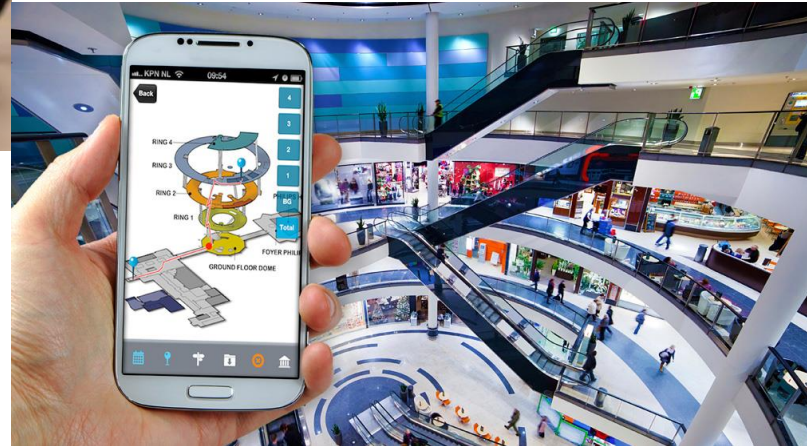# LocAP: Autonomous Millimeter Accurate Mapping of WiFi Infrastructure
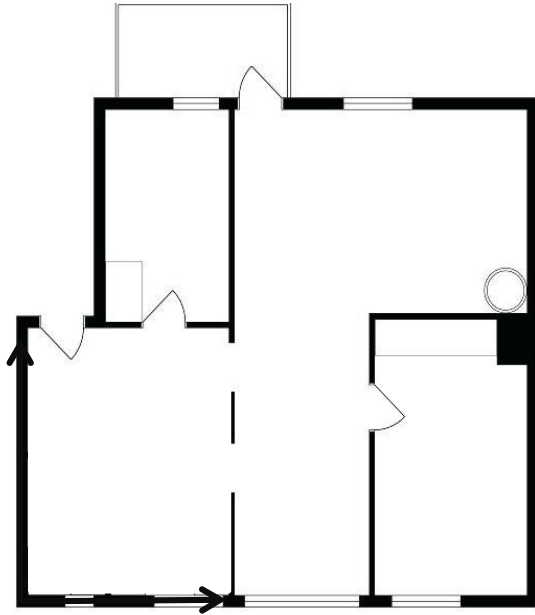
Roshan Ayyalasomayajula, Aditya Arun, Chenfeng Wu, Shrivatsan Rajagopalan, Shreya Ganesaraman, Aravind Seetharaman, Ish Kumar Jain, Dinesh Bharadia

http://wcsng.ucsd.edu/locap/

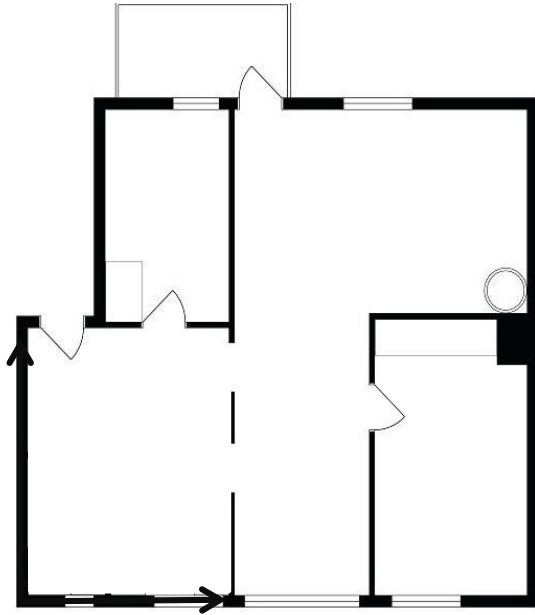# Indoor Navigation: Applications

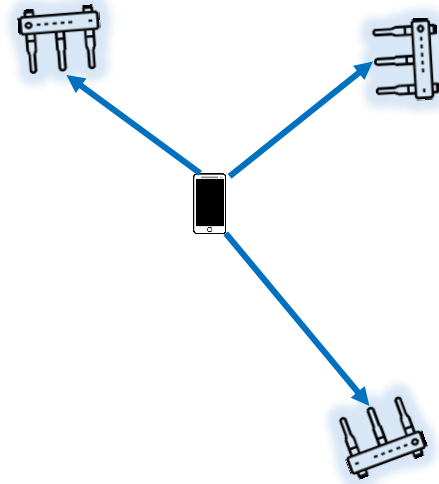# Indoor Navigation: Mapping

Mapping

Indoor Navigation: Mapping

Mapping

Indoor Navigation: Localization

Localization

Indoor Navigation: Localization

DLoc [Mobicom'20]

MonoLoco [MobiSys'18]

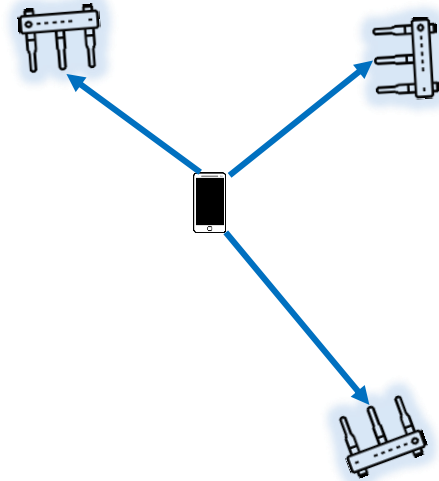Chronos [NSDI'16]

ToneTrack [Mobicom'15]

SpotFi [Sigcomm'15]

ArrayTrack [NSDI'13]

EZ [Mobicom'10]

Horus [MobiSys'05]

RADAR [Infocomm'00]

Localization

Indoor Navigation: Localization

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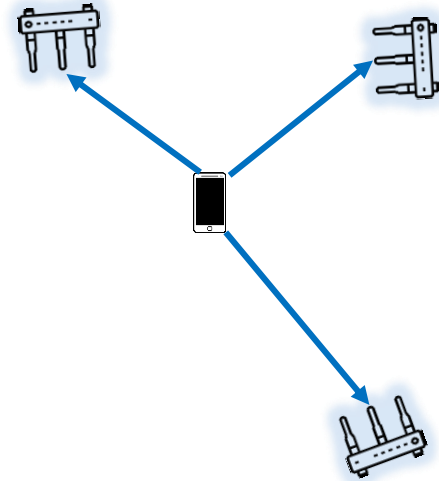
Horus [MobiSys'05]

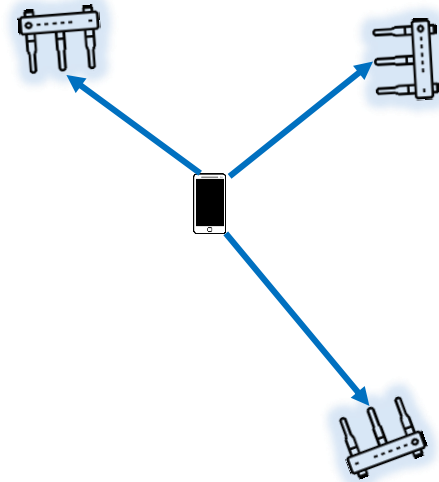RADAR [Infocomm'00]

RSSI

~10 meter accuracy

Localization

Indoor Navigation: Localization

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CSI
<1 meter accuracy

EZ [Mobicom'10]

Horus [MobiSys'05]

RADAR [Infocomm'00]

RSSI
∼10 meter accuracy
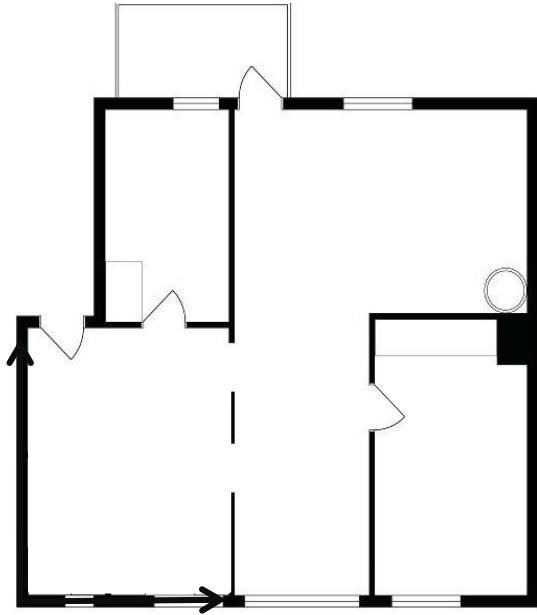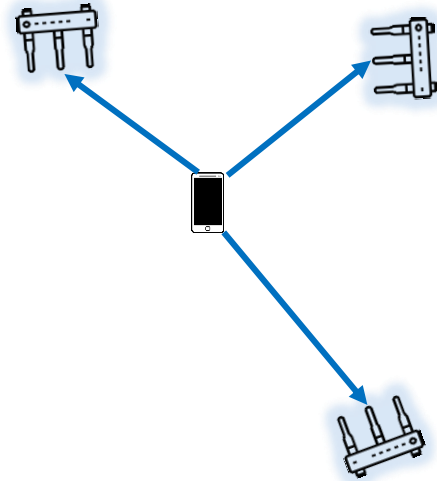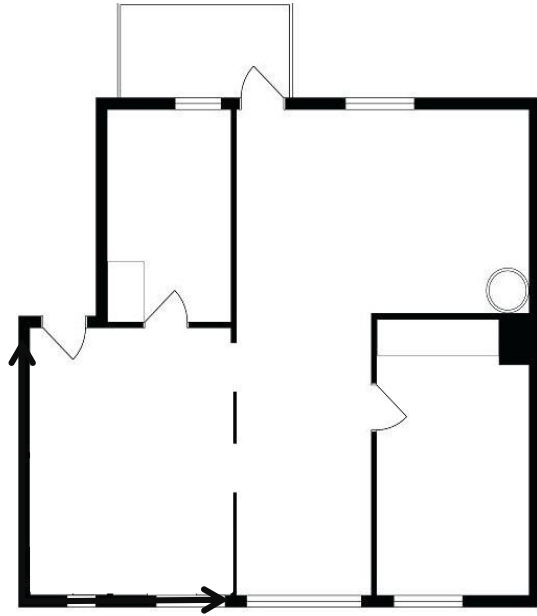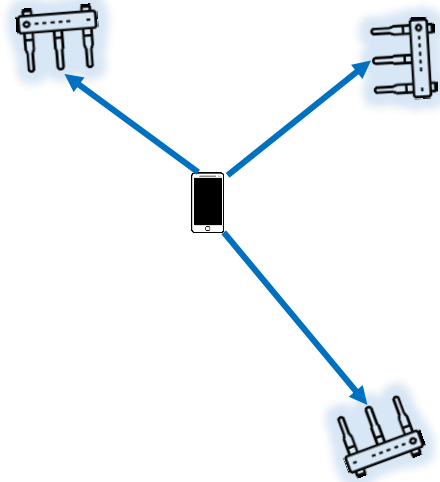
Localization

Indoor Navigation: What is missing?

Mapping

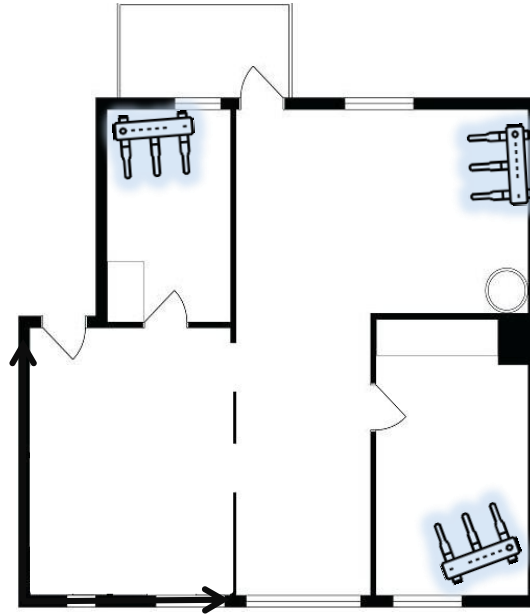Localization

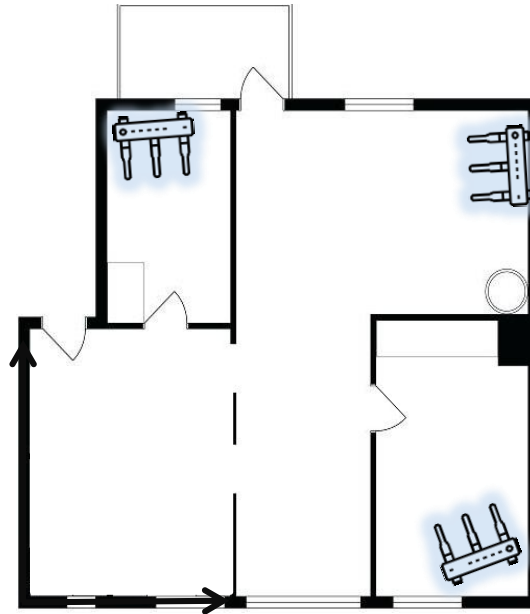# Indoor Navigation: What is missing?

Mapping

Localization

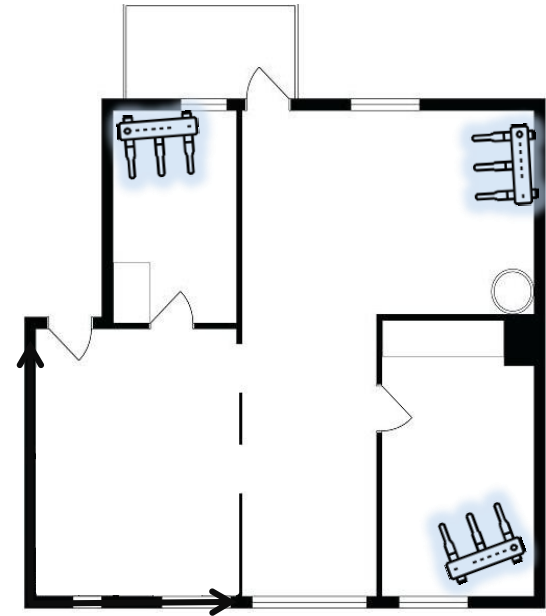# Indoor Navigation: What is missing?

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Anchor Locations are not accurately known in physical space
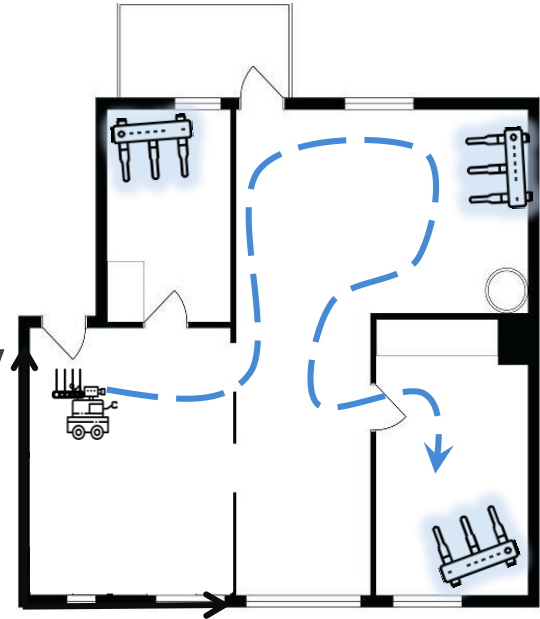
Contributions of LocAP: *Reverse Localization*

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❖ First to establish requirements for *Reverse Localizing* the anchor points
  ◦ Needs millimetre accurate reverse localization

❖ Developed a novel algorithm that accurately *reverse localizes* the anchor points

❖ Deployed it on an autonomous system

❖ Demonstrated it in a real world that performs 50x times better than state-of-the-art

