The Inner Life of UWB

A Story of nanoseconds

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Peter Khoury

Wireless Systems Research Engineer



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Agenda – You Are Here

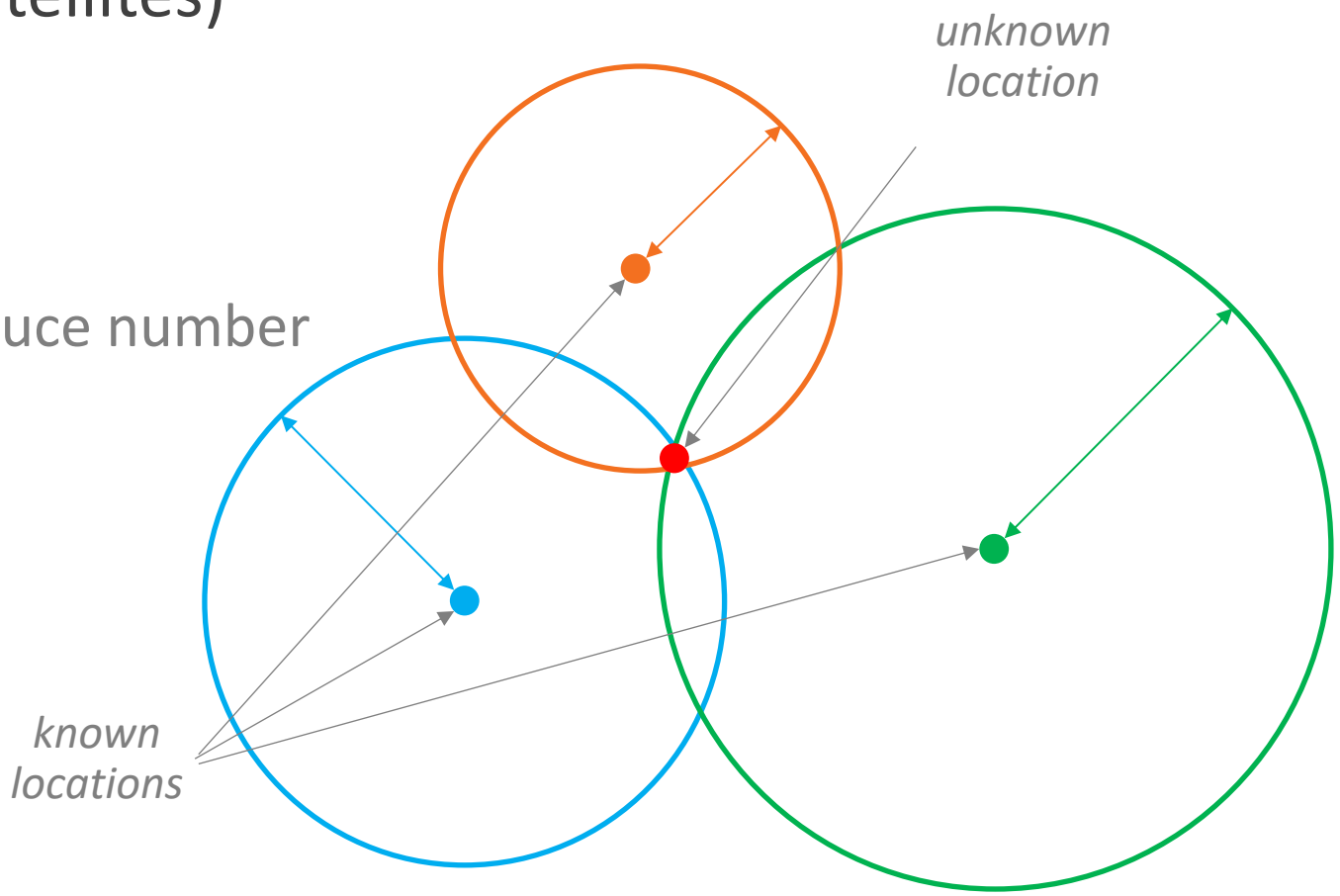
- Basics of Location Systems
- Differences of UWB vs Wi-Fi
  - Physical Layer
  - Protocol
  - MAC Layer
- Consequences / Important Details
  - Sensitivity
  - Clock Synchronization
- Proof of Concept Example
- Conclusions / Summary

Won't be discussing BLE locationing.

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Basics of Locationing – Number of Measurements

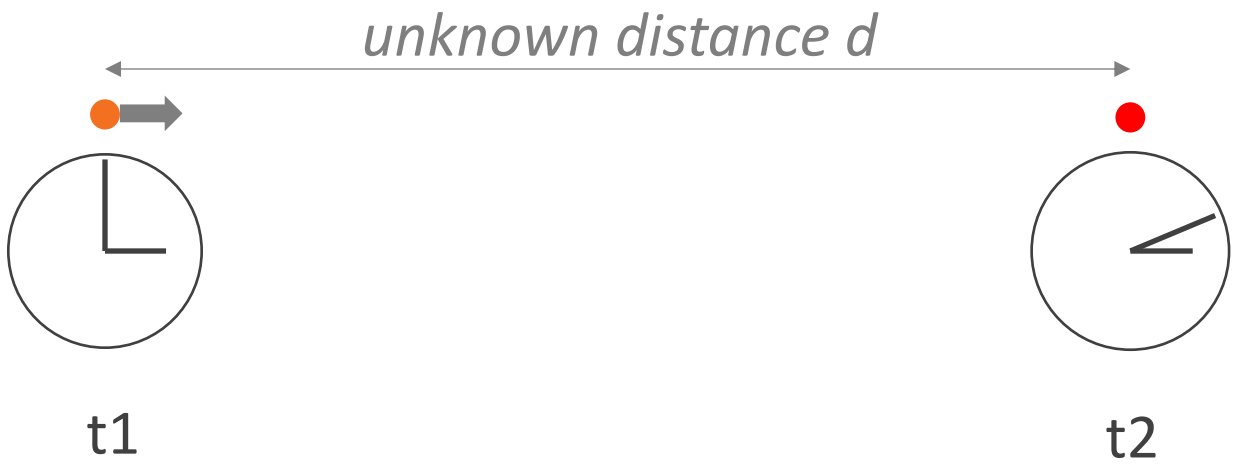
- Measure Distance between unknown (tag) & multiple known (anchors or satellites)
  - At least 3 known for 2D, d1, d2, d3
  - At least 4 known for 3D
  - More to get better accuracy
  - Measuring Angle of Arrival could reduce number of anchors



