CSE570 Spring 2020
Wireless and Mobile Networks

RF Sensing – I (Basics)

Mallesham Dasari

What is Sensing?

- Acquire information, detect and observe the changes in an environment

Types of Sensing

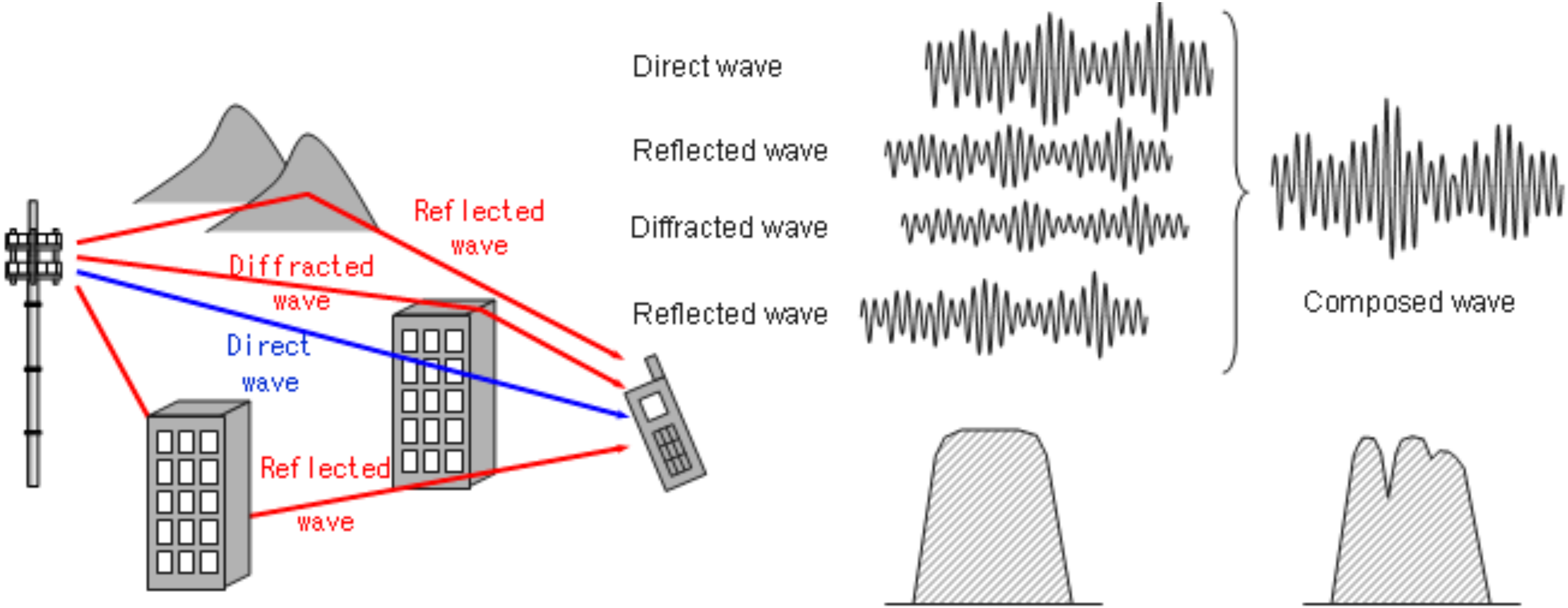
- RF sensing
- Acoustic sensing
- Smartphone sensing
- Camera sensing
- More sensors

- Environment sensing
- Human sensing

RF Sensing: Theory behind

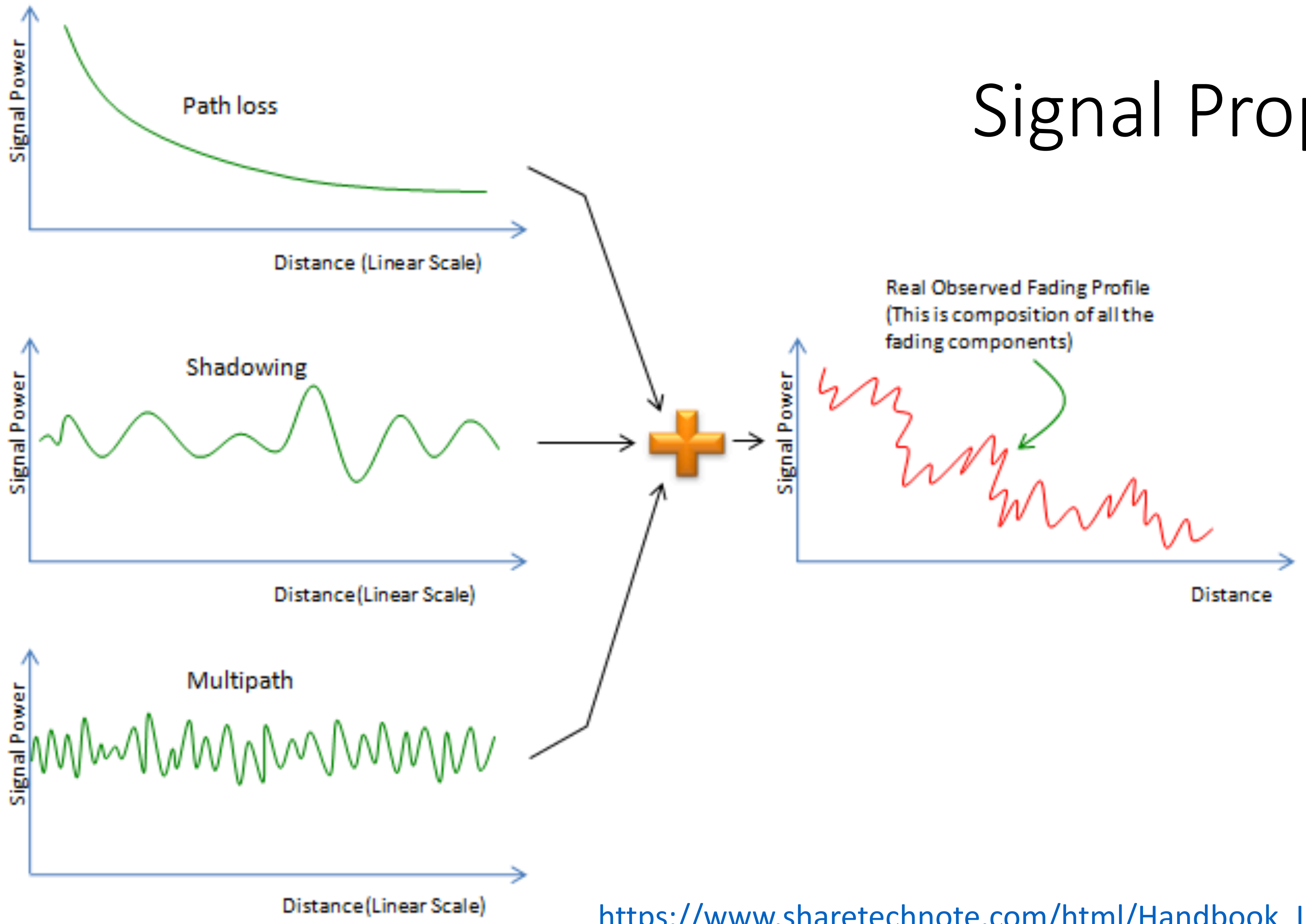
- Shadowing
- Reflection
- Diffraction
- Scattering
- More properties

