Synchronization in distributed SDR for localization applications

The challenge of nanosecond accuracy

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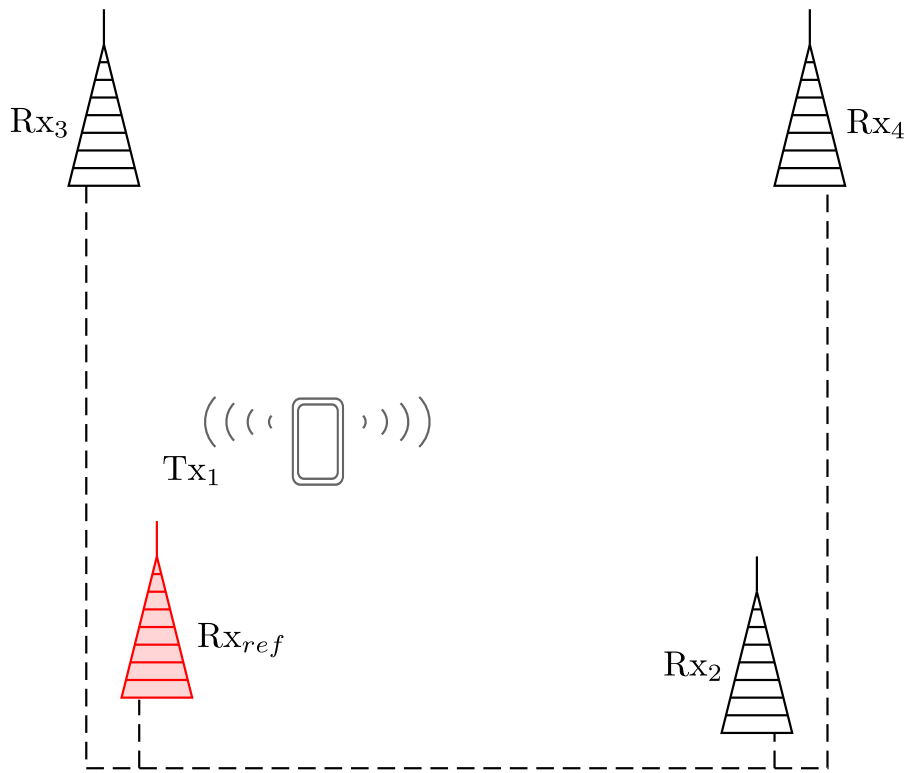
Introduction

- Time synchronized receivers (sensors, anchors, anchor nodes)
- Able to exchange samples
- Reference receiver (fusion center)
- Time difference of arrival (TDOA) measurements



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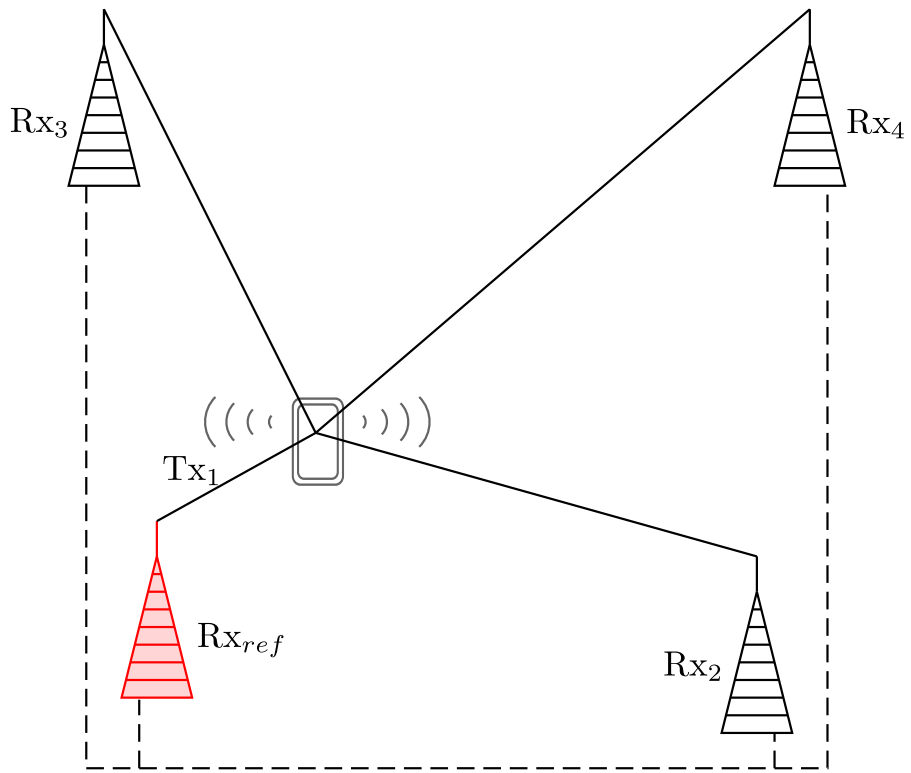

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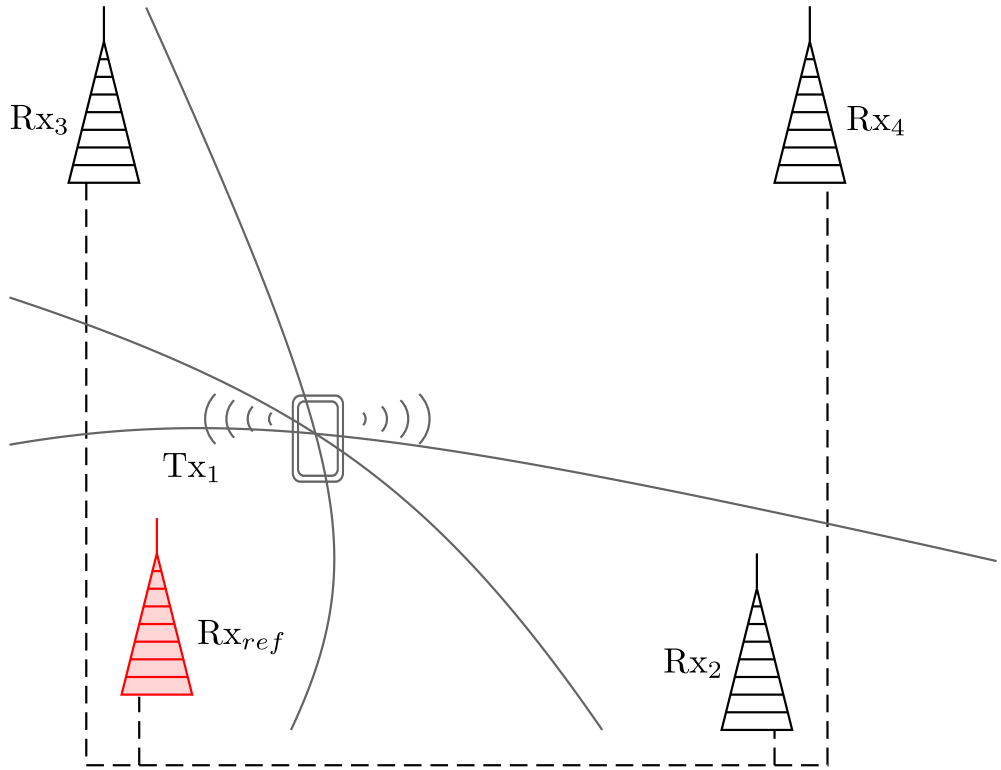
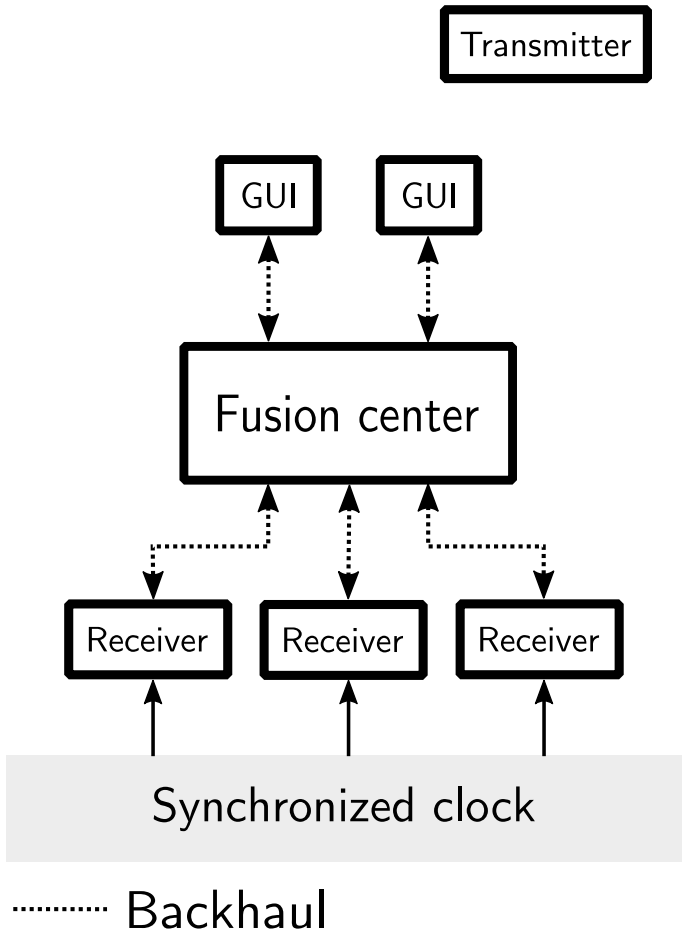


