Lecture 11: Wireless Localization

Why do we want to do wireless localization?

Applications:
- Advertisements (Targeted ads)
- Virtual Reality
- Indoor Navigation (inside shopping mall, lab, etc.)
- Smart Homes (energy efficiency, e.g. light automatically turns off when nobody in room)
- Location Based Service (tagging, reminder, etc.)
- Behavior Analytics (health, Ads, etc.)
- Locating Misplaced Items (where are my keys?)
- Gestures / Writing in the Air

Why do we want to use wireless? Why not something else?

Reasons:
- Portable (small form factor)
- Ubiquitous (Wi-Fi are already around)
- GPS does not work indoors, and its accuracy is not good enough (~meters, but we want ~cms)

How to use wireless for localization?

- Method: RSSI (Signal Strength)

Using signal strength to do **trilateration**.

\[
P_R = P_t \frac{G_t G_r \lambda^2}{(4\pi d)^2}, \quad h \propto \frac{1}{d^2} e^{-\frac{2\pi h}{\lambda}}, \quad |h|^2 \propto \frac{1}{d^2}
\]

Received Power vs. Distance
Pros:
- Very Simple: No hardware modification. Most devices report this value directly.

Cons:
- Inaccurate for longer distance.
- Doesn’t work with multipath.

\[ h \propto \frac{1}{d_1} e^{-\frac{2\pi d_1}{\lambda}} + \frac{1}{d_2} e^{-\frac{2\pi d_2}{\lambda}} \]

Solution: Fingerprint (A measuring device records the signal strength fingerprint at each location)

Pros:
- We don't need to know where the APs are placed.

Cons
- The environment changes as things move, thus we need continuous training
- The training itself takes a lot of effort

- **Method: AoA (Angle of Arrival)**

Using angles of arrival to do **triangulation**.
The more APs we have, the more accurate we will do in AoA triangulation.

There is a $2\pi$ ambiguity, which happens when

$$\frac{2\pi s}{\lambda} \cos \theta_1 = \frac{2\pi s}{\lambda} \cos \theta_2 , \quad \theta_1 \neq \theta_2$$

The solution is to set $s = \frac{\lambda}{2}$.

We set $s = \frac{\lambda}{2}$

$$-1 < \cos \theta < 1 , \quad -\frac{2\pi s}{\lambda} < \phi < \frac{2\pi s}{\lambda} , \quad s = \frac{\lambda}{2}$$

- $-\pi < \phi < \pi$

Pros:
- Better accuracy.
- Reasonably simple (but getting AoA may not be easy in commercial devices).

Cons
- $\cos(\theta) = \cos(-\theta)$ ambiguity.
- Does not work well with multipath
- Error goes up with longer distance
- Measurement ($\cos(\theta)$) is not changing linearly with $\theta$. 
This paper

Use multipath profile to detect direct path

Antenna Array

\[ h_k = e^{j2\pi \frac{d+k\lambda \sin \theta}{\lambda}} \]

\[ P(\theta) = \left| \sum_{k=0}^{N-1} h_k e^{j2\pi \frac{k\lambda \sin \theta}{\lambda}} \right|^2 \]

Let's say we have only two paths,

\[ h_k = \alpha_k e^{-j2\pi \frac{d_k k \lambda \sin \theta}{\lambda}} + \alpha_k e^{-j2\pi \frac{d_k + k \lambda \sin \theta}{\lambda}} \]

For the first path,

\[ P(\theta_1) = \left| \sum_{k=0}^{N_1} \alpha_k e^{-j2\pi \frac{d_k}{\lambda}} + \sum_{k=0}^{N_0} \alpha_k e^{-j2\pi \frac{d_k + k \lambda \sin \theta_1}{\lambda}} \right|^2 \]

\[ \approx \left| \sum_{k=0}^{N_1} \alpha_k e^{-j2\pi \frac{d_k}{\lambda}} \right|^2 \]

Similarly, \[ P(\theta_2) \approx \left| \sum_{k=0}^{N_2} \alpha_k e^{-j2\pi \frac{d_k}{\lambda}} \right|^2 \]

From that we know which directions correspond to different paths.

But, how do we know which direction is the LOS (Line of Sight) direction?

Is it the strongest one? Not necessarily. Due to blockage, LOS can sometimes be weaker.
**The paper’s solution**

**Observation:** When the device has small movements, the direct-path peak on the AoA spectrum is usually stable while the reflection-path peaks usually change significantly.

But in reality, this may not be true...

Cannot give a good justification for that.

But why the evaluation looks good?

Possibly because of redundancy... Number of APs and antennas per AP is huge in small areas, mitigating the multipath issue.

**Other ways to detect LOS?**

LOS path is Shortest path. This is always true, as the direct path signal always arrives first.

(If in direct path signal travels slower because of other medium such as water, it turns out signal will quickly fade away and be too weak to be detected.)

But, because speed of light is so fast, it has a very high requirement of sampling frequency.

Consider in a classroom where the difference between the length of LOS path and a non-LOS path is 3 meters.

\[
\frac{\Delta d}{c} = \frac{3}{c} = \frac{10}{\text{sec}} = 10 \text{ ns} \quad \therefore \quad \frac{1}{T} = 100 \text{ MHz}.
\]

Most commercial APs don’t have that bandwidth.

**Using OFDM to detect LOS.**
Why this still works even if the time contains packet detection time and processing time? Because the latter two are roughly the same, so they don’t change the order.