A Time-of-Flight based Localization Option for 5 GHz Wireless LAN

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Outline

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Motivation and Methods for Distance Measurements

WLAN and similar wireless communication systems are widely used.

Localization option is a nice add-on for many applications.

Requirements, scenarios, and solutions / efforts may be quite different.

Primary Localization Systems (no communication), passive peer "station":

- Satellite navigation: outdoor – precision around 10 m – I can localize myself
- Radar based systems: precision downto millimeters – I can localize others or myself

Coming from Communication Systems, requiring an active peer station:

- RSSI-based methods: simple, but calibration required – sensitive to environment changes
- Two-way ranging in WiFi: precision @ 60 GHz: few cm (with special signal sequences)
  precision @ 5-6 GHz: ≈ 20 cm (100 MHz bandwidth, special sequences)
- Ultra wide band systems: pulses @ around 7 GHz – precision about 1 cm (IHP system)

Goal of this work is a simple hardware solution for WiFi in the 5 GHz band (IEEE 802.11a).

Measurement Principle for Two-Way-Ranging

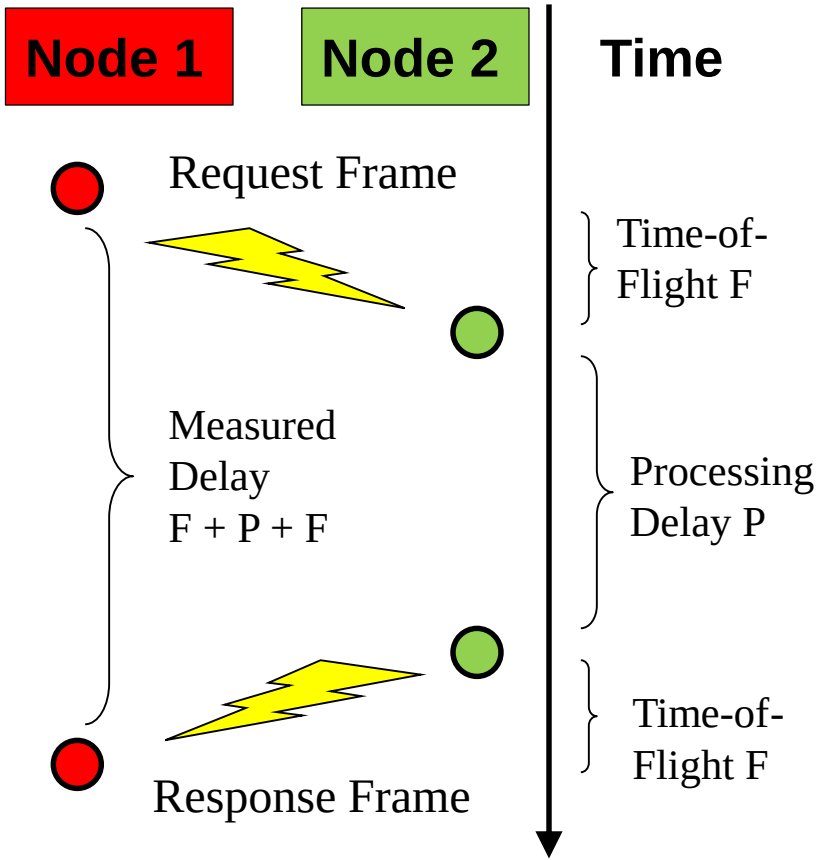
One pair of frames is exchanged between two nodes while timestamping TX and RX times of the frame at both nodes.

For typical WLAN scenarios:

- time-of flight “F“ is up to a few 100 ns
- processing delay “P“ is up to a few ms
- clock accuracy is better than 20 ppm
  clocks at nodes need not to be synchronized

Timestamping shall be done in hardware, not software, to achieve good accuracy.

