TDoA for in-flight relative localization in UAV swarm using Ultra-Wide Band

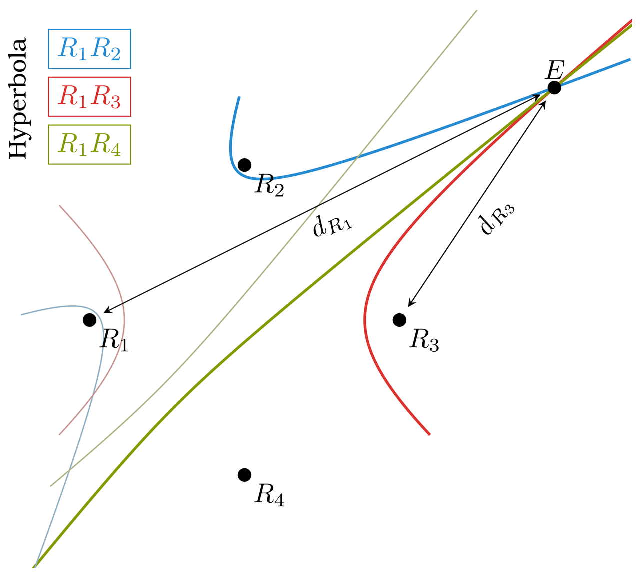
Stéphane D'Alu, Hervé Rivano, Olivier Simonin

INSA Lyon, Inria, Université de Lyon, CITI Lab. France

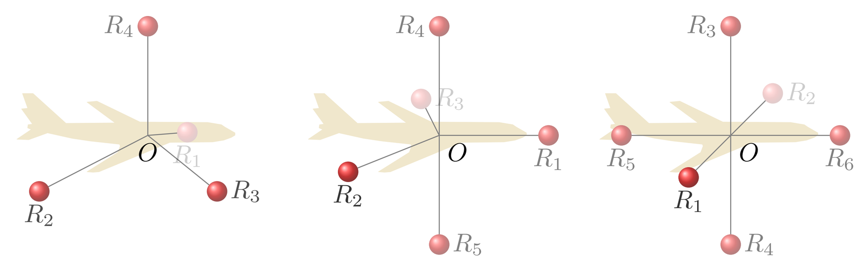
Proposed multi-receivers architecture

UAV A with several embedded receivers R_i performing position estimation by listening for a single packet emitted by UAV B at position E

TDoA principle (2D):



Possible receivers placement on UAV:



TDoA equation for resolving $E(x, y, z)$:

$$\|ER_i\| - \|ER_1\| = d_{R_i} - d_{R_1}$$
$$= (t_{R_i} - t_{R_1}) \cdot c_{\text{air}}$$

Synchronized clocks

Problems and goals

- Perform localisation without using an external costly localisation system (Indoor: motion capture [2], Outdoor: global navigation satellite system [1])
- Perform distance measurements inside the swarm using Ultra-Wide Band *time of flight*, as RSSI has been proven inefficent [3]
- Use of a single packet for position measurement
  $\Rightarrow$ efficient use of radio channel capacity
  $\Rightarrow$ immunity to UAV velocity

References

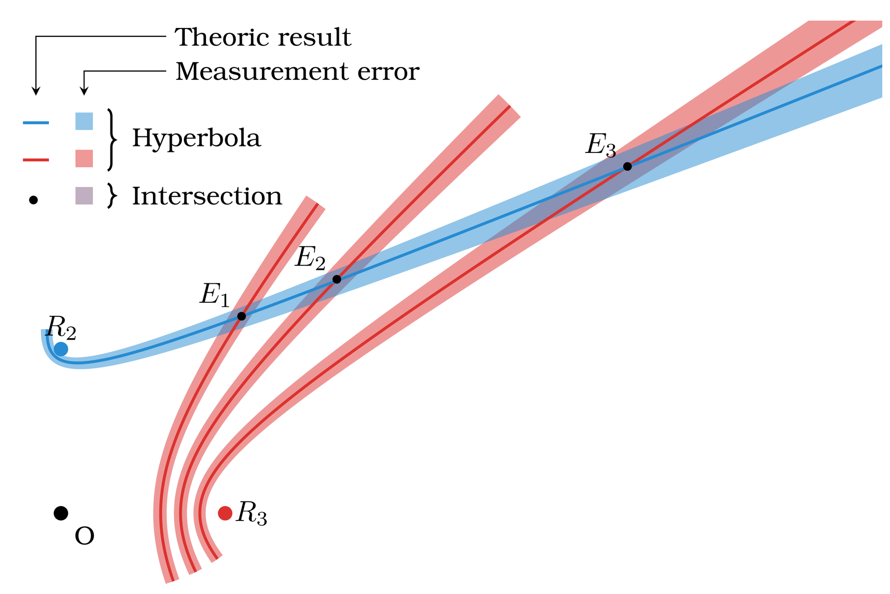
[1] M. Andrianarison, M. Sahmoudi, and R.Jr. Landry. "New Strategy of Collaborative Acquisition for Connected GNSS Receivers in Deep Urban Environments". In: *Positioning* 9 (2018), pp. 23–46.