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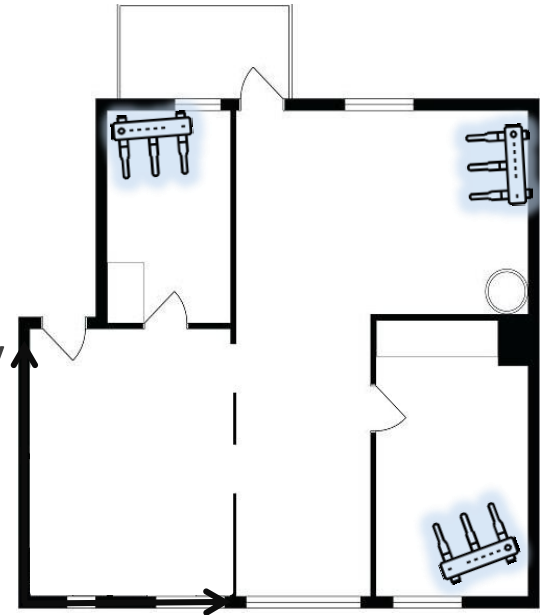
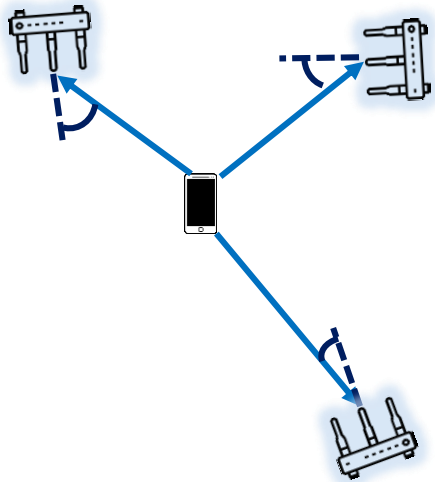❖ Demonstrated it in a real world that performs 50x times better than state-of-the-art
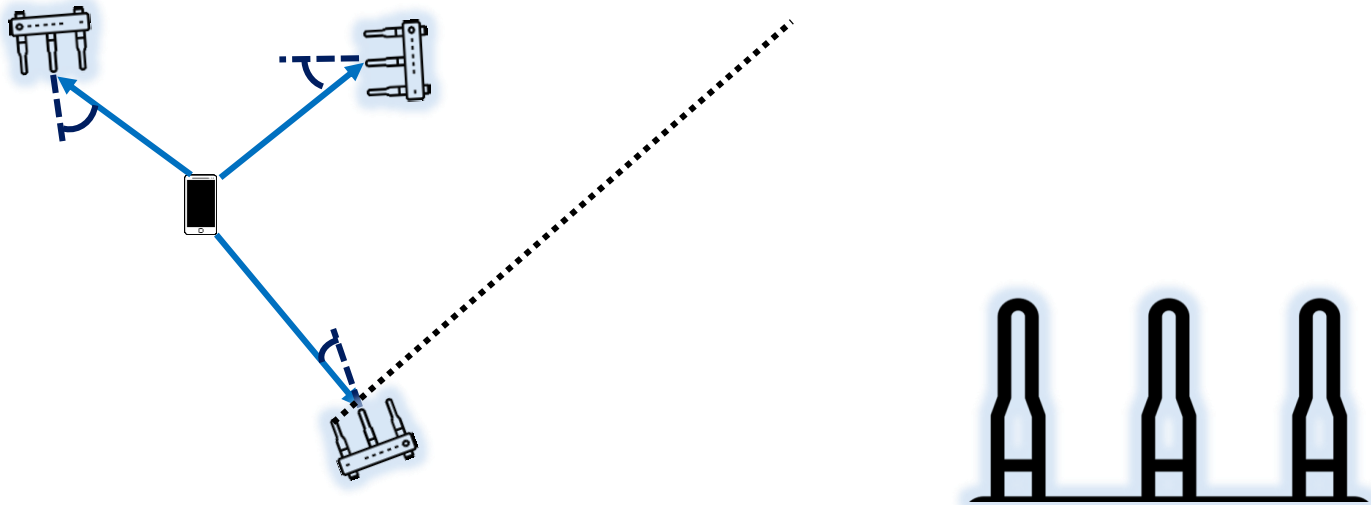
Primer: WiFi-based User Localization
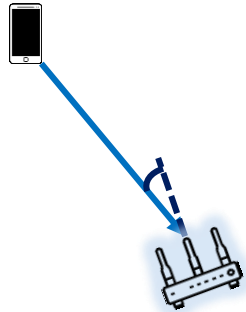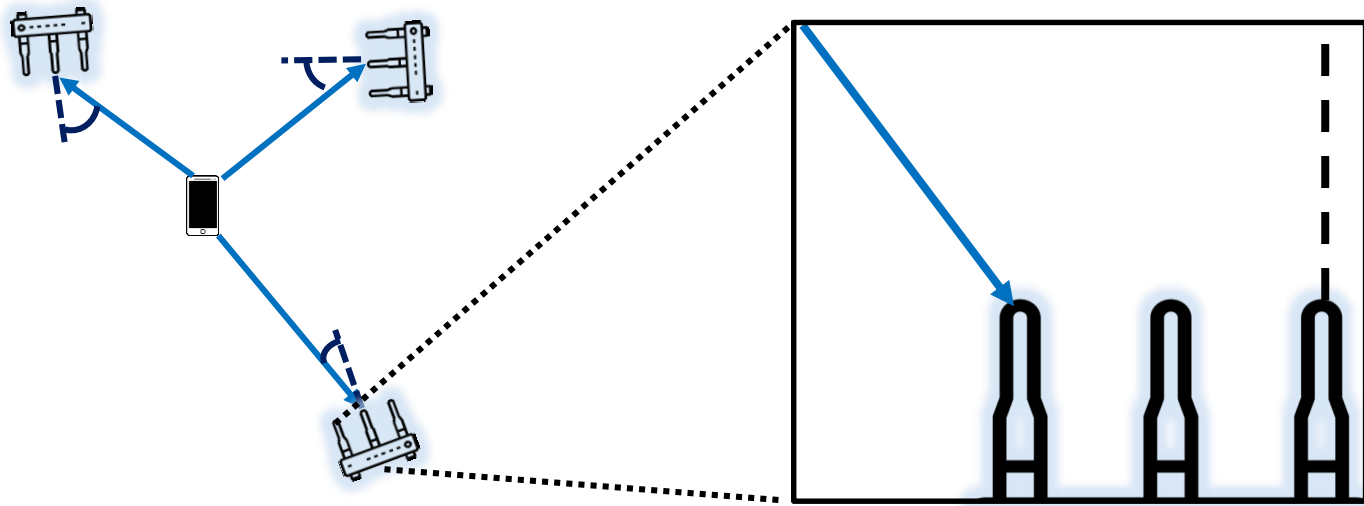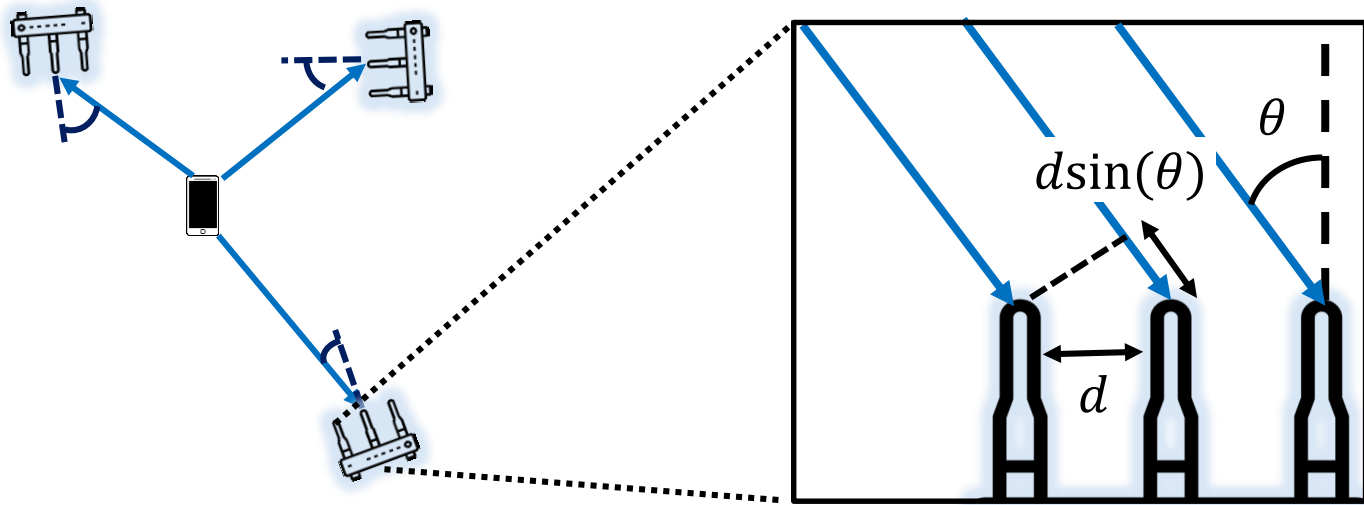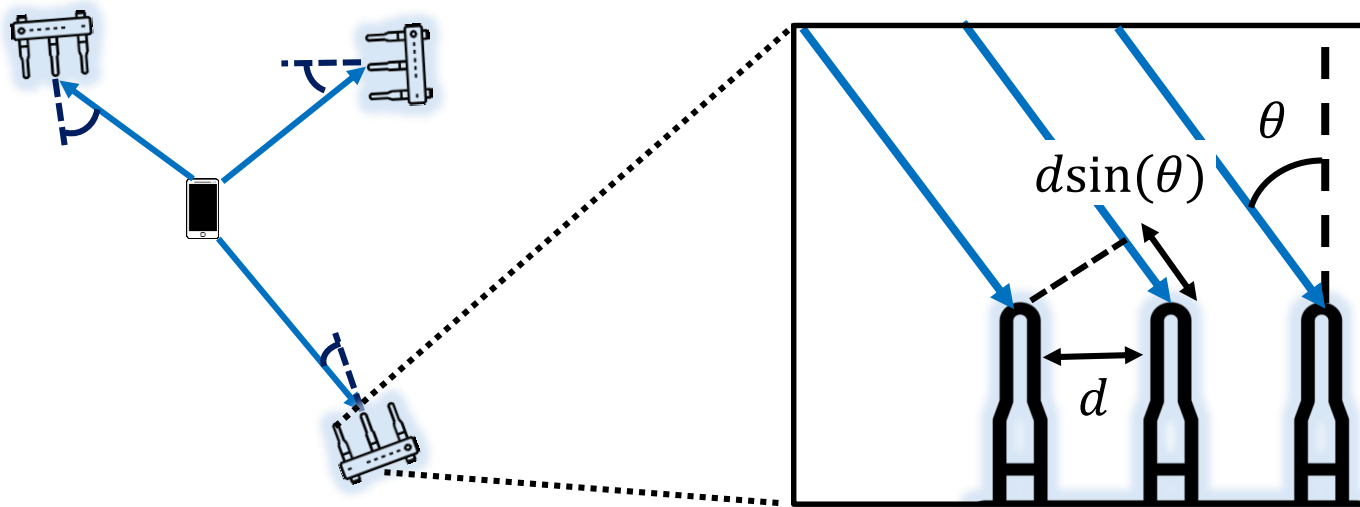
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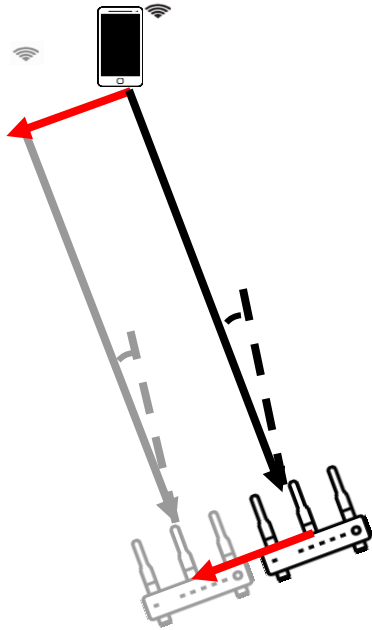
Primer: WiFi-based User Localization

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Primer: WiFi-based User Localization

$d\sin(\theta)$

θ

d

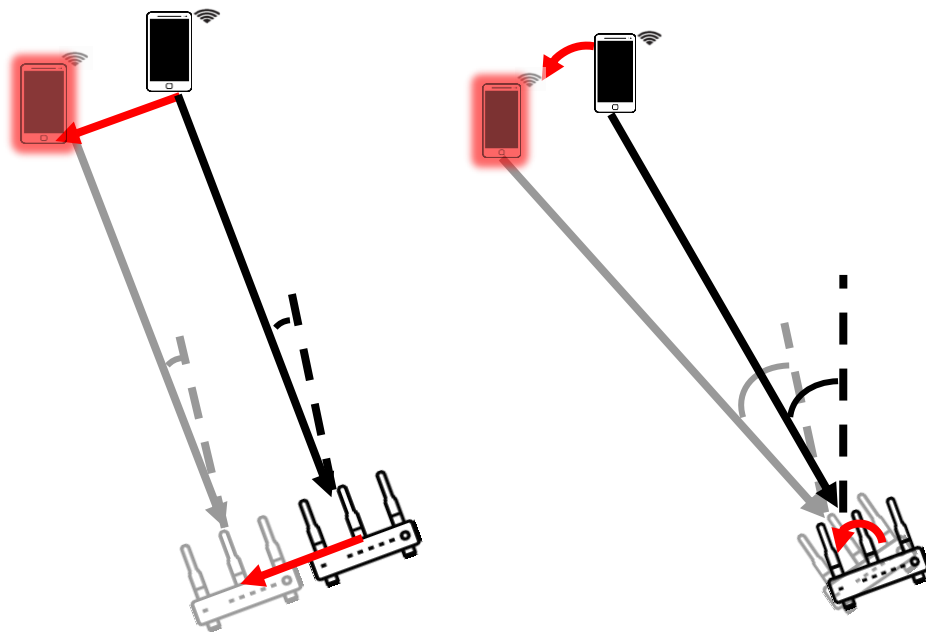What happens when there are errors in Anchor Attributes

Errors in Anchor Attributes mis-locates the User

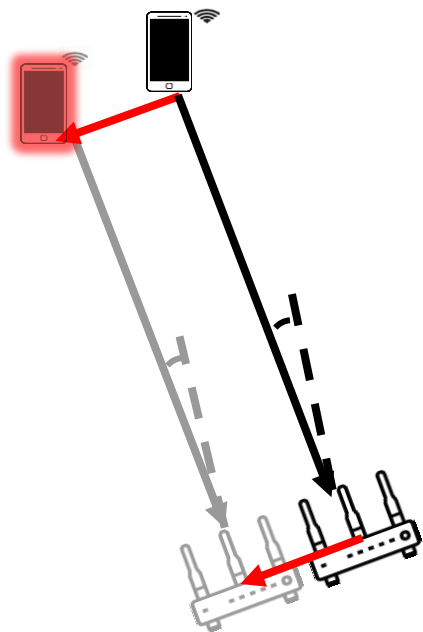# Errors in Anchor Attributes mis-locates the User

Location Error

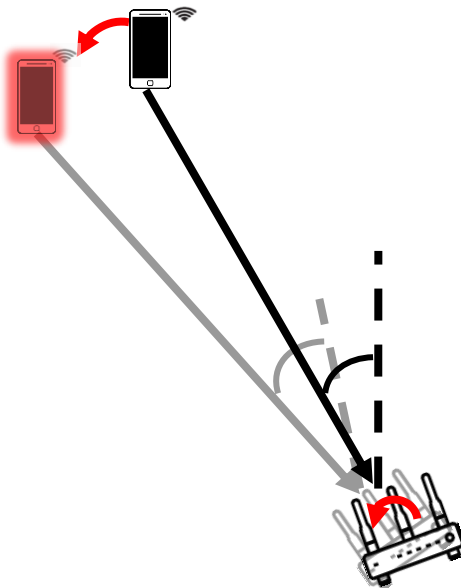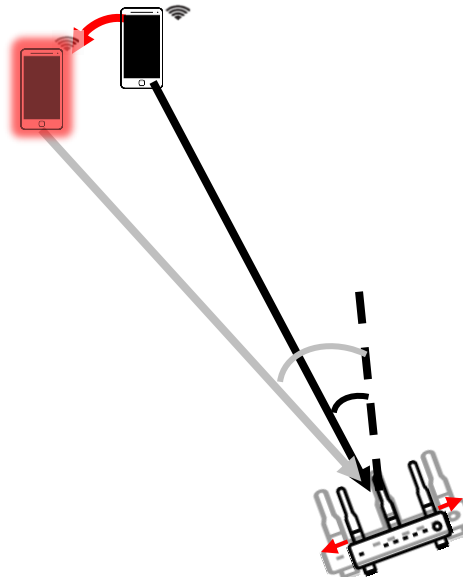# Errors in Anchor Attributes mis-locates the User

