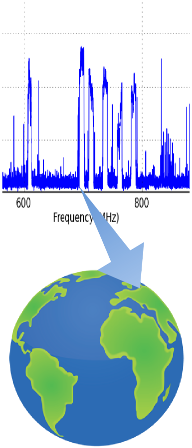
Synchronization of Low-Cost Distributed Spectrum Sensing Nodes for Multilateration-based Geolocation

Stefan Grönroos, Kristian Nybom and Jerker Björkqvist
Åbo Akademi University/Turku Centre for Computer Science (TUCS)

March 2015

Background

- Previously (WInnComm Eu 2014) built a distributed spectrum sensing network using very low-cost nodes ($< \$100$ USD)
- Low cost nodes are clearly inferior to application-specific high-quality equipment.
- ...but a very low-cost nodes can be deployed in greater numbers, providing a more dense network.
- For this paper, we explored wether such a network could also be used for locating radio emitters.

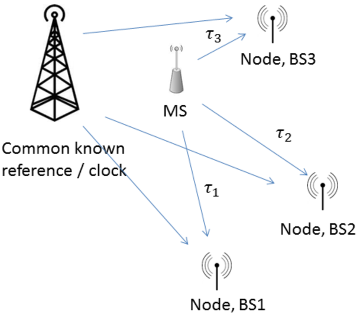


TDOA-based geolocation

- Multilateration is a technique for locating the source of signals using geographically distributed receiving nodes
- Often based on time of arrival (TOA) of the signal at each node, or the time difference of arrival (TDOA) between pairs of nodes
- TDOA can be estimated for example by cross-correlating signals received at two nodes
- Each difference in arrival time between two nodes translates to an infinte number of possible locations along a hyperbola(2D)/hyperboloid(3D)
  - The intersection point between hyperbolas resulting from several TDOA measurements is the unknown location.

TDOA contd.

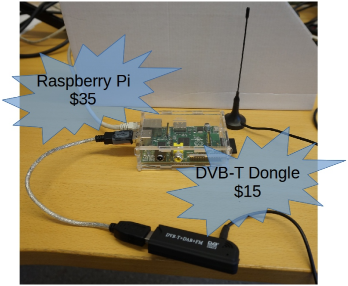
- Nodes need to be synchronized
- Often, GPS is used
- We could also synchronize using signals of opportunity (TV, Radio, Mobile...)



Åbo Akademi

Experimental setup

- Nodes consist of:
- Raspbery Pi computer
  - 700MHz single-core ARM CPU
  - 512 MB RAM
  - 3.5W
  - Price: $35 USD
- DVB-T dongle
  - Realtek RTL2832U demodulator chip
  - Tuner: Elonics E4000, Rafael Micro R820T, etc.
  - Can output raw 8-bit I/Q samples at 2.5 MS/s
  - Price: $15 USD



Nodes

- Nodes are connected to the internet.
- An ordinary PC sends commands to the nodes, and receives their samples for processing.
- Tuning commands and I/Q samples are sent over TCP/IP in this implementation
- This means tuning commands are subject to varying network as well as USB bus latencies
    - USB bus latency is unavoidable and unknown
    - Network latency uncertainty could be lessened by having nodes synchronized by a precise network timing protocol and sending a timestamp of when the retune should take place

Åbo Akademi

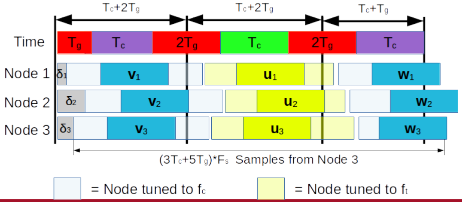
Receiver synchronization

- Considered GPS first, however
  - GPS timing pulse would have to be injected into the dongle somehow (perhaps into antenna?)
  - A GPS receiver with appropriate timing output would significantly affect price of a node, and would require hardware modifications
- Instead, we use signals of opportunity, such as known broadcast signals
  - The origin location of the signals of opportunity needs to be known
- Possible since the dongle does not drop samples when tuning to a different frequency
- The dongles have a rather inaccurate 28.8 MHz crystal oscillator on the order of 100ppm
  - Used for both tuner and ADC

Sampling algorithm

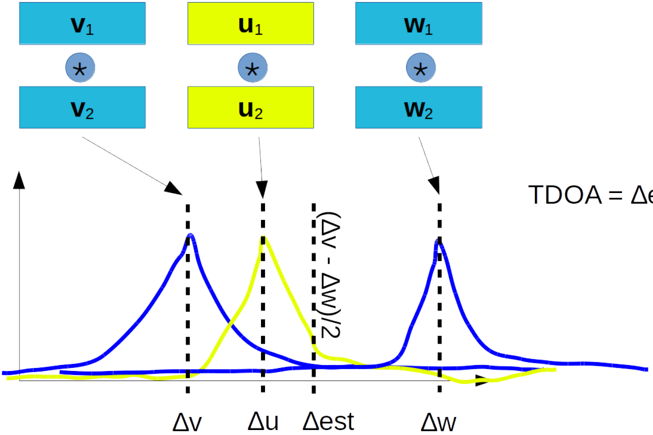
1. Command each node to receive samples at reference frequency f_c.
2. At time $T_c + 2T_g$, command nodes to tune to frequency of interest f_t
3. After an additional $T_c + 2T_g$, command nodes to tune back to f_c.
4. Stop receiving samples after $(3T_c + 5T_g)F_s$ samples have been received.