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Basics of Locationing – Time is Distance

- Measure Time of Flight (ToF)
  - Send Packet between anchor & tag
  - Distance = Velocity * Delta Time
- Velocity is Speed of Light
  - Literally nothing faster
  - Small time uncertainty creates big distance uncertainty
- What if you used sound?



known velocity v

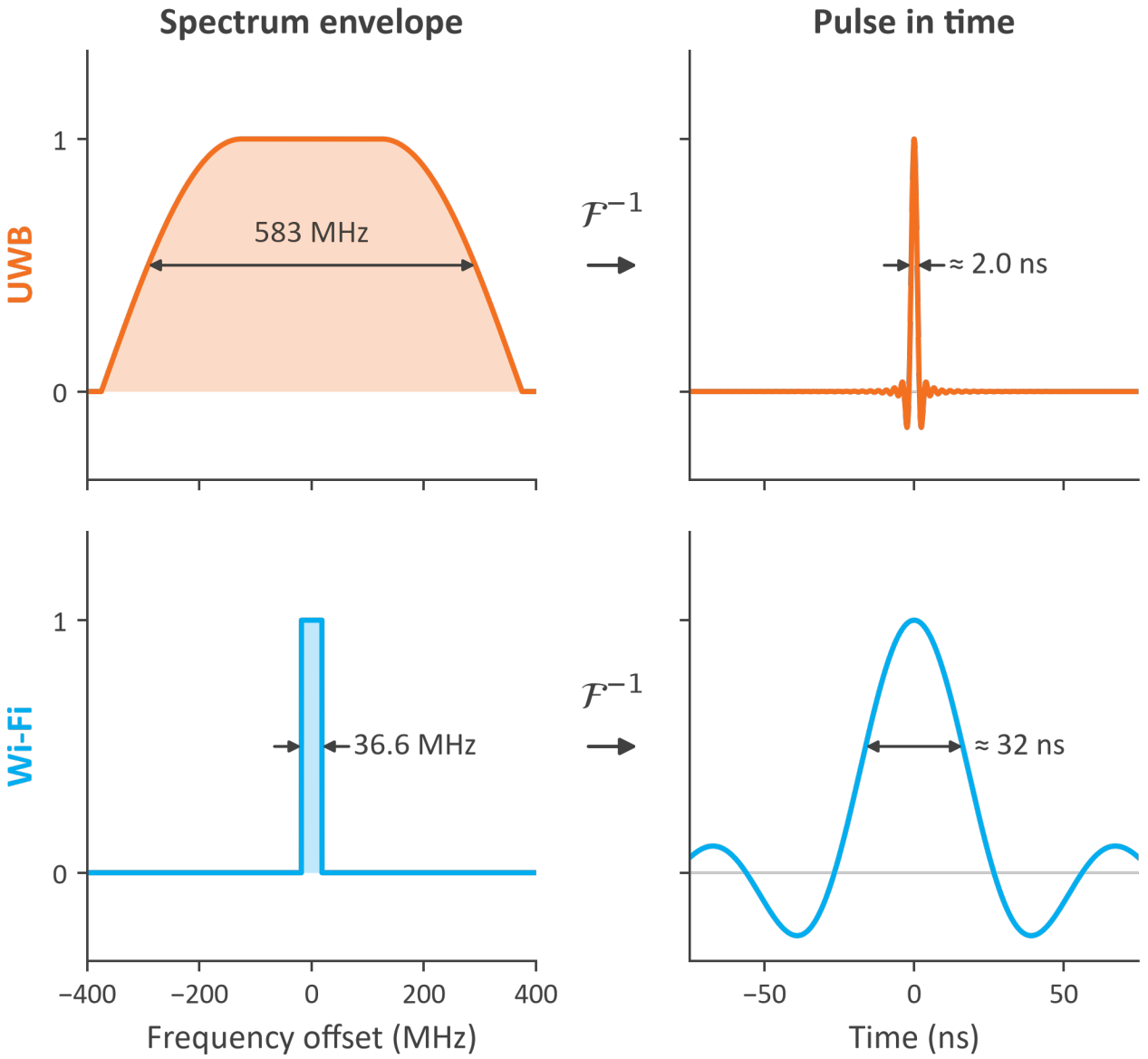
measured delta time (t2-t1)

$$d = v * (t2-t1)$$

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Physical Layer – UWB has wider Bandwidth

- Fourier Transform -> Δt = 1/ Δf
- 500MHz -> 2 ns -> 0.6 m
- 40MHz -> 25ns -> 7.5 m