Signal Properties



https://www.sharetechnote.com/html/Handbook_LTE_Fading.html

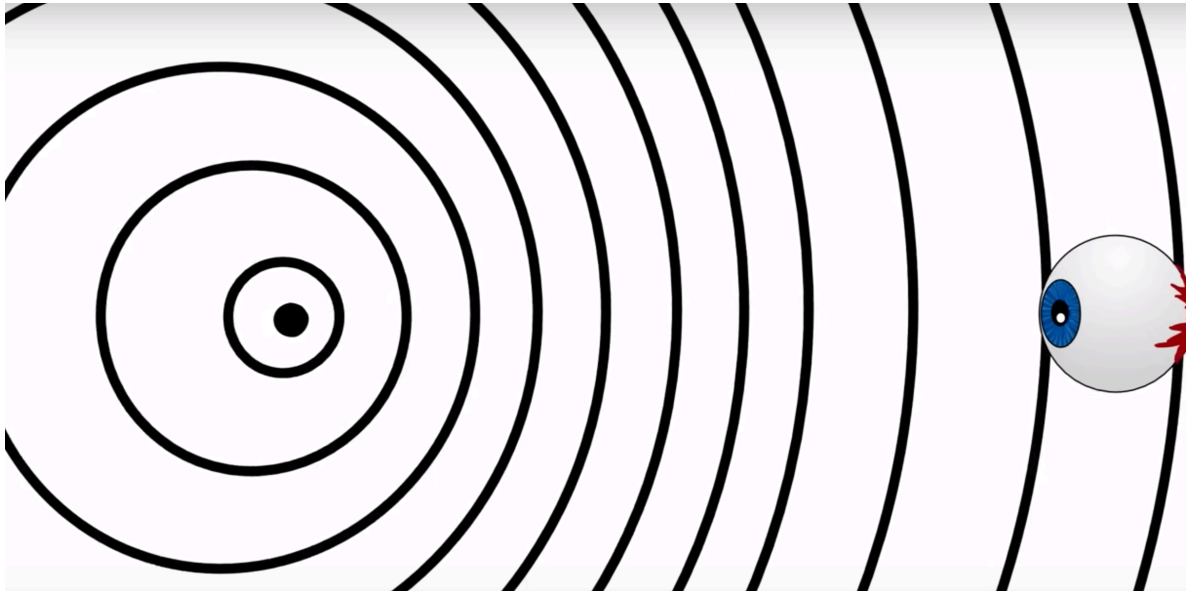
Signal Properties

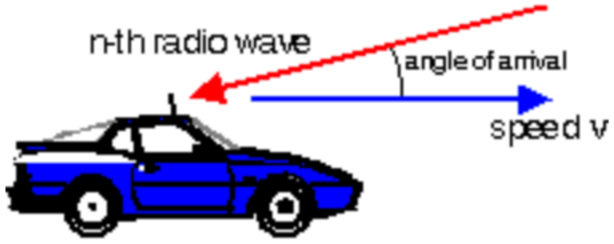


https://www.sharetechnote.com/html/Handbook_LTE_Fading.html

Doppler Spread

- Doppler effect: change in the frequency a wave due to relative motion between Tx and Rx





The Doppler shift of this wave is

$$\Delta f_n = \frac{v}{\lambda} \cos \alpha_n,$$

where v is the speed of the antenna.

RF Sensing: Theory behind

- Signal Strength
- Phase
- Channel State Information
- ToF
- AoA
- More parameters

Theory (Signal Parameters)

RSS

- Received signal power
- Mainstream wireless technology, such as WiFi, Zigbee, GSM/3G/4G, Bluetooth, FM, and TV, could provide RSS information directly
- Pro: Easy to get
- Con: Too noise

Phase

- More sensitive than RSS
- Easy to get
- Need synchronization between Tx and Rx

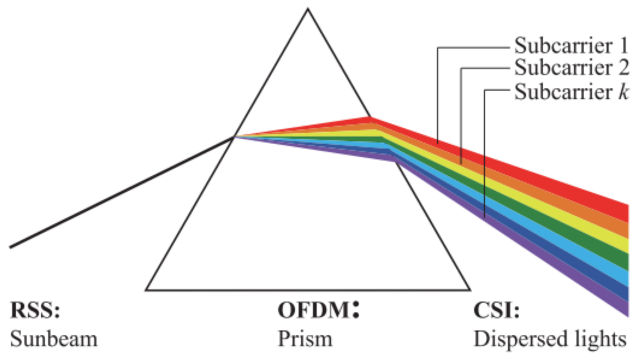
Theory (Signal Parameters)

ToF

- Robust to Noise
- Need synchronization between Tx and Rx

CSI

- RSS on multiple channels
- Most used recently



http://tns.thss.tsinghua.edu.cn/~cswu/papers/TST15_sensorless_paper.pdf

Things to keep in mind

- Do you need extra hardware?
- Do you need change the existing hardware?
- Do you need to change the software?
- No need to change anything?

Signal	Protocol	Frequency	Bandwidth	Max. data rate (theoretical)	Approximate indoor rage	Pros	Cons
WiFi [5]	802.11 a/b/g/n/ac	11–2.4 GHz 11a–3.7/5 GHz 11b–2.4GHz 11g–2.4 GHz 11n–20/40 MHz 11ac–5 GHz	11–22 MHz 11a–20 MHz 11b–20 MHz 11g–20 MHz 11n–20/40 MHz 11ac–20/40/80/ 160 MHz	11–2 Mb/s 11a–54 Mb/s 11b–11 Mb/s 11g–54 Mb/s 11n–450 Mb/s 11ac–1.73 Gb/s	11–20 m 11a–35 m 11b–35 m 11g–35 m 11n–70 m 11ac–35 m	1. Low cost 2. Ubiquitousness 3. Large coverage	1. Susceptible to environmental influence
RFID [6]	ISO11784/85 ISO15693 ISO14443 EPCglobal	LF: 125–134 kHz HF: 13.553–13.567 MHz UHF: 868 MHz, 915 MHz	LF: 10 kHz HF: 15 kHZ UHF: 500 kHz (North America)	26.7 kb/s up to 640 kb/s	LF: 0.2 m–1 m HF: 0.1 m–0.7m UHF: 3 m–10 m	1. Directional performance 2. Privacy	1. Signal collision and data loss 2. Security concerns
UWB	802.15.7	3.1–10.6 GHz	>500 MHz	480 Mb/s up to 1.6 Gb/s	10 m	1. Large bandwidth 2. Low power requirement 3. Low probability of intercept and detection 4. NLOS and LOS could be easily distinguished 5. Large coverage	1. Hardware dependency
Acoustics	N/A	20 to 20 kHz	N/A	N/A	Several meters	1. Ubiquitousness 2. High speed resolution 3. High resolution in detecting phase shift	1. Susceptible to environment 2. Small coverage 3. Bad user experience

