Loco Positioning

An Open Source Local Positioning System

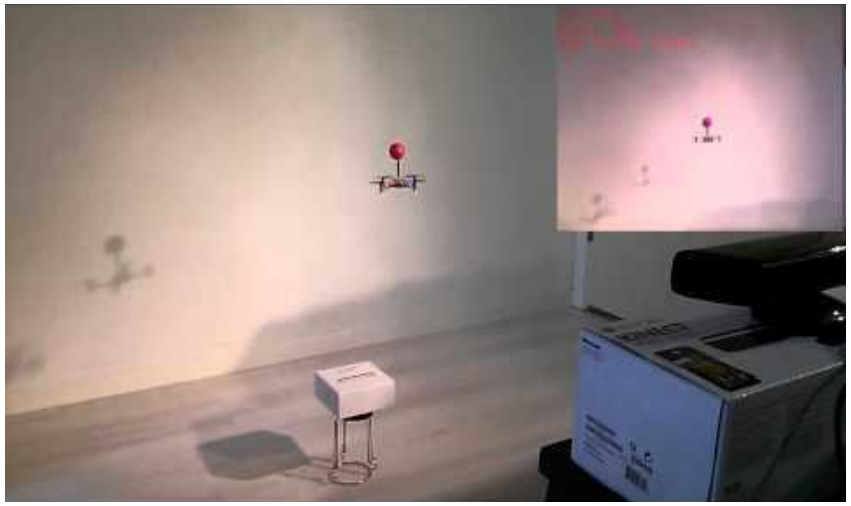
FOSDEM 2017

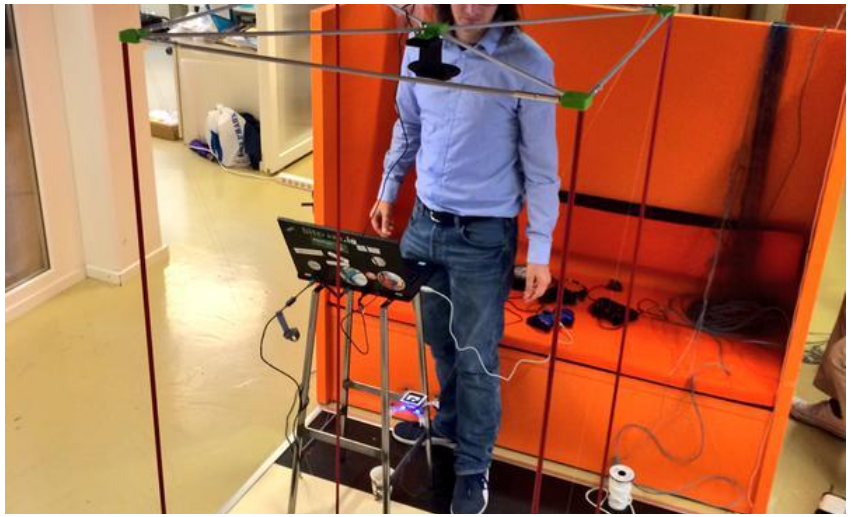
Arnaud Taffanel
Bitcraze AB

Crazyflie 2.0

- Open source flying development platform
- Designed to be expandable in both software and hardware
  - 168MHz Cortex-M4 CPU with FPU (stm32f405)
  - Deck expansion port

Our autonomous flight attempts





The decawave DW1000

- Radio chip available of the shelf
- Standard based: IEEE802.15.4a UWB PHY
- 500MHz bandwidth with 5 channels from 3 to 7GHz
- Radio that can range: potential to be used as a base for a Local Positioning System

What is a local positioning system ?

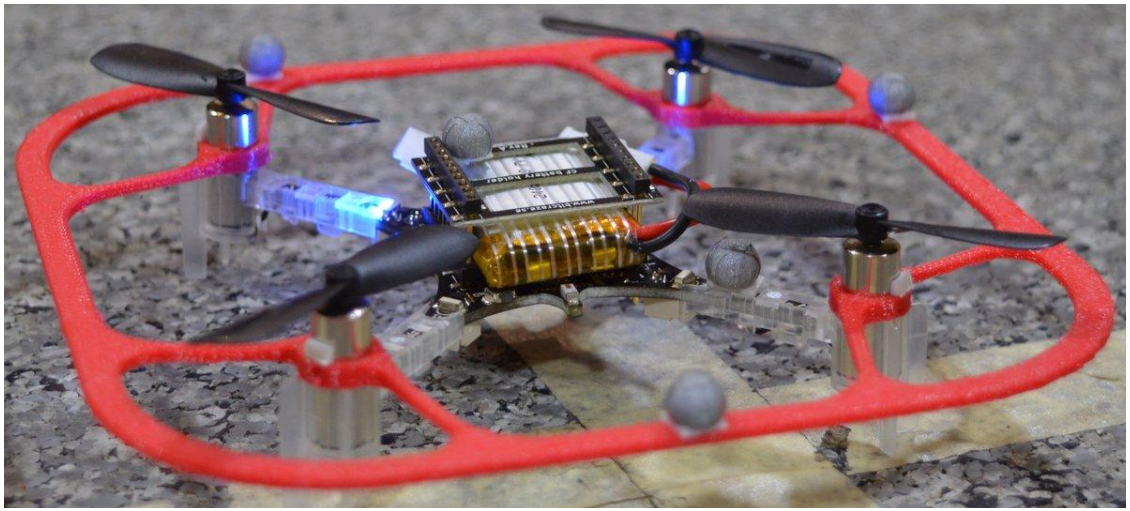
- Similar to GPS but local (ie. indoor)
- Provides absolute position

Why a local positioning system ?

