Land & Localize: An Infrastructure-free and Scalable Nano-Drones Swarm with UWB-based Localization

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Vlad Niculescu[4], Eliseo Ferrante[2], Daniele Palossi[5,4], Luca Benini[1,4]

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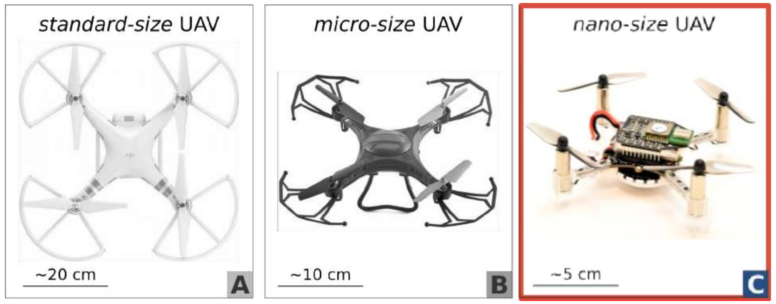
[4] IIS - ETH Zurich, Switzerland
[5] IDSIA, USI and SUPSI, Switzerland

Why Nano-Drone Swarm?

What are Nano-drones?

- Small form factor (~10cm)
- Limited payload (~15g)
- Limited computing power budget (<100mW)



UAV	Standard-sized	Nano-sized
Size [⌀, weight]	~50cm / ~ few Kg	~10cm / ~50g
Tot. Power	~ 100 W	~ 5W
Processing device	High-end CPU	Low-power MCU

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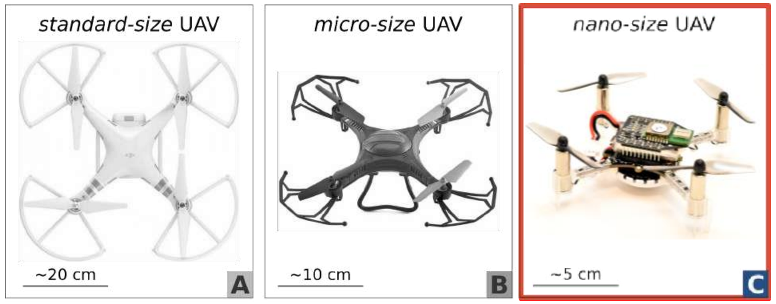

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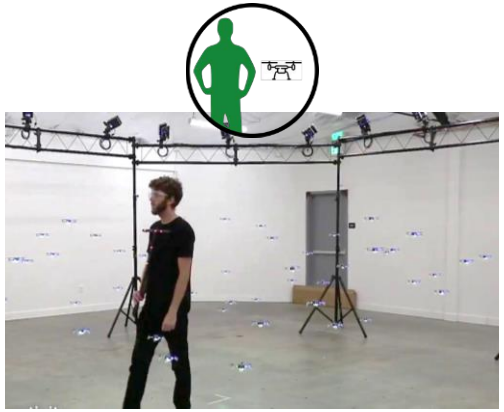
Why Nano-Drone Swarm?

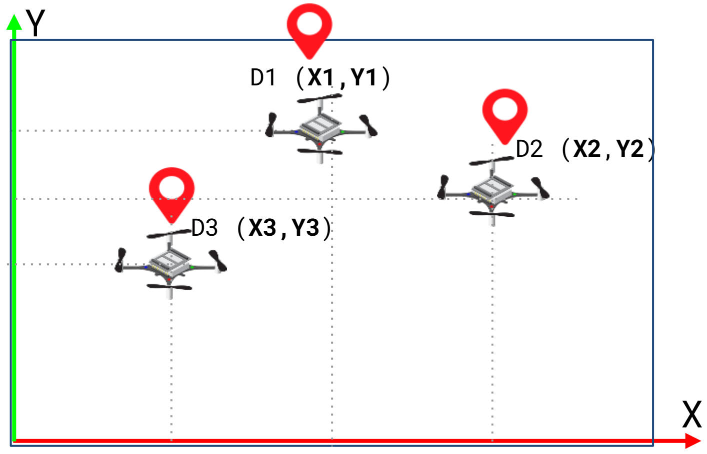
- Small form factor enabling indoor applications
- Ensure safe Human-Robot Interaction (HRI)
- Reduced costs



Localizing Nano-Drone Swarm

What is Localization?

- Localization is the ability of the Swarm agents to identify **their positions**



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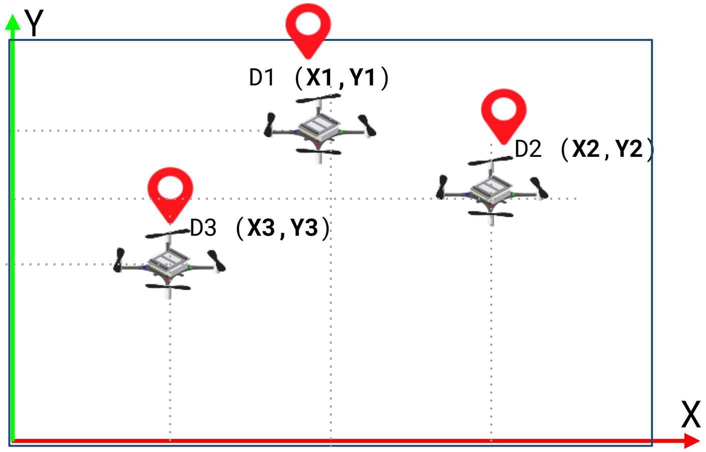


Why Localizing a Nano-Drone Swarm?

- A Wide range of **indoor applications** can benefit from the Nano-Drone swarm
- **Localization is a key** for any Nano-drone Swarm applications

Indoor Inspection*

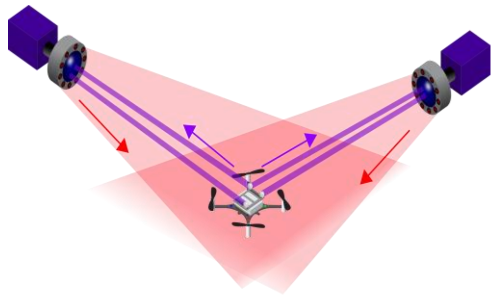
Flight Formation

Research

[*] Sniffy Bug: A Fully Autonomous Swarm of Gas-Seeking Nano Quadcopters in Cluttered Environments.” IROS 2021

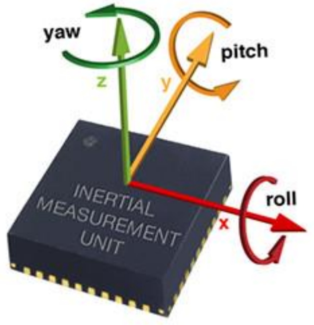
Common indoor positioning approaches

Motion Tracking Systems



- ✔ *High resolution*
- ✔ *Light computation*
- ✔ *Low power*
- ✘ *Costly infrastructure*

IMUs

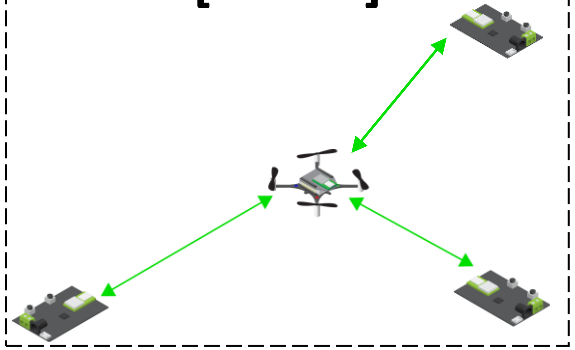


- ✘ Low resolution
- ✔ Light computation
- ✔ Low power
- ✔ Low cost

Visual Odometry

- ✔ High resolution
- ✘ *Heavy computation*
- ✘ *High power*
- ✘ *medium cost*

Ultra Wideband [UWB]



- ✔ *cm-level resolution*
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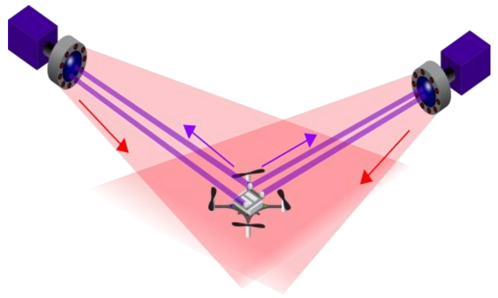

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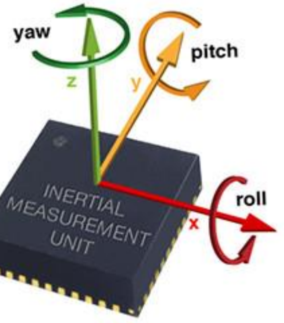

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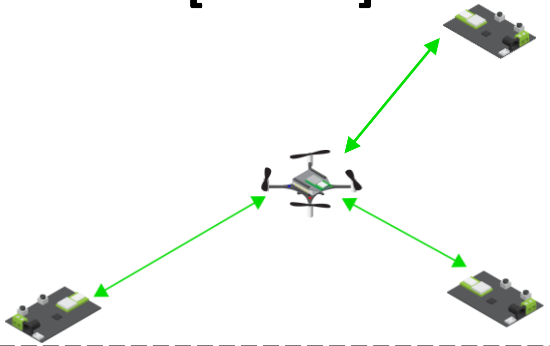

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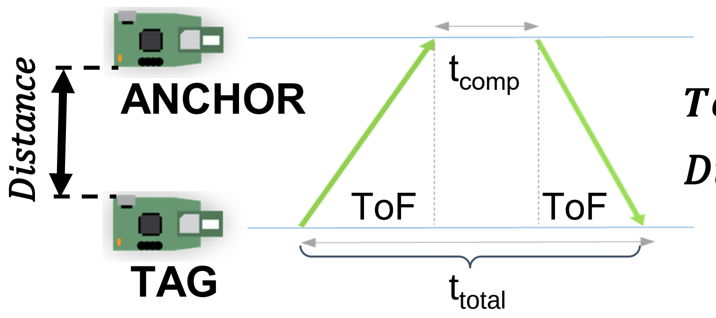
UWB-Localization & challenges

UWB Ranging



$$\boldsymbol{ToF} = (\boldsymbol{t}\_total - \boldsymbol{t}\_comp)/2$$

$$\boldsymbol{Distance} = ToF \times speed\_of\_light$$

UWB-Localization & challenges

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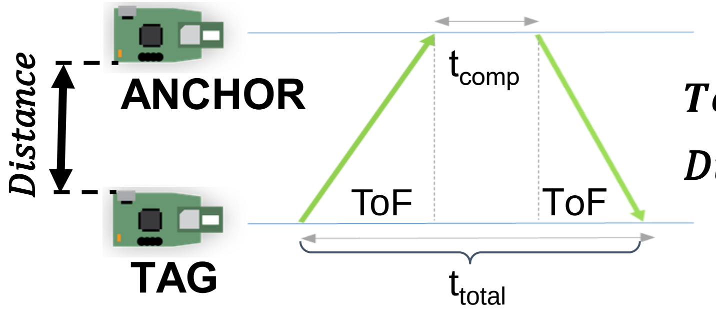

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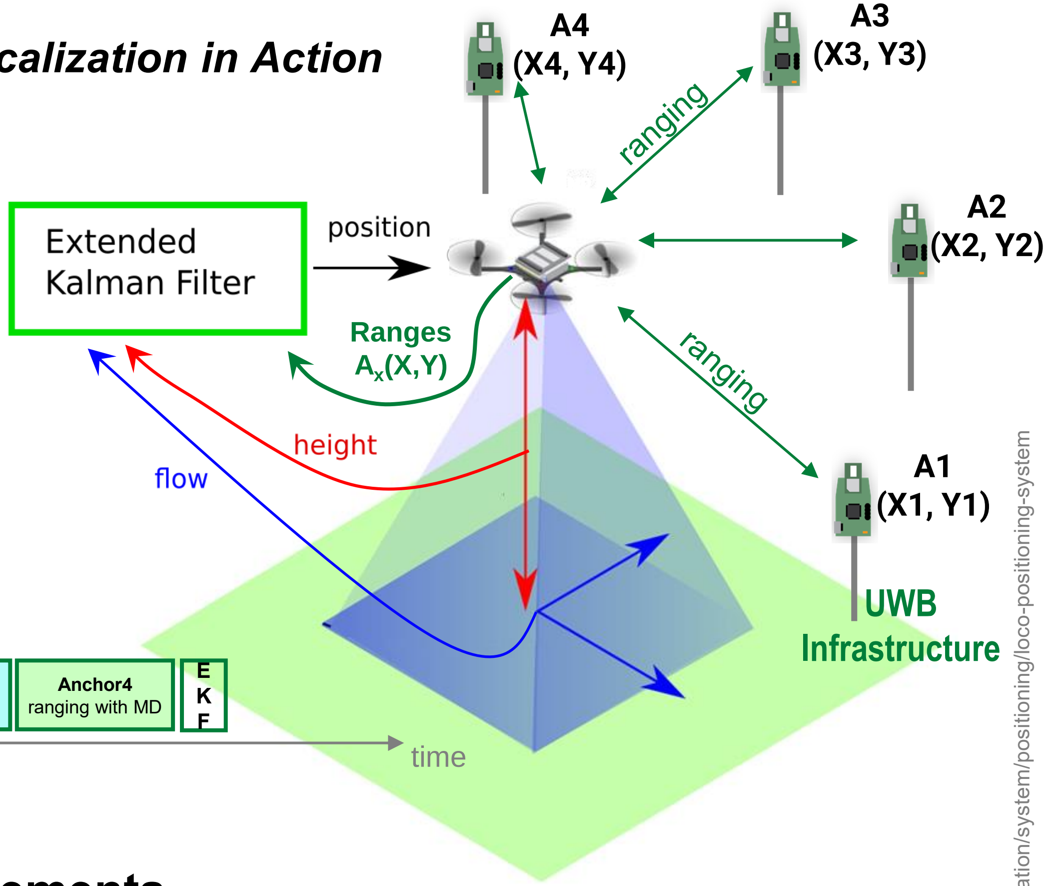
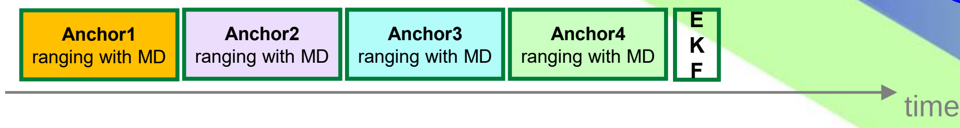
UWB Localization in Action





Requirements

1. **Installation** of Anchor modules infrastructure
2. Anchors' positions must be ***known***

www.bitcraze.io/documentation/system/positioning/loco-positioning-system

UWB-Localization & challenges

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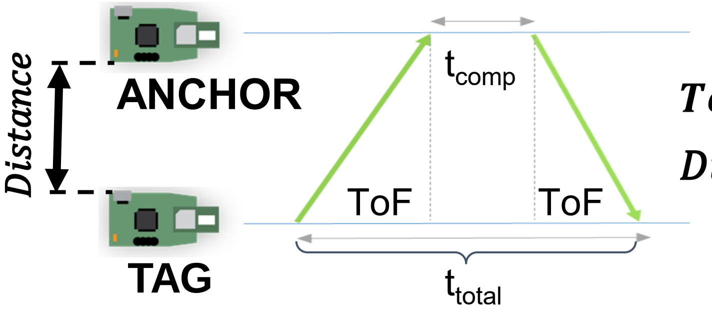

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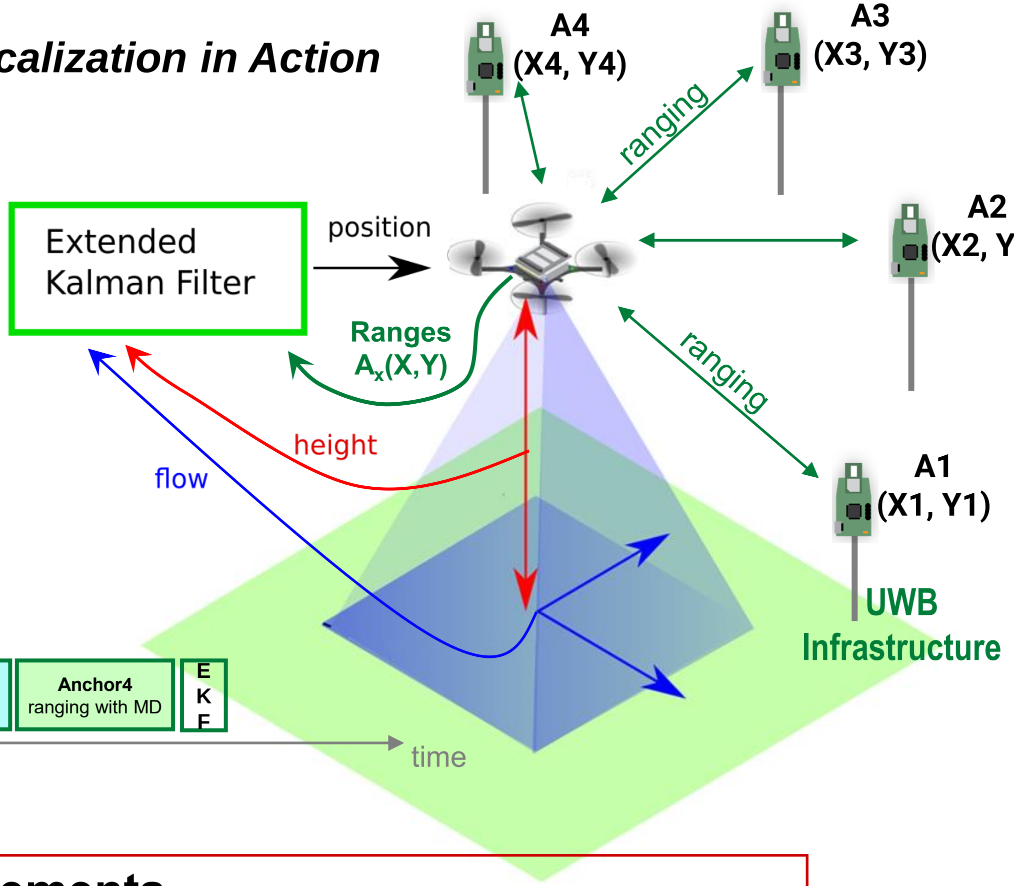

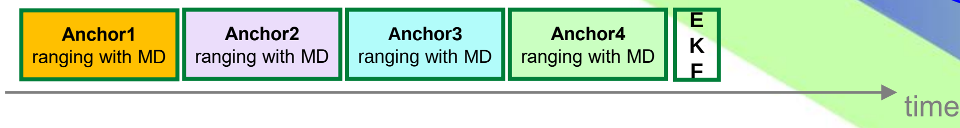

Limit usefulness due to need for in-advanced installation of infrastructure

Static UWB infrastructure imposes a major rigidity!

