The Loco Positioning System

Algorithms

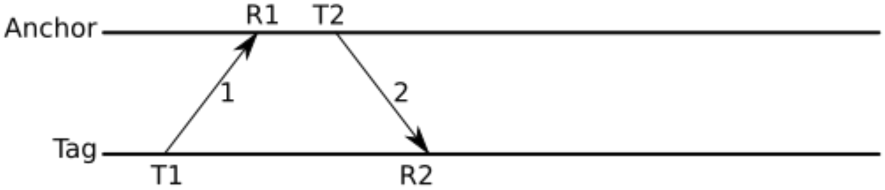
Goal

Thorough understanding of the message flow and calculations in the Two way ranging and the TDoA modes. Understanding the properties of the different modes.

Modes

- Two Way Ranging
  - One Crazyflie
  - Robust
  - Straight forward
- TDoA2
  - Multiple Crazyflies
  - Single point of failure
  - Max 8 anchors
- TDoA3
  - Multiple Crazyflies
  - Scalable
  - Slightly more noise

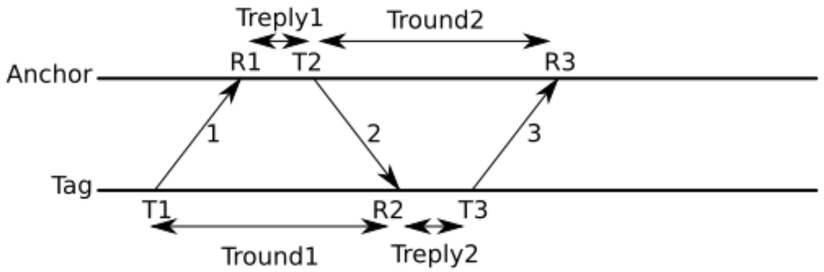
Two Way Ranging - step 1



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

- Basically a ping
- TX timestamps (t_{T1} and t_{T2}) are included in the packet when transmitted
- RX timestamps are recorded when packet is received
- Anchor and tag have different clocks: very big error if $t_{T2} - t_{R1}$ is not close to 0
- Note: t_{R1} is passed on from the Anchor to the Tag as data in the radio packet

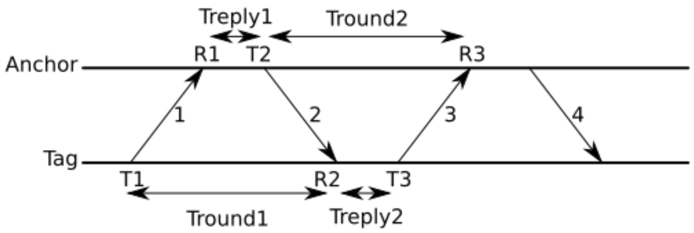
Two Way Ranging - step 2



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

- One exchange added to cancel difference in clock rate
- We are assuming the clock rates are not changing during the transaction
- The distance between Tag and Anchor can now be calculated
- The only problem is that the information is not available in the Tag where it is needed

Two Way Ranging - step 3



- Last packet transfers timestamps to the Tag as data
- Actual calculations done in the Tag
- Active distance measurement
  - The tag controls the distance measurement rate
  - Bi-directional communication