RF Sensing in the Internet of Things: A General Deep Learning Framework, IEEE Communications Magazine, 2018

RF Sensing: Applications

- Localization
- Gesture recognition
- Motion detection
- Activity detection
- More general applications (e.g., Healthcare, VR/AR, Security)

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RF Sensing – II (Applications)

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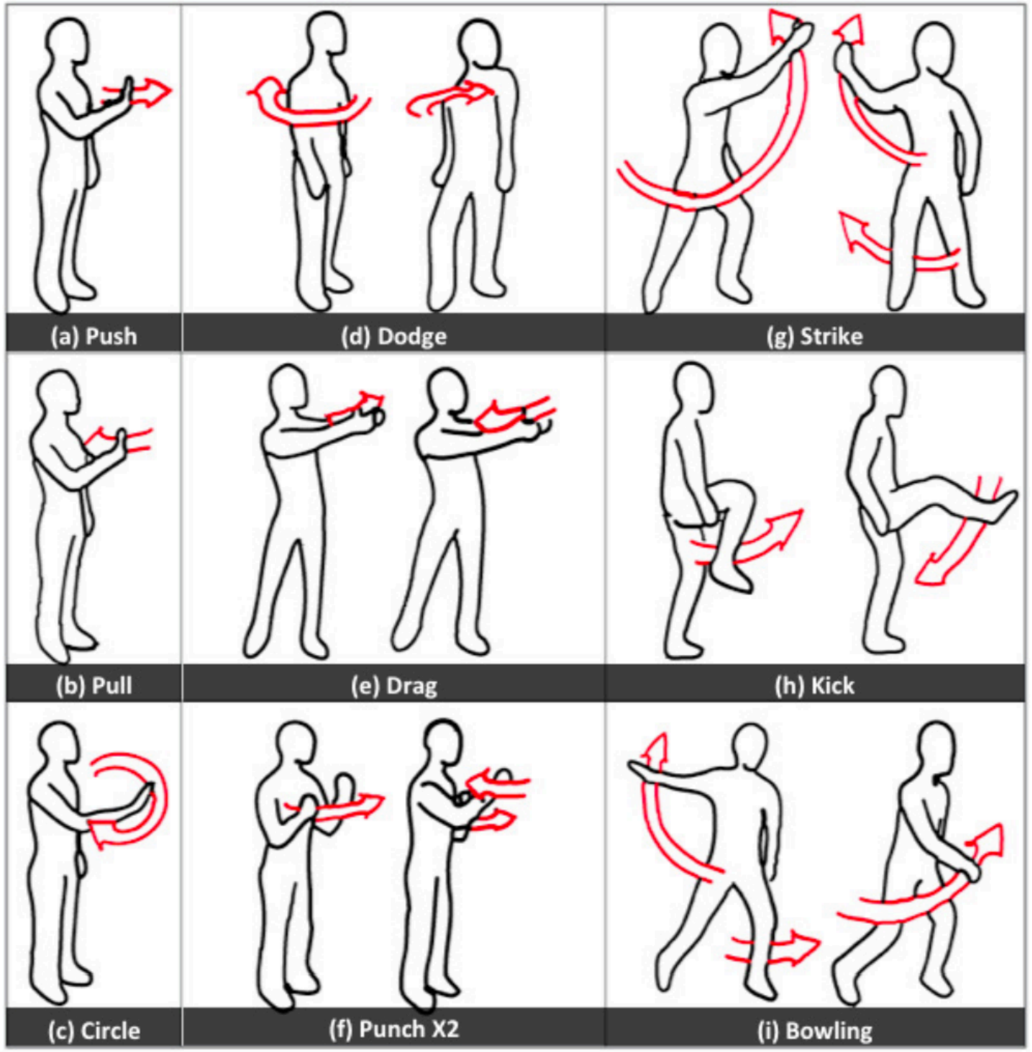
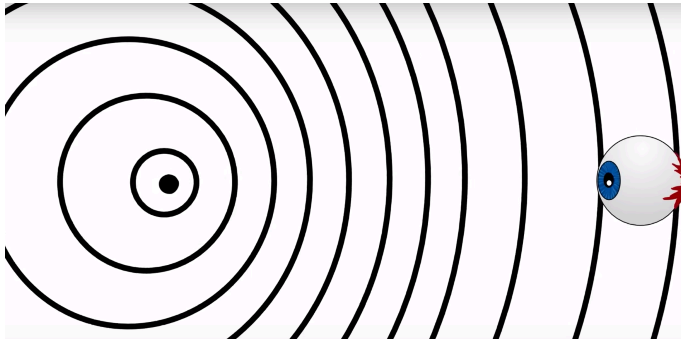
Gesture Recognition: WiSee

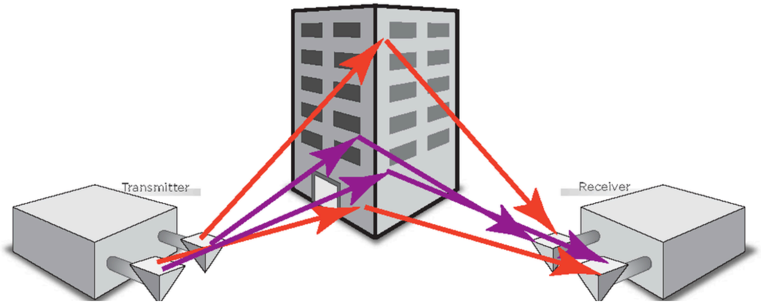


Gesture Recognition: WiSee

- Key questions
  - How to capture gesture information from wireless signals?
    - Doppler shift
  - How to deal with gesture interference from multiple people
    - MIMO technology



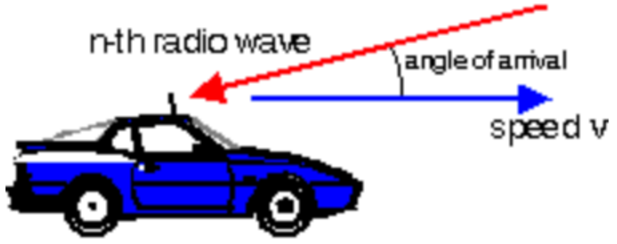
Doppler shift



MIMO

Some Doppler shift properties

- Reflected signals are from new virtual transmitters (i.e., the human body).
- Doppler shift depends on the direction of motion with respect to the receiver
- Multiple gestures relates to multiple transmitters -> multiple Doppler shifts
- Faster speeds result in larger shifts, while slower speeds result in smaller shifts.



