PinPoint
Localizing Interfering Radios

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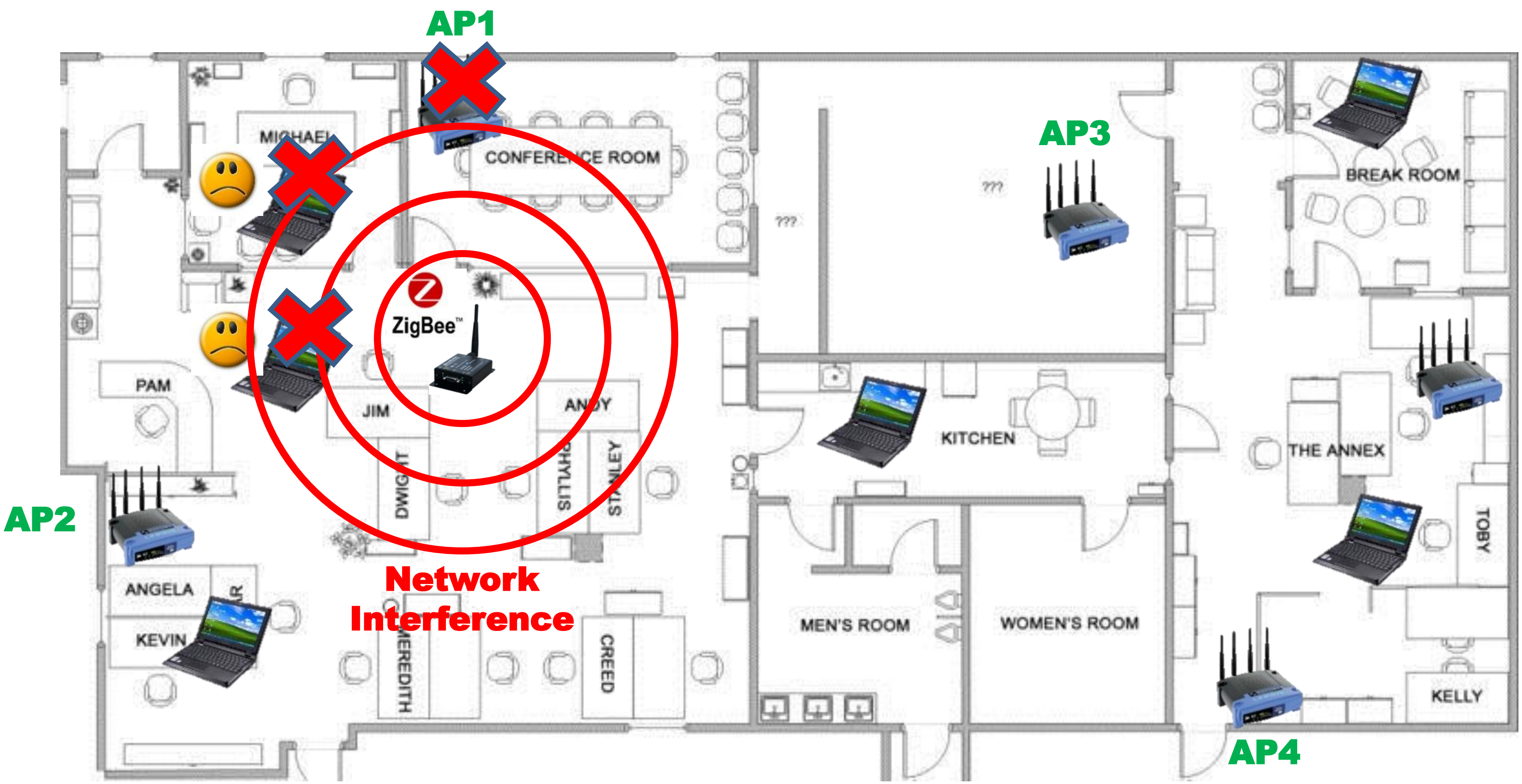
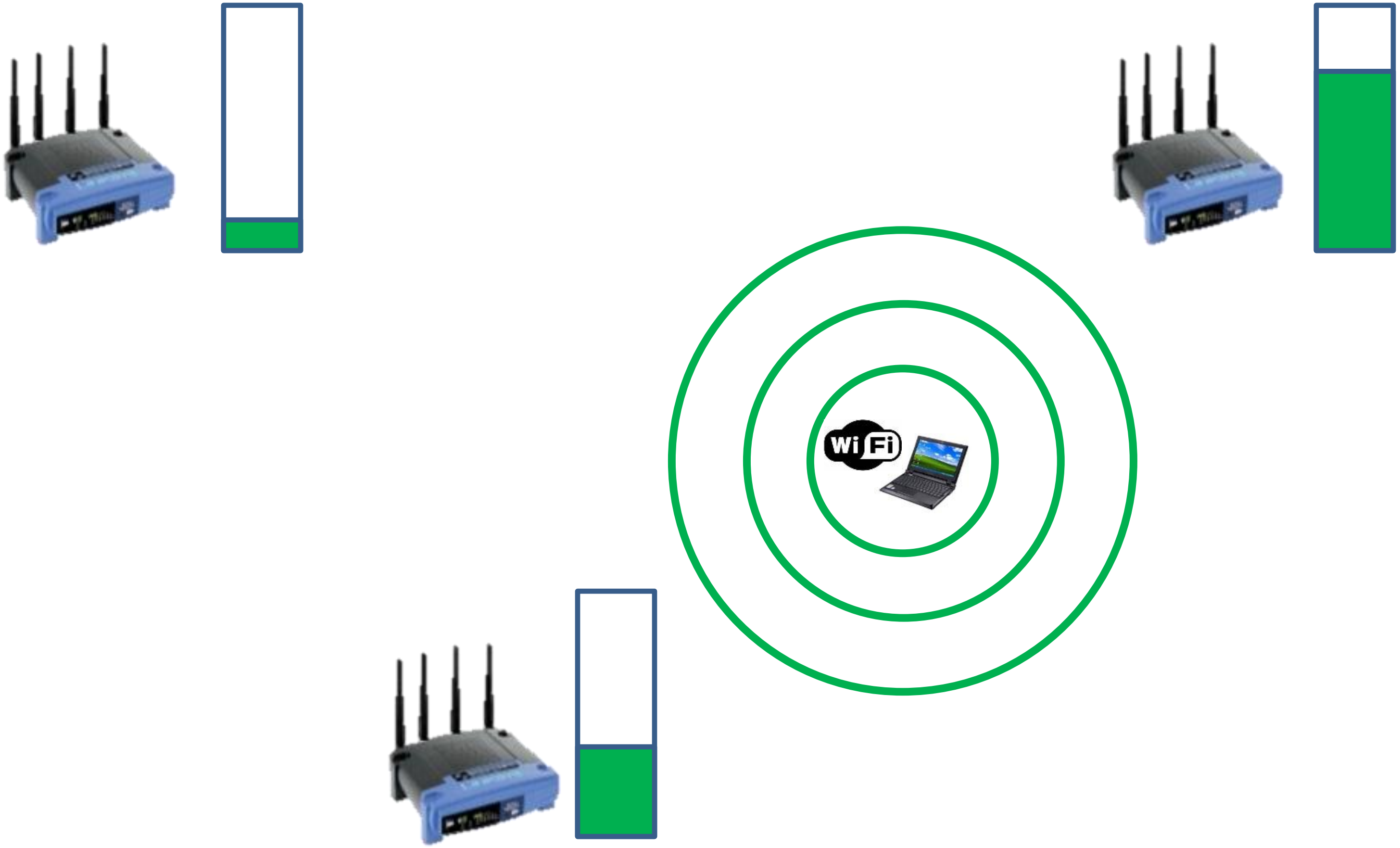
Interference Degrades Wireless Network Performance



Interference Degrades Wireless Network Performance

Without precise localization, troubleshooting performance problems is difficult

Can Existing Localization Work Be Leveraged?