Introduction

- To our knowledge no existing open source SDR framework for real-time TODA based radio localization
- Its pretty tough mainly due to the speed of light
  - 1 ns equals 30 cm (one foot) of propagation!
- Many people have build ultrasound based systems
- Some ultra wideband systems exist
- Some people do signal recording and "offline" processing
- Commercial or military systems extremly expensive
- It's a distributed system
  - A lot of hardware, logistic problems, network programming

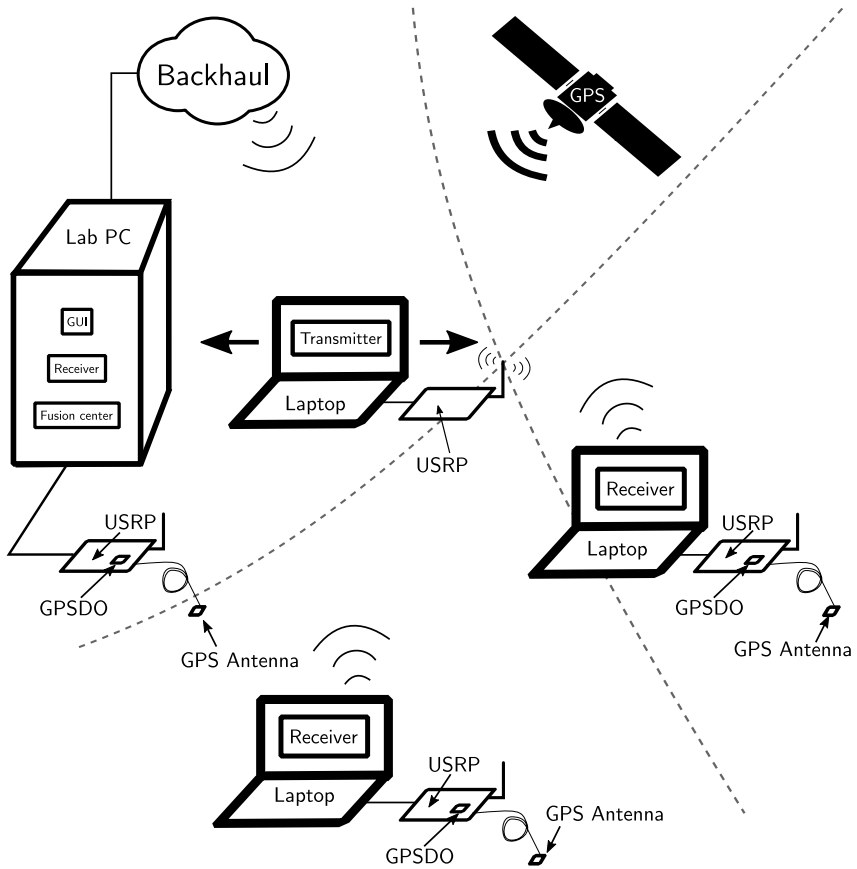
System architecture: Software layer

- Flexible architecture for different scenarios and algorithms
- Software components
  - GNU Radio
  - Python
  - Qt
  - ØMQ
- Nodes require a backhaul connection to communicate both samples and commands



System architecture: Hardware layer

- Distributed system
- Variable number of nodes
- Real time results
- Compatibility with different GPS disciplined oscillators (GPSDOs)
  - Jackson Labs/Ettus LCXO
  - Jackson Labs LTE Lite
  - ...



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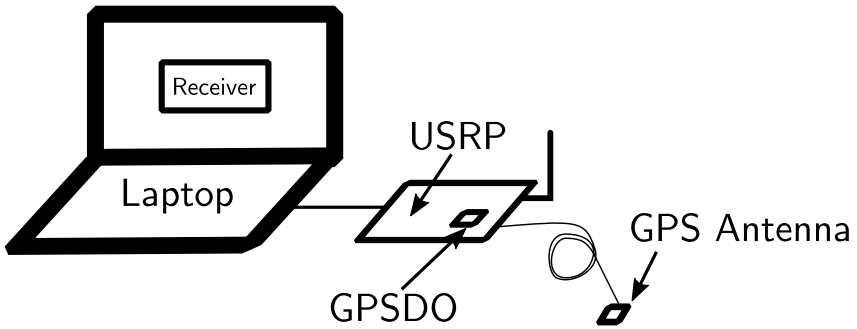