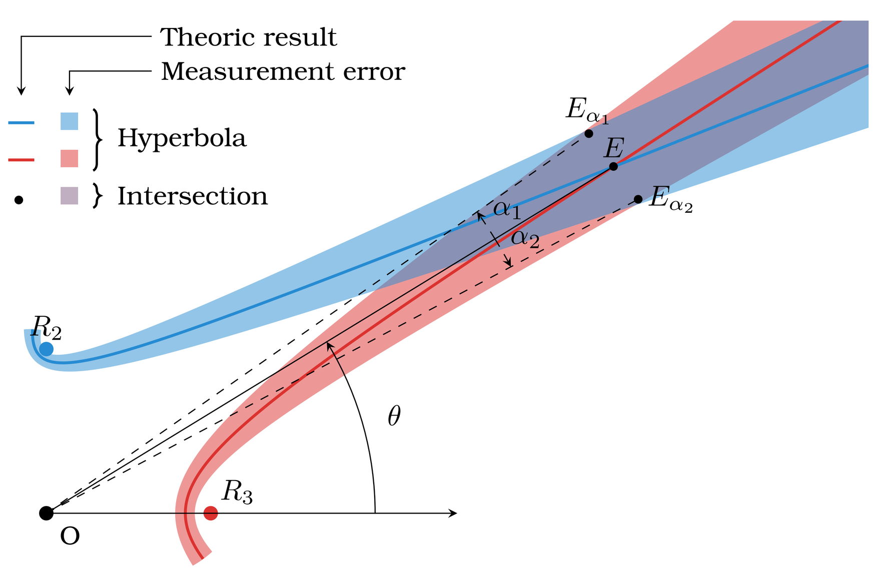
[2] James A. Preiss et al. "Crazyswarm: A Large Nano-Quadcopter Swarm". In: *IEEE/RSJ International Conference on Intelligent Robots and Systems IROS*. 2016, pp. 3449–3450.

[3] Karel Heurtefeux and Fabrice Valois. "Is RSSI a Good Choice for Localization in Wireless Sensor Network?" In: *2012 IEEE 26th International Conference on Advanced Information Networking and Applications*. 2012, pp. 732–739. DOI: 10.1109/AINA.2012.19.

TDoA localization challenge

TDoa behaviour outside receivers' convex hull





Encountered problem

Accuracy decrease with distance in oblong shape, expecting:
- high impact on distance error
- low impact on angle error

Checking for

- Convergence of Nelder-Mead resolution algorithm
- Errors: distance, angle, distribution
- Usefulness for close range (0 to 10 m) navigation

Experimental validation (simulation)

Parameters and configurations

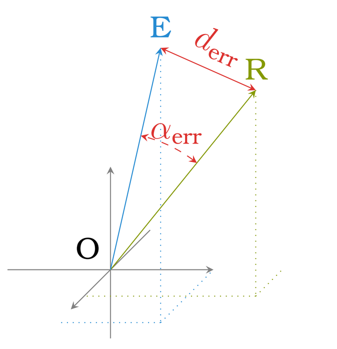
Clock timestamping resolution is 15 ps

a: timestamping error (in ticks).
s: number of receivers (4, 5, or 6) in the architecture.
S: receivers distance to the UAV center.

configuration	max error	receivers	wingspan
a0s5S25	*no error*	5	50 cm
a4s4S25	4 tick	4	50 cm
a2s6S25	2 tick	6	50 cm
a5s5S40	5 tick	5	80 cm

