Low-Cost WLAN based Time-of-flight Trilateration

Precision Indoor Personnel Location and Tracking
for Emergency Responders
Third Annual Technology Workshop,
August 5, 2008
Worcester Polytechnic Institute, Worcester, MA

Dr. Christian Hoene

Computer Science Department, University of Tübingen, Germany

Outline

- Motivation
- Four-way TOA
- Quantization Issues
- Implementation
- Evaluation
- Summary

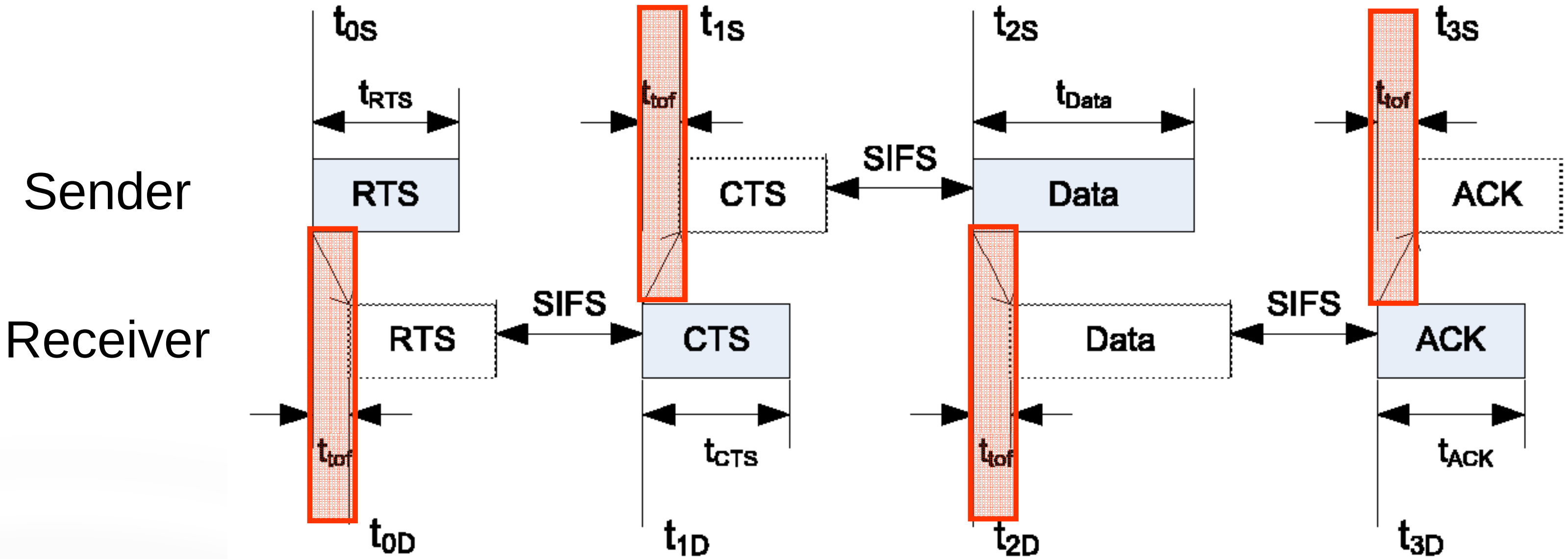
Motivation for Indoor Locating with WLAN

- Sophisticated location systems might not always be available
  - because they are too expensive especially for developing countries
  - because they are not available if needed.
- Instead, why not use WLAN
  - it is cheap and virtually everywhere available.
- In addition, WLAN can transmit various data, such as
  - speech to command and control first responders,
  - video streams from first responders, and
  - physiological status monitoring

Locating Tracking with Wireless LAN

- State of the Art:
  - Using Received Signal Strength Indications (RSSI)
- Alternative:
  - Time of arrival (TOA) using the two-way time of flight of WLAN packages between sender and receiver [McCrady2000]
- Advantage:
  - TOA measurements scale linearly with open-air propagation distances
- Challenge:
  - Can we use cheap, off-the-shelf hardware?

