Targeted GPS spoofing

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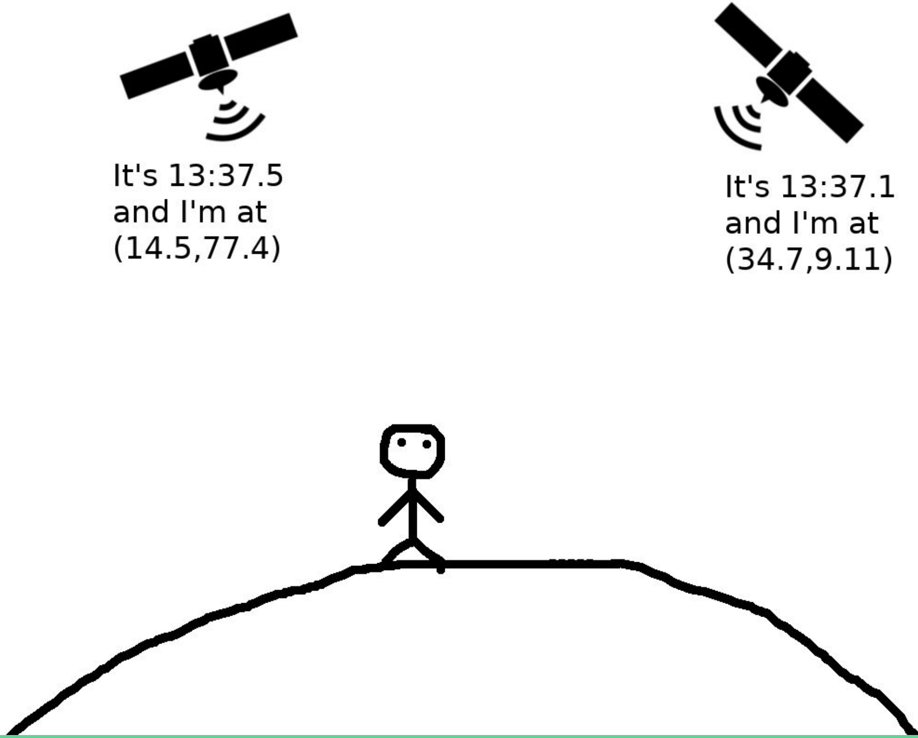
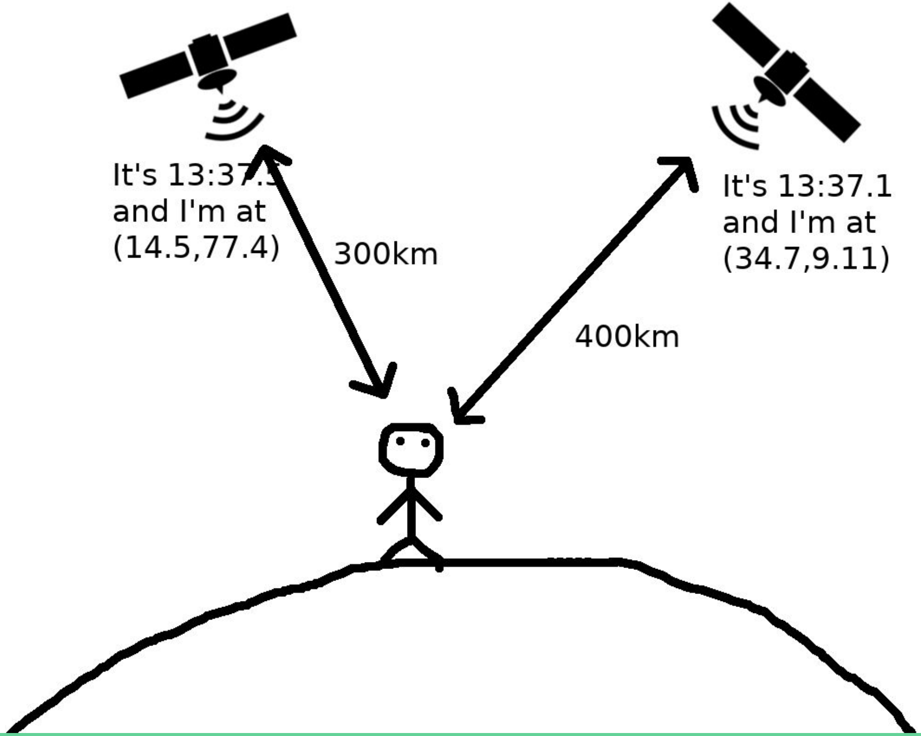
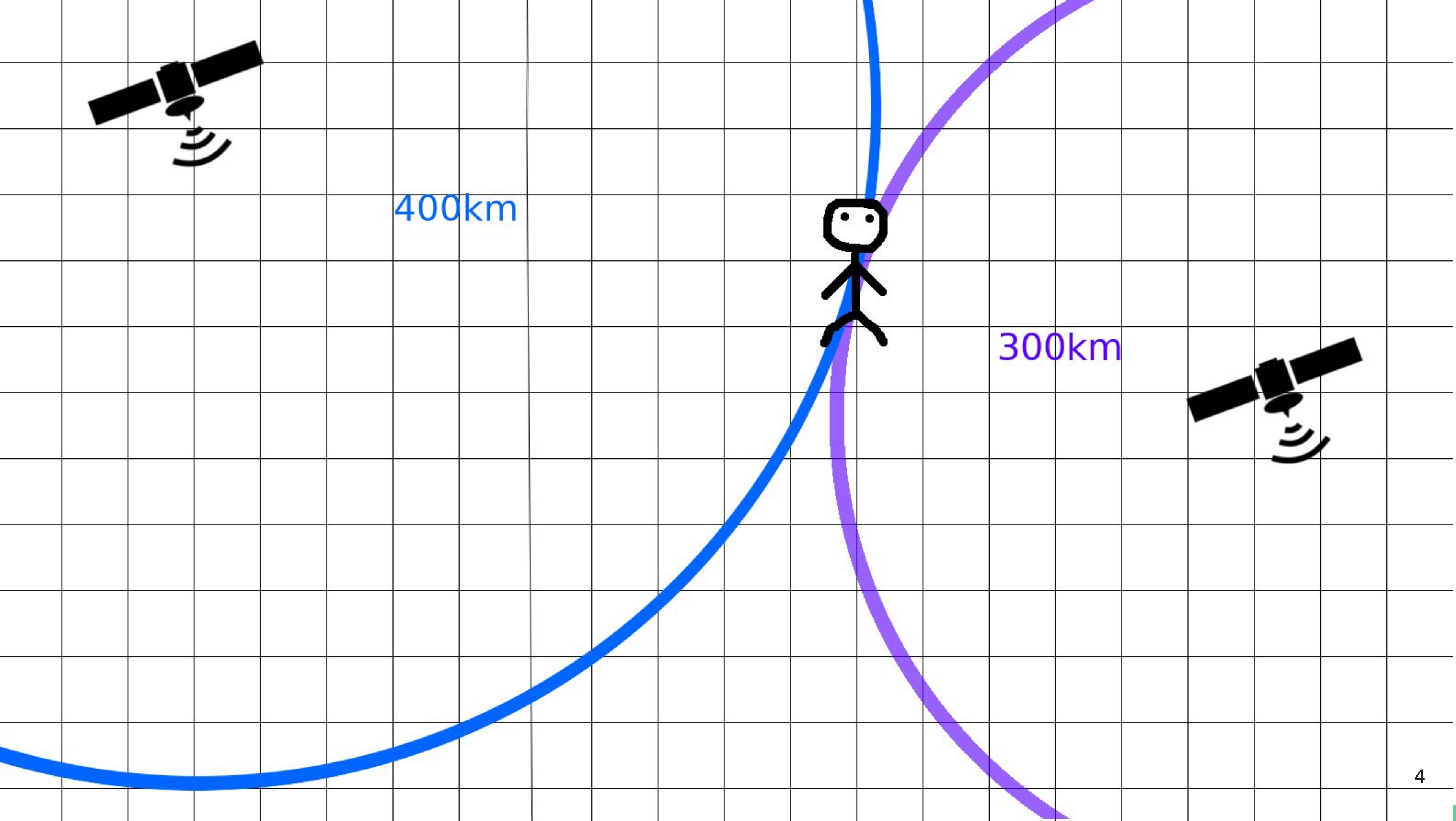
How does GPS work?