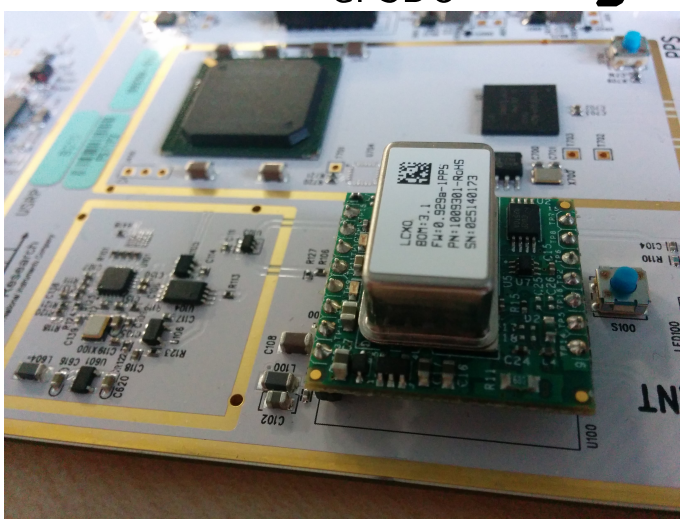

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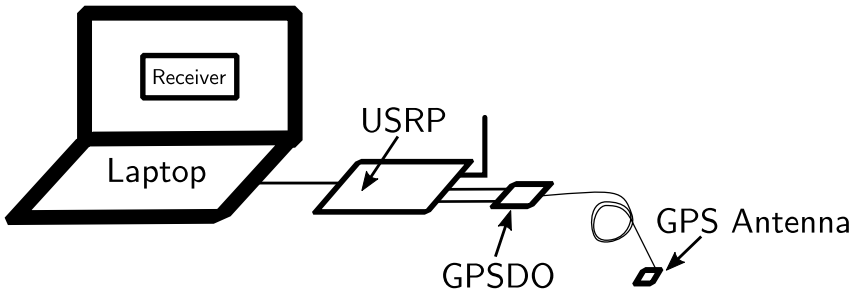
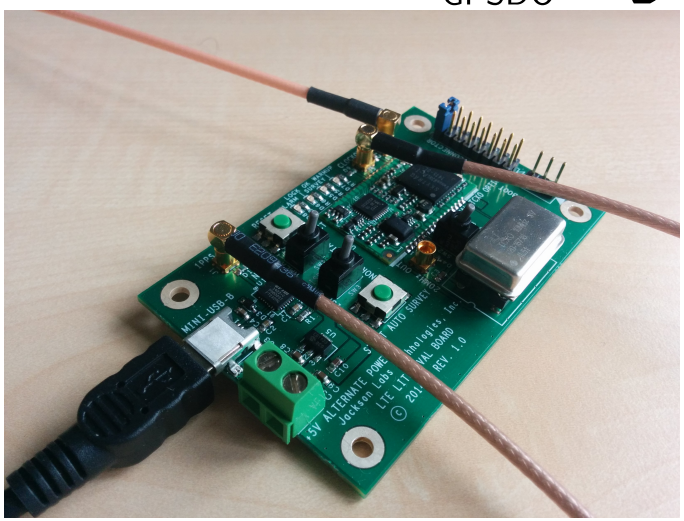
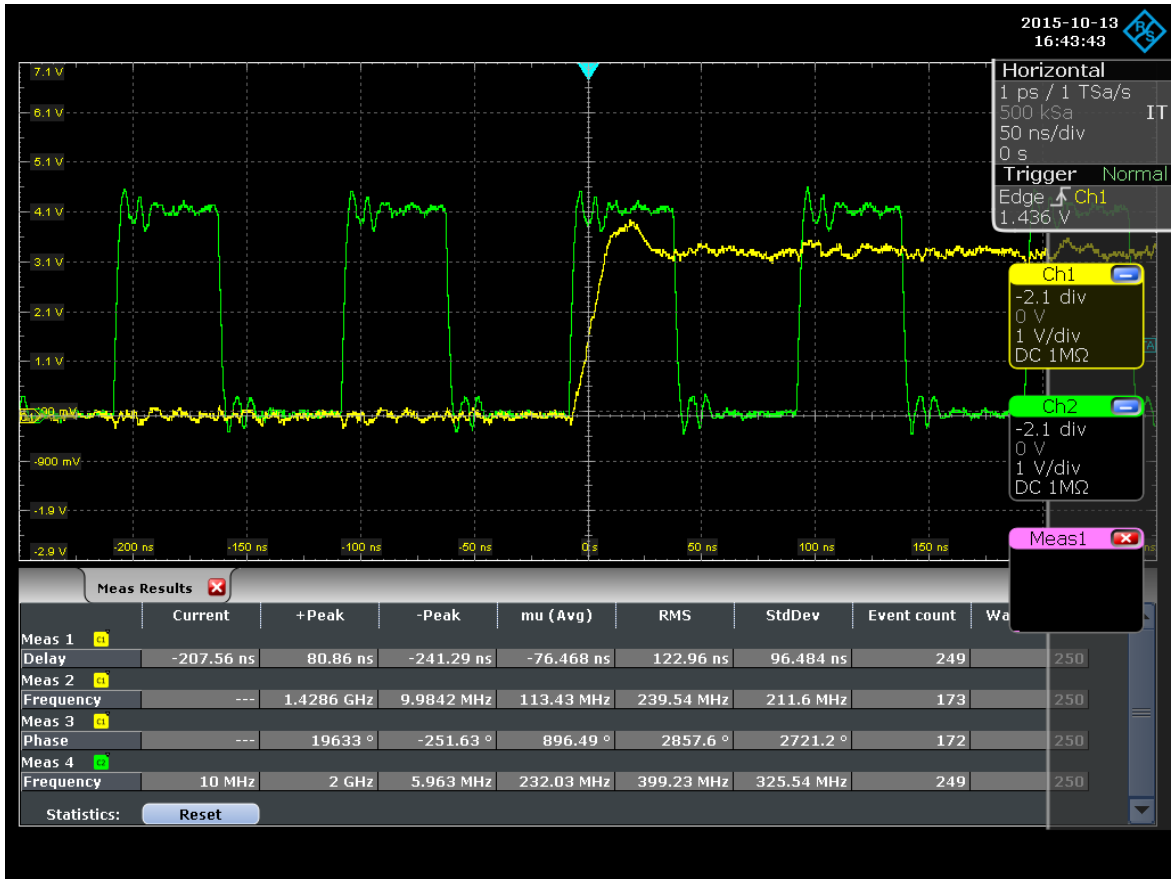




System architecture: Hardware layer

Timing synchronization

- Coordinated Universal Time (UTC)
- Pulse per second (PPS)
- 10MHz Clock
- Matching issues (50 Ohm)



