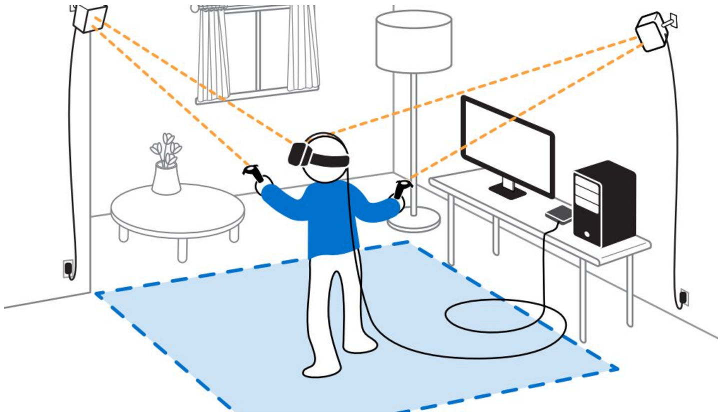
Position Tracking for Virtual Reality Using Commodity WiFi

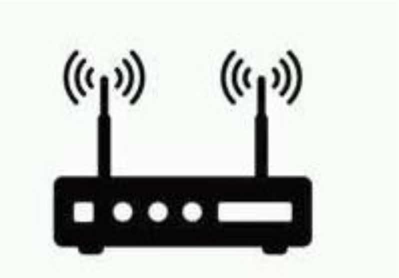
[CVPR ’17] Position Tracking for Virtual Reality Using Commodity WiFi



- Motivation:
  - Making VR free of dedicated infrastructure (IR cameras and sensors)
- Contribution:
  - Works even under occlusion
  - Higher range
  - Ubiquity and ease of deployment

How is it done?

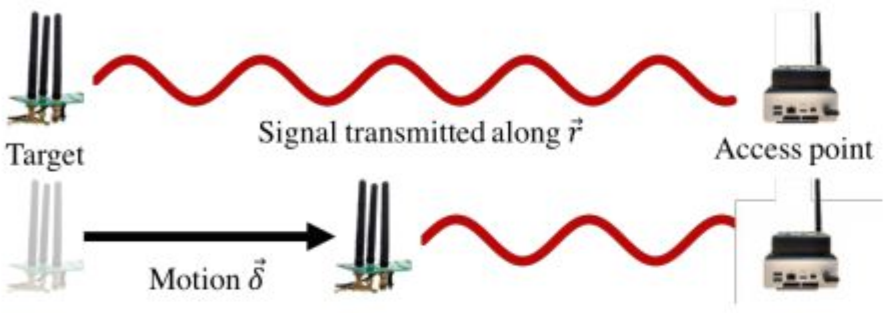
- Replace IR cameras with wifi APs



Replace IR sensors on the headset with a WiFi transmitter

Basic idea:

Change in path length causes change in phase.



If we can detect the change in phase, we can track the position. But there is Multipath

Handling Multipath

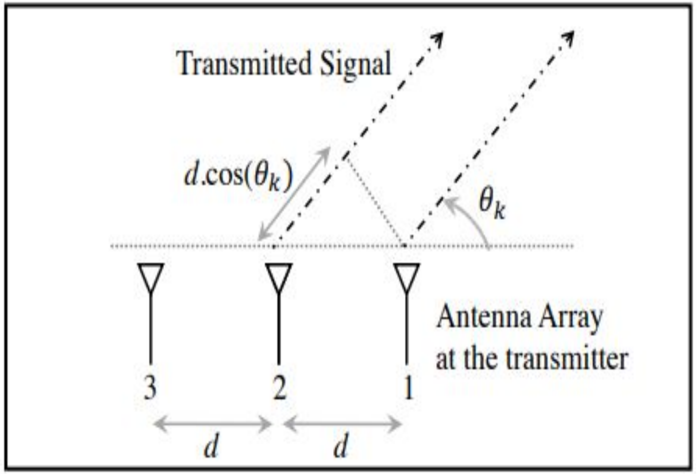
- Use Antenna array at the transmitter

- Consider L paths

$$\mathbf{H} = [\vec{a}(\theta_1) \ \ldots \ \vec{a}(\theta_L)]\mathbf{F} = \mathbf{AF}$$

H: Channel matrix

F : vector of weights of L paths



$$\vec{a}(\theta_k) = [1 \; \mathrm{e}^{-j2\pi d\cos(\theta_k)/\lambda} \; \mathrm{e}^{-j4\pi d\cos(\theta_k)/\lambda}]^{\top}.$$

CSI calculation:

$$\hat{h}_q = \frac{1}{T}\int_0^T h_q \mathrm{e}^{j2\pi f t} \mathrm{e}^{-j2\pi f t + j\nu}\, dt = h_q \mathrm{e}^{j\nu},$$

Phase offset between carriers at the AP and the transmitter.

So, Observed channel matrix is $\widehat{\mathbf{H}} = \mathbf{H}\mathrm{e}^{j\nu}.$

CSI measurements are done at the beginning of every WiFi packet.