How does GPS work?




400km
300km

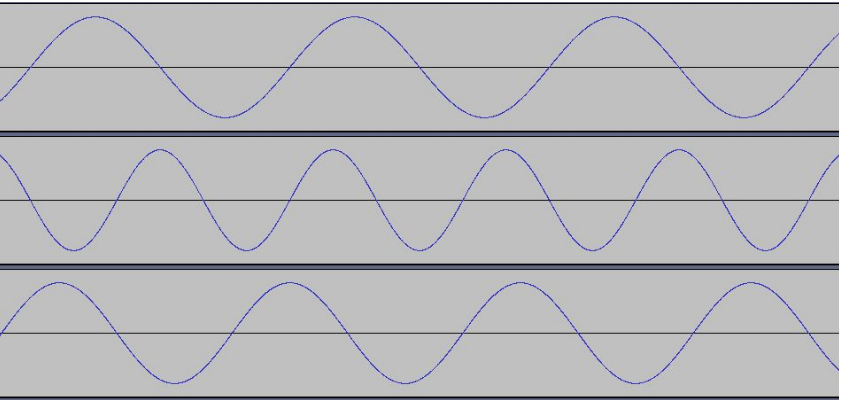
How does GPS work?

In reality:

- You don't actually know the current time (third variable)
- You don't know whether you are on the surface (fourth variable)
- Time traveling
  - Due to the high speed and weaker gravity, time dilutes about 38µs a day faster
  - Stations on earth adjust this
- Signal properties
  - Very, very low power (~-166dBw when the signal hits the Earth's surface)

How does GPS spoofing work?

- Spoofing software calculates what you would receive on a certain position



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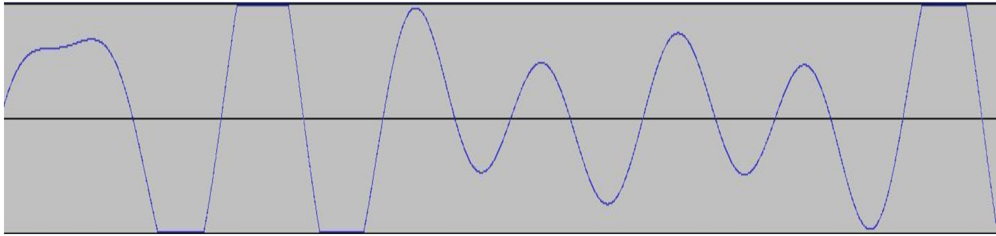


- Signal transmitted from a single antenna

Problem statement

Move away GPS-assisted drones
from locations such as:

- Air ambulance landing site
- Crowds
- Airports (if the owner disabled geofencing)

Drone nieuwe ramptoerist

0 0 0

Gisteren bracht een drone in het Zeeuwse Hulst het leven van een zwangere
vrouw en haar ongeboren kind in gevaar. Een traumahelicopter kon niet landen,