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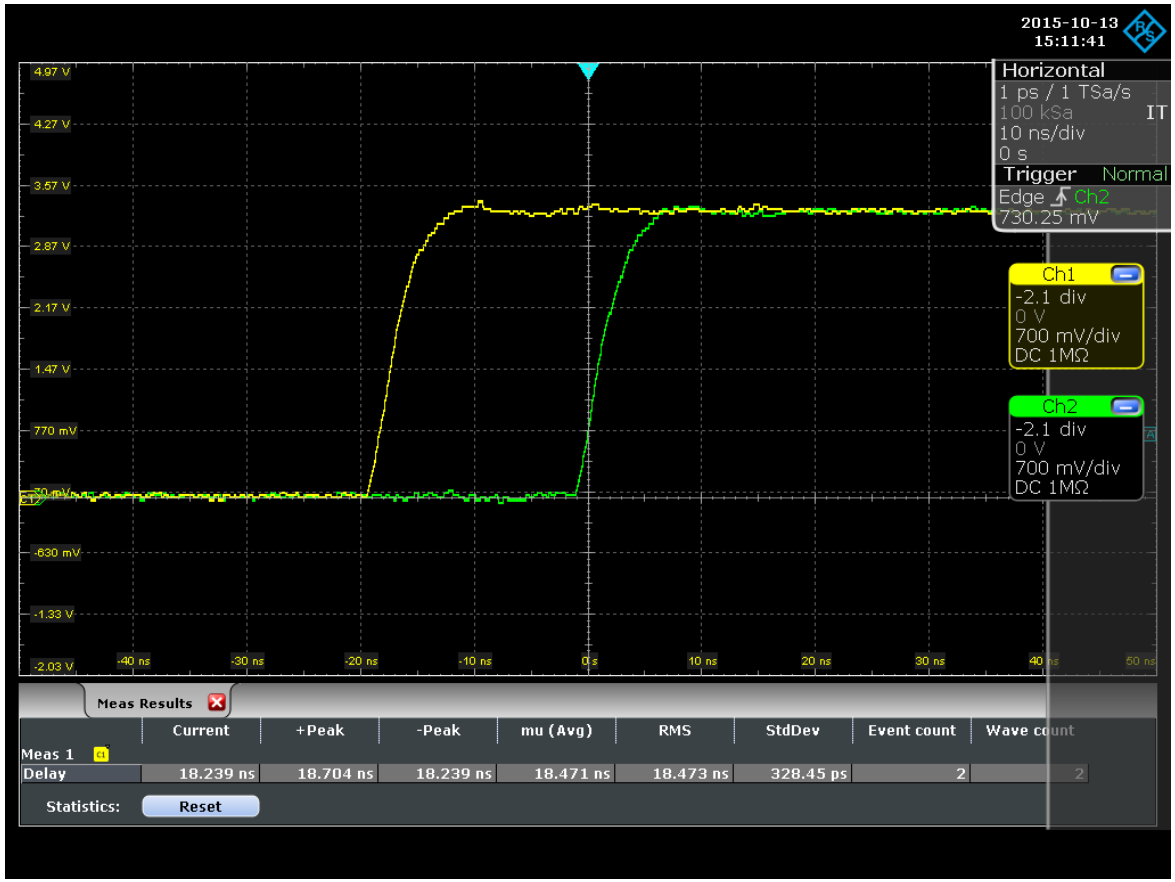
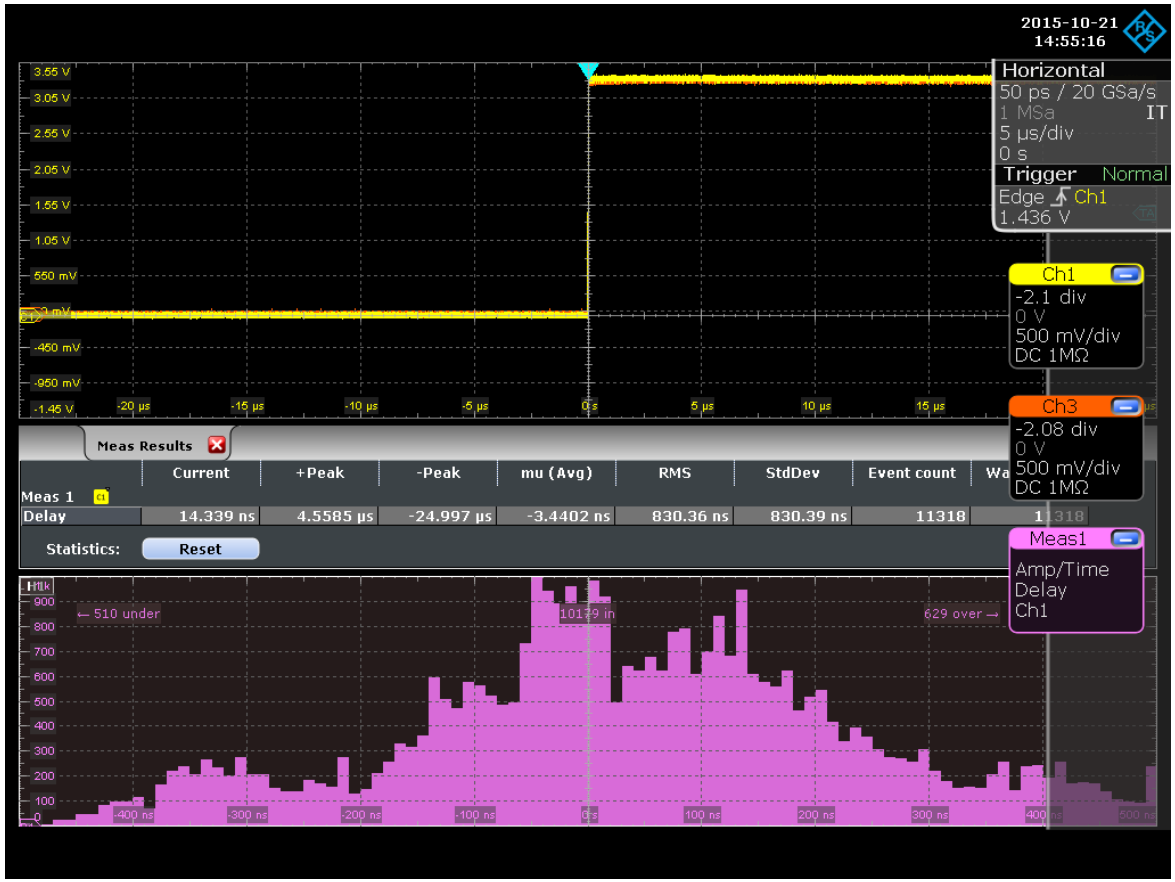


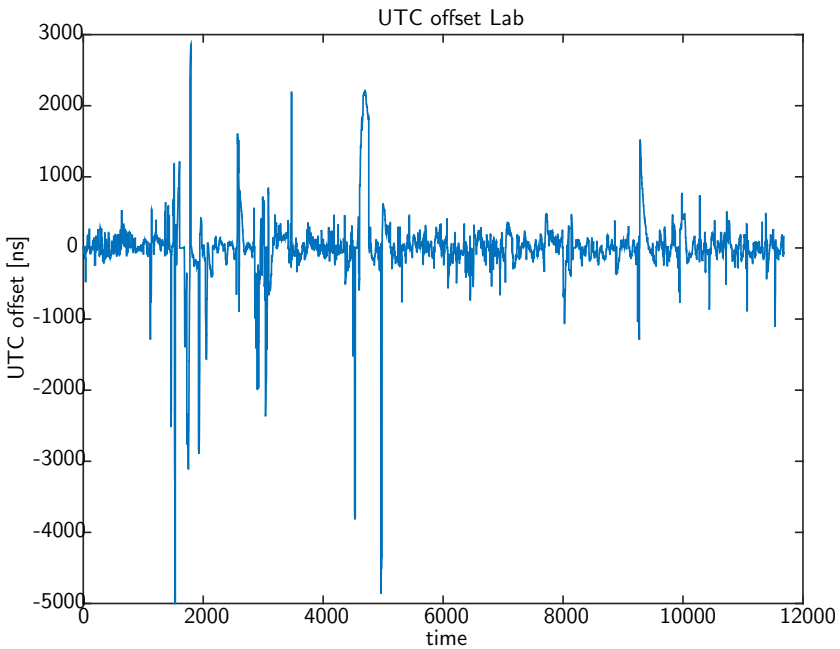
Timing synchronization

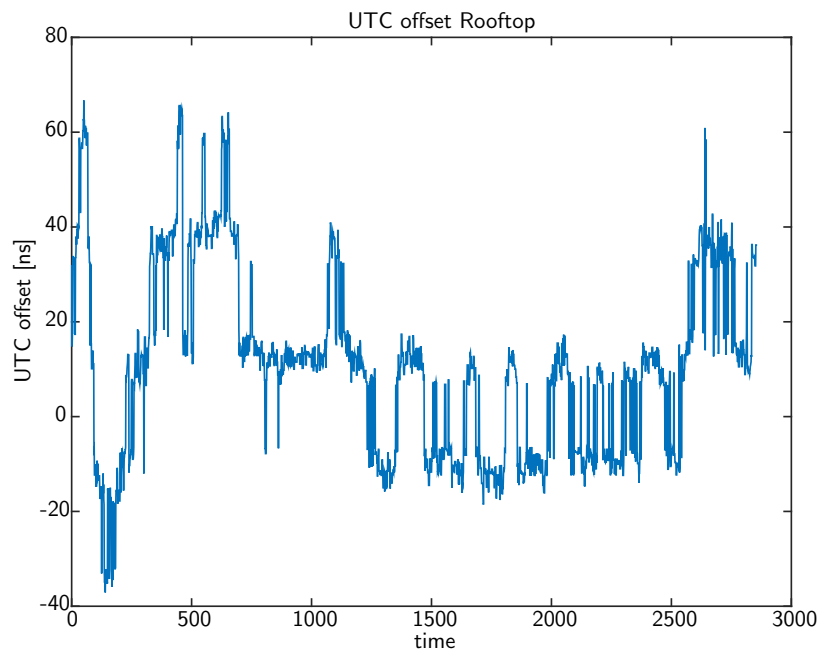
- Coordinated Universal Time (UTC)
- Pulse per second (PPS)
- 10MHz Clock
- Matching issues (50 Ohm)
- Can take one hour to have a good and stable fix