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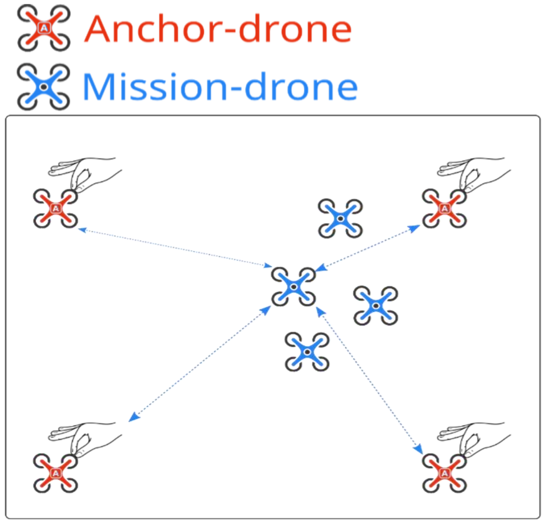
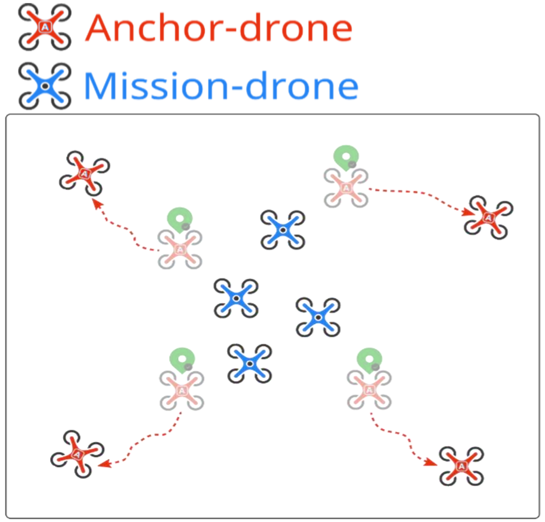
Contribution

Infrastructure-less UWB localization systems

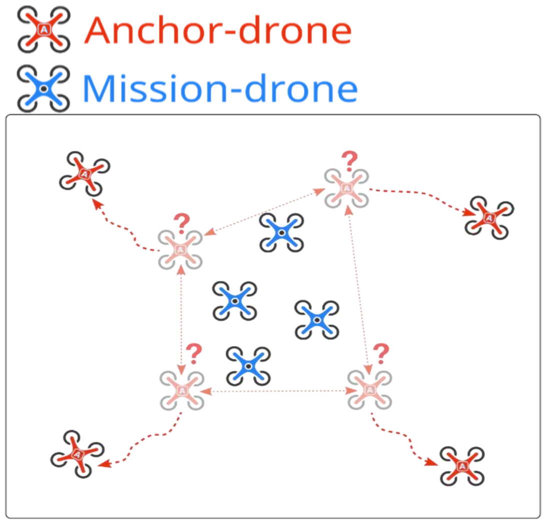
1. Exploiting **Drones as Dynamic Anchors** to provide anchor deployment at run-time
2. A **Self-Localization system** to compute anchor drones' initial position
3. An open-source **UWB Software Library (USL)** enabling fast prototyping of UWB localization



Ideal Landing



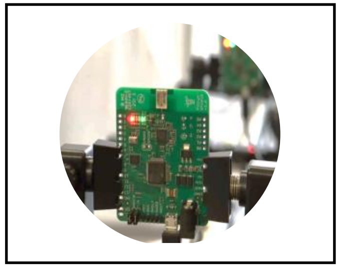
Dynamic Anchors



Self-localize

More Flexible Systems

Anchor Infrastructure



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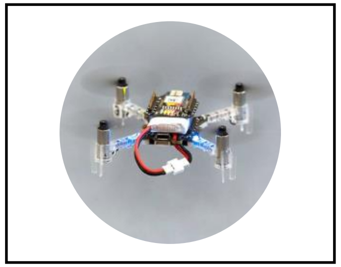
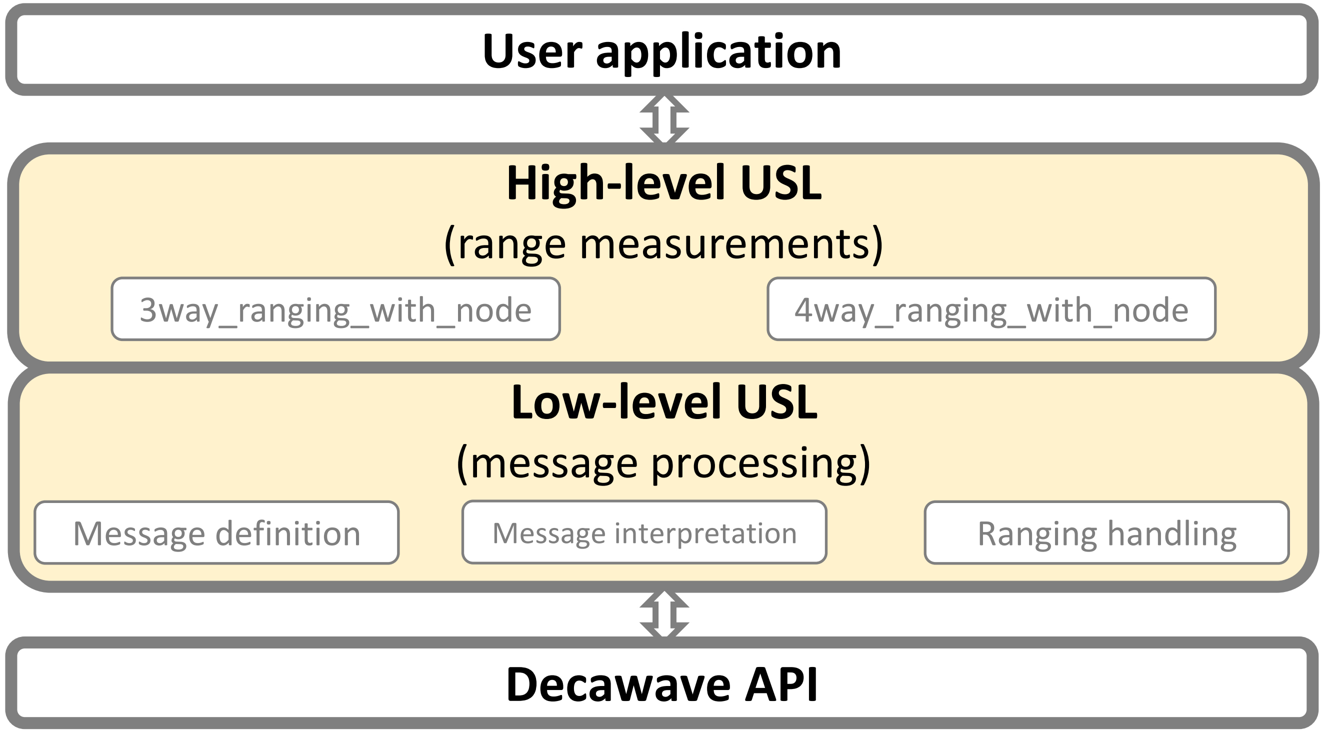


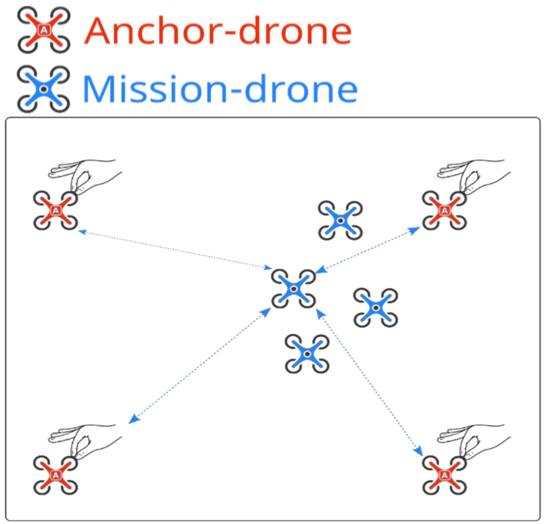
UWB Software library (USL)

- *An open-source Library*
- *High-level API*
- *Enable Fast prototyping*
- *Minimal interaction with HW-level complexities*

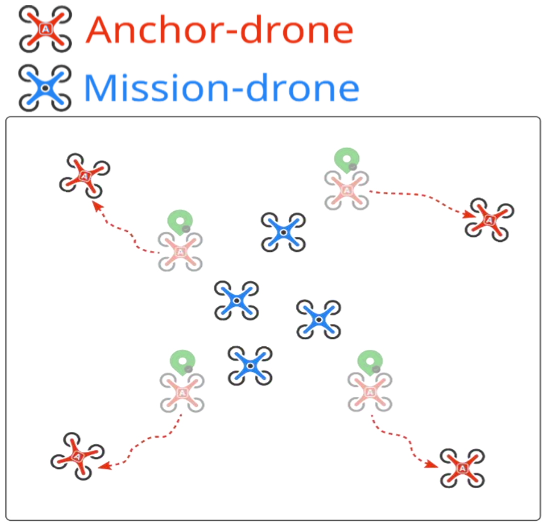


GitHub: https://github.com/vladniculescu/uwb-software-library

Ideal Landing (Baseline)



Ideal Landing



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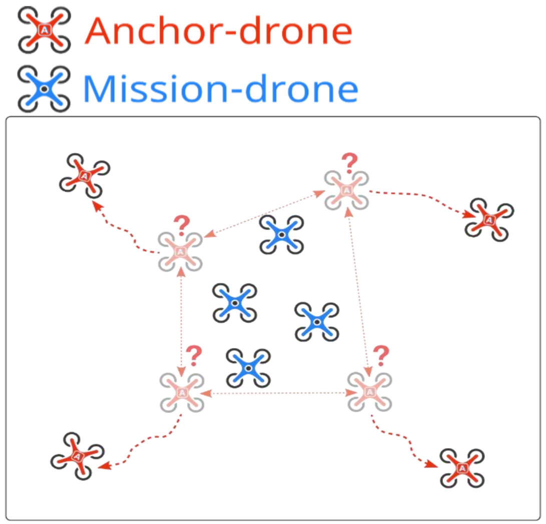
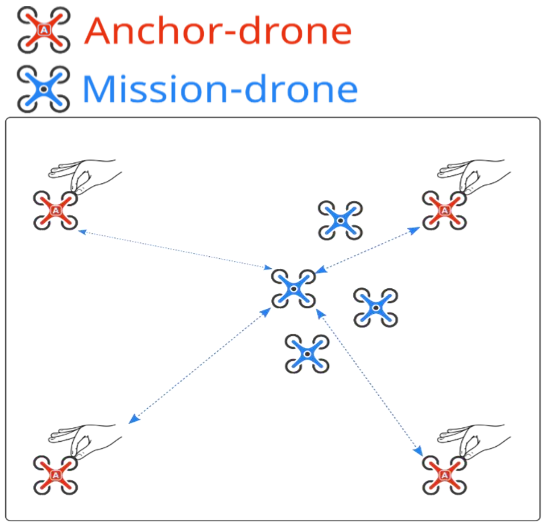


Self-localize

Assumptions:

- Anchor installation
- Anchors' positions must be ***known***

Dynamic Anchor System



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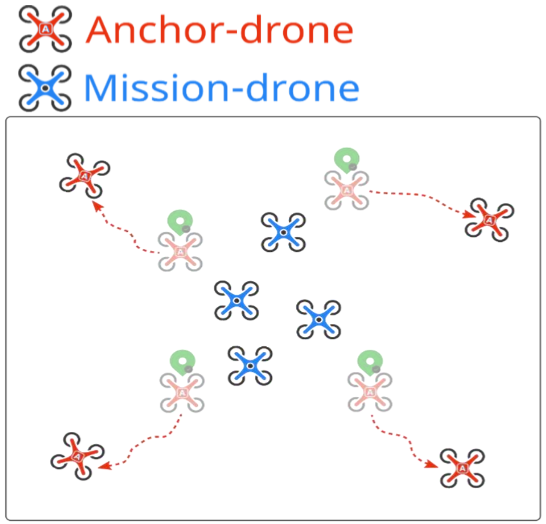

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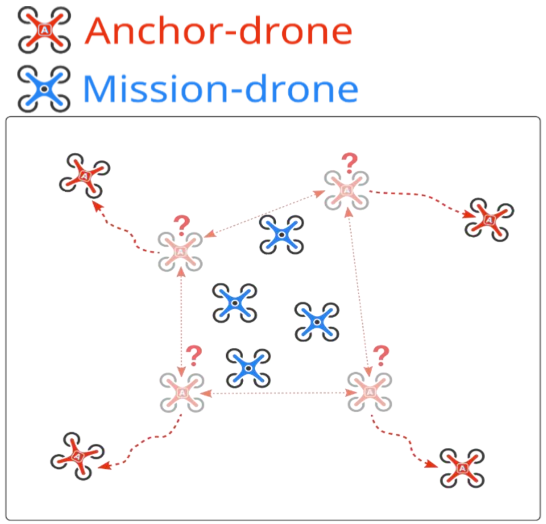