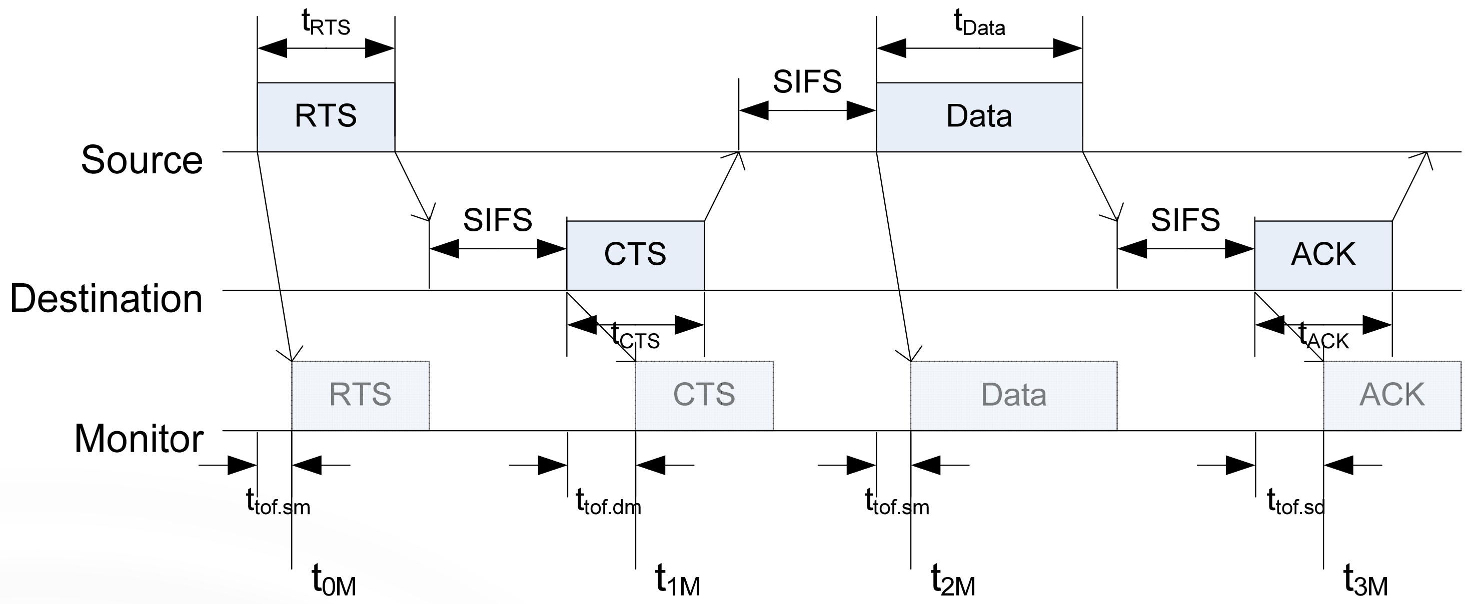
Accurate Measurement with Four-way TOA



$$t_{tof} = \frac{1}{4}\left(t_{3S} - t_{0S} - t_{DATA} - t_{CTS} - t_{RTS} - 3t_{SIFS}\right)$$

- Every IEEE 802.11 card supports RTS/CTS.
- TOA measurement conforming to IEEE 802.11 protocol using 4 transmission steps [Hoene2008]

Indirect and Cooperative TOA



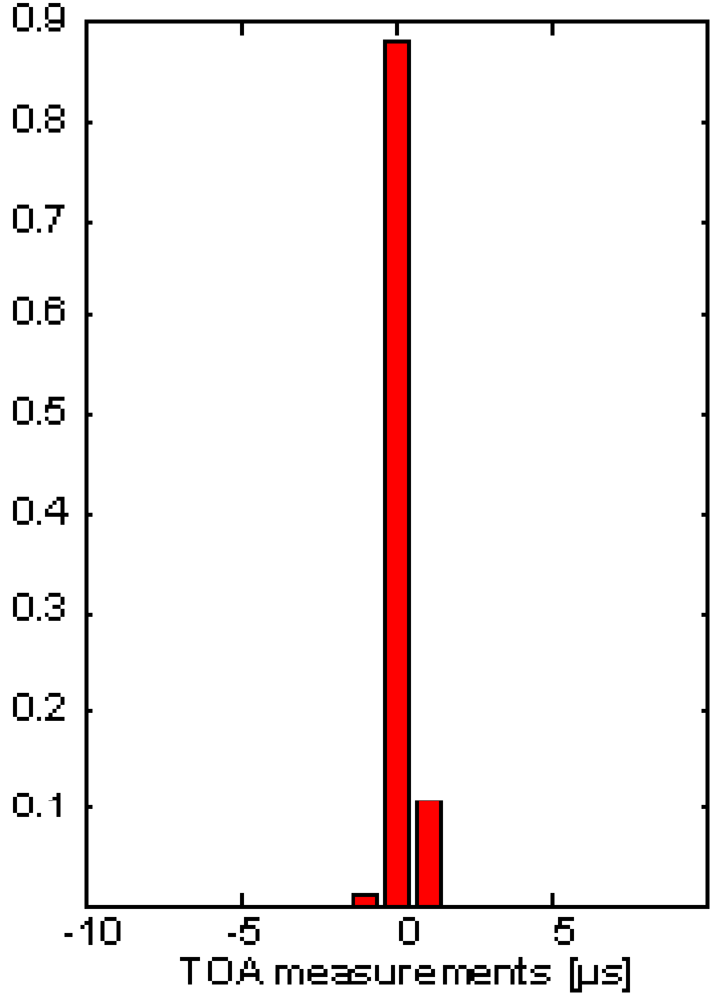
- Assume a third node monitors the transmission
- Then it also can calculate the time of flight:

$$t_{0M} - t_{tof.sm} = t_{2M} - t_{tof.sm} - 2t_{SIFS} - 2t_{tof} - t_{CTS} - t_{RTS}$$

$$\Leftrightarrow \quad t_{tof} = \tfrac{1}{2}\left(t_{2M} - t_{0M} - 2t_{SIFS} - t_{CTS} - t_{RTS}\right)$$

Overcoming Quantization 1/2

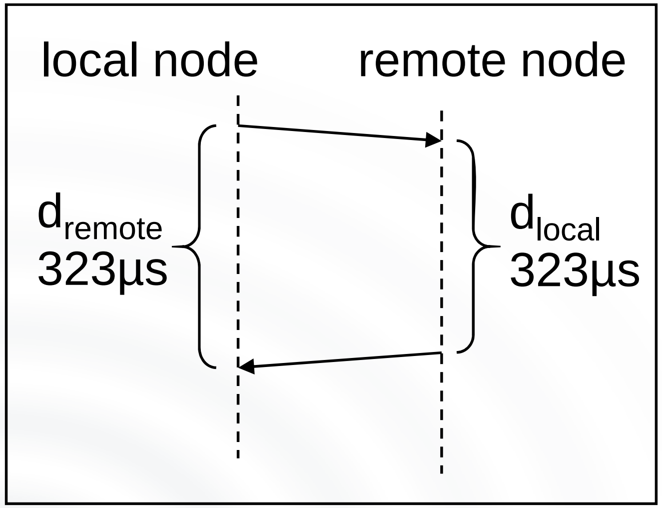
- WLAN clocks have low resolution.
- Time is „quantized“.
- For example, WLAN cards provide a clock resolution of 1µs to the device drivers.
- Example of typical two-way TOA measurement with WLAN cards (right)



Overcoming Quantisation 2/2

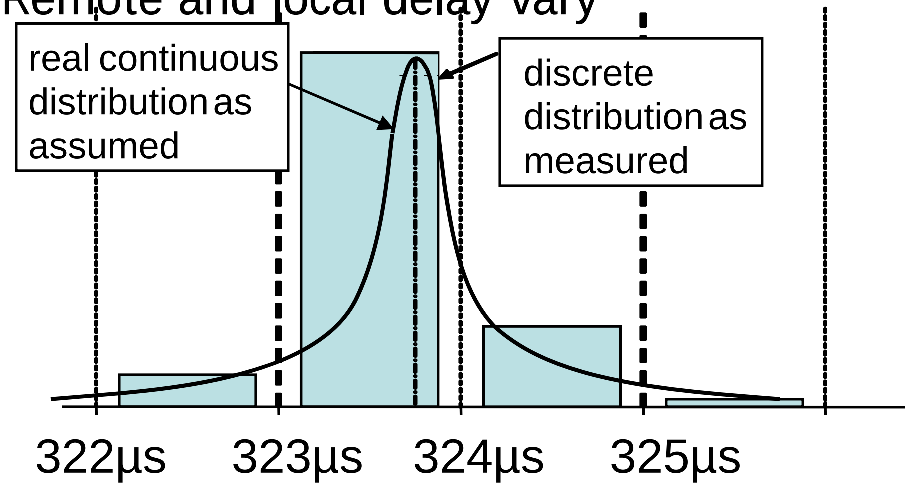
Problem

- WLAN cards' max. resolution = 1 µs (1µs → 300m)
- time-of-flight cannot be measured directly