Location Error

Orientation Error

Errors in Anchor Attributes mis-locates the User

Location Error   Orientation Error   Antenna Spacing Error

WCSNG

Quantifying *Reverse Localization* Requirements

Requirement for Deployment Orientation

Requirement for Deployment Orientation

Requirement for Deployment Orientation

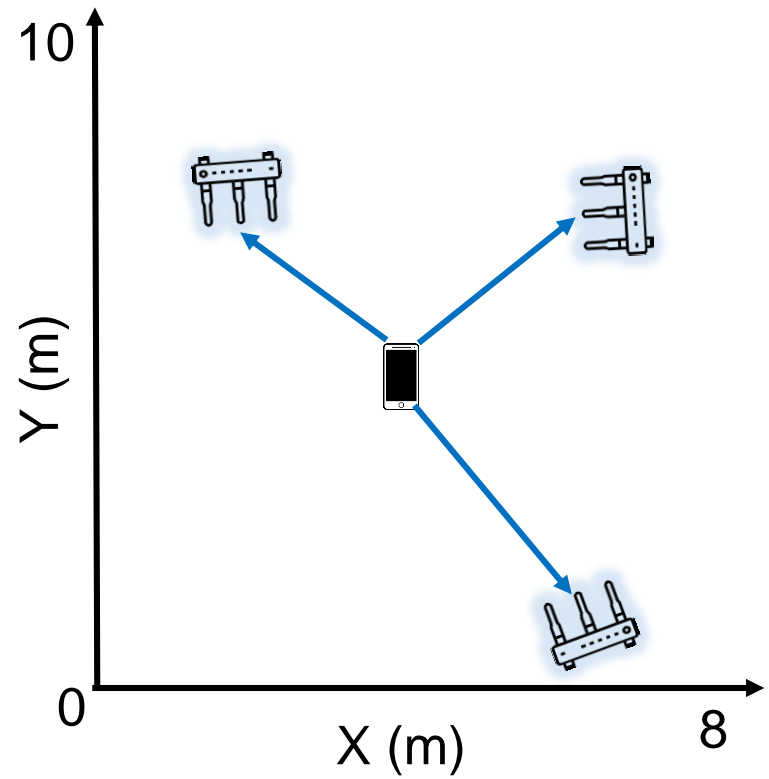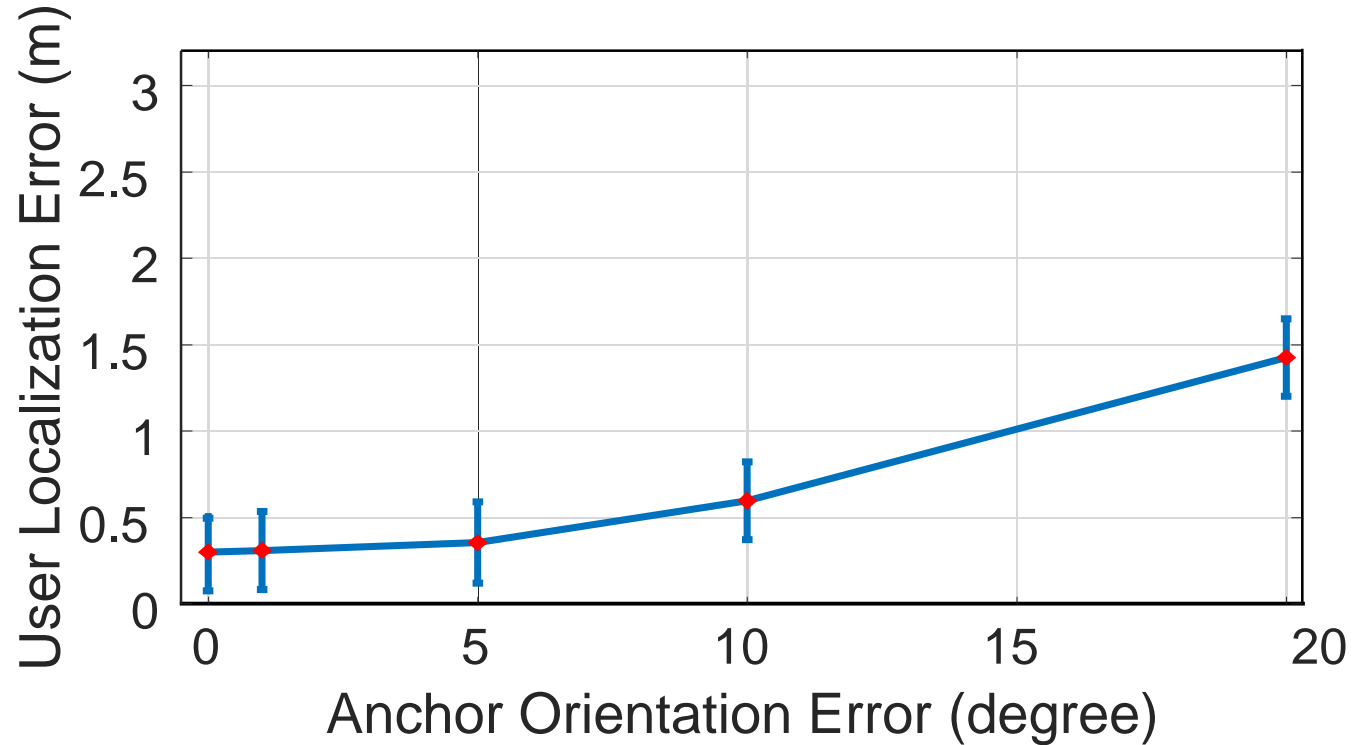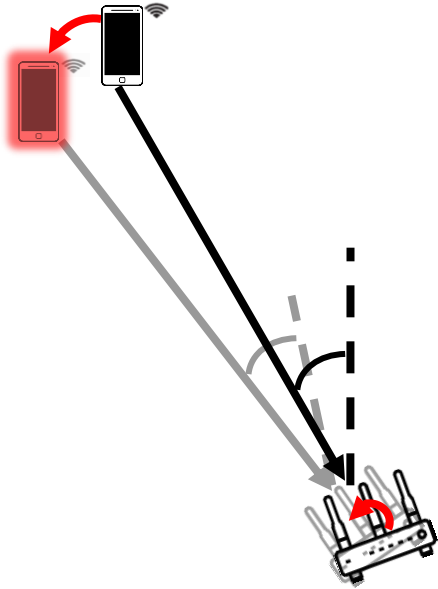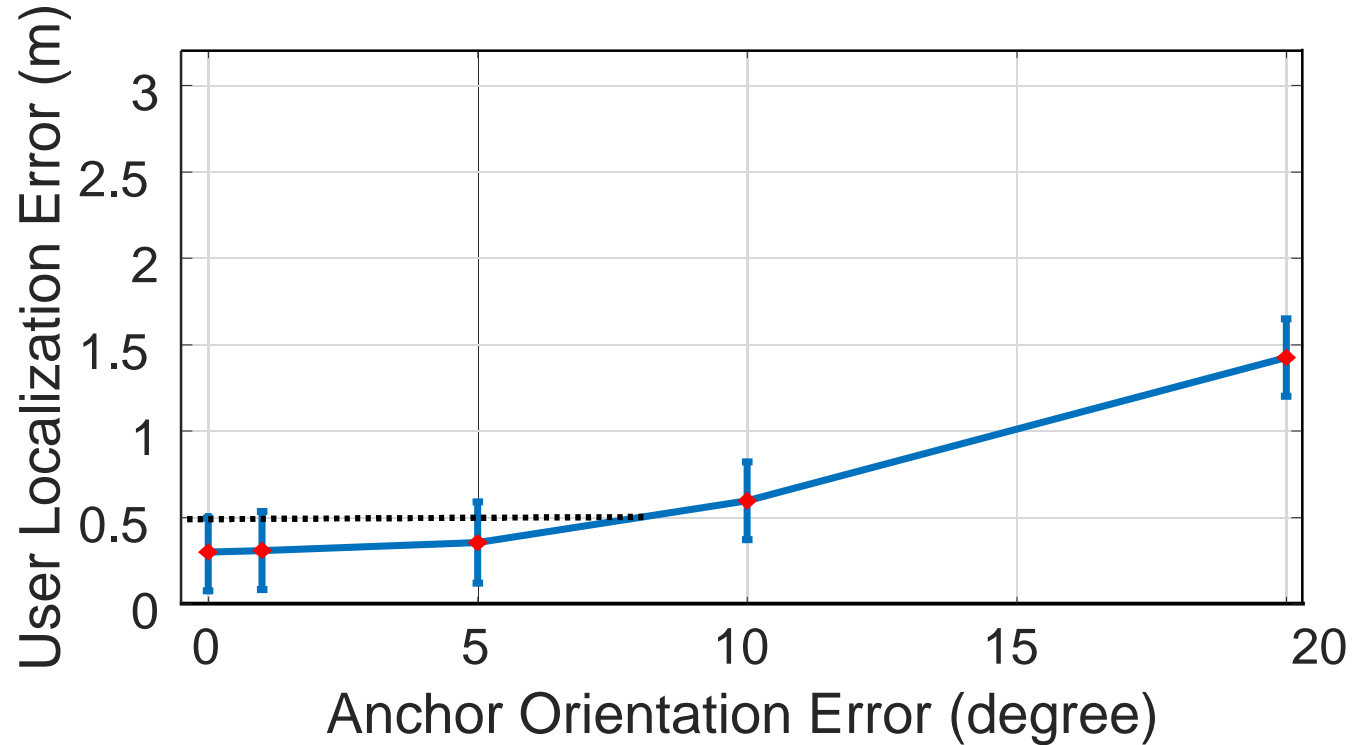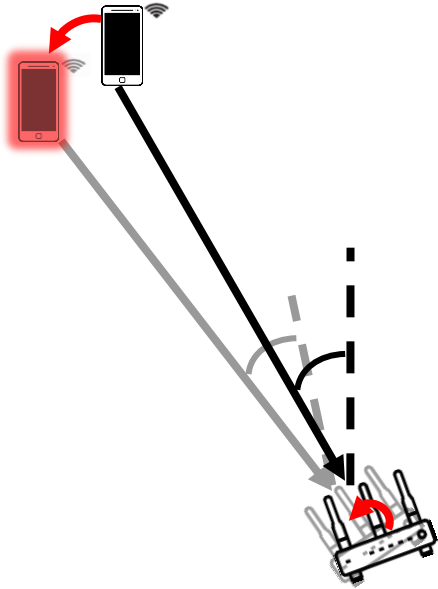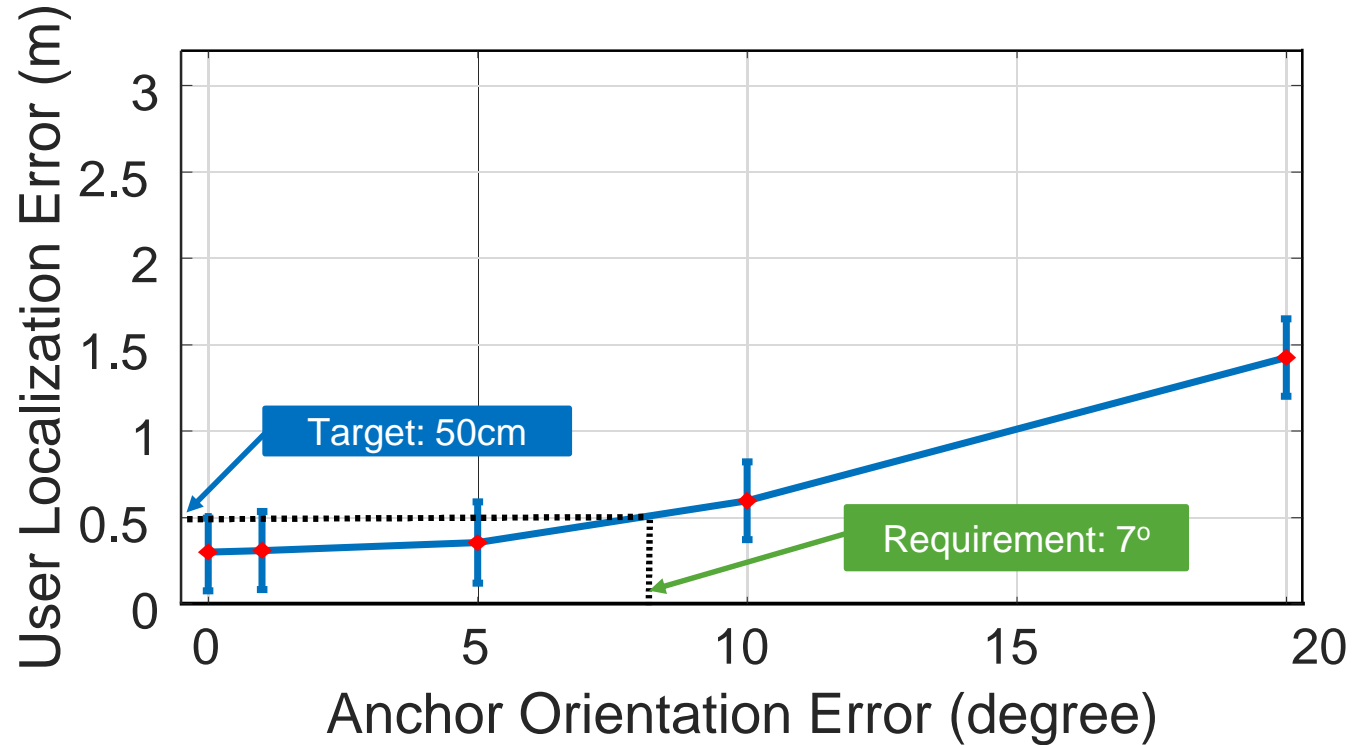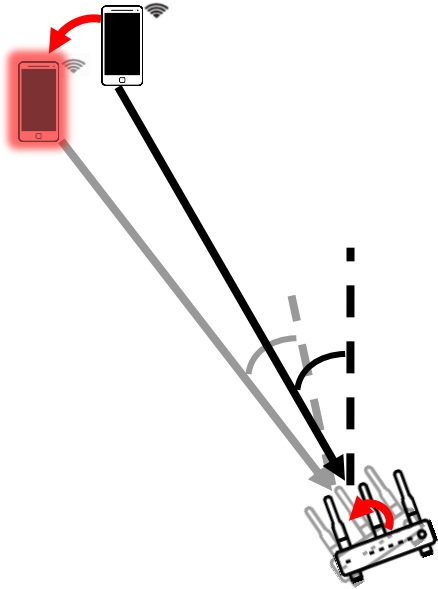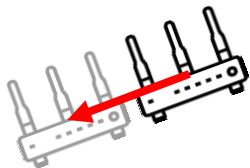# Stringent Requirements for *Reverse Localization*

❖ Requirement of median error →

Location Error
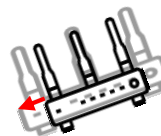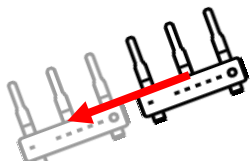

Orientation Error

Antenna Spacing Error

Stringent Requirements for *Reverse Localization*

❖ Requirement of median error →

<center>

< 25 cm   < 7°   < 5 mm

</center>
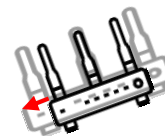
Millimeter requirements make manual mapping impossible

LocAP Deploys an Autonomous System
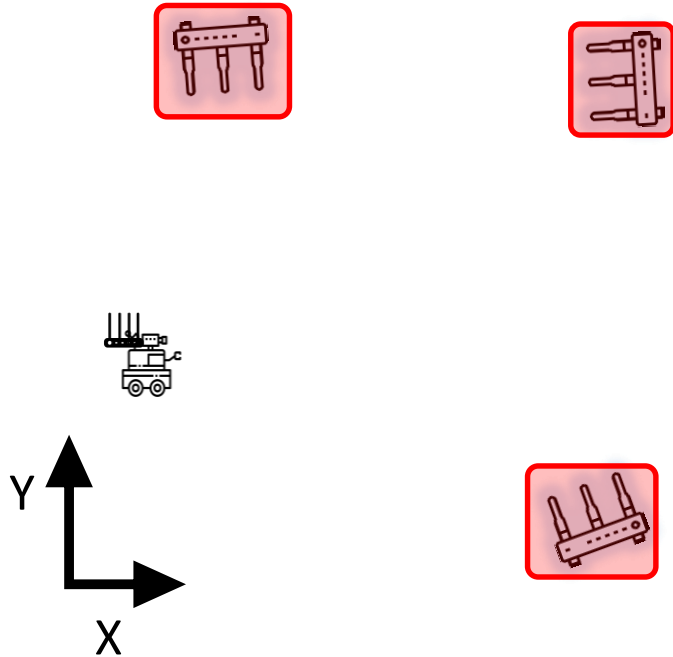
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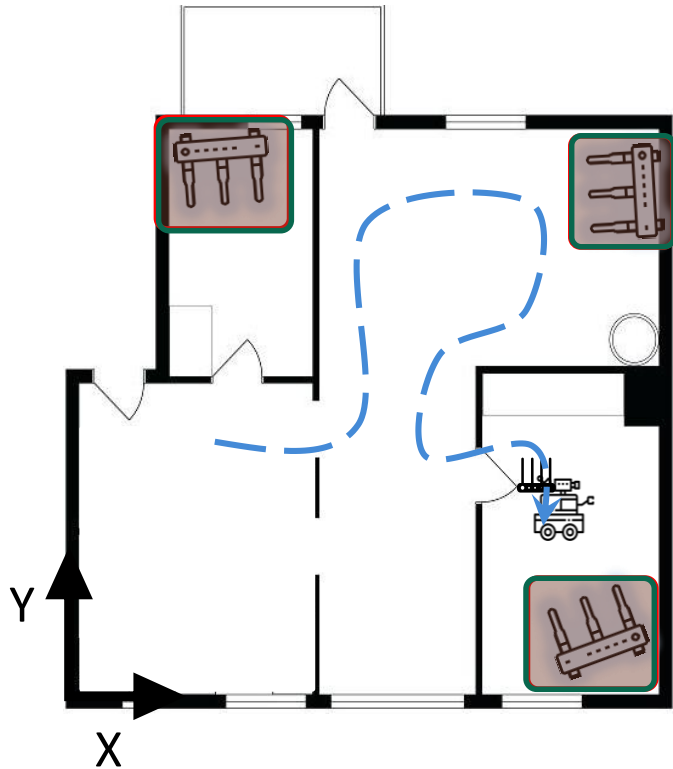
Anchor Localization

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❖ Locating Anchor is equivalent to Locating any one of the Antenna – *First Antenna*

