Decimeter-Level Localization with a Single WiFi Access Point

Deepak Vasisht

Swarun Kumar, Dina Katabi

wireless
@mit

Indoor Localization is Cool!

SpotFi [SIGCOMM' 15], ToneTrack [Mobicom' 15], Phaser [Mobicom' 14], Tagoram [Mobicom' 14], LTEye [SIGCOMM' 14], ArrayTrack [NSDI'13], PinPoint [NSDI'13], PinIt [SIGCOMM'13], Zee [MobiCom'12], PinLoc [MobySys'12], EZ [MobiCom'10], ….

- Locate **off-the-shelf devices**
- Accuracy of **tens of cm**

But… They Need 4-5 Access Points

Homes and small businesses have **ONE** access point (AP)

Application : Control heating based on occupancy

Application : WiFi Geo-Fencing

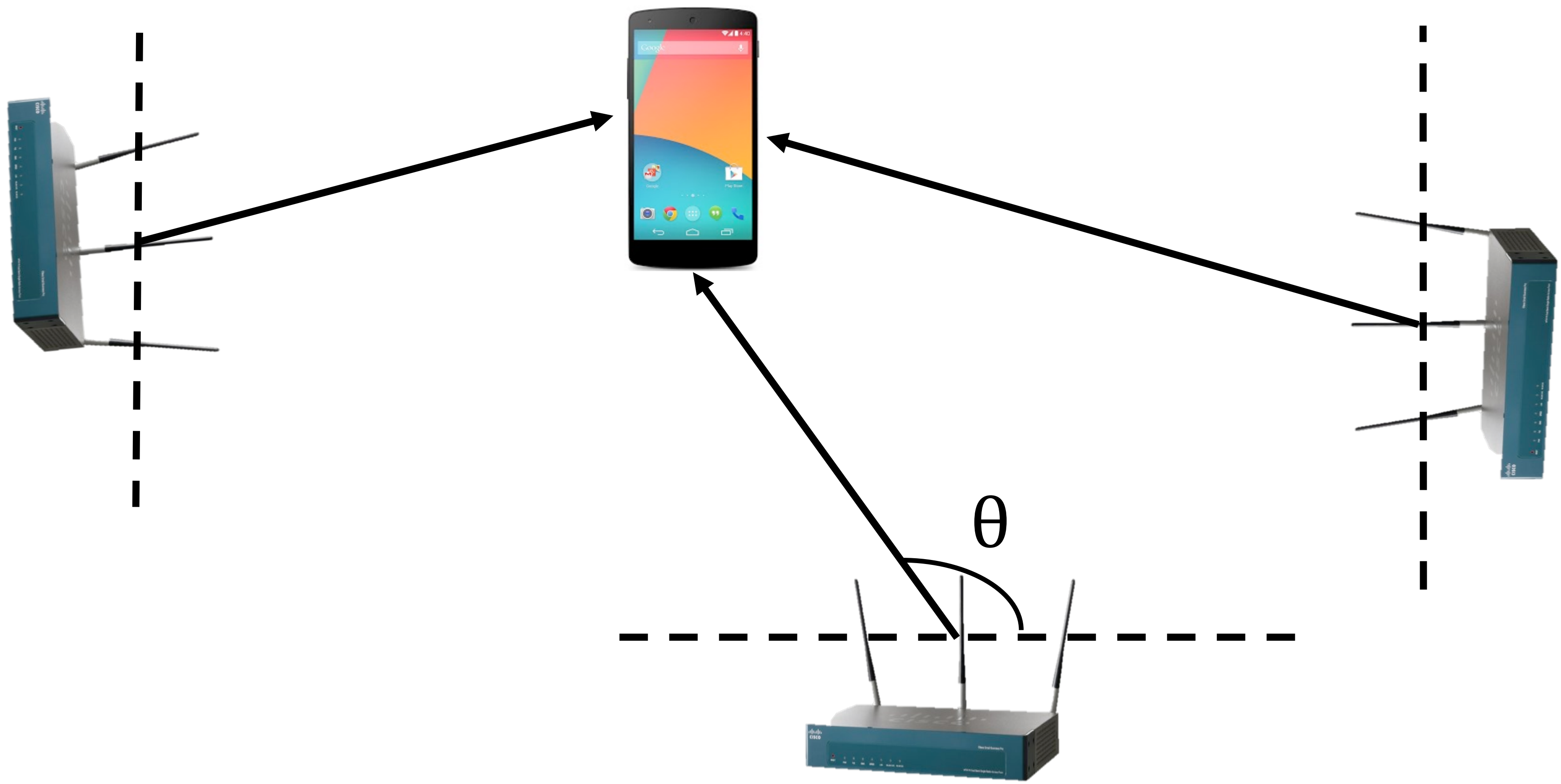
Application : Device-to-device Localization

Enable device-to-device localization without infrastructure support

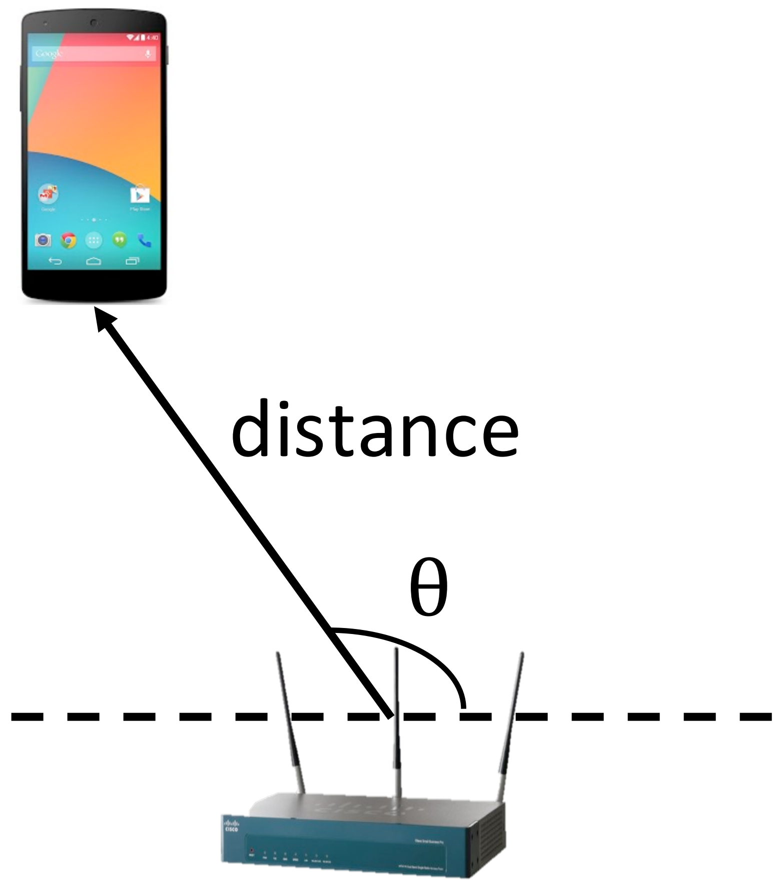
Chronos

- Enables decimeter-accurate localization using a single off-the-shelf WiFi card
- A novel algorithm to estimate propagation time to sub-nanosecond accuracy using a WiFi card
- Implemented and evaluated in practical settings

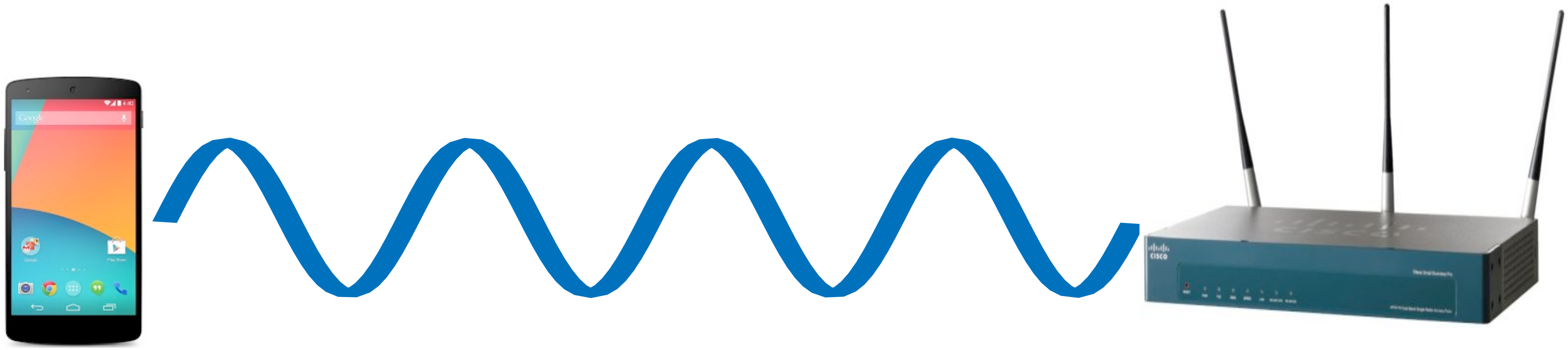
Why past work needs multiple AP's?



Single Access Point?