Solution

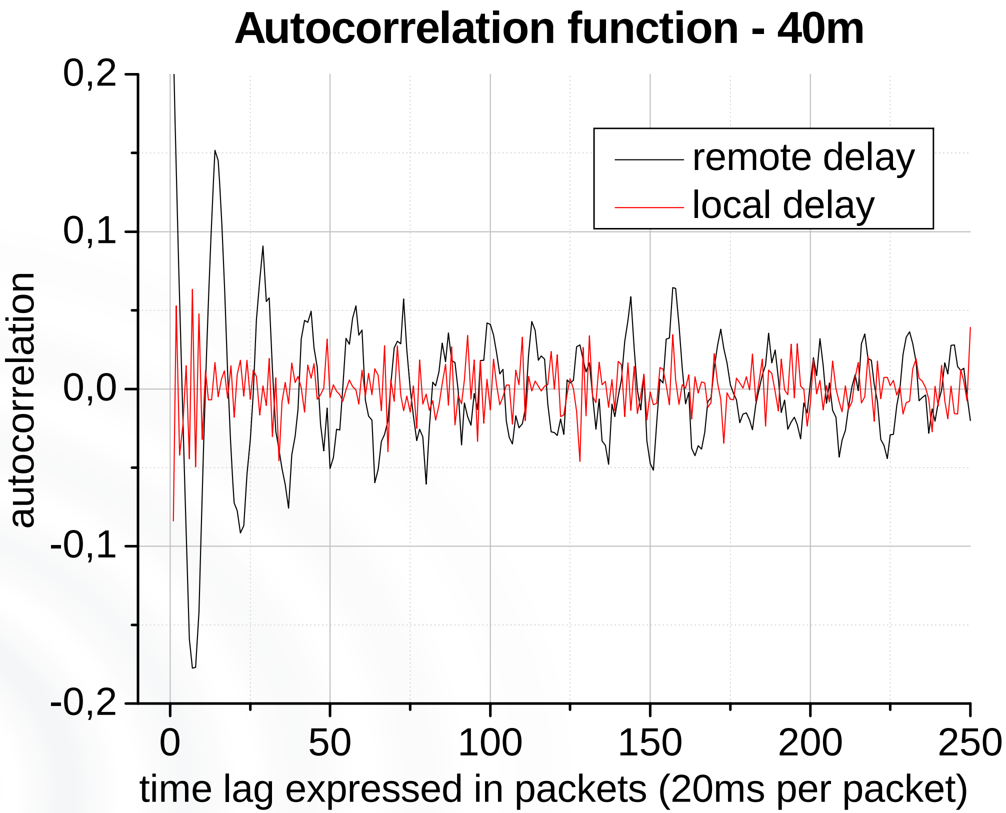
- Remote and local delay vary



- due to
  - *Thermal Gaussian noise* ?
  - *Multi path?*

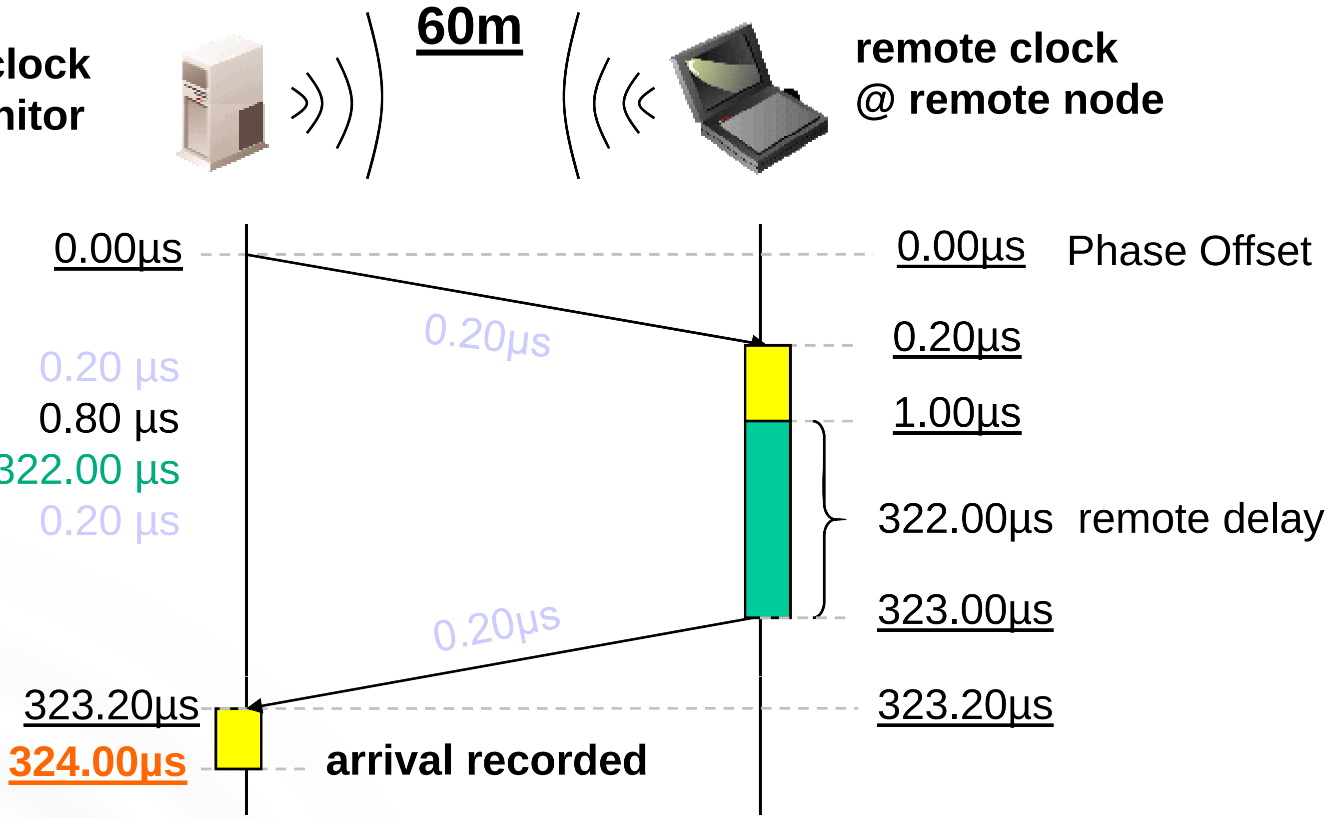
Beat Frequencies 1/4

- Two-way TOA delay measurements are not random
  → no Gaussian noise!
- Block pattern results in an alternating autocorrelation function (frequency 3.5 Hz)