- Indoor navigation
- Assets tracking
- Bitcraze focuses on indoor positioning and navigation for robotics

Existing systems: Optical

- Motion capture systems
  - State of the art for flying robotic and swarm research

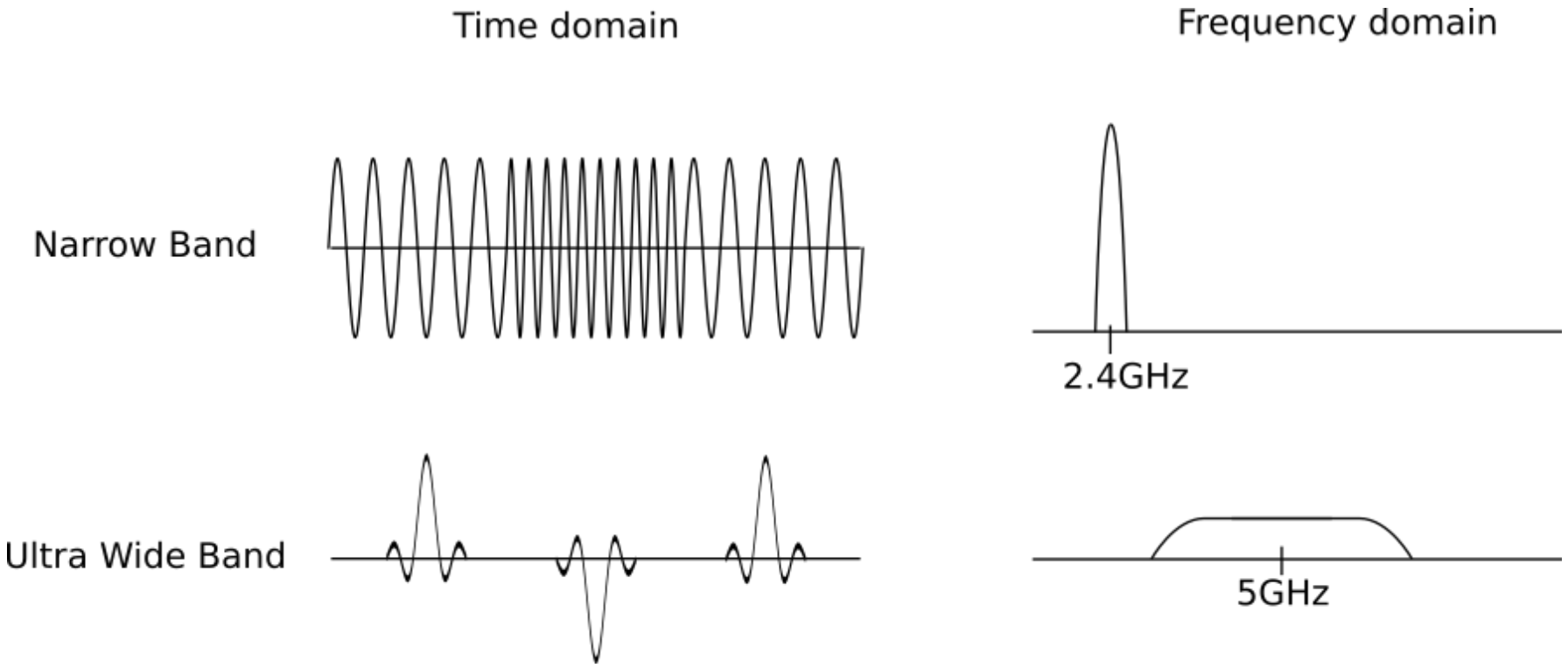


  - Very precise but expensive
- Optical flow mounted on platform

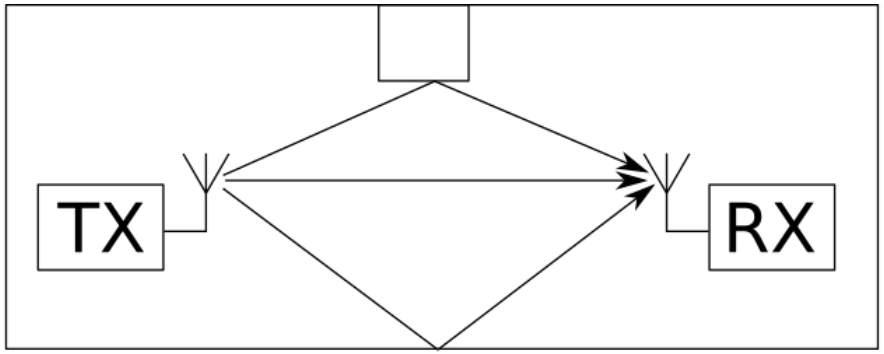
Existing systems: Radio-based

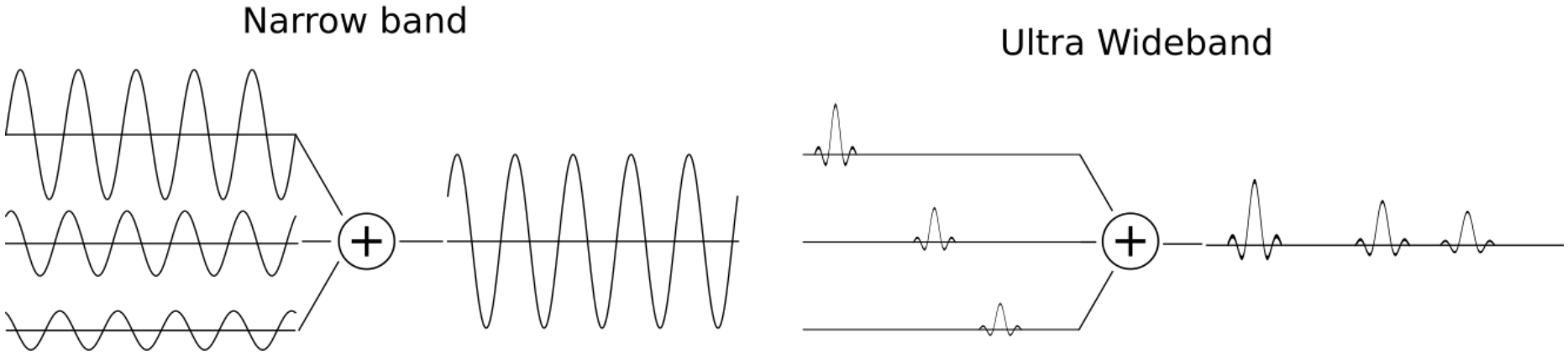
- Received signal strength (ex. Bluetooth low energy tag)
  - Coarse accuracy
- Angle detection
  - Angle of arrival