- T_c - corr. window length
- T_g - guard interval
- F_s - sampling freq.



Åbo Akademi

Correlation

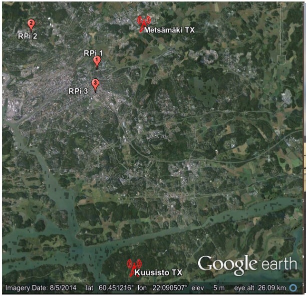


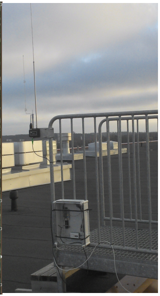
TDOA = Δest - Δu

- As sampling rates differ slightly between the nodes, we apply a set of frequency shifts and select the highest peak.

Node Placement

- 3 nodes in Turku, Finland
- 2 broadcast antennas used in experiments
  - Metsämäki (FM)
  - Kuusisto (DVB-T, FM)





Node	Antenna	Placement
RPi 1	Wideband double discone	On balcony
RPi 2	Simple wire antenna	Inside apartment
RPi 3	Wideband antenna	Roof of office bldg.

Experiment 1: Kuusisto - Kuusisto

- Both reference and target frequency transmitters located at the same site.
- $F_s = 1.8MS/s$, i.e. 1 sample is 165.5 meters.
- Correlation window length of 146ms
- FM radio: 120 kHz low-pass filter, DVB: no filter
- Ideally, we should get a TDOA of 0.

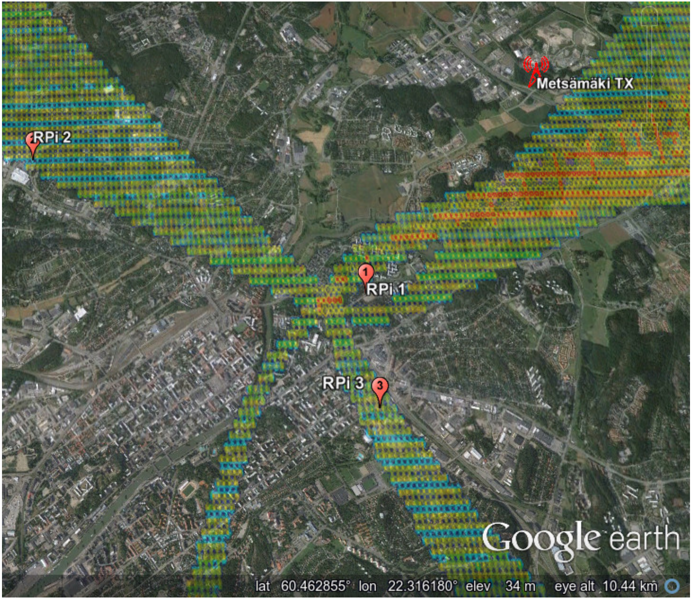
Measure	RPi (1,2)	RPi (1,3)	RPi (2,3)
f_c = 103.9 MHz (FM Radio) and f_t = 89.8 MHz (FM Radio)			
Average error (m)	513	291	416
Standard deviation (m)	479	907	96
f_c = 698 MHz (DVB-T) and f_t = 714 MHz (DVB-T)			
Average error (m)	42	125	97
Standard deviation (m)	267	142	217

Experiment 2: Kuusisto - Metsämäki

- Both reference and target frequency transmitters located at the same site.
- $F_s = 1.8MS/s$, i.e. 1 sample is 165.5 meters.
- Correlation window length of 146ms
- Reference: DVB-T transmitter at Kuusisto (698 MHz)
- Target: FM transmitter at Metsämäki (105.5 MHz)

Measure	RPi (1,2)	RPi (1,3)	RPi (2,3)
Average error (m)	733	230	806
Standard deviation (m)	144	221	144

Åbo Akademi


Metsämäki TX
RPi 2
RPi 1
RPi 3
Google earth
lat 60.462855° lon 22.316180° elev 34 m eye alt 10.44 km

Åbo Akademi

Results discussion

- RPi Node 2 a weak link, as it was placed indoors, with a simple antenna
  - ...also non-line of sight (NLOS) wrt. the transmitters
  - This is also indicated by the high average errors despite quite low standard deviations
- Antennas/placement important
- NLOS mitigation techniques exist, and should be looked into
- Especially with many nodes, one can be selective on which results to trust

Åbo Akademi

Conclusions

- The method works
- Provides useful location information despite low accuracy at times
- With a larger network, and NLOS mitigation, the system could be better
- Very low-cost hardware should enable dense networks