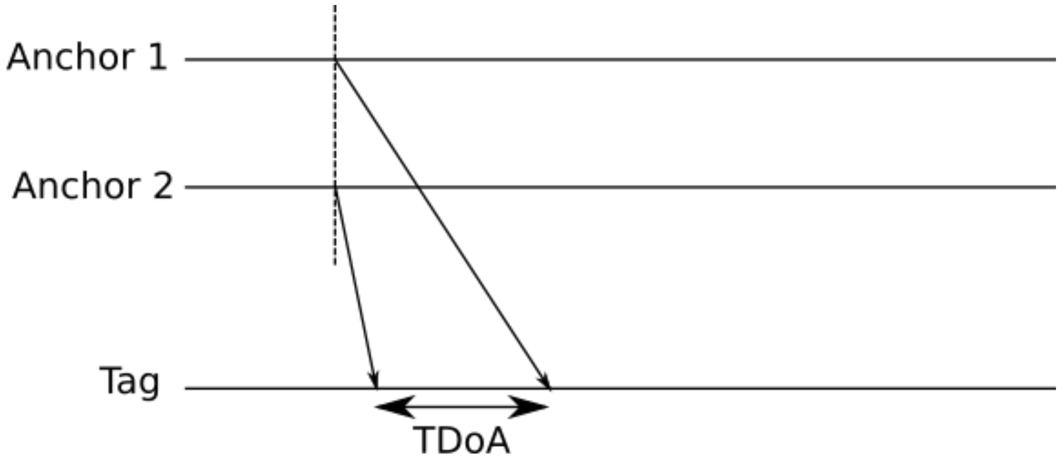
Two Way Ranging - step 4

- Remove antenna delay
- Convert to distance by multiplying with speed of light
- End result: distance from Tag to one Anchor

Two Way Ranging - continuous ranging

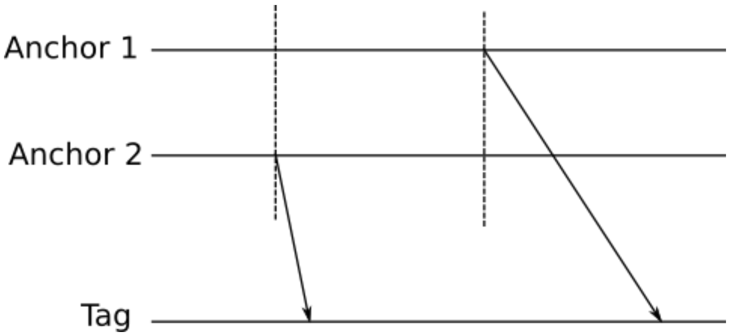
- The Tag ranges Anchors in a round Robin fashion
    - 480 times/second (60 times/s/anchor with 8 anchors)
- The Anchors are configured with their absolute position
- The Anchors transmit their position to the Tag as data in the radio packets
- When the Tag has calculated the distance to an Anchor it sends this information + the Anchor position to the estimator for further processing

Time Difference of Arrival - step 1



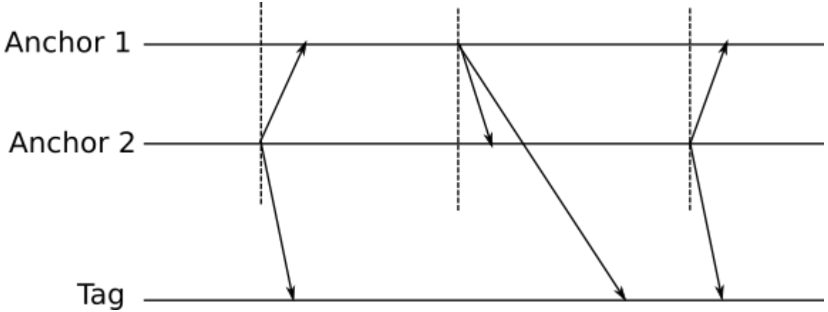
- If two Anchors could send packets at exactly the same time
  - Difference between receive time is the difference of time flight
  - Can be used to calculate relative distance to Anchor 1 compared to Anchor 2

Time Difference of Arrival - step 2



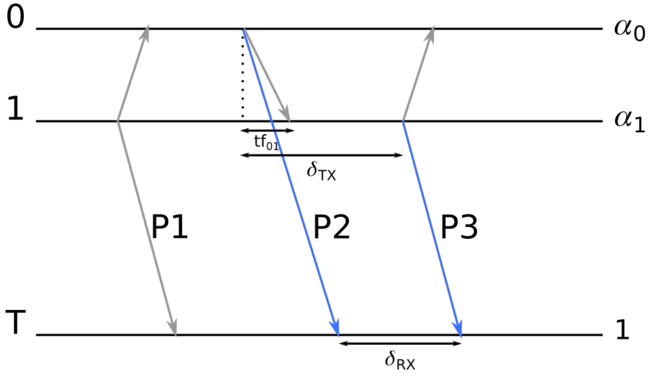
- Receiving multiple packets at the same time is not possible
- Anchors must transmit at different times
- At the reception the difference in transmission times is subtracted from TDoA