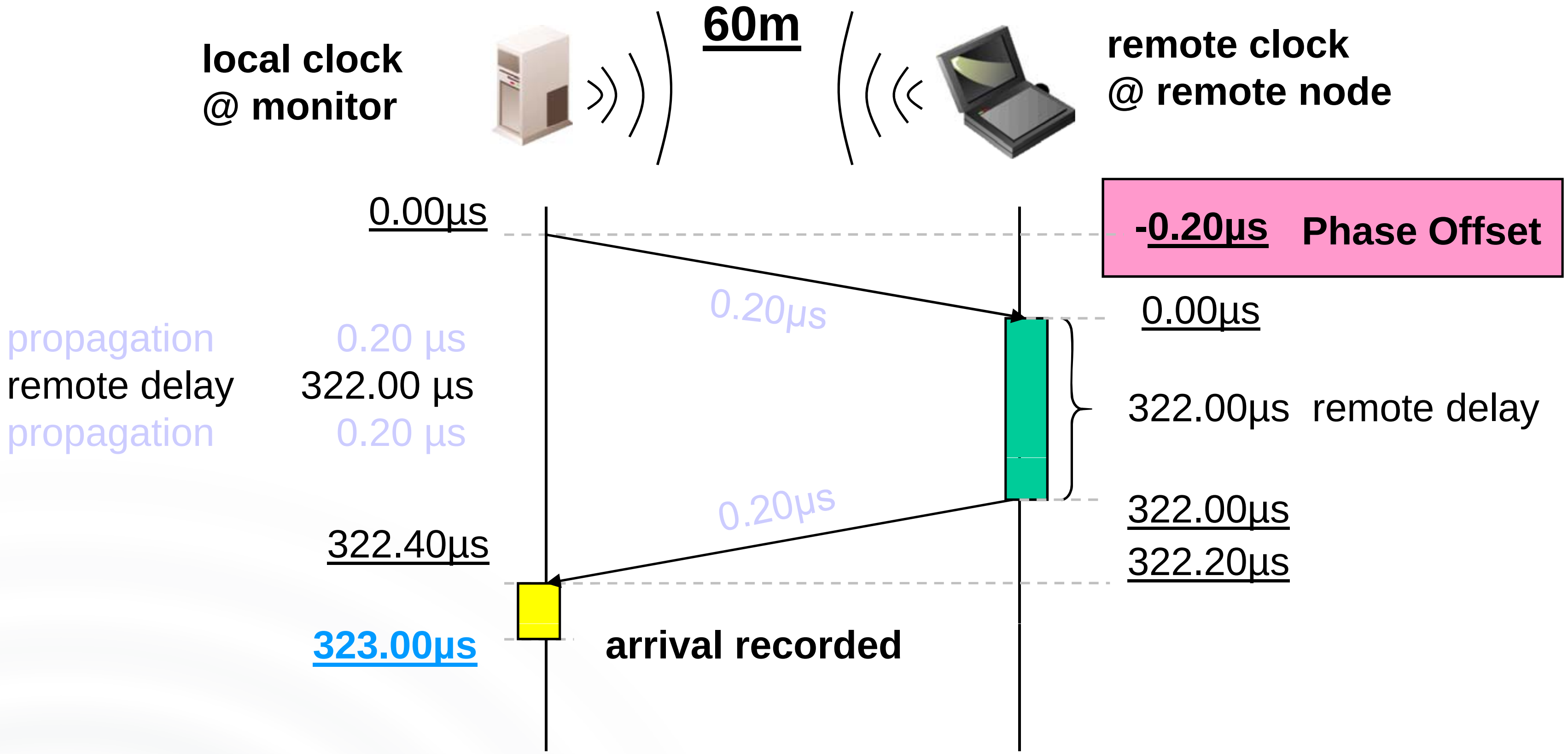
Beat Frequencies 2/4

propagation	0.20 µs
wait to receive	0.80 µs
remote delay	322.00 µs
propagation	0.20 µs



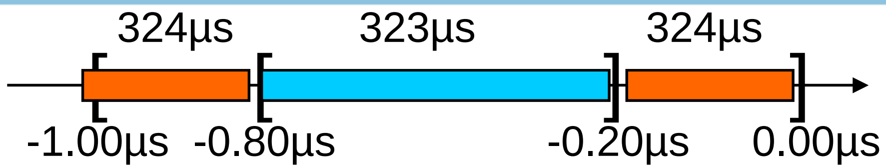
- Assumptions :
  - MAC protocol works in discrete time steps (1µs)
  - Local and remote clocks have same speed and phase offset

Beat Frequencies 3/4



- Assumptions :
  - MAC protocol works in discrete time steps (1µs)
  - Local and remote clocks have same speed but **different phase offset**

Beat Frequencies 4/4



phase offset