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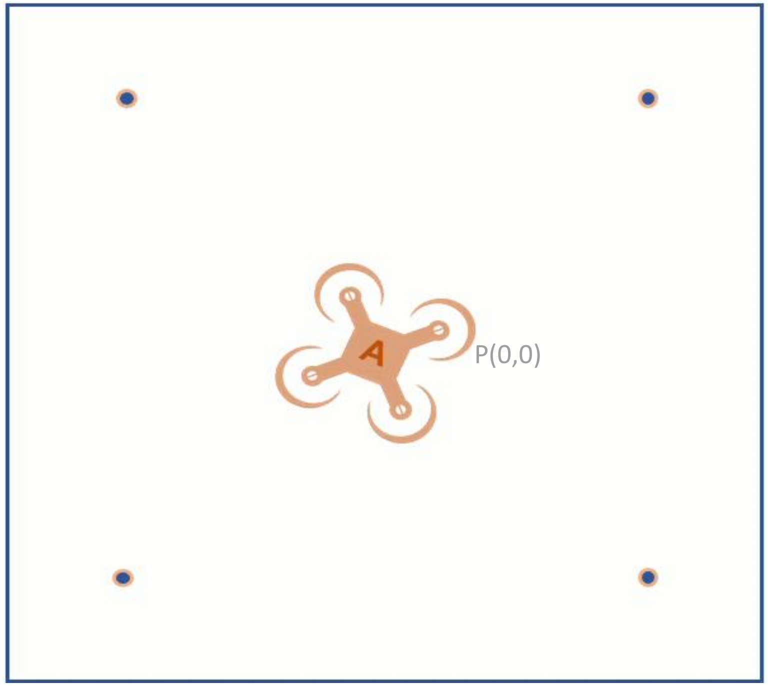
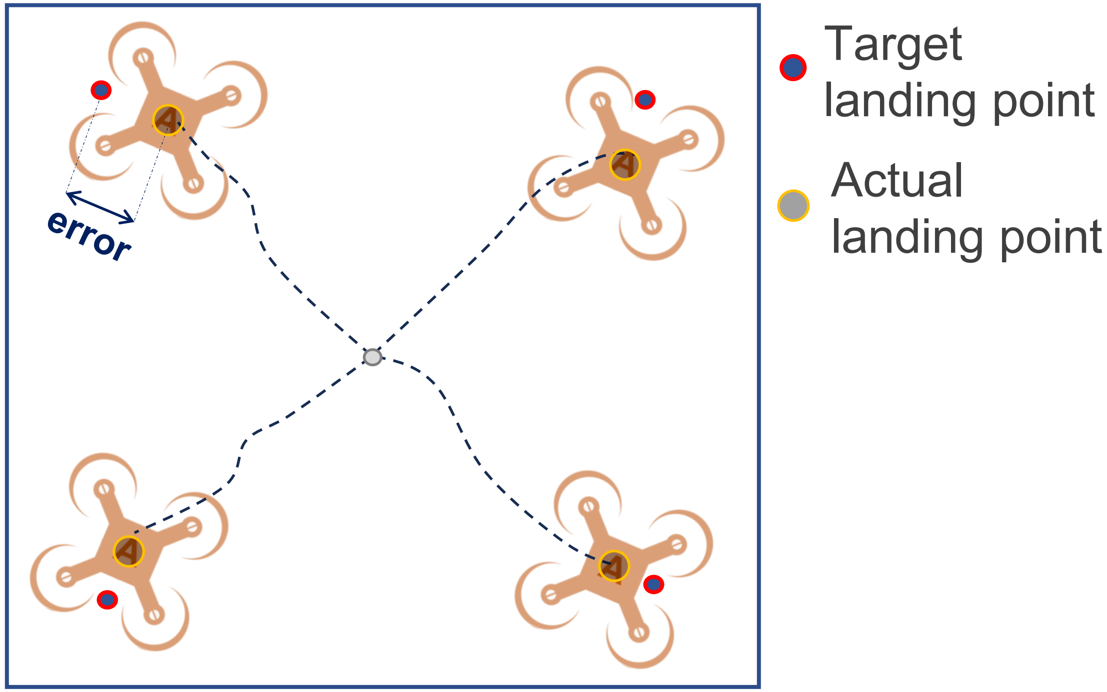
Dynamic Anchor System

1 Anchor-Drones **fly** & **land** to a target location



Navigation based only on the onboard state estimation (Optical-Flow, IMU)

2 After landing Anchor-Drones start **ranging** with MDs



There is an **error** between target landing point and the actual one

Dynamic Anchor System

2

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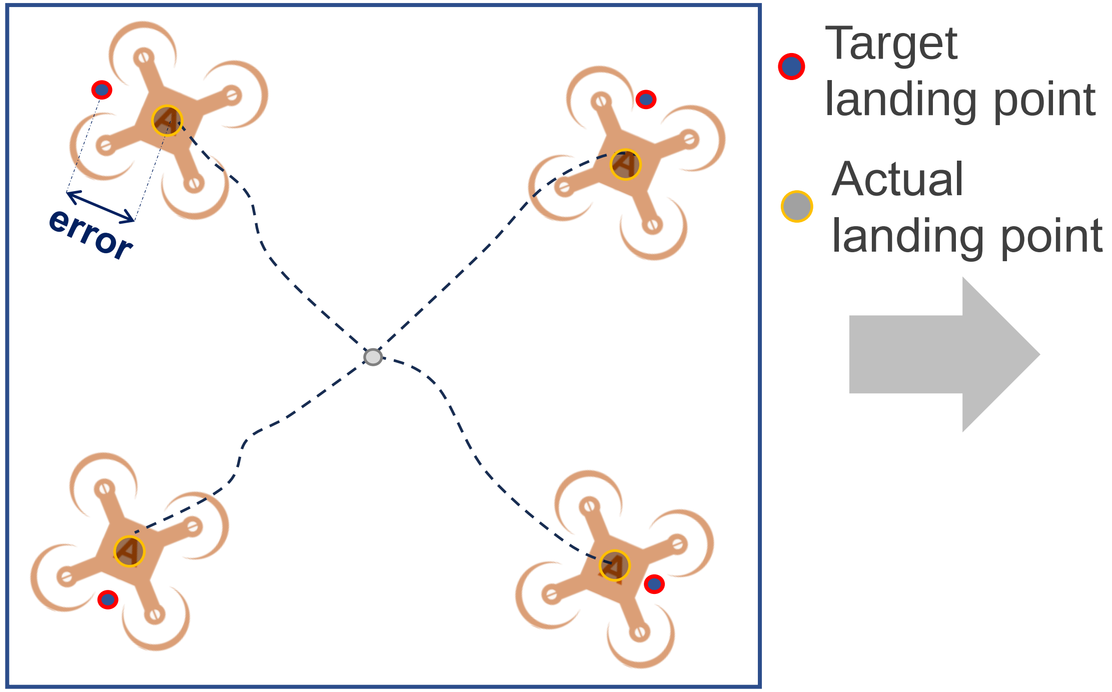
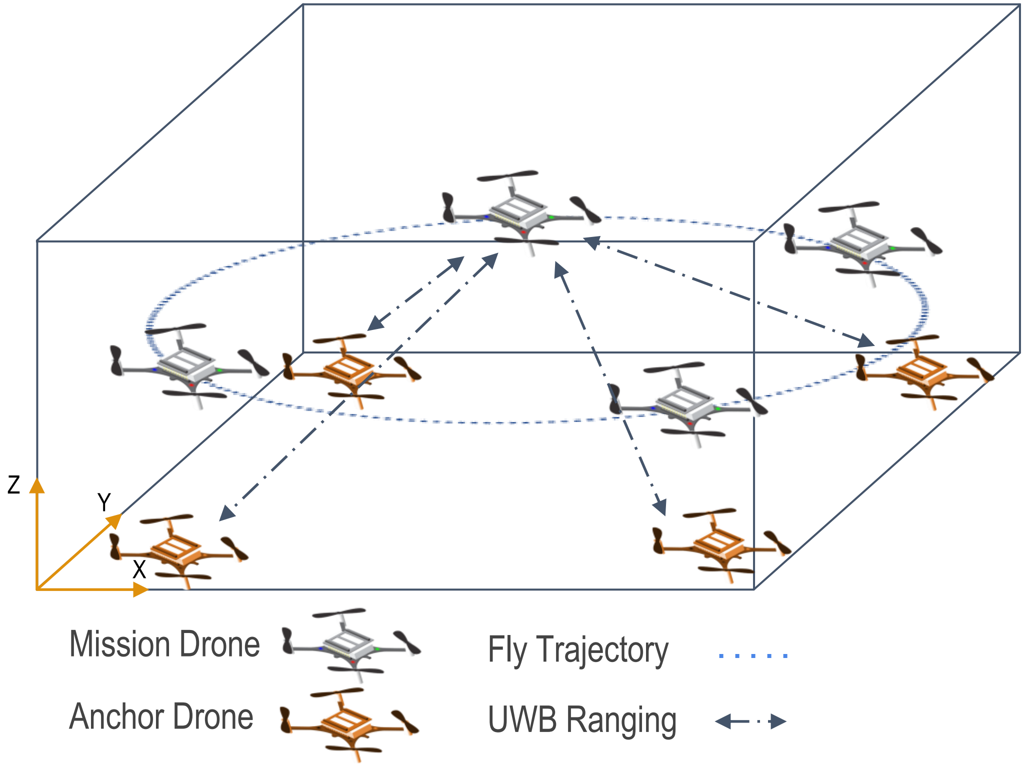
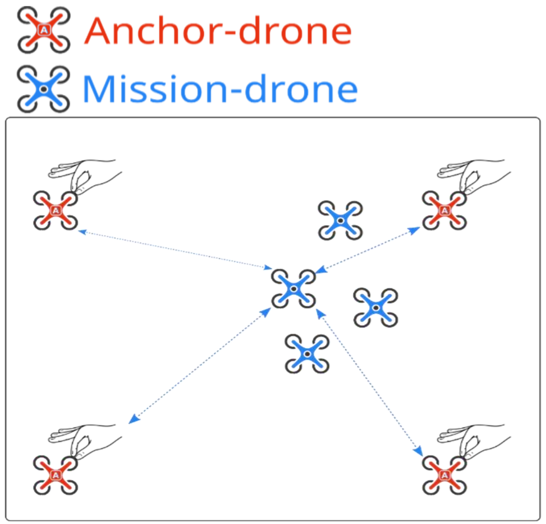


There is an **error** between target landing point and the actual one

Mission-Drones are receiving **ranging information** containing Estimated Anchor Drones' positions



Dynamic Anchor System



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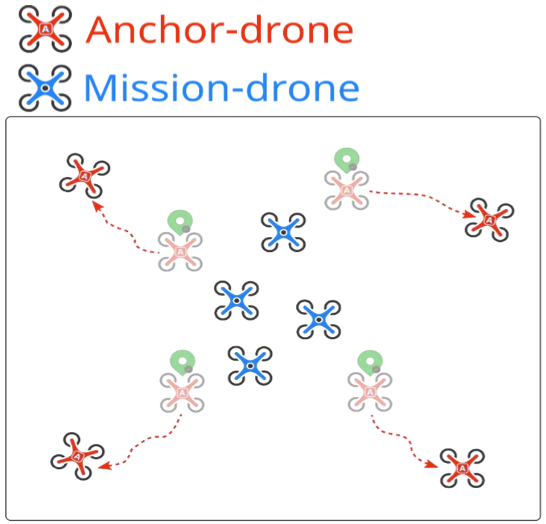

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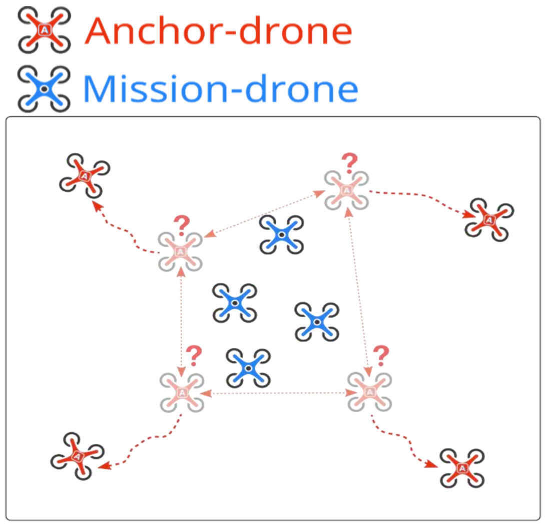
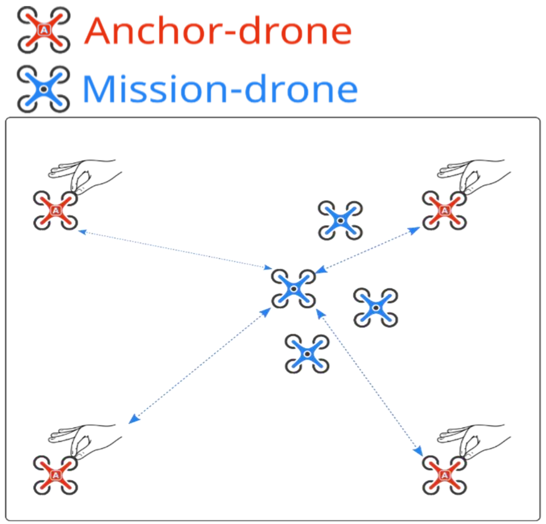


Self-localize

- ☑ ~~installation of anchor infrastructure~~
- ✗ Anchors' positions must be ***known***

Dynamic Anchor System



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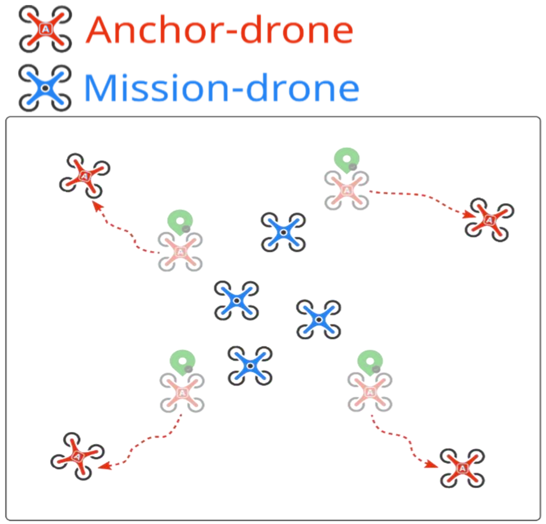

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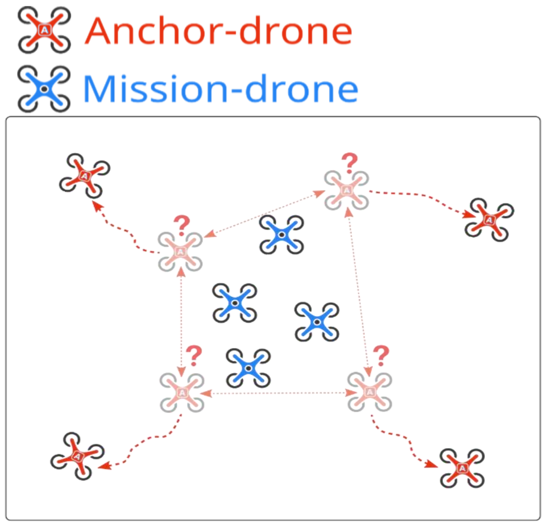

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How does Self-localization System work?

Convention:

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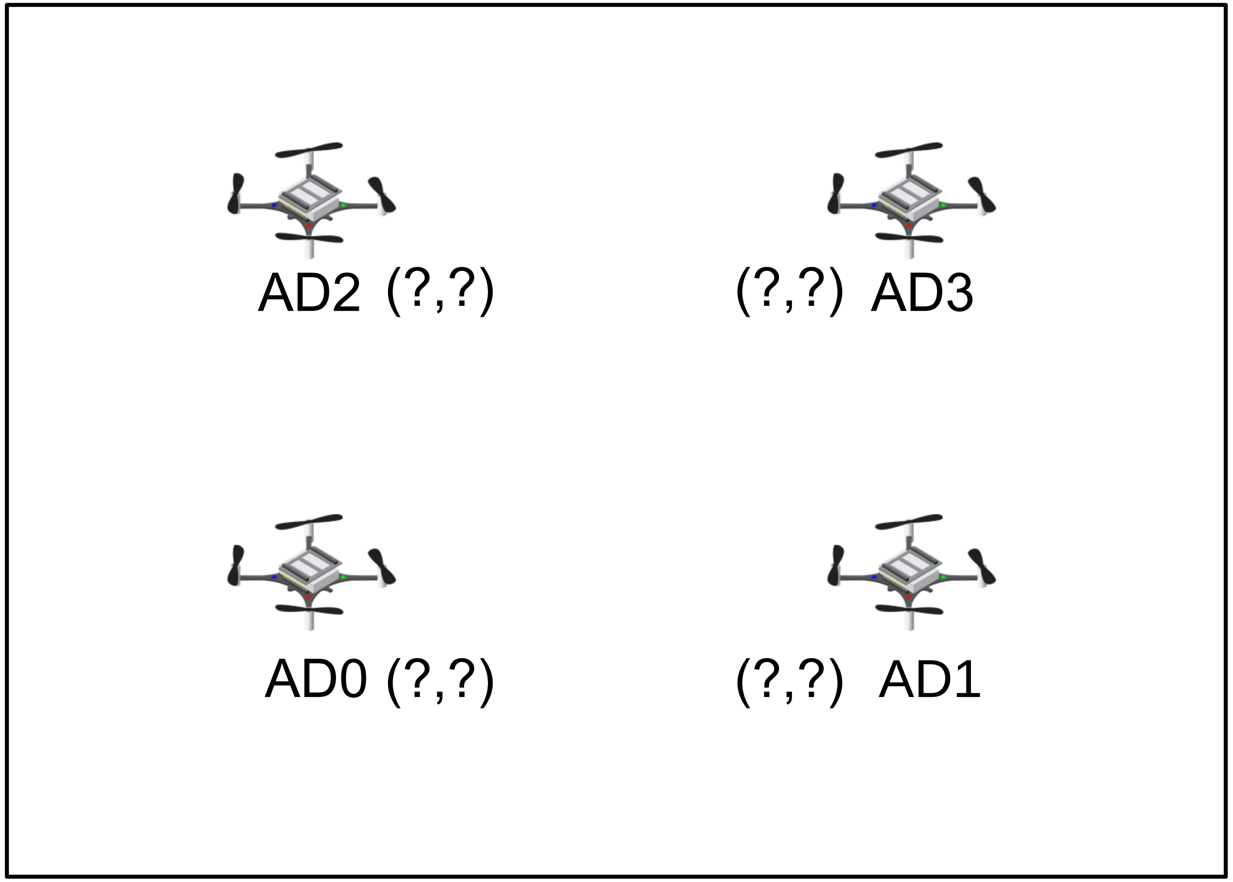