Source: RTL Nieuws

Police: Ohio Man's Drone Prevents Medical Helicopter from Landing at Crash Scene

Man says he was shooting crash scene video as a hobby

Tue, Apr 15, 2014

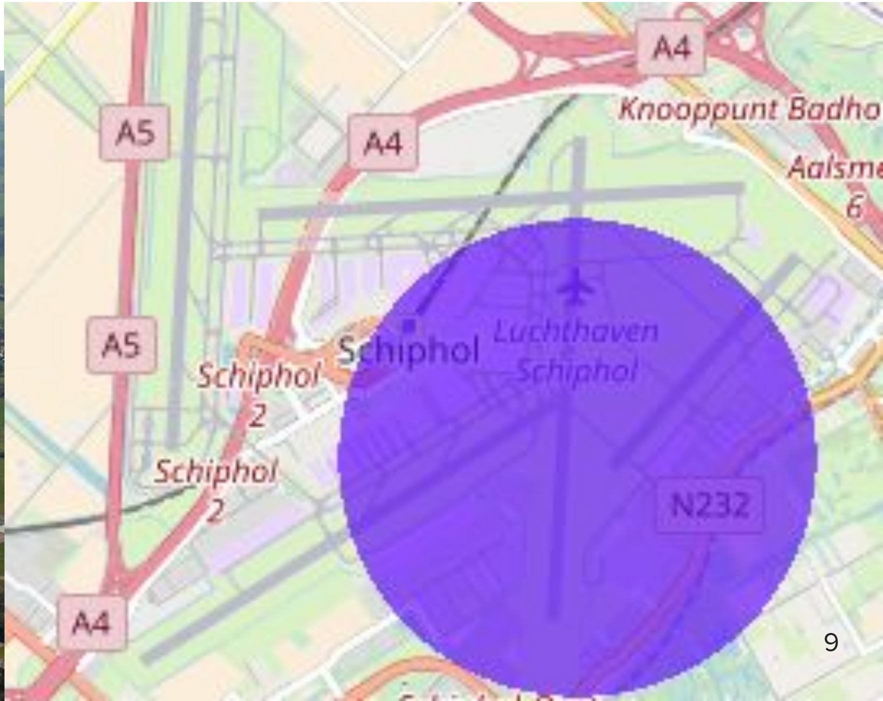
Source: JEMS

Problem statement

Currently:

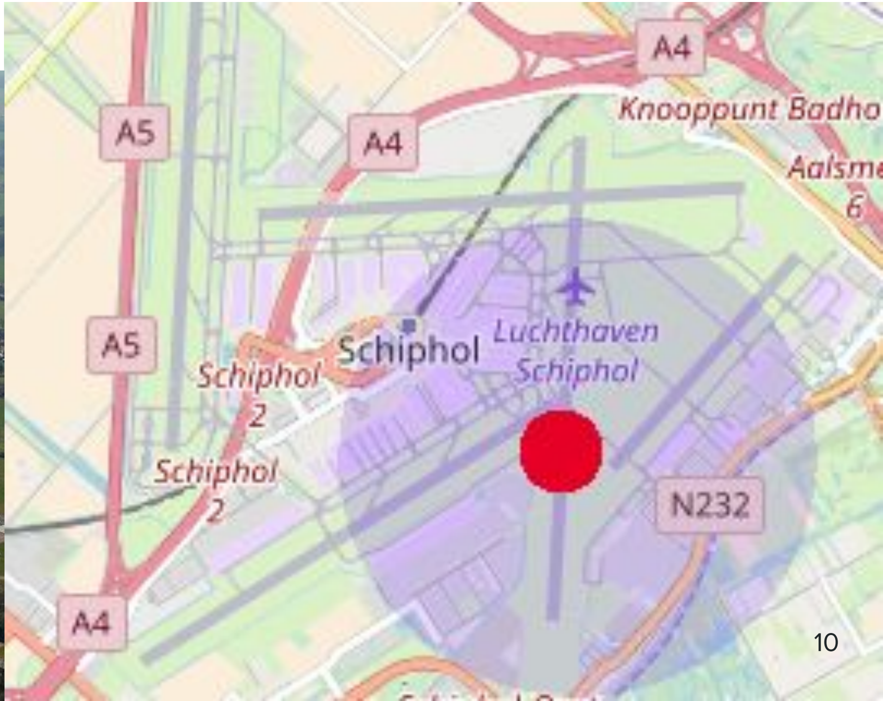
Problem statement

Currently:



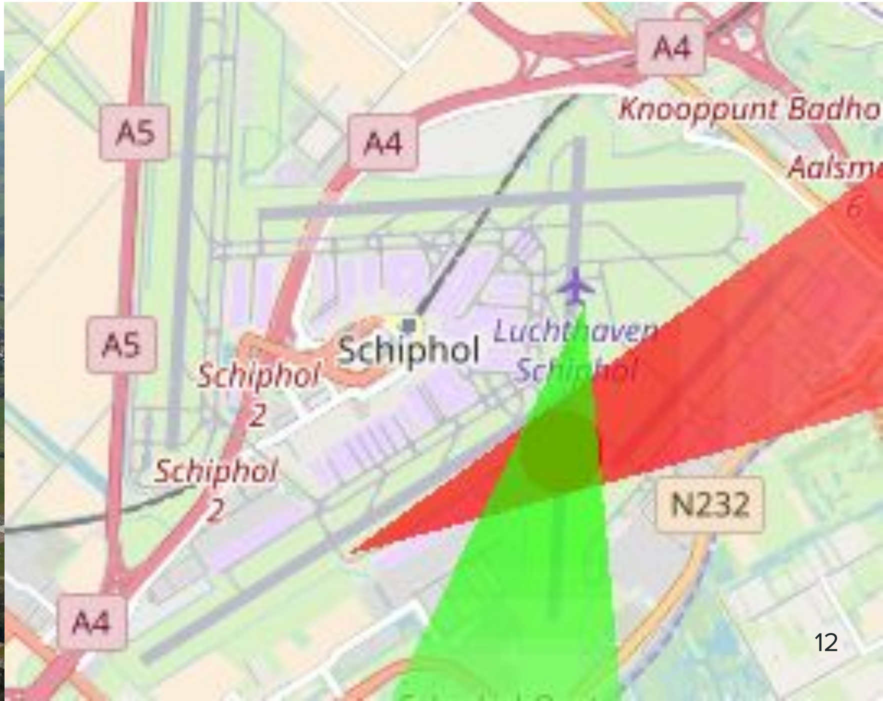
Problem statement

Target:



Problem statement

Problem statement



Research Question

Principal research questions:

Is it possible to limit GPS spoofing to a single receiver?

Sub-questions:

1. Can a spoofed GPS signal be contained within a radius of 10 meters without the use of a Faraday cage?
2. Is it possible to direct spoofed GPS signals using a directional antenna?
3. Does the GPS receiver still compute an accurate position when dividing the spoofed GPS signal over two transmitters?