  - Azimut from the transmitting antenna (ex. VOR system used for airplanes)
- Time of flight
  - Requires wide bandwidth to be resilient to multipath

Ultra Wideband (UWB) radio: What is it ?

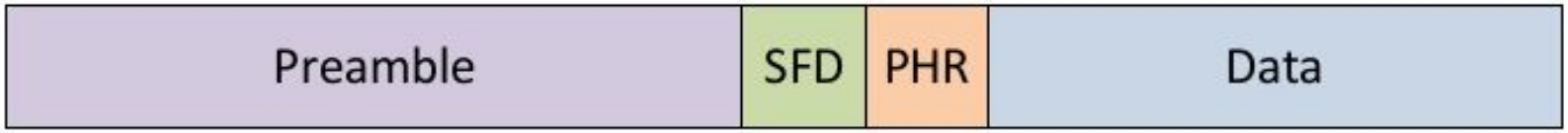


Ultra Wideband radio: Multipath



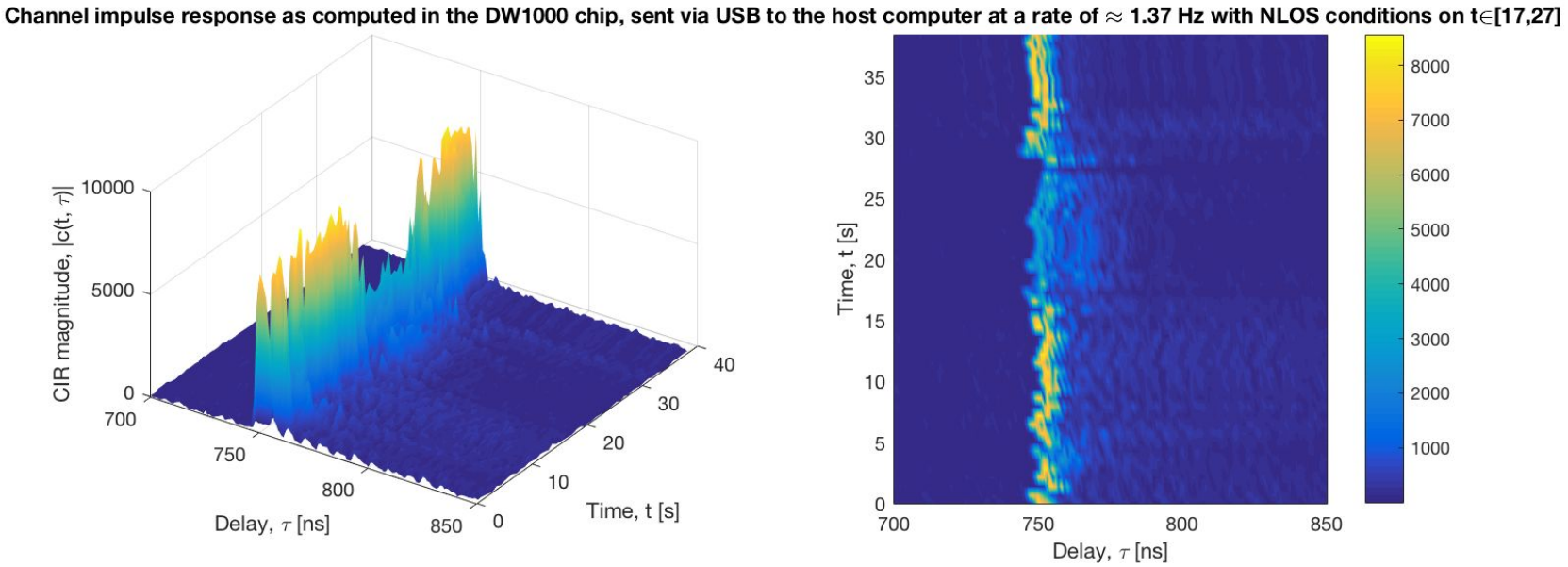


Ultra Wideband: Packet format and timing



- Very long preamble
- SFD (start frame delimiter) is the timestamped instant
- Packets can carry up to 127 Bytes of data
  - 1024 with a Decawave proprietary extension
- Packets contains source and destination address
  - IEEE802 MAC header (MAC addresses)