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Physical Layer – Power

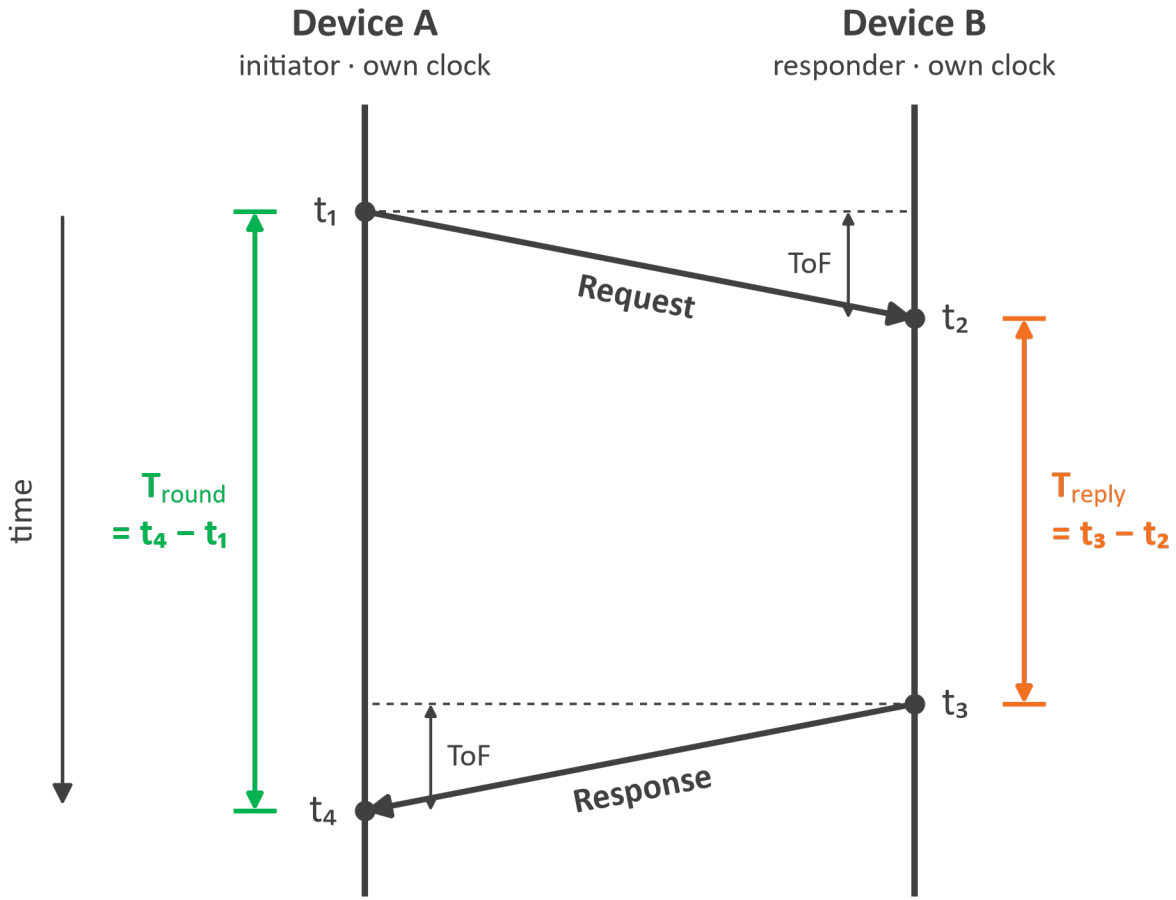
- PSD limits
  - UWB -41.3dBm/Mhz
  - Wi-Fi 5dBm/MHz
- TxPwr Limit
  - UWB -14.3dBm = -41.3dBm/MHz + 27dB
  - Wi-Fi roughly 18dBm to 22dBm

- Range
  - UWB 10m - 20m
  - Wi-FI 20m – 35m

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Protocol – Single Sided Two Way Ranging (SS-TWR)

- TWR Modes exist in Wi-Fi and UWB
- Clock Drift causes Error
  - Proportional to reply time



$ToF = (T_{round} - T_{reply}) / 2$

Clock offset cancels, but clock-frequency error does not:

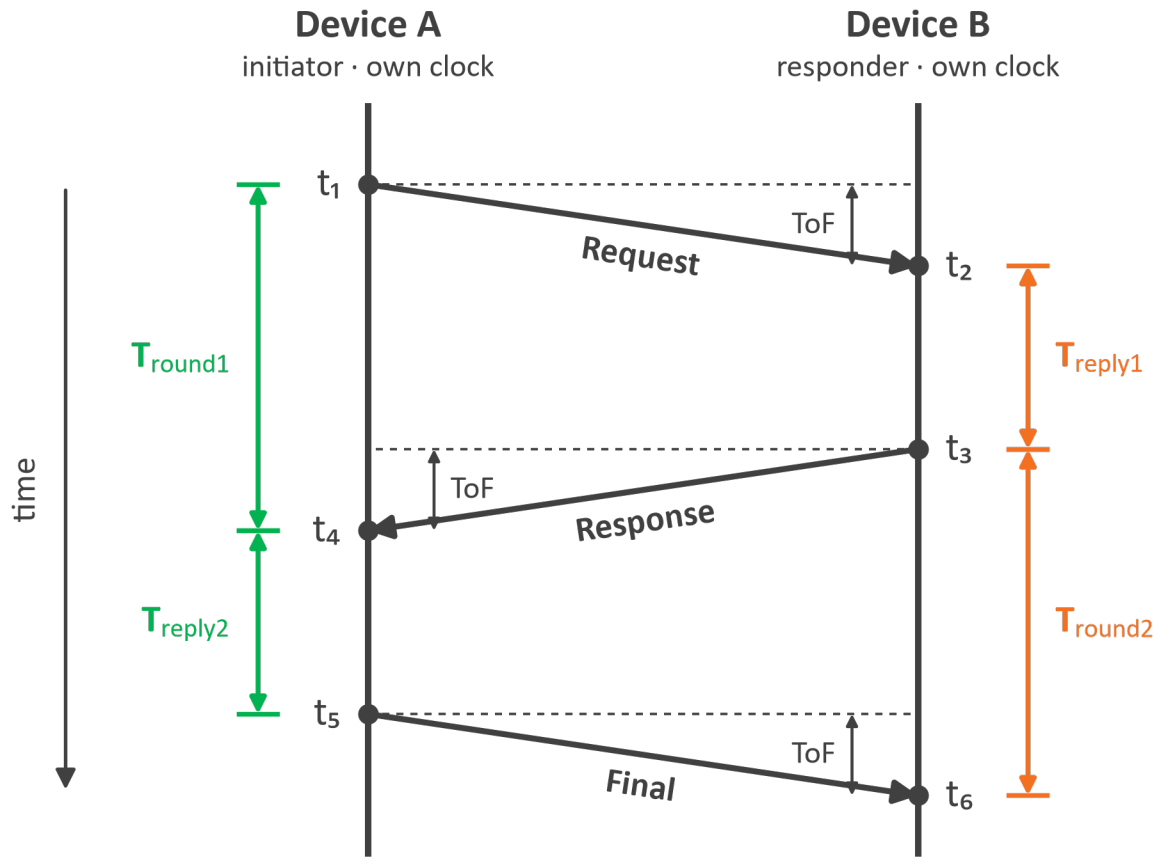
ToF error ≈ ½ · T_{reply} · ($e_A - e_B$)

e.g. 20 ppm, T_{reply} = 200 µs → ≈ 0.6 m

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Protocol – Double Sided Two Way Ranging (DS-TWR)