❖ Existing User Localization algorithms applied in reverse

❖ 100s of bot locations to triangulate the *First Antenna*

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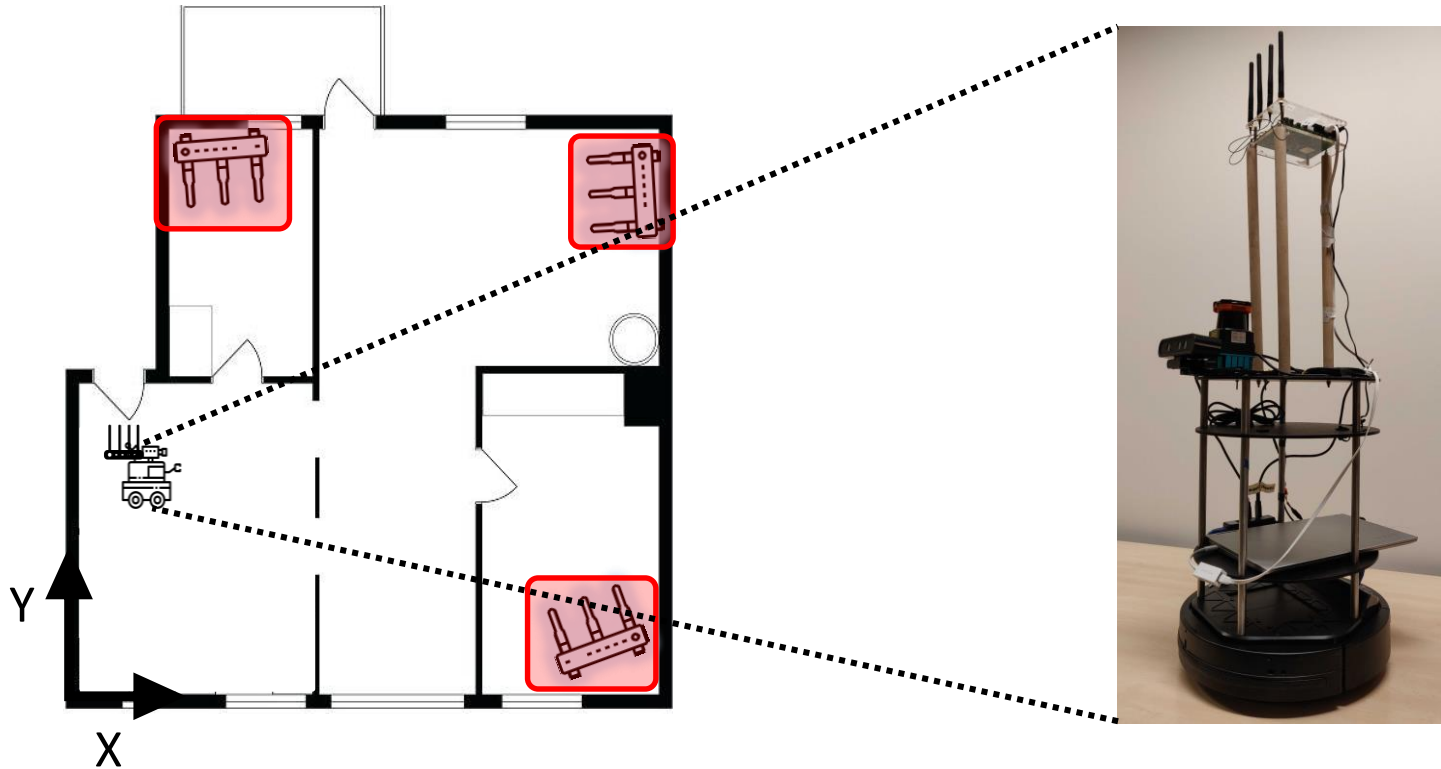
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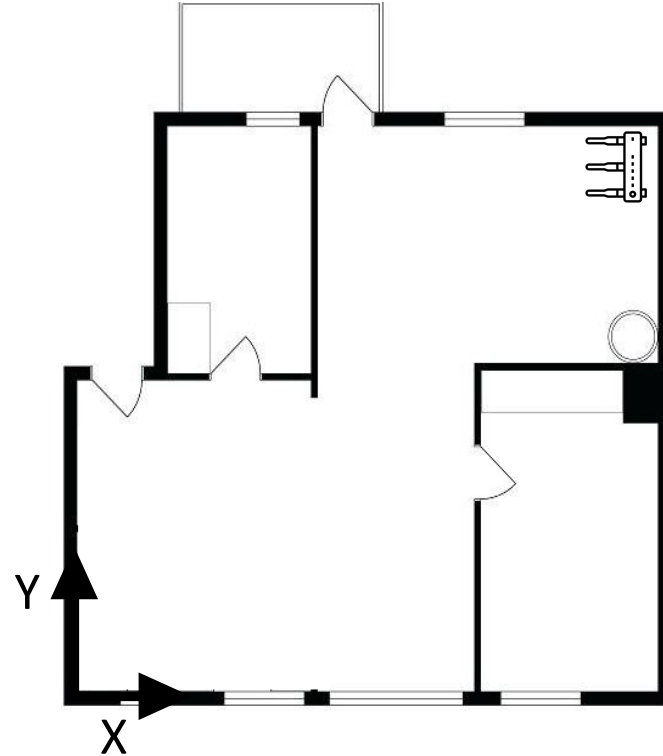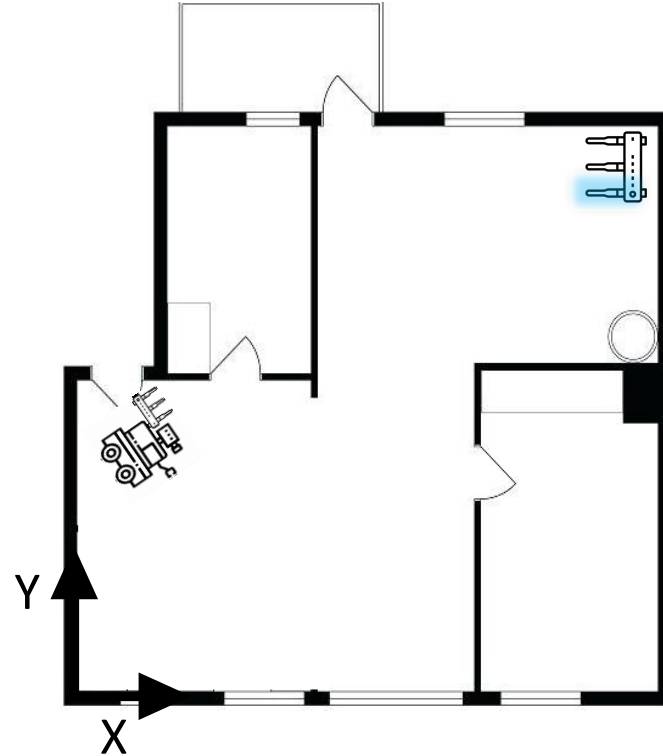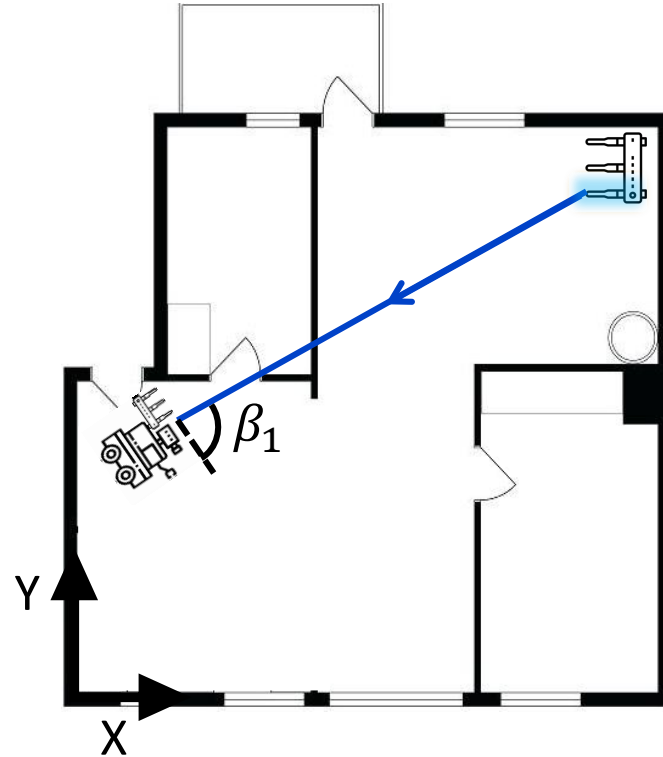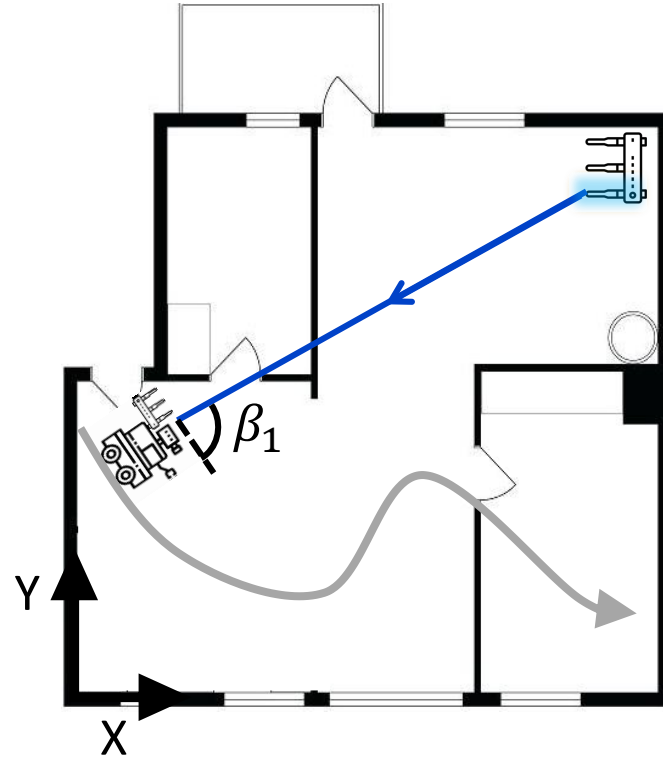
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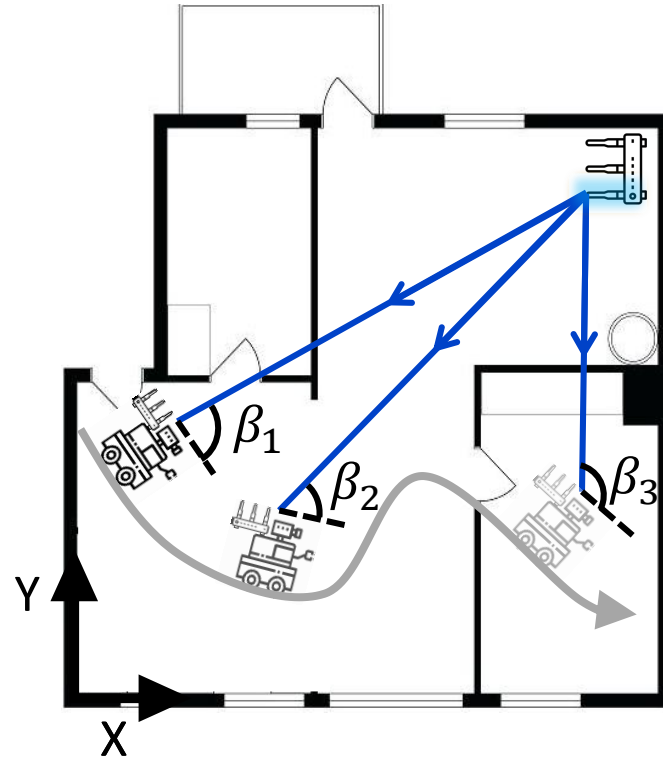❖ 100s of bot locations to triangulate the *First Antenna*

Anchor Localization: Handling Bot Errors

❖ A few bot locations can be erroneous

❖ We propose a novel Visual Sensors based *Confidence Metric*
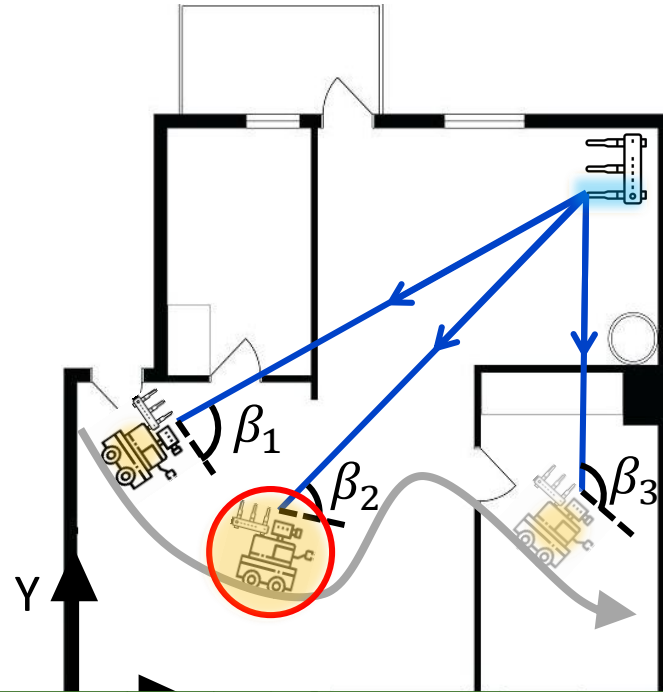
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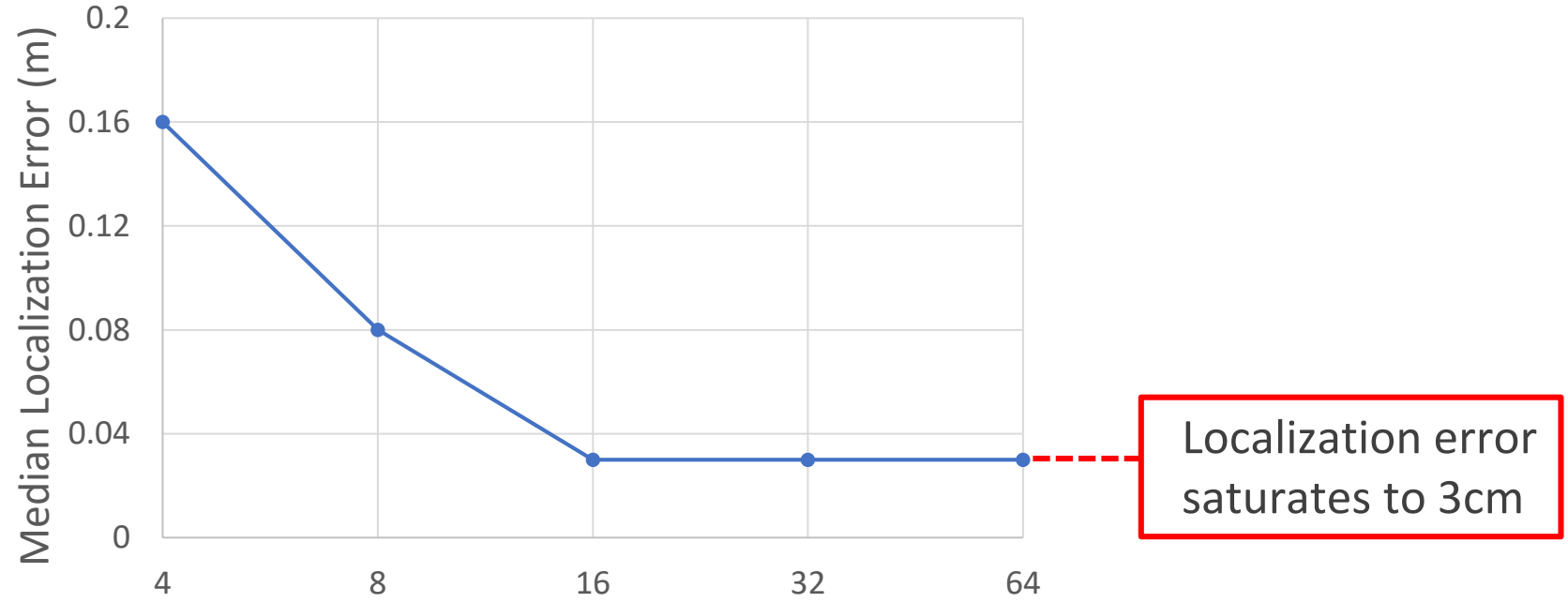❖ We neglect Locations with less *Confidence*

Achieved cm-accurate anchor locations

Can we locate each antenna in a similar way?

Can we locate each antenna in a similar way?

Can we locate each antenna in a similar way?

Localization error saturates to 3cm
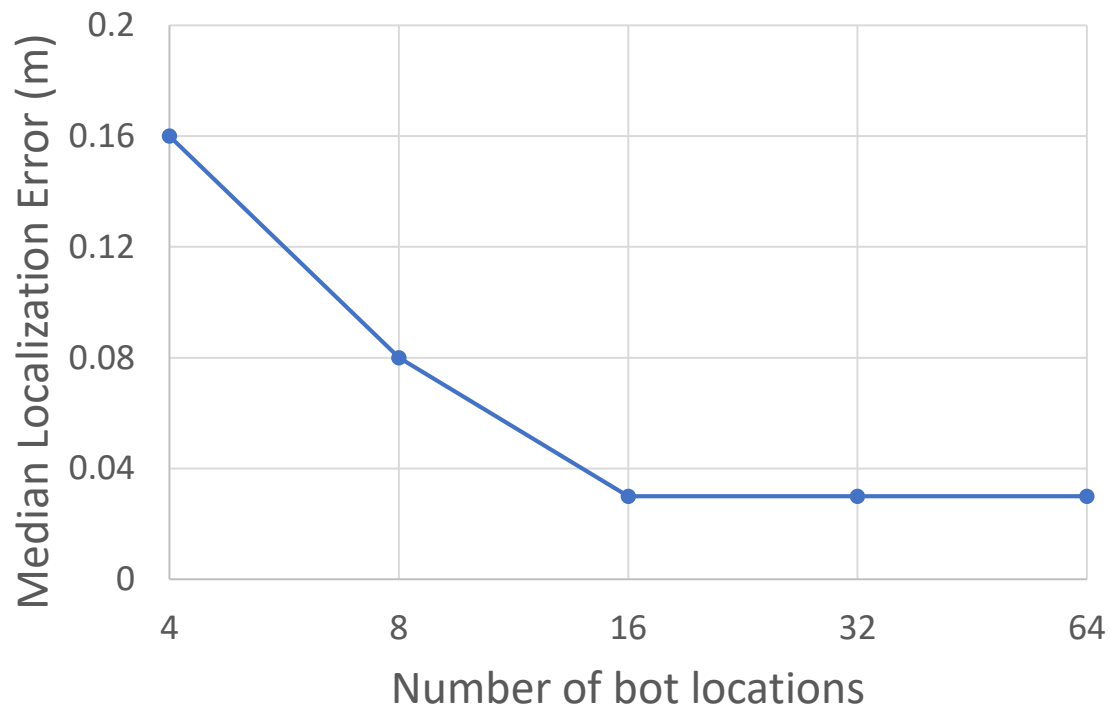
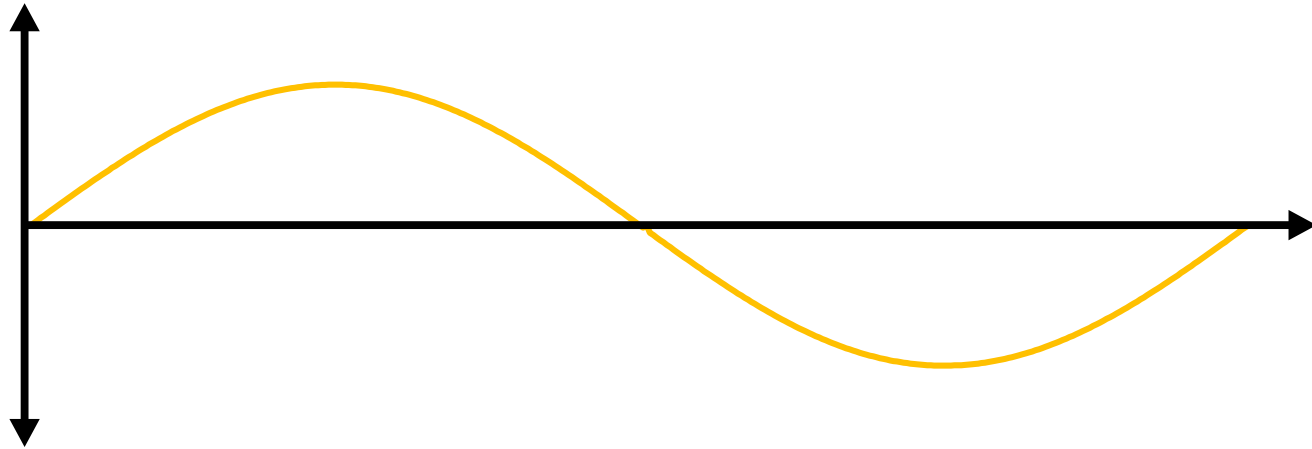Does not meet mm-accurate requirement for antenna separation

How to bridge this gap?