Scope

- Off-the-shelf hardware
  - Use what can be delivered within a week
- No antenna design
- Focus on the transmitter's RF and spoofing properties
  - Leave the properties of the receiver as is.
- Use the 1.8775 GHz frequency band for experiments
  - Only transmit with a maximum bandwidth of 4.5 MHz and ERP of 50 mW (regulations)
- No experiments on the GPS frequency
  - No testing on commercial GPS receivers
- No research on GNSS technologies other than civilian L1 GPS signal
- No research on use cases of our research

Related Work

- **2001** - *Carles Fernandez-Prades et al.* - GNSS-SDR: an open source tool for researchers and developers
- **2005** - *Hengqing Wen et al.* - Countermeasures for GPS signal spoofing
- **2011** - *Nils Ole Tippenhauer et al.* - On the requirements for successful GPS spoofing attacks
- **2014** - *Andrew J Kerns et al.* - Unmanned aircraft capture and control via GPS spoofing

Experimental setup

- Transmitting SDRs: 2x BladeRF x40
  - Internal clock accuracy of 1 parts per million (ppm), calibrated with GSM before use
- GPS spoofing software: GPS-SDR-SIM
  - Precomputed version for experiments with the antenna
  - Real-time version for the experiment with transmitting over multiple antennas
- Receiving SDR: 1x HackRF One
- GPS receiver software: GNSS-SDR
- Antennas: 2x 2.4 GHz dipole and 2x 2.4 GHz Yagi-Uda

Experiment: directionality and range

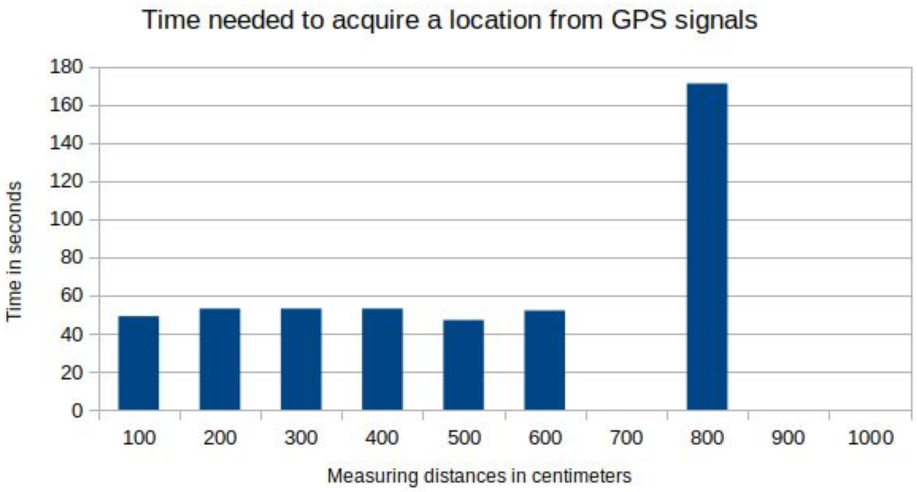
- Open field
  - To minimise reflection and interference
- Compare monopole antenna with a directional Yagi-Uda antenna
  - Different distances (measured in steps of 100cm)
  - Different angles (measured in steps of 90°)
- Monopole ERPs: 18.6 mW and 11.7 mW
- Yagi-Uda ERP: 46.1 mW

Experiment: multiple transmitters

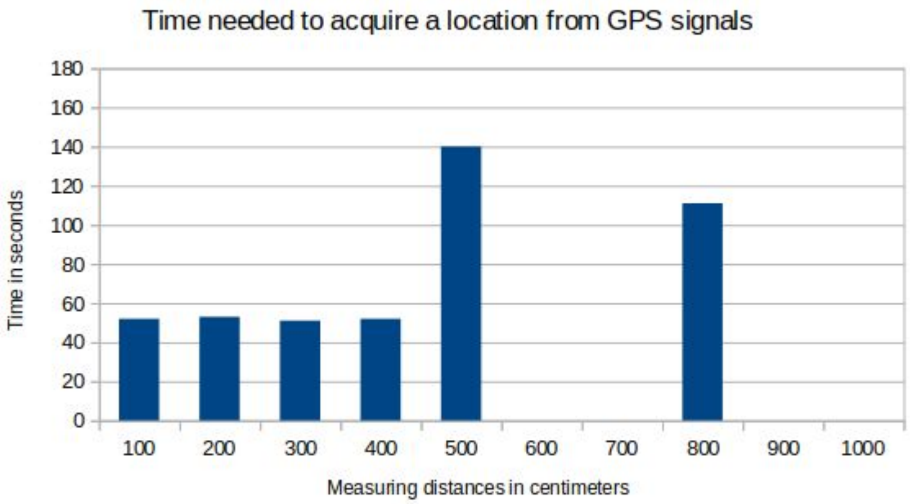
- Signal synchronisation
- Dividing satellites' signals over multiple transmitters
    - 3 satellites per signal
- Monopole ERP at 18.6 mW
- Yagi-Uda ERP at 46.1 mW