- TWR Modes exist in Wi-Fi and UWB
- Clock Drift Error almost Eliminated
- Every distance measurement needs an exchange
- Doesn’t scale up



$$\mathbf{ToF} = \frac{T_{round1}\,T_{round2} - T_{reply1}\,T_{reply2}}{T_{round1} + T_{round2} + T_{reply1} + T_{reply2}}$$

Clock-frequency error now scales with ToF, not T_{reply}:

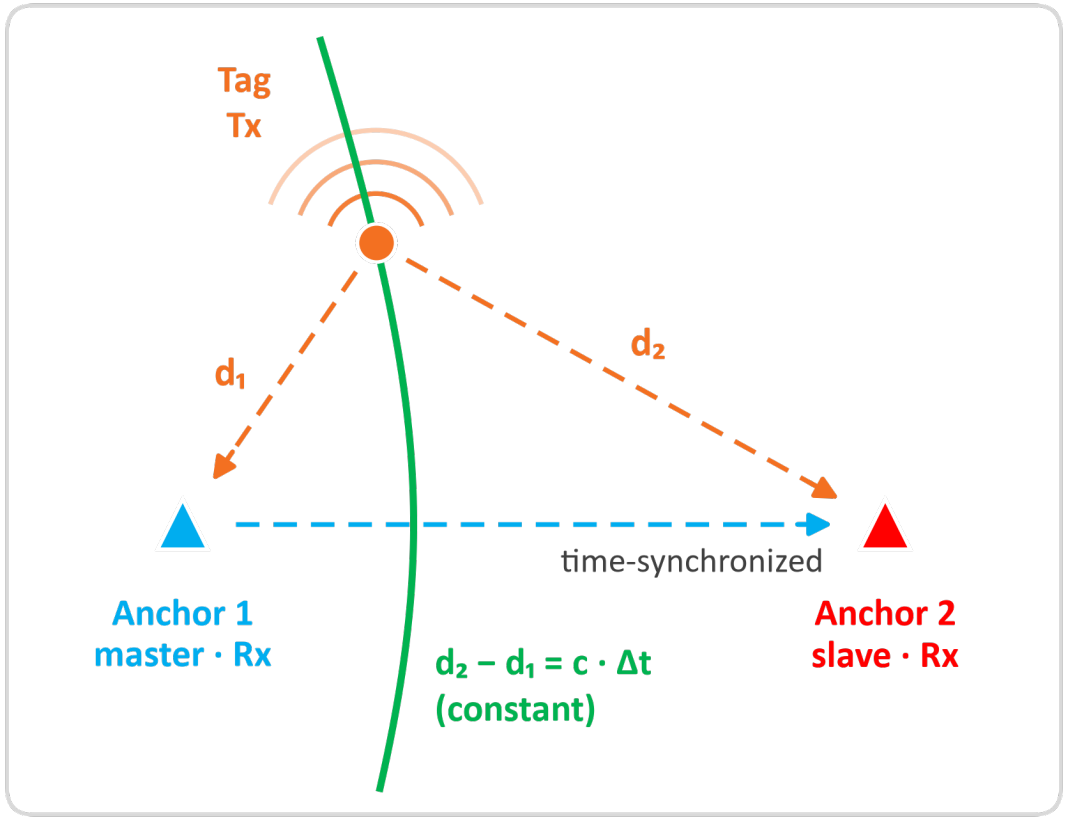
ToF error ≈ ½ · ToF · $(e_A + e_B)$

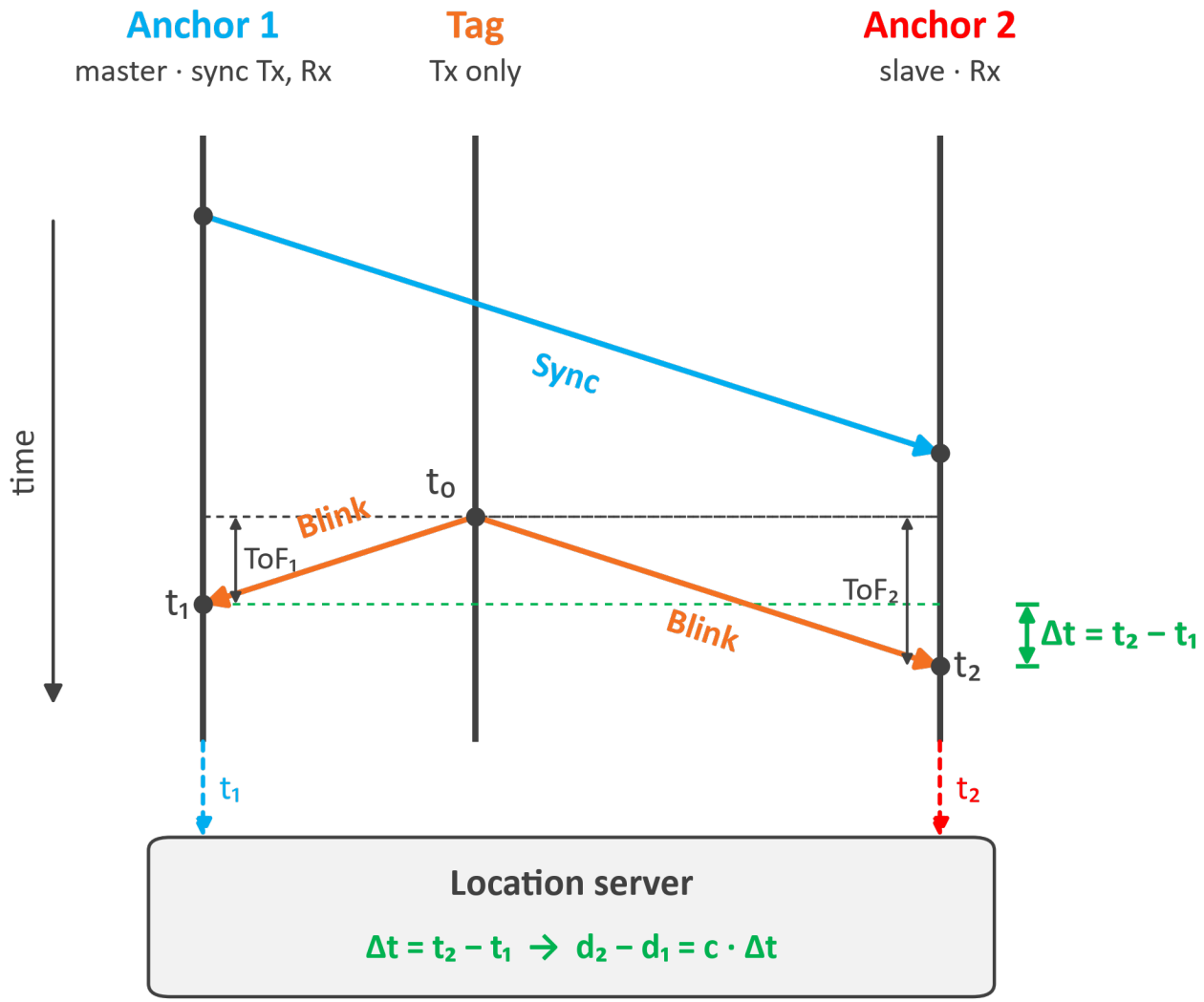
e.g. 20 ppm, T_{reply} = 200 µs → < 1 mm