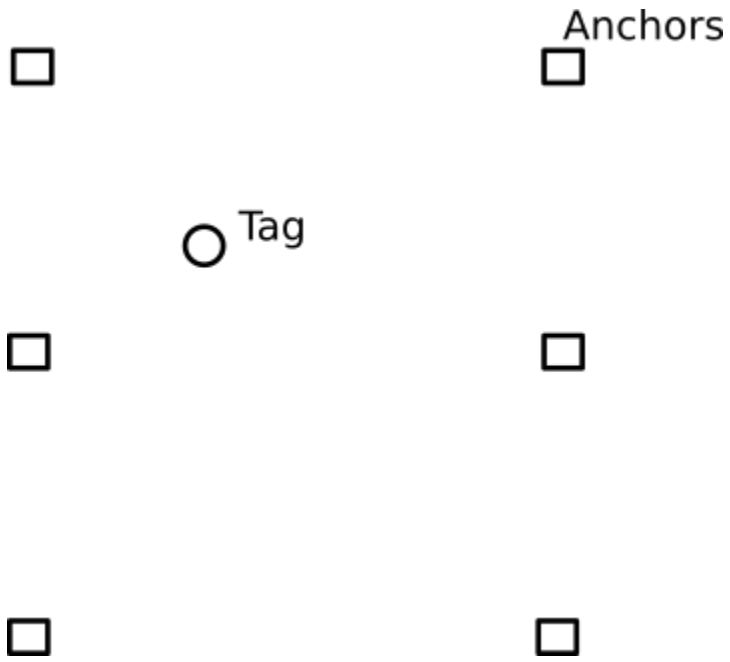
Ultra Wideband: Preamble detection



Ultra Wideband radio: Timestamping

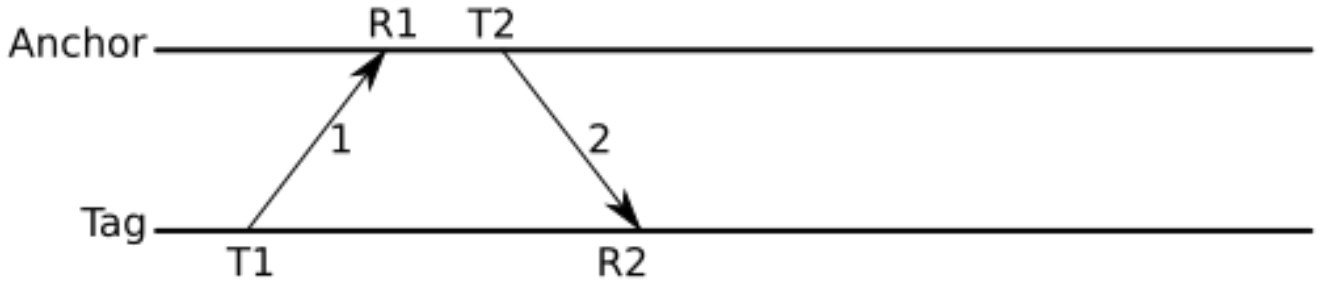
- Precise timestamping of packets at transmission and reception
  - 64GHz timer, 1.5ps timer tick -> ~5mm
  - Decawave DW1000 specifies +/-100mm distance measurement accuracy
- Robust to multipath
- Not so robust to non-line-of-sight (NLOS)
- NLOS induces an offset measurement

UWB-based LPS architecture



- Anchors are part of the infrastructure: UWB radios placed at known location
- Tag is what we want to locate: mobile UWB radio

Two Way Ranging (TWR): 2 Packets

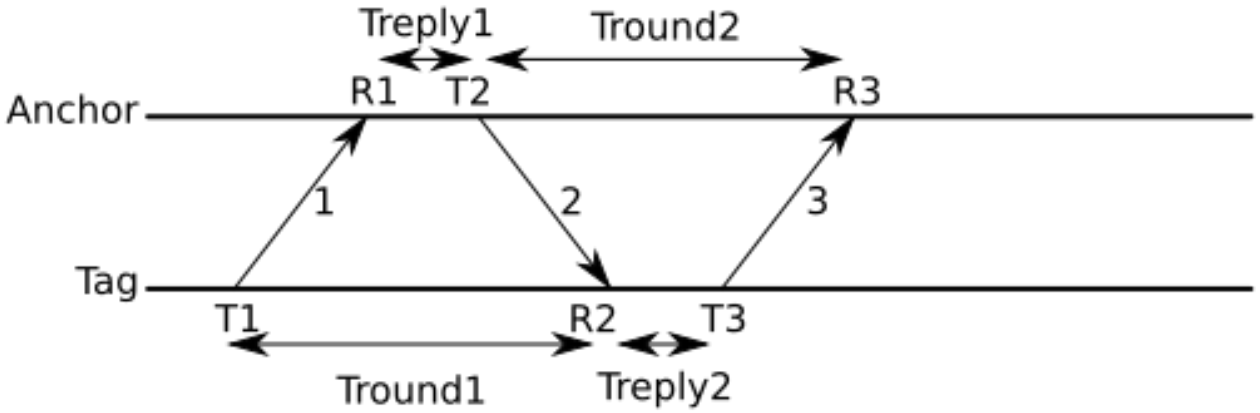


- Basically ping:

$$t_f = \frac{(t_{R2} - t_{T1}) - (t_{T2} - t_{R1})}{2}$$

- Anchor and tag have different clocks: very big error if anchor response time is not close to 0