Results: directionality and range

8dBm

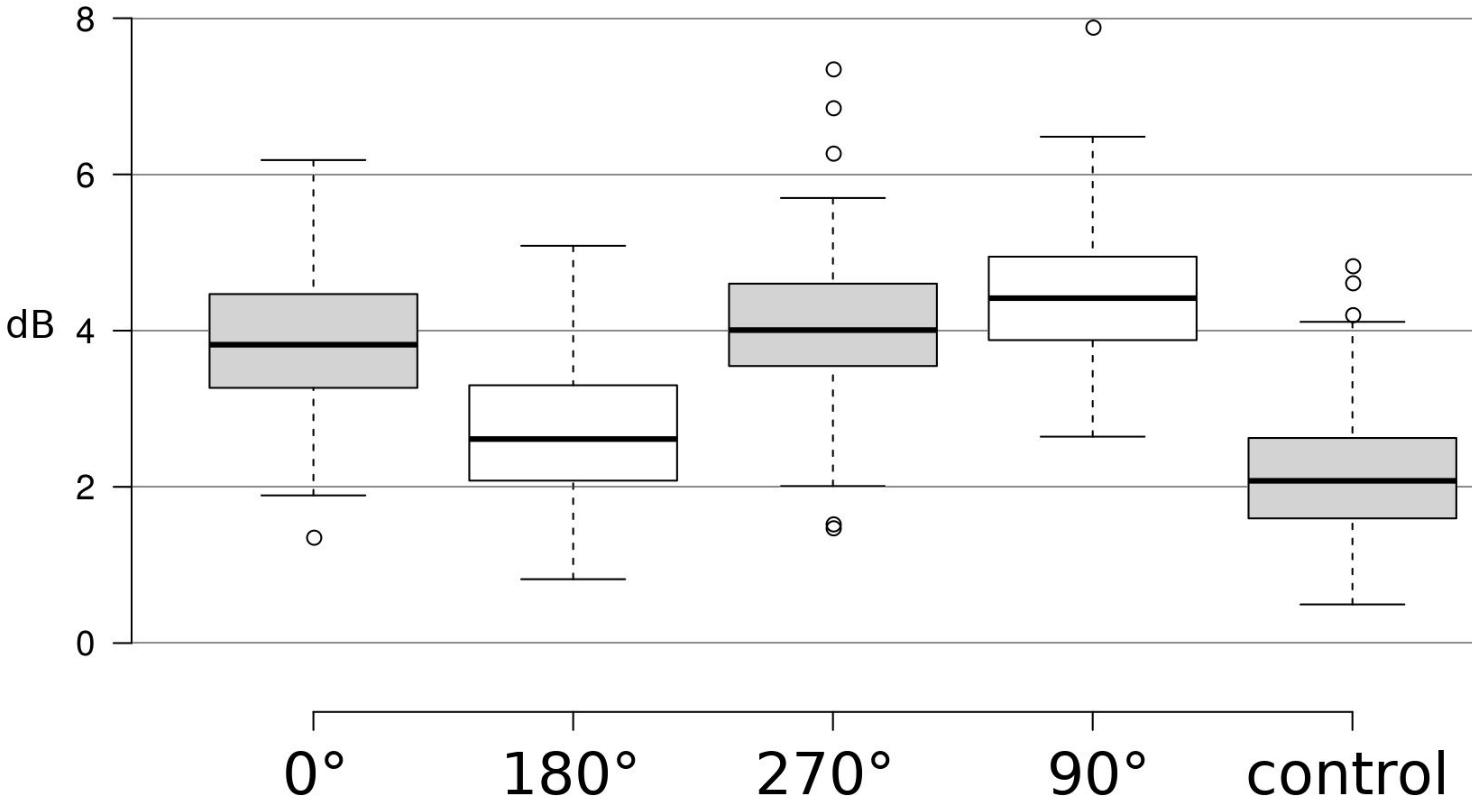


10dBm



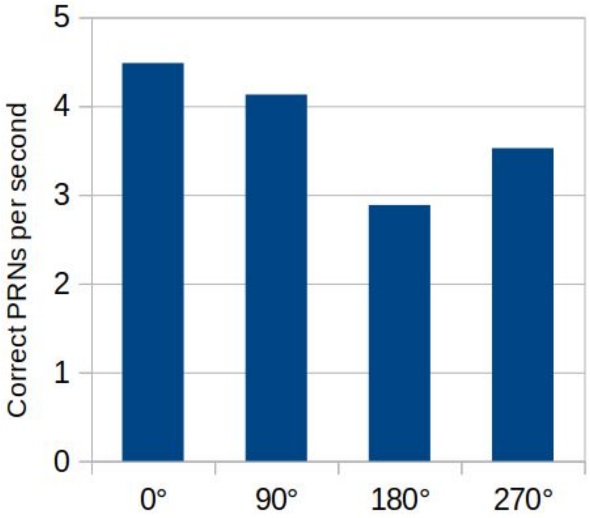
(lower is better)

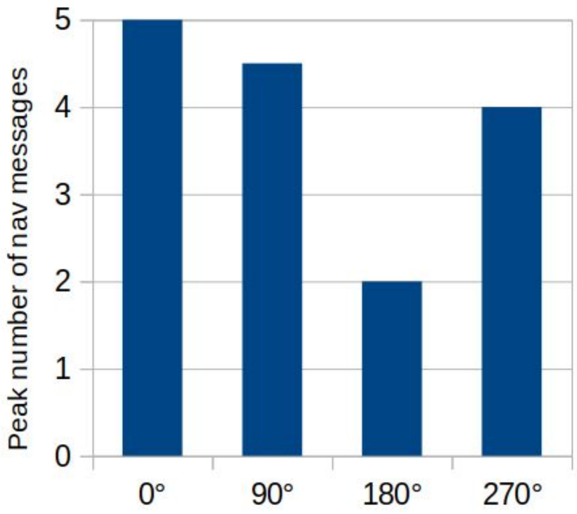
Results: directionality and range



Results: directionality and range

Orientation	0°	90°	180°	270°
Test run 1	56 seconds	No fix obtained	No fix obtained	175 seconds
Test run 2	71 seconds	86 seconds	No fix obtained	56 seconds