Results: LTE Lite reception comparison

- GPS reception big issue
- Outside window of lab peaks of thousands of ns
- On the rooftop stable within 50ns





UHD/GNU Radio API

- Very helpful:
  `http://files.ettus.com/manual/page_sync.html`
- in general relatively large delays in SDR systems!
  - need to synchronize the frontends for high accuracy

1. query the GPSDO for seconds and find PPS
2. now you have $\sim$ 1s to react before the next PPS
3. tell the device to set the internal time (+1s) on the next PPS
   - UHD/GNU Radio: `set_time_next_pps(...)`
4. use ntp for synchronization of the hosts

Issues and comments

- Ettus devices:
  - works well with UHD 3.8.5
  - issues (multichannel, synchronization) with 3.9 series
    - Wait for 3.10
    - Maybe some additional information in the manual/documentation for API changes (something changed according to changelog)
    - If necessary work with support to track down the bugs
    - Test cases in internal Ettus quality control for signal integrity along all channels?
  - Phase coherent synchronization is a different story

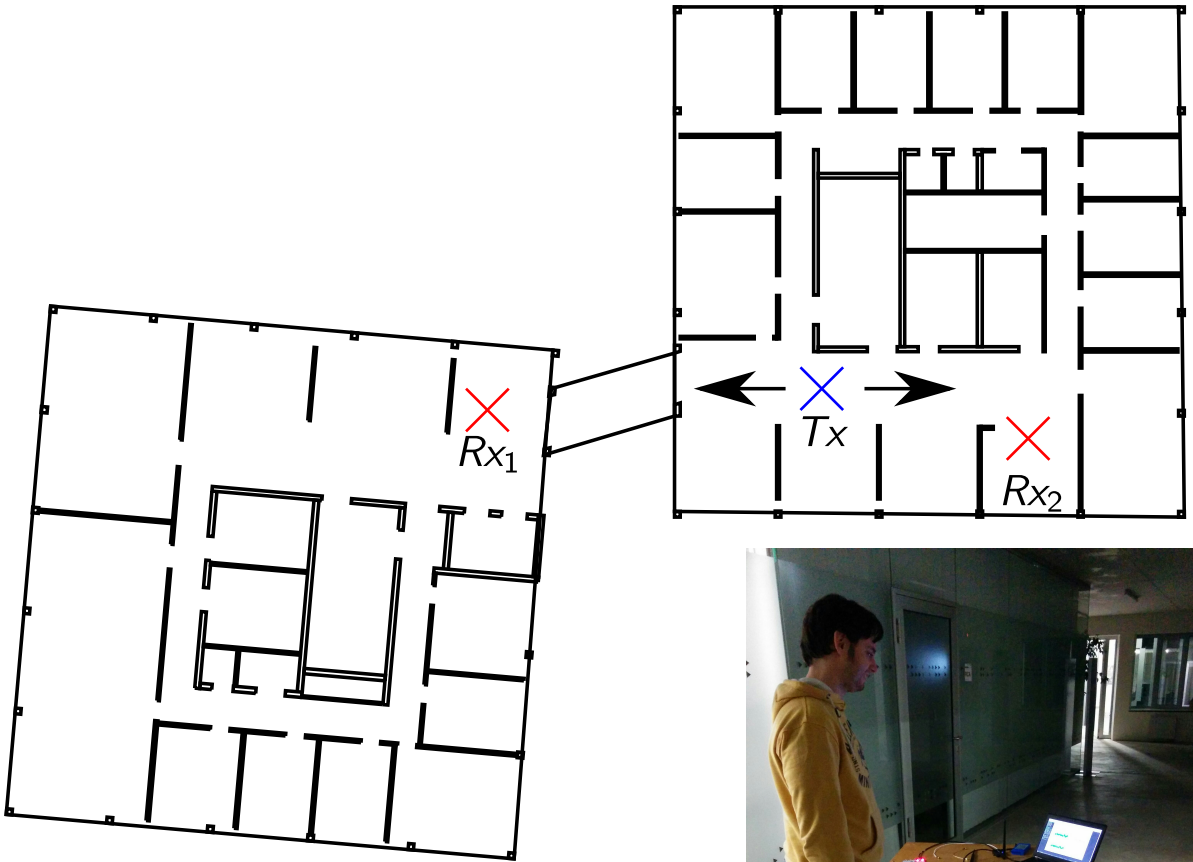
Network programming

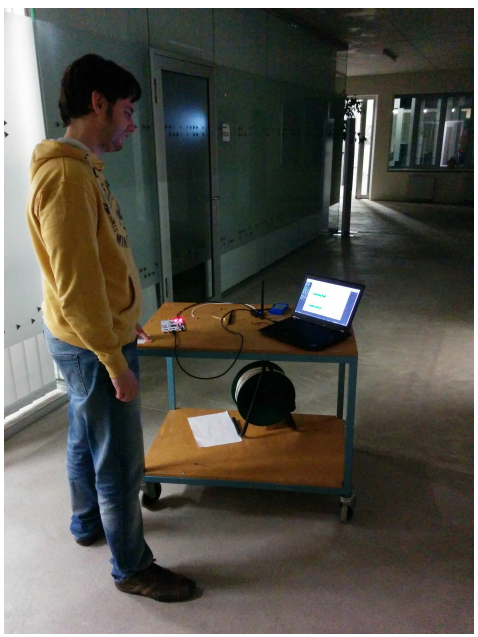
- Send message from fusion center to all receivers with time to receive and number of samples
  - use UHD/GNU Radio stream command API

```
stream_cmd =
   uhd.stream_cmd(uhd.stream_cmd_t.STREAM_MODE_NUM_SAMPS_AND_DONE)
stream_cmd.num_samps = samples_to_receive
stream_cmd.stream_now = False
stream_cmd.time_spec = time_to_sample
self.usrp_source.issue_stream_cmd(stream_cmd)
```

- Wait for the samples and process in the fusion center
- provide results to all GUIs
- We use GNU Radio zeromq blocks for this
- General problems: throughput limit of the backbone, e.g., WiFi