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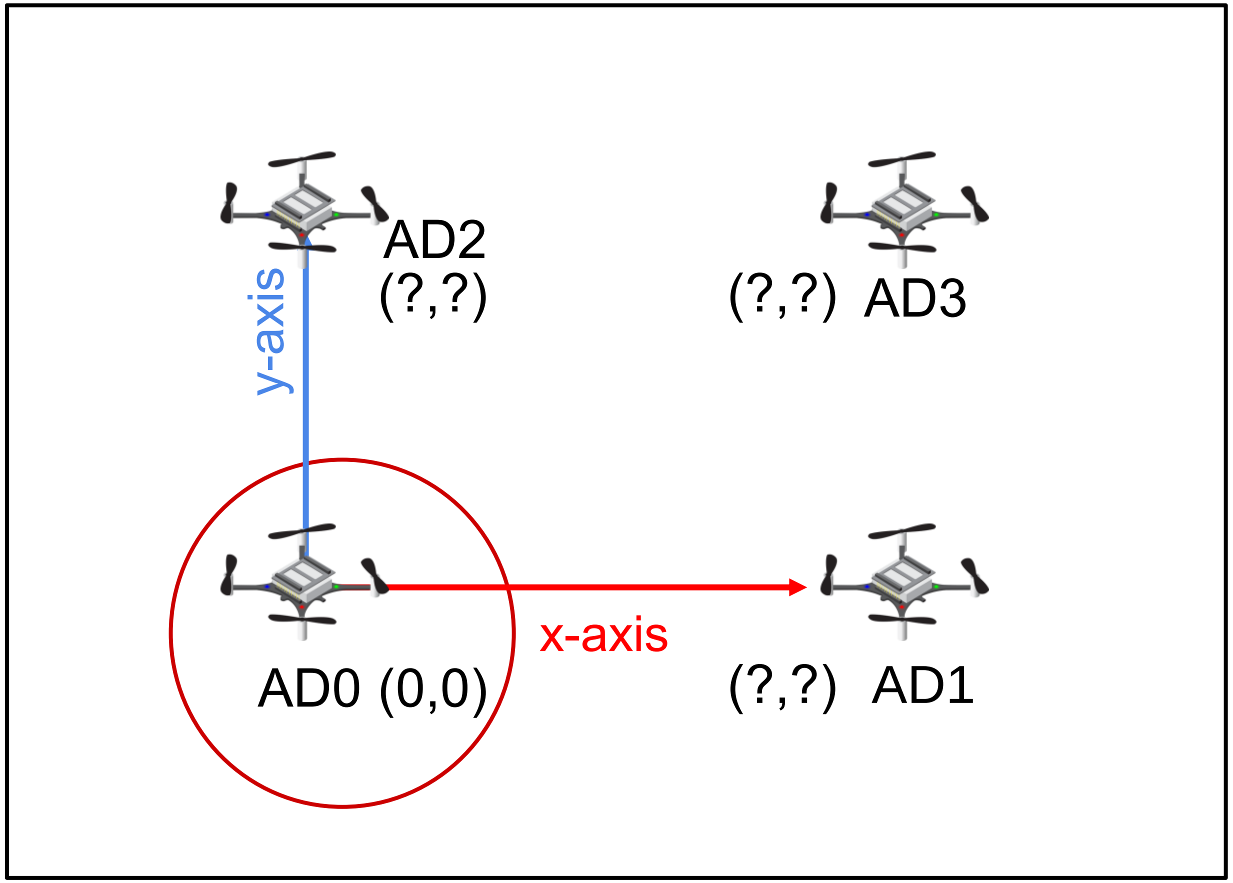

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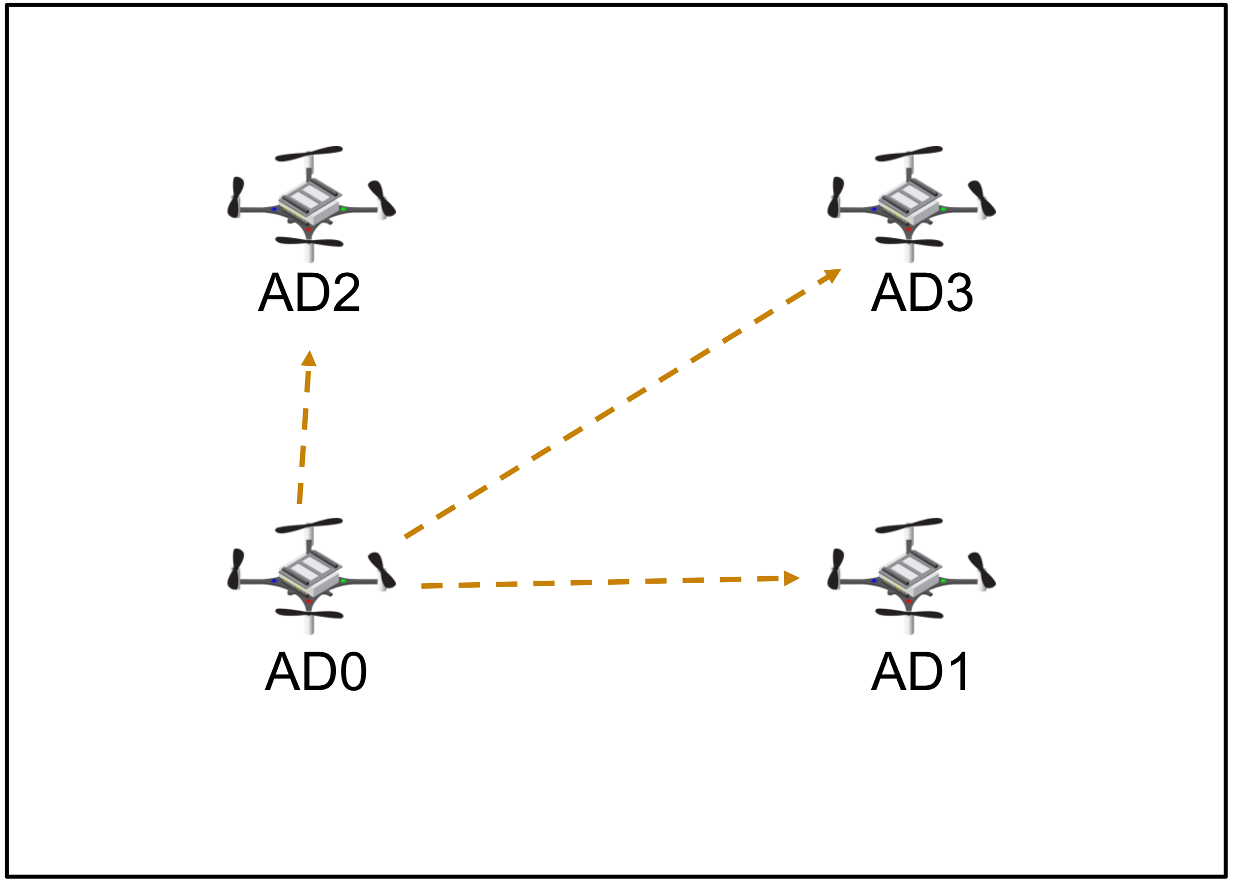

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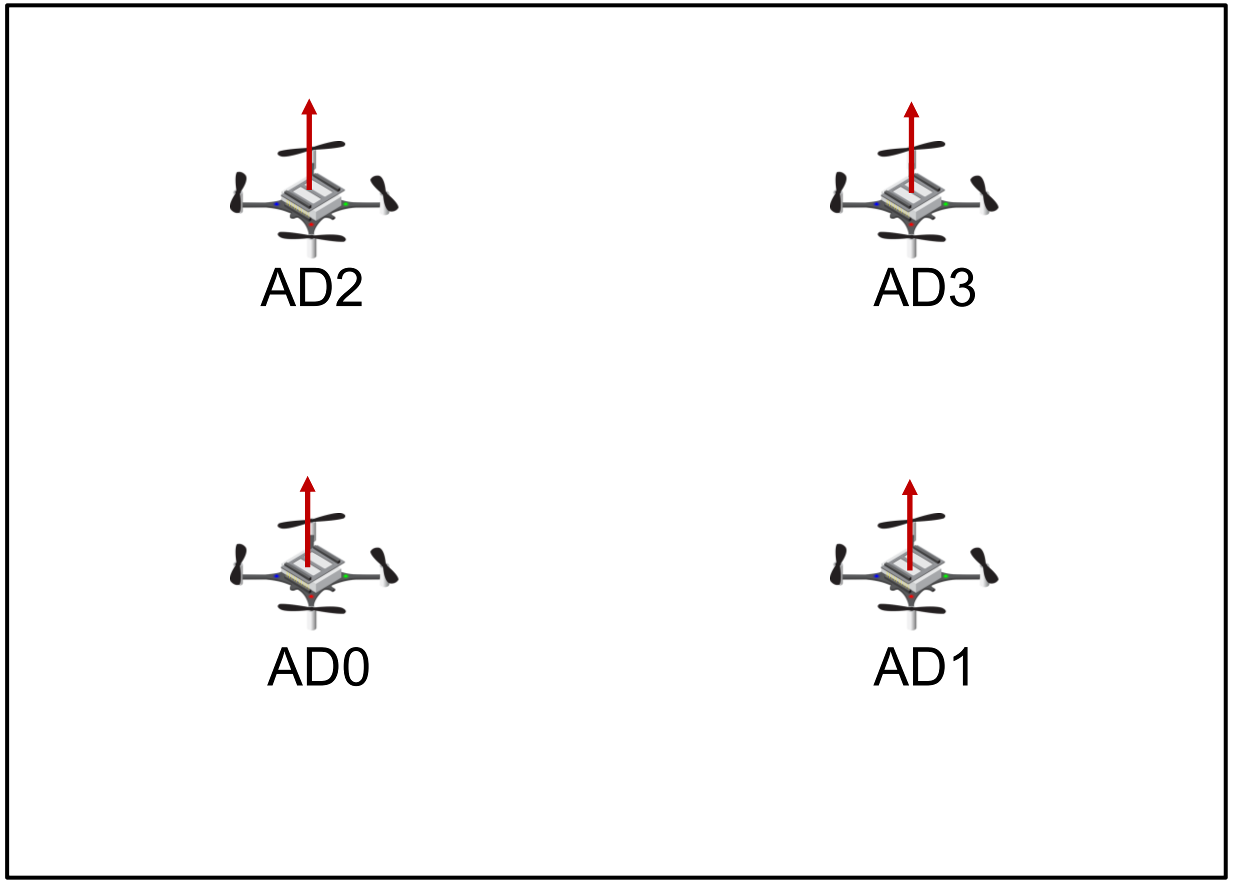

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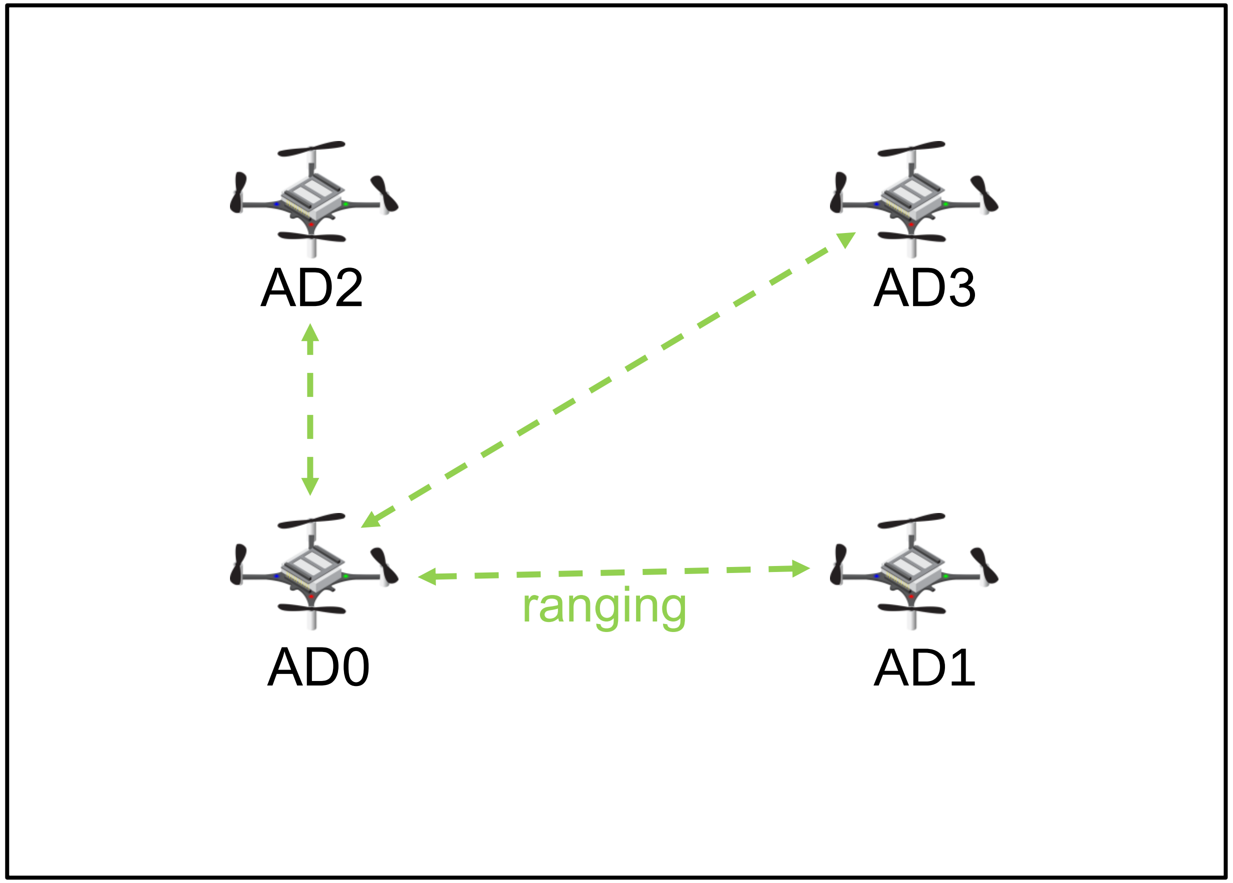

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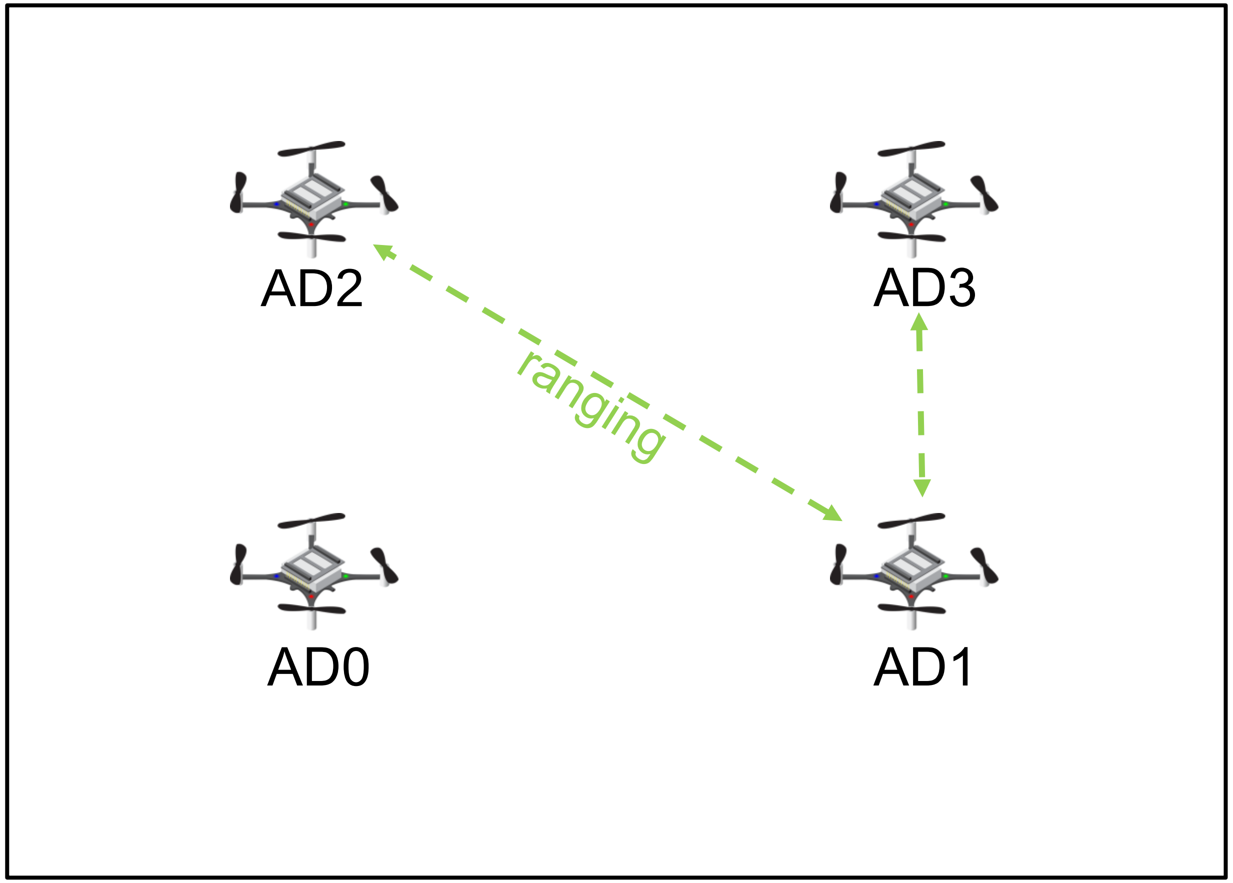