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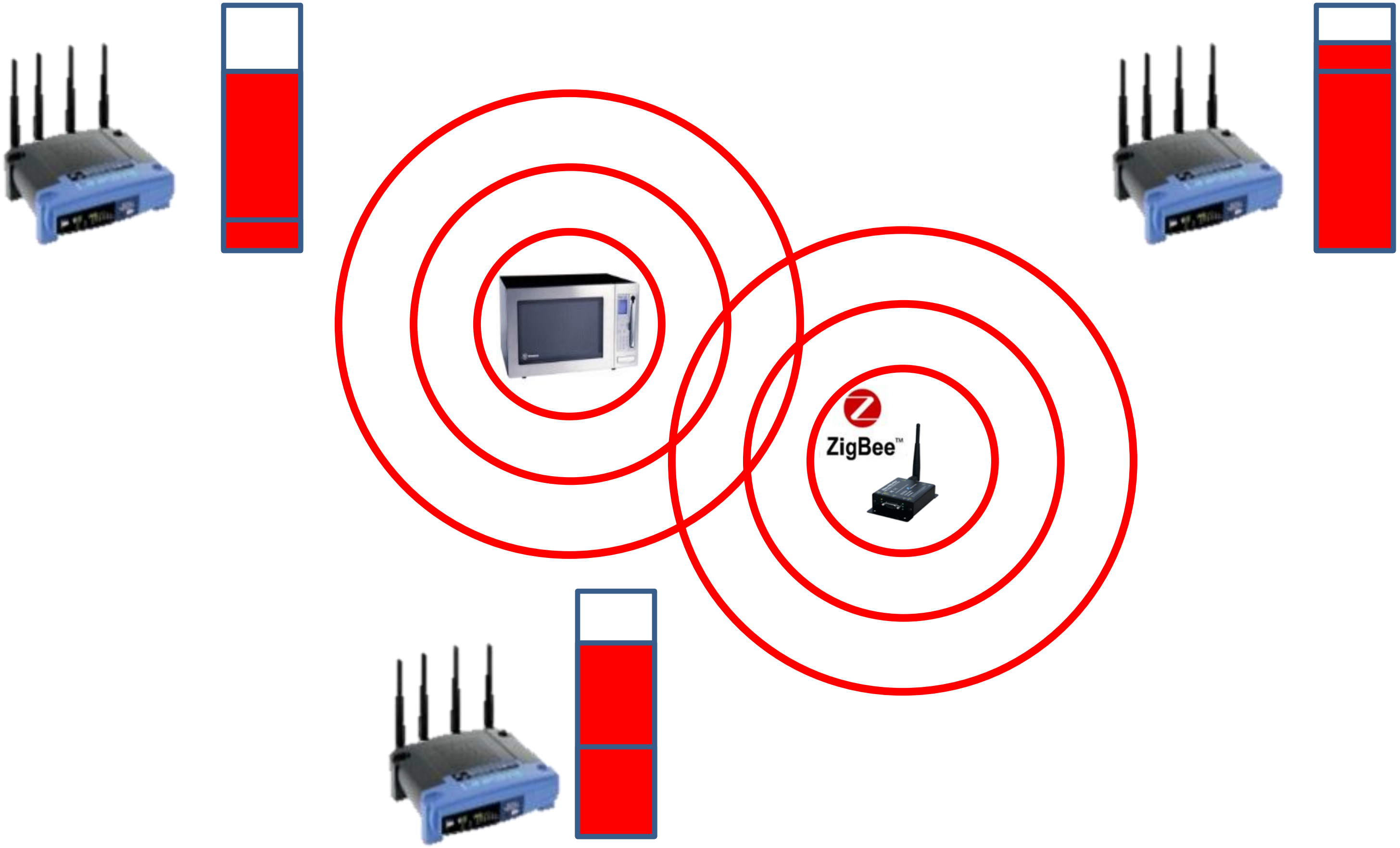
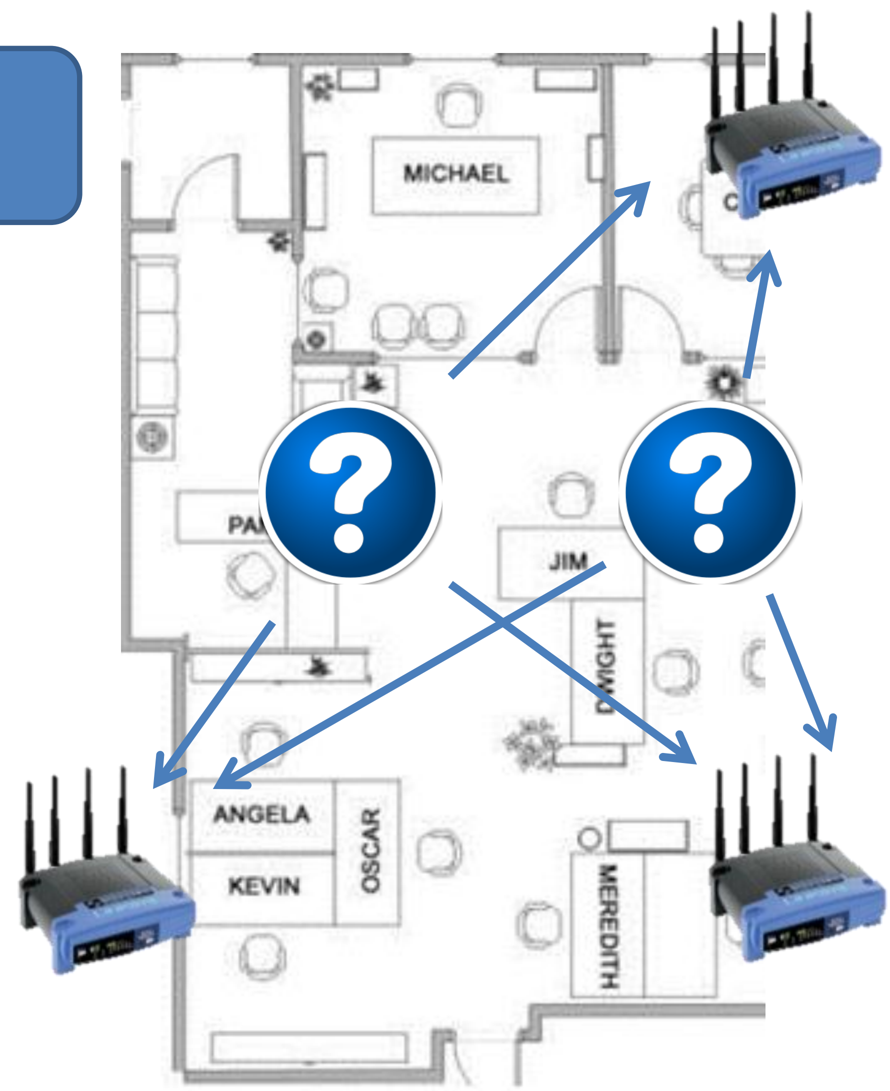


RSSI techniques cannot distinguish between multiple concurrent signals

PinPoint Contributions

1. Differentiate between multiple interfering uncooperative signals



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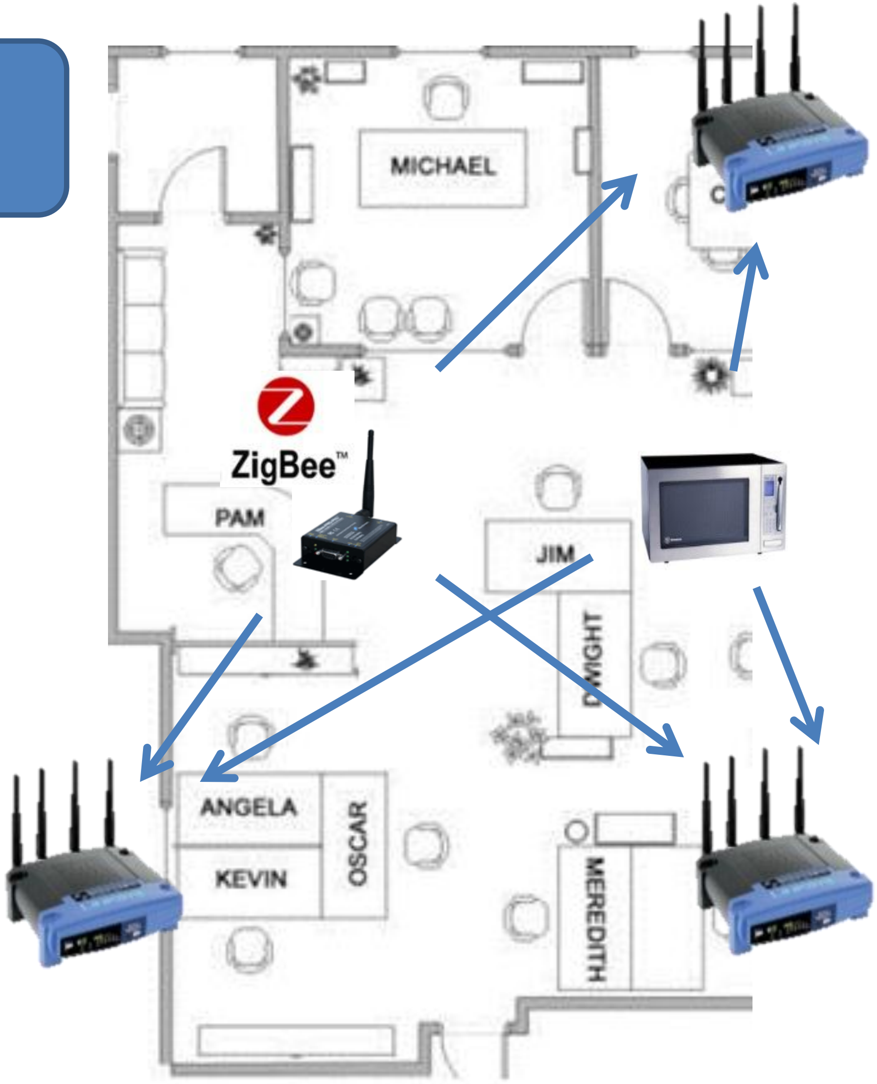
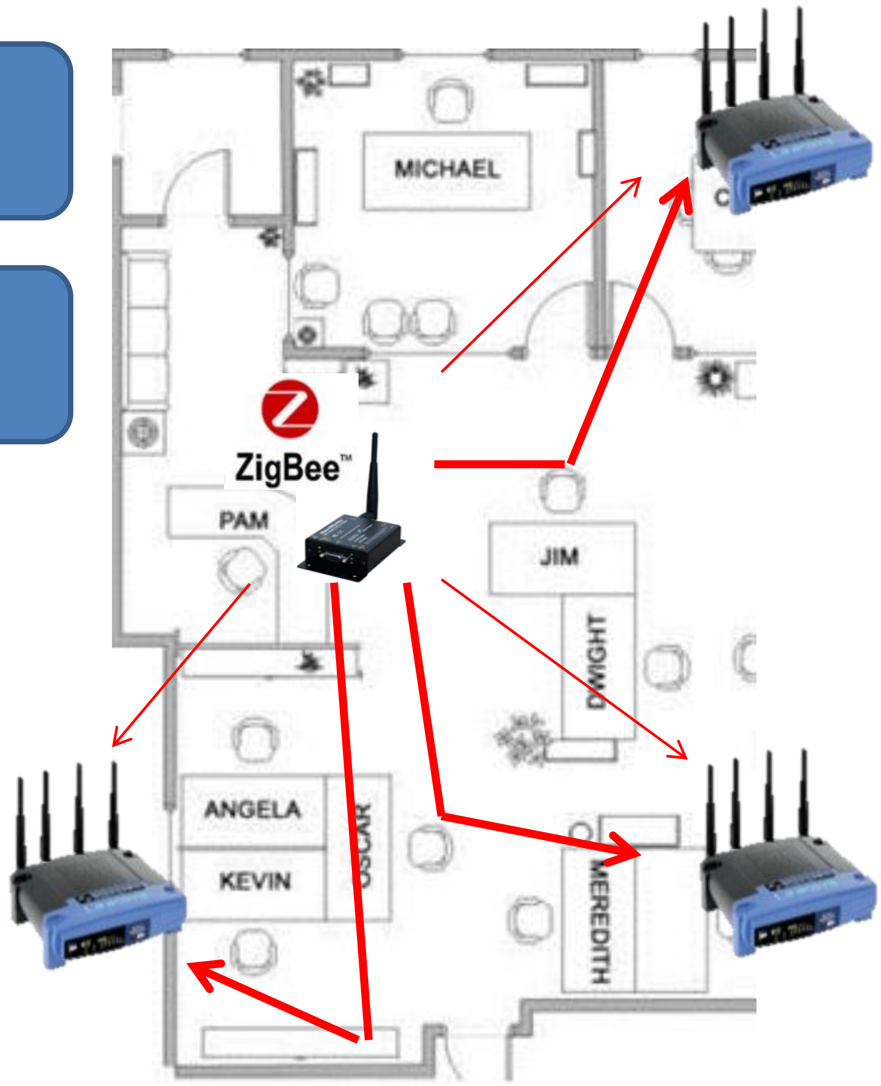