Measuring Distance

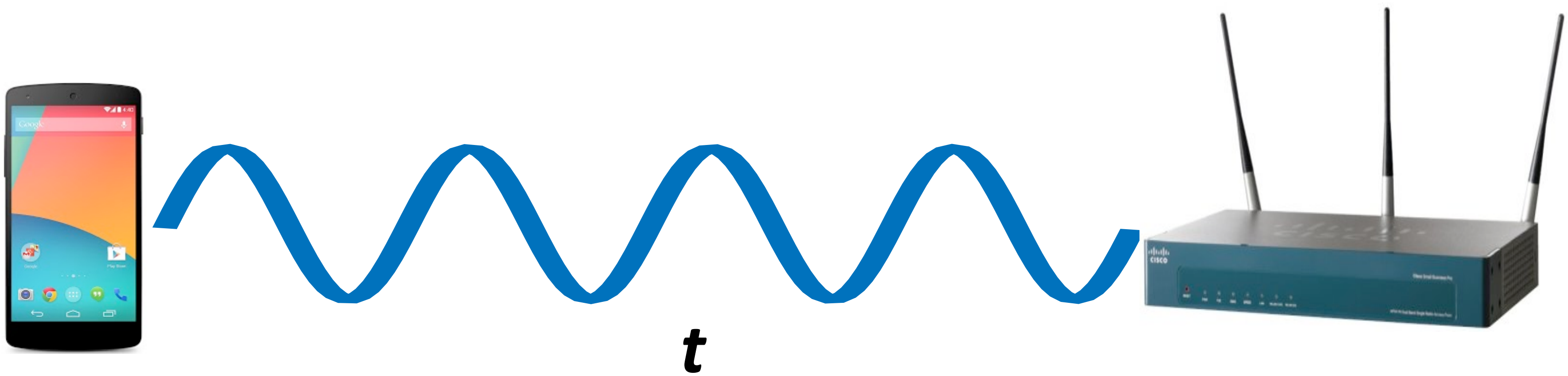


Distance = speed of light x propagation delay

Measuring Distance

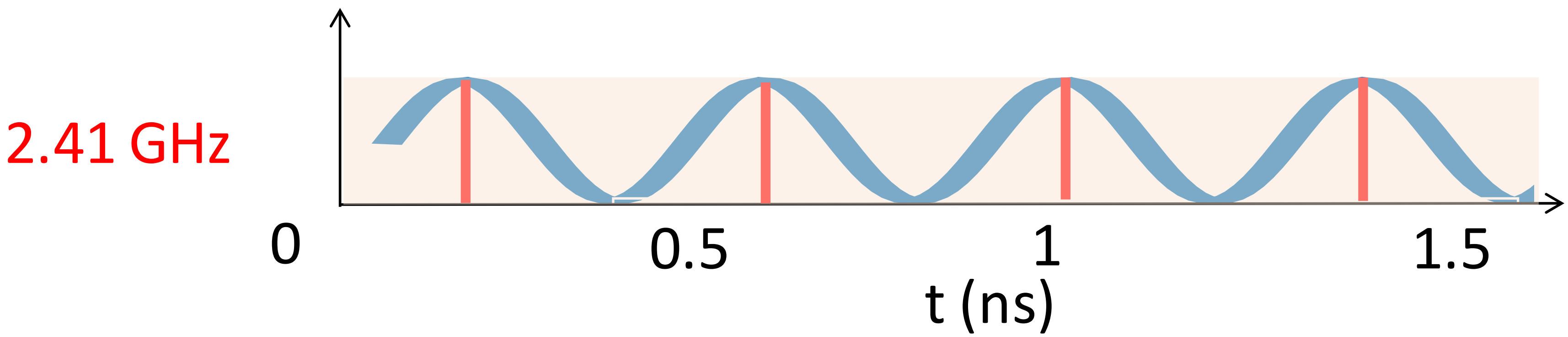
How do we measure propagation delay?

Propagation Delay



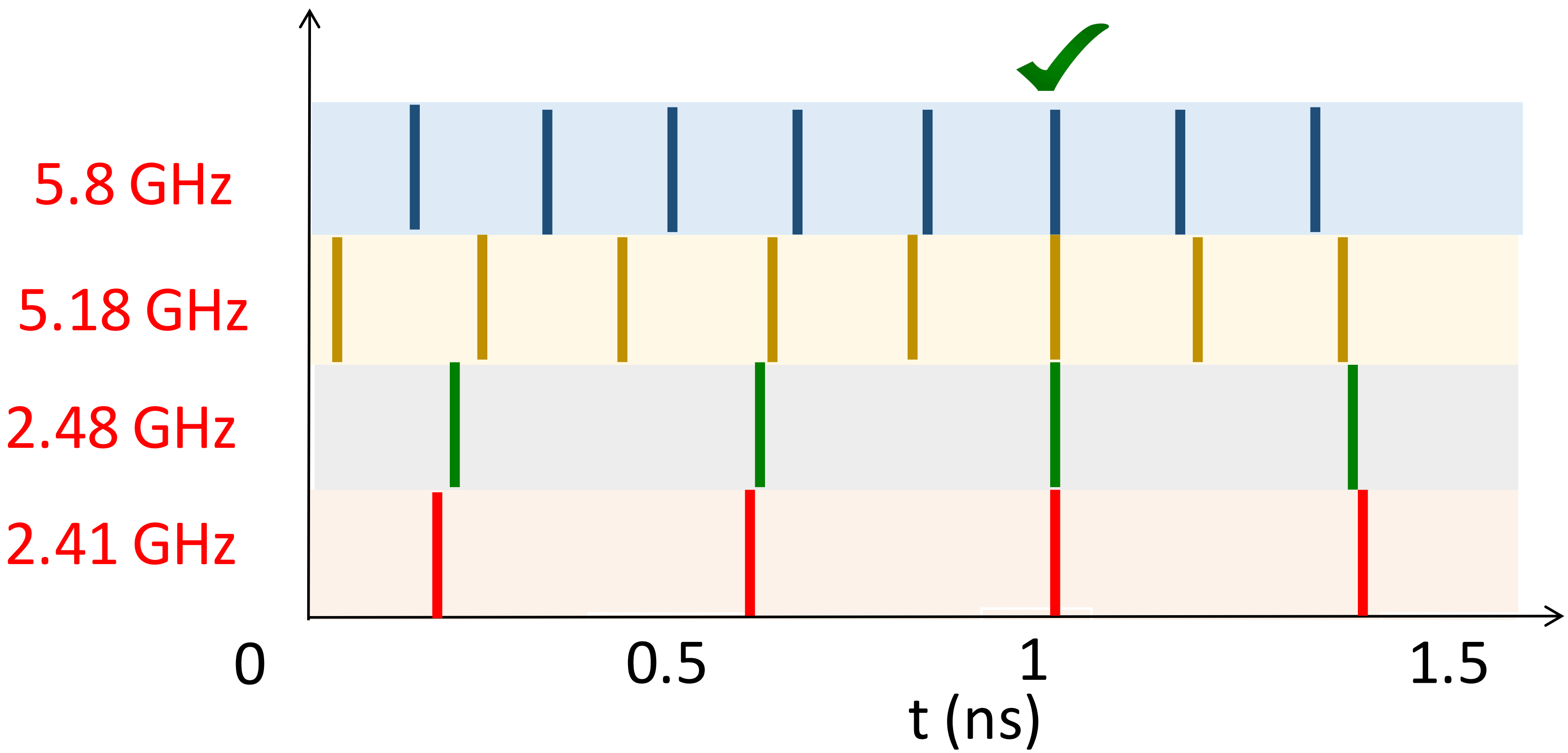
Phase of the signal(ϕ) = $2\pi f t \bmod 2\pi$

Propagation Delay: Example



$$\phi = 2\pi f t \bmod 2\pi$$

Propagation Delay: Example



Mathematically

$$\phi_1 = 2\pi f_1 t \ mod \ 2\pi$$

$$\phi_2 = 2\pi f_2 t \ mod \ 2\pi$$

$$\vdots$$

$$\phi_N = 2\pi f_N t \ mod \ 2\pi$$

Mathematically

$$\phi_1 = 2\pi f_1 t \ mod \ 2\pi$$

$$\phi_2 = 2\pi f_2 t \ mod \ 2\pi$$

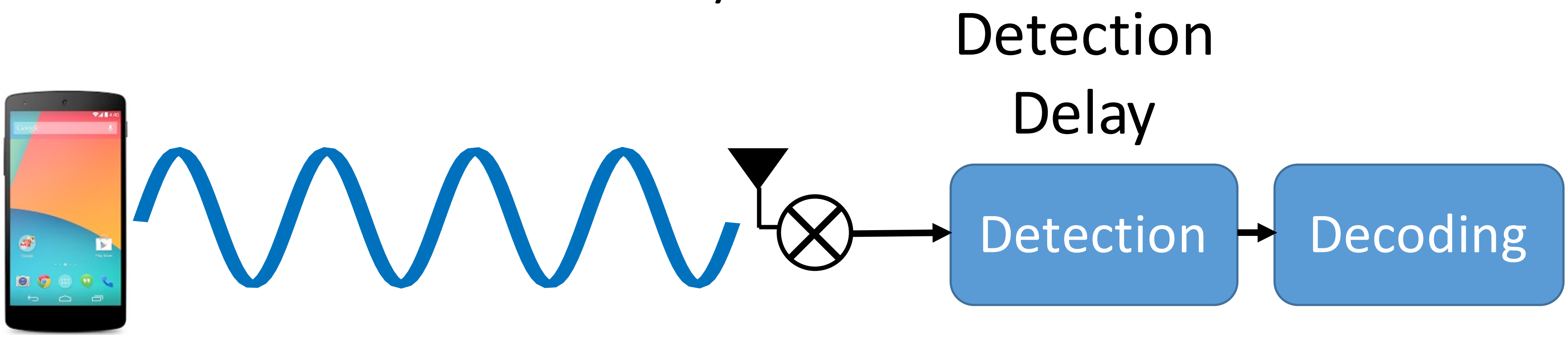
Use Chinese Remainder Theorem to get the propagation delay

Can’t measure propagation delay without detection delay

Distance = speed of light x propagation delay

Measured delay = propagation delay + detection delay

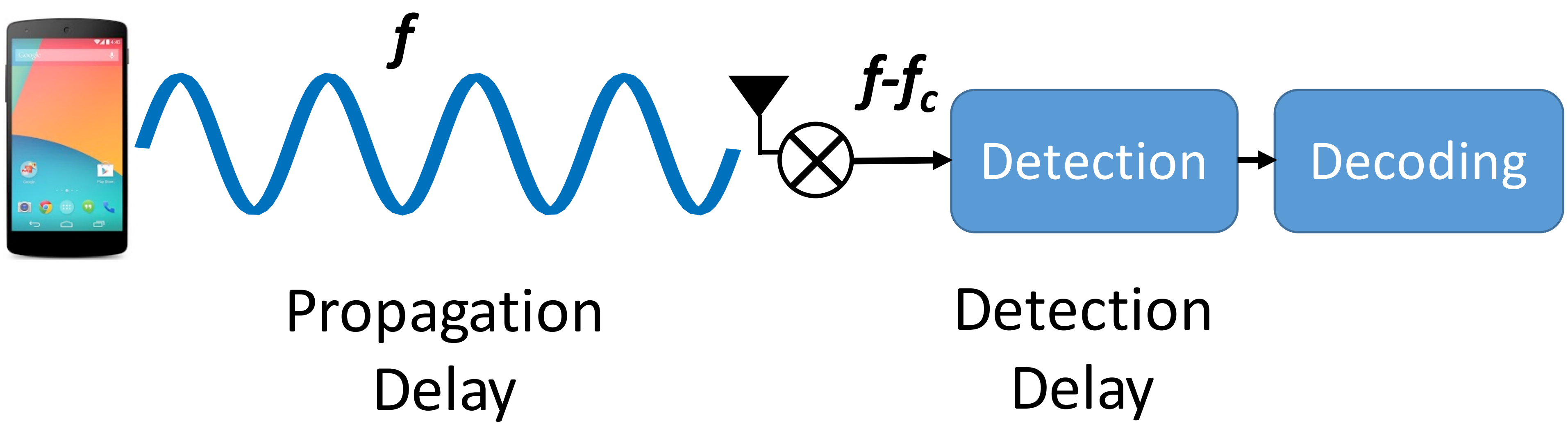
Packet Detection Delay

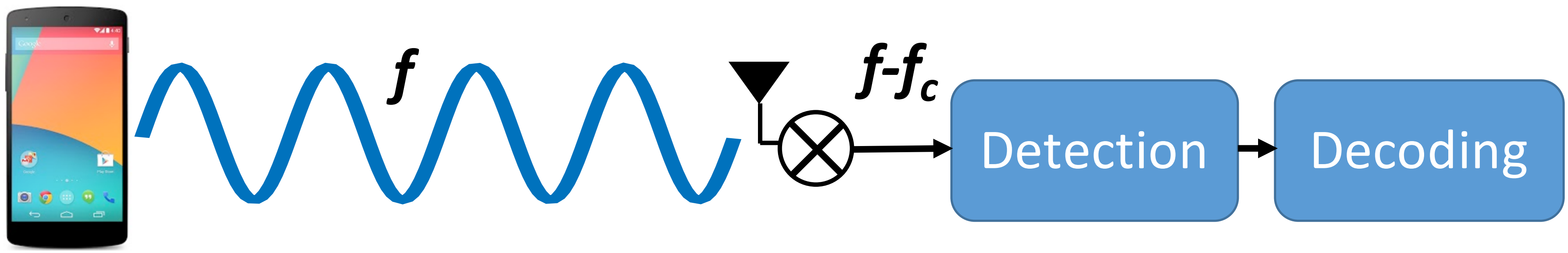


How do we eliminate detection delay?

