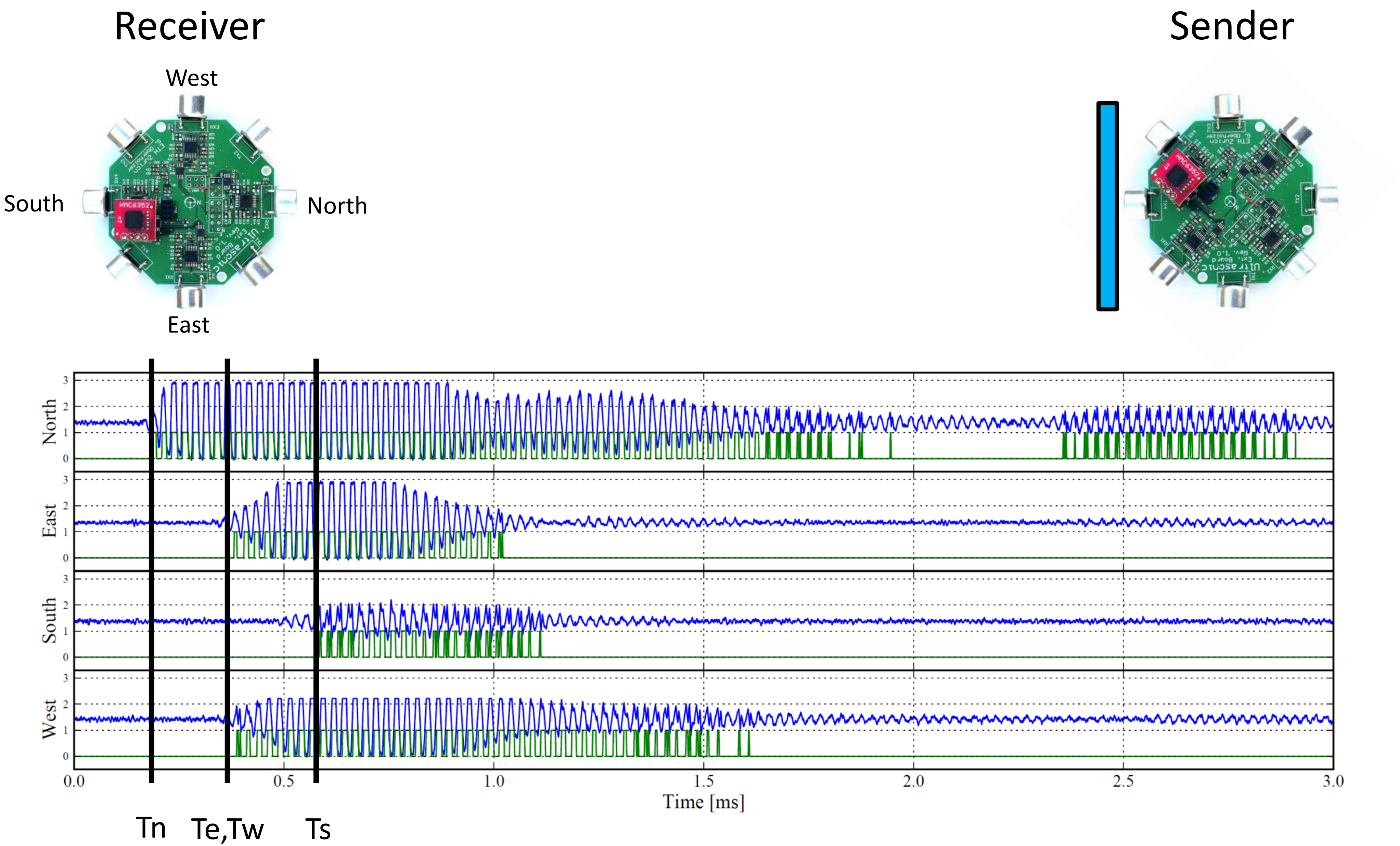
TinyOS

Accuracy of Distance Measurements

- Measurement errors are in the order of a few millimeters
  - Std. dev of error is 5.39 mm (0.21 inch) at 14 m (45.9 feet)