How to bridge this gap?

❖ Maximum Bandwidth of WiFi is 160MHz = ~2 meter resolution

❖ First key insight of LocAP is that the carrier frequency f_c of these signals is 5GHz ~mm accurate resolution

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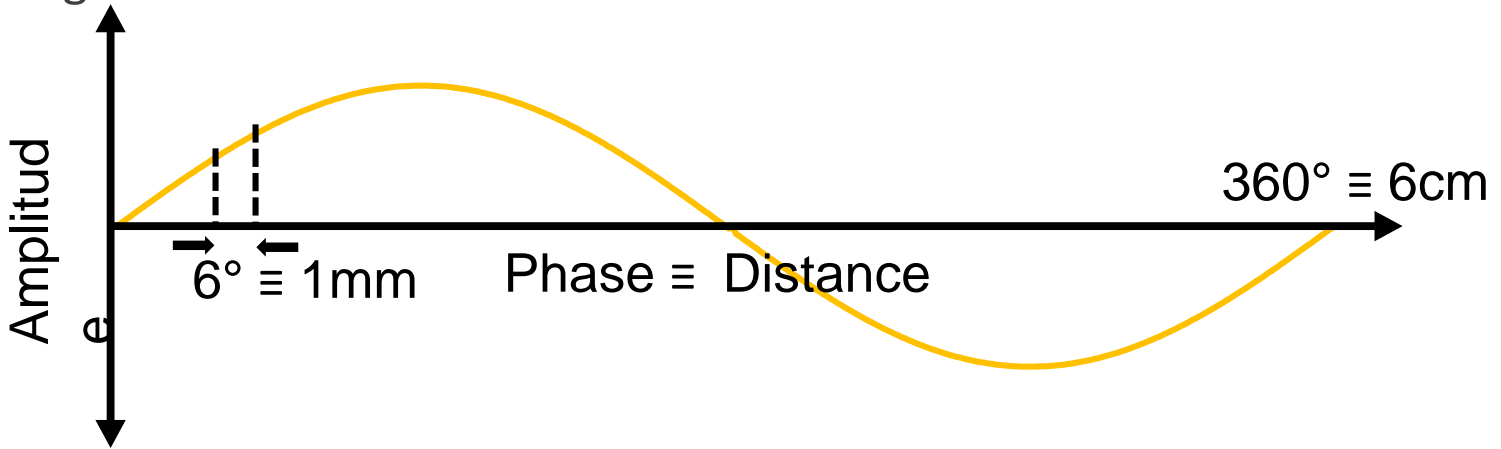❖ First key insight of LocAP is that the carrier frequency f_c of these signals is 5GHz ∼mm accurate resolution
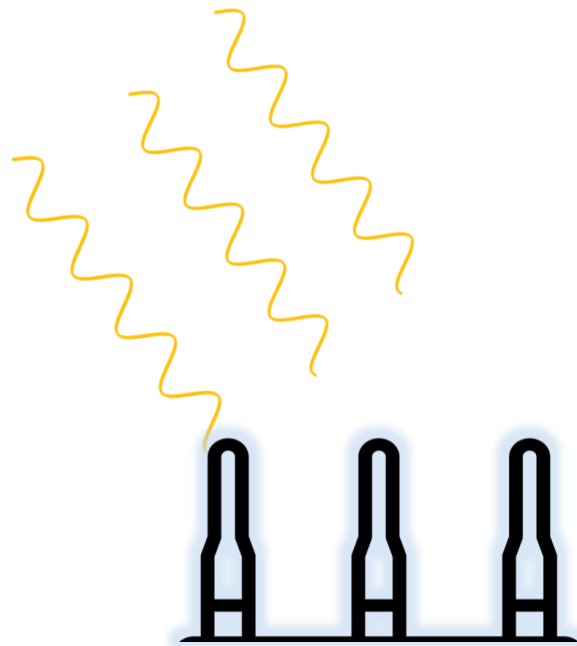
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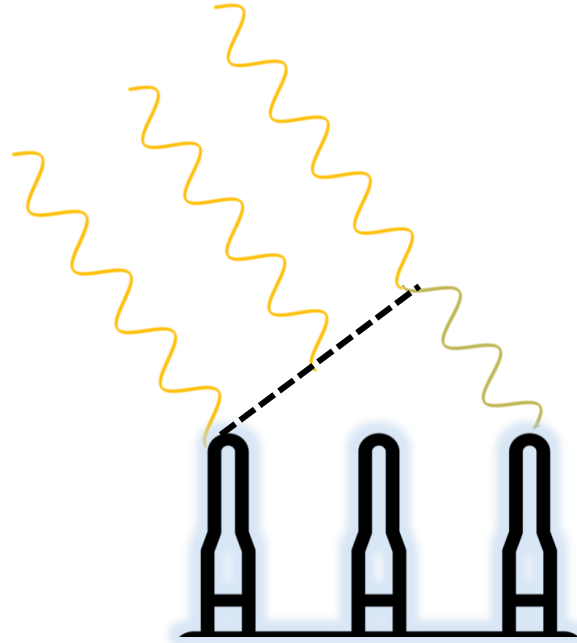

360° ≡ 6cm

6° ≡ 1mm   Phase ≡ Distance
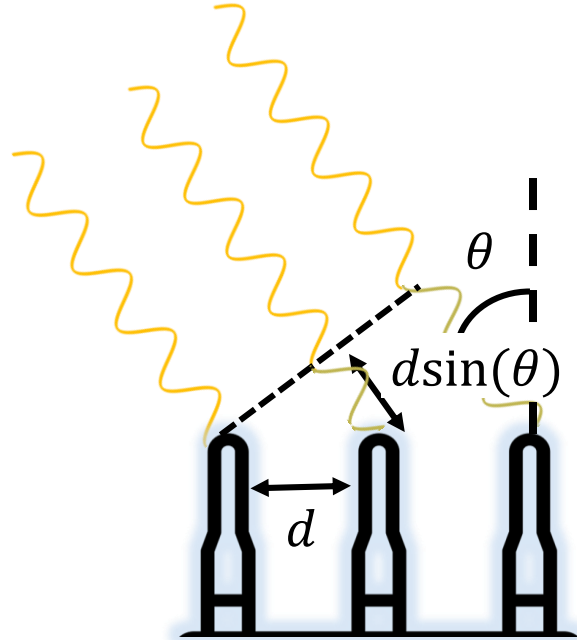
Amplitude

Phase Difference at f_c

Phase Difference at f_c

Phase Difference at f_c
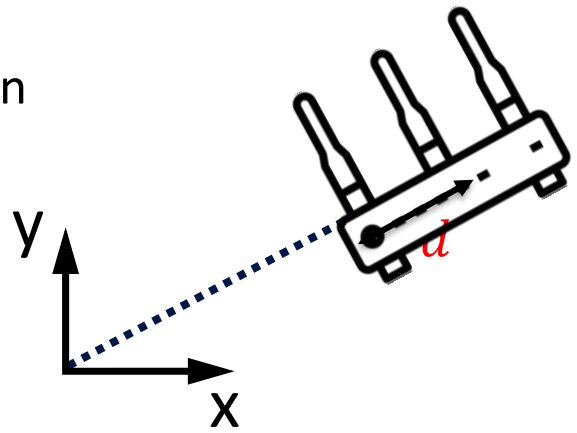
Phase Difference at f_c
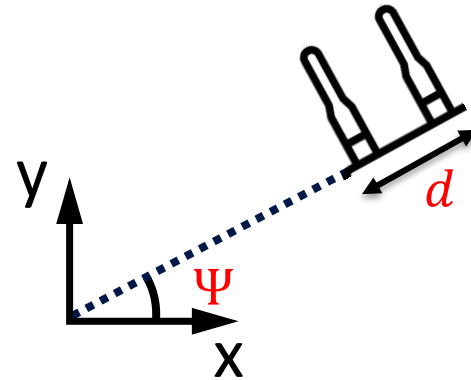

Relative antenna localization can achieve millimeter accuracy

Relative Antenna Localization: LocAP

❖ LocAP locates the rest of anchor's antenna relative to *First Antenna*

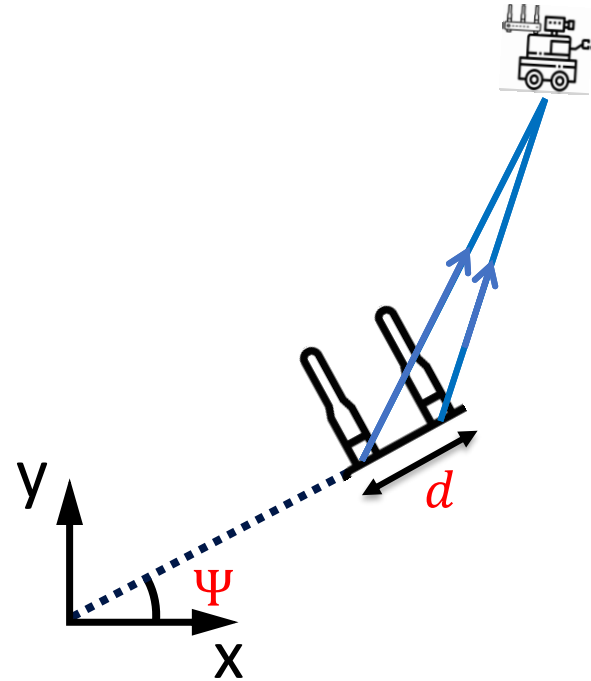❖ Estimate $\begin{cases} d = \text{Antenna Separation} \\ \Psi = \text{Deployment Orientation} \end{cases}$

Relative Antenna Localization: LocAP

Relative Antenna Localization: LocAP

❖ Leverage phase difference across two antennas

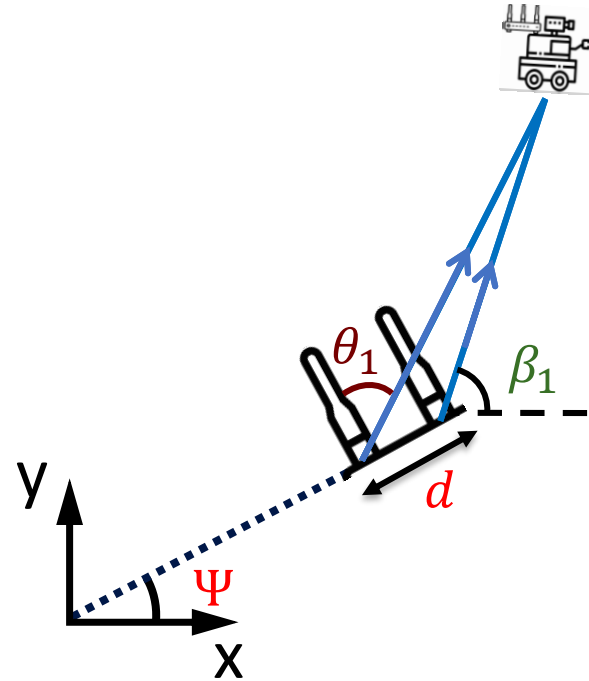❖ Recall, we measured direction of *First Antenna* from the bot (β_1)

Relative Antenna Localization: LocAP

❖ Leverage phase difference across two antennas

$$\Delta \emptyset = \frac{2\pi}{\lambda} d \sin(\theta_1)$$

❖ Recall, we measured direction of *First Antenna* from the bot (β_1)
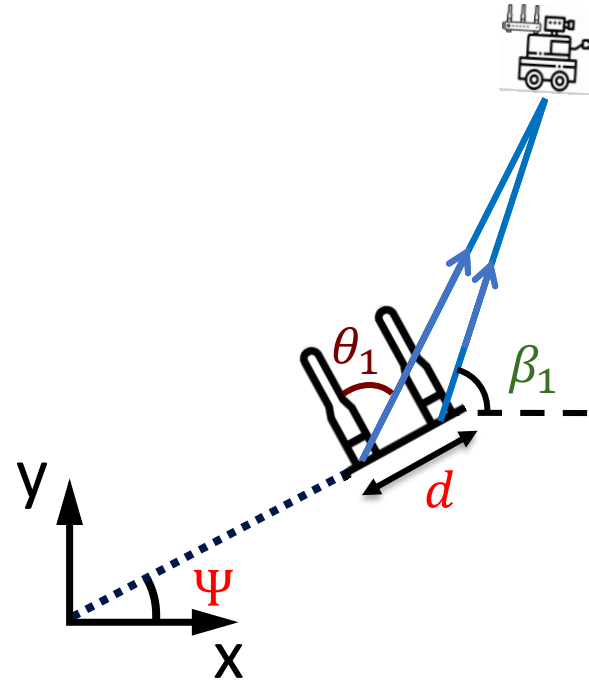
Relative Antenna Localization: LocAP

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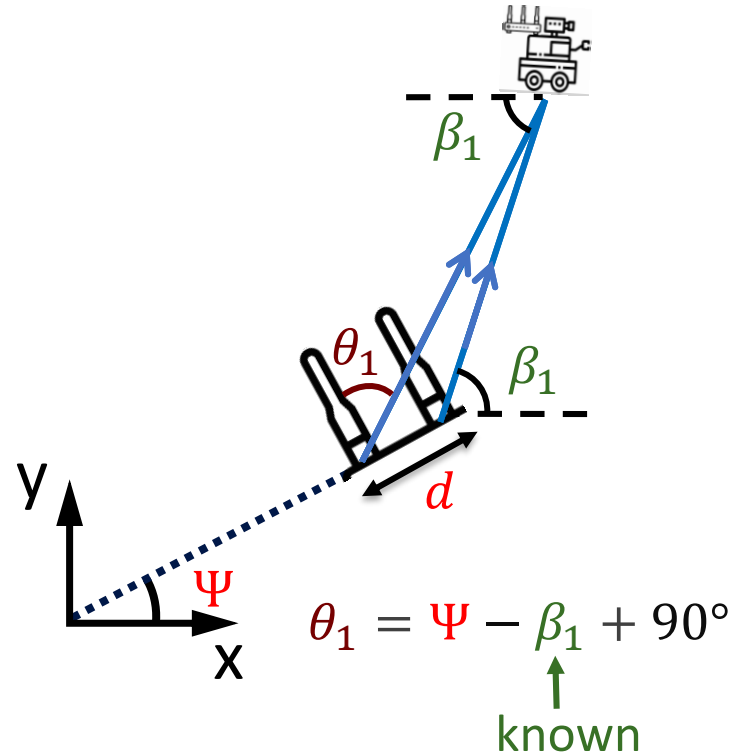❖ Recall, we measured direction of *First Antenna* from the bot (β_1)
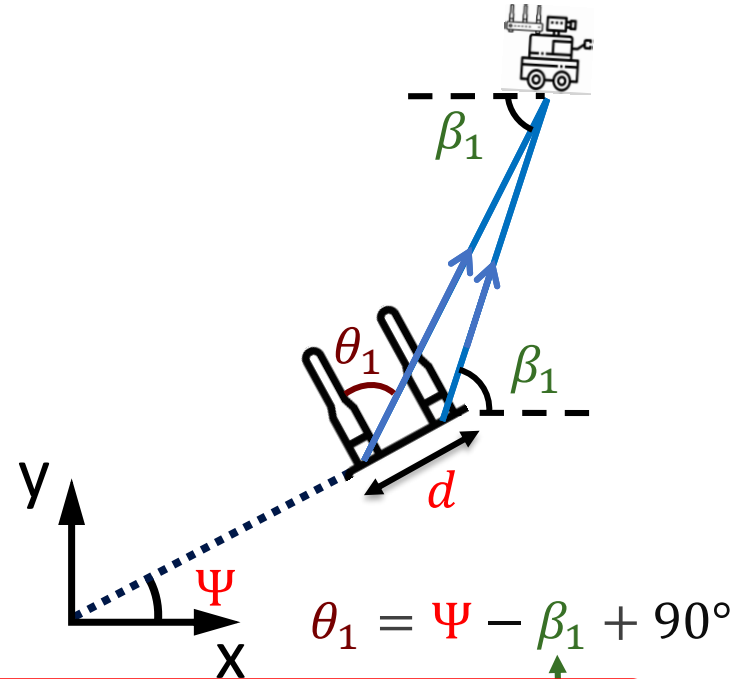
Relative Antenna Localization: LocAP