Problem: Separate detection delay from propagation delay

Solution: Leverage that propagation delay and detection delay happen at different frequencies



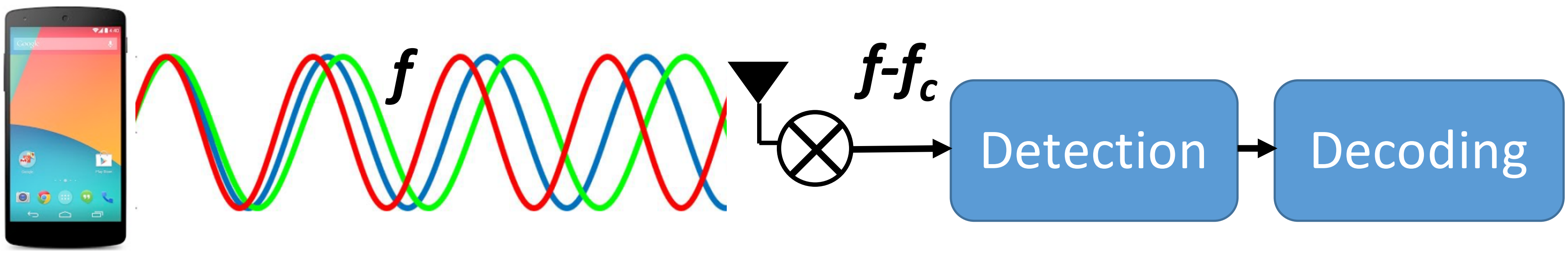


Propagation Delay (t)

Detection Delay (t')

$$\phi = 2\pi f t \; mod \; 2\pi$$

$$\phi = 2\pi f t + 2\pi \, (f - f_c) t' \; mod \; 2\pi$$



Propagation Delay (t)

Detection Delay (t')

$$\phi = 2\pi f t \bmod 2\pi$$

$$\phi = 2\pi f t + 2\pi \underbrace{(f - f_c)}_{0} t' \bmod 2\pi$$

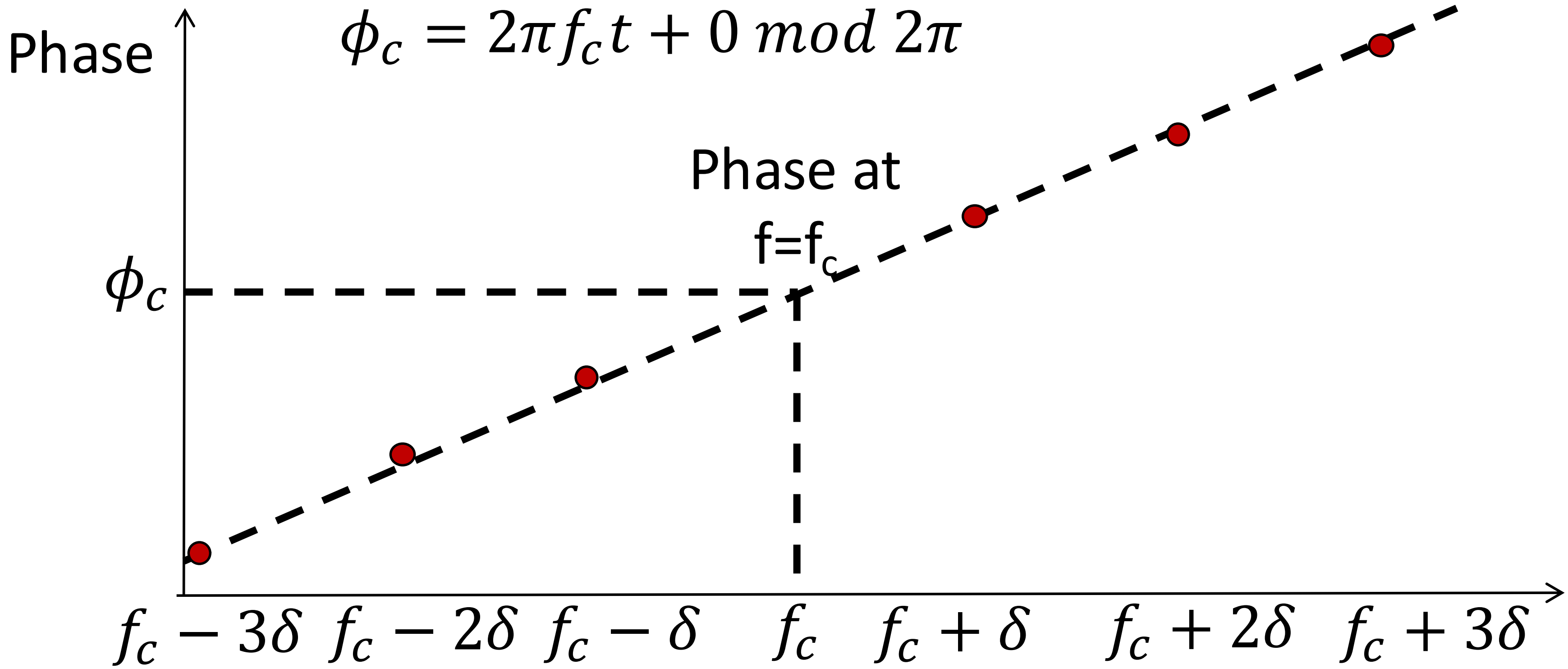
Idea: Use OFDM to measure phase at $f = f_c$