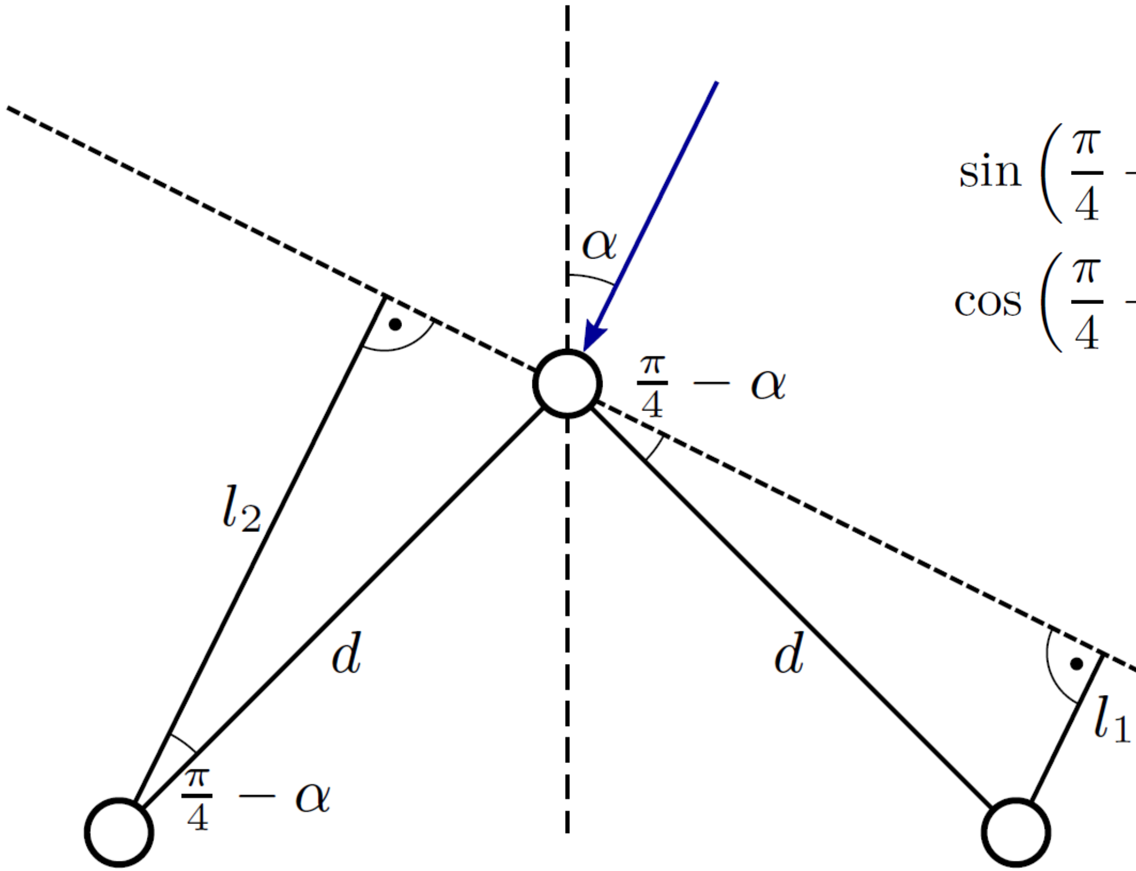


Angle-of-Arrival Measurements with SpiderBat



Angle-of-Arrival Estimation

- We can calculate the angle based on the TDoA at the receivers



$$\sin\left(\frac{\pi}{4}-\alpha\right) = \frac{l_1}{d} = \frac{c \cdot \Delta t_1}{d}$$