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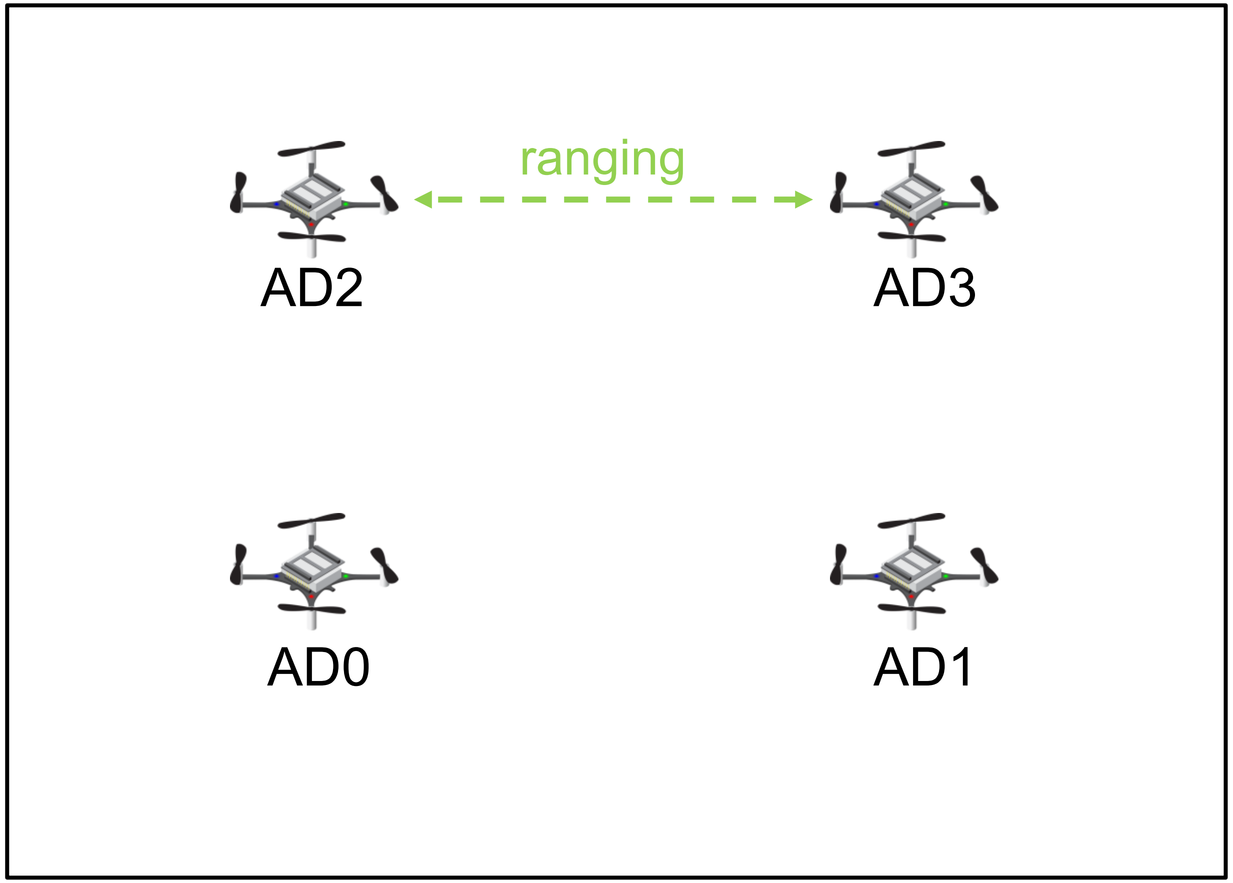

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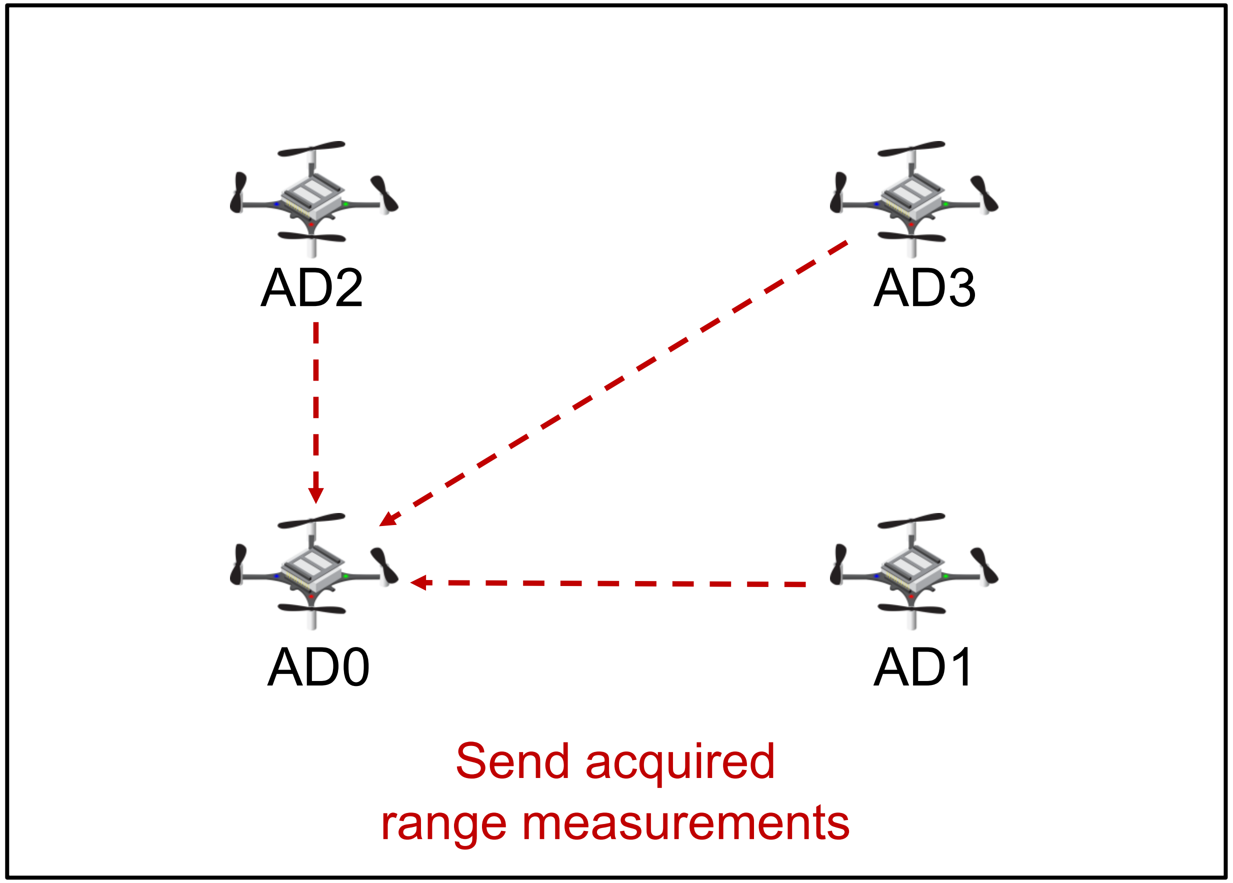
4. ADs send all measurements to AD0



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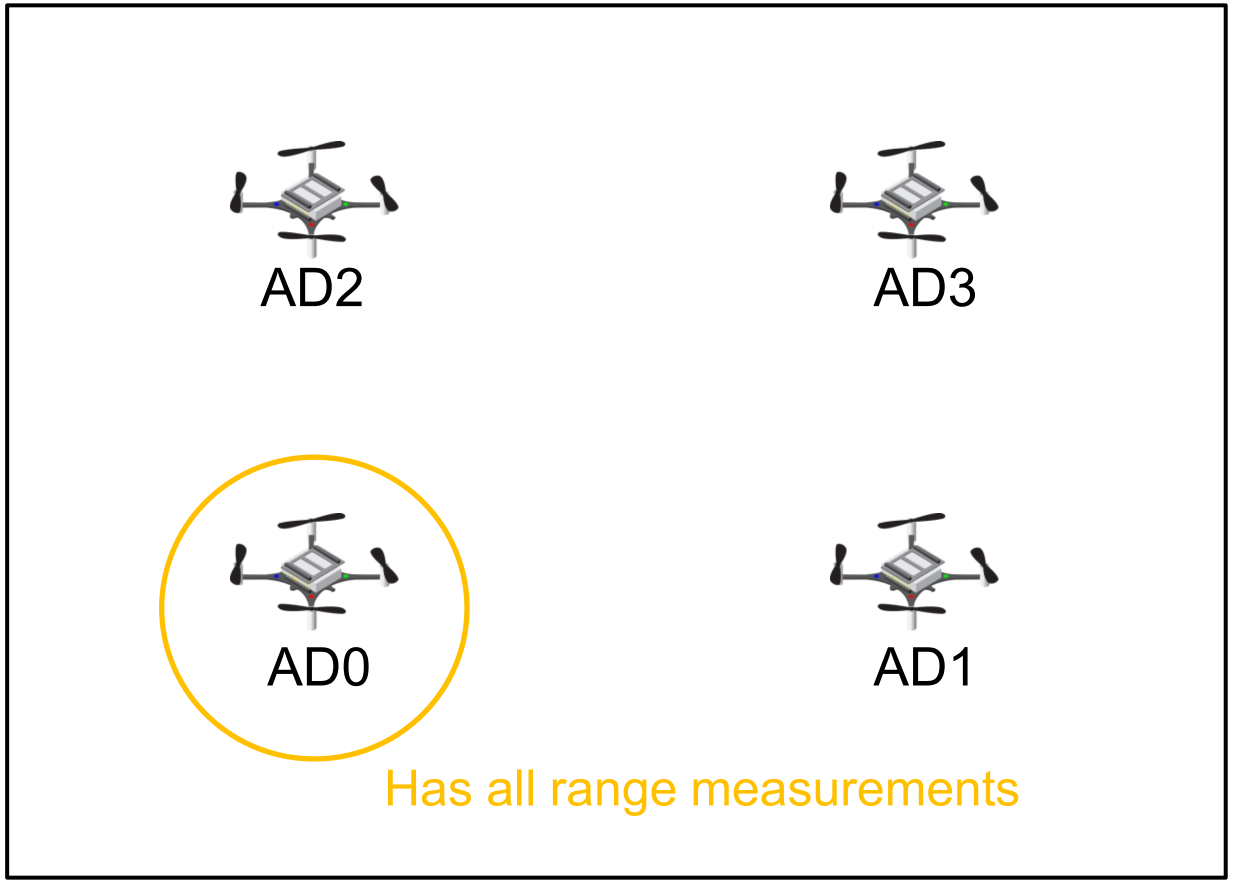
4. ADs send all measurements to AD0
5. AD0 builds the distance matrix D and runs **Multi-Dimensional Scaling** (MDS)



$$D := \begin{pmatrix} d_{1,1} & d_{1,2} & \cdots & d_{1,M} \\ d_{2,1} & d_{2,2} & \cdots & d_{2,M} \\ \vdots & \vdots & & \vdots \\ d_{M,1} & d_{M,2} & \cdots & d_{M,M} \end{pmatrix} \rightarrow \boxed{\text{MDS}} \rightarrow$$

Runs on AD0

Anchor Drone Positions AD0, AD1, … ADM

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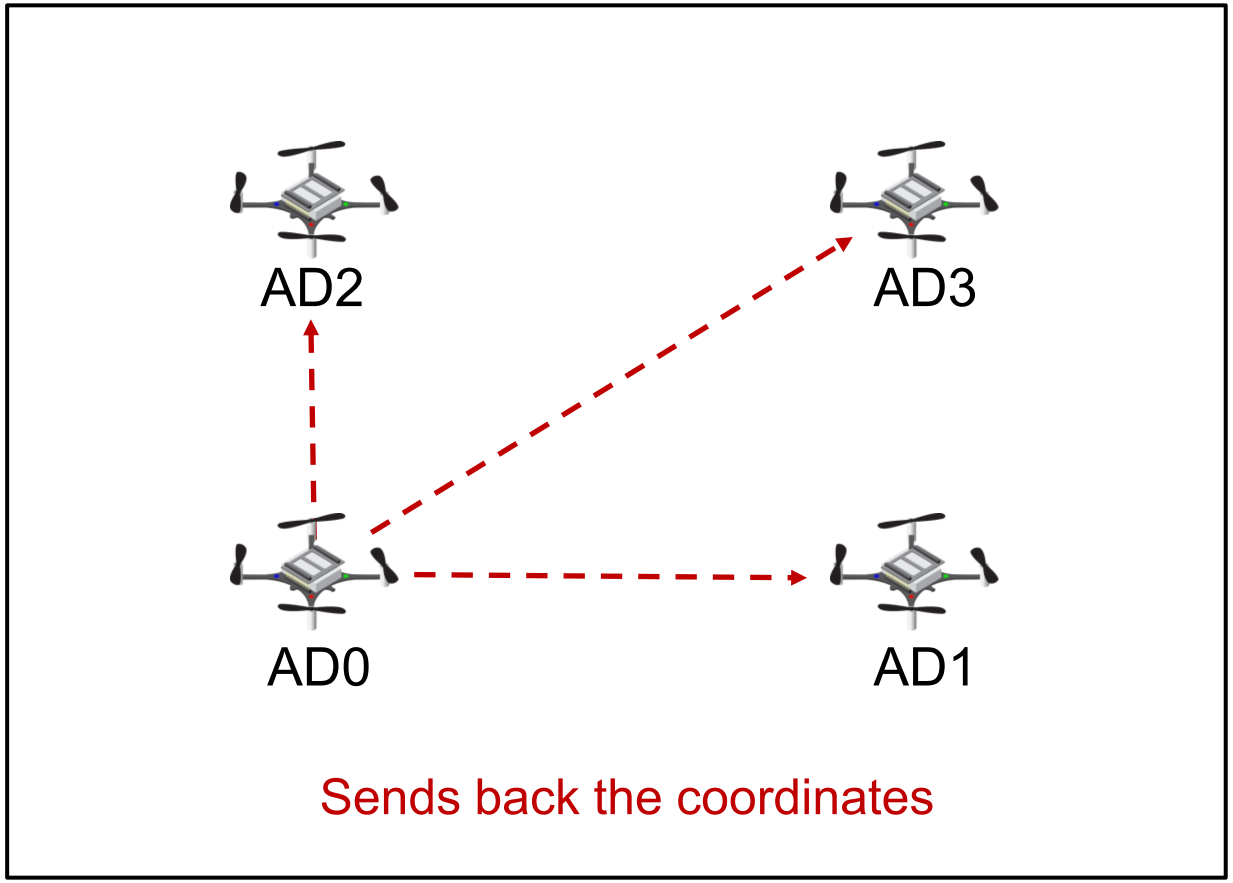
4. ADs send all measurements to AD0
5. AD0 builds the distance matrix D and runs
6. AD0 sends the coordinates to AD1..N



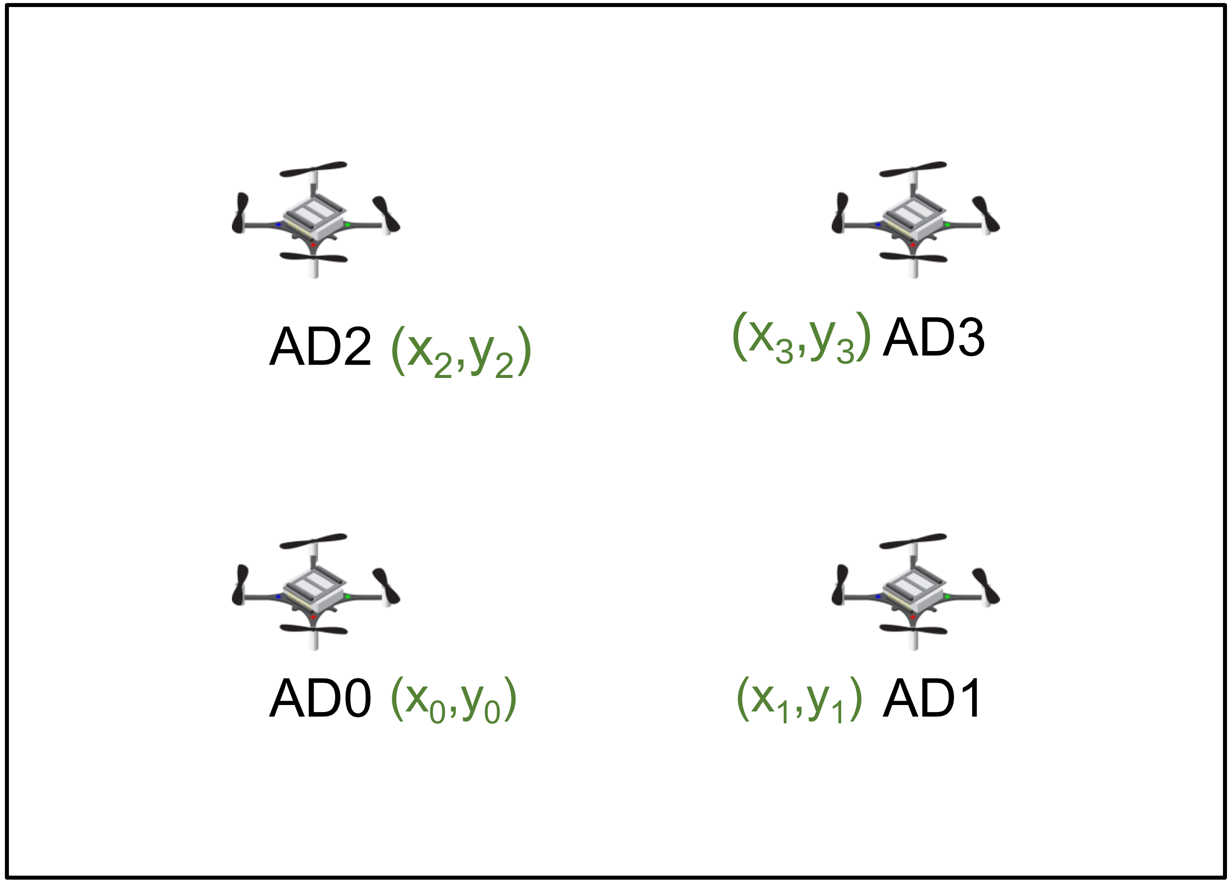
How does Self-localization work?