But WiFi does not transmit at $f=f_c$

Solution: Leverage OFDM

$$\phi = 2\pi f t + 2\pi\,(f\ - f_c)t'\ mod\ 2\pi$$

$$\phi_c = 2\pi f_c t + 0\ mod\ 2\pi$$



Mathematically

$$\phi_{c,1} = 2\pi f_{c,1} t \; mod \; 2\pi$$

$$\phi_{c,2} = 2\pi f_{c,2} t \; mod \; 2\pi$$

Chronos eliminates packet detection delay by leveraging OFDM properties

Additional System Components

- Initial Phase Offset Compensation

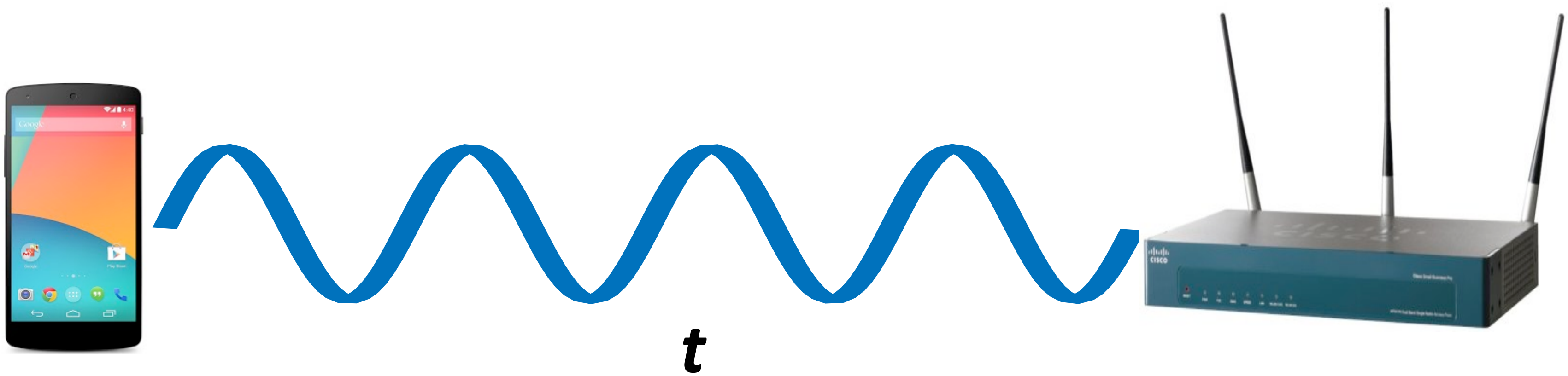
- Multipath resolution

Additional System Components

- Initial Phase Offset Compensation

- Multipath resolution

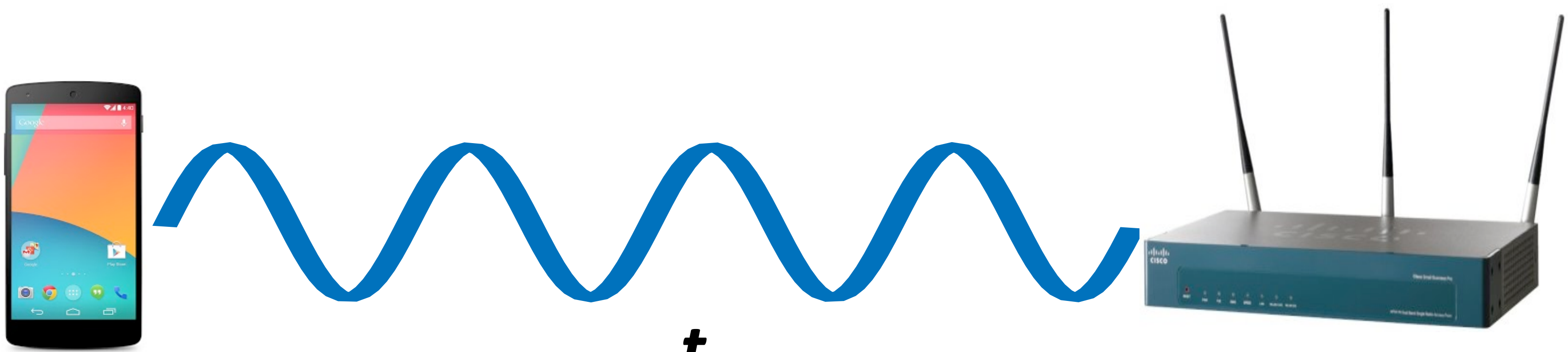
Initial Phase Offsets



$$\phi = 2\pi f t \bmod 2\pi$$

$$\phi = 2\pi f t + \Delta\phi \bmod 2\pi$$

Idea: Use Acknowledgements



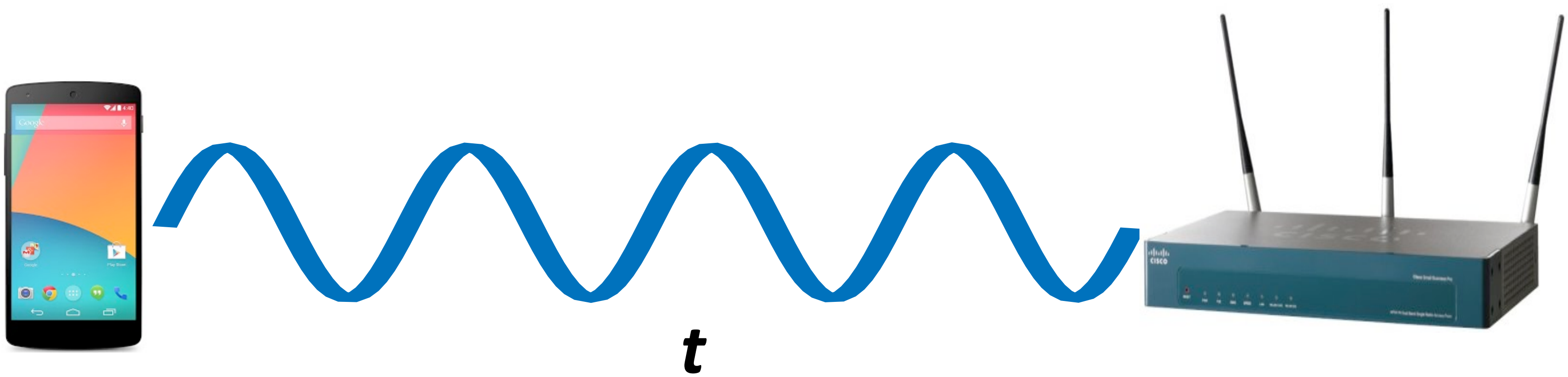
t

$$\phi_1 = 2\pi f t + \Delta\phi \; mod \; 2\pi$$

$$\phi_2 = 2\pi f t - \Delta\phi \; mod \; 2\pi$$

$$\phi_1 + \phi_2 = 4\pi f t \; mod \; 2\pi$$

Idea: Use Acknowledgements



$$\phi_1 = 2\pi f t + \Delta\phi \bmod 2\pi$$

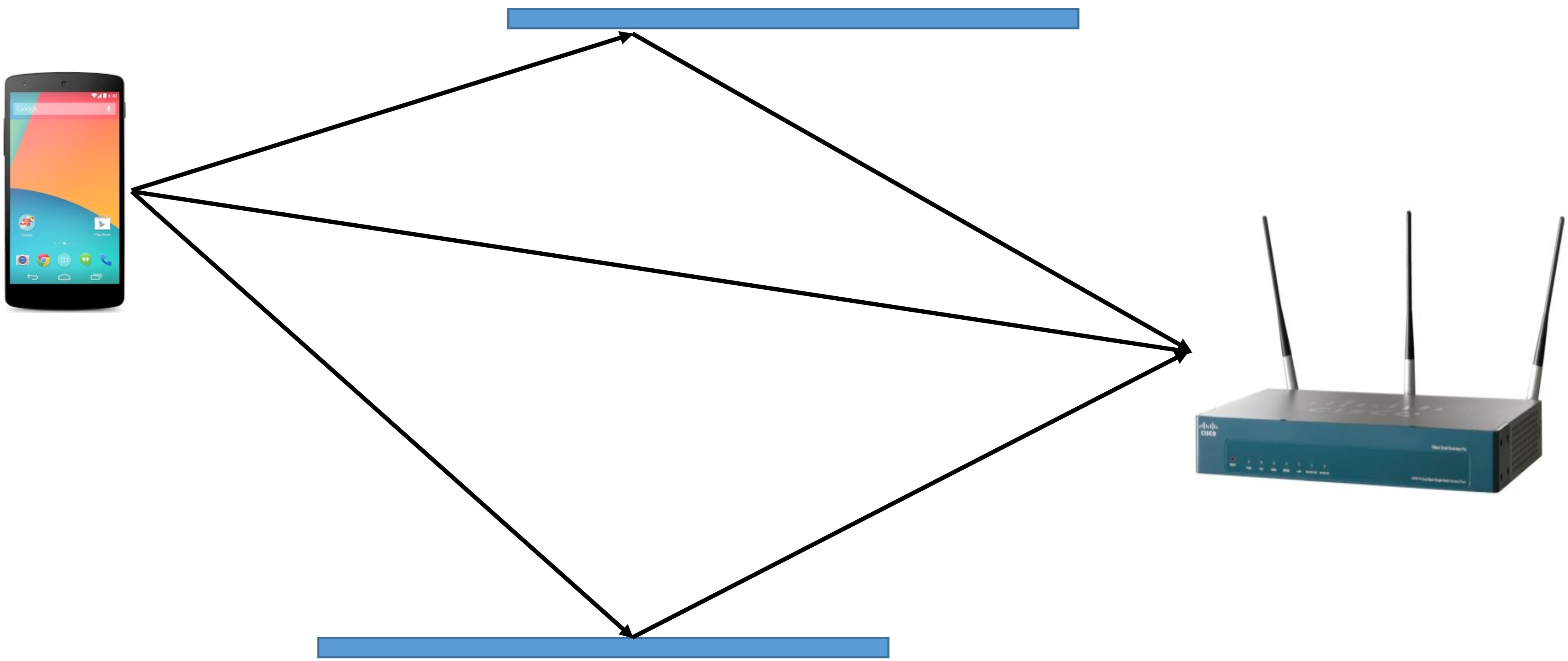
Chronos eliminates phase offsets by using acknowledgements

Additional System Components

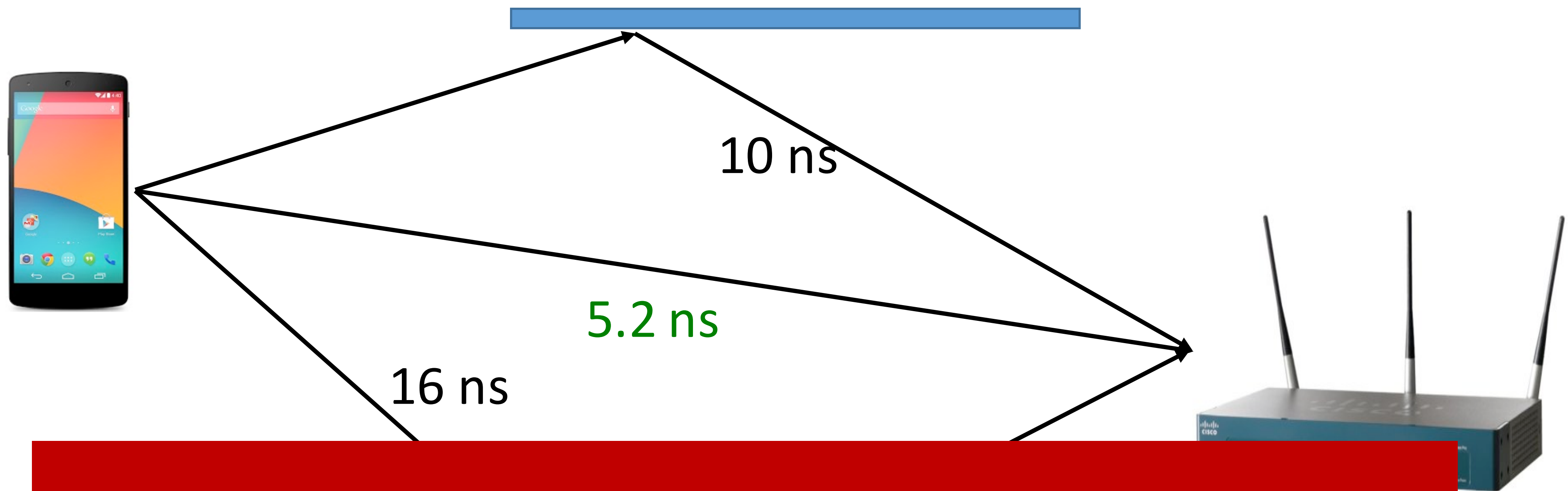
- Initial Phase offset Compensation

- Multipath resolution

Problem: Multipath Effect



Solution: Find delays for each path



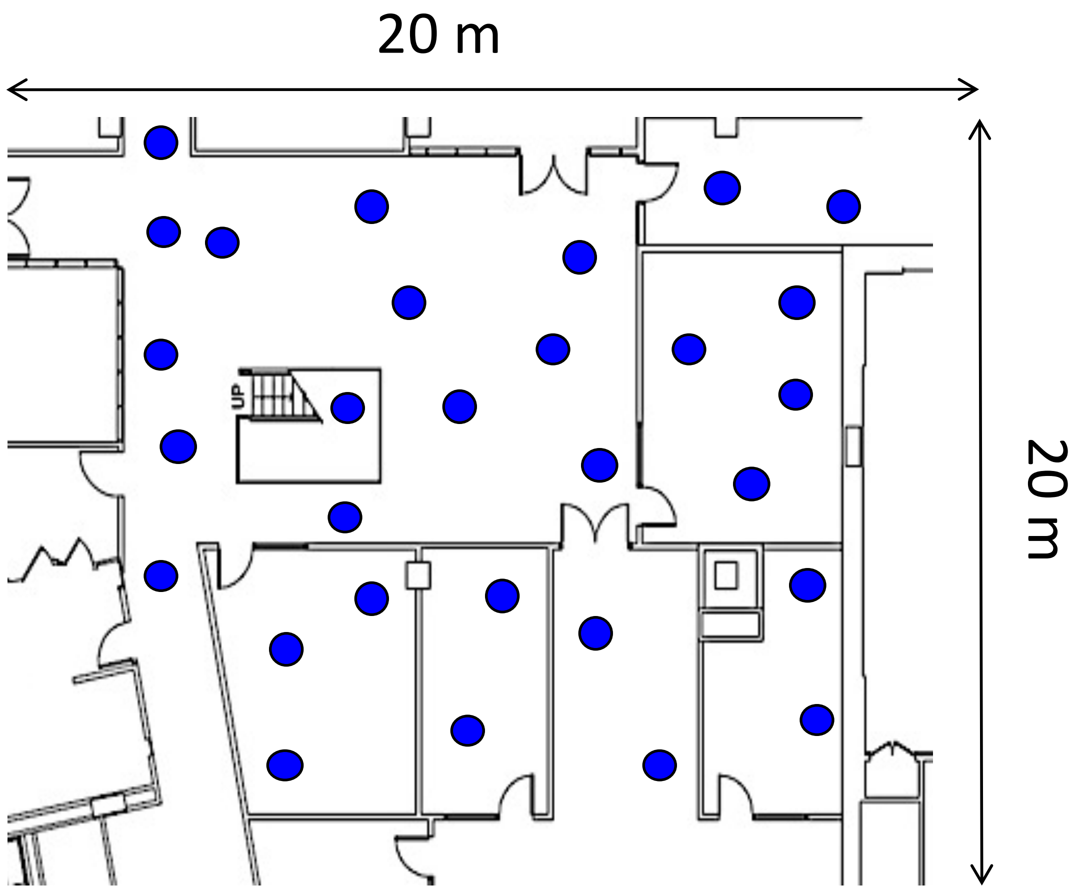
Distance to source corresponds to the smallest delay.

