Triangulation for Local Positioning System

Introduction

- Our solution requires infrastructure - beacons
- WiFi Fingerprinting - training of distance measurements corresponding to access points
- None of the solutions till date has reached users because of deployment of new infrastructure or fingerprinting to learn the spatial distribution of the signal strength

Principle

- If mobile devices/computers can be fitted with large antenna arrays then they can accurately find the spatial direction of incoming RF signal
- Hence the devices can locate themselves w.r.t the wifi AP
- Not possible to mount a large antenna array on a computing device
- Need to emulate a large antenna array on devices

How to do this ???

- SAR can be an option right ??

Synthetic Aperture Radar (SAR)

- Isolate and analyze the multiple signal paths emanating from wireless transmitter using a single-wireless antenna receiver
- Computes multipath-profile = measures the relative signal power received along different spatial direction
- Moving antenna performs SAR by taking signal snapshots as it moves along the trajectory → then jointly processing these snapshots to emulate a large antenna array traced out by the trajectory
- Apply standard antenna array equations on the signals received at each antenna position
- Assumption of SAR: accurate knowledge of device position at different points in time required relative to some fixed origin in space
- Requirement : CSI providing tool/software , motion sensors

Challenges with SAR

- **Requirement** - Position of the moving antenna along the trajectory need to be known
- In radar systems or satellites, the speed and movement of antenna movement is finely controlled
- But in case of mobile/computers, trajectory of antenna attached to device held by user cannot be accurately controlled
- Motion sensors do not provide accurate translation data but do provide accurate orientation data
- Also SAR requires sub-centimeter accuracy in device position (2 cm deviation => 60 degrees angle error)

Translation-Resilient SAR

- Rotate device → even if twisting device involves unknown trajectories → compute SAR multipath profile using only rotation from gyroscope
- Use the MIMO capability of modern NIC → suppose mobile device has two antennas → relative vector between two antennas fixed when translation → and rotates while rotation
- The two antennas sample (snapshots which emulate virtual array of antennas) the wireless channel at each point in device trajectory
- New SAR formulation that depends only on relative wireless channel to estimate the direction of AP's signal
- Based only on device orientation, no info required-position/translation

Continued ...

- Feed SAR the relative wireless channel between two physical antennas
- Relative channel only depends on the relative position vector between two antennas
- Relative wireless channel captures the relative phase between channels at the two antennas connected to device
- Device Translation = no change in relative position vector
- Device rotation = relative position vector also rotates

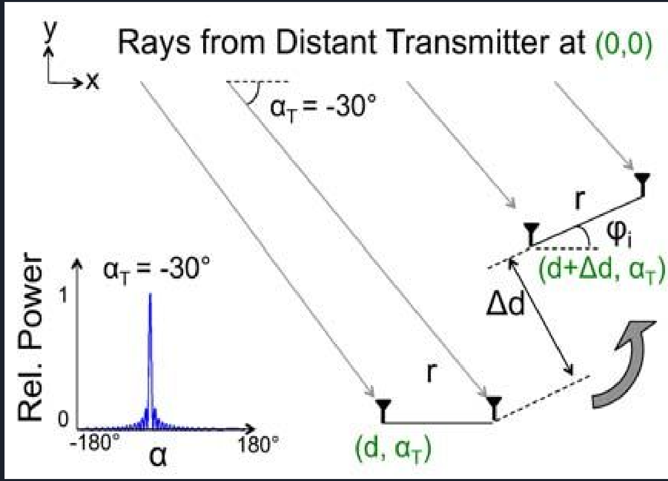
How it is Translation-Resilient ???

- Initial and final position of two antennas (after movement) shown in figure
- Assuming distance to the transmitter is large compared to ΔX , ΔY << d so that the angle(to be estimated) doesn't changes
- Relative Channel is given by -

$$h_i = h_{2,i} h_{1,i}^* = (1/d^2)\exp(-j(2\pi/\lambda)r\cos(\alpha t - \Phi i))$$

- Above equation - no dependence on ΔX , ΔY

$$P(\alpha) = \left| \frac{1}{n} \sum_{i=1}^{n} \hat{h}_i e^{\frac{+j2\pi}{\lambda} r \cos(\alpha - \phi_i)} \right|^2$$