PinPoint Contributions

1. Differentiate between multiple interfering uncooperative signals

2. Compute LOS AoA in an NLOS/ multipath channel environment



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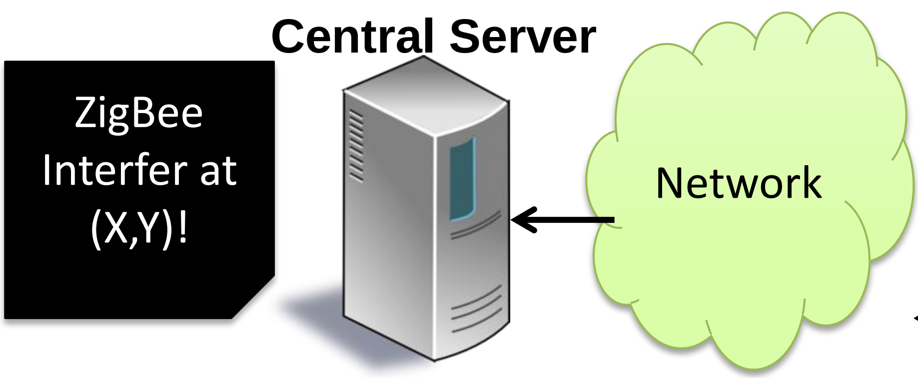
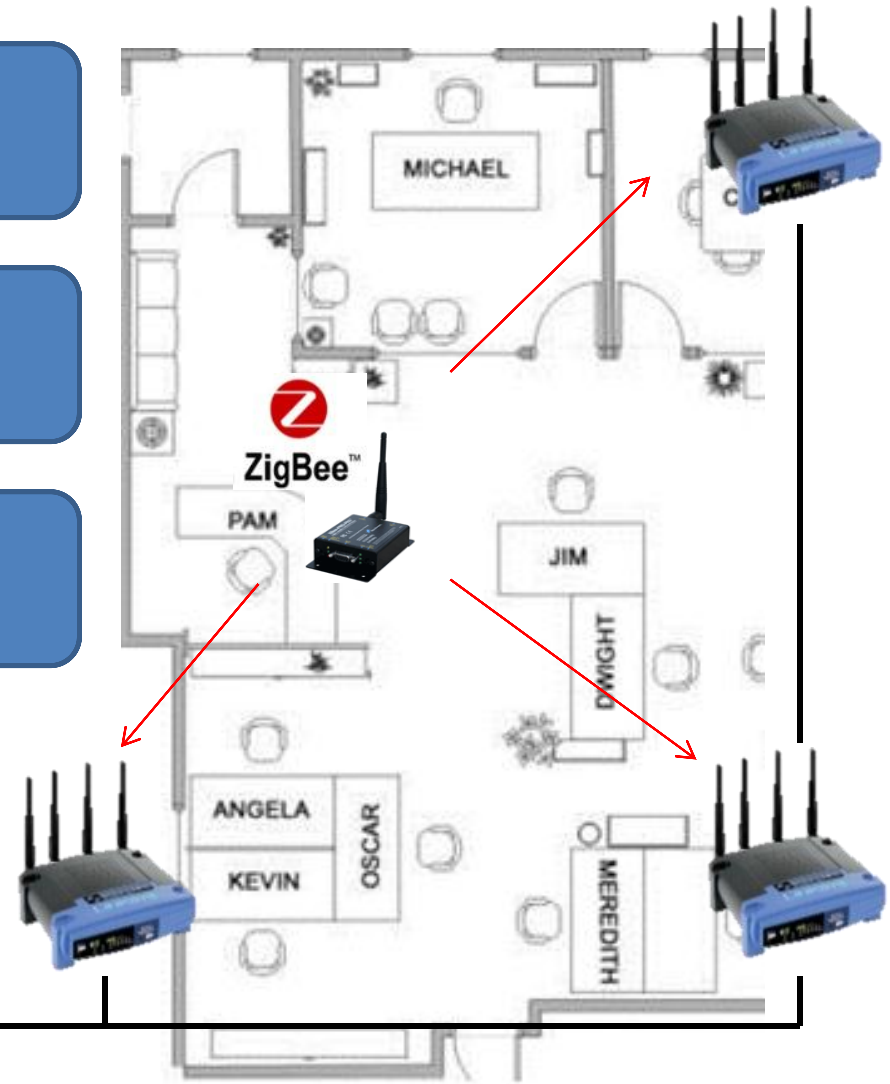
1. Differentiate between multiple interfering uncooperative signals
2. Compute LOS AoA in an NLOS/ multipath channel environment
3. Aggregate and process noisy data from APs to localize interference





More Than Just Interference Localization

Targeted Location Based Advertising

Indoor Navigation (e.g. Airport Terminals)

Real Life Analytics (Gym, Office, etc..)

Indoor localization platform providing sub-meter accuracy could enable a host of applications

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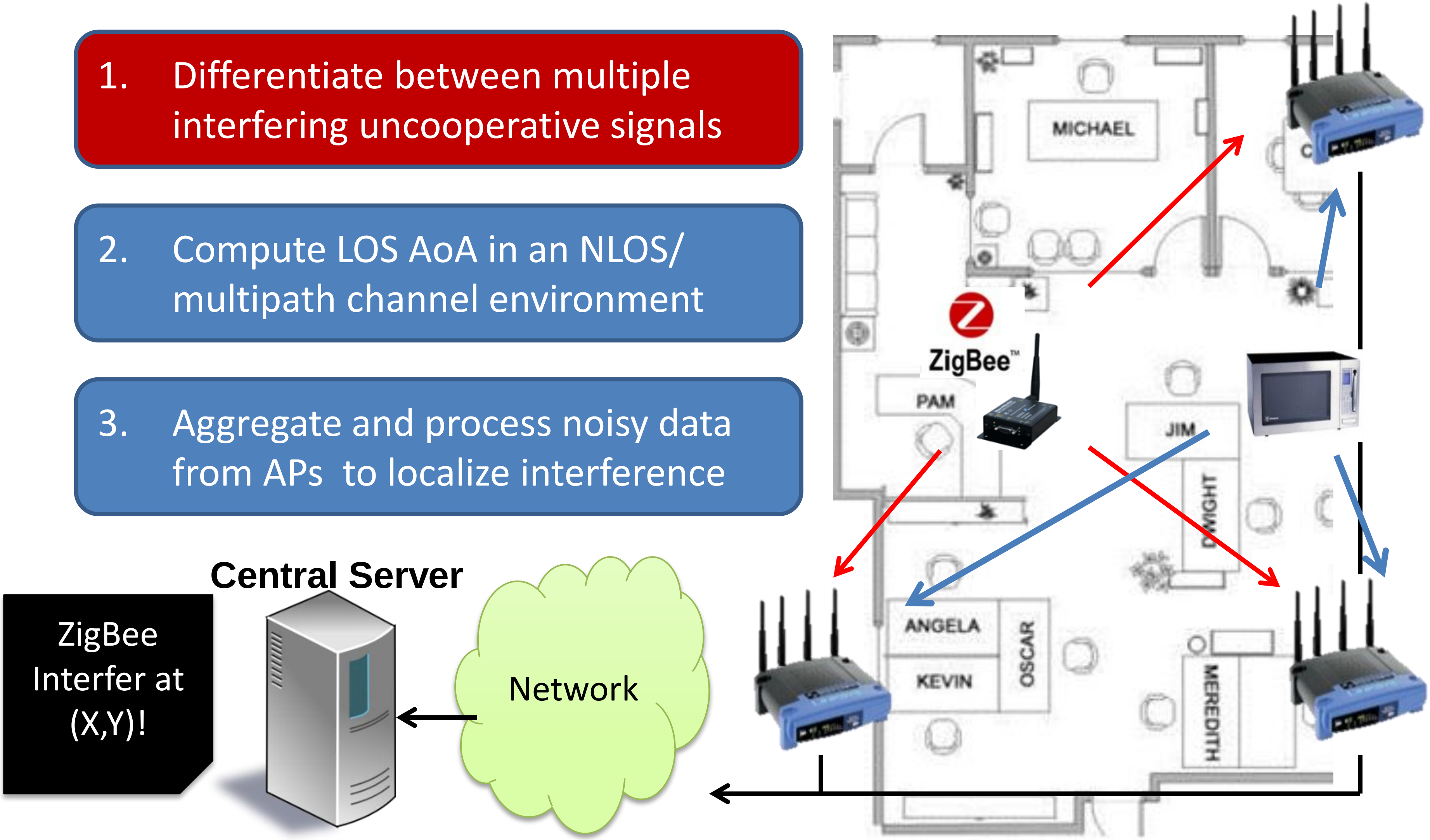
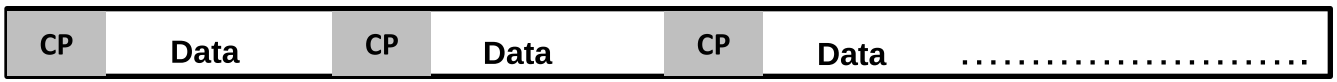
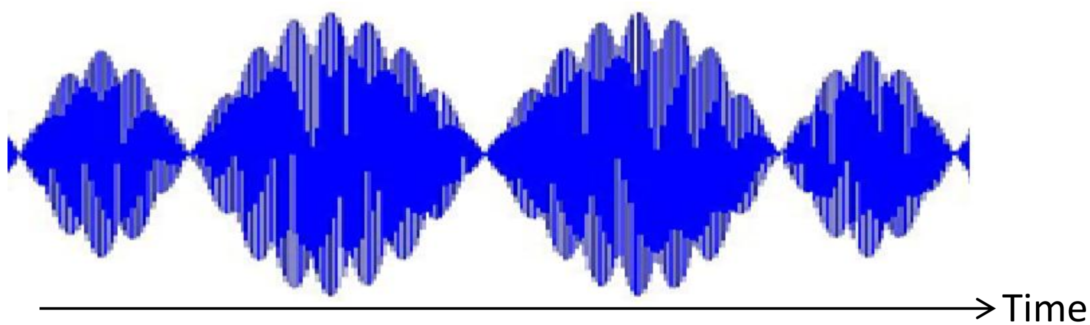