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UWB Ranging – Uplink Time Difference of Arrival

- UL-TDoA exists as UWB Mode
- Assumes Satellites / Anchors are Synchronized



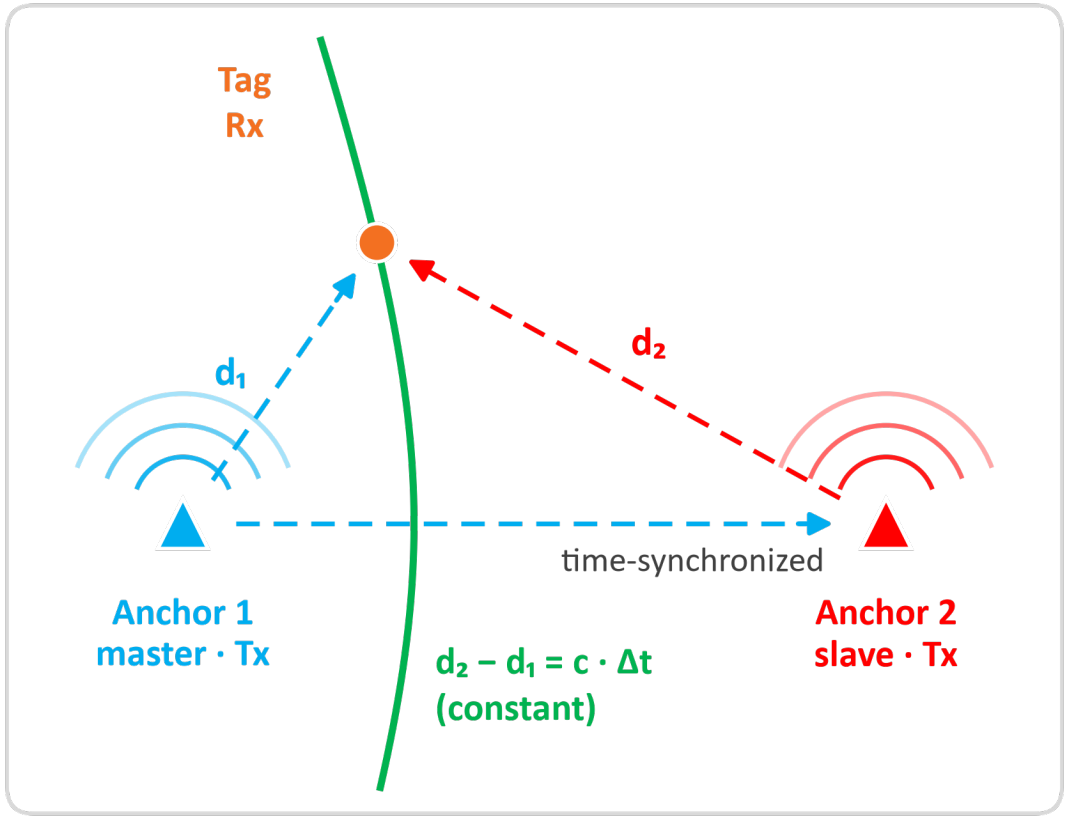


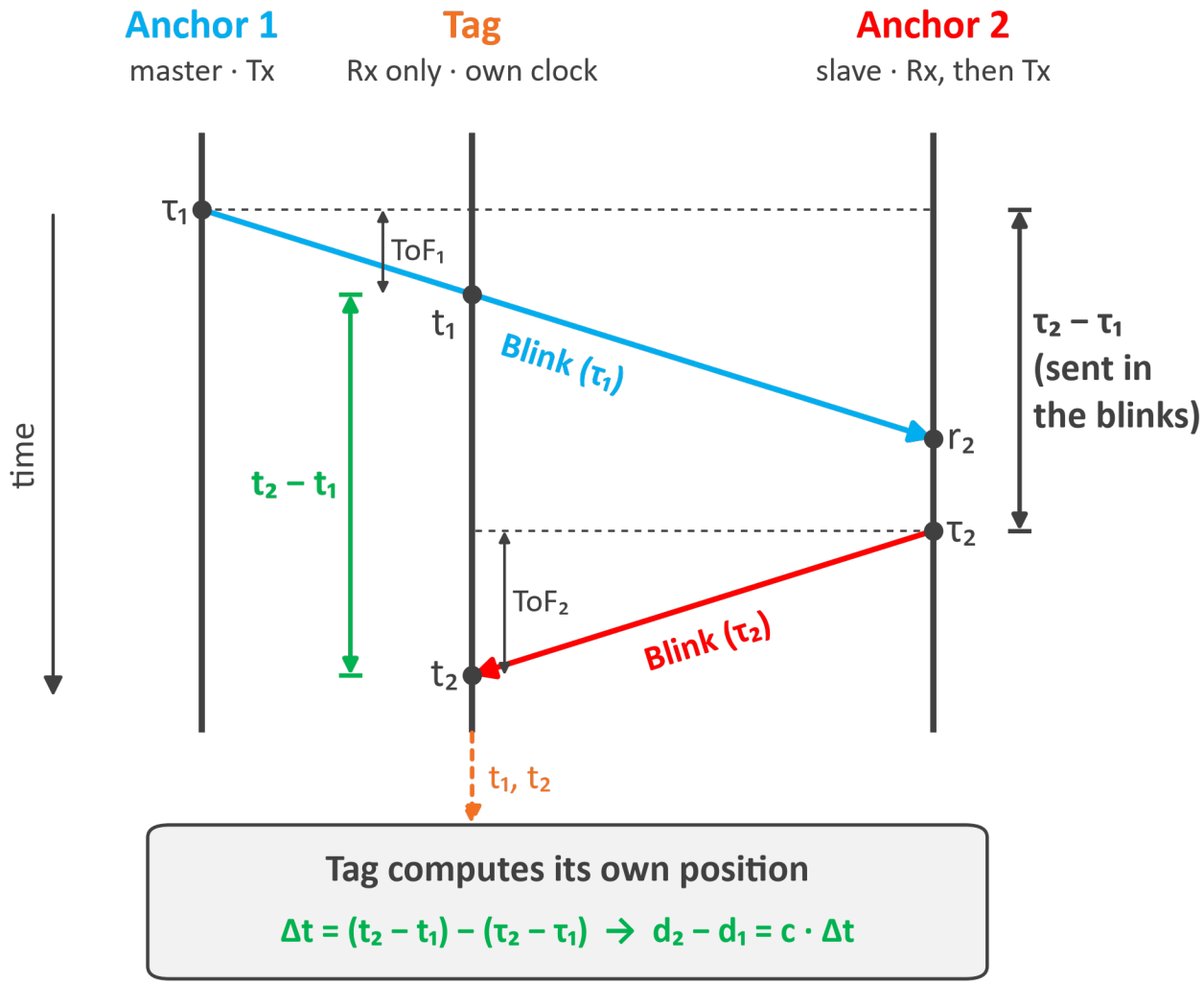
The tag only transmits; its clock and t_o are never needed

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UWB Ranging – Downlink Time Difference of Arrival