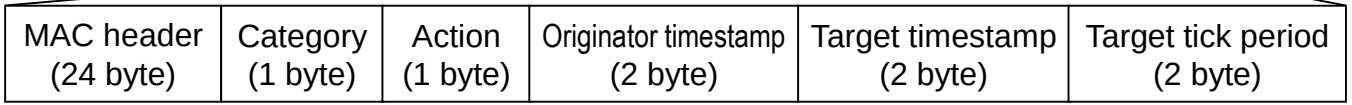
Standard IEEE 802.11 frame format + preamble shall be used.



Compliance with IEEE 802.11 MAC Protocol and Frame Formats

Basic frame format in IEEE 802.11(a):

Use “Action“ frame for delay measurement:



“Category”: ID must be assigned by IEEE

“Action”: = 0: DelayMeas.request
= 1: DelayMeas.response

“Originator timestamp”: timestamps of Node 1

“Target timestamp”: timestamps of Node 2

“Target tick period”: clock tick period in 1/12 ns
only in DelayMeas.response frames
permits systems operating at different clocks

Actions to be performed for a Delay Measurement

DelayMeas.request frame

- Originator: MAC (Software) — build DelayMeas.req frame, wait till TX is allowed by protocol
  Baseband (FPGA) — insert Originator timestamp, re-calculate CRC
- Target: Baseband (FPGA) — insert Target timestamp, re-calculate CRC
  MAC (Software) — receive frame, check CRC

optionally: Acknowledgement

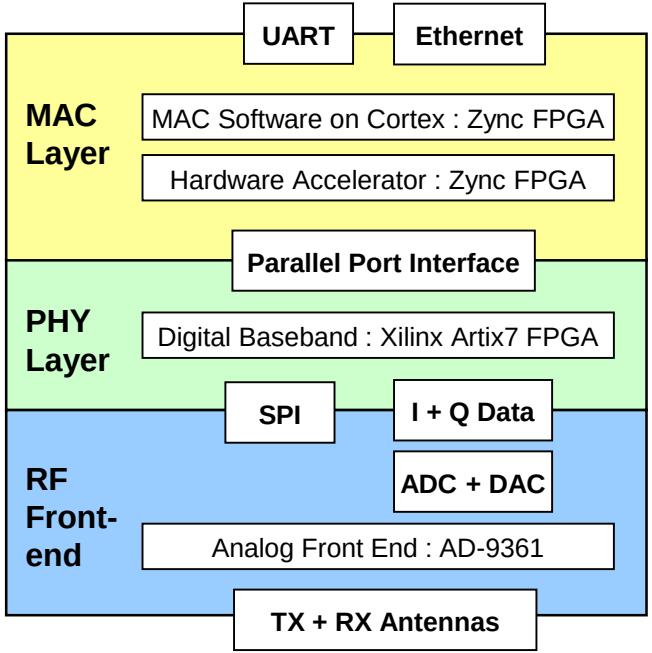
DelayMeas.response frame

- Target: MAC (Software) — build DelayMeas.rsp frame, copy both timestamps, insert "Target tick period", wait till TX is allowed
  Baseband (FPGA) — replace Target timestamp with difference of 'current time' – 'old timestamp', re-calculate CRC
- Originator: Baseband (FPGA) — replace Originator timestamp with difference of 'current time' – 'old timestamp', re-calculate CRC
  MAC (Software) — receive frame, check CRC
  calculate 'Originator timestamp' – 'Target timestamp'