Results: Walk along the corridor





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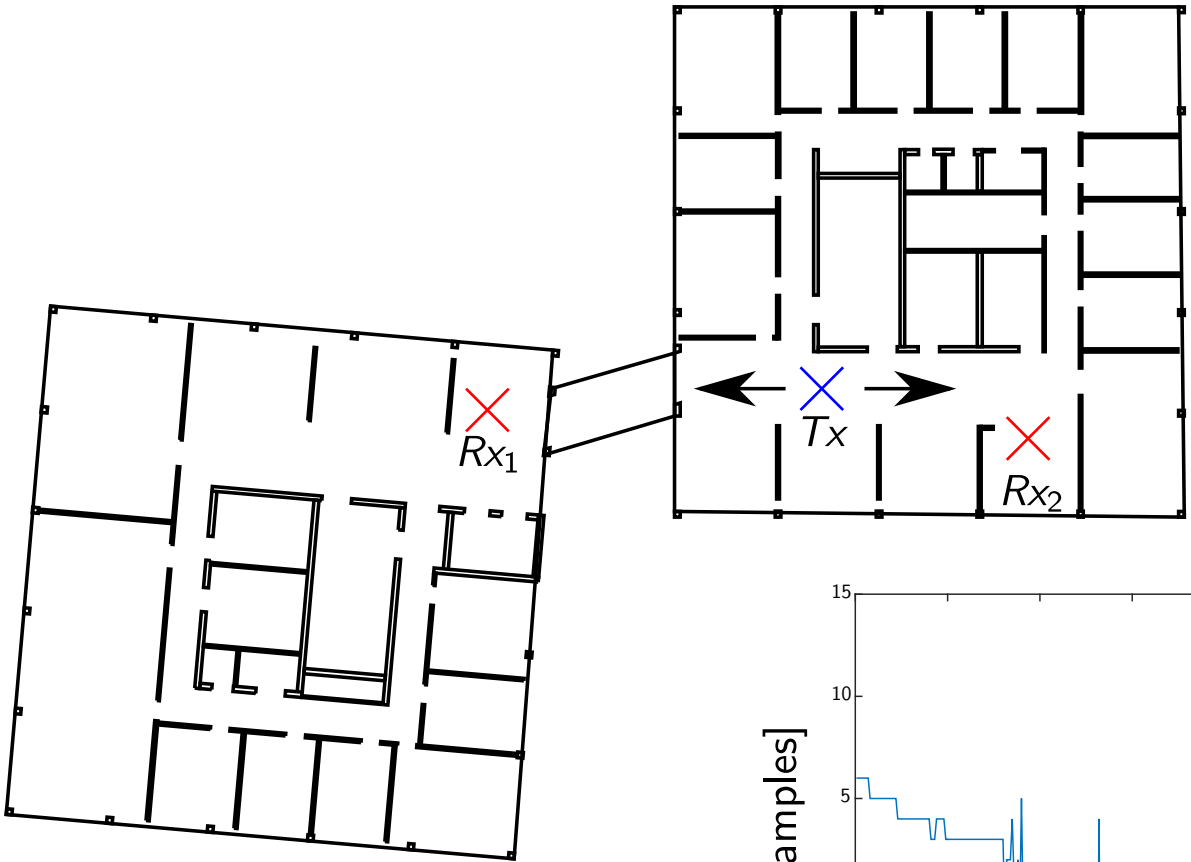
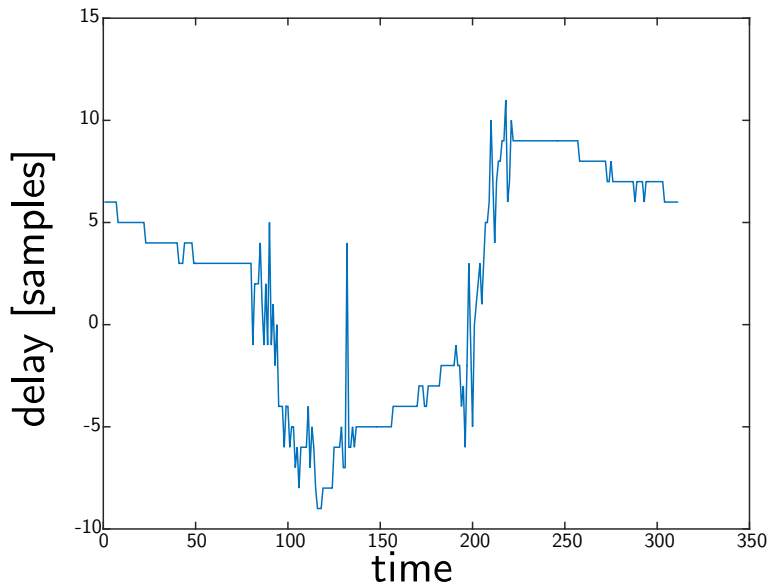
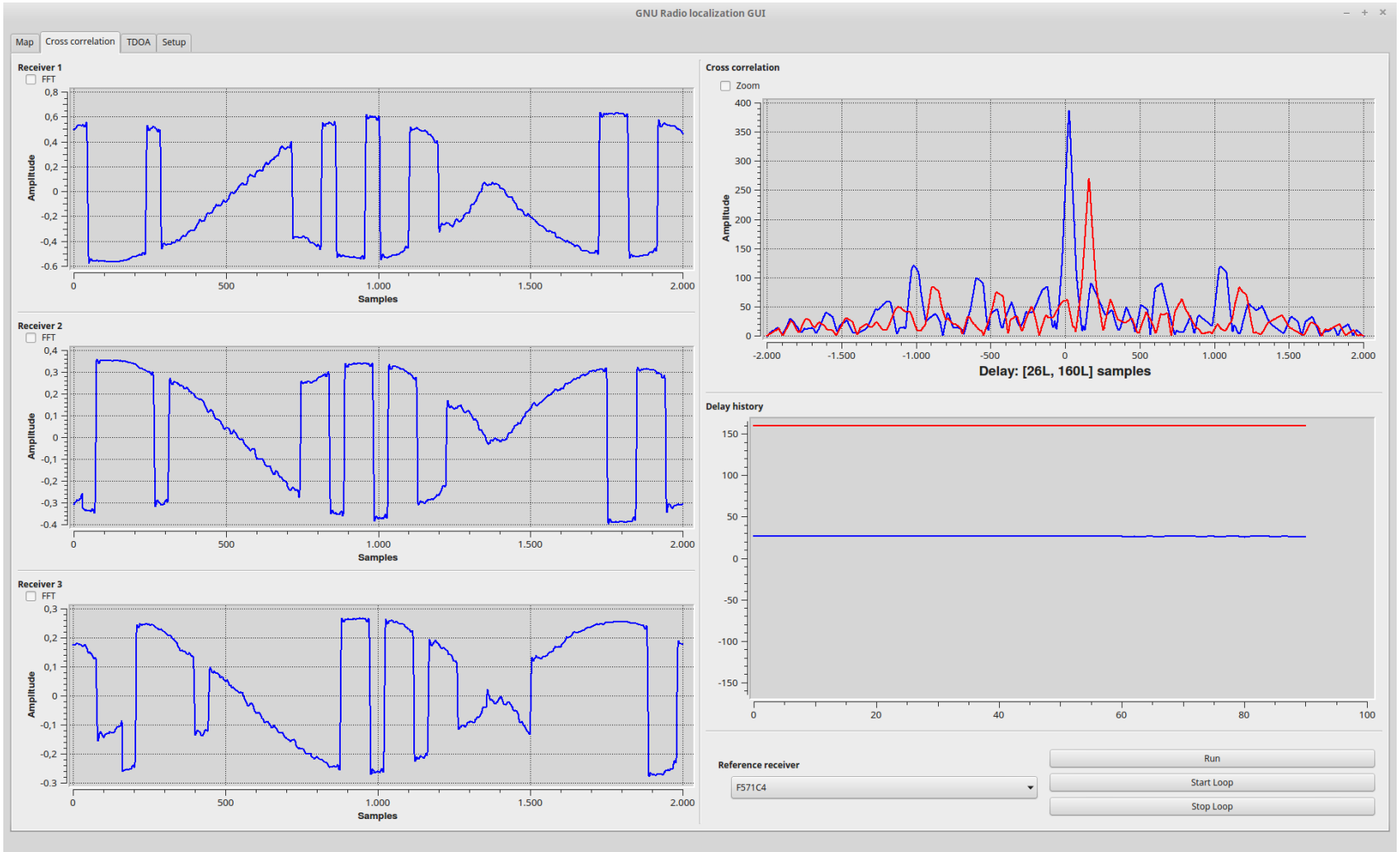