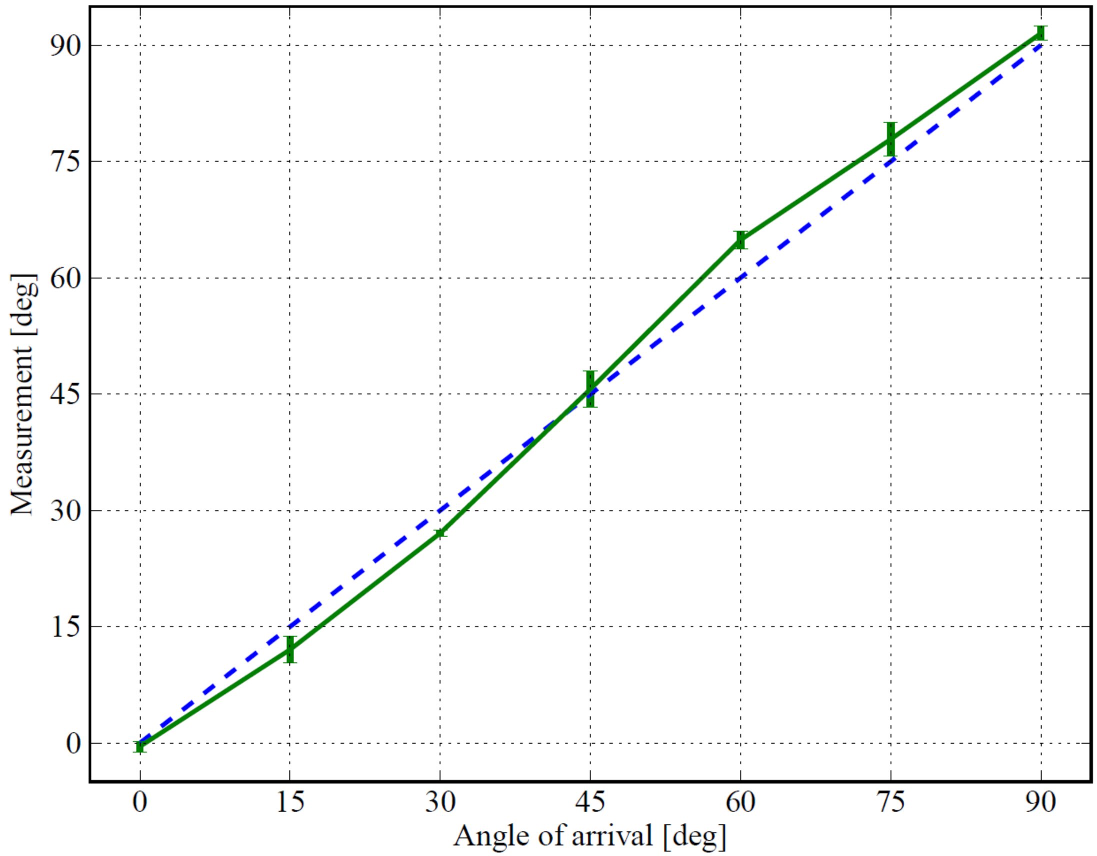
$$\cos\left(\frac{\pi}{4}-\alpha\right) = \frac{l_2}{d} = \frac{c \cdot \Delta t_2}{d}$$

$$\alpha = \frac{\pi}{4} - \arctan\left(\frac{\Delta t_1}{\Delta t_2}\right)$$

Accuracy of Angle Measurements

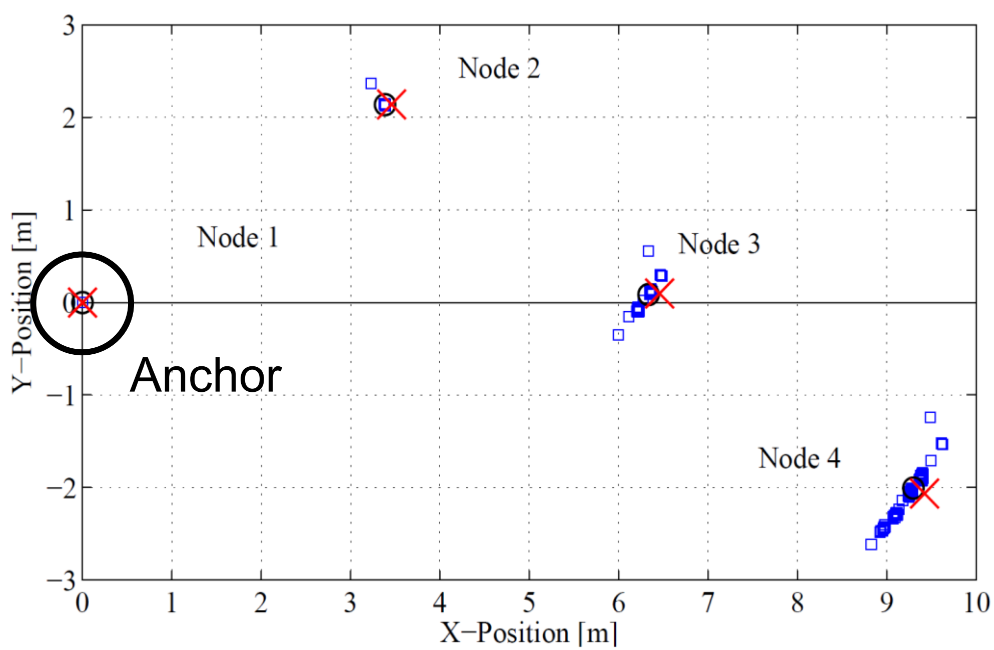
- Estimation of the angle-of-arrival within a few degrees