The Doppler shift of this wave is

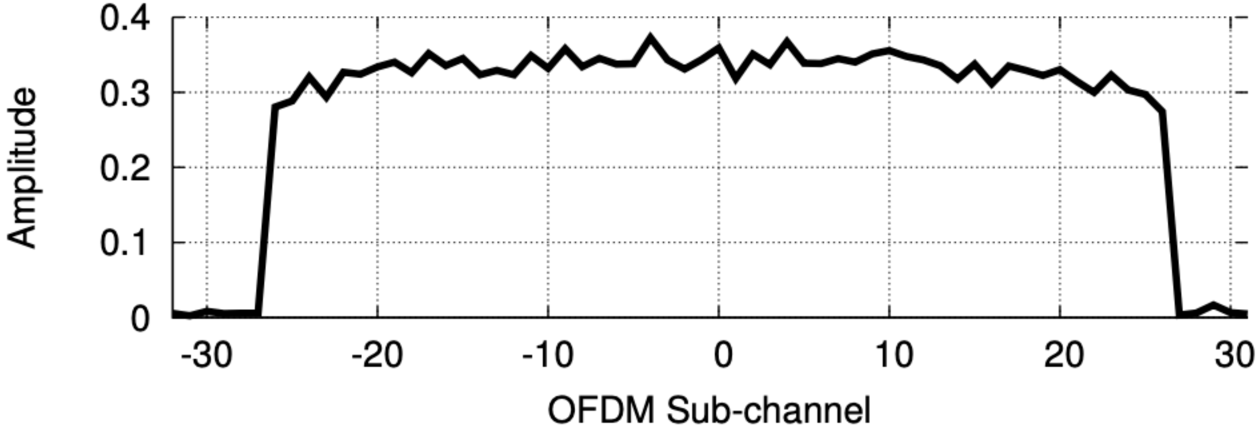
$$\Delta f_n = \frac{v}{\lambda}\cos\alpha_n,$$

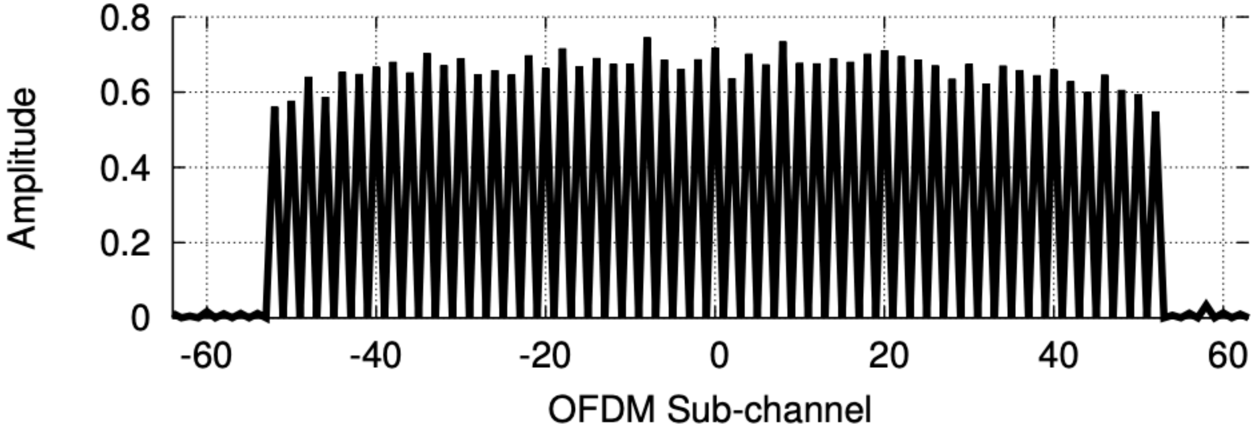
where v is the speed of the antenna.

Extracting Doppler shifts

- Problem
  - Small shifts
- Solution
  - Create a narrowband signal
  - When the receiver performs an MN -point FFT over an OFDM symbol that is repeated M times, the bandwidth of each sub-channel is reduced by a factor of M .