Results: directionality and range

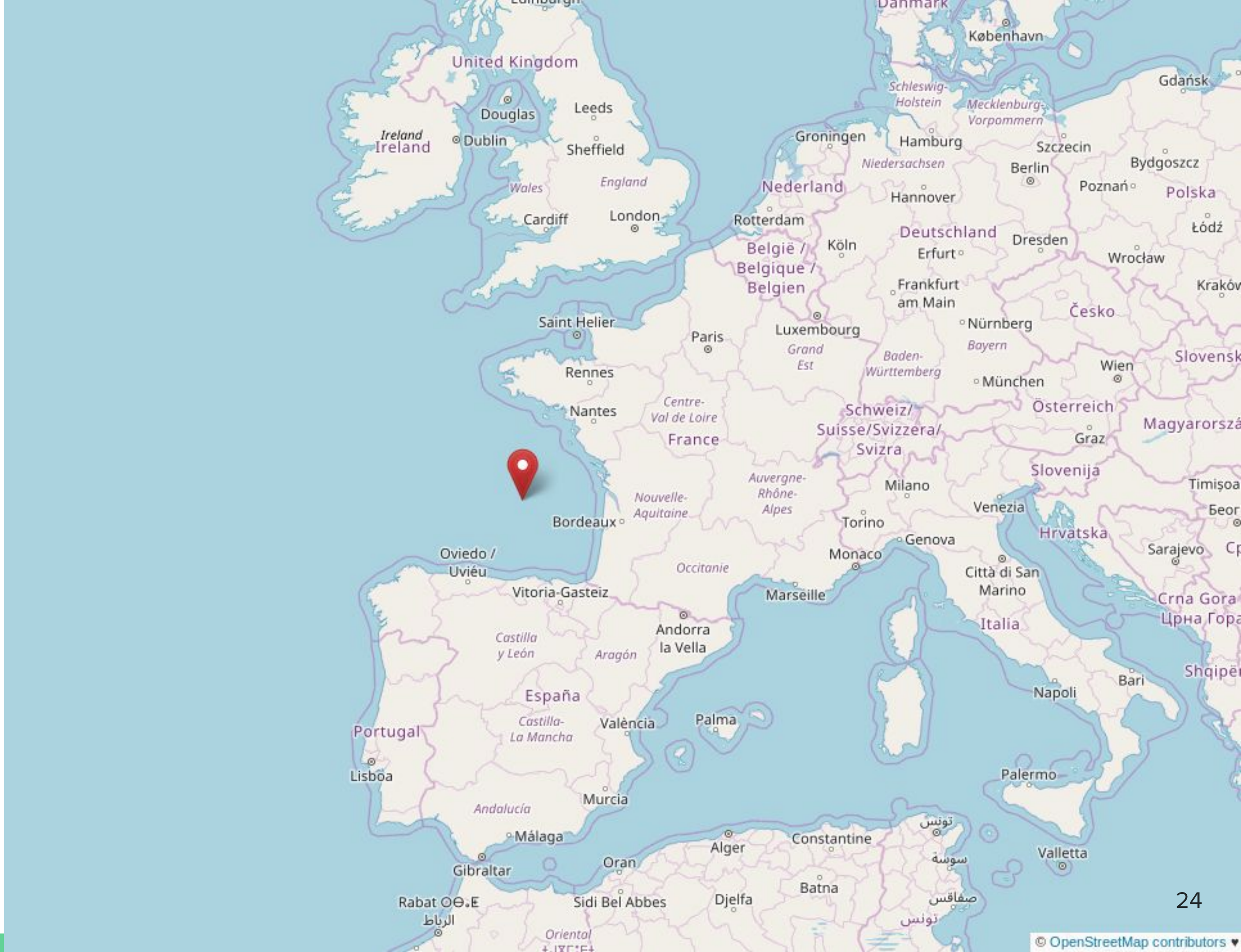
- Best signal at 0°

- Side lobes are large, back lobe clearly smaller

Results: multiple transmitters

- Modified the software to modulate only selected satellites per antenna

- Signal synchronisation
  - First attempt not so successful...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Ireland
Ireland
Dublin
Sheffield
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Cardiff
London
København
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Mecklenburg-Vorpommern
Gdańsk
Groningen
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Szczecin
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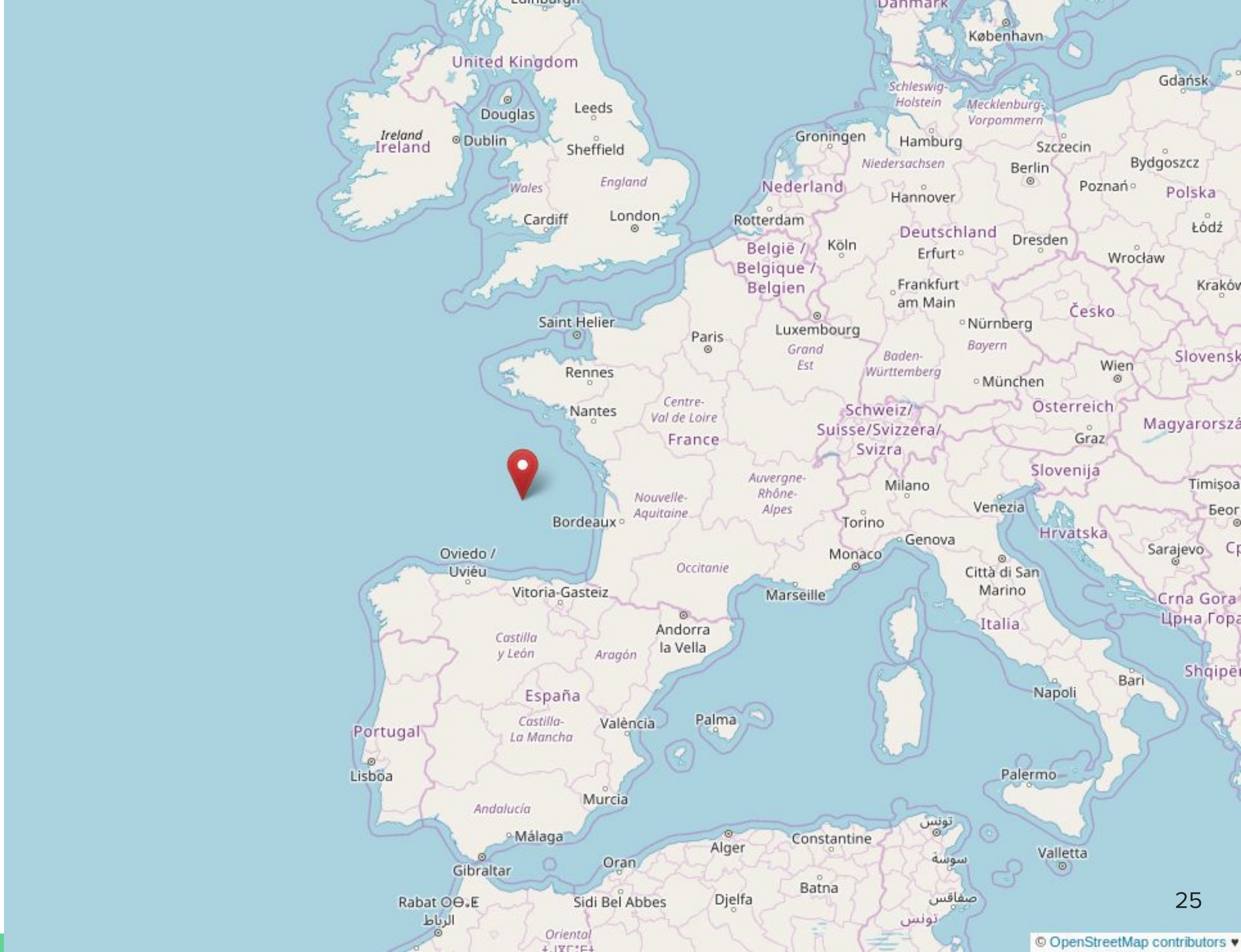
Altitude: 118 000 km