  Error is less than 5° for short distances between sender and receiver



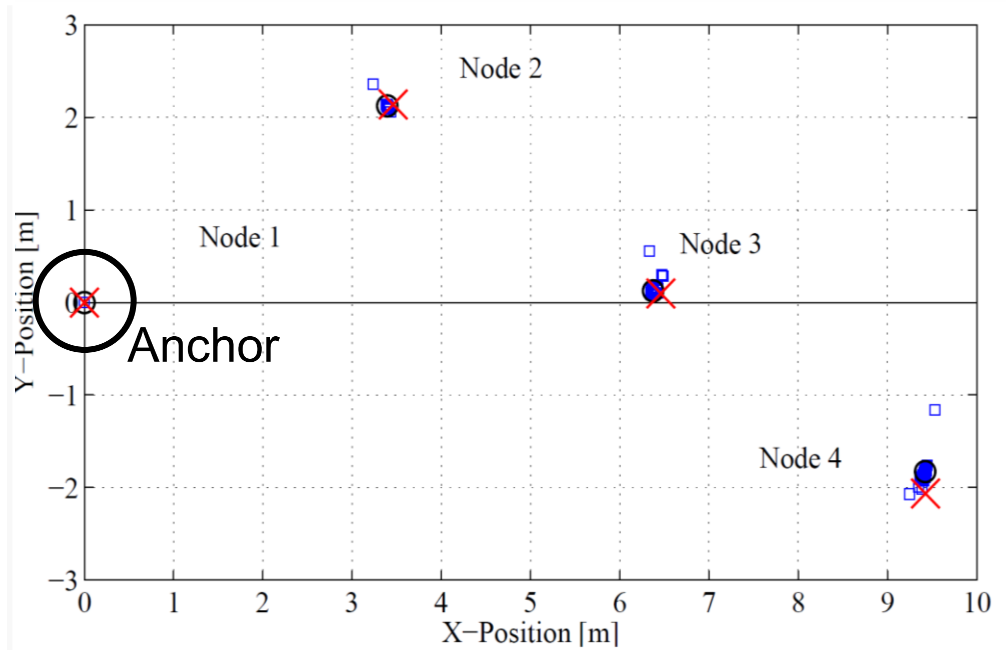
Indoor Experiments

- 4 nodes placed in a gym hall, single anchor node (Node 1)
- 200 measurements for each node