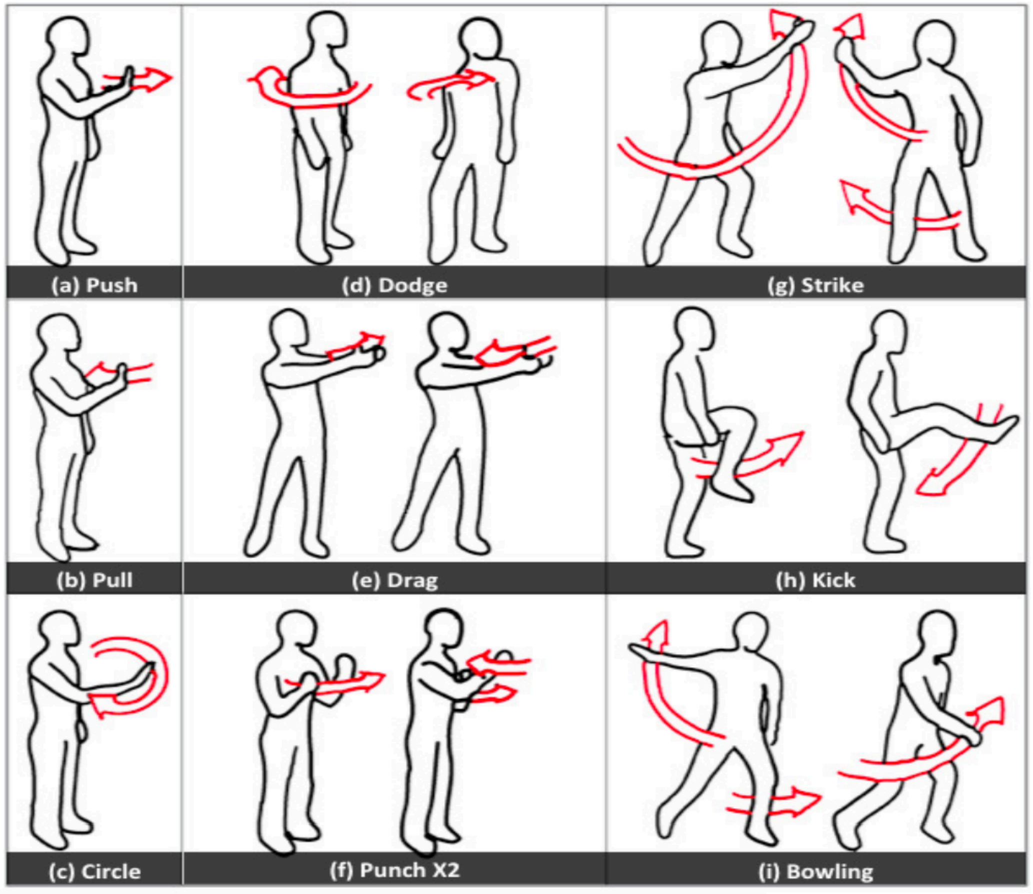
Extracting Doppler shifts

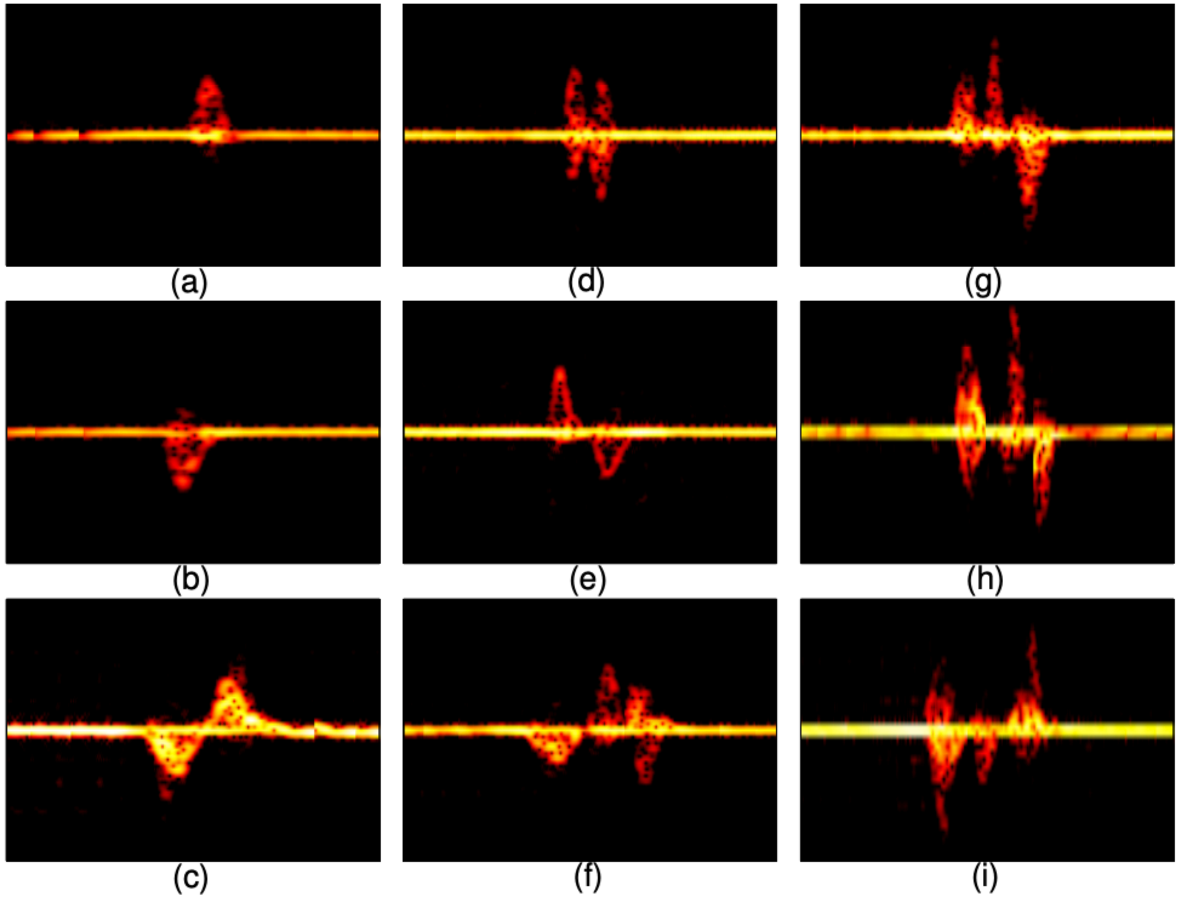




Larger FFT on identical OFDM symbols reduces the bandwidth

Mapping Doppler Shifts to Gestures





Gesture Interference

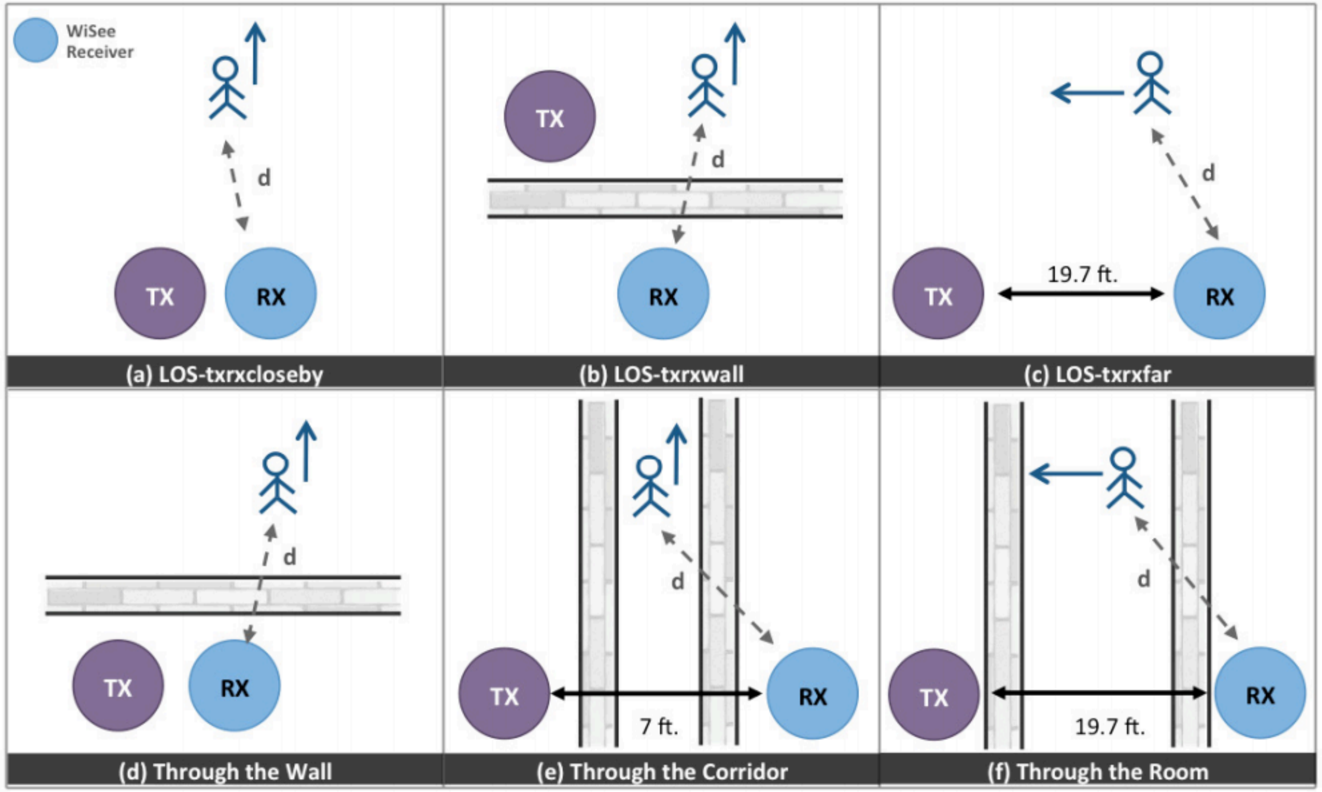
- MIMO captures multiple users
- Use a repetitive gesture to identify the user
- As the interfering users change, the optimal MIMO direction that maximizes the Doppler energy also changes.