Two Way Ranging (TWR): 3 Packets

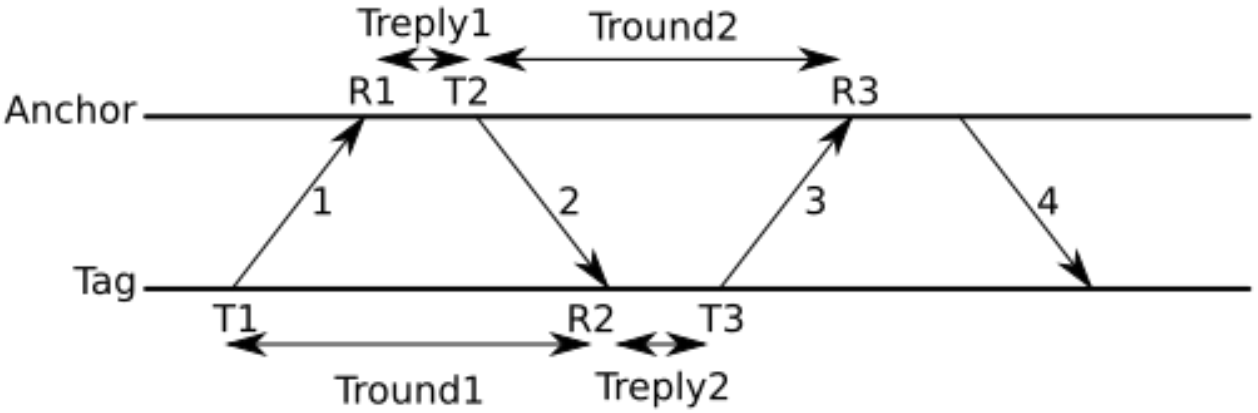


- One exchange added to cancel clock drift error

$$t_f = \frac{T_{round,1} \times T_{round,2} - T_{reply,1} \times T_{reply,2}}{T_{round,1} \times T_{round,2} + T_{reply,1} \times T_{reply,2}}$$

- Now there is information left in the anchor

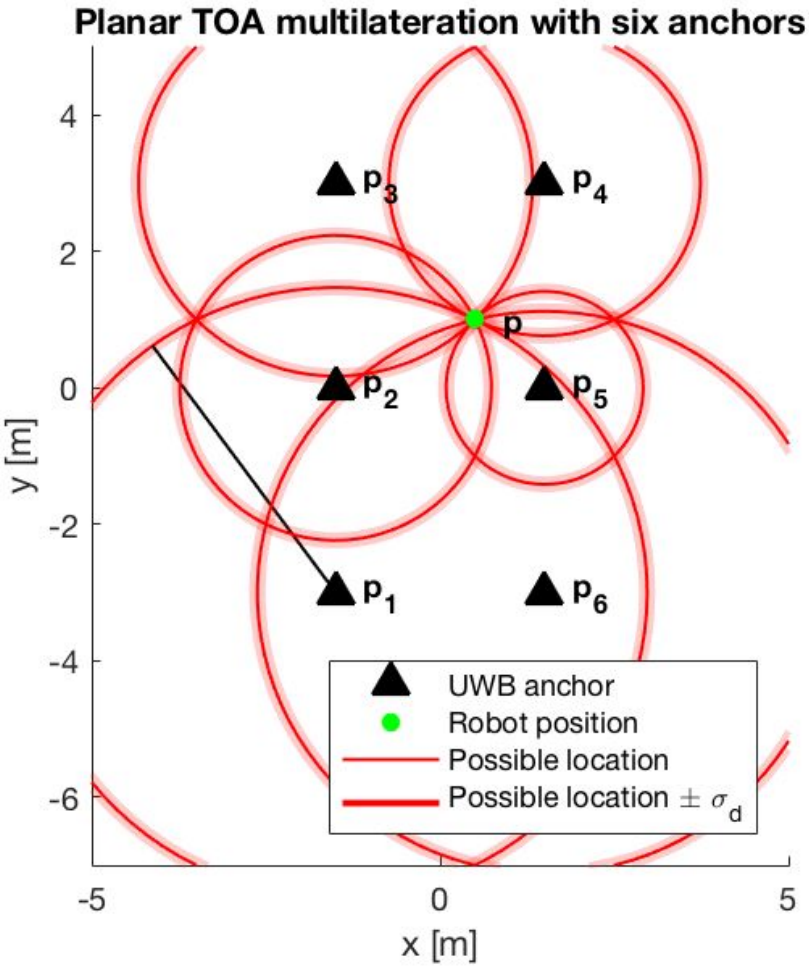
Two Way Ranging (TWR): 4 Packets



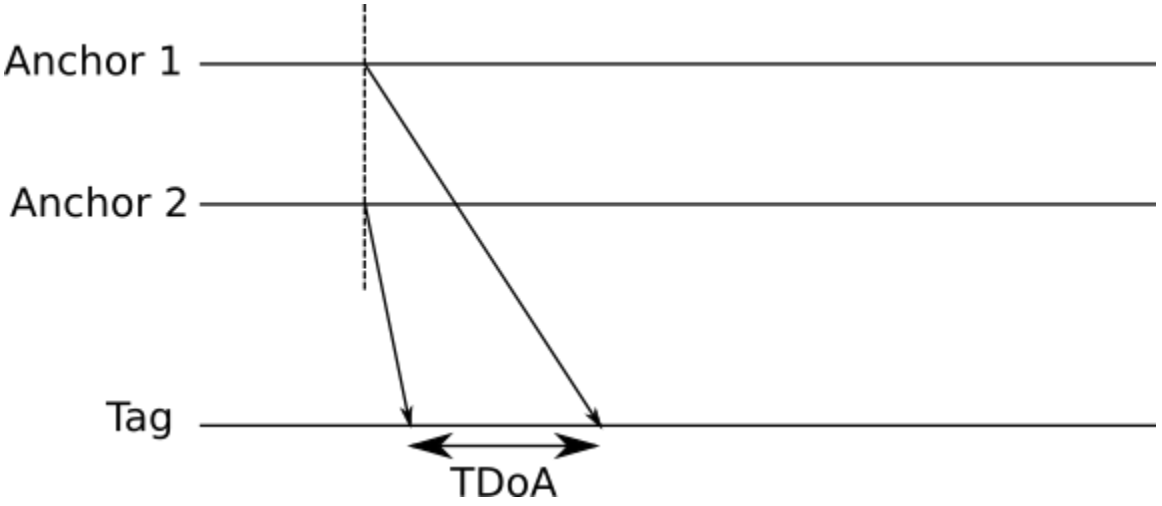
- Last packet transfers timestamps to the tag
- Active distance measurement
  - The tag controls the distance measurement rate
  - Bi-directional communication

