Lecture 11: Wireless Localization I

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Application of indoor localization:

- Advertisement (Targeted Ads)
- VR
- Indoor navigation (Mall, Lab)
- Smart homes (Energy Efficient)
- Emergency Response
- Location-based tagging / reminder
- Behavior Analysis (for Health / Ads)
- Misplaced items
- Gesture / Writing in Air

Why wireless?

- Portable / Form factor
- Ubiquitous
- GPS doesn't work indoor (low accuracy)

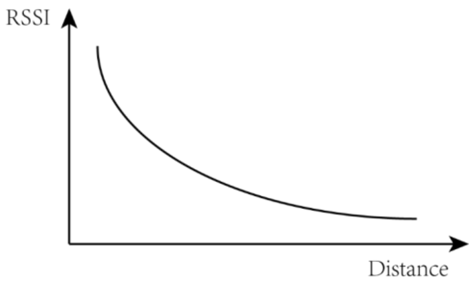
1. RSSI based Indoor Localization Techniques

Received signal power:

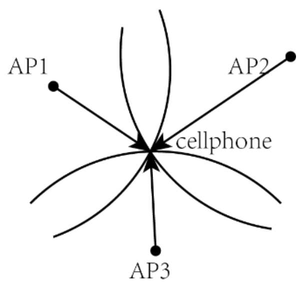
$$P_R = P_T \frac{G_T G_R \lambda^2}{(4\pi d)^2} h \propto \frac{1}{d} e^{-j2\pi\frac{d}{\lambda}}$$

$$\left|h^2\right| \propto \frac{1}{d^2}$$

Relationship between RSSI and distance:



1.1 Trilateration



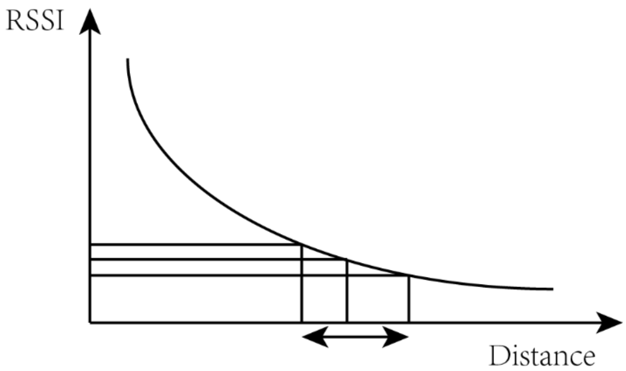
(Trilateration is different from triangulation.)

Measure the RSSIs from at least three APs; Estimate distances; Localize the cellphone.

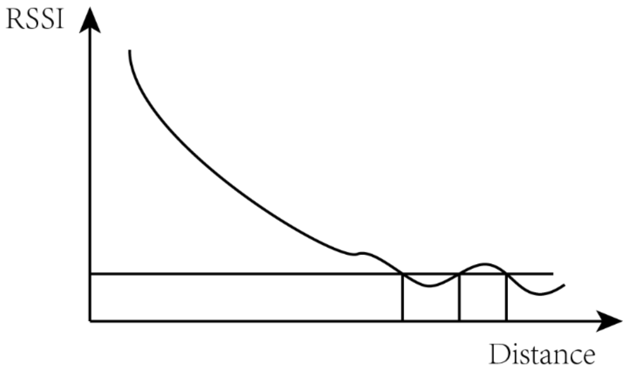
Pros: Very simple -> No hardware modification.

Cons:

- Inaccurate for large distance. Small RSSI measurement error would cause large distance error.



- Doesn't work with multipath.



$$P_R = P_T \frac{G_T G_R \lambda^2}{(4\pi d)^2} h \propto \frac{1}{d_1} e^{-j2\pi\frac{d_1}{\lambda}} + \frac{1}{d_2} e^{-j2\pi\frac{d_2}{\lambda}}$$

Solution: Fingerprinting

1.2 Fingerprinting

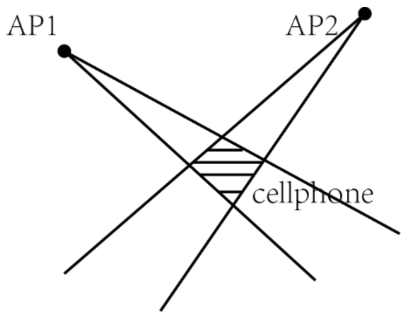
Pros:

- No need to know where APs are!