- Mean remote delay over all phase offsets is 323.40=322+1+2*0.20
- Crystal oscillators have Frequency tolerances
  → Relative clock drift between the two wireless LAN card clocks
- Assumption
  - no clock drift during a round trip time period
  - but phase offset changes for the next RTT observation
- Phase offset changes slowly over time and repeats
- Phase change results in a frequency that equals the beat frequency.

Beat Frequency:

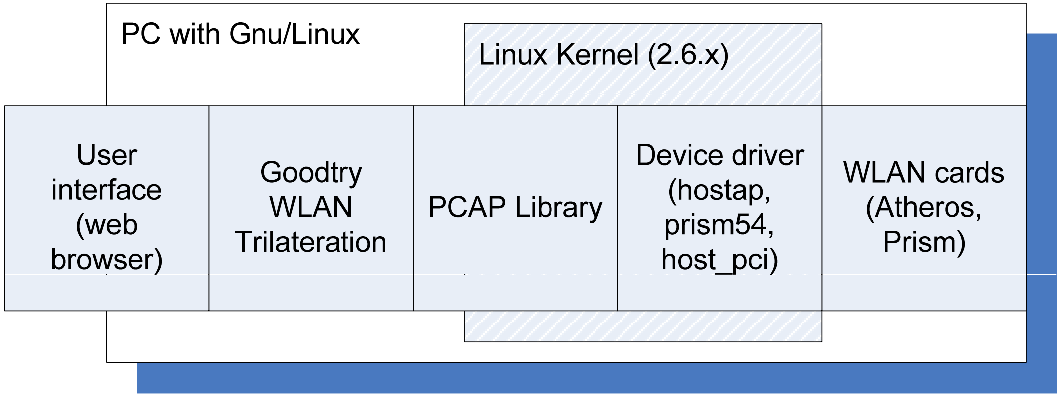
$$f_{beat} = | f_{local} - f_{remote} |$$