Differentiating Between Multiple Interfering Signals

For almost all “man-made” signals – ***there are hidden repeating patterns that are unique and necessary for operation***



Repeating Patterns in WiFi OFDM signals



Repeating Patterns in Zigbee signals

We can leverage DOF [SIGCOMM’10] identify signal types and generate unique feature vectors

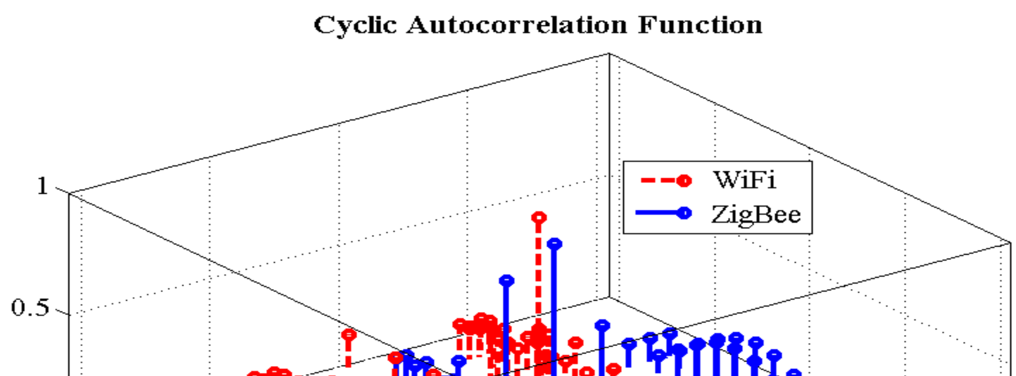
Extracting Features from Patterns

If a signal has a repeating pattern, then when we

- Correlate the received signal against itself delayed by a fixed amount, the correlation will peak when ***the delay is equal to the period at which the pattern repeats.***

$$R_x^{\alpha}(\tau) = \sum_{n}^{\infty} x[n][x^*[n-\tau]]e^{-j2\pi\alpha n}$$

Pattern Frequency (α) – The frequency at which the pattern repeats



<u>CSSI</u>

•Strength of Correlation at a particular pattern frequency

<u>Advantages</u>

•Robustness to noise,

•Unique for each protocol

Cyclic Signal Strength Indicator (CSSI) can be computed for each interfering source

PinPoint Contributions

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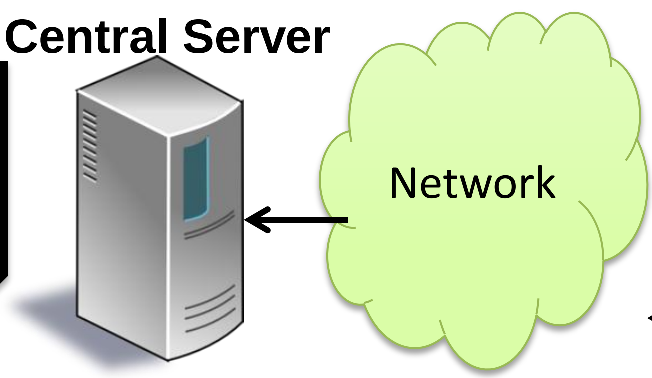
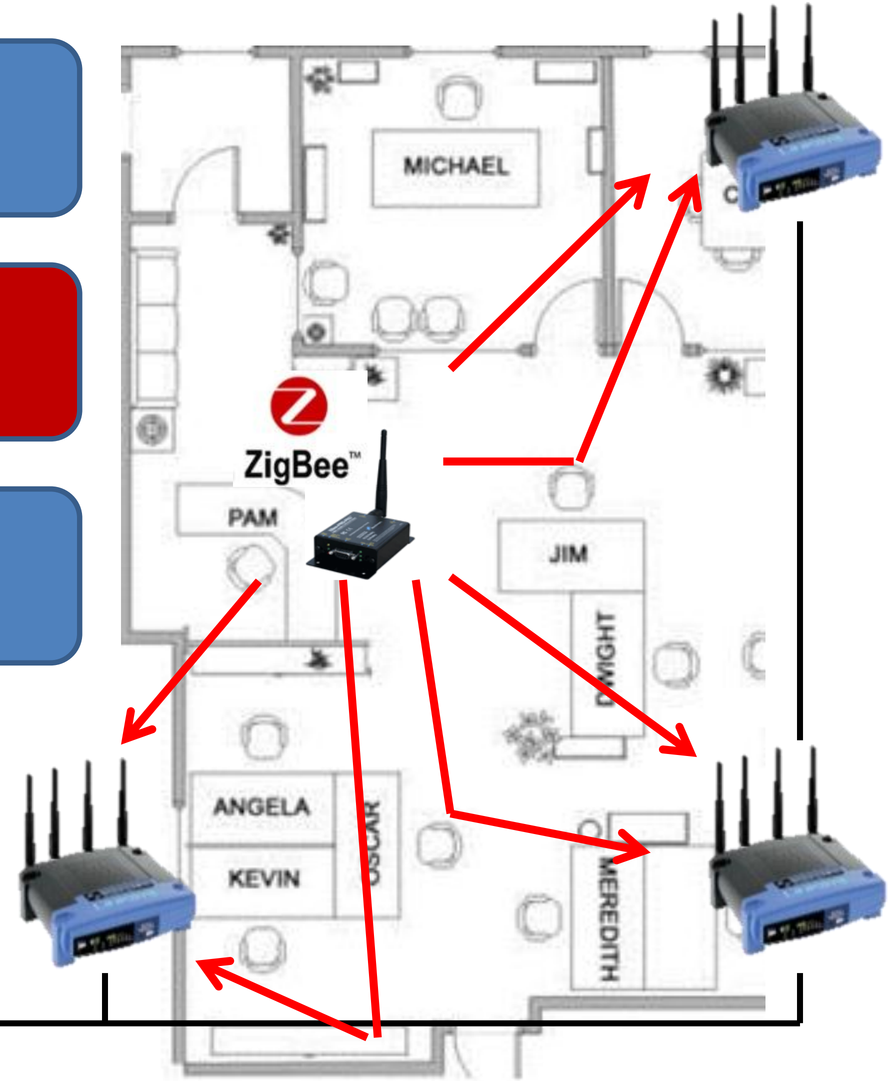
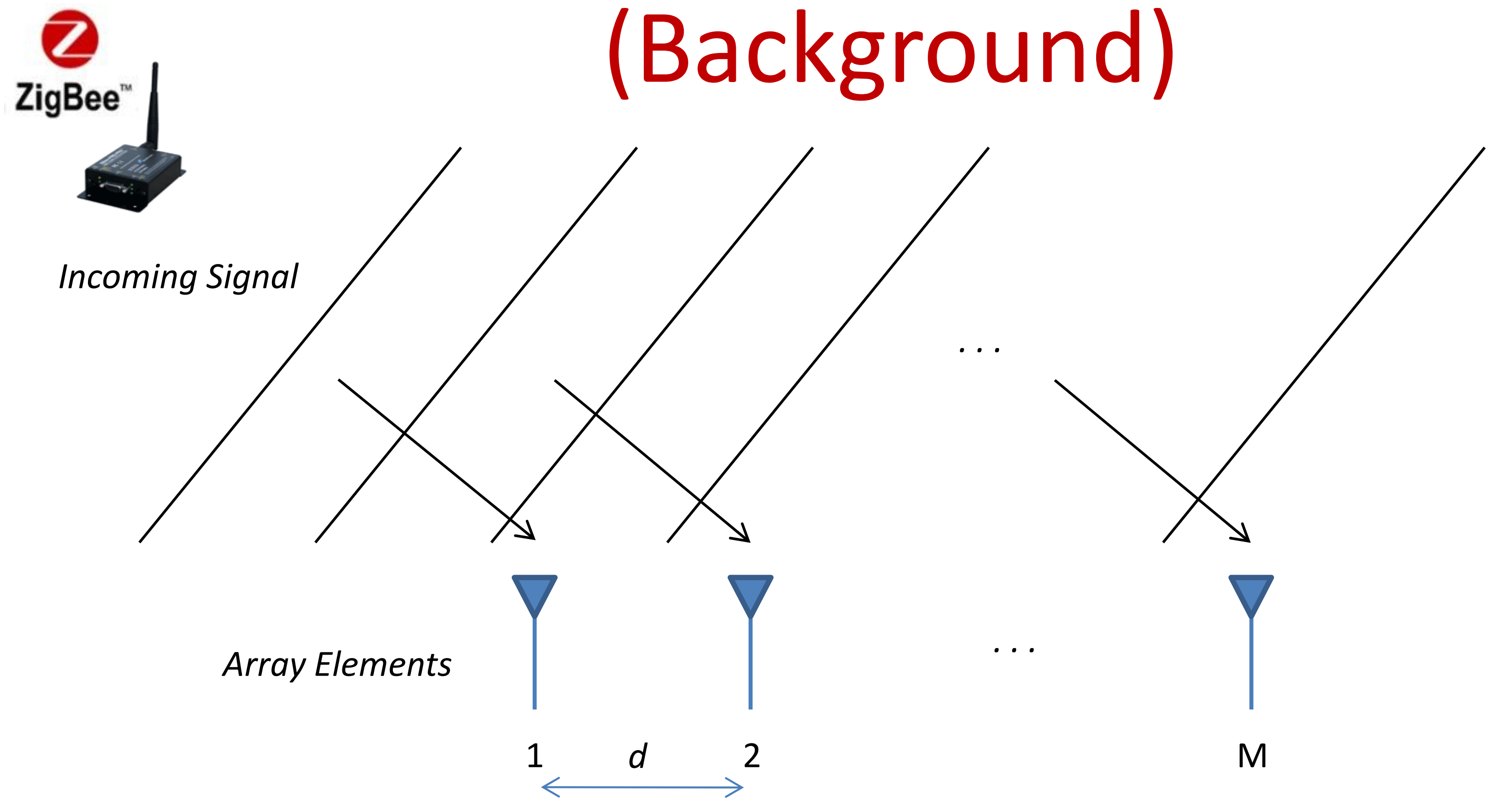
ZigBee Interfer at (X,Y)!