System architecture: GUI



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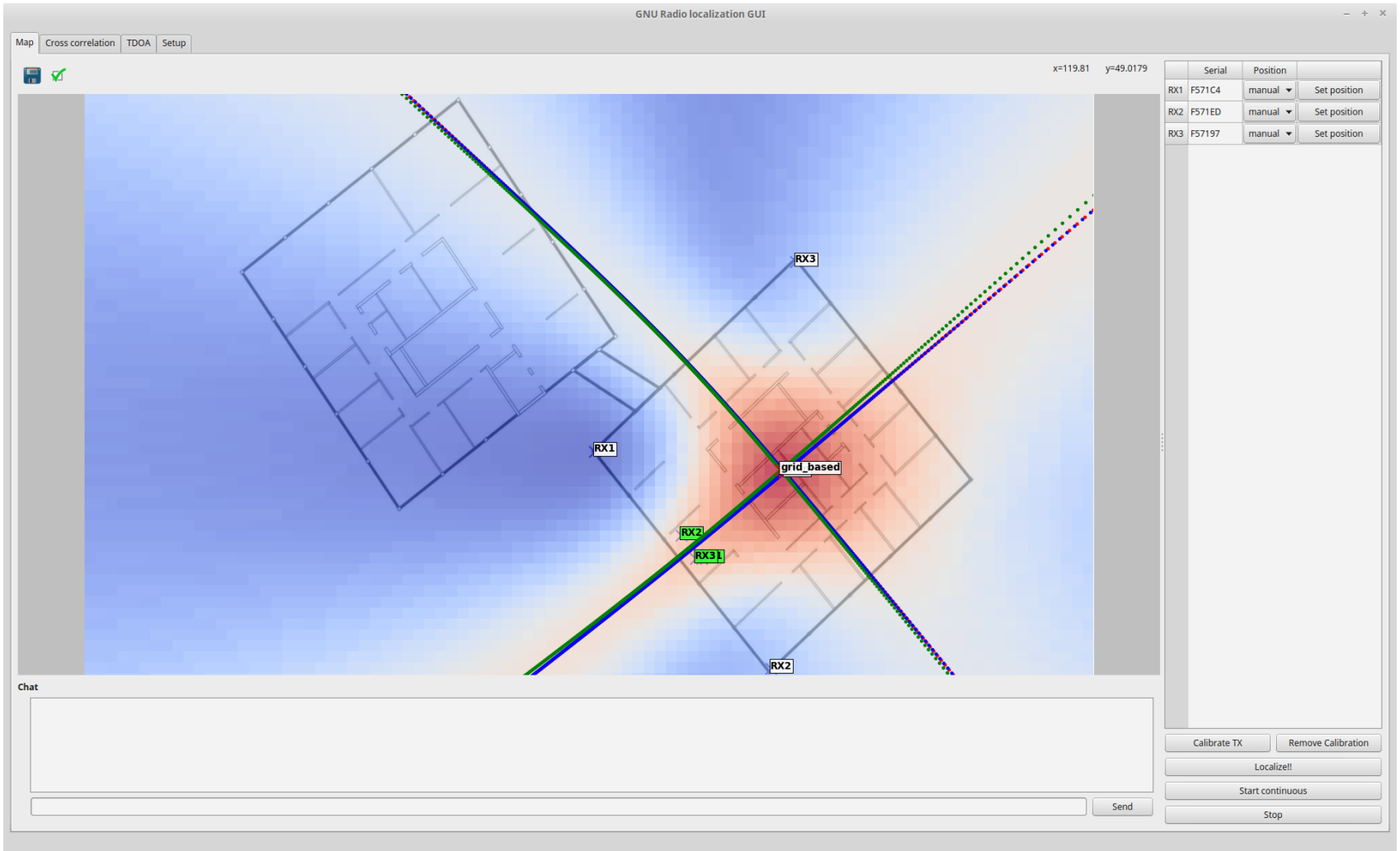


Final comments and outlook

- Timing improvement: use a GPSDO that is able to run in "1D-Mode" with fixed position
- Use a reference station with a known position to calibrate out the timing drift
  - problems with fast retuning of USRPs
  - need stream command type of API for tune requests
- Ideal solution: RTK (Differential GPS)
  - provide GPS raw data through UHD

Finish

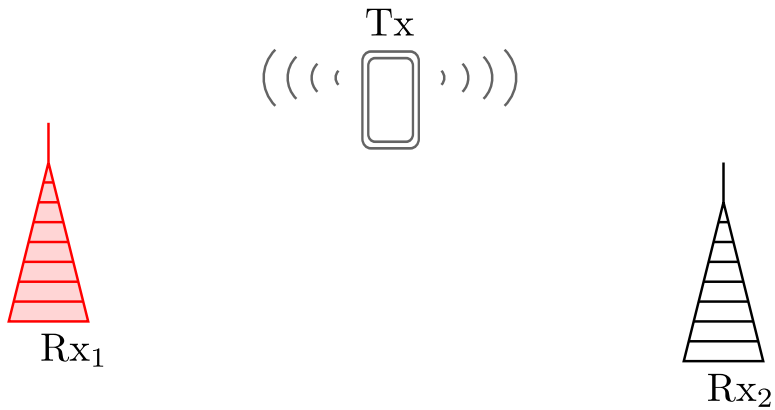
Thank You! Questions?

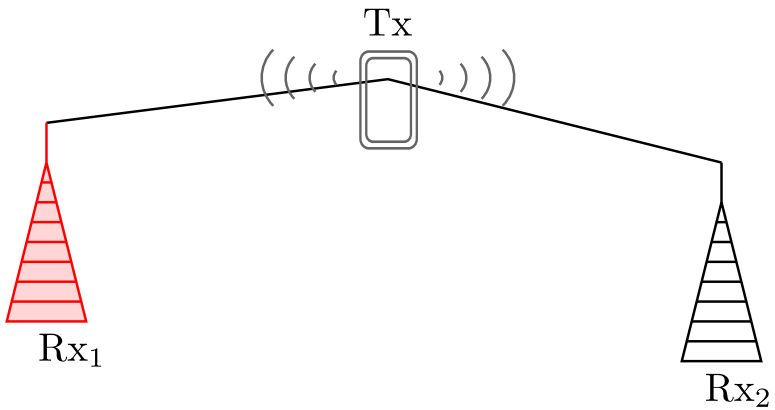
Finish

Backup slides

TDOA

Recap





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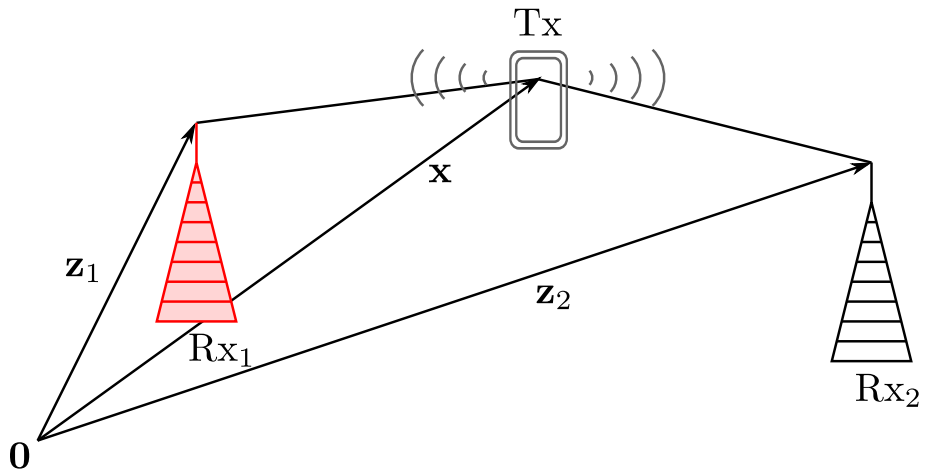

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- Use time **difference** of arrival (TDOA), c is the speed of the wave
  $\rightarrow \Delta(\mathbf{x}, \mathbf{z}_k, \mathbf{z}_l) = \frac{1}{c}\|\mathbf{z}_k - \mathbf{x}\|_2 - \frac{1}{c}\|\mathbf{z}_l - \mathbf{x}\|_2$