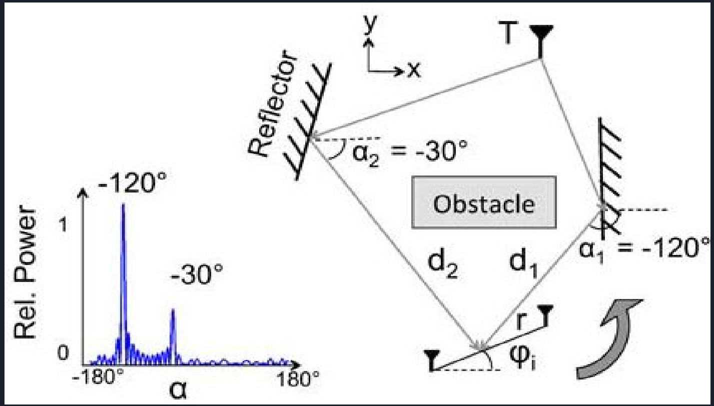
- Plug in this relative channel h_i into SAR power profile to get the multipath profile of transmitter's signal
- In OFDM systems(802.11n), avg of power profile for each subcarrier needed

Multipath Scenarios

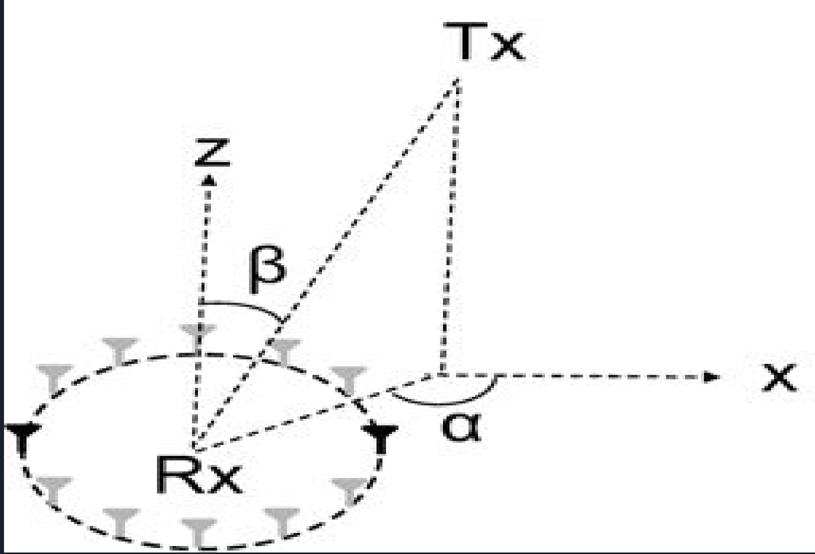
- Device receives signals from m distinct paths of lengths $d_1, d_2, \dots d_m$ arriving along directions $\alpha_1, \alpha_2, \dots \alpha_m$
- Resilient to translation in these scenarios, while generating correct multipath profiles, indicating the direction of the various paths of the signal.

$$\hat{h}_i = \sum_{k=1}^{m} \frac{s_k}{d} e^{\frac{-j2\pi}{\lambda}\left(d + \frac{\Delta y_i}{\sin \alpha_k} + r\cos(\alpha_k - \phi_i)\right)} \sum_{k=1}^{m} \frac{s_k}{d} e^{\frac{+j2\pi}{\lambda}\left(d + \frac{\Delta y_i}{\sin \alpha_k}\right)}$$

$$= \sum_{k=1}^{m} \frac{s_k}{d_k} e^{\frac{-j2\pi}{\lambda} r\cos(\alpha_k - \phi_i)} \left[\frac{s_k}{d_k} + \sum_{l \neq k} \frac{s_l}{d_l} e^{\frac{+j2\pi}{\lambda}\left(\frac{\Delta y_i}{\sin \alpha_l} - \frac{\Delta y_i}{\sin \alpha_k}\right)} \right]$$



3-d Generalization



$$P(\alpha,\beta) = \left| \frac{1}{n} \sum_{i=1}^{n} \hat{h}_i e^{\frac{+j2\pi}{\lambda} r \cos(\alpha-\phi_i)\sin(\beta-\theta_i)} \right|^2$$