Multipath problem

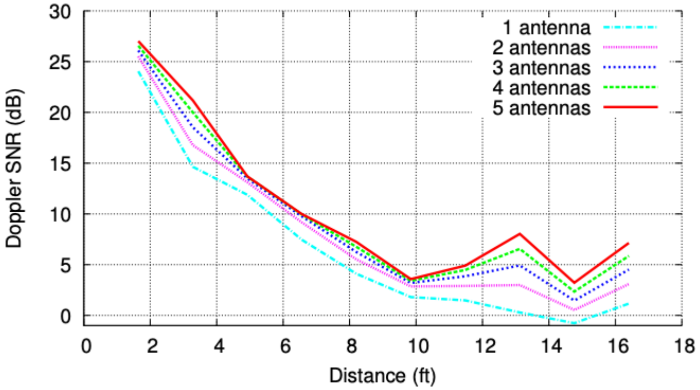
- Other strong reflections may change the Doppler shifts
- Repetitive gestures solves the problem

WiSee Implementation

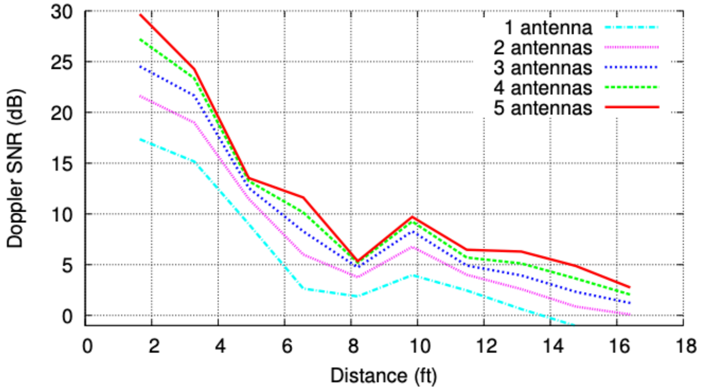
- USRP SDRs



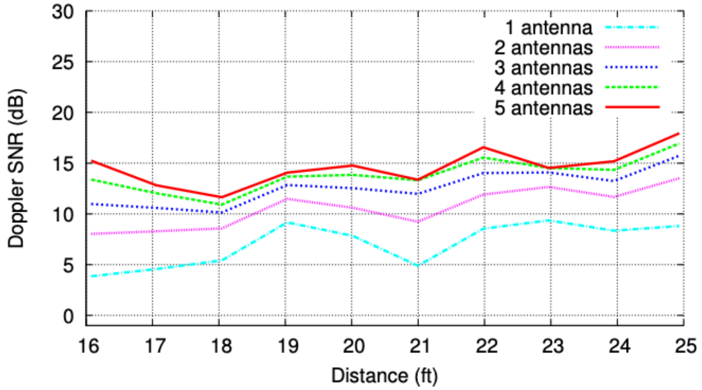
WiSee Results



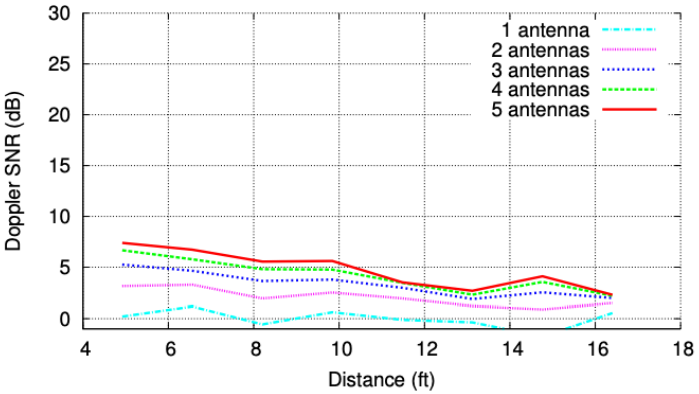
(a) LOS-txrxcloseby



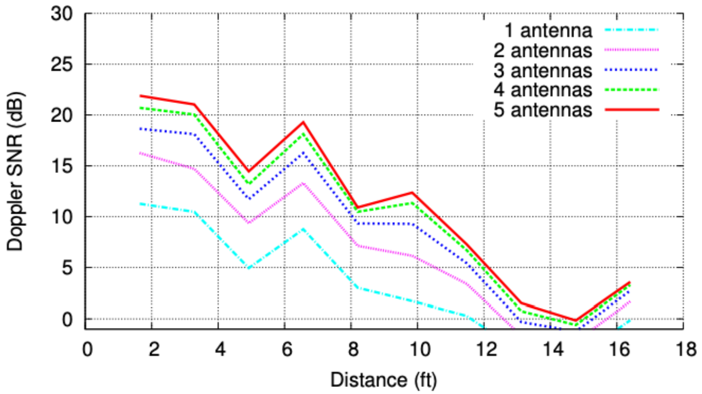