Experimental Evaluation

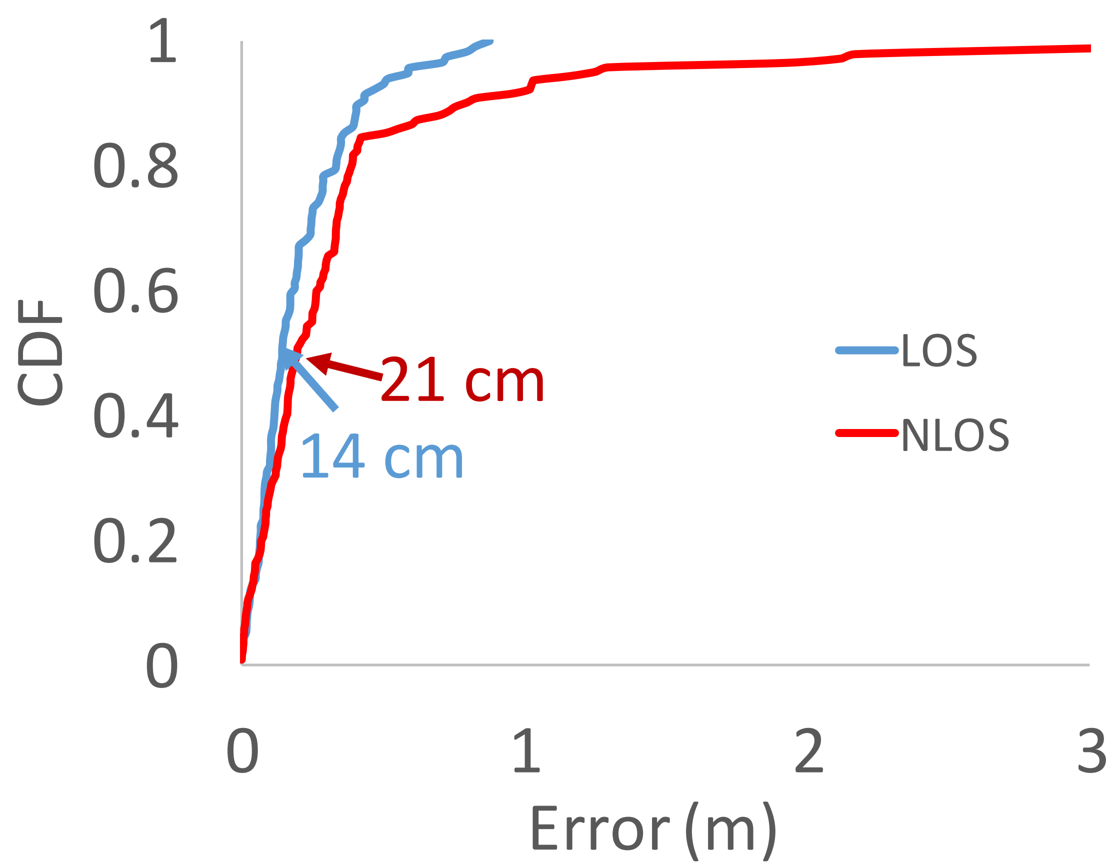
Implementation

- Evaluation with off-the-shelf Intel WiFi 5300 cards
- Kernel modifications to the iwlwifi driver in the Ubuntu kernel
- Ground truth measurements using laser distance measurement device (1mm accurate)

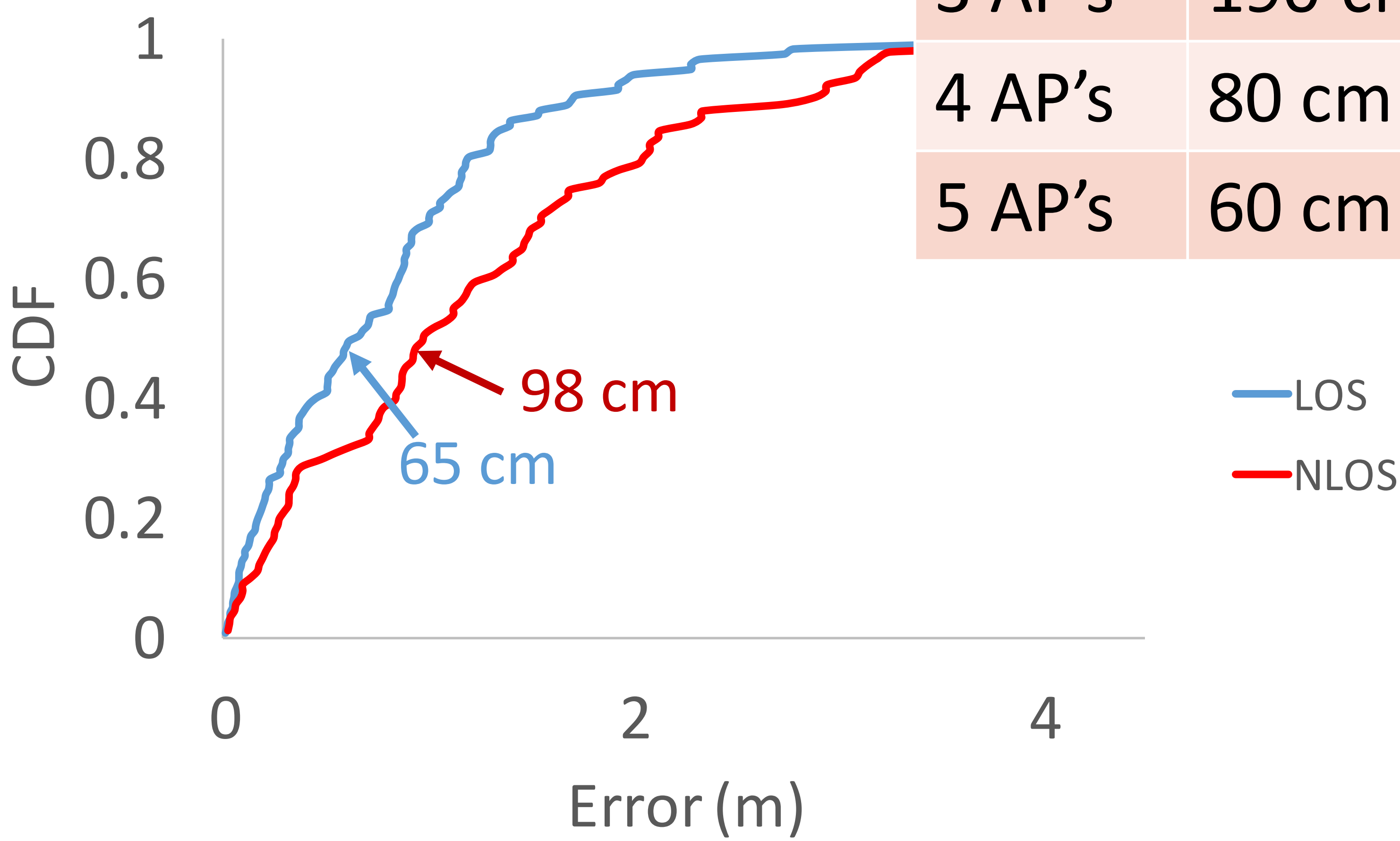
Evaluation Testbed: Office Environment



Distance Measurement Accuracy



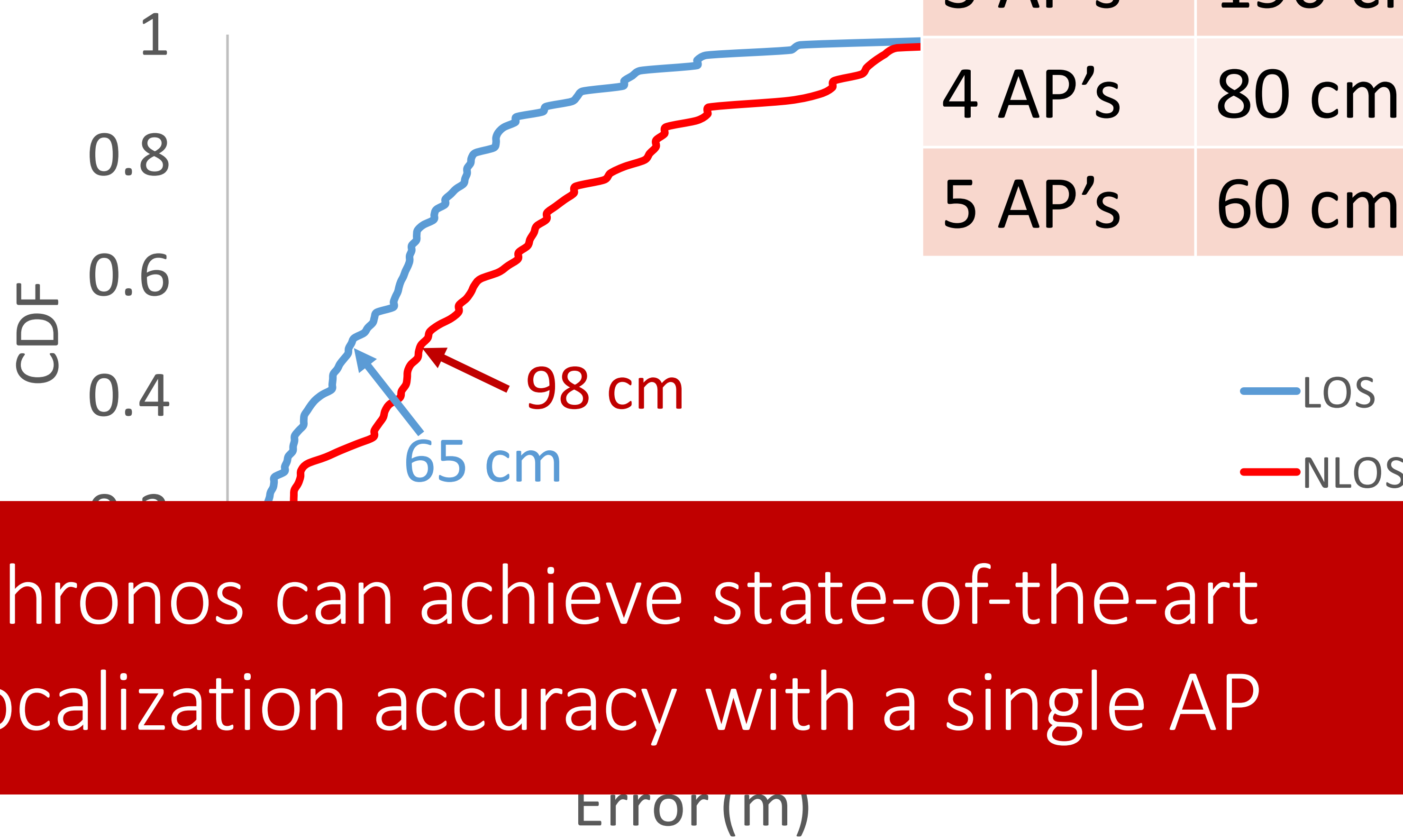
Localization Accuracy



SpotFi (SIGCOMM' 15)