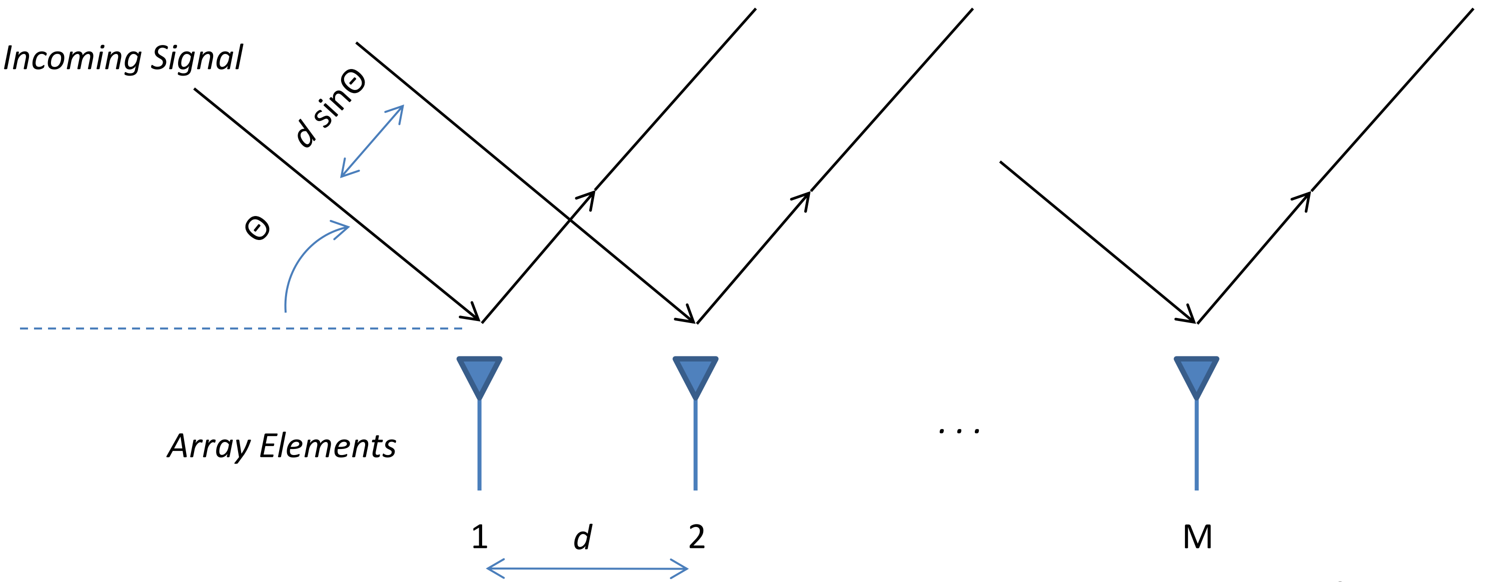


Estimating Angles of Arrival (Background)



The m^{th} array element experiences a time delay of τ relative to the first array element

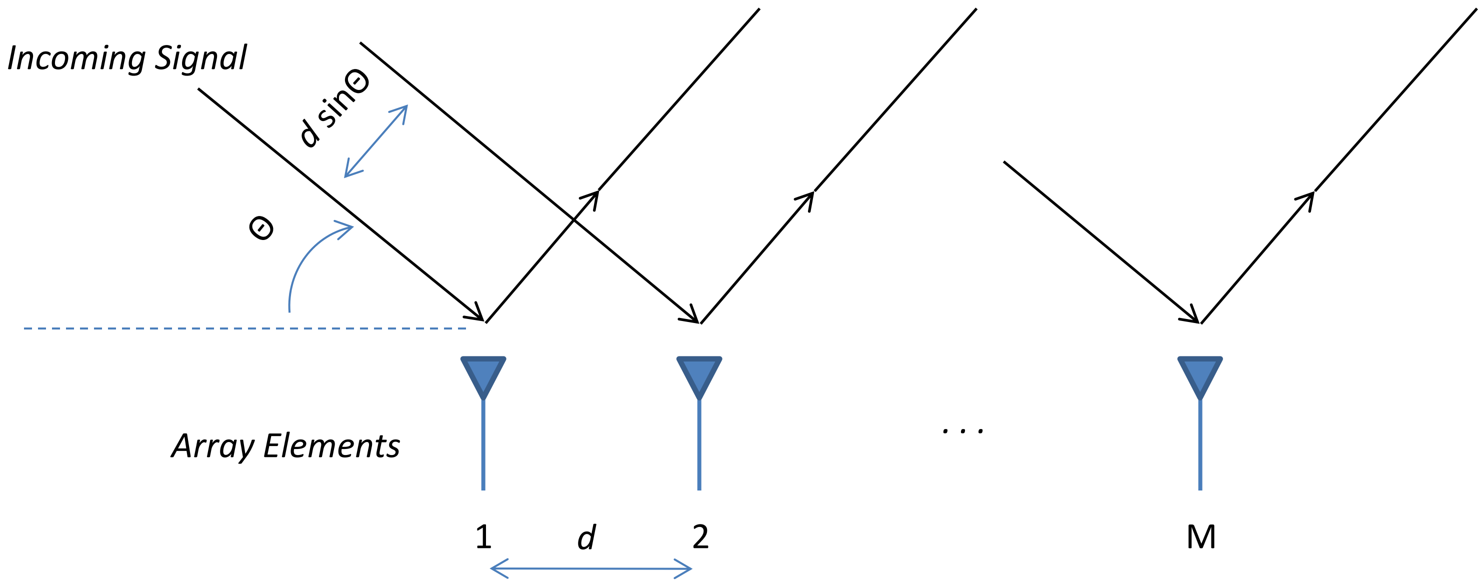
Estimating Angles of Arrival (Background)



Received Signal at Antenna i $y_i(t) = x(t)e^{-j2\pi f_c \tau_i} + n_i(t)$

This delay, τ, is a function of the inter-element spacing, as well as the <u>*Angle of Arrival (AoA)*</u>

Estimating Angles of Arrival (Background)



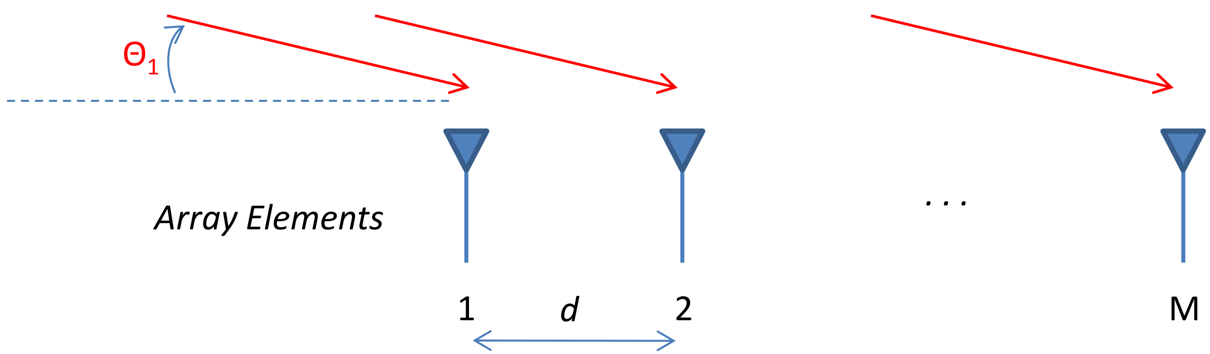
Array

$$\boldsymbol{y}(t) = \boldsymbol{\phi}(\boldsymbol{\theta})x(t) + \boldsymbol{n}(t)$$

where $$\boldsymbol{\phi}(\boldsymbol{\theta}) = \begin{bmatrix} 1 & e^{-j2\pi f_c \tau_2(\theta)} & \ldots & e^{-j2\pi f_c \tau_M(\theta)} \end{bmatrix}$$

What happens when there is multipath?

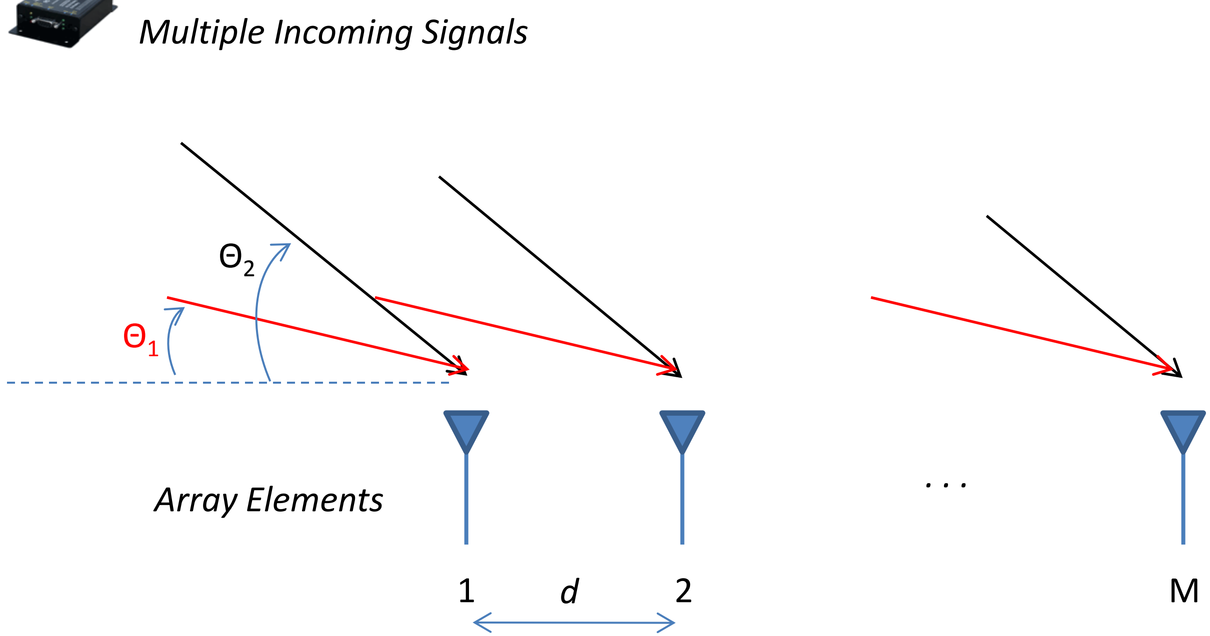
Multiple Incoming Signals



<u>Array</u>

$$\boldsymbol{y}(t) = \boldsymbol{\phi}(\theta_1)x_1(t) + \boldsymbol{n}(t)$$

What happens when there is multipath?