- DL-TDoA exists as UWB Mode
- Assumes Satellites / Anchors are Synchronized





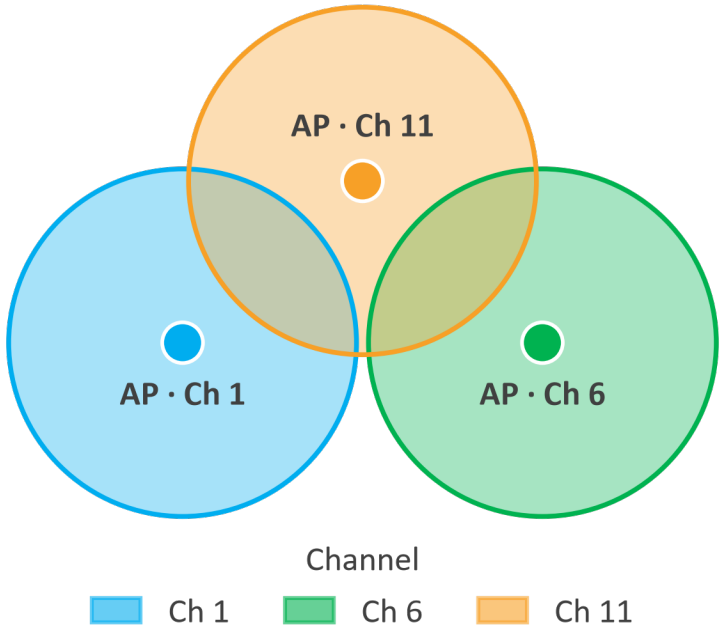
Only the anchors transmit; tags just listen,
so any number of tags can locate themselves

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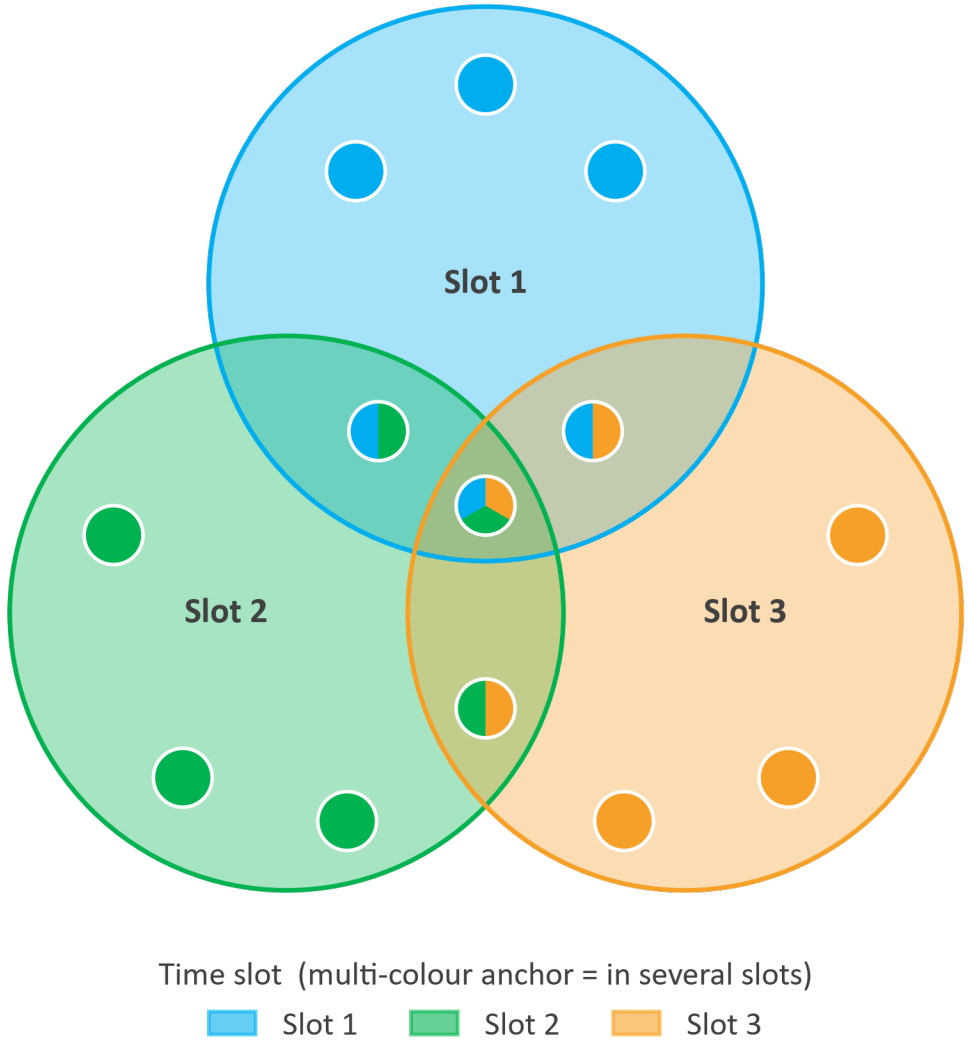
MAC / Network Design – Channels vs Slots