6 370 km

International
Space Station

370 km

GPS satellites

20 000 km

Earth Calculated position Moon

188 000 km 363 000 km

Results: multiple transmitters

- Signaling through FIFO pipe
  - `FILE* tmpfile = fopen("/tmp/fifo", "r");`
  - mean 8.6µs, stddev 10µs, median 1.3µs

- High-resolution clock
  - `int status = clock_gettime(CLOCK_MONOTONIC, &result_time);`
  - Busy wait: mean 8ns, stddev 6ns, median 6ns

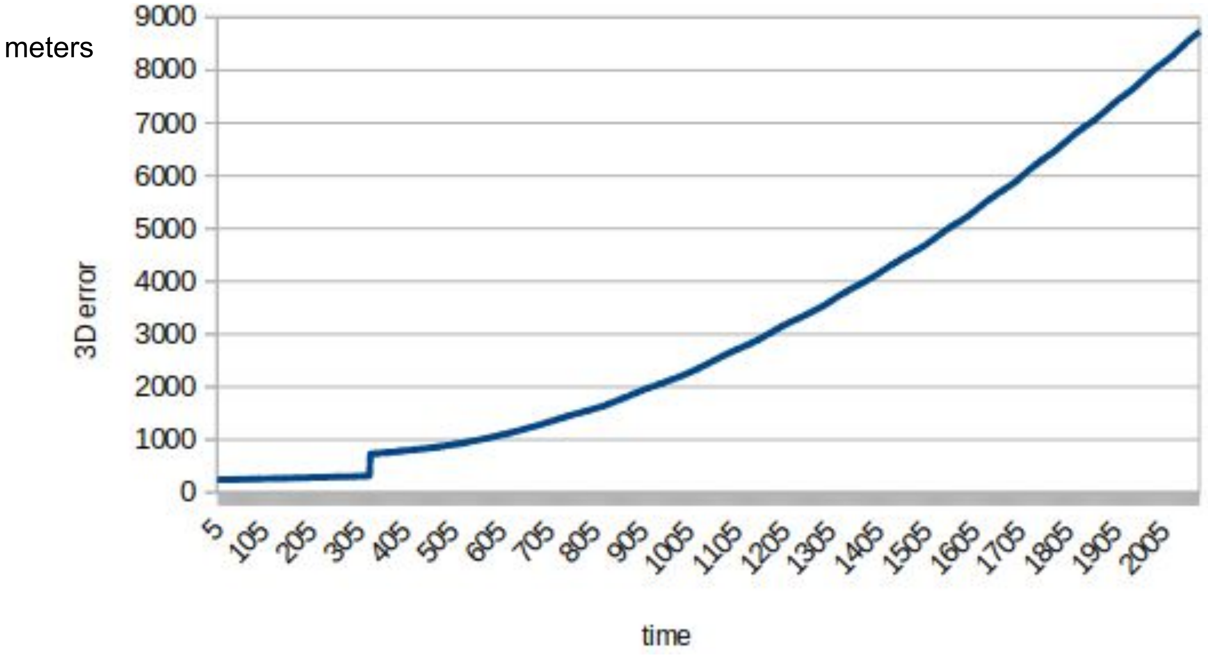
Results: multiple transmitters

- Quite variable test runs

	3D error (m)	Horizontal error (m)	Altitude error (m)
Run 1	18 451	14 753	11 081
Run 2	250	235	87
Run 3	7 751	7 126	3 049
Run 4	4 440	4 075	1 764
Run 5	5 195	4 782	2 029
Run 6*	482 106	89 198	482 106
Run 7	9 552	8 773	3 778