Measurements

Error decomposition



R = position real

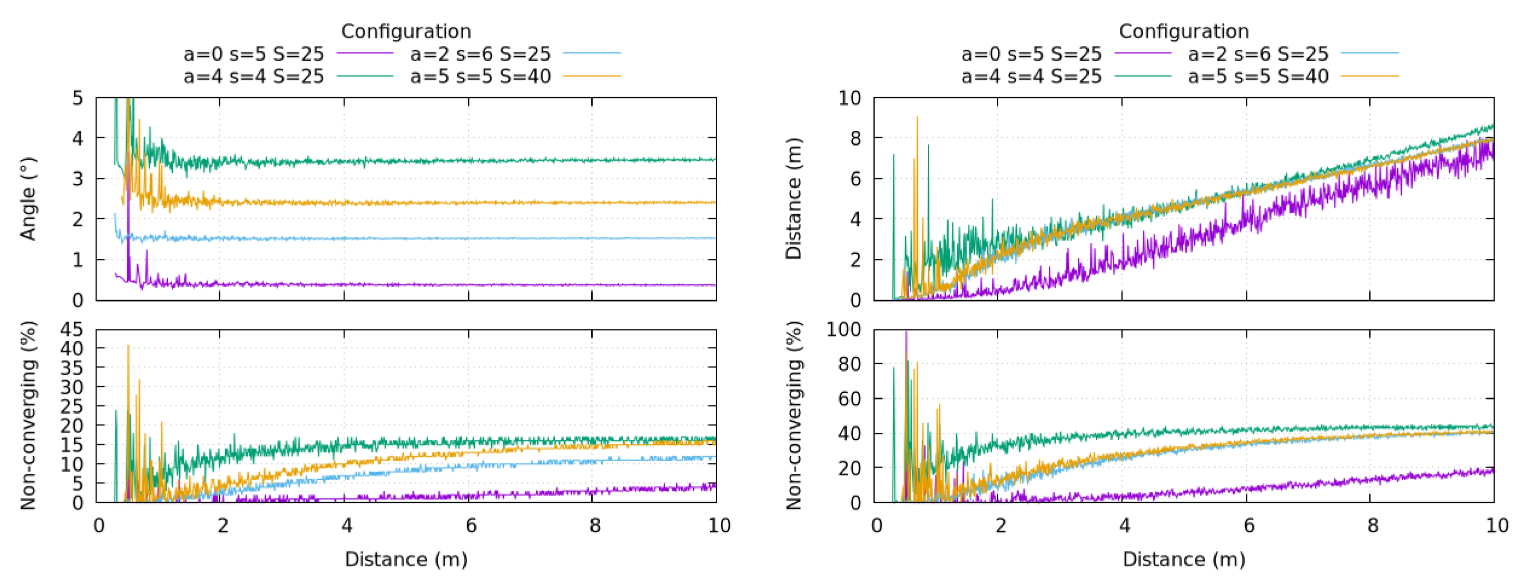
E = position estimated

$d_{\text{err}} = \|\overrightarrow{OE} - \overrightarrow{OR}\|$

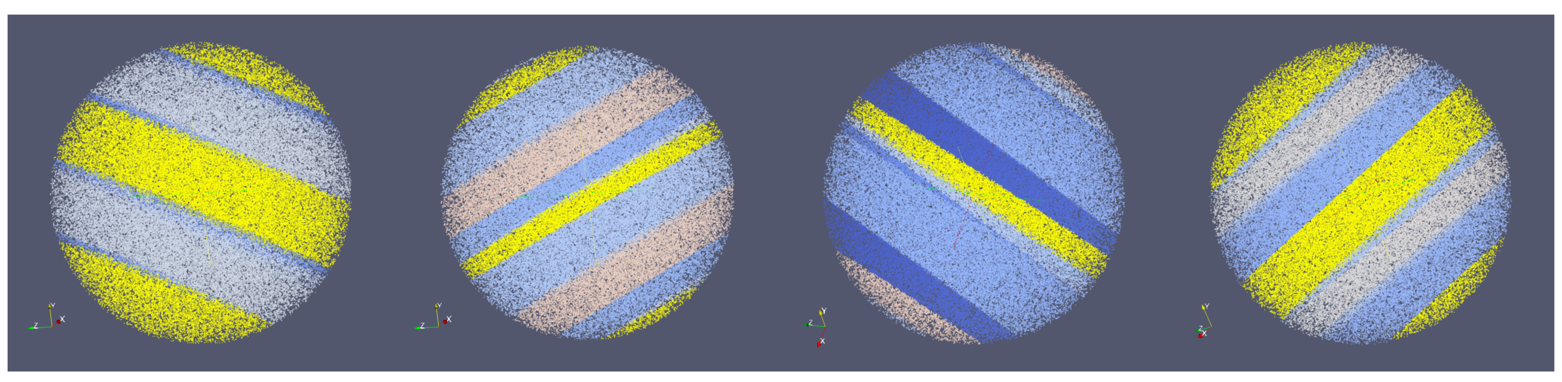
$\alpha_{\text{err}} = \frac{\arccos(\overrightarrow{OE} \cdot \overrightarrow{OR})}{\|\overrightarrow{OE}\| \cdot \|\overrightarrow{OR}\|}$

Errors in relative positioning

Average errors and non-convergence percentage for different configurations using TDoA



Error exploration around a position p_0 with a radius $\delta = 0.5$ cm (configuration a0s5S25)



Conclusion

▶ Good angle measurement
- for all configurations
- even with timestamping errors

▶ Distance measurement need improvements
- Local exploration, identifying minimum error (several transmission, not trivial)
- Opportunistic TWR
- Fusing information (telemeter, relative speed, ...)

▶ Characterizing timestamping error

citi lab

INSA INSTITUT NATIONAL DES SCIENCES APPLIQUÉES LYON

Inria

UNIVERSITÉ DE LYON