3 AP's	190 cm
4 AP's	80 cm
5 AP's	60 cm

Localization Accuracy



SpotFi (SIGCOMM' 15)

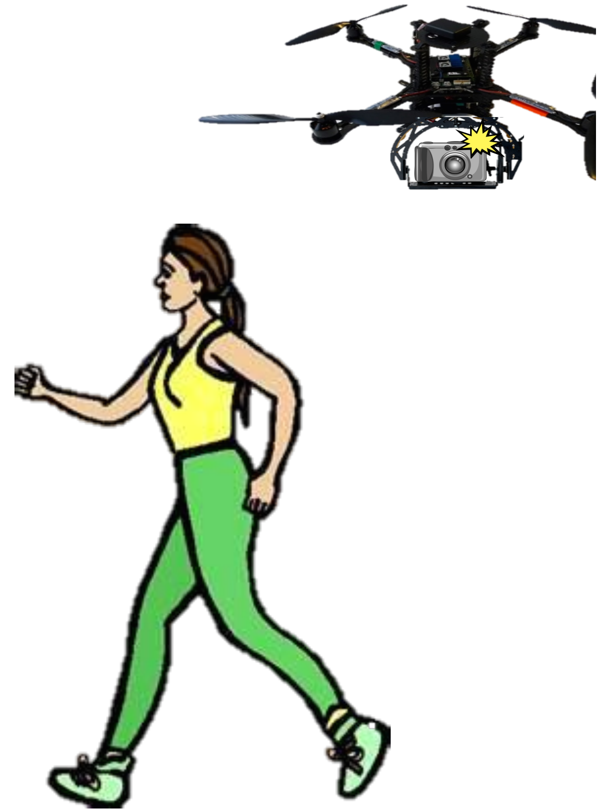
3 AP's	190 cm
4 AP's	80 cm
5 AP's	60 cm

Chronos can achieve state-of-the-art localization accuracy with a single AP

Applications

Smart Homes

WiFi Geo-fencing

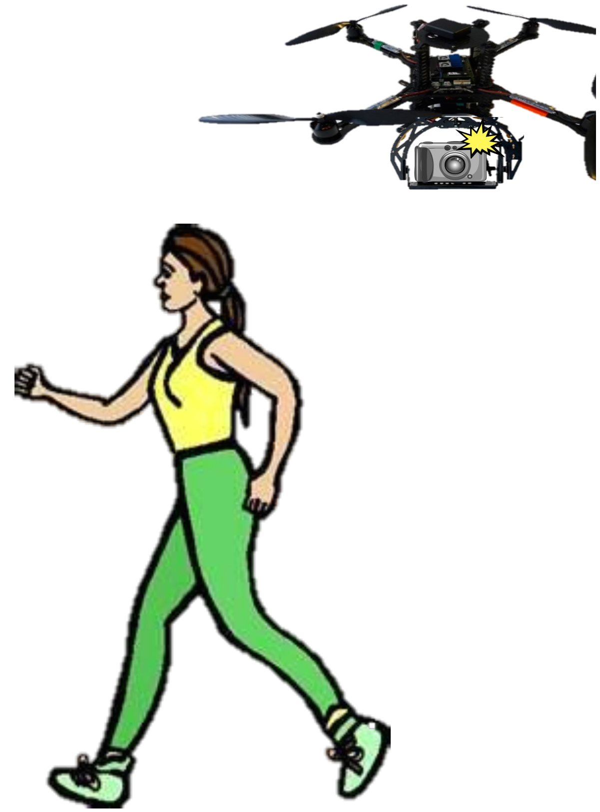


Device to Device localization

Applications

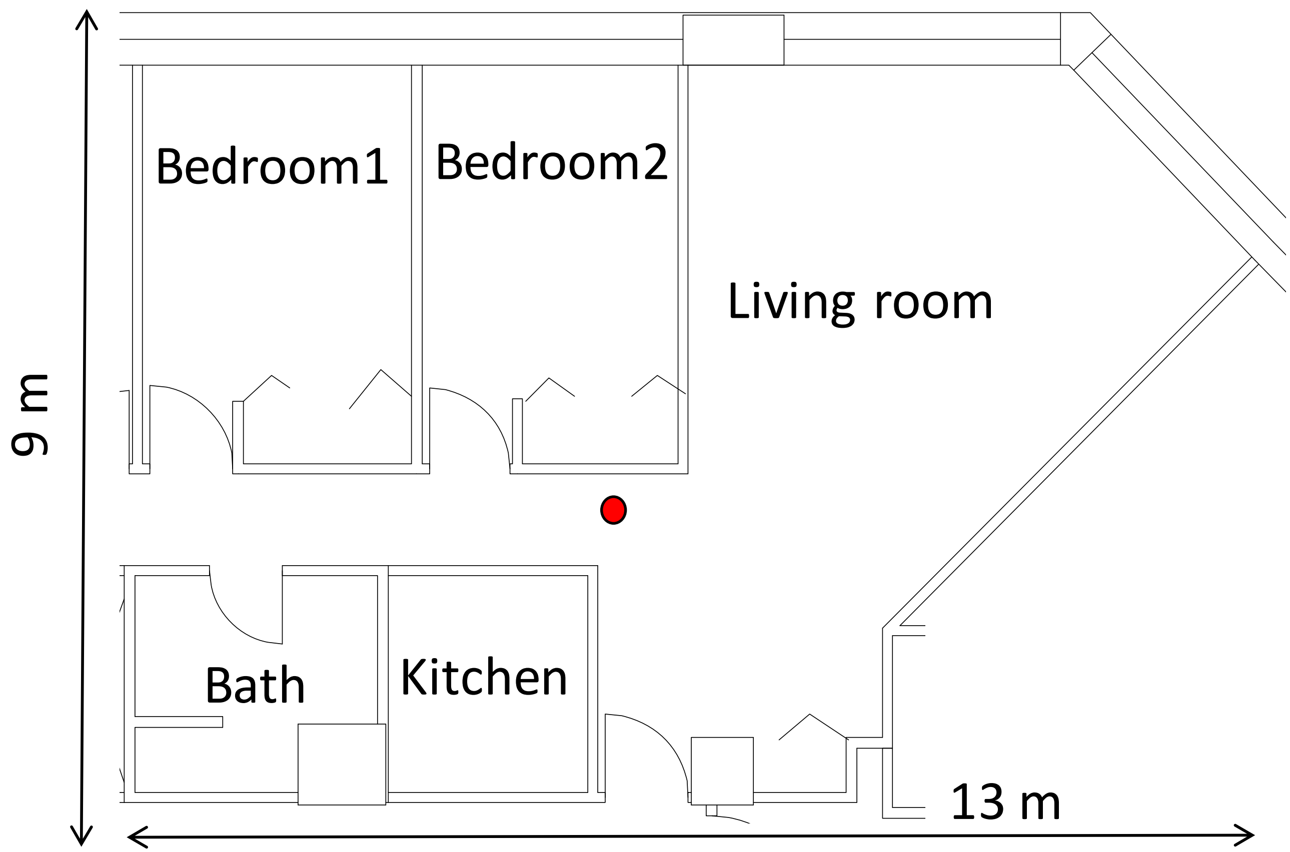
Smart Homes

WiFi Geo-fencing

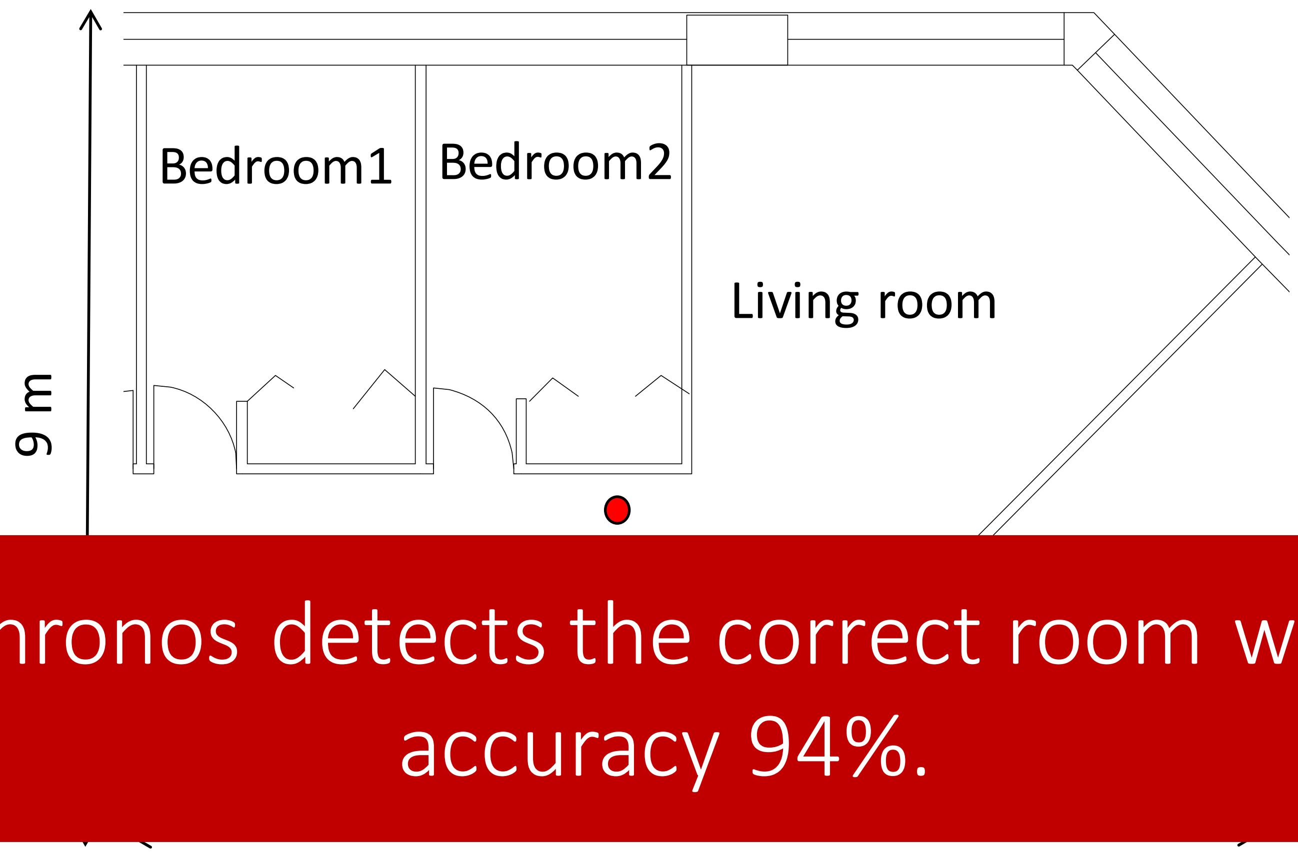