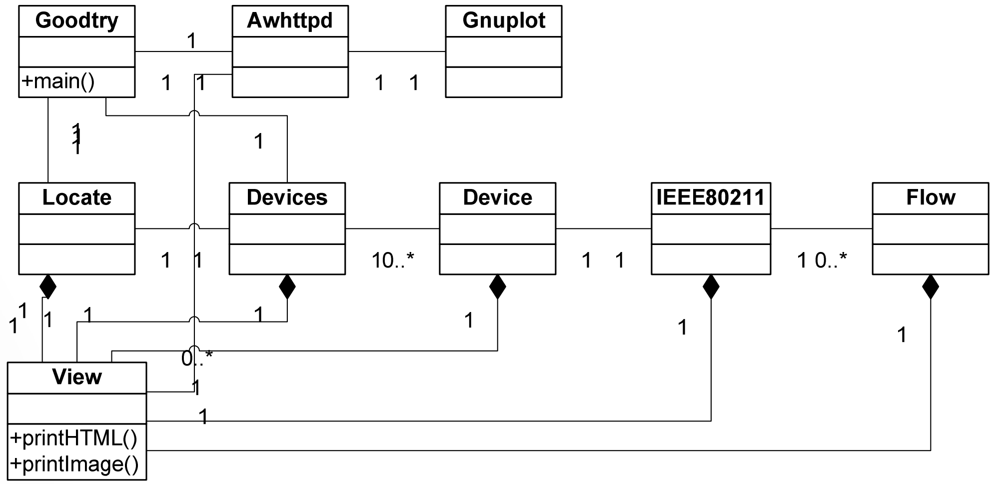
Relative clock drift:

$$\frac{f_{beat}}{f_{MACclocking}} = \frac{3.5\text{Hz}}{1\text{MHz}} = 3.5\text{ppm}$$

Implementation named "Goodtry"

- „Goodtry“ implements the above mentioned algorithms.
- Uses off-the-shelf WLAN cards
- Open-source available under BSD license www.ambisense.org
- But, does it works?





Device: ath37 - Mozilla Firefox

File Edit View History Bookmarks Tools Help

http://10.159.1.200:8000/P0x806b460

AmbiSense Project
Tracking
WLAN Devices
Contact

Device: ath37

Hardware	Atheros (168C):AR5212/AR5213 (0013)
Type	RADIOTAP
Received Packets	3542007
Show details	

IEEE 802.11

Beacons

MAC address	ESSID	Clock drift	Details
00022D879219	WSI_Abt_RA	0 ± 0 ppm	details
004096575809	BELWUE	12.6387 ± 0.00063 ppm	details
061B2FAFBA33	AmbiSenseAP2	5.0119 ± 0.00013 ppm	details

Flows

Source MAC address	Destination MAC address	Packet sequences	Distance [m]	Details
southwest	robin	89501	13.3 ± 0.9	details
northwest	robin	89931	9.7 ± 0.9	details
southeast	robin	99066	6.3 ± 0.9	details
west	robin	89559	3.8 ± 0.9	details
east	robin	100884	6.7 ± 1	details
northeast	robin	98949	4.4 ± 0.9	details
0020E08F9588	004096408187	1	nan ± nan	details
robin	0001360DD091	11612	nan ± nan	details
robin	southwest	112136	12.3 ± 0.9	details

Experimental Setup 1/2

- What is the accuracy?

WLAN antennas

Mobile service robot (RWI B21)

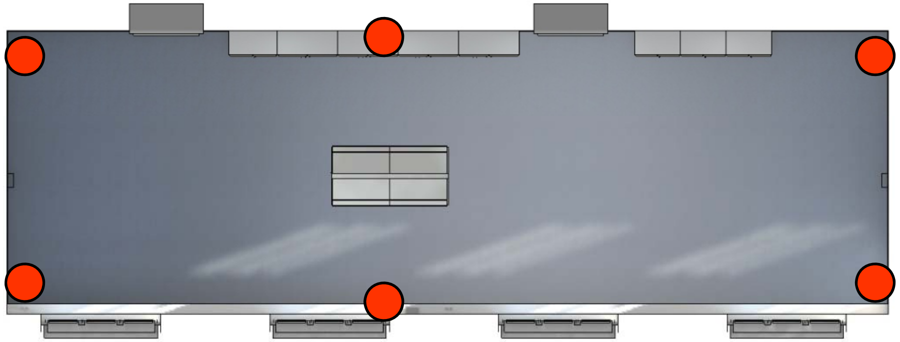
- 2 WLAN PCI cards + antennas (for pings and TOA measurements)
- 240° laser scanner (reference positioning)