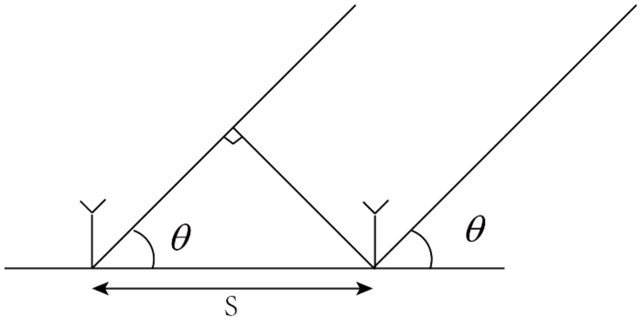
Cons:

- Fingerprint changes as things move -> need continuous training.
- Lot of effort. (Need to manually measure RSSI map.)

2. AoA (Angle of Arrival) based Indoor Localization Techniques



Use the method of triangulation to localize the cellphone.
Use multiple antennas to estimate the angle of arriving signal.



$$\angle h_1 = \Phi_1 = -2\pi \frac{d}{\lambda}$$

$$\angle h_2 = \Phi_2 = -\frac{2\pi d + s\cos\theta}{\lambda}$$

$$\Delta\Phi = \Phi_1 - \Phi_2 = 2\pi \frac{s\cos\theta}{\lambda} \bmod 2\pi$$

So we can estimate θ by calculating $\Delta\Phi$. We set $s = \frac{\lambda}{2}$ because:

$$-1 < \cos\theta < 1$$

$$-2\pi \frac{s}{\lambda} < \Delta\Phi < 2\pi \frac{s}{\lambda}$$

If we set $s = \frac{\lambda}{2}$, we can have:

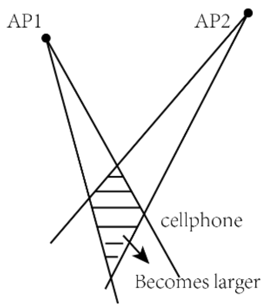
$-\pi < \Delta\Phi < \pi$.

Pros:

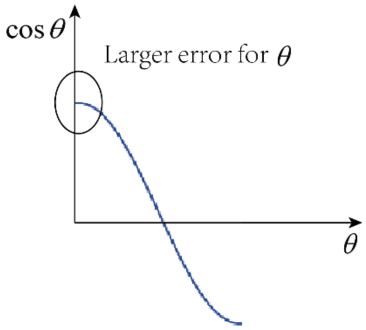
- Better accuracy.
- Simple (not true. Many devices such as commercial cellphone cannot measure AoA.)

Cons:

- Since $\cos\theta = \cos(-\theta)$, the angle would flip.
- Doesn't work with multipath.
- Higher error for larger distance.

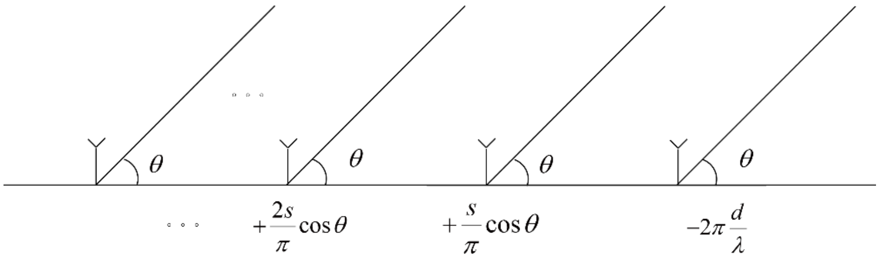


- Error is larger when θ is around 0.