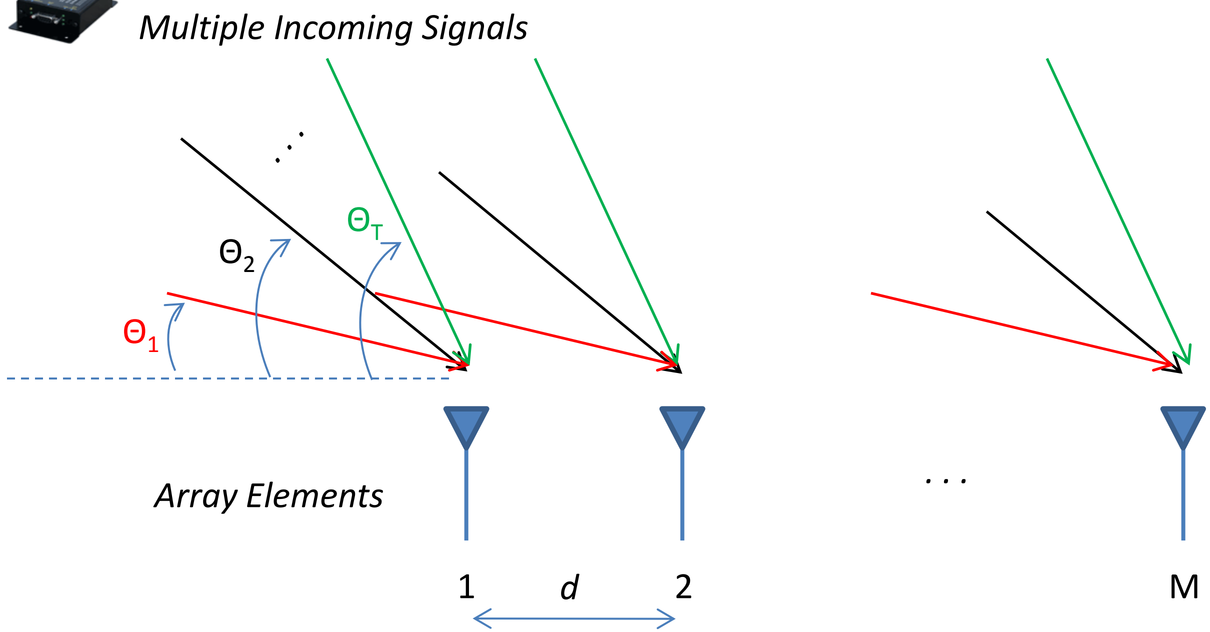


<u>Array</u>

$$\mathbf{y}(t) = \boldsymbol{\phi}(\theta_1)x_1(t) + \mathbf{n}(t)$$

$$\mathbf{y}(t) = \boldsymbol{\phi}(\theta_1)x_1(t) + \boldsymbol{\phi}(\theta_2)x_2(t) + \mathbf{n}(t)$$

What happens when there is multipath?

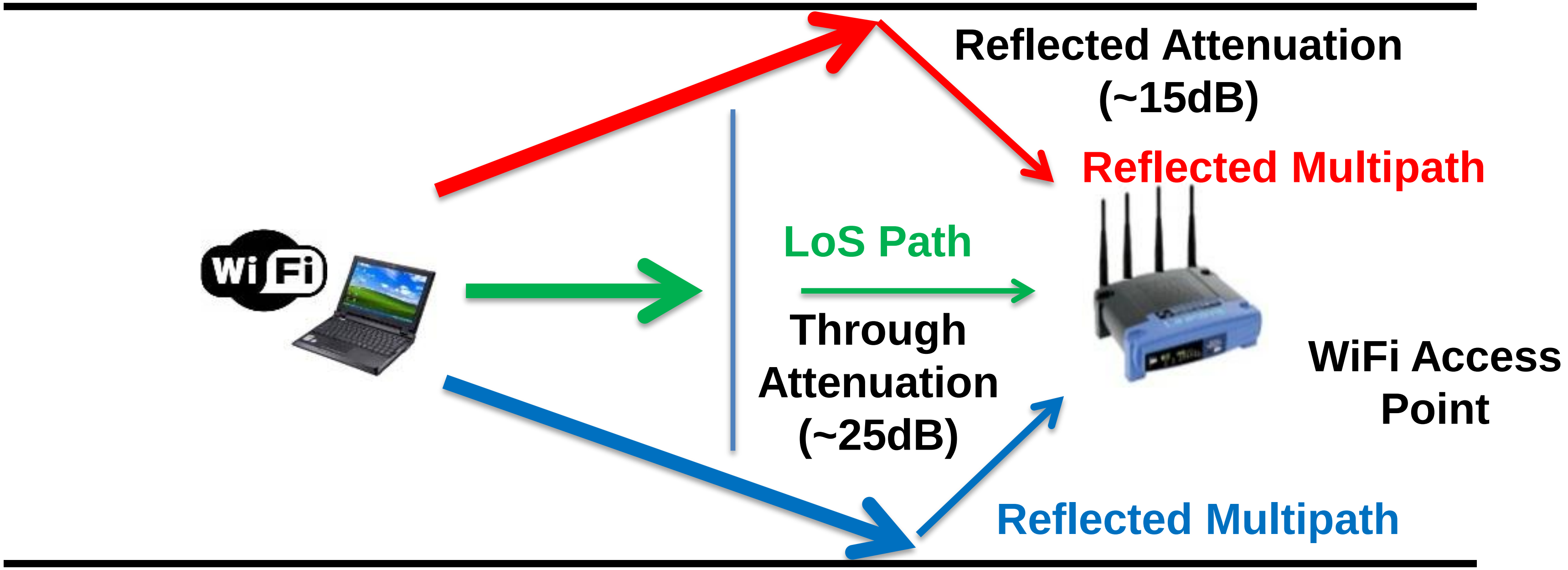


Array

$$y(t) = \sum_{i=1}^{T} \phi(\theta_i) x_i(t) + n(t) = \Phi x(t) + n(t)$$

$$\Phi = [\phi(\theta_1) \;\; \phi(\theta_2) \;\; \ldots \;\; \phi(\theta_T)]$$

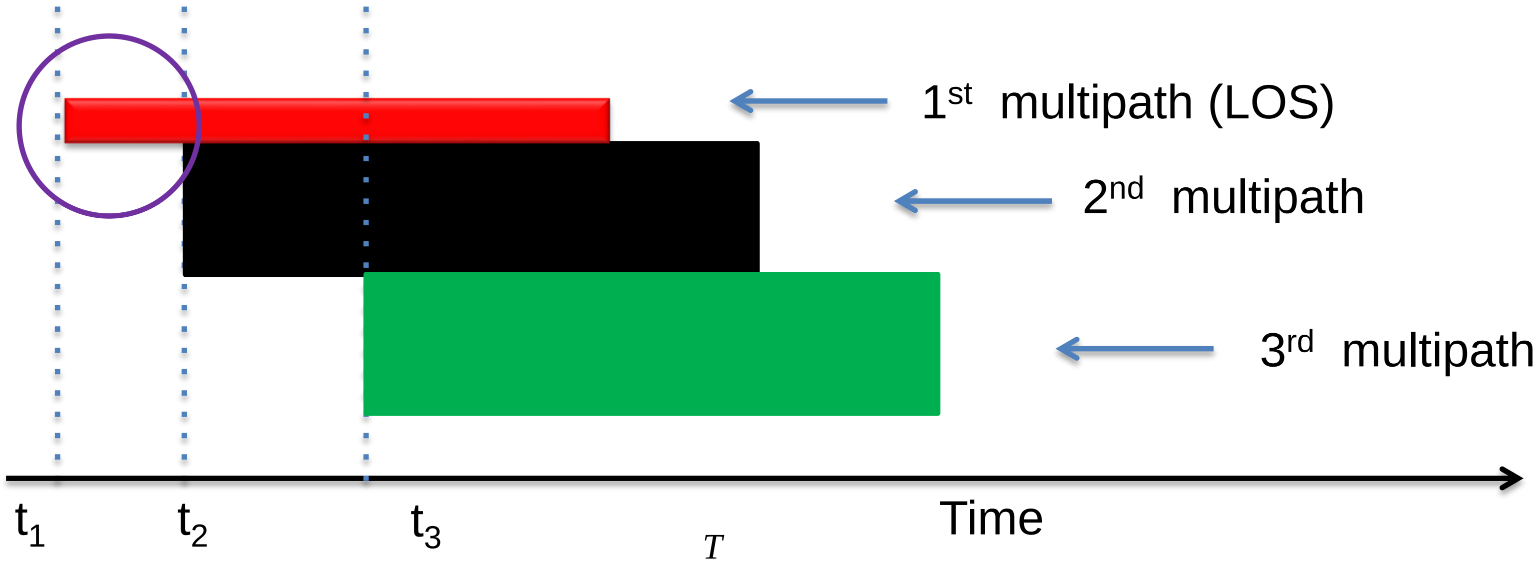
Challenge: Reflected Paths Mask the LOS Component



PinPoint applies novel techniques to detect this LOS component, even when it is >10dB weaker

LOS Path Impinges First, Even When Obstructed

$$\boldsymbol{y}(t) = \boldsymbol{\phi}(\boldsymbol{\theta}_1)x_1(t) + \boldsymbol{n}(t)$$