Step 1: Distance + angle to nearest neighbor

Std. dev. **< 15.5 cm (6.1 inch)**

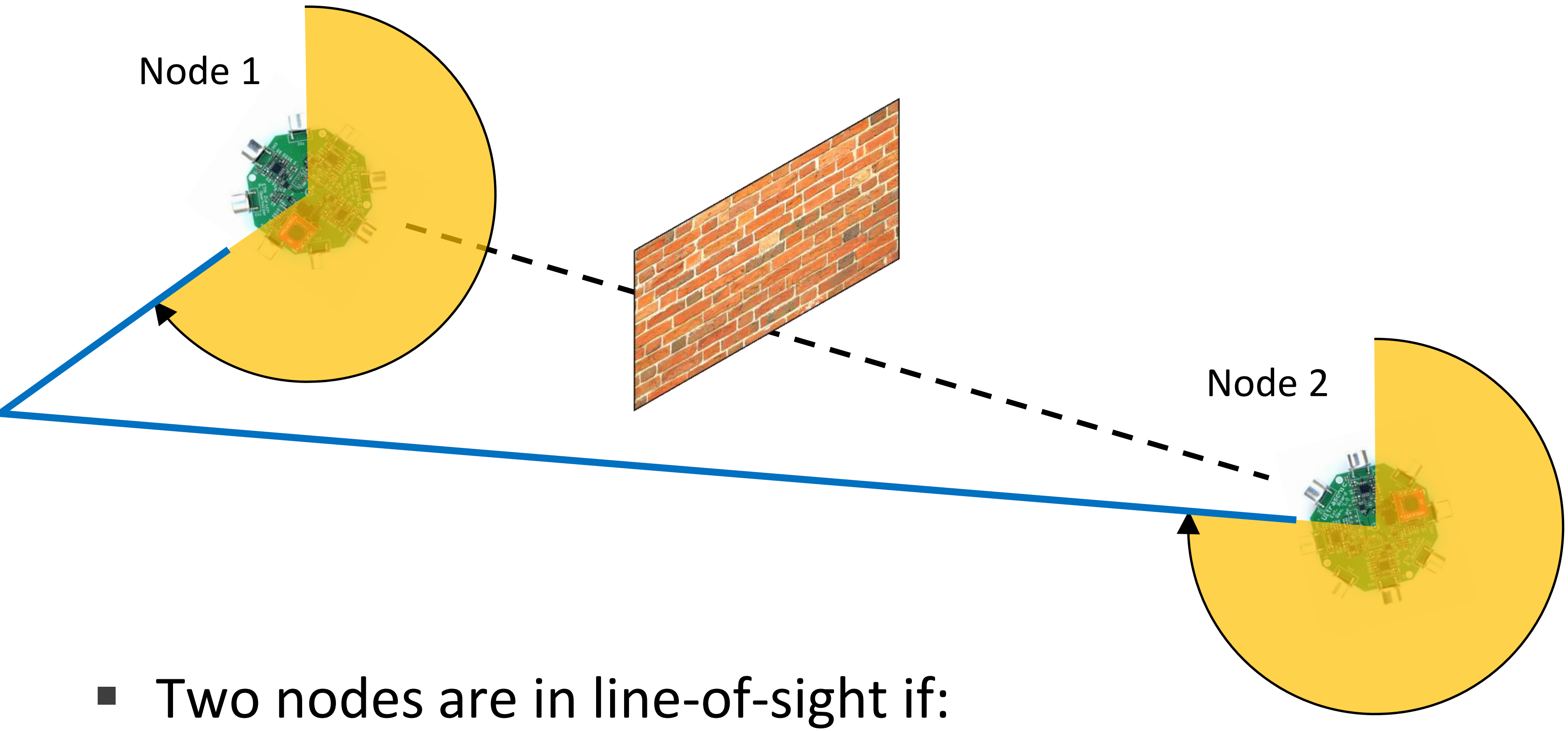


Step 2: Minimize distance errors (method of least squares)

Std. dev. **< 5.7 cm (2.2 inch)**

Non Line-of-Sight Propagation

- What if the direct path between two nodes is obstructed?

