PinPoint
Localizing Interfering Radios

Kiran Joshi, Steven Hong, Sachin Katti

Stanford University

April 4, 2012
Interference Degrades Wireless Network Performance
Interference Degrades Wireless Network Performance

Without precise localization, troubleshooting performance problems is difficult.
Can Existing Localization Work Be Leveraged?
Can Existing Localization Work Be Leveraged?

RSSI techniques cannot distinguish between multiple concurrent signals
PinPoint Contributions

1. Differentiate between multiple interfering uncooperative signals
1. Differentiate between multiple interfering uncooperative signals
PinPoint Contributions

1. Differentiate between multiple interfering uncooperative signals

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

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

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

- **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.
PinPoint Contributions

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
Differentiating Between Multiple Interfering Signals

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

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 \textit{the delay is equal to the period at which the pattern repeats}.

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

Pattern Frequency ($\alpha$) – The frequency at which the pattern repeats

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

\textbf{Advantages}
- Robustness to noise,
- Unique for each protocol
PinPoint Contributions

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
The $m^{th}$ array element experiences a time delay of $\tau$ relative to the first array element.
Estimating Angles of Arrival (Background)

This delay, $\tau$, is a function of the inter-element spacing, as well as the **Angle of Arrival (AoA)**.
Estimating Angles of Arrival (Background)

Incoming Signal

Array Elements

Array

\[ y(t) = \phi(\theta)x(t) + n(t) \]

where

\[ \phi(\theta) = \begin{bmatrix} 1 & e^{-j2\pi f_c \tau_2(\theta)} & \ldots & e^{-j2\pi f_c \tau_M(\theta)} \end{bmatrix} \]
What happens when there is multipath?

Multiple Incoming Signals

Array Elements

Array

\[ y(t) = \phi(\theta_1)x_1(t) + n(t) \]
What happens when there is multipath?

Multiple Incoming Signals

Array Elements

\[ y(t) = \phi(\theta_1)x_1(t) + n(t) \]

\[ y(t) = \phi(\theta_1)x_1(t) + \phi(\theta_2)x_2(t) + n(t) \]
What happens when there is multipath?

Multiple Incoming Signals

Array Elements

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

\[ y(t) = \phi(\theta_i)x_i(t) + n(t) \]

\[ y(t) = \sum_{i=1}^{T} \phi(\theta_i)x_i(t) + n(t) \]

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

\[
\phi(\theta) = \begin{bmatrix} 1 & e^{-j2\pi f_c \tau_2(\theta)} & \cdots & e^{-j2\pi f_c \tau_M(\theta)} \end{bmatrix}
\]

\[
y(t)/y_1(t) - \phi(\theta) = \text{residual}
\]

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

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
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
Median Errors (.9m, 3m, 3.4m)

90th Percentile (3m, 10m, 11m)

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