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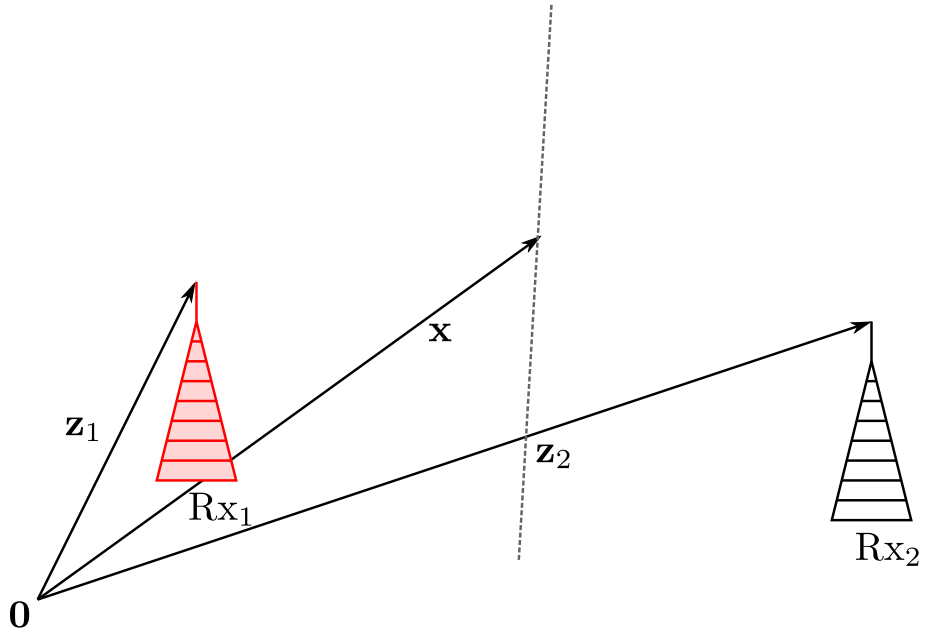

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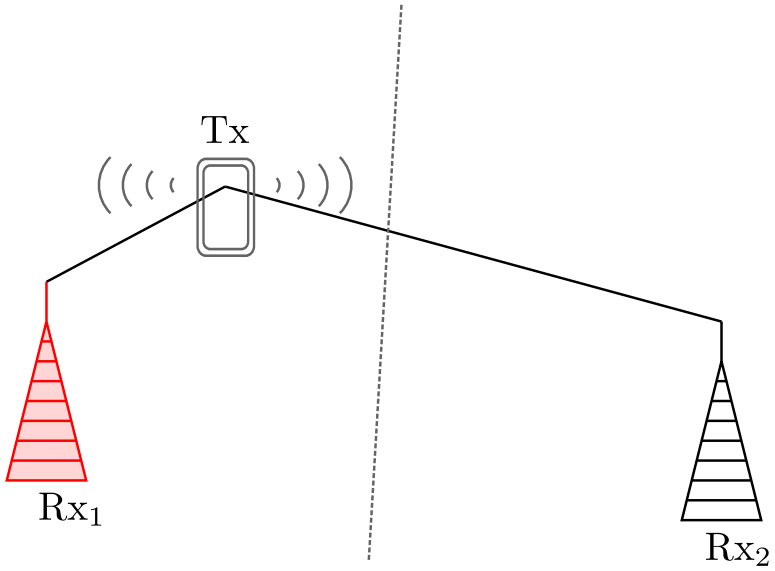

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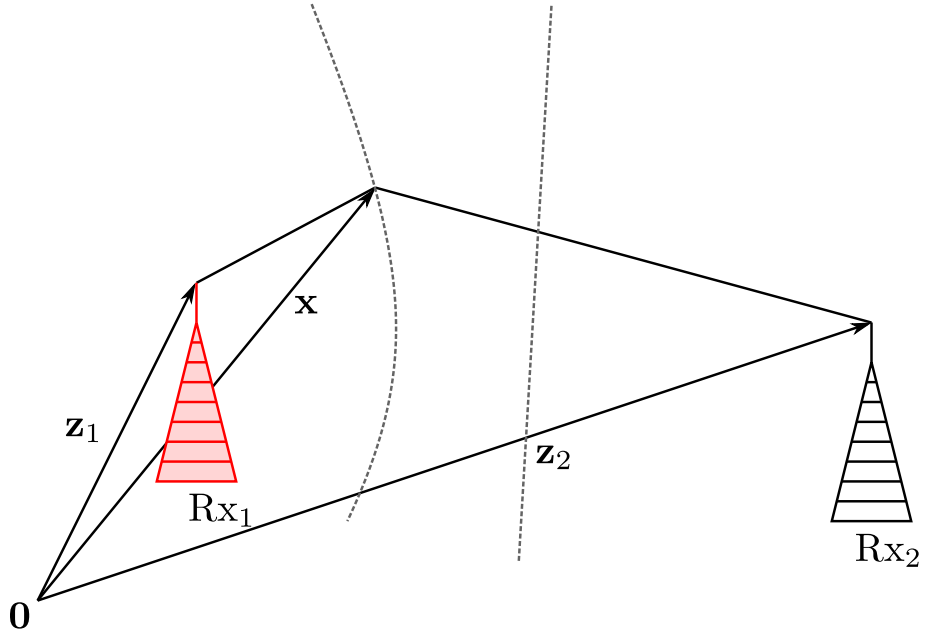

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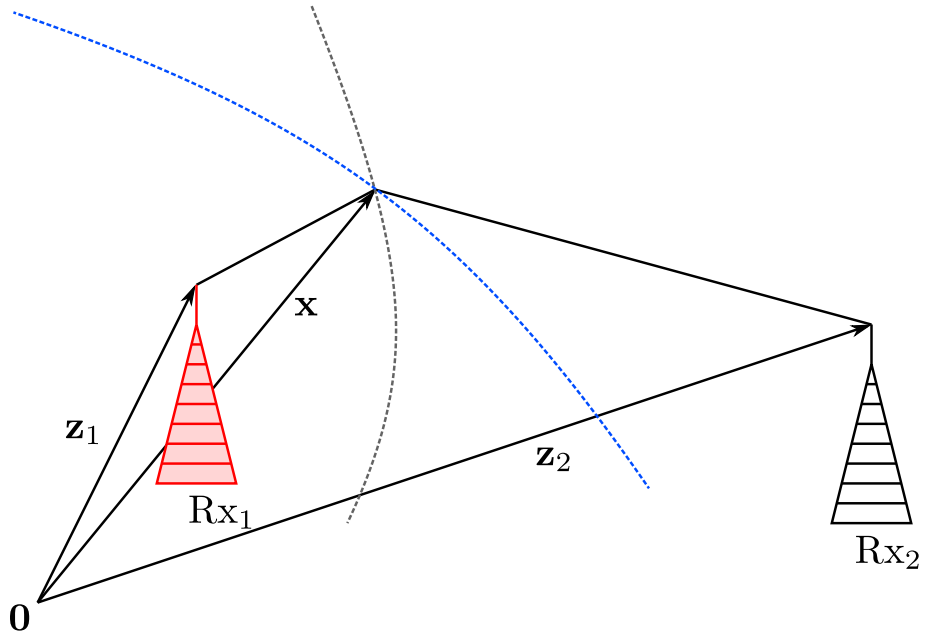

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- Well known classical algorithms, e.g., [CH94]
- Grid based algorithm [SDM15]

Bibliography

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A simple and efficient estimator for hyperbolic location.
IEEE Trans. Signal Process., 42(8):1905–1915, Aug 1994.

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Compressed time difference of arrival based emitter localization.
In *Proc. 3rd Int. Workshop on Compressed Sensing Theory and its Applications to Radar, Sonar and Remote Sensing (CoSeRa 2015)*, pages 1–5, Pisa, Italy, June 2015.