Device to Device localization

Application: Smart Homes



Application: Smart Homes

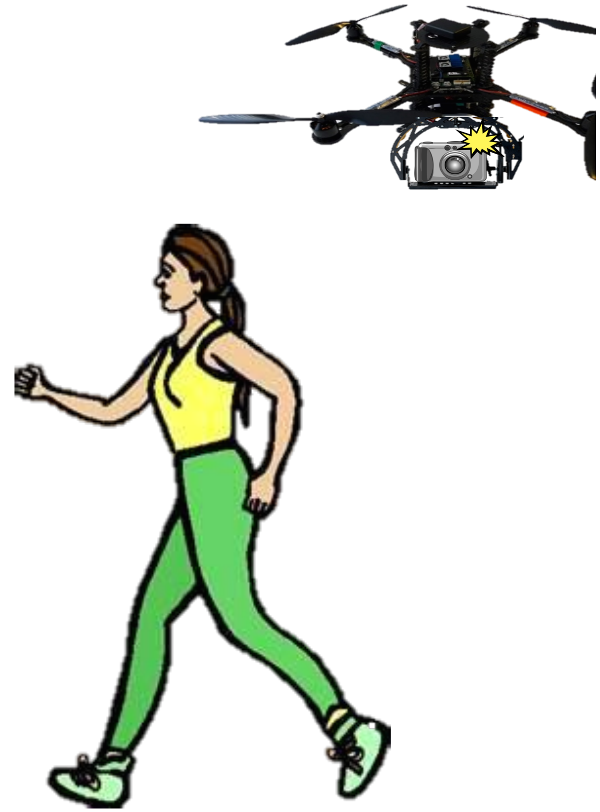


Chronos detects the correct room with accuracy 94%.

Applications

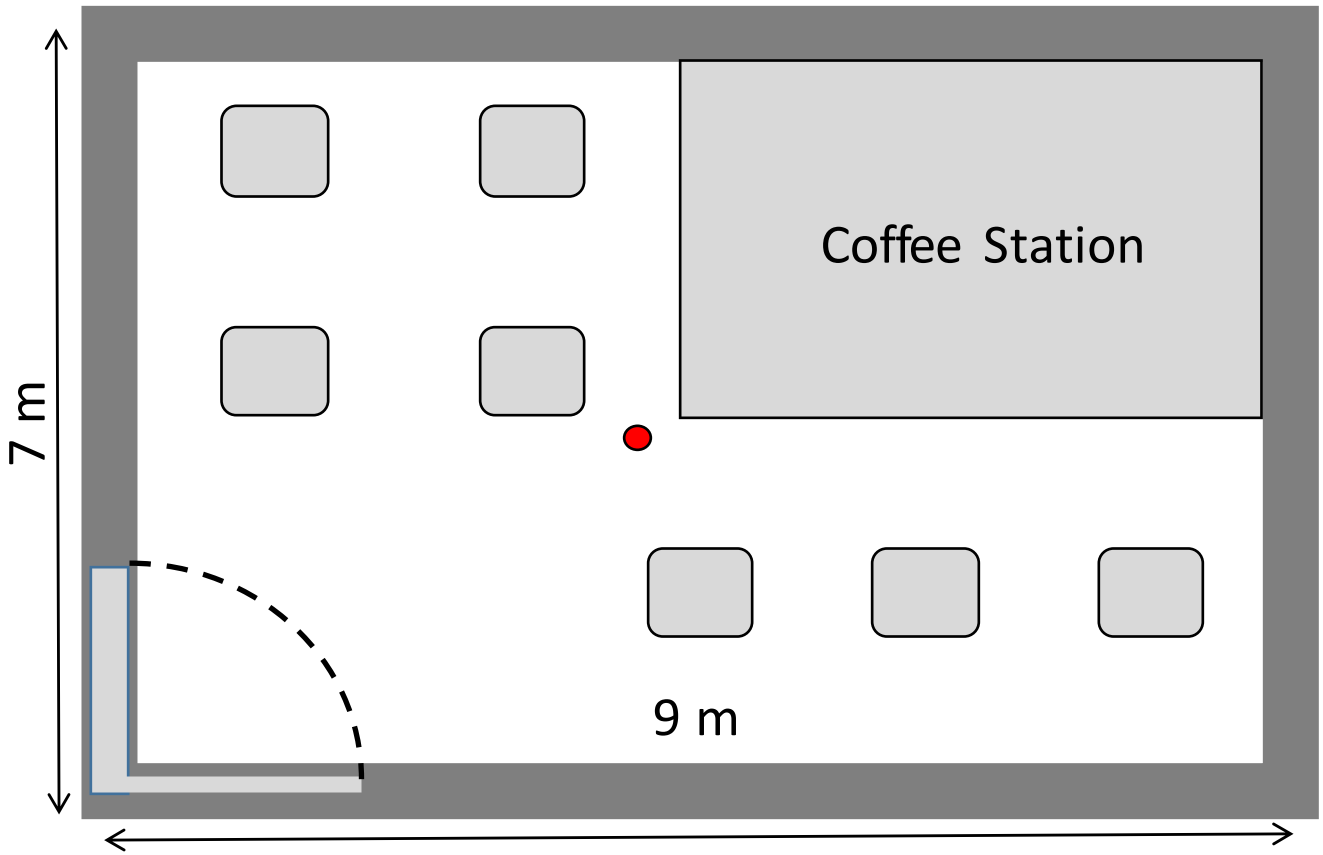
Smart Homes

WiFi Geo-fencing

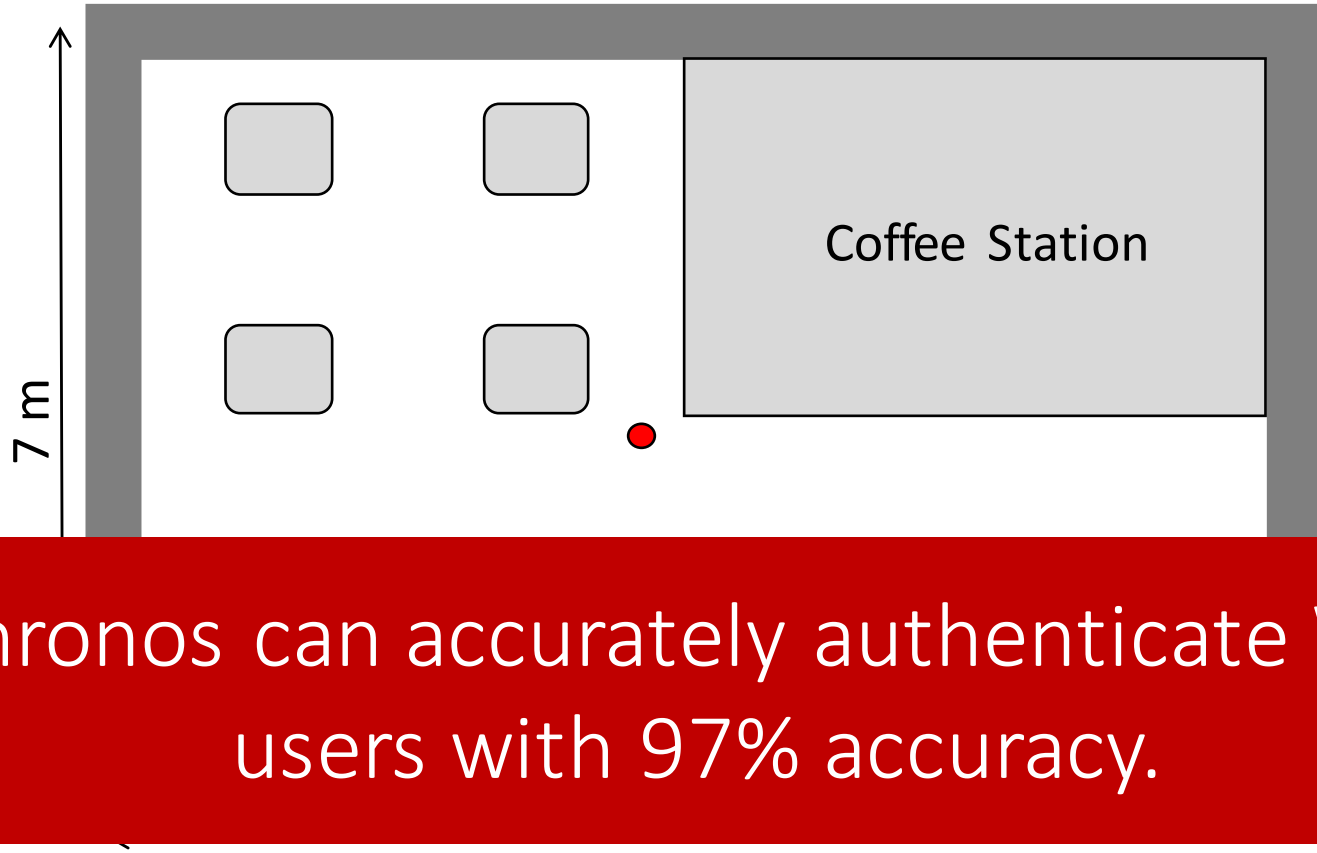


Device to Device localization

Application: GeoFencing



Application: GeoFencing



Chronos can accurately authenticate WiFi users with 97% accuracy.