Time Difference of Arrival - step 3



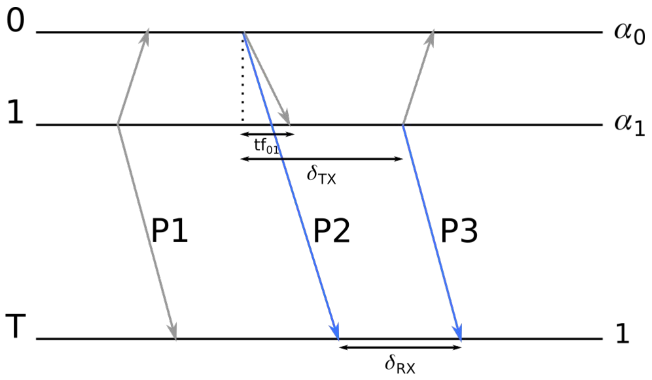
- Packets are broadcast, the Anchors listen to other Anchors
- The same packet that are used by the Tag are used for measuring time of flight between anchor (TWR!)
- Remember Anchor 1, Anchor 2 and the Tag all have different clocks

Time Difference of Arrival - step 4



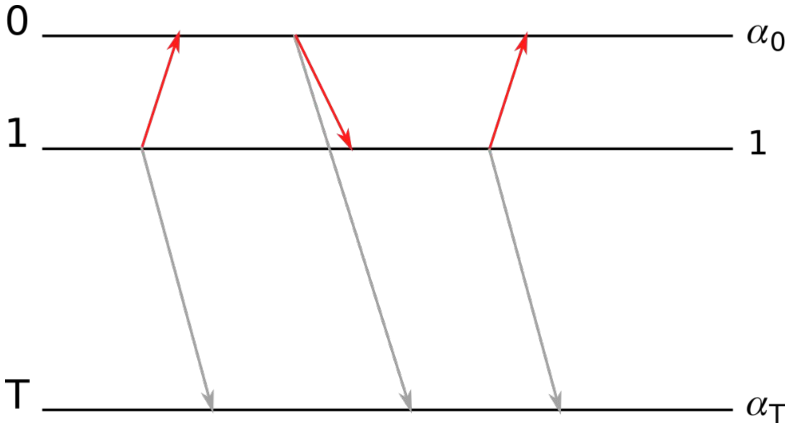
- Consider the 3 last packets sent from anchor 0 and 1
- We can calculate the difference in time of flight (which is the same as the TDoA) by calculating the difference between δ_{TX} and δ_{RX}
- δ_{RX} is measured when receiving the two packets. It is measured using the Tag clock

Time Difference of Arrival - step 5



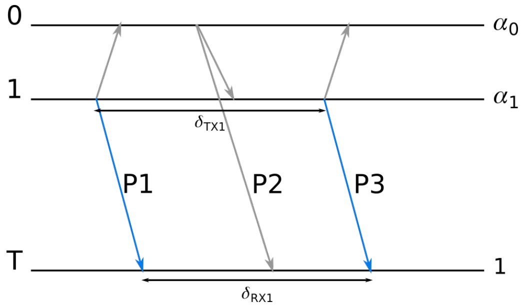
- We want to know δ_{TX}
- Anchor 1 measures the time of arrival of the packet P2
- Anchor 1 knows the time when P3 is sent
- If we knew tf_{01} (time of flight from 0 to 1) we could calculate δ_{TX} in the Anchor 1 clock