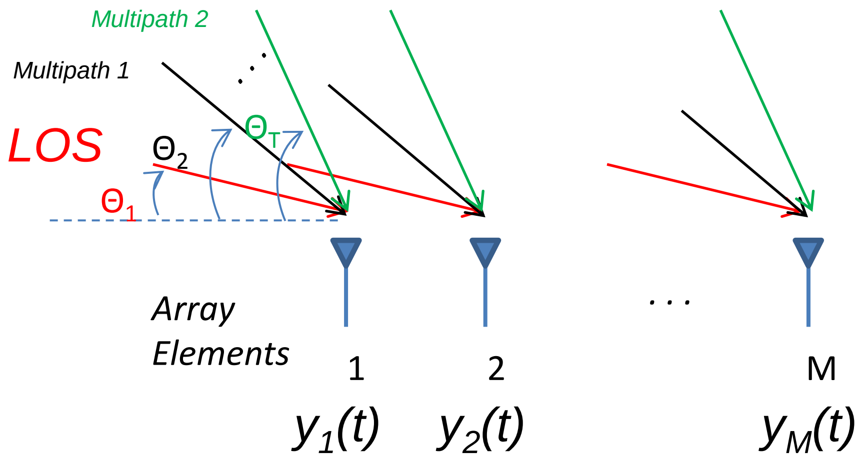


$$\boldsymbol{y}(t) = \sum_{i=1}^{T} \boldsymbol{\phi}(\boldsymbol{\theta}_i)x_i(t) + \boldsymbol{n}(t)$$

We want to detect the portion of the received signal that is un-interfered by the multipath

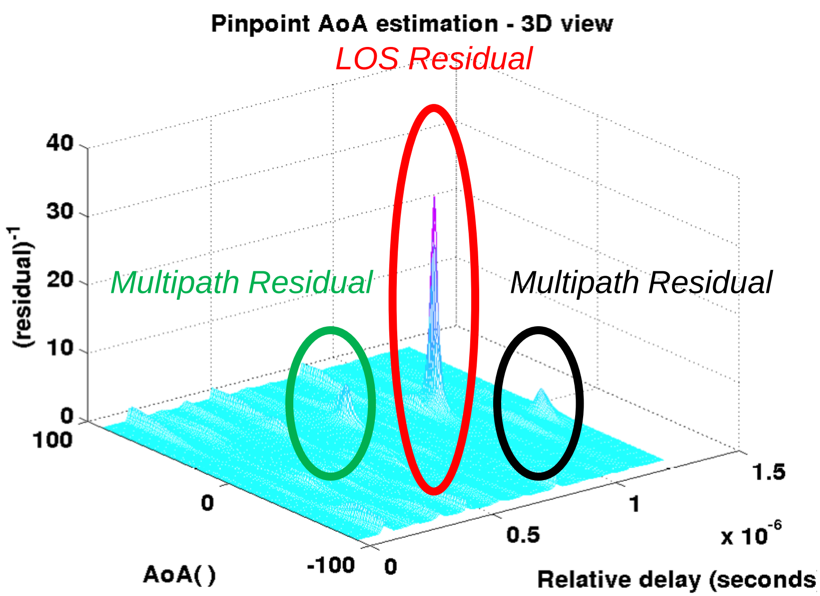
LOS Path Impinges First, Even When Obstructed

Can't directly measure ***x***…measure the relative phase delay in the signal



$$\phi(\theta)=\left[1 \;\; e^{-j2\pi f_c \tau_2(\theta)} \;\; \ldots \;\; e^{-j2\pi f_c \tau_M(\theta)}\right]$$

$$\mathbf{y}/_{y_1(t)} - \phi(\theta) = residual$$



We can compute the relative delay and AoA simultaneously – LOS is the first arriving AoA

PinPoint Contributions

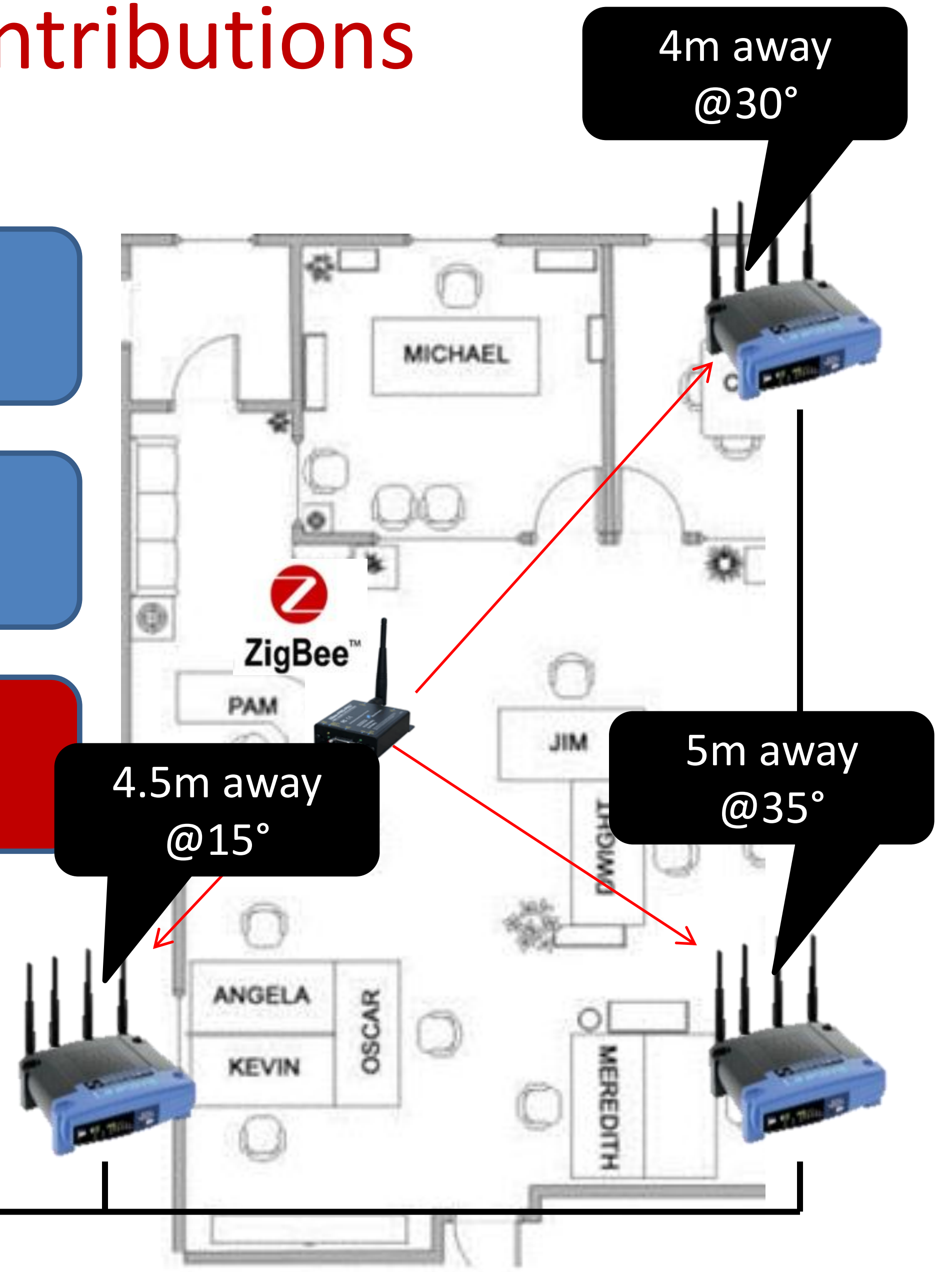
CSSI + Type

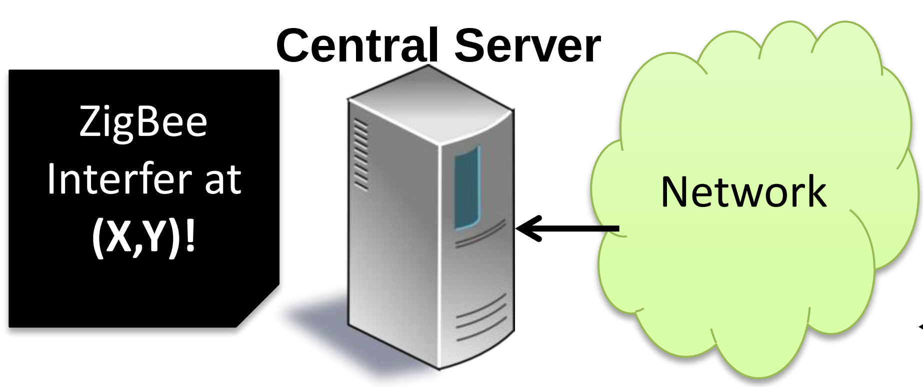
1. Differentiate between multiple interfering uncooperative signals

AoA

2. Compute LOS AoA in an NLOS/ multipath channel environment

3. Aggregate and process noisy data from APs to localize interference





Experimental Setup

Comparison Setup

- Single floor 15,000 square feet office environment
- Five APs deployed to provide uniform coverage
- Random subset of 3 different radios are selected in each "run" (WiFi, Bluetooth, ZigBee, Microwave) with varying PHY parameters
- 30 Different "runs" for each signal combination