- UWB Mac better for Locationing
  - Slots set for listening and transmitting
  - Don’t cover a space with different channels
  - No changing channels and retransmitting

Wi-Fi: each AP on its own channel

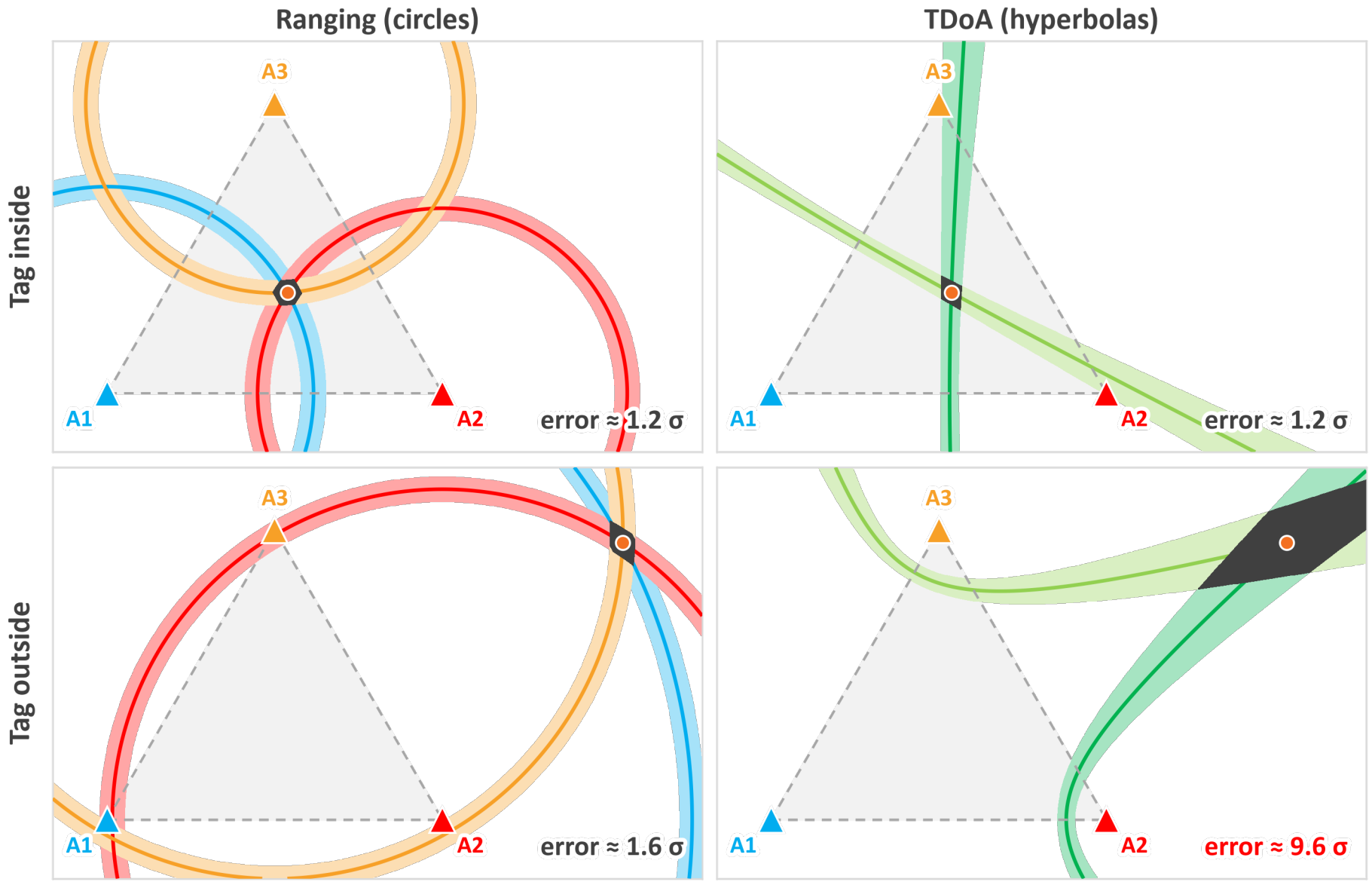


UWB: one channel, anchors share time slots



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Consequences – TDoA Sensitivity Outside Interior