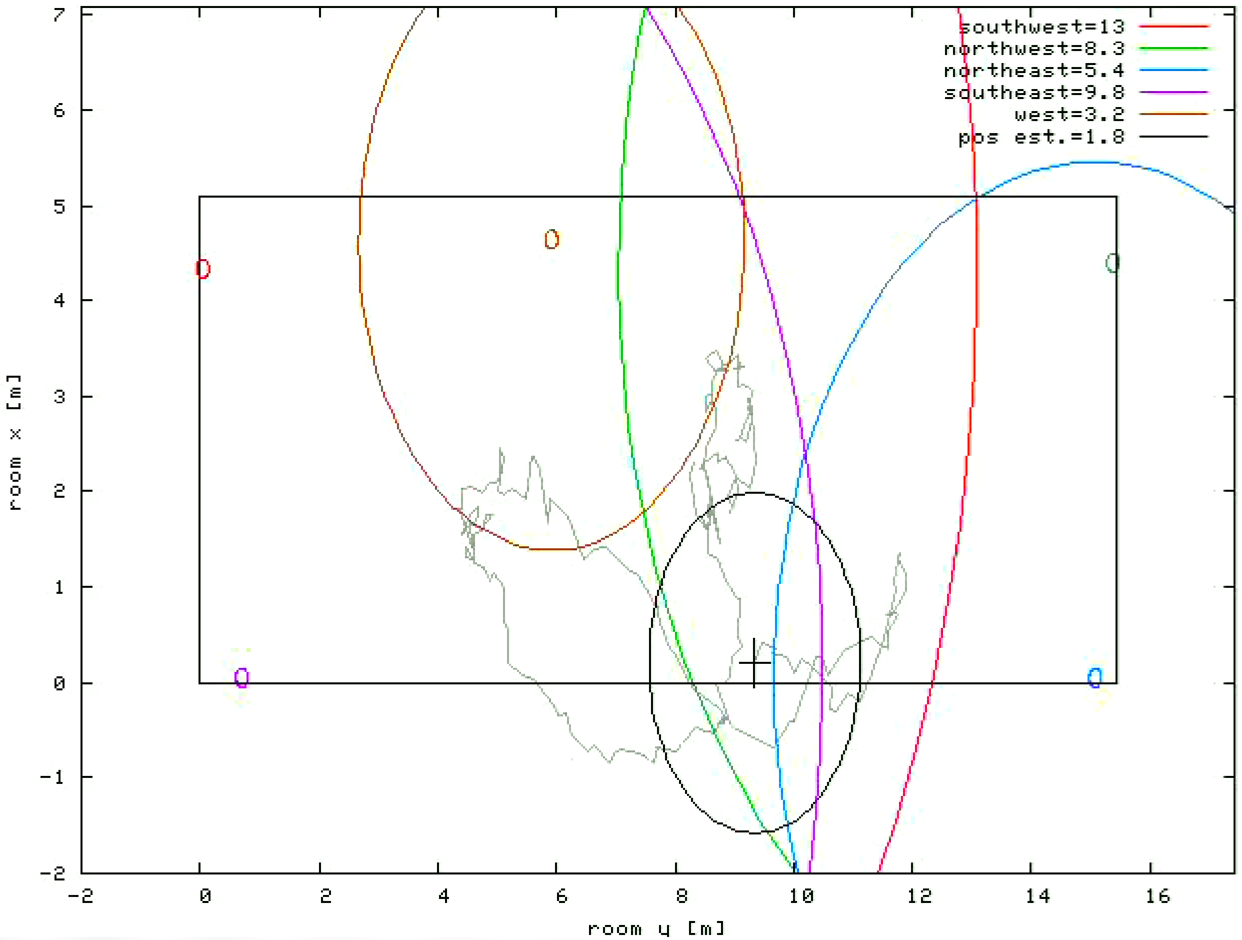
Laser scanner ⇨ accurate reference positioning

Experimental Setup 2/2

Laboratory with landmarks of known positions

- 6 WLAN access points





southwest=13
northwest=8.3
northeast=5.4
southeast=9.8
west=3.2
pos est.=1.8
room x [m]
room y [m]

Summary

- The IEEE 802.11 MAC protocol is inherently time synchronous, why not use this feature for TOA measurement?
- Interoperability is given.
- An interface for TOA and RSSI tracking has been included into IEEE draft 802.11v (2006)
- Multiple research groups have verified these results.
- This method is still in research
- Its application for indoor locating seems promising!

Thank you for your interest!

Acknowledgments

- This work was funded by the Landesstiftung Baden-Württemberg in the scope of the BW-FIT project AmbiSense.

References

- [McCrady2000] D. McCrady, L. Doyle, H. Forstrom, T. Dempsey, and M. Martorana, "Mobile ranging using low-accuracy clocks," IEEE Transactions on Microwave Theory and Techniques, vol. 48, pp. 951, 2000.
- [Hoene2008] Christian Hoene and Jörg Willmann. Four-way TOA and software-based trilateration of IEEE 802.11 devices. In *IEEE PIMRC*, Cannes, September 2008.
- [Günther2005] A. Günther and Christian Hoene. Measuring round trip times to determine the distance between WLAN nodes. In *Networking 2005*, Waterloo, Canada, May 2005.