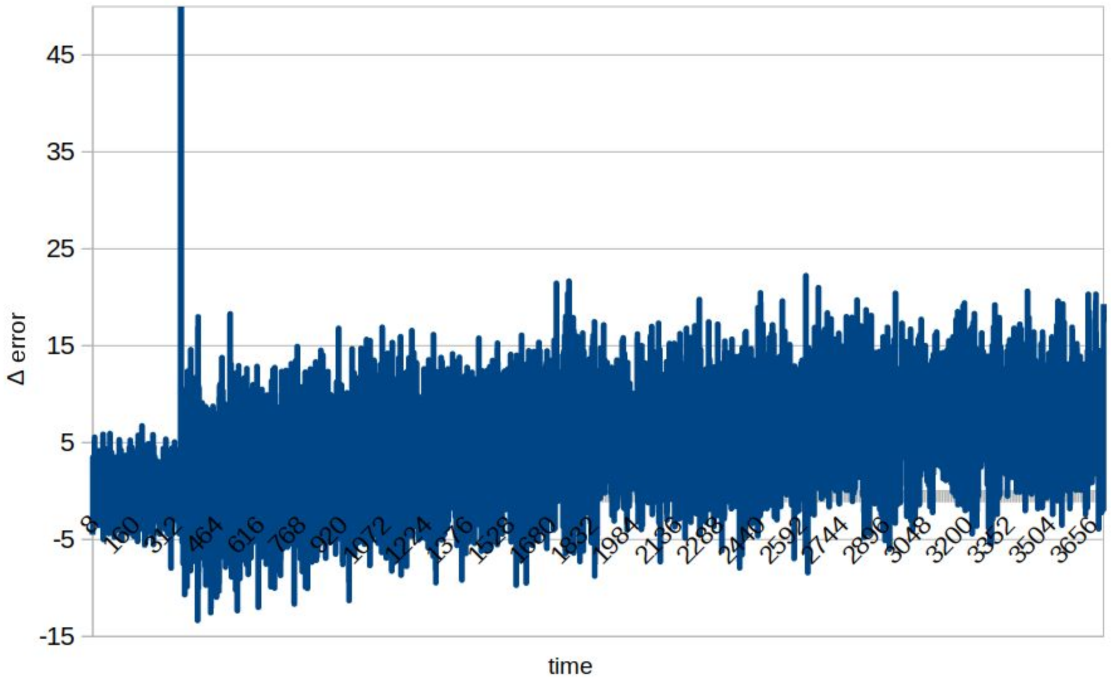
Results: multiple transmitters

- Error over time (monopole) of run 2



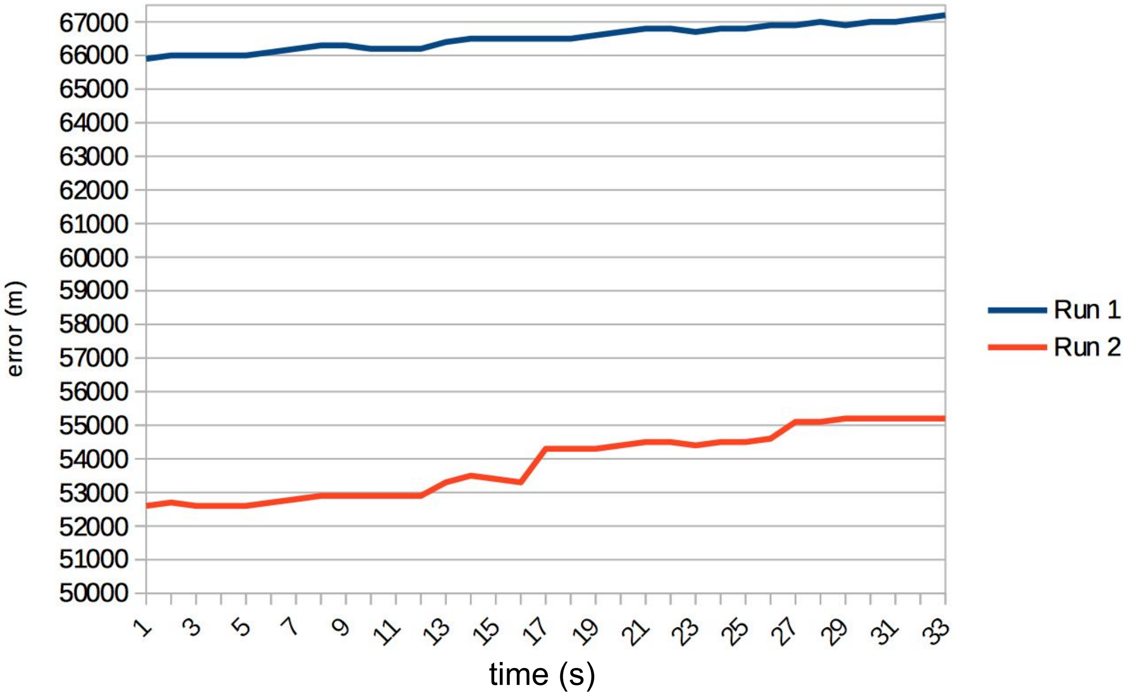
Results: multiple transmitters

- Error drift (monopole)



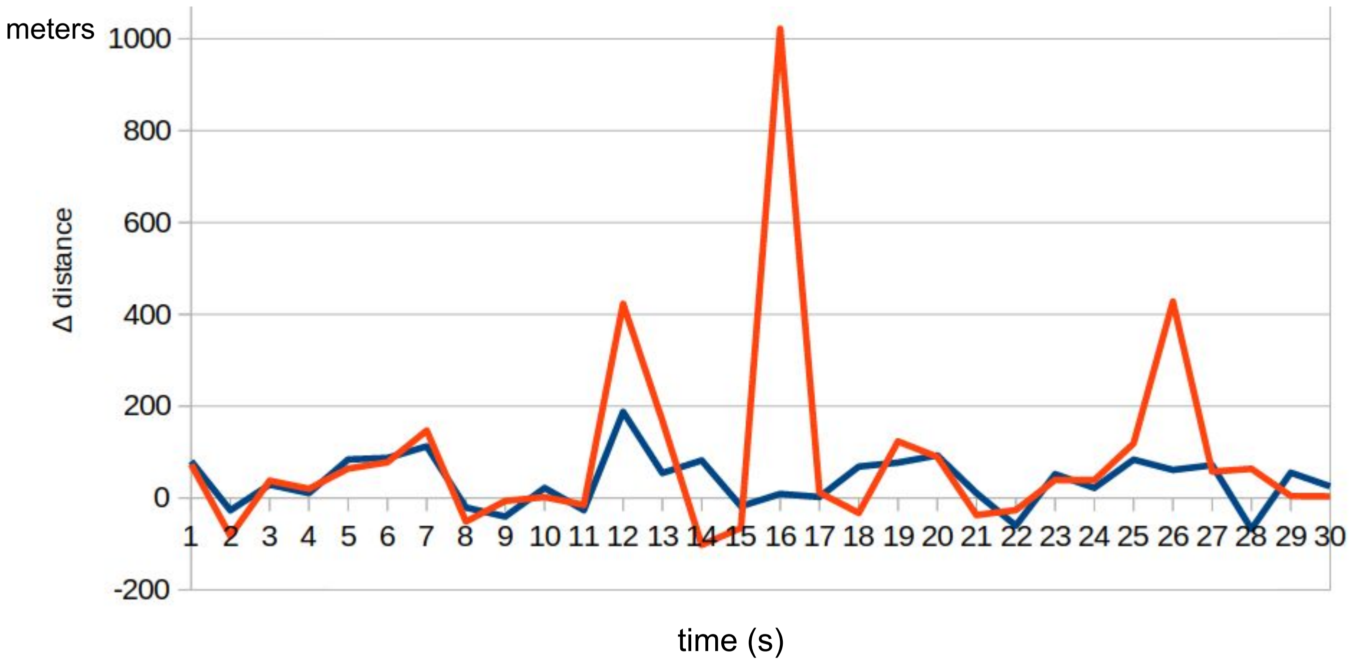
Results: multiple transmitters

- Error over time (Yagi-Uda)



Results: multiple transmitters

- Error drift (Yagi-Uda)



Discussion

- Different frequency band used.
  - 0.30208 GHz difference between 1.8775 GHz and 1.57542 GHz

- 2.4 GHz antennas in our experimental setup
  - 1.8775 GHz (omni)directional antennas hard to find or didn't exist

- Absence of a low noise amplifier (LNA)

Conclusion

Is it possible to limit GPS spoofing to a single receiver?

We failed to prove this, however:

- Dividing signals and time synchronisation works well
- Yagi-Uda antenna not adequate

Future work

- Different antenna with smaller side and back lobes
- Testing in a Faraday cage on the GPS frequency
- Low-noise amplifier
- Spoofing with the presence of the "genuine" signal

Questions