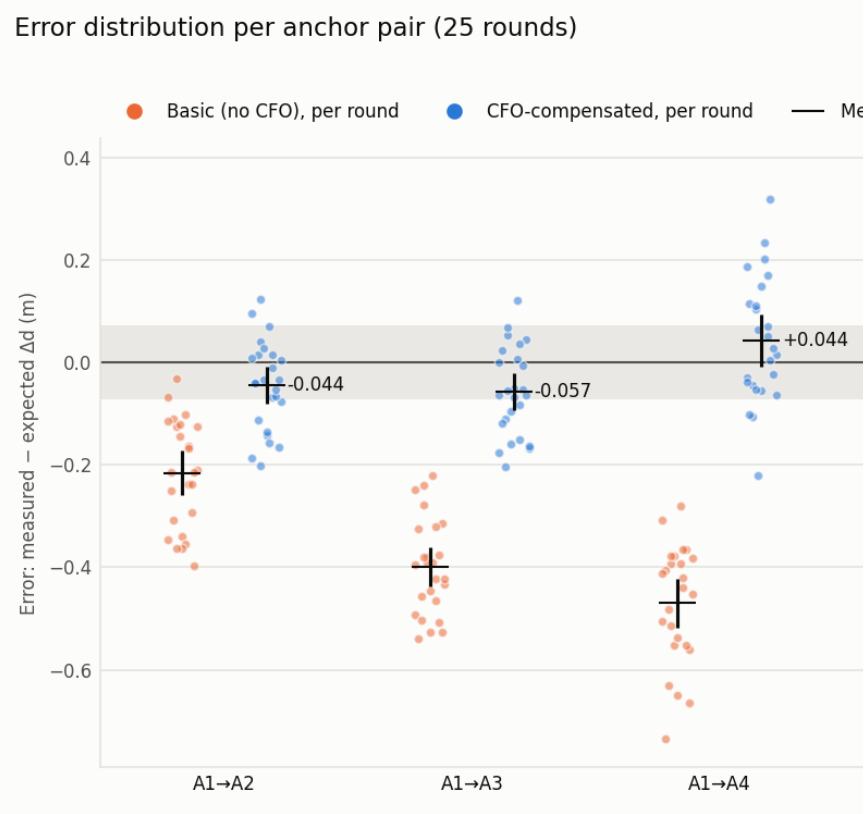


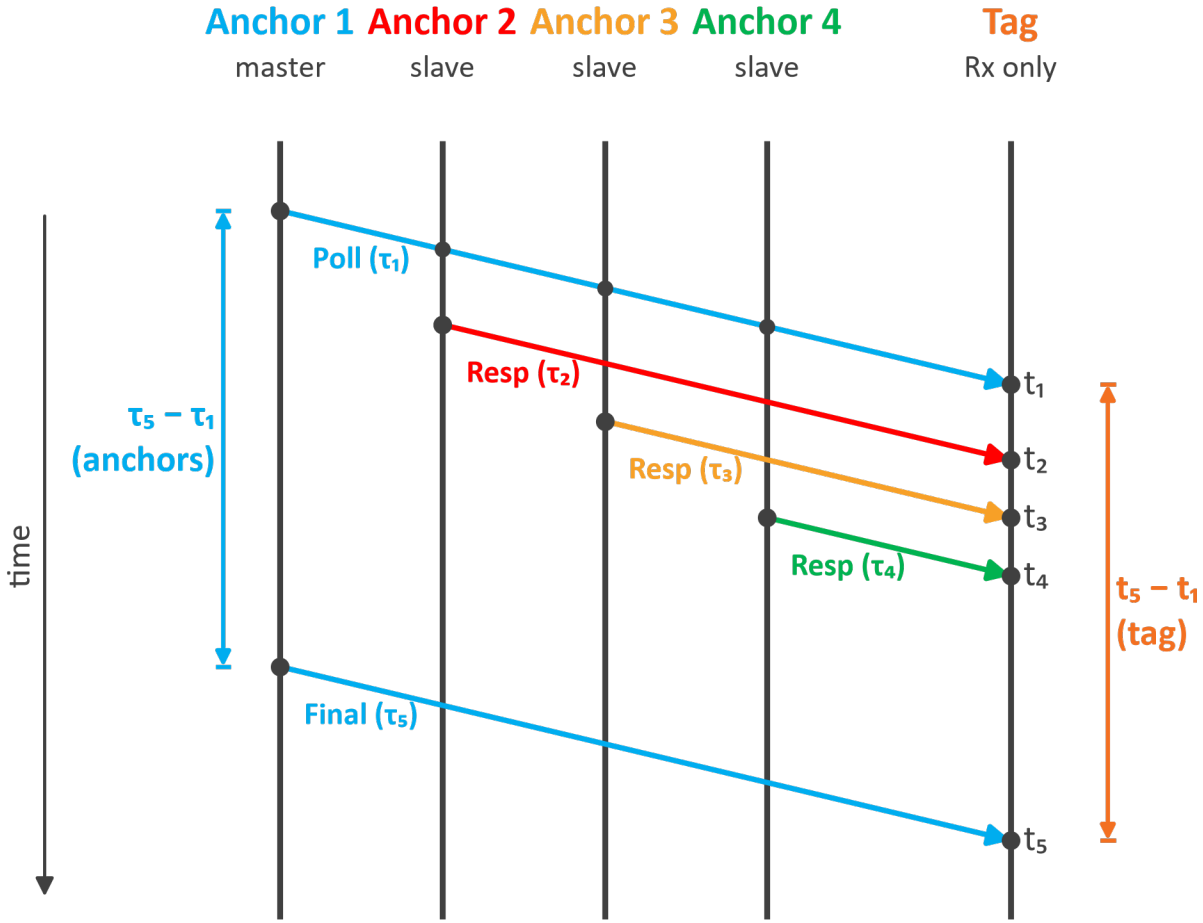
Same timing error σ on every arrival time (bands exaggerated); dark region = where the tag could be

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Consequences – Tight Time Synchronization

- Closer Look at DL TDoA
  - Anchors synchronized
  - Client not synchronized





Clock-rate offset: $(t_5 - t_1) / (\tau_5 - \tau_1) - 1$

The master's second blink lets the tag measure and remove its ppm drift before computing the time differences

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Example – TWR Proof of Concept

- Apple’s current NI UWB Interaction
  - Dev Kit w Existing App
  - Modified Existing App
  - Exported and Post Processed data



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Conclusions / Summary – UWB Built for Locationing

- UWB is built for locationing
- Wi-Fi Ranging bolted on

- UWB Advantages
  - Narrow precise pulse
  - Fewer Packet exchanges
  - Slots with many satellites / anchors listening
  - Anonymity built in

- Wi-Fi Advantages
  - Range
  - Existing radio

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