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❖ Recall, we measured direction of *First Antenna* from the bot (β_1)

$$\theta_1 \rightarrow \Psi$$

$$\theta_1 = \Psi - \beta_1 + 90°$$

known

Relative Antenna Localization: LocAP

❖ Leverage phase difference across two antennas

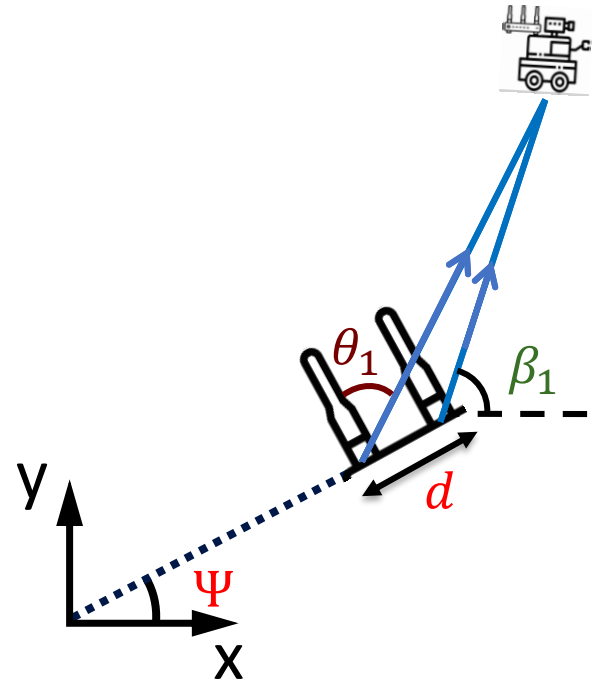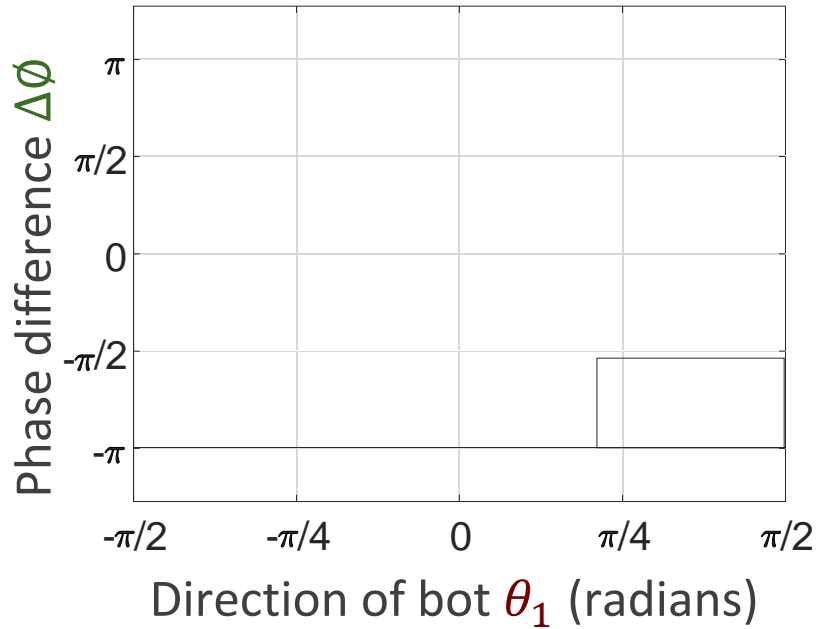$$\Delta\emptyset = \frac{2\pi}{\lambda} d \sin(\theta_1)$$

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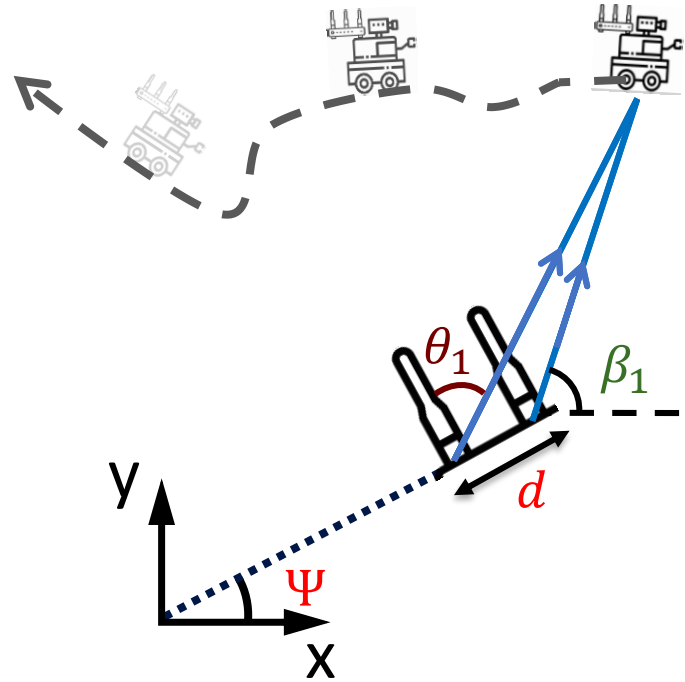
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Only one equation, but two unknowns (d, θ_1)

UC San Diego
JACOBS SCHOOL OF ENGINEERING
Electrical and Computer Engineering

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Leverage from 100s of bot locations

Phase difference $\Delta\phi$ (y-axis, from $-\pi$ to π) vs. Direction of bot θ_1 (radians) (x-axis, from $-\pi/2$ to $\pi/2$)
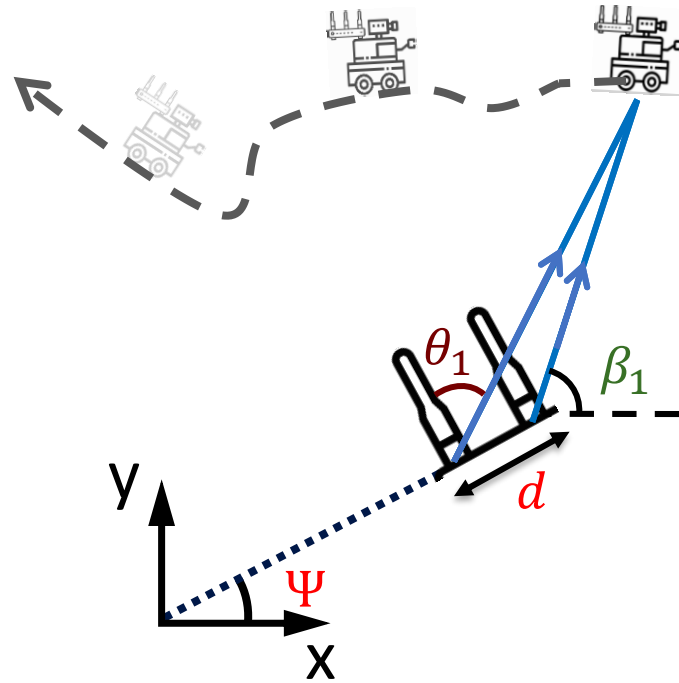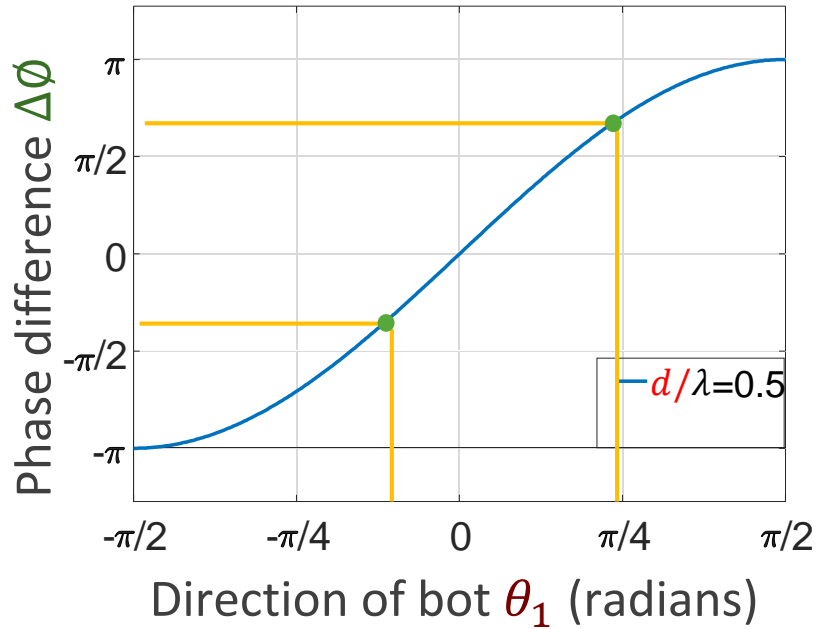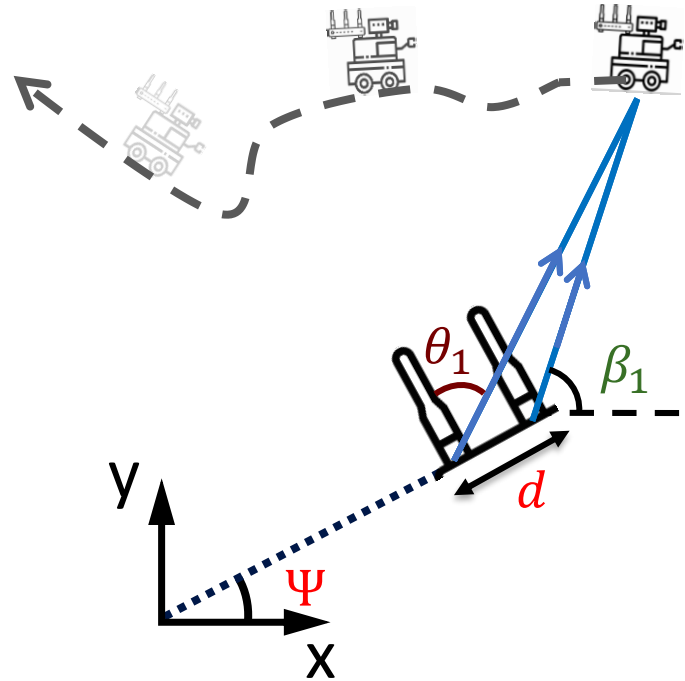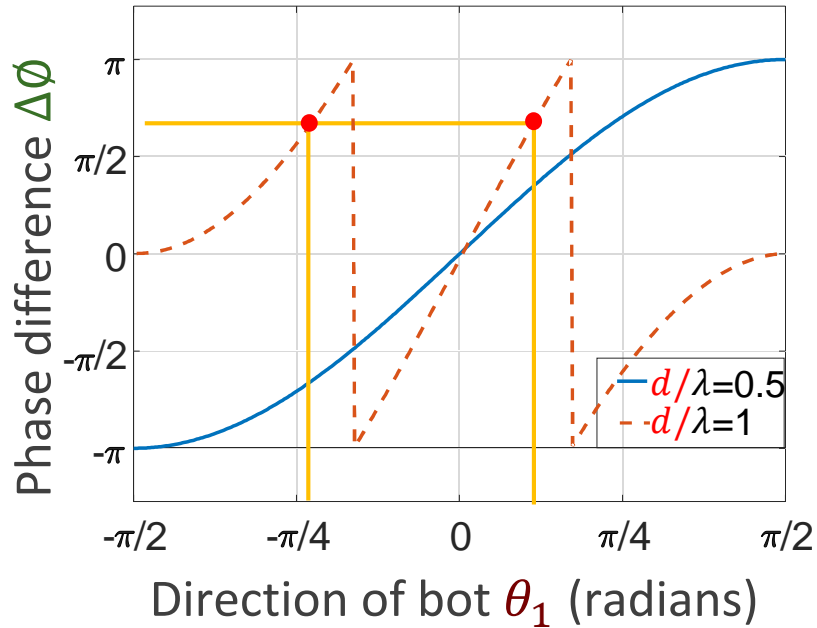
Leverage from 100s of bot locations
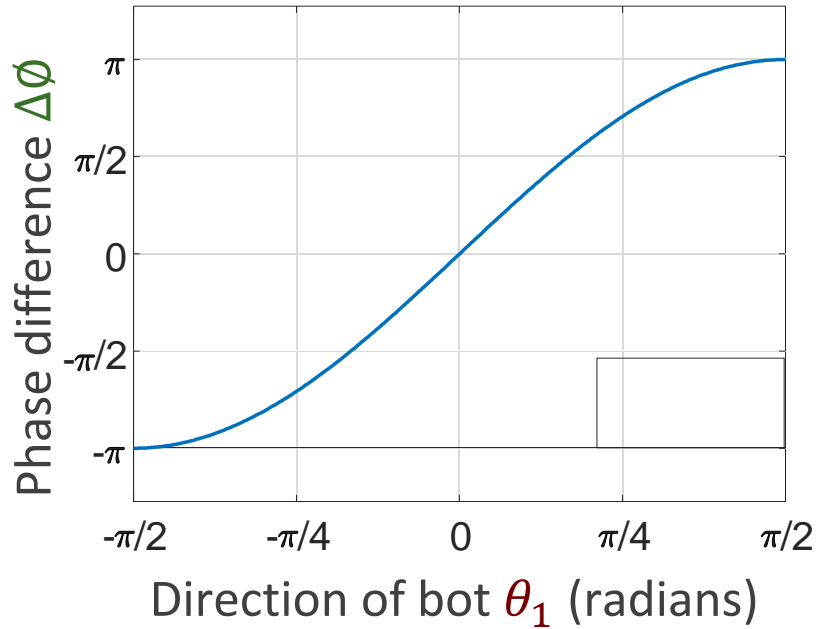
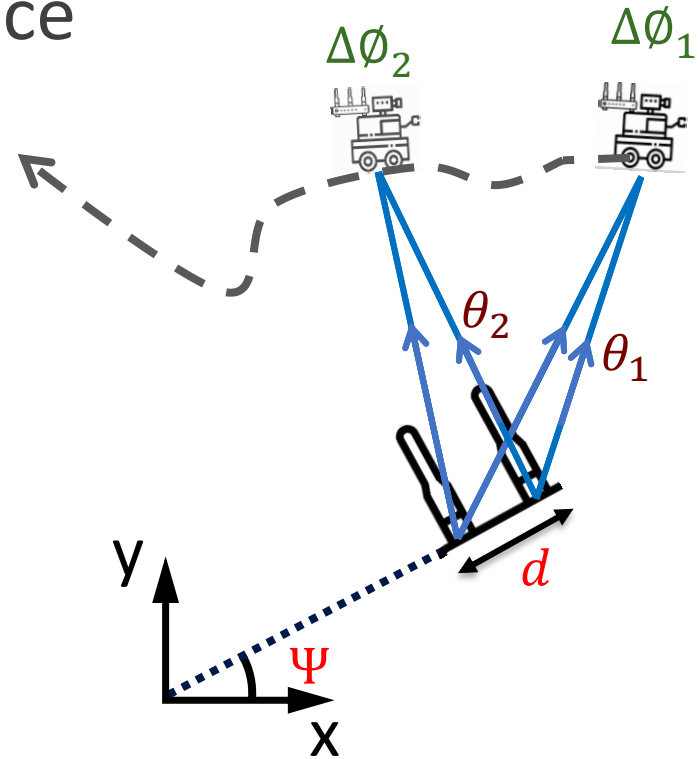# Leverage from 100s of bot locations