(b) LOS-txrxwall



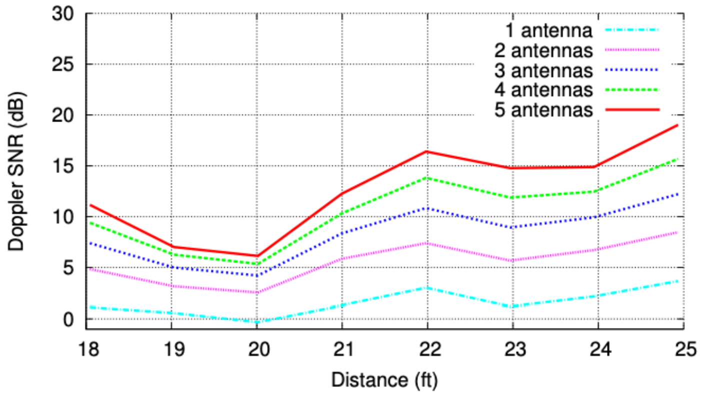
(c) LOS-txrxfar



(d) Through-the-Wall

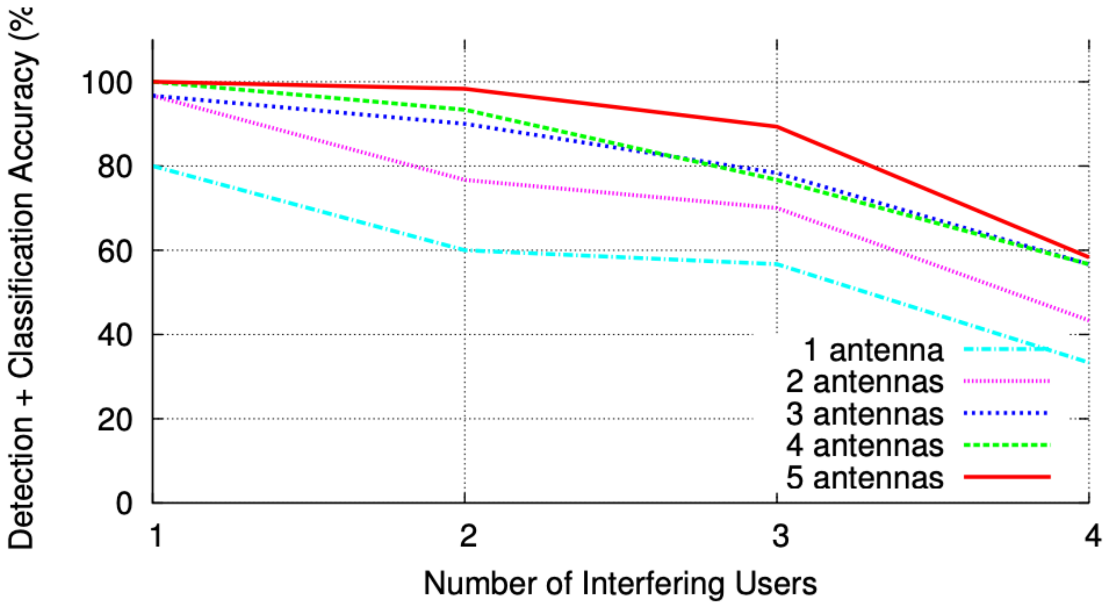


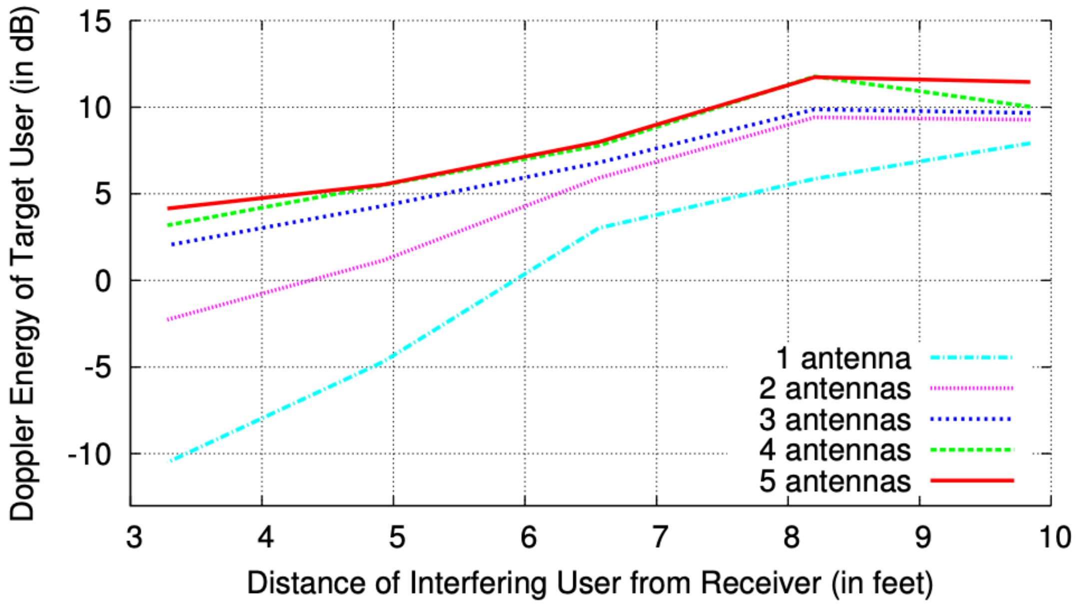
(e) Through-the-Corridor



(f) Through-the-Room

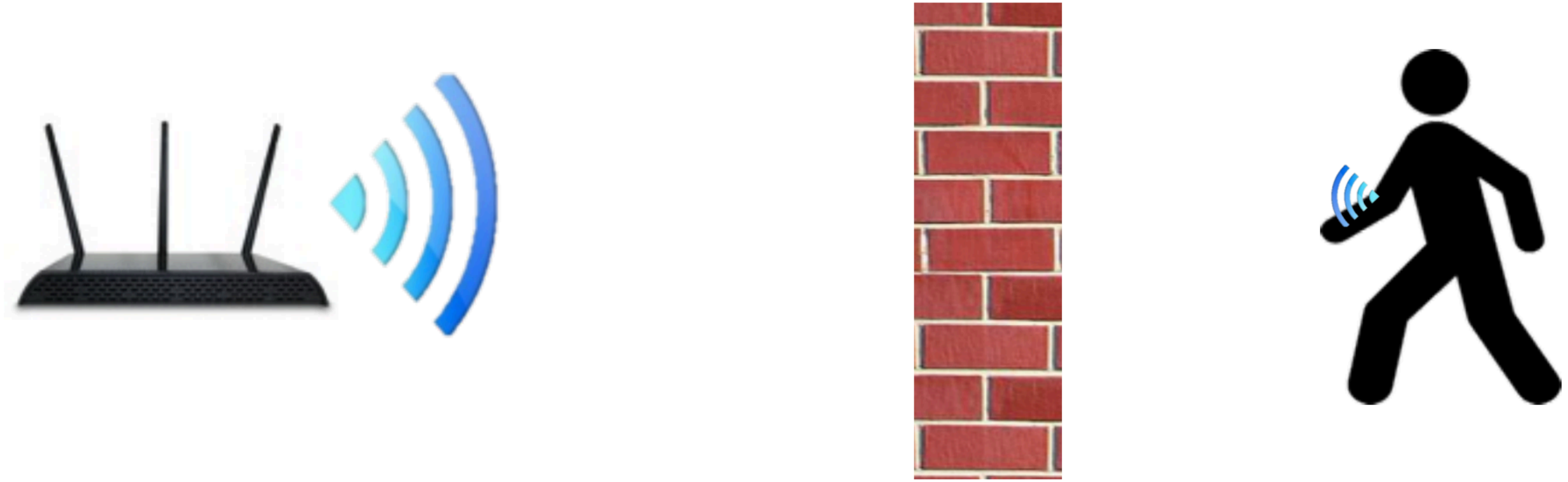
WiSee Results





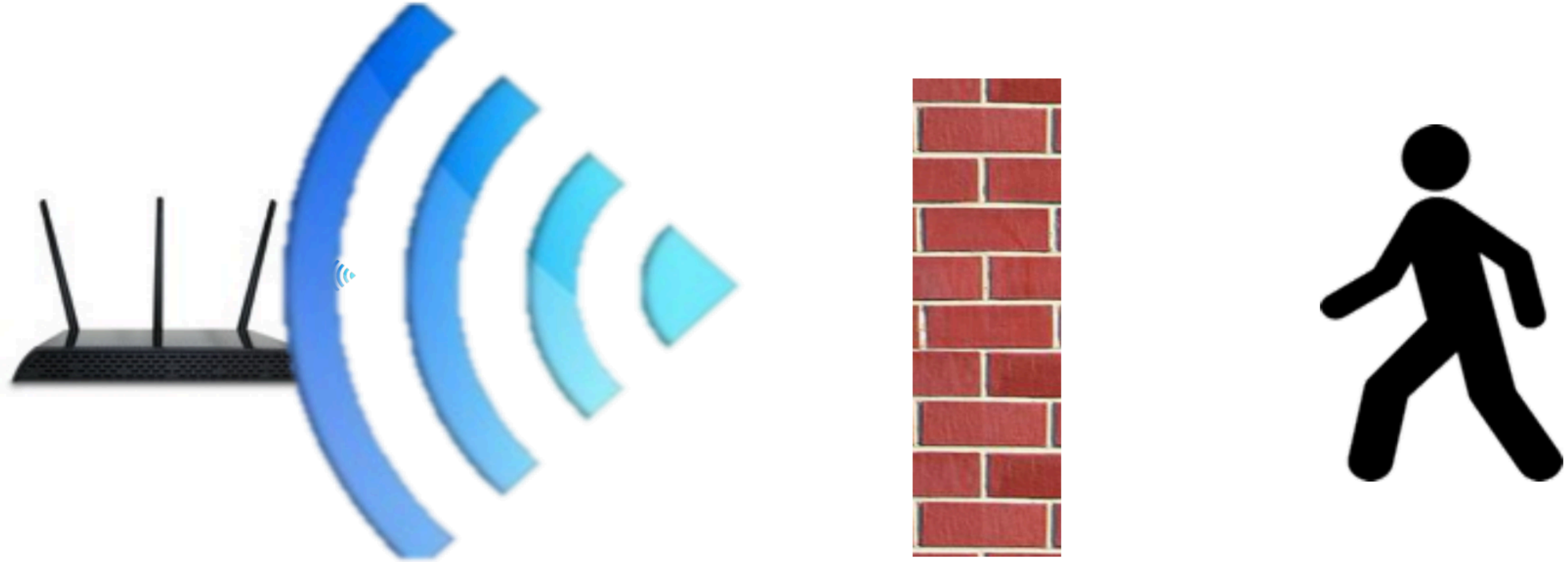
See Through Walls with Wi-Fi: WiVi

Key Idea



https://people.csail.mit.edu/fadel/wivi/