Two Way Ranging (TWR): Positioning

- Tag at intersection of
  - 2D: circles
  - 3D: spheres
- Noise properties scale well with distance
- Good performance in and near the Anchor convex hull
- Requires active distance measurements: does not scale with number of Tags

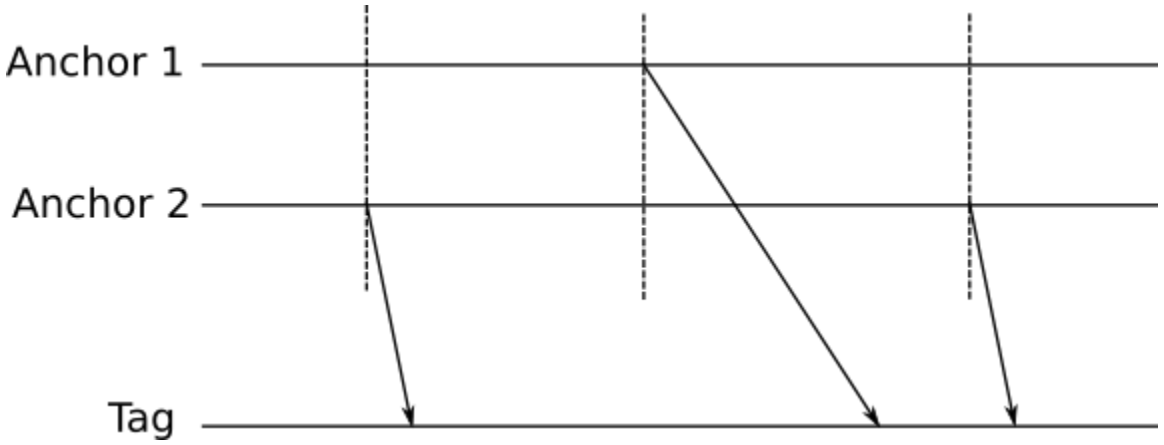


Time Difference of Arrival (TDoA)



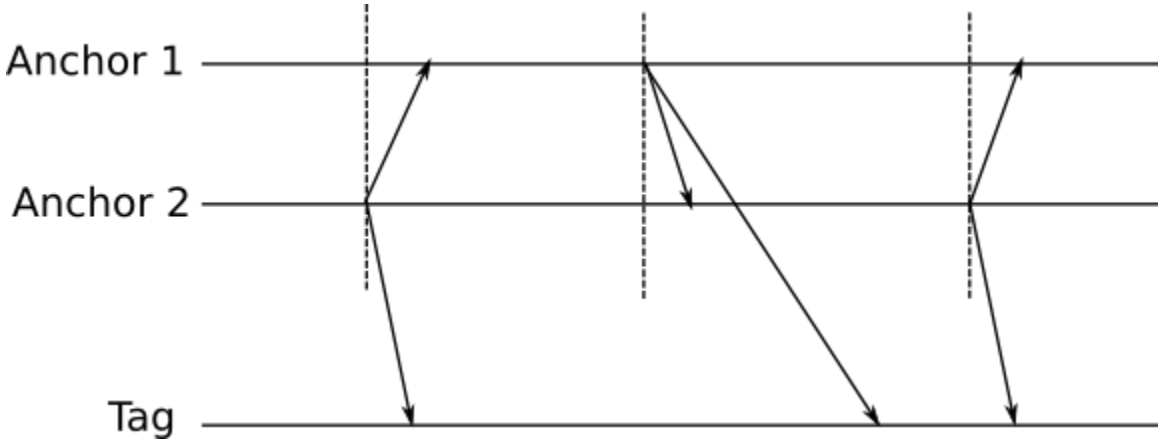
- If packets were sent at the same time
  - Difference between receive time is the difference of time flight
  - Can be used to calculate relative distance to Anchor 1 compared to Anchor 2

Time Difference of Arrival (TDoA)



- Sending many packets at the same time is not possible so:
  - We assign one time slot to each anchor
  - At the reception the time slot time is subtracted from TDoA
  - Two packets from the same anchor can be used to synchronize the local clock to the remote clock
- How to synchronize transmit times between anchors?