Compared Approaches

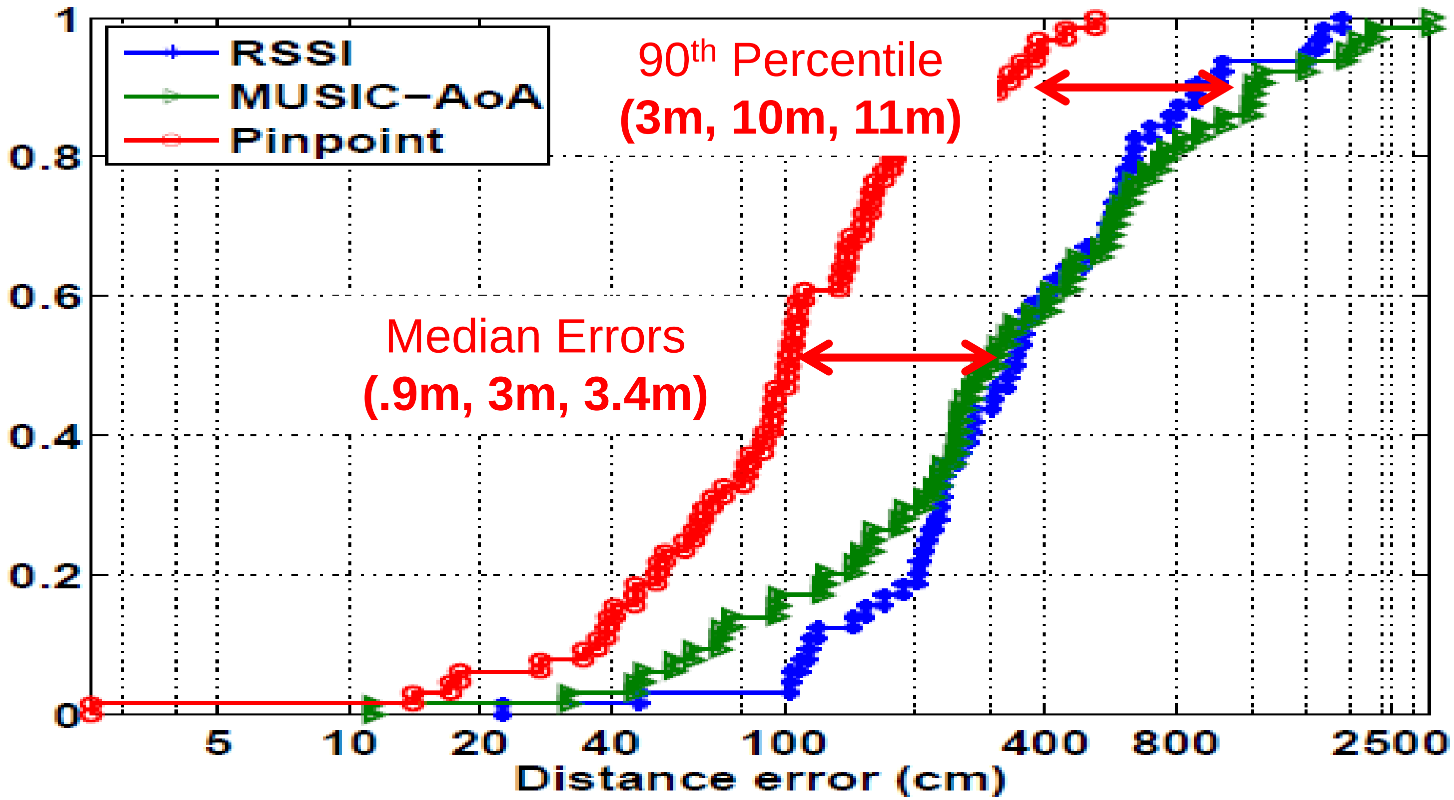
MUSIC-AoA Based Localization

- Angle of Arrival estimation directly on received time samples

RSSI Based Cooperative Localization

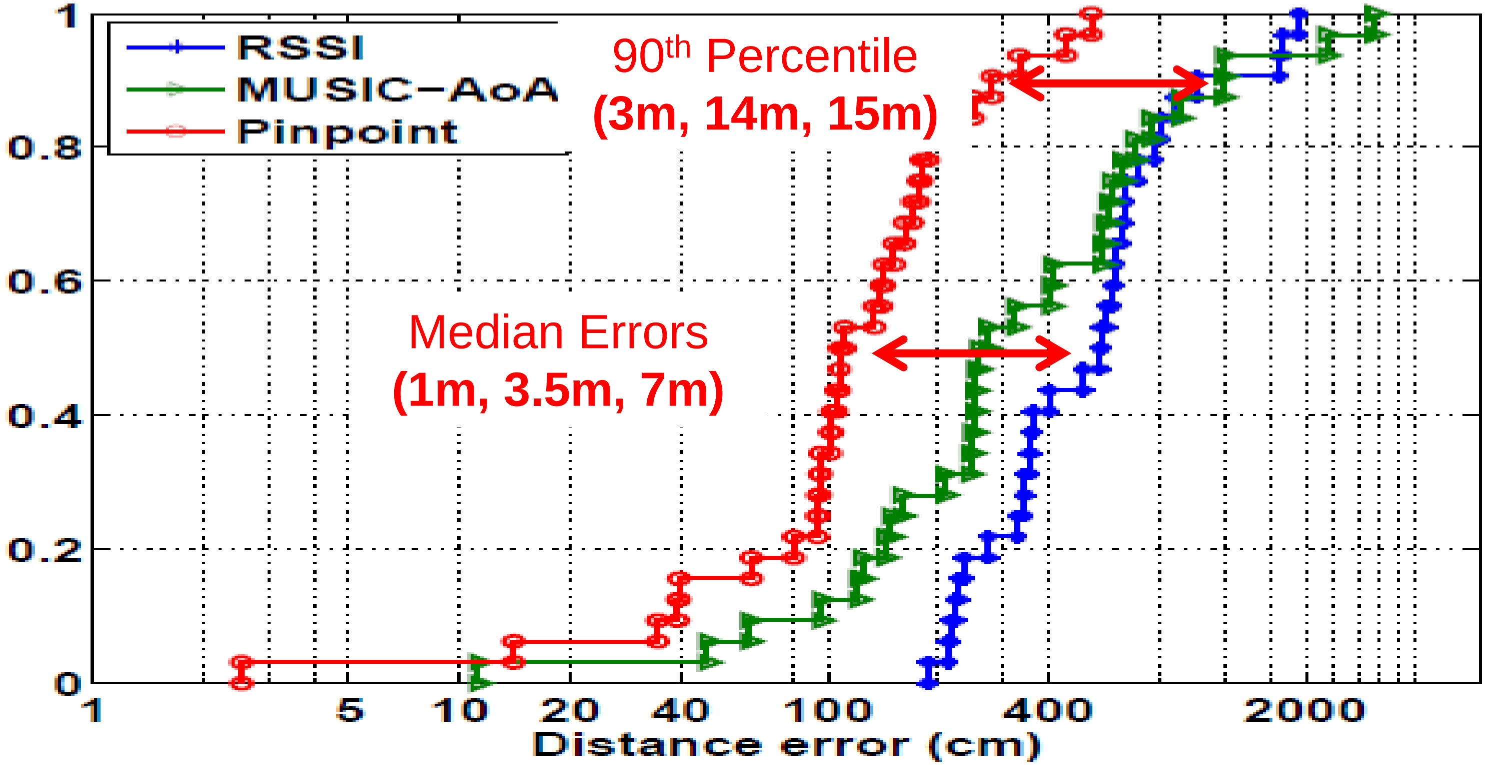
- APs have knowledge of client transmit powers, NLOS path model used to estimate range

Overall Localization Performance CDF



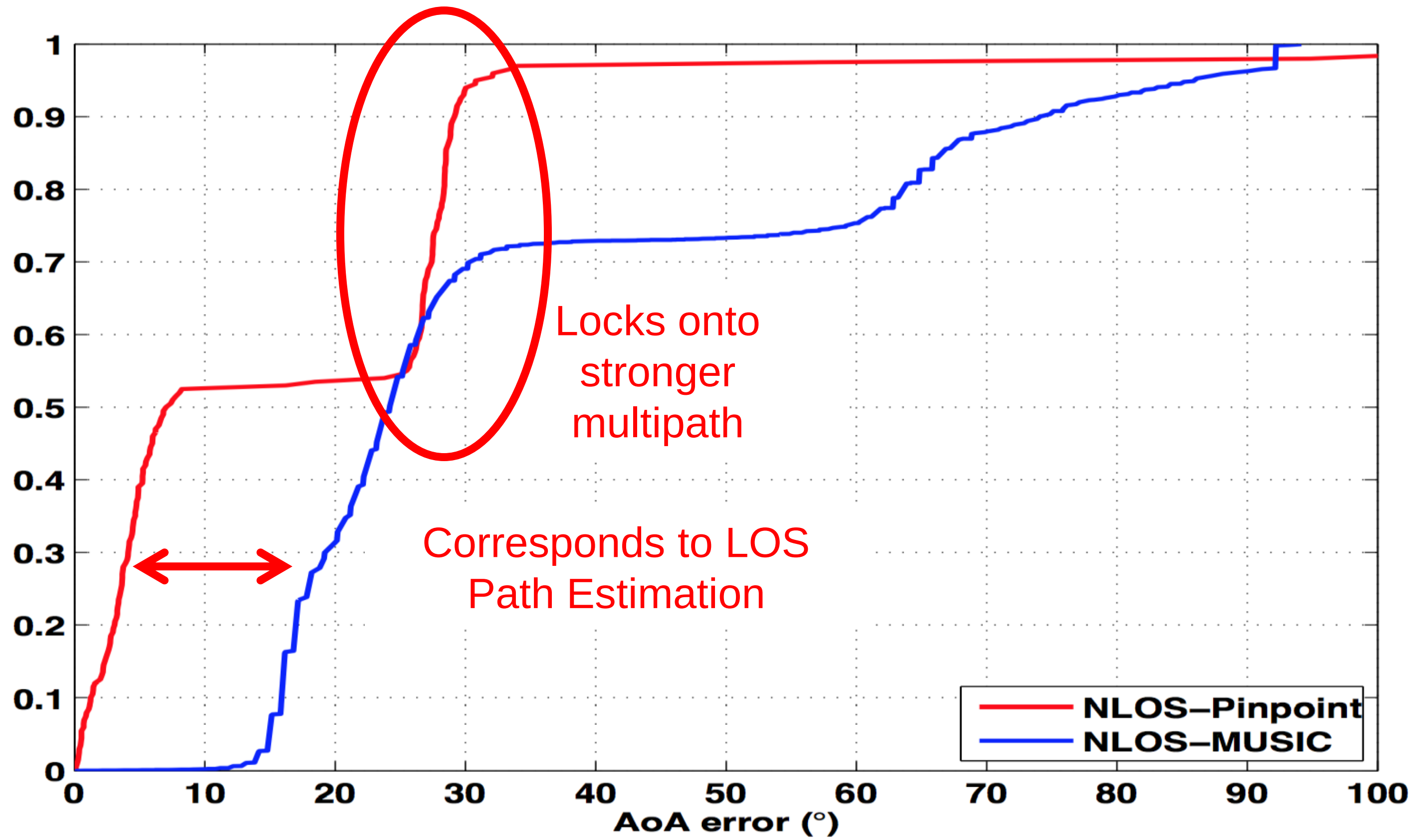
PinPoint's ability to 1) Disentangle interference and 2) Identify the LOS component allows it to achieve sub meter accuracy

Localization Performance With Overlapping Interference



Overlapping interference minimally impacts PinPoint

Comparison of NLOS AoA Performance



PinPoint can identify the LOS even when it is 10dB weaker than the strongest multipath reflection

Conclusion

PinPoint…

- Leverages WiFi infrastructure as backbone
- Capable of differentiating between multiple interfering sources
- Develops novel signal processing algorithms to compute the LOS AoA even in NLOS/multipath environments
- Central optimization algorithm results in sub-meter localization accuracy