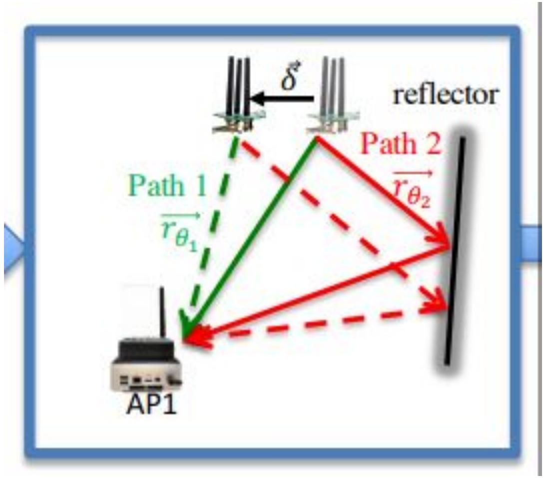
Change in channel due to Displacement

- Each path incurs a phase change $e^{-j2\pi(\vec{r}_{\theta_k}^{\top}\cdot\vec{\delta})/\lambda}$

  Channel matrix changes to

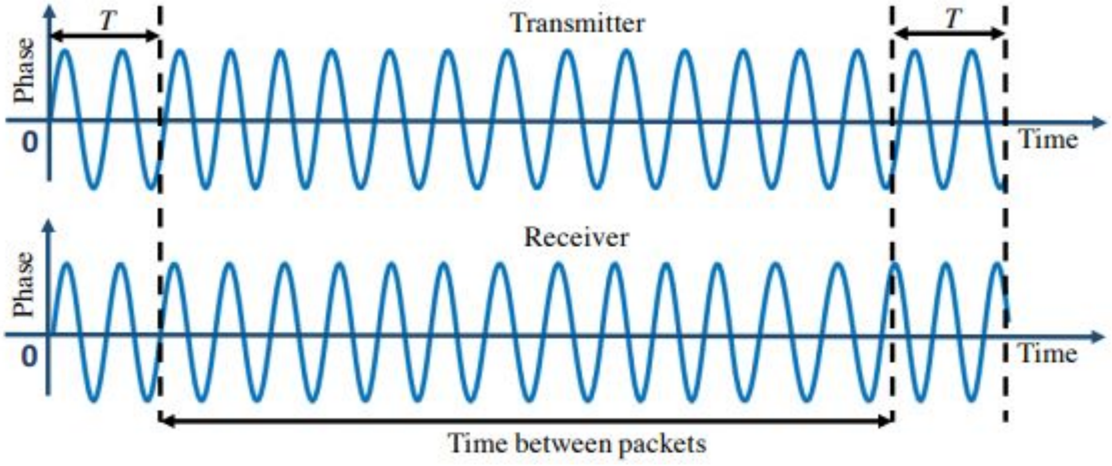
$$\mathbf{H}_2 = \mathbf{ADF},$$

D => $\mathbb{C}^{L\times L}$ is a diagonal matrix with entries $e^{-j2\pi(\vec{r}_{\theta_1}^{\top}\cdot\vec{\delta})/\lambda}, \ldots,$ $e^{-j2\pi(\vec{r}_{\theta_{L-1}}^{\top}\cdot\vec{\delta})/\lambda}$, and $e^{-j2\pi(\vec{r}_{\theta_L}^{\top}\cdot\vec{\delta})/\lambda}$.



Phase distortion due to Frequency offset

Consider two consecutive wifi packets



$$\widehat{\mathbf{H}}_1 = \mathbf{AF}e^{j\nu_1}, \widehat{\mathbf{H}}_2 = \mathbf{ADF}e^{j\nu_2}.$$

The phase offset can be so huge compared to the change in phase due to the displacement.

It is random too!

Estimate AoD of all paths

Remember $$\mathbf{H} = [\vec{a}(\theta_1)\ \ldots\ \vec{a}(\theta_L)]\mathbf{F} = \mathbf{AF},$$

To estimate steering vectors from single CSI measurement is impossible!

Collect CSI for P consecutive packets $$\mathbf{X} = [\widehat{\mathbf{H}}_1\ \widehat{\mathbf{H}}_2\ \ldots\ \widehat{\mathbf{H}}_P] = \mathbf{AG},$$

Apply **MUSIC** to find the steering vectors.

$$\widehat{\mathbf{F}}_p = \mathbf{A}^{\dagger}\widehat{\mathbf{H}}_p.$$

$$\widehat{\mathbf{F}}_1 = \mathbf{F}e^{j\nu_1}, \widehat{\mathbf{F}}_2 = \mathbf{DF}e^{j\nu_2}$$

Estimating the displacement during Packet duration

$$\begin{aligned} \underset{\mathbf{D}}{\text{minimize}} \quad & \|\widehat{\mathbf{F}}_2 - \mathbf{D}\widehat{\mathbf{F}}_1\| \\ \text{subject to} \quad & \mathbf{D} \text{ is diagonal.} \end{aligned}$$

Note that $\mathbf{D}_{k,k}$, is an estimate of $e^{-j2\pi(\vec{r}_{\theta_k}^{\top} \cdot \vec{\delta})/\lambda + j\nu_2 - j\nu_1}$

- All the diagonal elements contain the same random phase offset term
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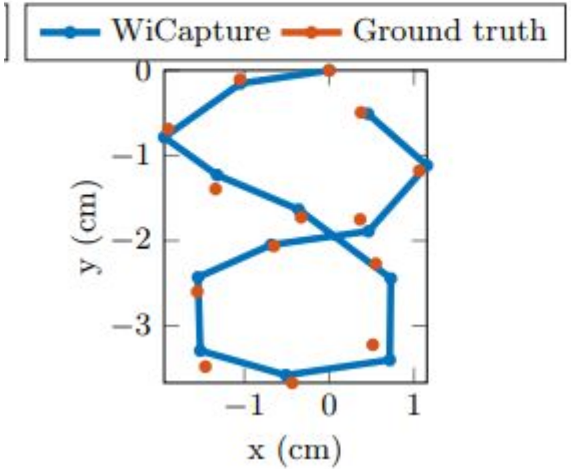
Results

(a) Indoor office deployment



Comments:

- How do we get a vector of CSI measurements at the APs?