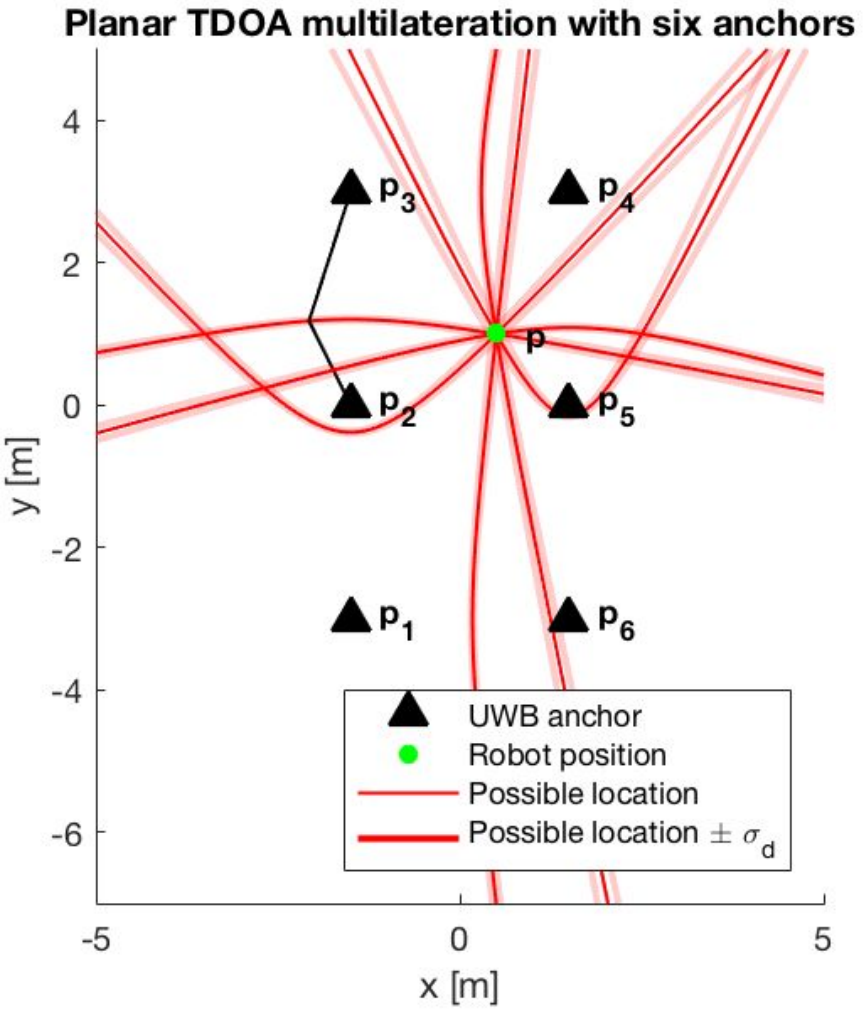
Time Difference of Arrival (TDoA)



- Packets are broadcast
- The same packet are used for measuring time of flight between anchor (TWR!)
  - If we have time of flight between two anchors we can synchronize their clock

Time Difference of Arrival: Positioning

- Tag at intersection of
  - 2D: parabola
  - 3D: paraboloid
- Tag needs to be in anchor convex hull for good precision
- Scales very well: Tags just listen



Loco Positioning System (LPS)

- Based on of-the-shelf UWB radio: DWM1000
- Open source local positioning system for robotic
  - Currently with a focus on Crazyflie 2.0
- Useful for robotics and more generally anything that needs real time absolute positioning

LPS Architecture: Nodes

- STM32F072 Cortex-M0 MCU
- DWM1000 UWB module
- Firmware using FreeRTOS
- Open source DW1000 driver
- Can be used as Anchor, Tag or UWB sniffer
  - This is why it is called Node and not Anchor
- Upgradable and configurable via USB
  - Radio (OTA) update and configuration in development

LPS Architecture: Crazyflie 2.0 deck

- Based on DWM1000 UWB module
- Ranging, positioning and control implemented in Crazyflie 2.0 firmware

LPS Architecture: Firmware

- TWR stable, TDoA experimental
- More than just ranging required for autonomous robotics
  - Positioning using sensor fusion (Kalman)
  - Position and trajectory control