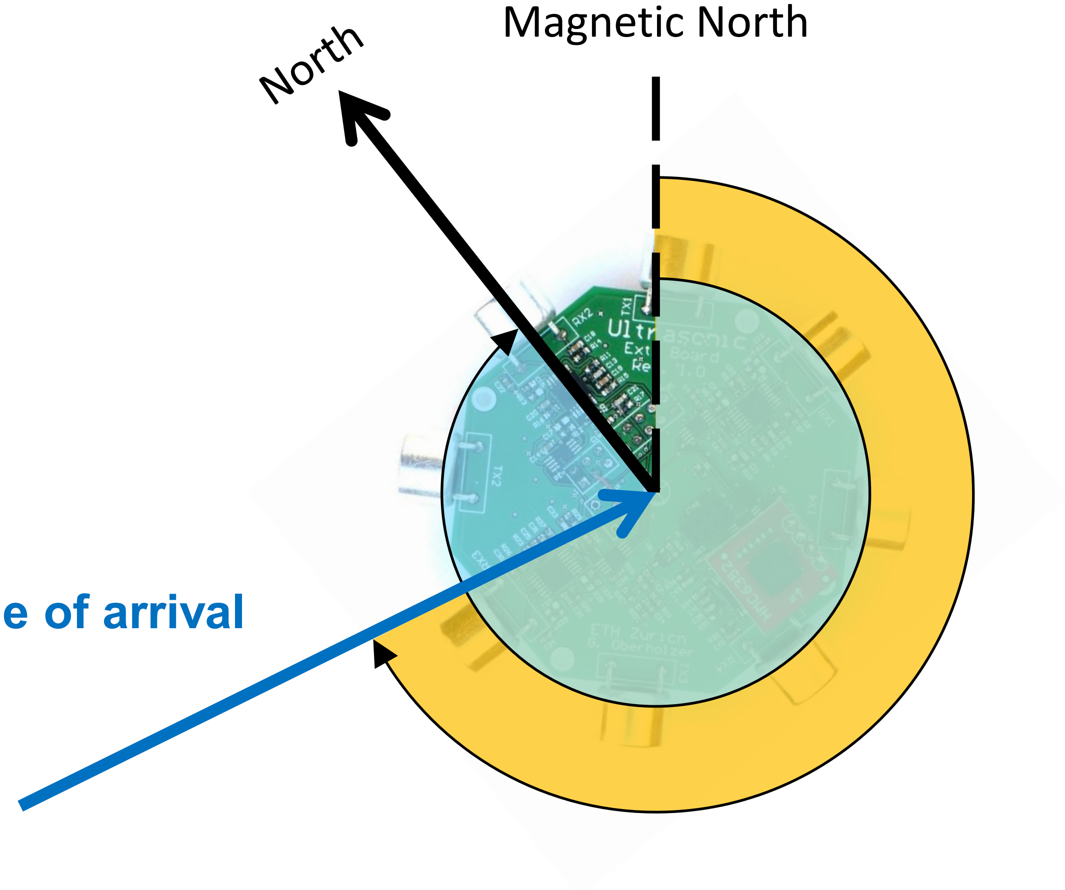


- Two nodes are in line-of-sight if:

$$\alpha_{\text{Node1}} = \alpha_{\text{Node2}} - \pi \pm \epsilon$$

Non Line-of-Sight Propagation

- We use the digital compass to get the node orientation



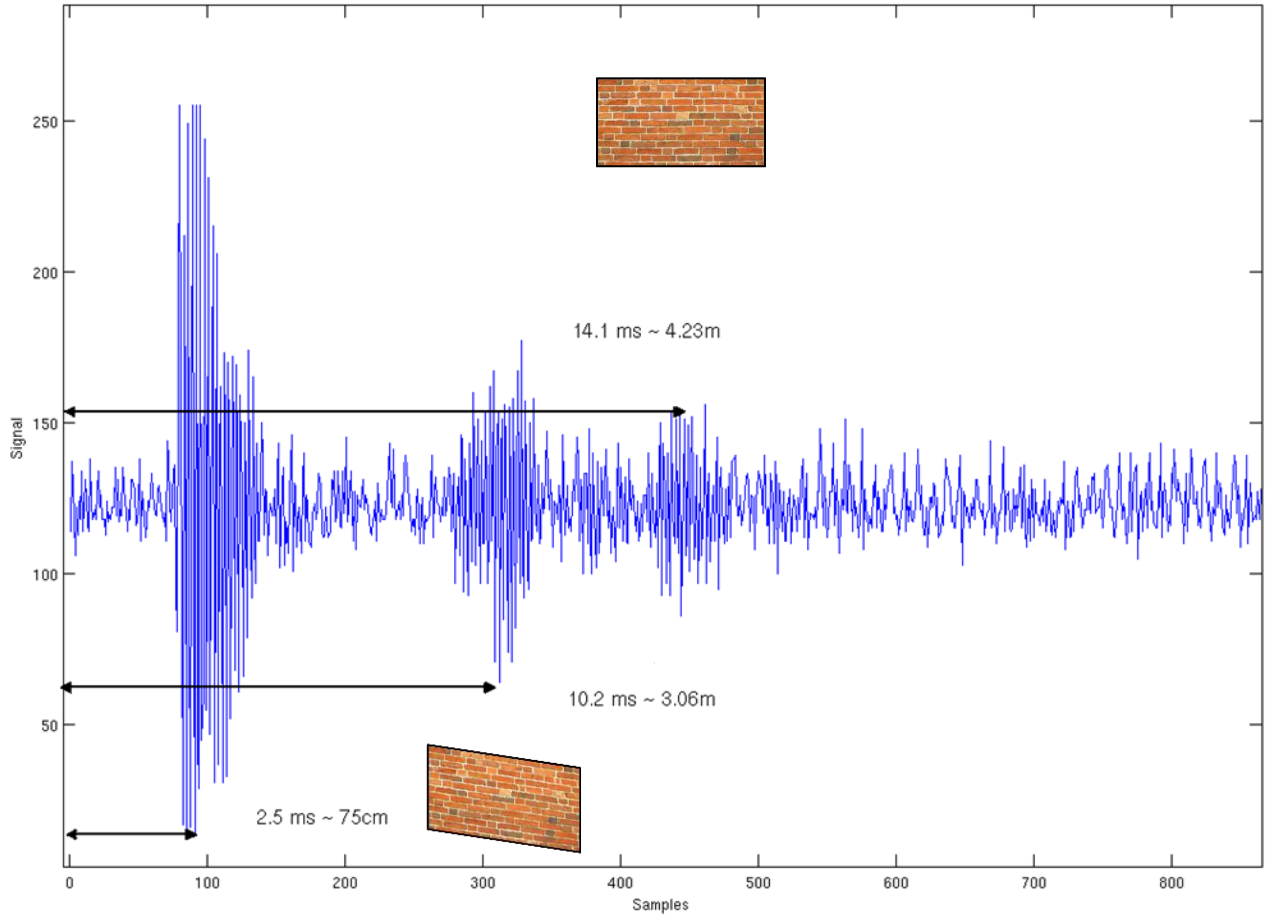
Honeywell HMC6352

We can use the digital compass to identify non-line of sight paths

Outlook: Learning about the Proximity of Nodes

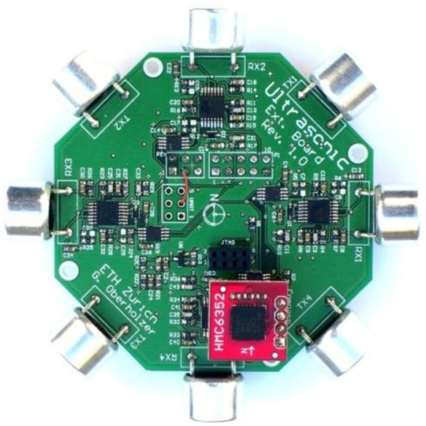
- Sampling the received ultrasound signal

  Idea: Identify reflection at nearby obstacles

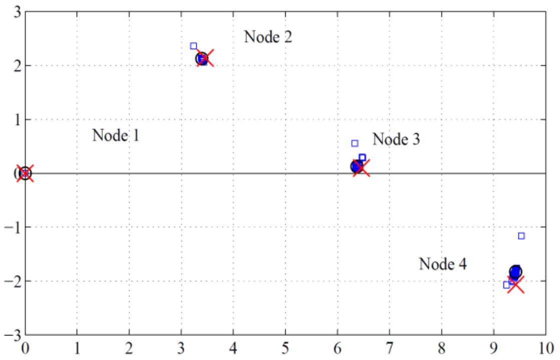


Conclusions

- SpiderBat platform
  - Ultrasound extension board for sensor nodes
  - **Distance** and **angle** measurements
  - Digital compass



- Experiments
  - Std. dev. of localization error below 5.7 cm (indoor setup)



- Non-line of sight propagation
  - Detect obstacles between nodes