Convention:

- ADs placed in unknown positions
- AD0 act as the origin of the coordinate system
- AD0 - AD1 form x-coordinate
- AD2 considered the positive y-coordinate

Communication flow:

1. AD0 broadcasts a UWB message to all Ads
2. The ADs take off and hover at 0.5m
3. ADi does ranging with AD(i+1)..N
4. ADs send all measurements to AD0
5. AD0 builds the distance matrix D and runs
6. AD0 sends the coordinates to AD1..N
7. ADs know their relative position



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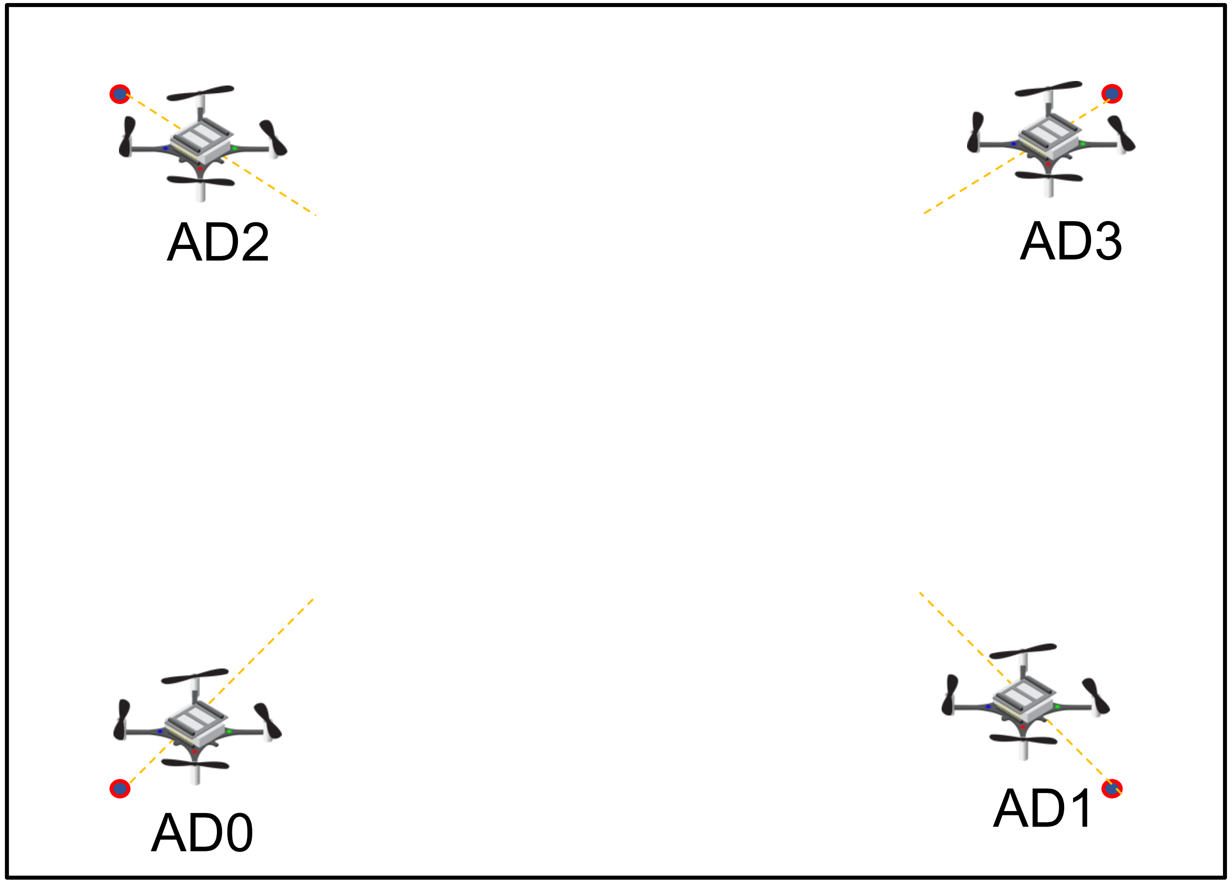
7. ADs know their relative position
8. ADs fly toward the target landing point



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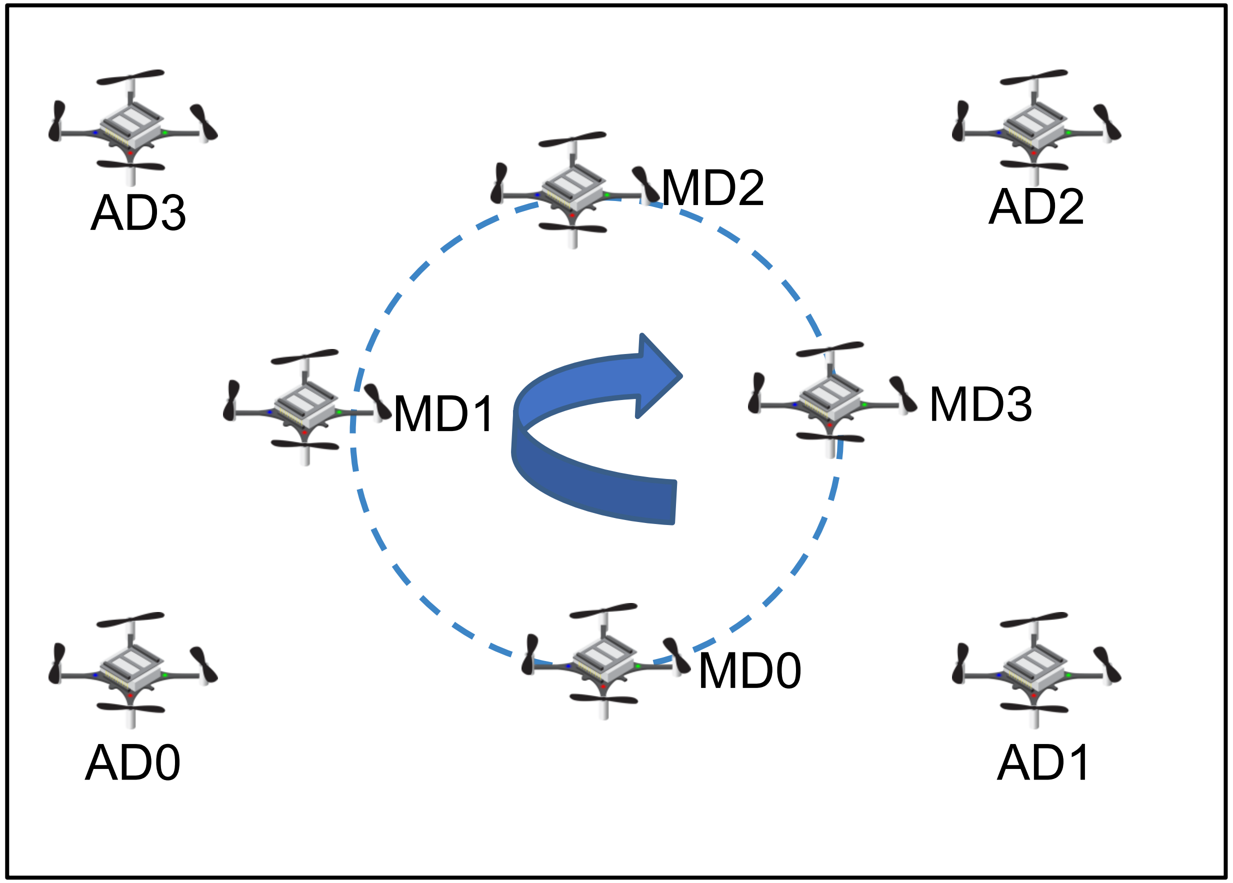
8. ADs fly toward the target landing point
9. Ranging starts and the MDs start flying



In-field Results

Experiment Setup

- 4 Anchor Drones
- 4-8 Mission Drones
- 3 times flying around a 1.5[m] radius circle
- ~1 m/s velocity

Evaluation Metrics

- Localization RMSE
- Control RMSE

Nano-Drone Platform

Crazyflie 2.1

UWB deck

Flow deck v2

In-field Results

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Evaluation Metrics

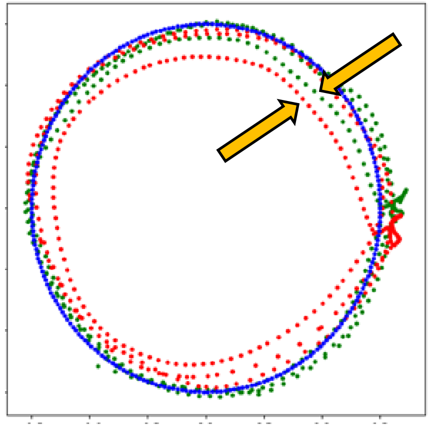
- Localization RMSE → Error: **Estimate** – **GT**
- Control RMSE

Nano-Drone Platform


Crazyflie 2.1


UWB deck


Flow deck v2



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Nano-Drone Platform

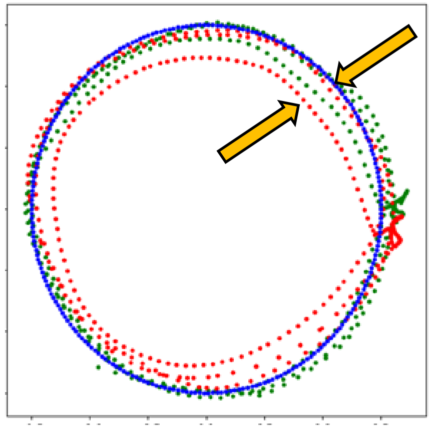

Crazyflie 2.1


UWB deck


Flow deck v2

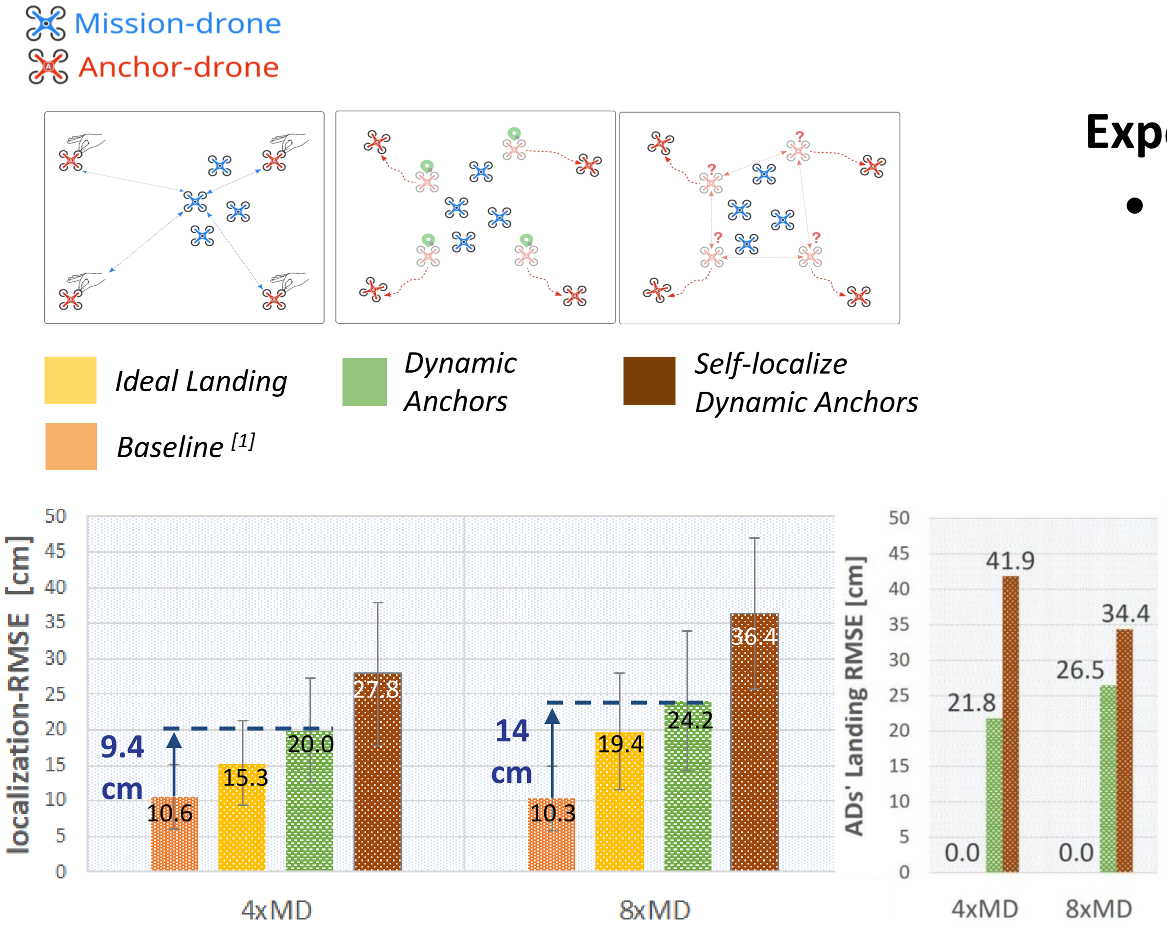
Evaluation Metrics

- Localization RMSE
- Control RMSE → $\underbrace{\textbf{Ideal} \quad \textbf{GT}}_{\text{Error}}$



● Ideal ● Estimation ● Ground-truth

In-field Results

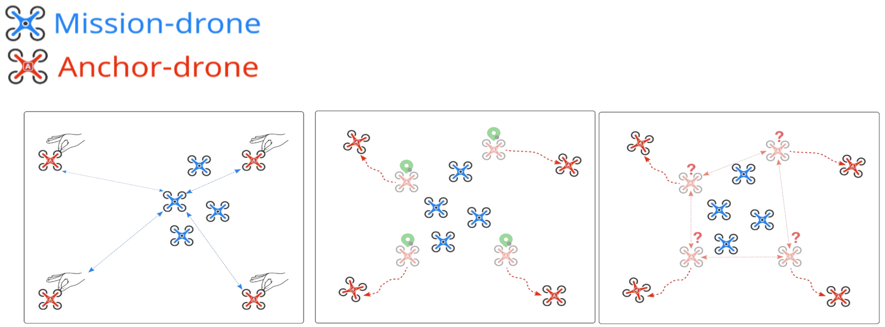


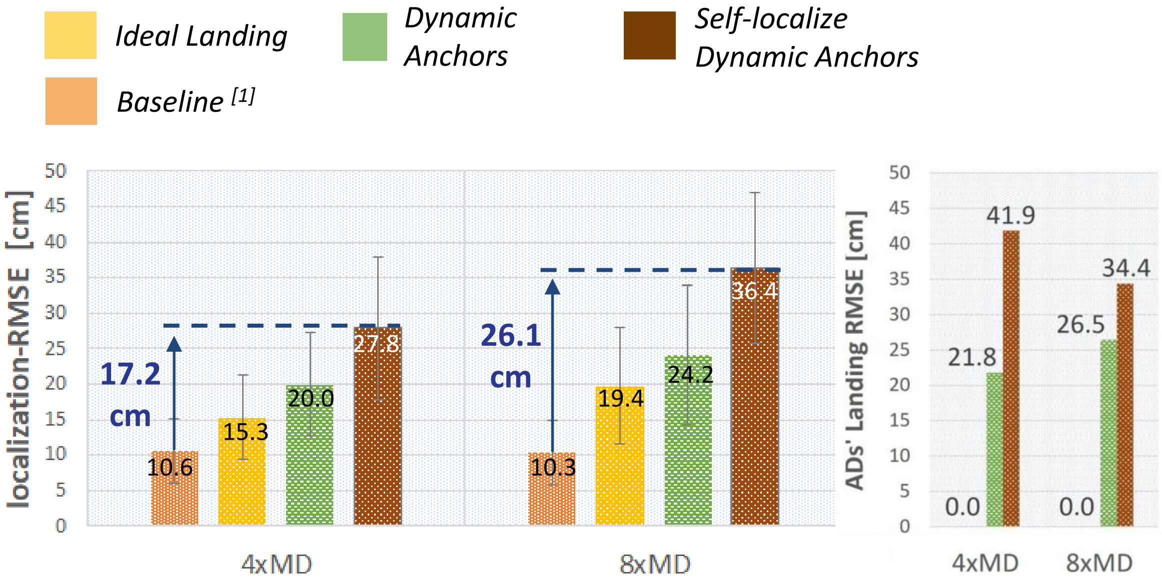
Experiments with 4/8 MDs and 4 ADs:

- Flexibility at the cost of a higher localization error

[1] Fixed 6x Anchor module setup using Bitcraze's UWB localization firmware as the baseline

In-field Results - self-localization





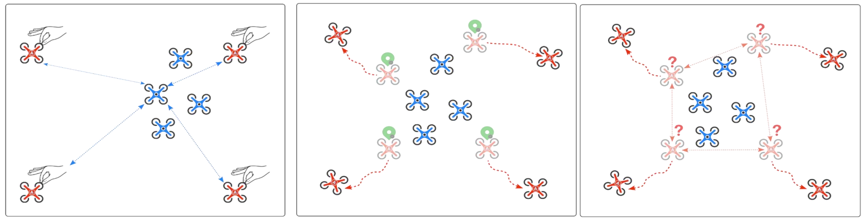
Experiments with 4/8 MDs and 4 ADs:

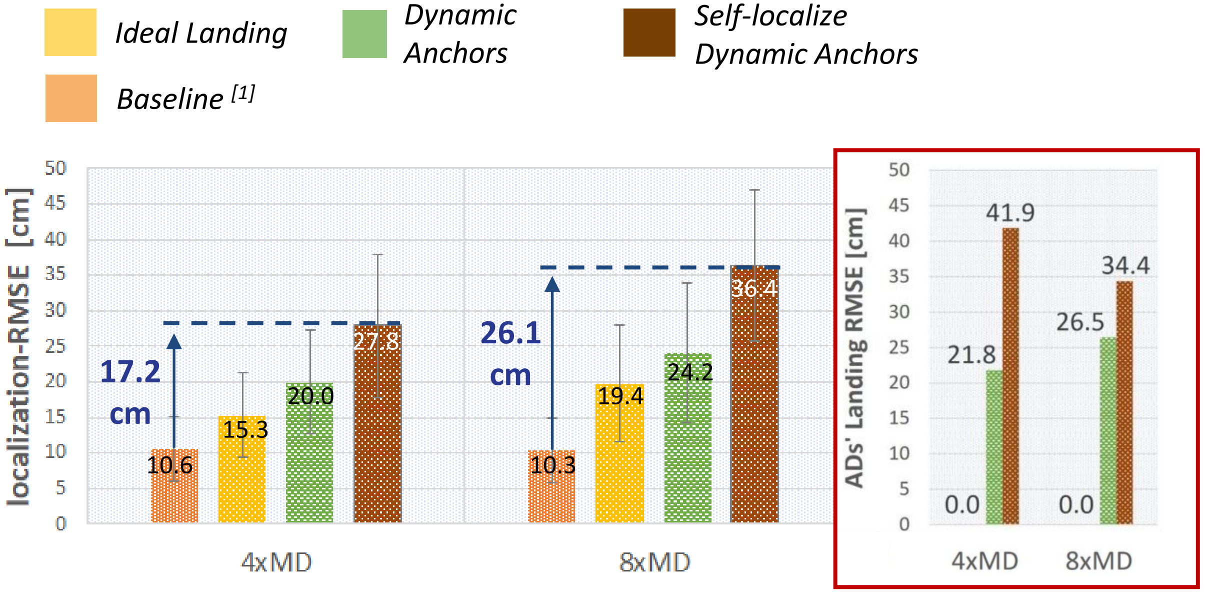
- Flexibility at the cost of a higher localization error
- Self-Localization runs on-board in 5 sec

[1] Fixed 6x Anchor module setup using Bitcraze's UWB localization firmware as the baseline

Results - Impact of AD self-localization

Mission-drone
Anchor-drone



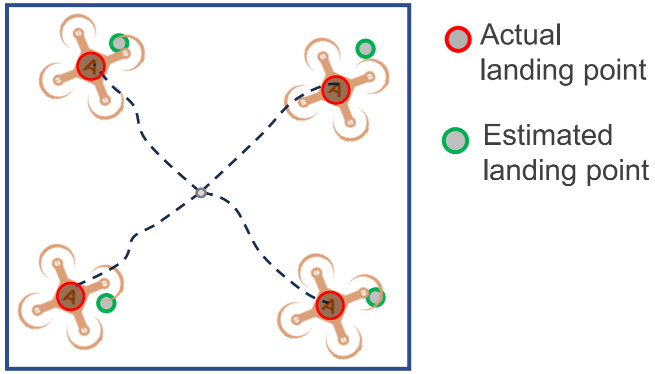


Experiments with 4/8 MDs and 4 ADs:

- Flexibility at the cost of a higher localization error
- Self-Localization runs on-board in 5 sec

Localization Error is contributed by

- UWB Error (also on static anchors)
- **Anchors' Landing Error**



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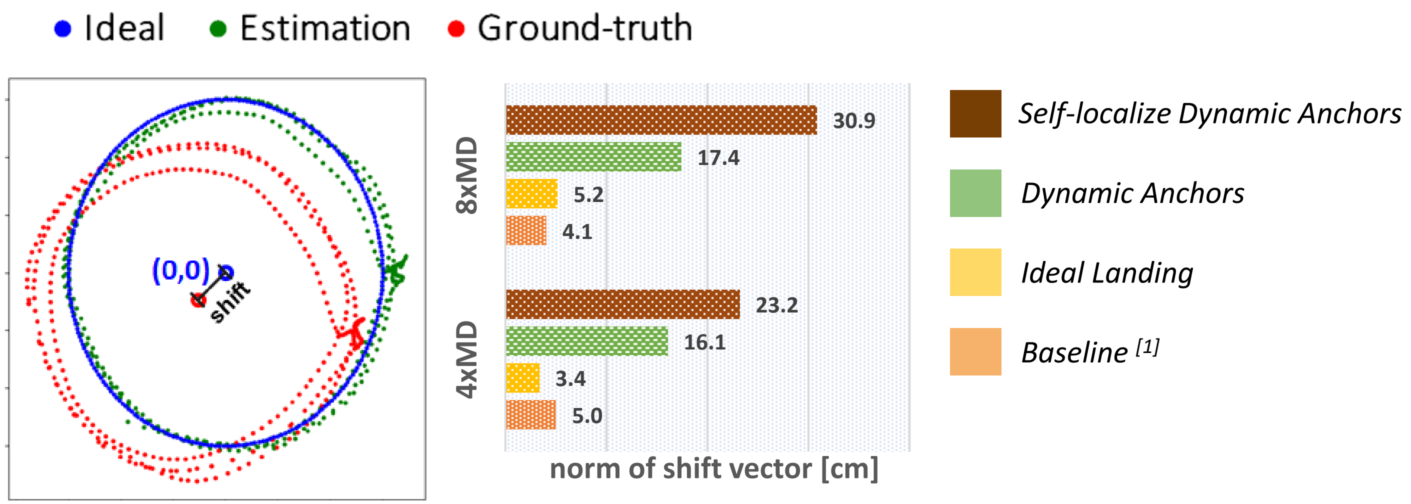
Results



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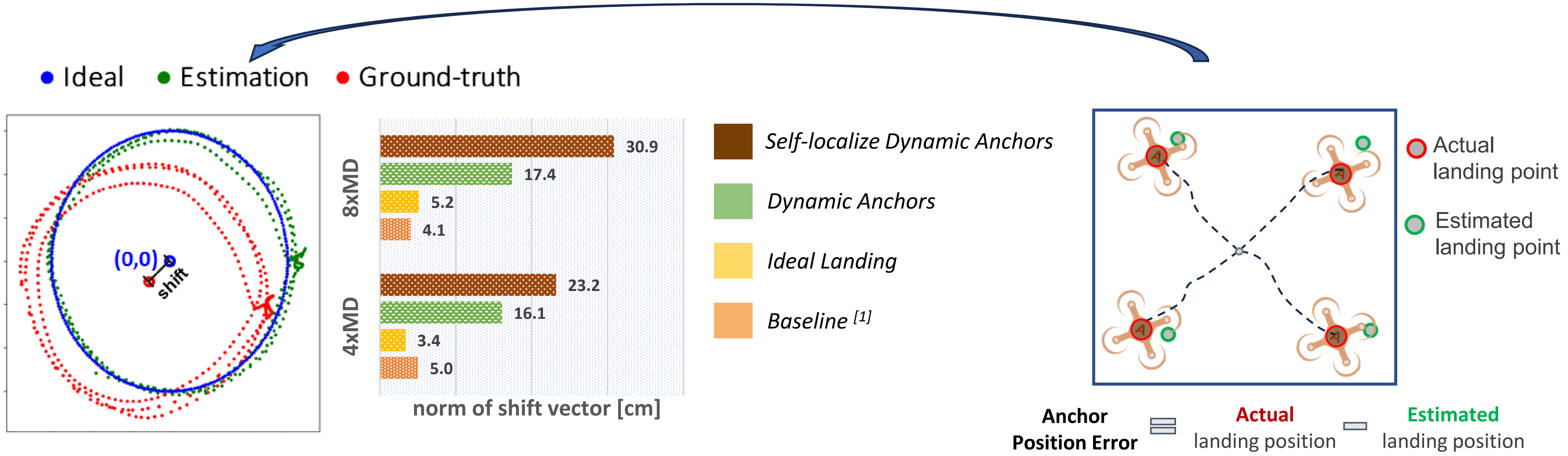

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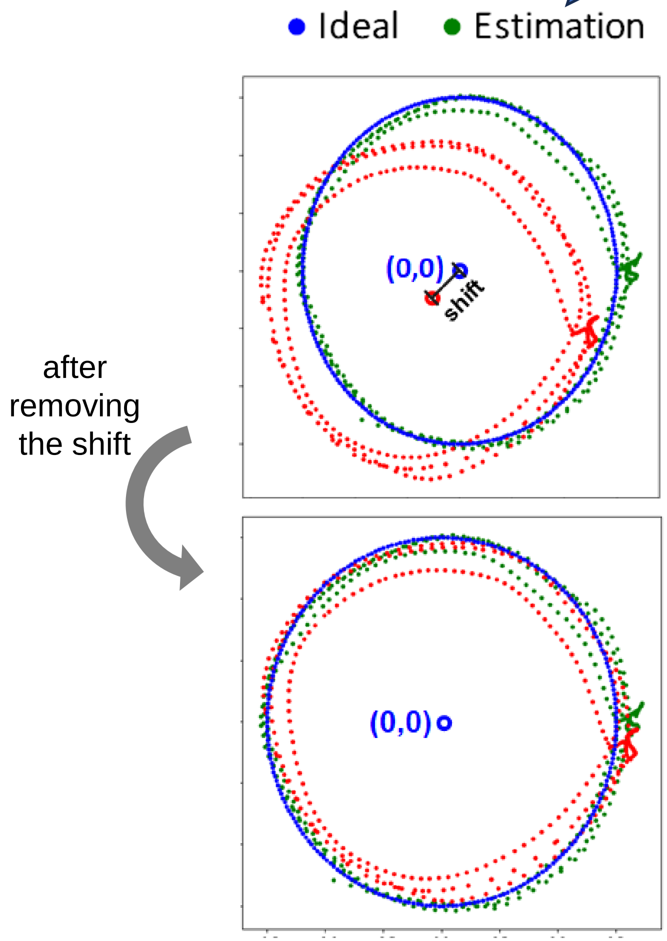