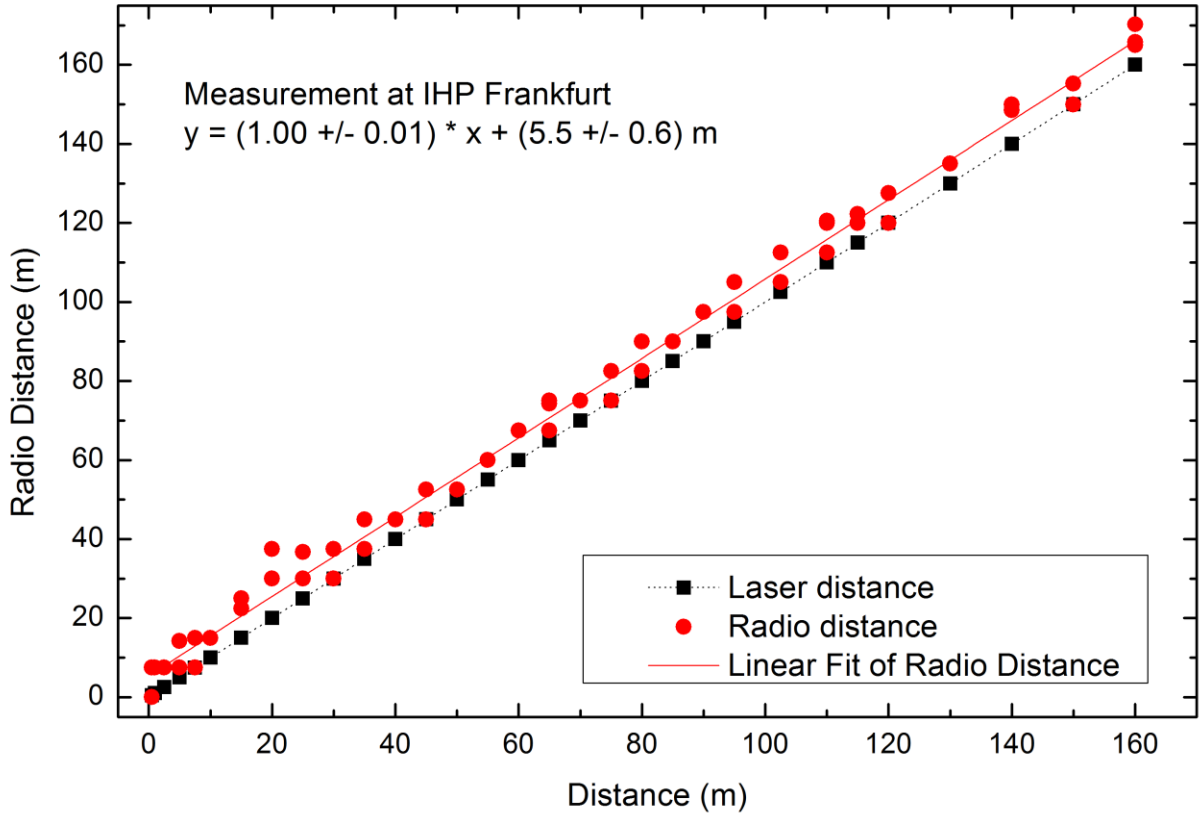
optionally: Acknowledgement

Hardware Implementation

Block diagram of *Fast-Traffic* radio module
(IEEE 802.11a, 5 GHz band, OFDM)



Experimental Distance Measurement Results for line-of-sight



Speed of light is reproduced with 1 % accuracy (slope of graph).

Offset correction needs to be a bit more precise.

Theoretical granularity of one measurement is 7.5 m = 1/2 clock period of 50 ns @ speed of light.

Examples of raw Measured Data

For each selected distance (as measured by Laser distometer, accuracy few cm):

- 3 measurement series, where module returns average from 10 frame exchange sequences
- We were expecting some more or less normally (gaussian) distributed result, but this was not observed.

Distance	1st value	2nd value	3rd value
15 m	22.5 m	22.5 m	25 m
20 m	37.5 m	30 m	30 m
25 m	30 m	30 m	36.75 m
30 m	30 m	30 m	37.5 m

- typically, measured distances are integer multiples of the granularity of a single measurement = 7.5 m
- the absence of non-integer multiples indicates very low scatter between the 10 averaged values

Conclusions

- Two-Way-Ranging option has been added to 5 GHz WiFi / IEEE 802.11a
- Timestamping is done in hardware (baseband processor)
- Frames are compliant with IEEE 802.11 MAC Protocol and Frame Formats
- Measurements in range 1 – 160 m show good results (low jitter, correct slope)
- Data show “range binning” into intervals of 7.5 m
  (1/2 clock period of basic OFDM clock 20 MHz @ speed of light)
- Averaging of results does not result in much improvement
  (needs further investigation)

Thank you for your attention!

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Block Diagram of 802.11a OFDM Baseband processor