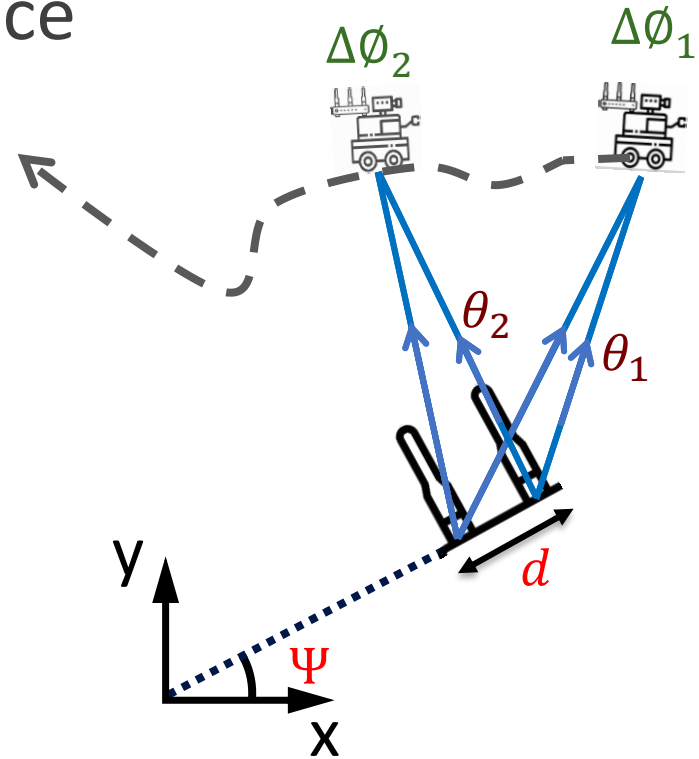# Leverage from 100s of bot locations

Differential Phase Difference

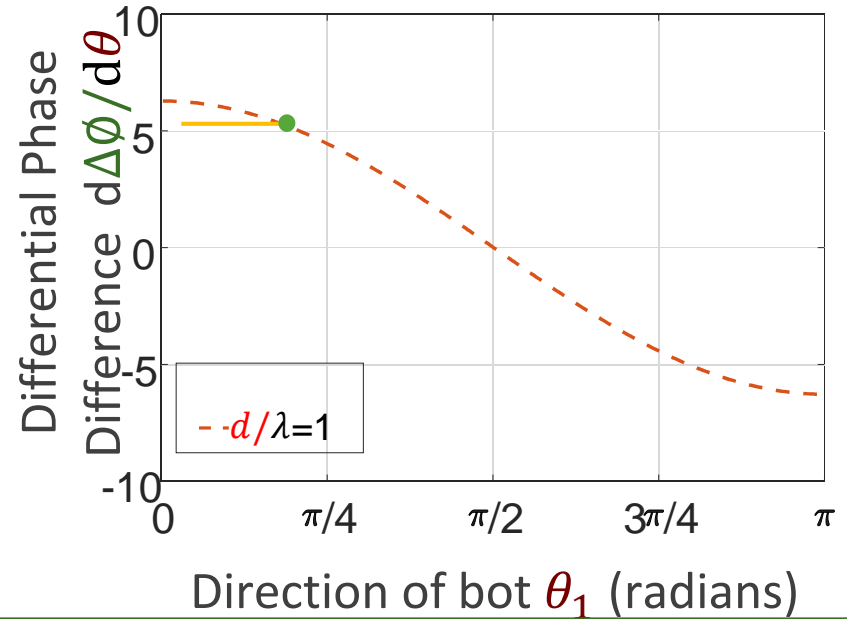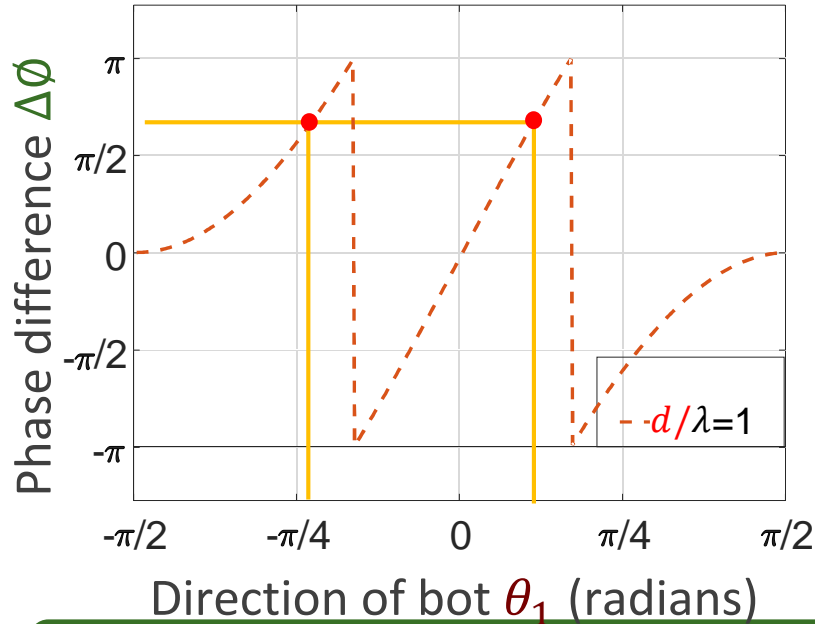❖ Differential Phase Difference from two nearby bot locations

Differential Phase Difference

❖ Differential Phase Difference from two nearby bot locations

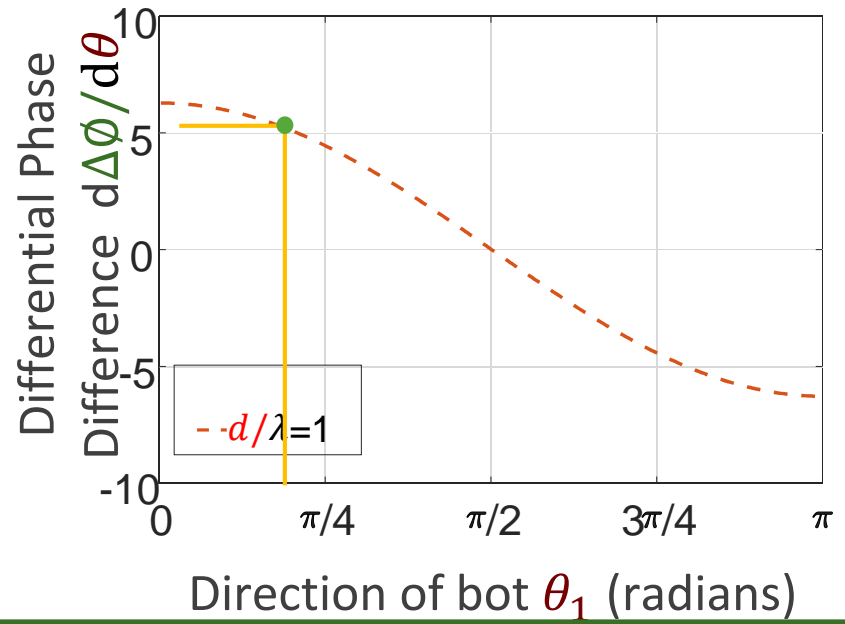$$\frac{d\Delta\emptyset}{d\theta} = \frac{\Delta\emptyset_2 - \Delta\emptyset_1}{\theta_2 - \theta_1}$$

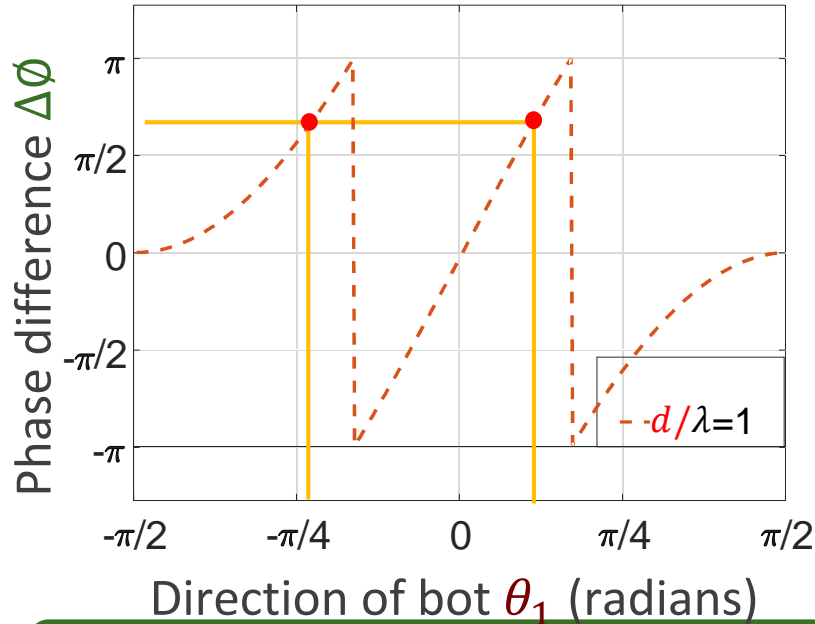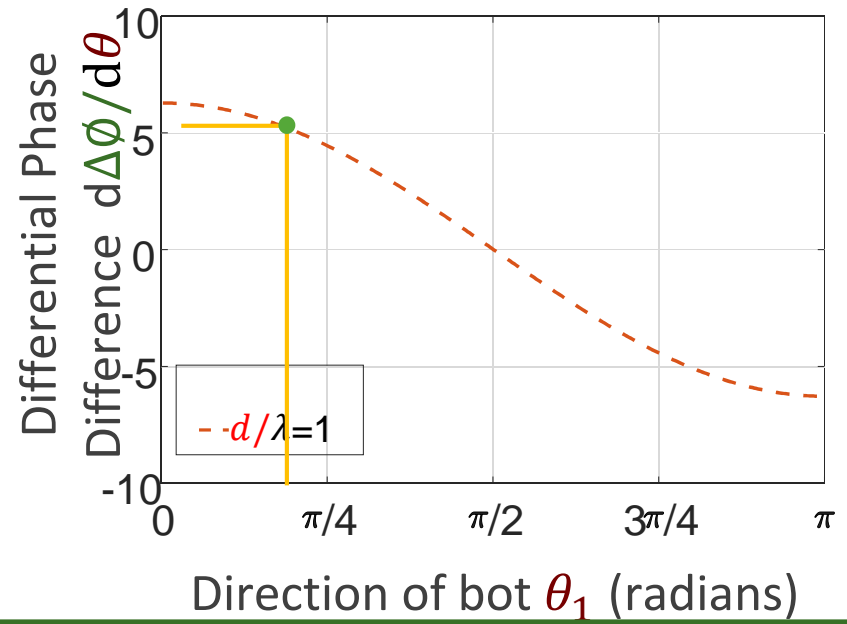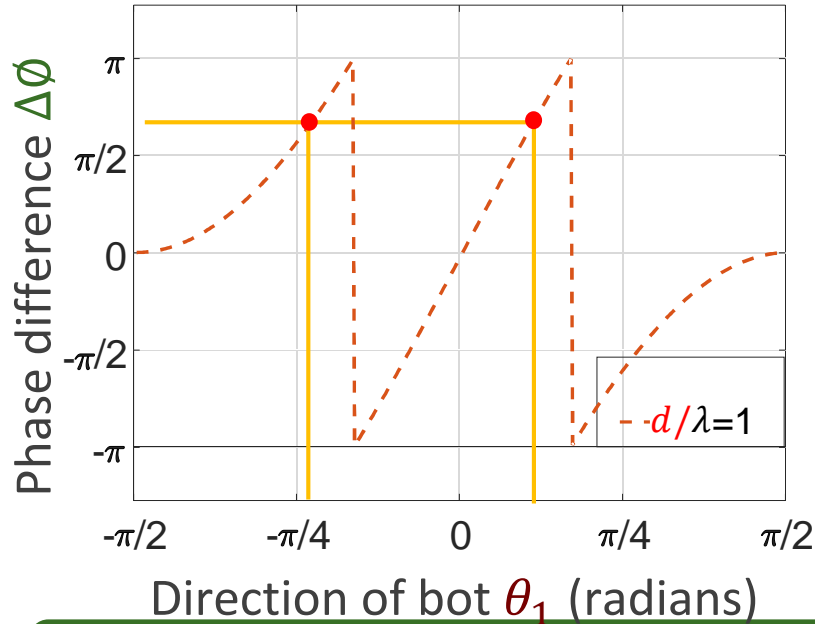# LocAP uses Differential Phase Difference

Achieves mm-accurate Antenna separation and $< 7°$ Orientation

LocAP uses Differential Phase Difference

Achieves mm-accurate Antenna separation and < 7° Orientation

LocAP uses Differential Phase Difference

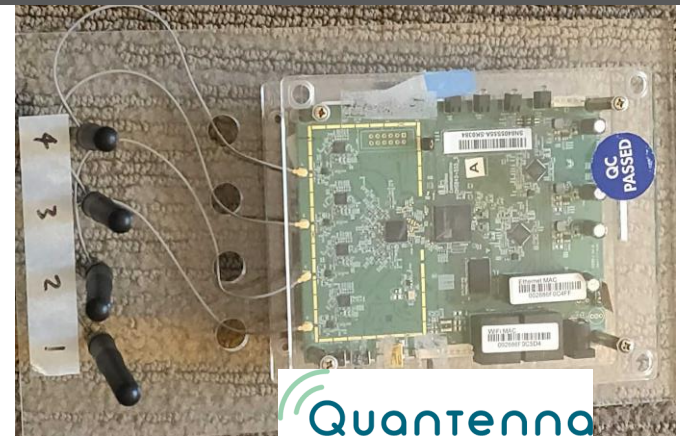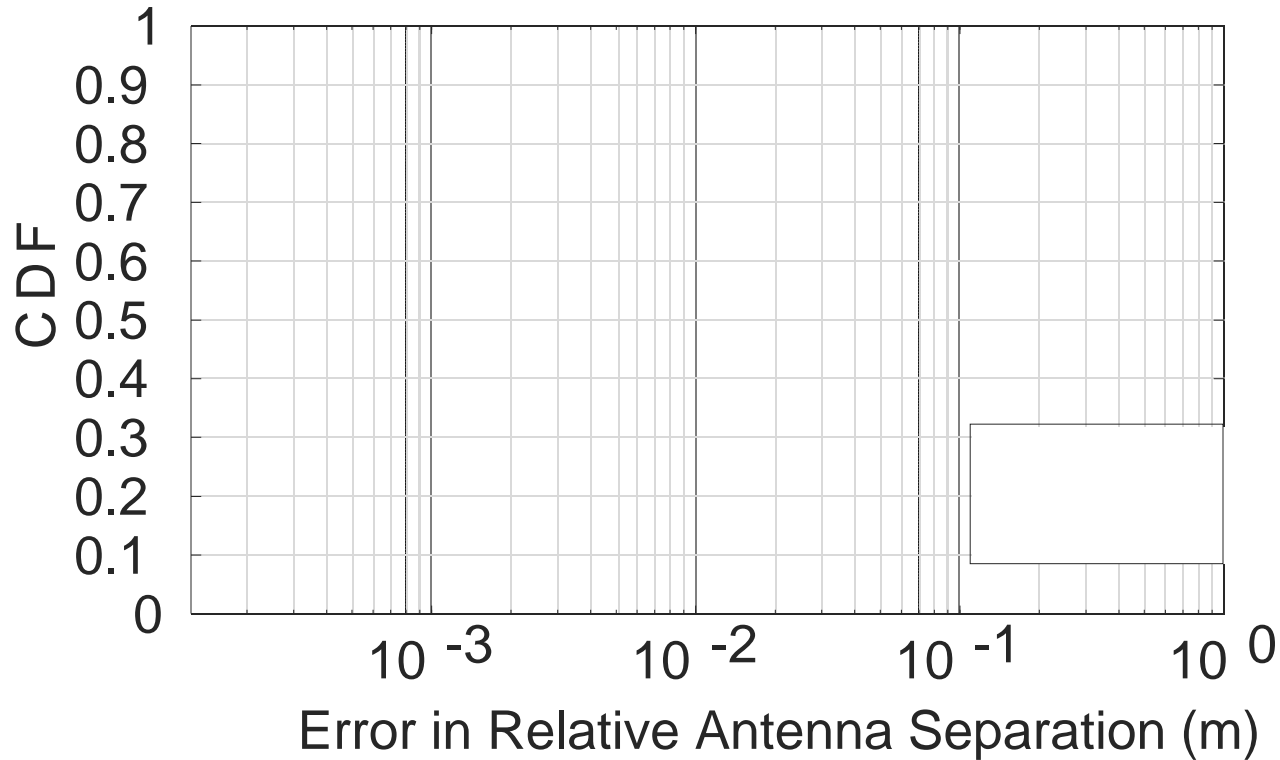Achieves mm-accurate Antenna separation and < 7° Orientation
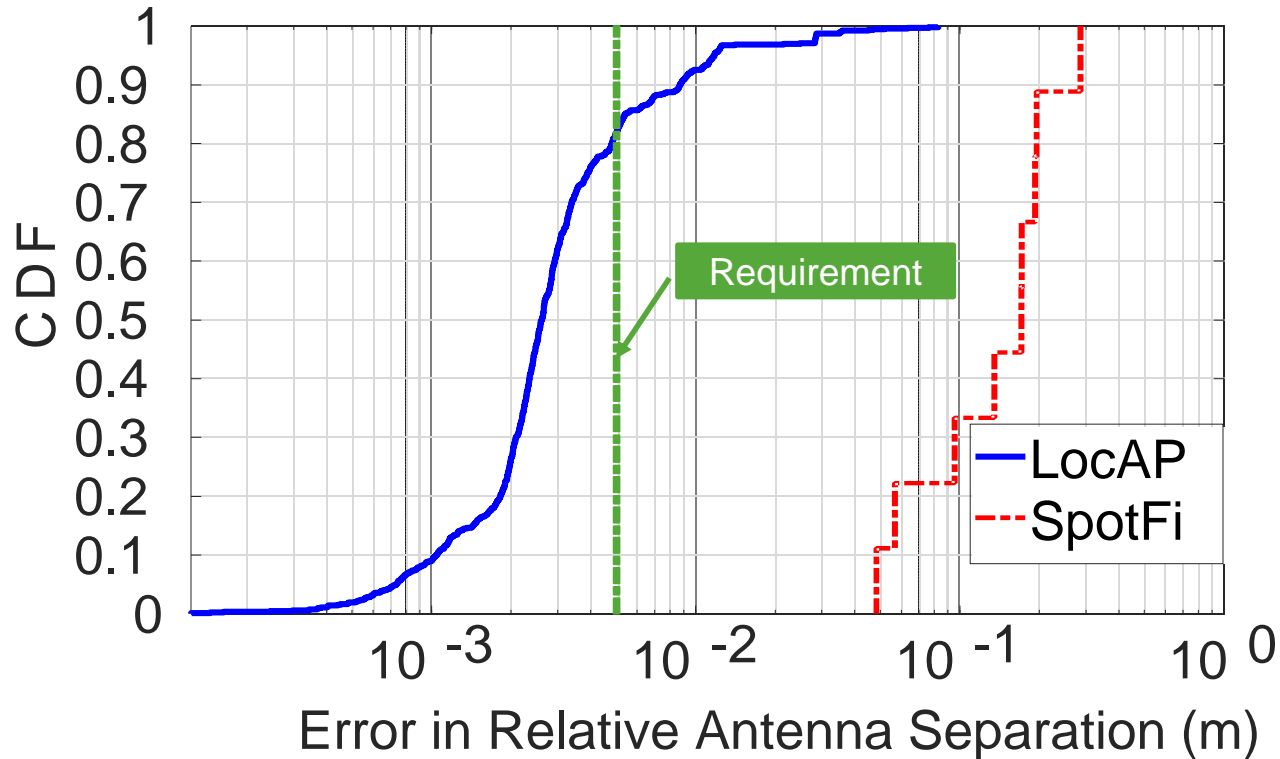
Evaluation Setup

- ❖ COTS Quantenna chipsets

- ❖ 8 different anchors in 2000 sq. ft.