3. How to Eliminate Multipath Effect

Antenna Array



$$h_k \propto e^{-j2\pi\frac{d+k\cos\theta}{\lambda}}$$

$$P(\theta)=\left|\sum_{k}^{N} h_k e^{j2\pi\frac{s}{\lambda}\cos\theta}\right|^2$$

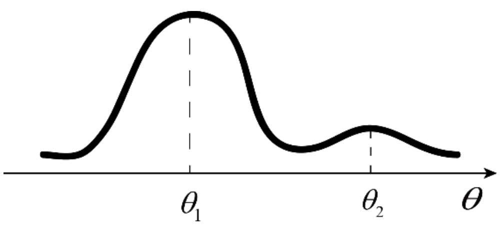
Assume that there are two paths with two arrival angles: θ_1, θ_2. Then

$$h_k=\alpha_1 e^{-j2\pi\frac{d_1+sk\cos\theta_1}{\lambda}}+\alpha_2 e^{-j2\pi\frac{d_2+sk\cos\theta_2}{\lambda}}$$

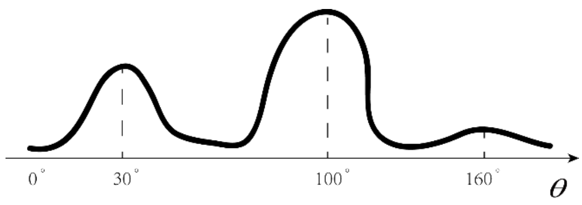
$$P(\theta_1)=\left|\sum_{k}^{N}\alpha_1 e^{-j2\pi\frac{d_1}{\lambda}}+\sum_{k}^{N}\alpha_2 e^{-j2\pi\frac{d_2+sk(\cos\theta_1-\cos\theta_2)}{\lambda}}\right|^2=\left|N\alpha_1 e^{-j2\pi\frac{d_1}{\lambda}}\right|^2$$

$$P(\theta_2)=\left|N\alpha_2 e^{-j2\pi\frac{d_2}{\lambda}}\right|^2$$

$P(\theta)=0$ if $\theta\neq\theta_1,\theta_2$., as shown in the following figure:

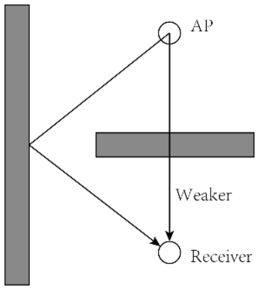


Another 3-path example is



Which is LoS(line of sight) path?

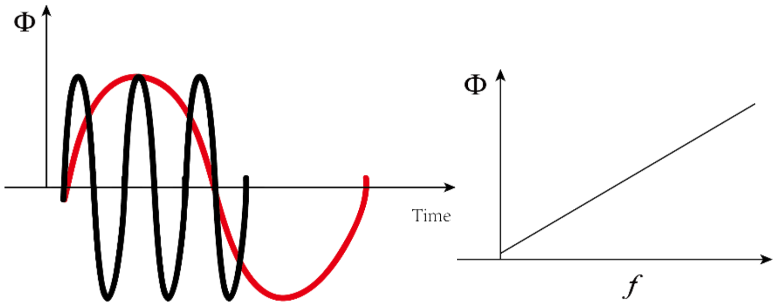
(1) Select the strongest one? Not always true. Because of blockage, LoS can be weaker. One example is shown in the following figure.



To solve this problem, the paper [1] (ArrayTrack) presents the method which utilizes the mobility of the mobile device. While the device is moving, the change of the LoS signal is slower than that of the reflected paths. However the lecturer doubts whether this is really true. The good performance of ArrayTrack would mainly benefit from the redundant antennas. During the evaluation phase, 6 APs are used, which equipped with 17 antennas. The same performance would be achieved if we deploy 6*17=102 antennas as anchor nodes.

(2) Select the shortest one?

$\Delta d / c$ is in the order of 10^(-8) second. So to distinguish the time difference between two arrived signals, the sampling rate should be higher than 1/T=100MHz, which is too high. Consider the feature of OFDM used by WiFi.



$$\Delta\Phi_{sub\_carrier} = 2\pi\Delta f T$$

So we can select the path with the smallest T. However, (1) T contains propagation delay, packet detection delay and processing delay. It is hard to accurately measure T; (2) sometimes the signal of LoS path is too weak to be separated. This method also requires to separate each path signal.

Reference:

[1] J. Xiong and K. Jamieson, “ArrayTrack: a fine-grained indoor location system,” in the 10th USENIX Symposium on Networked Systems Design and Implementation (NSDI 13), pp. 71-84, 2013.