Time Difference of Arrival - step 6



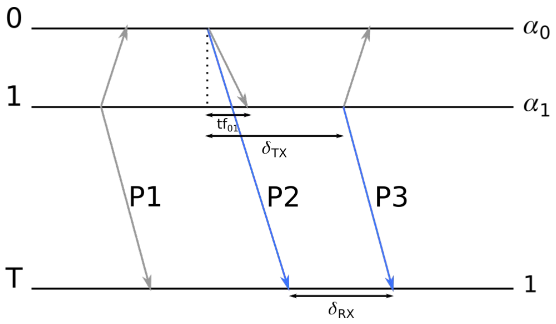
- tf_{01} (time of flight between 0 and 1) is what we did in TWR
- tf_{01} is measured and calculated by the anchors and is included in the data part of the packets
- tf_{01} is expressed in the Anchor 1 clock

Time Difference of Arrival - step 7



- The tag uses two consecutive packets from Anchor 1 to keep track of the difference in rate between the Tag clock and the clock in Anchor 1 (assuming the distance is constant)
- $\alpha_1 = \delta_{RX1} / \delta_{TX1}$

Time Difference of Arrival - step 8



- Once we know the transmit time of P2, we can calculate δ_{TX} expressed in the Anchor 1 clock
- We already know the clock rate factor α_1
- TDoA = δ_{RX} - (α_1 * δ_{TX}).

Time Difference of Arrival - step 9

- No need to remove antenna delay, it is canceled out in the calculations
- Convert to distance by multiplying with speed of light
- End result: difference in distance from Tag to two Anchors
- Side effect: Anchors keep track of distance to other anchors (TWR)

Time Difference of Arrival - continuous operation

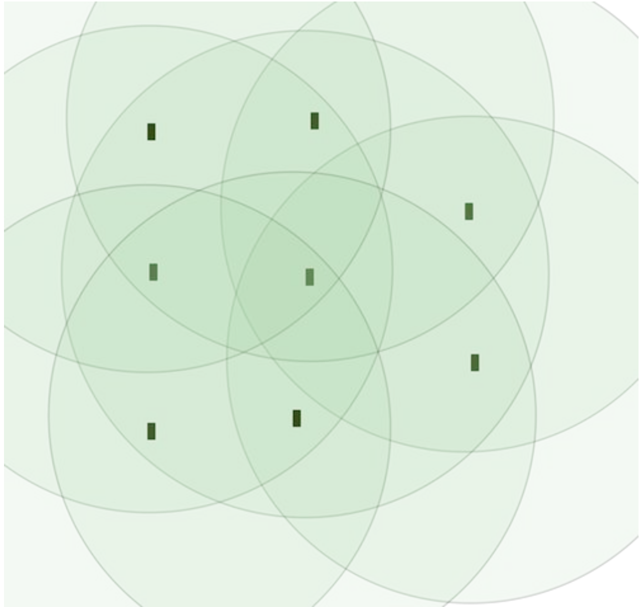
- The Anchors transmit continuously (rate depends on mode)
- The Anchors are configured with their absolute position
- The Anchors transmit their position to the Tag as data in the radio packets
- When the Tag has calculated the TDoA value for two Anchors, it sends this information + the Anchor positions to the estimator for further processing

TDoA2

- 8 Anchors
- Time slotted transmission times, Round Robin
- Anchor 0 is master
    - All anchors must “see” Anchor 0 to know when to transmit
    - Single point of failure
- 500 packets / second

TDoA3

- Randomized transmission times
- Packet collisions ⇒ lost packets
- Better than ALOHA
- No master
- Up to 256 Anchors
- Dynamic handling of Anchors
- System rate throttling, 400 packets / second
- Scalable in Anchors and space
- Each Anchor keeps track of the Anchors close by



LPP packet

- Appended to ranging packets
- Carries payload of auxiliary data
- Configuration settings: position
- Commands: mode change ⇒ reset

Conclusions

- TWR
  - 4 packets per ranging
  - Bi-directional
  - Get distance to anchor
- TDoA
  - 3 packets (2 + 1 from 2 anchors) for one measurement
  - Uni-directional
  - Get difference in distance to two anchors