- ❖ 5 different antenna separations

- ❖ 7 different orientations

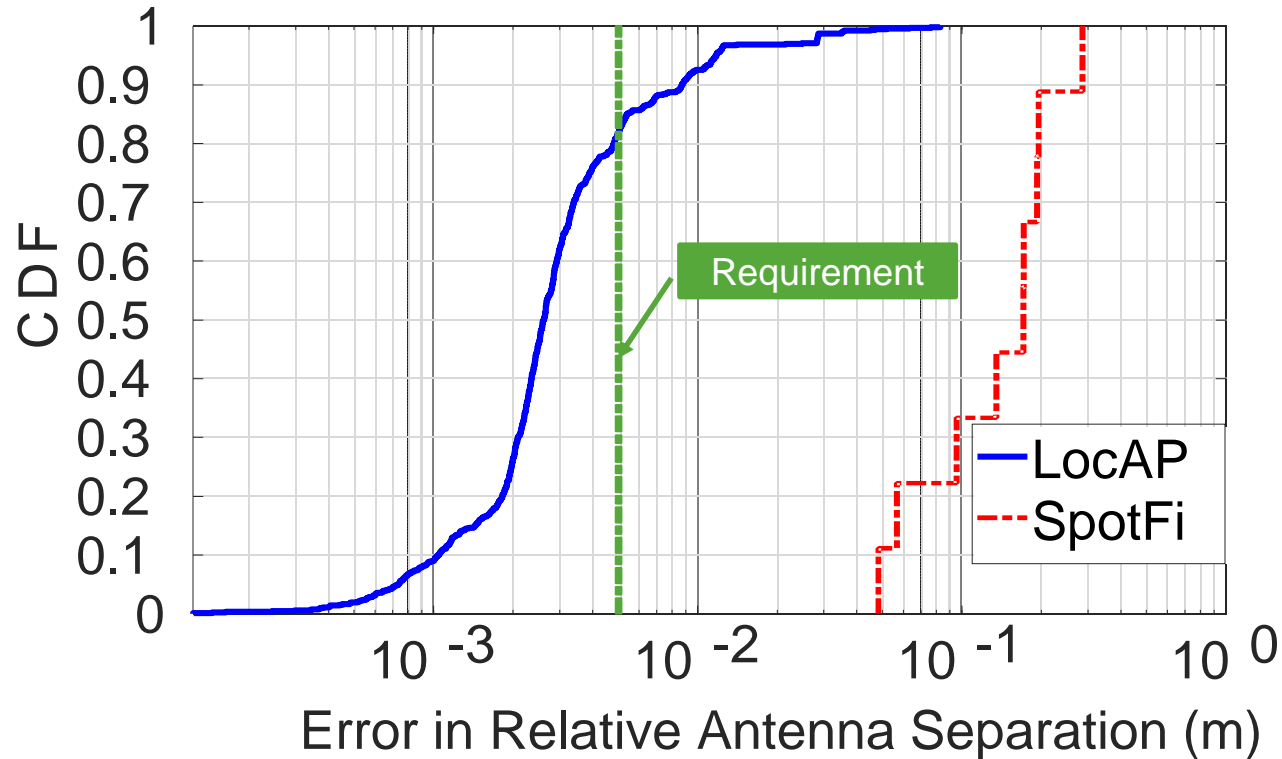- ❖ Most popular anchor spacing of both linear and rectangular arrays

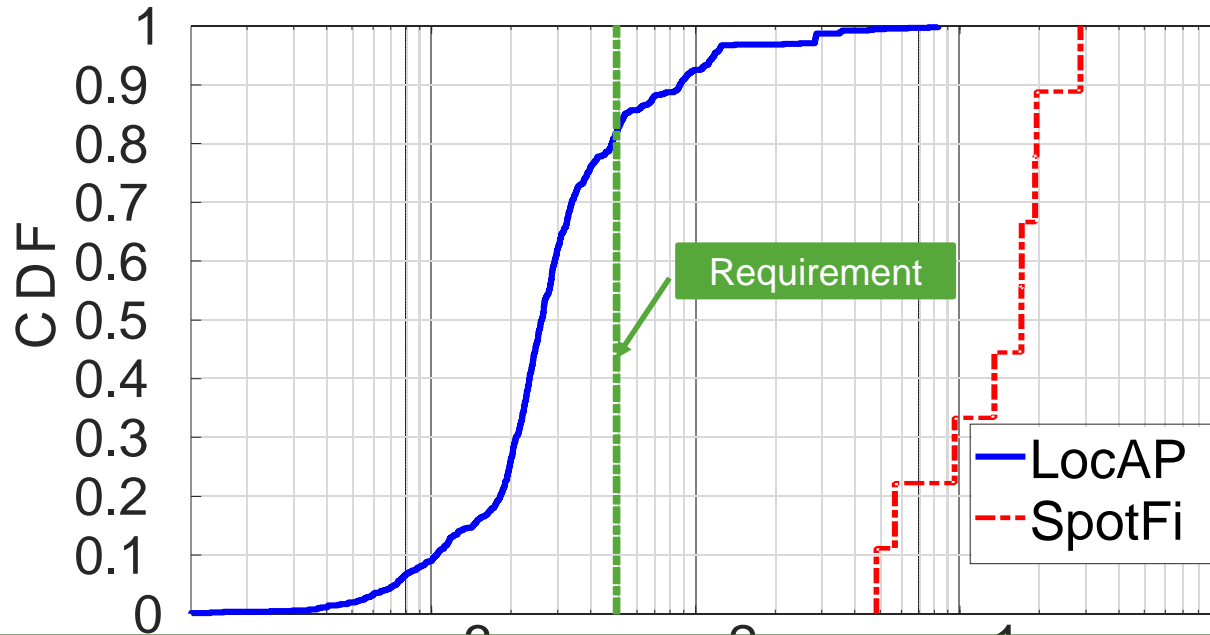# Antenna Separation Prediction Results

Antenna Separation Prediction Results

CDF vs Error in Relative Antenna Separation (m), comparing LocAP and SpotFi with a Requirement line.

Antenna Separation Prediction Results

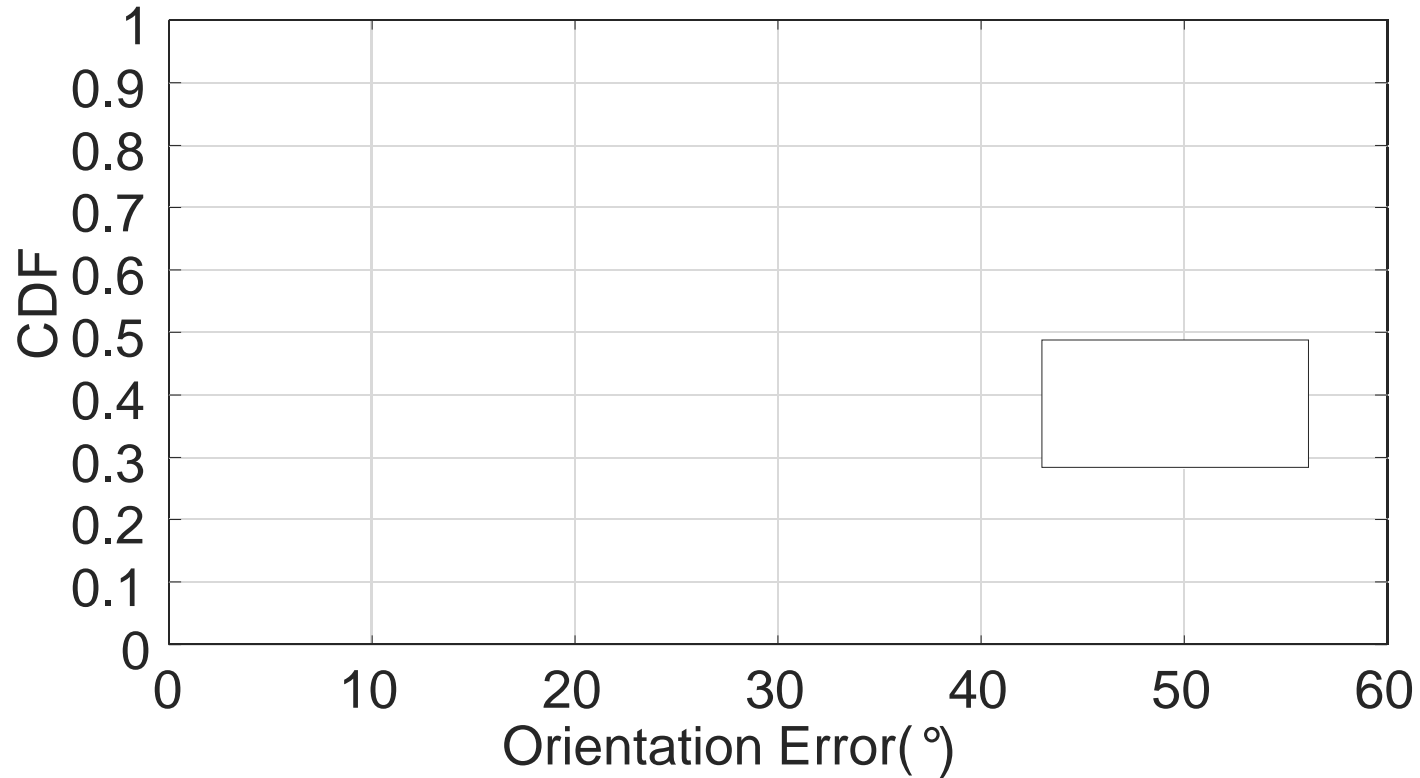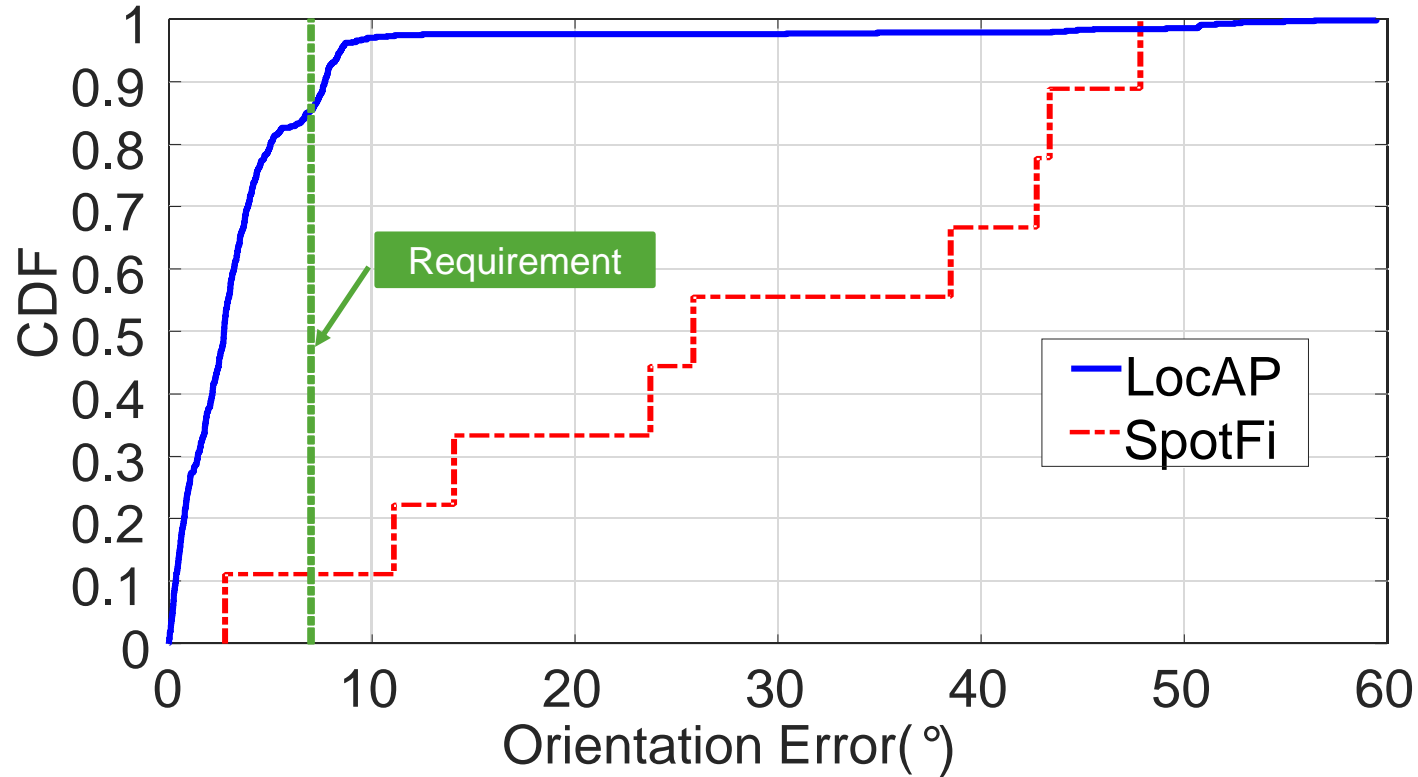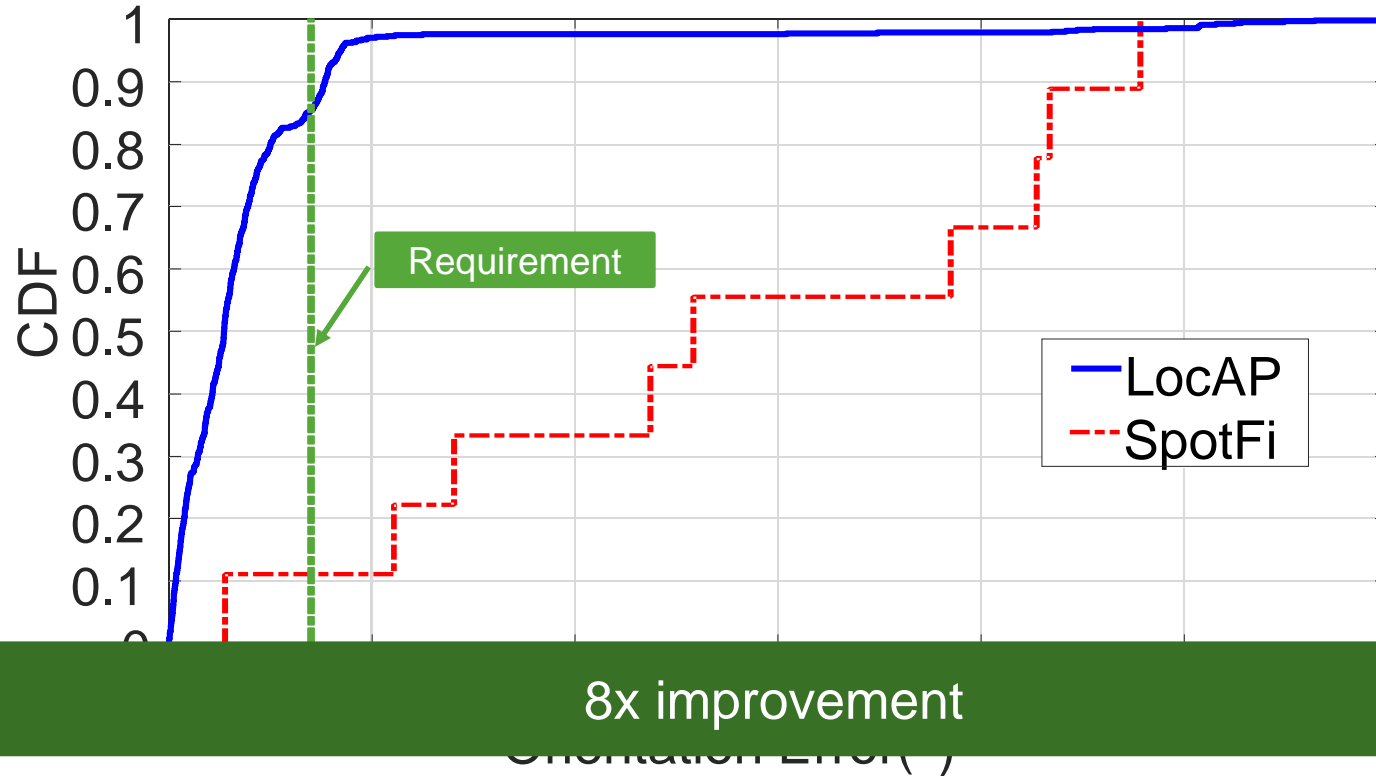# Antenna Separation Prediction Results

Deployment Orientation Prediction Results
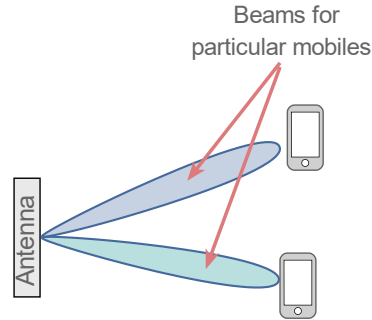
Deployment Orientation Prediction Results

Deployment Orientation Prediction Results

Conclusion and Future Work

❖ First Work to define the requirements for *Reverse Localization*

❖ Demonstrated millimeter accurate *Reverse Localization*

Beams for particular mobiles

Antenna

SCAN ME

http://wcsng.ucsd.edu/locap/

Quantenna