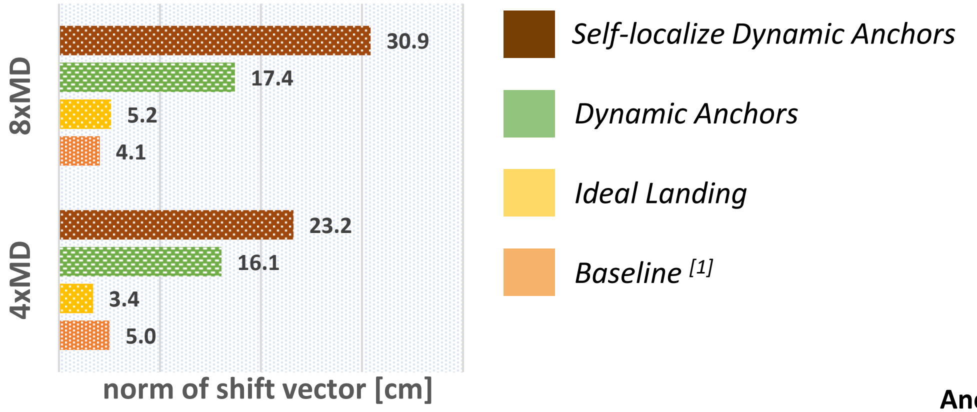

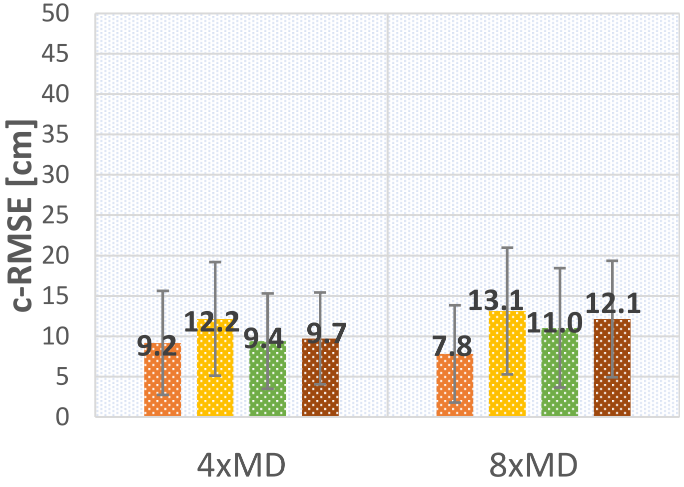

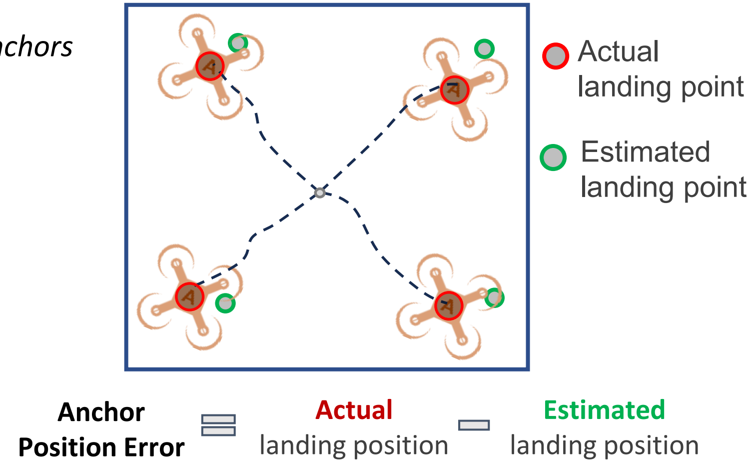

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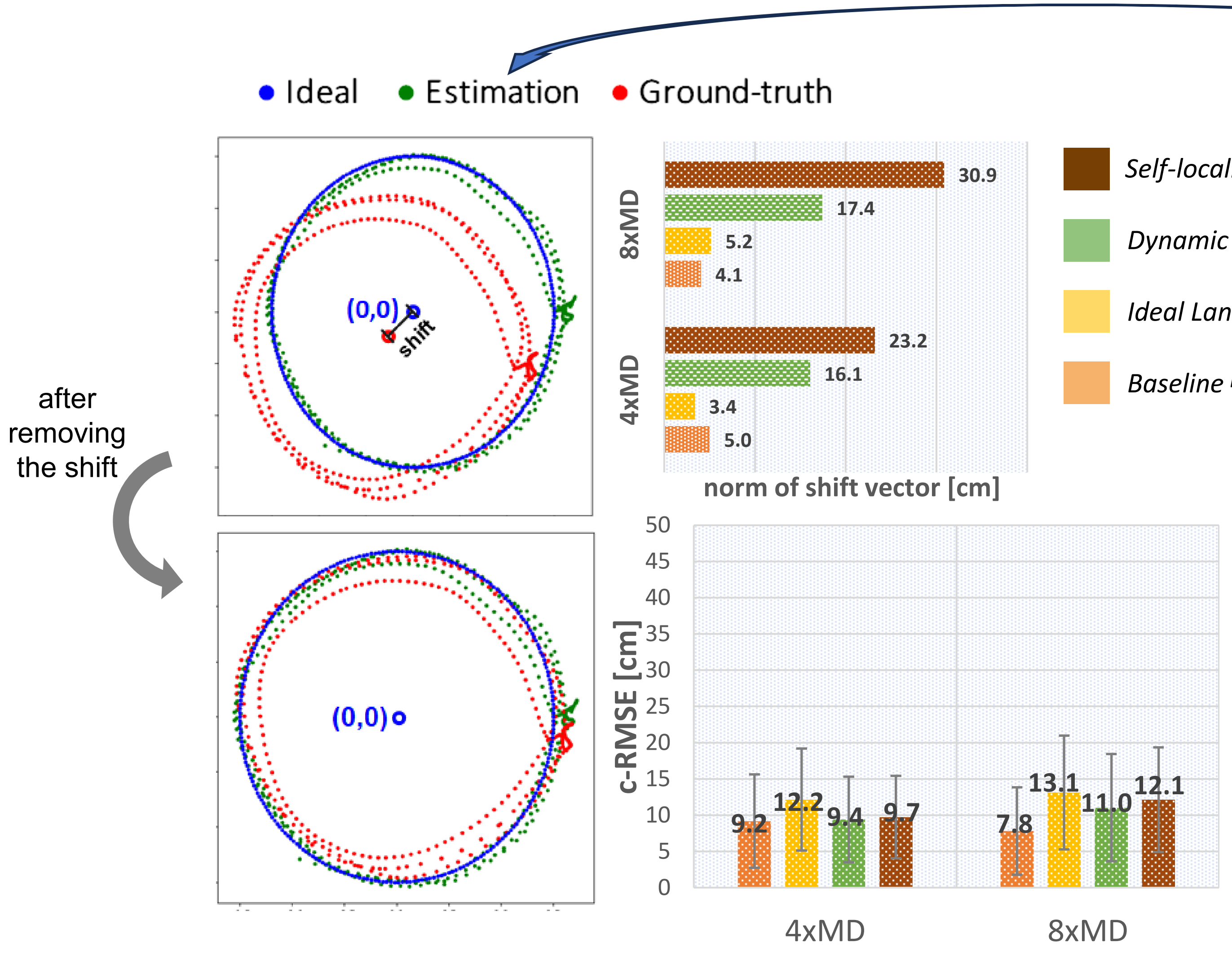

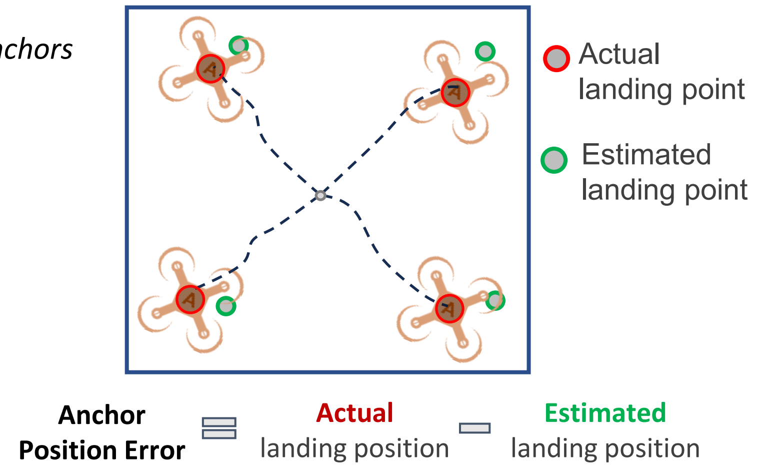

Take away message

Higher localization error in dynamic anchor systems is mainly impacted by a shift vector

However, the control error always remains low to enable drones to precisely follow the commanded trajectory

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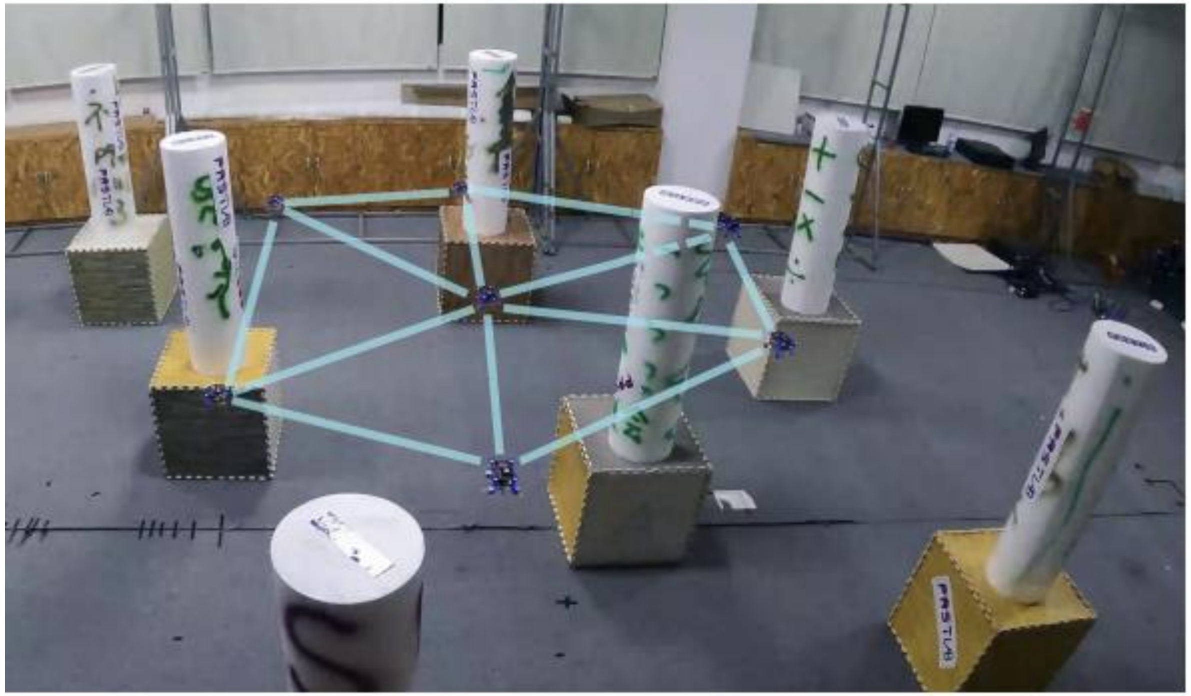
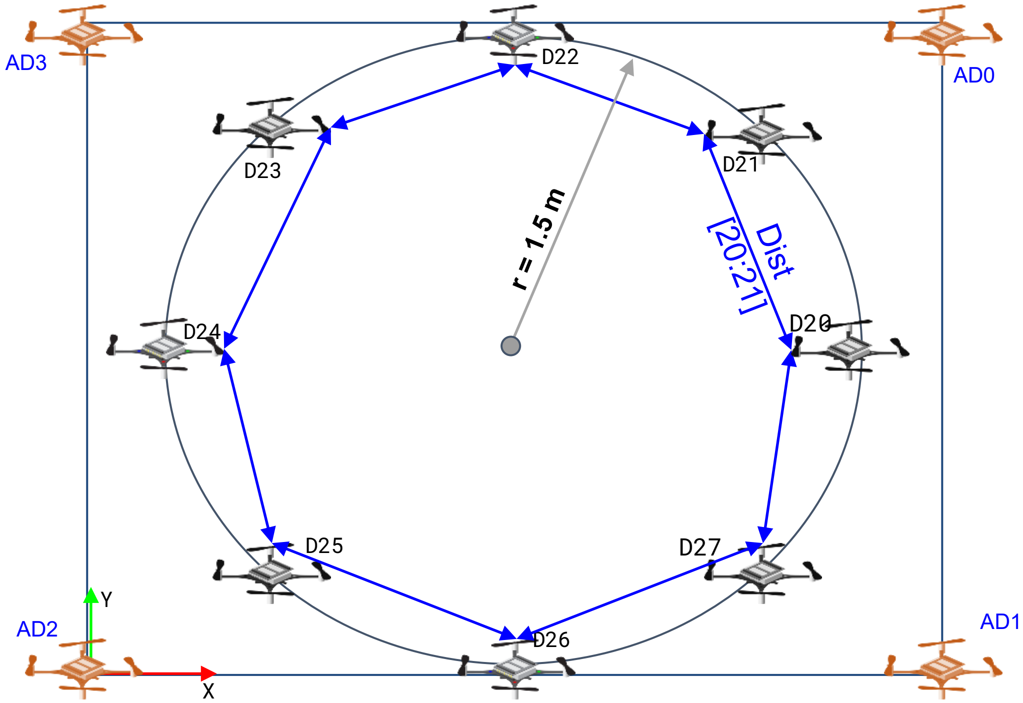
Results



Flight Formation*

Longitude inter-drone distance



Longitude inter-drone distance always bounded below 13.7% i.e., ±15.6 cm

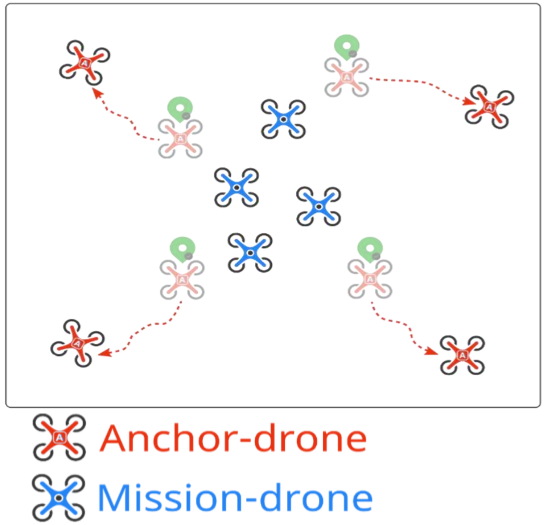
[*] https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=9812050

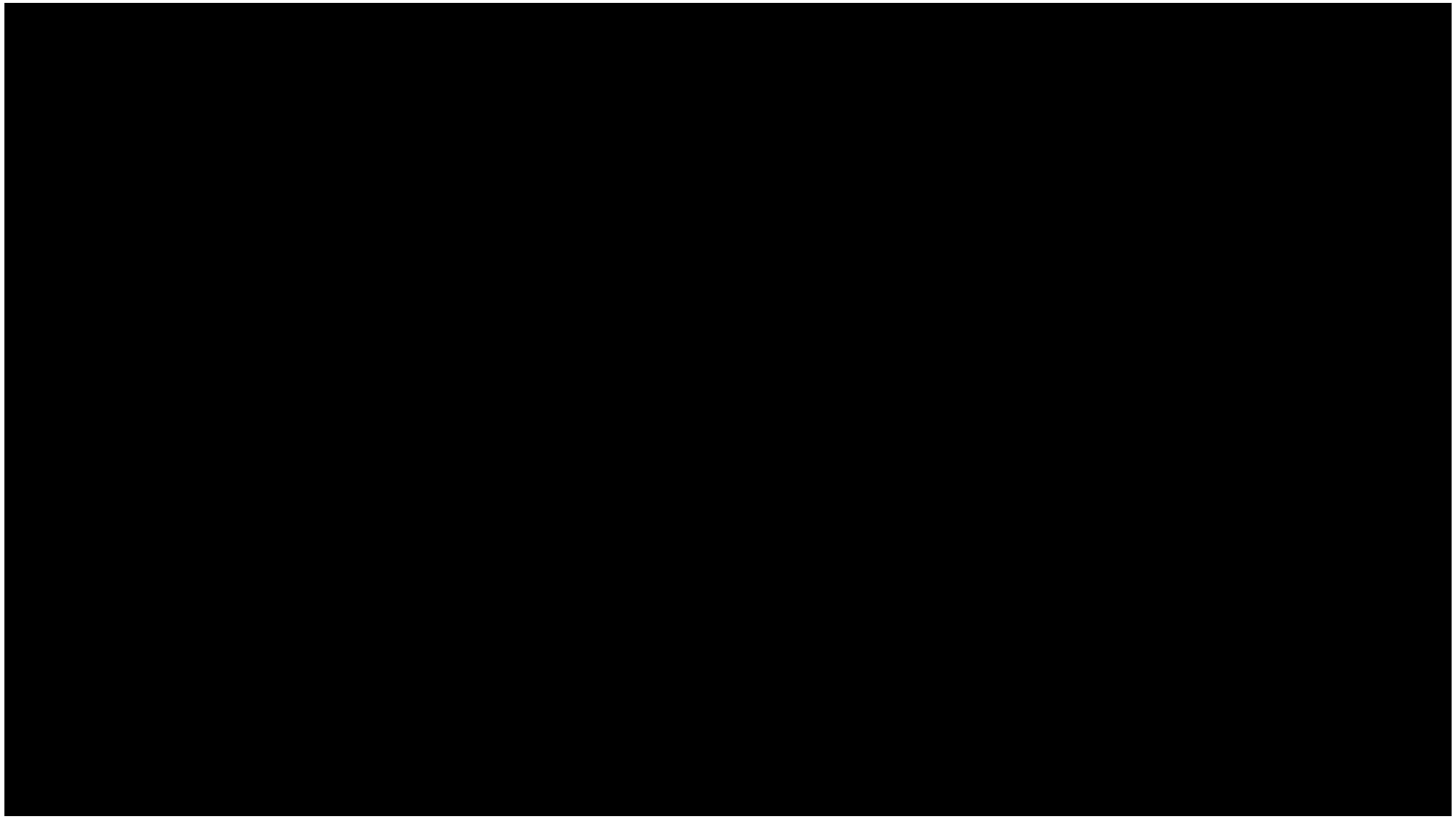
Demo

Setup

- 4 ADs and 8 MDs
- Dynamic Anchor Deployment
- MDs fly in a 1.5[m] circular trajectory

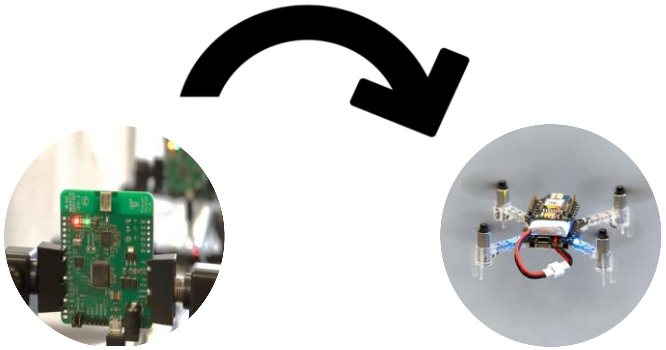
Dynamic Anchors





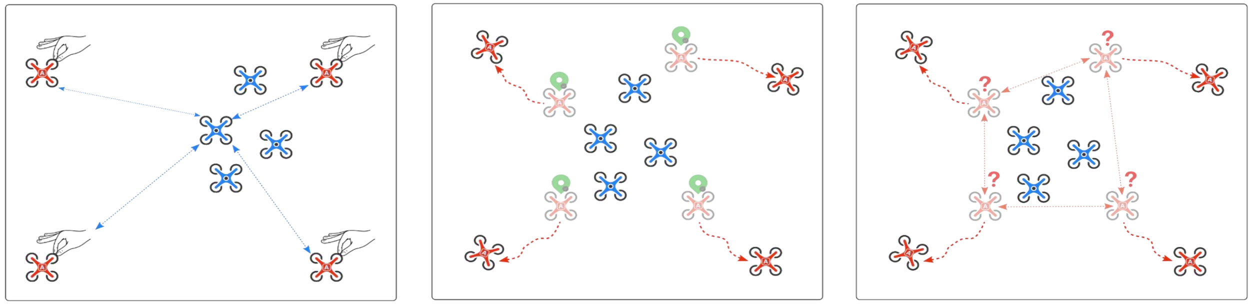
Conclusion

Leveraging Nano-drone as Dynamic Anchor to eliminate the need for a static UWB infrastructure



Anchor Infrastructure

Dynamic Anchor



	Most challenging configuration 8x MD		
	IDEAL LAND	DYNAMIC ANCHOR	SELF LOCALIZE
l-RMSE	19.4	24.2	36.4
c-RMSE	13.1	11.0	12.1

Longitude inter-drone distance always **<15.6 [cm]**

Thank you for your attention!

Mahyar Pourjabar

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mahyar.pourjabar2@unibo.it