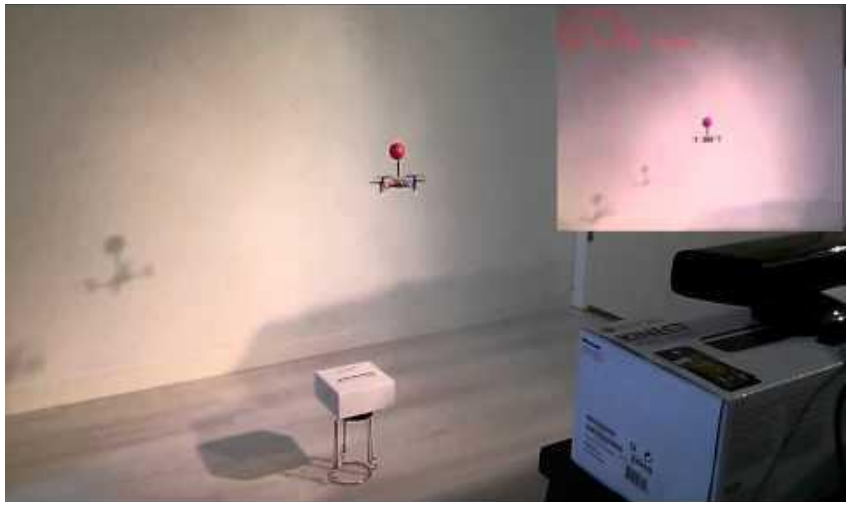
LPS Architecture: Software

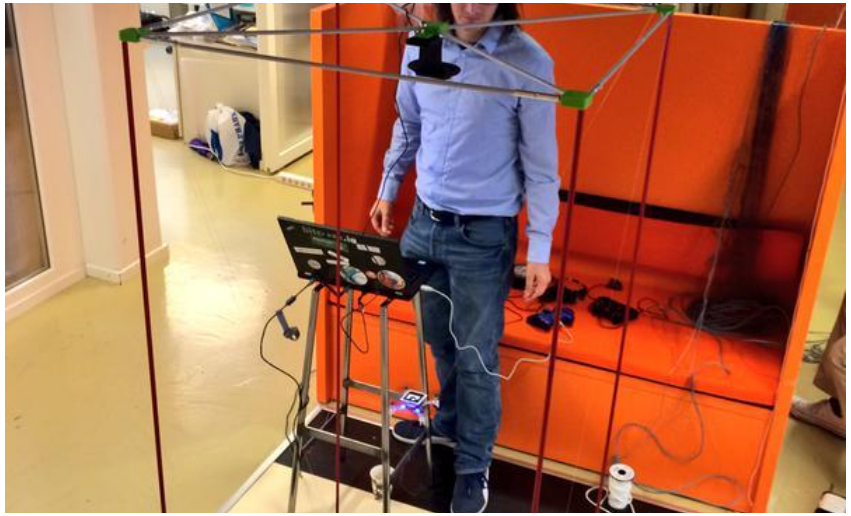
- ROS Support
- Support by Crazyflie lib and client in development
- System configuration and management tools in development

Project status and future

- Currently used by universities and industry
- Tech artists very interested by an open flying swarm for shows
- Lots of software planed or in development
  - Blender choreography authoring plugin
  - Swarm management software
  - Automatic anchor position measurement
- Small Tag with IMU and LPS planned

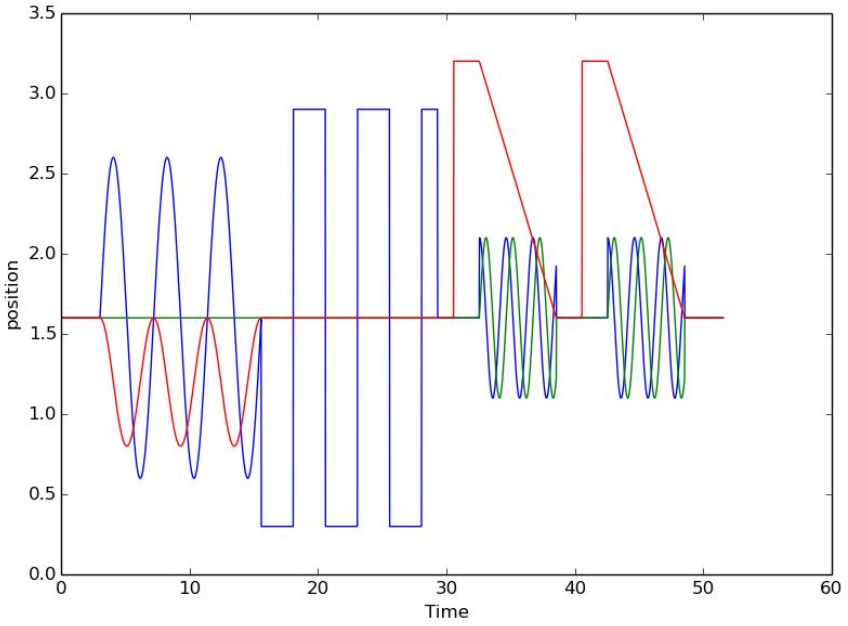
Our next autonomous flight attempts?

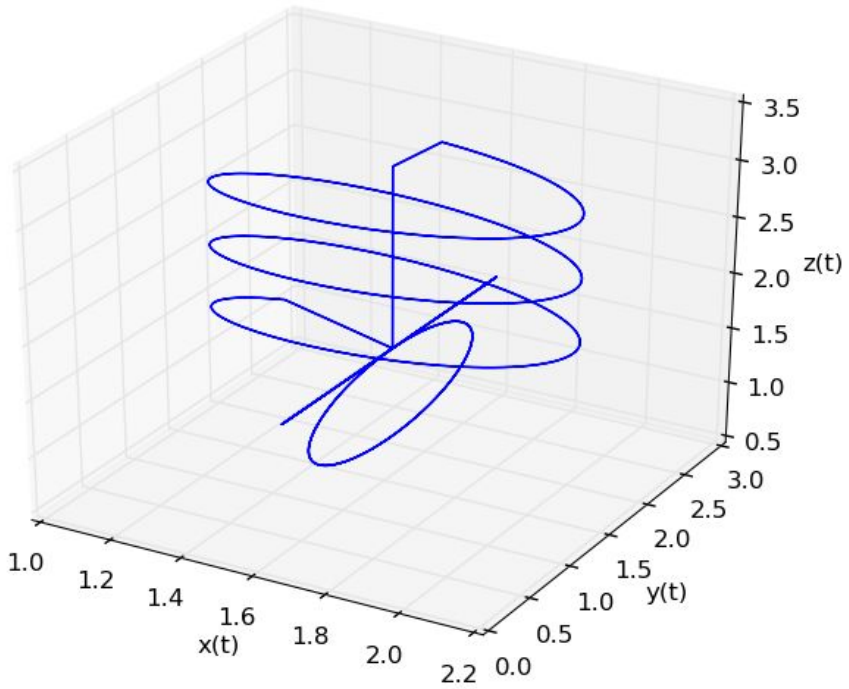




Demo!

Non-linear Quaternion controller





Questions?

Arnaud Taffanel
contact@bitcraze.io

Web: bitcraze.io
Twitter: @bitcraze_se