Applications

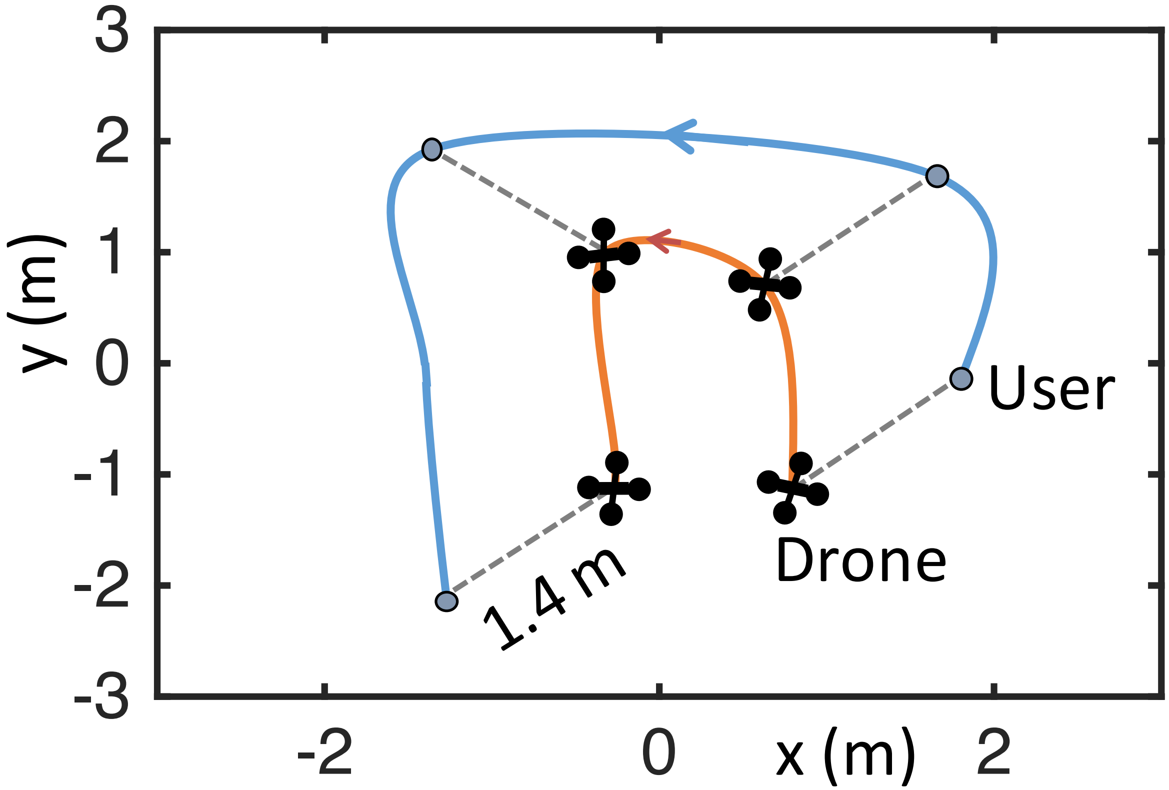
Smart Homes

WiFi Geo-fencing

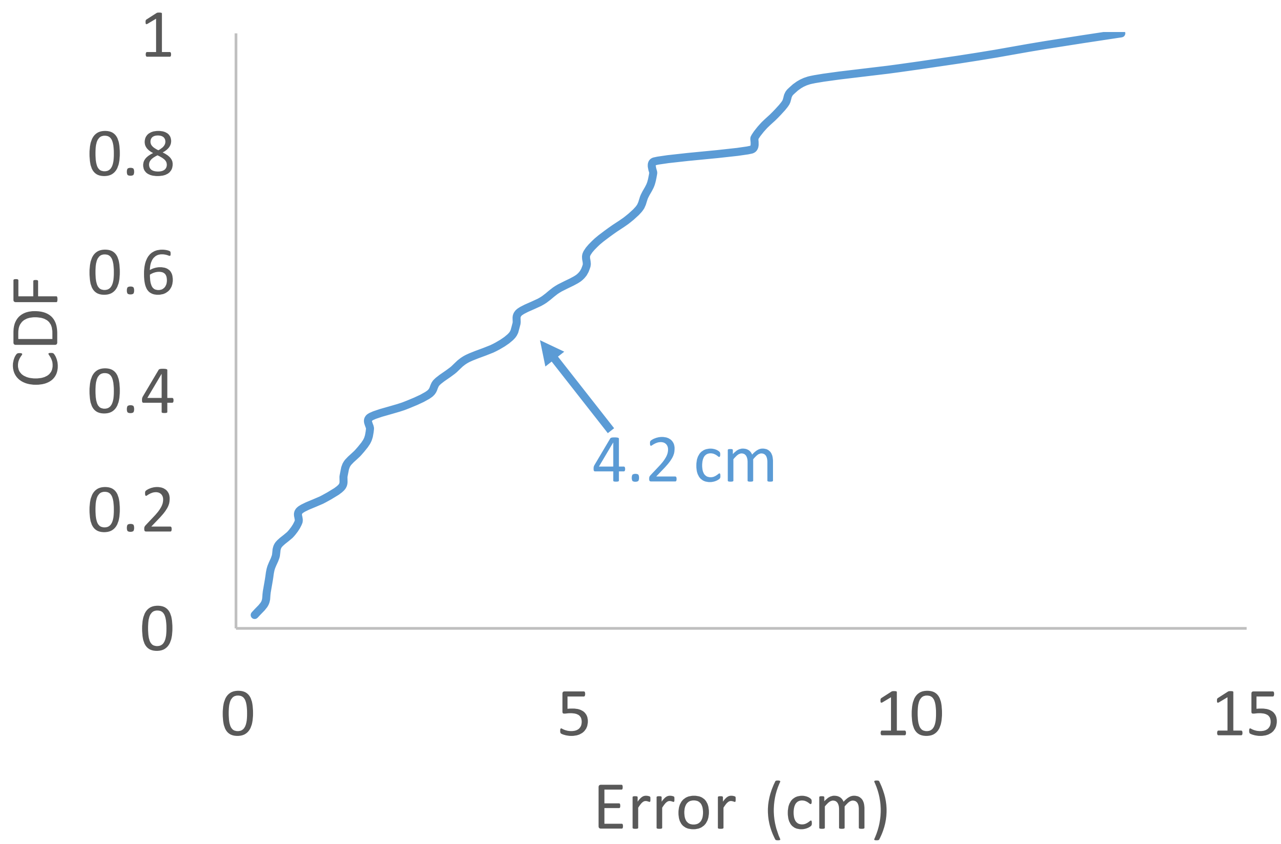
Device to Device localization

Application: TakeMyPicture Drone

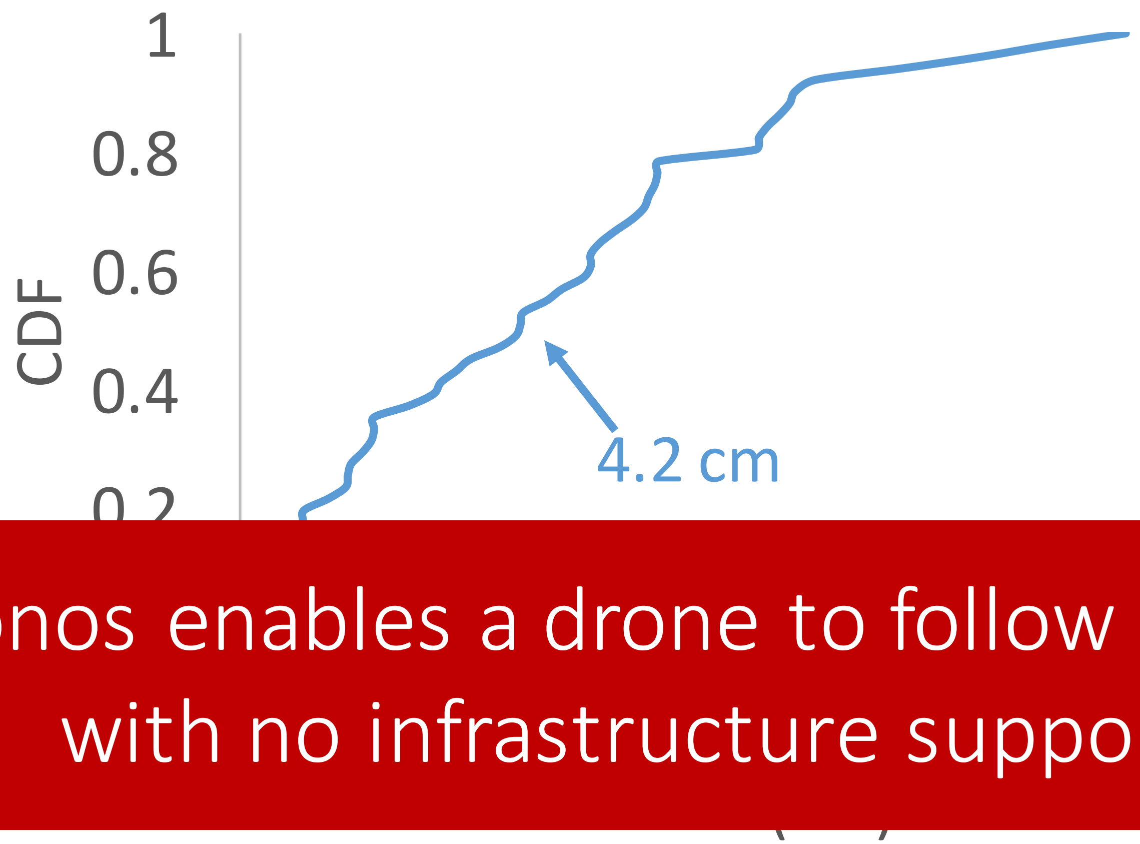
Application: TakeMyPicture Drone



Application: TakeMyPicture Drone



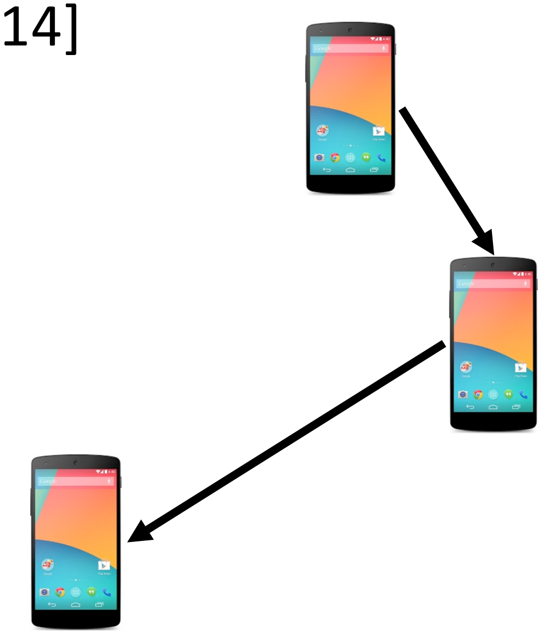
Application: TakeMyPicture Drone



Chronos enables a drone to follow the user with no infrastructure support.

Related Work

- WiFi Localization: SpotFi [SIGCOMM' 15], ToneTrack [Mobicom' 15], Phaser [Mobicom' 14], Tagoram [Mobicom' 14], ….
- Closest Work: SAIL [MobiSys' 14]



Conclusion

- Chronos is the first system to enable accurate localization on off-the-shelf WiFi cards

- Its key enabler is a novel algorithm that can estimate accurate propagation delay, by eliminating the detection delay