Challenges



Challenge #1: Wall reflection is 10,000x stronger than any reflections coming from behind the wall

Challenge #2: Tracking people from their reflections

How to eliminate the Wall's reflection?

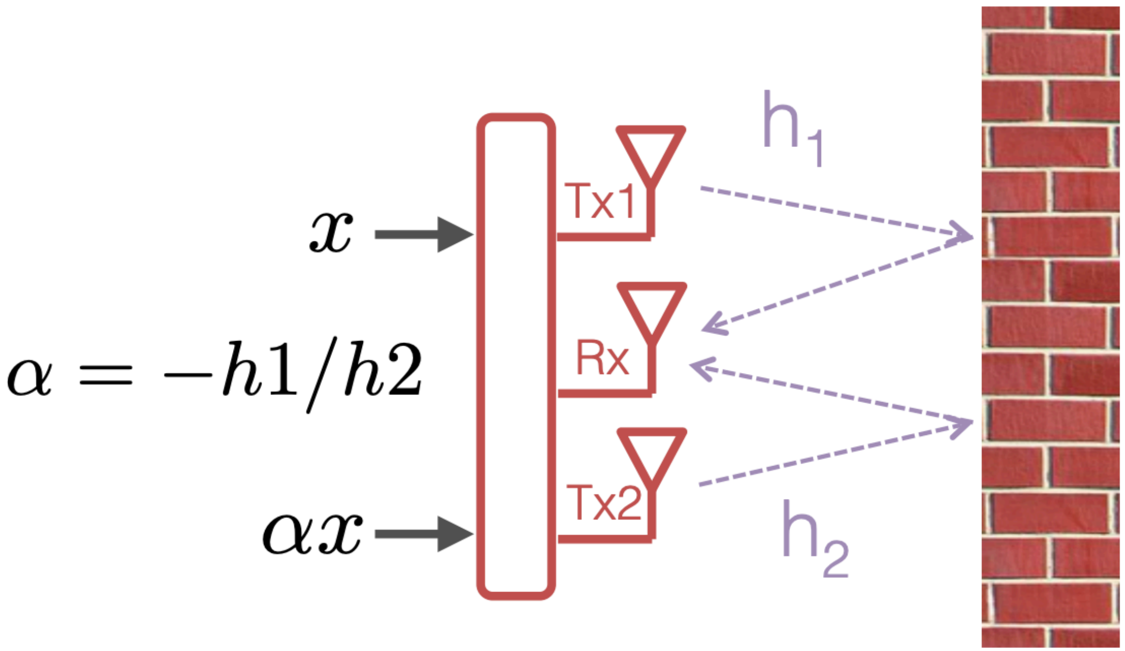
Idea: Transmit two waves that cancel each other when they reflect off static objects but not moving objects

Wall is static → disappears

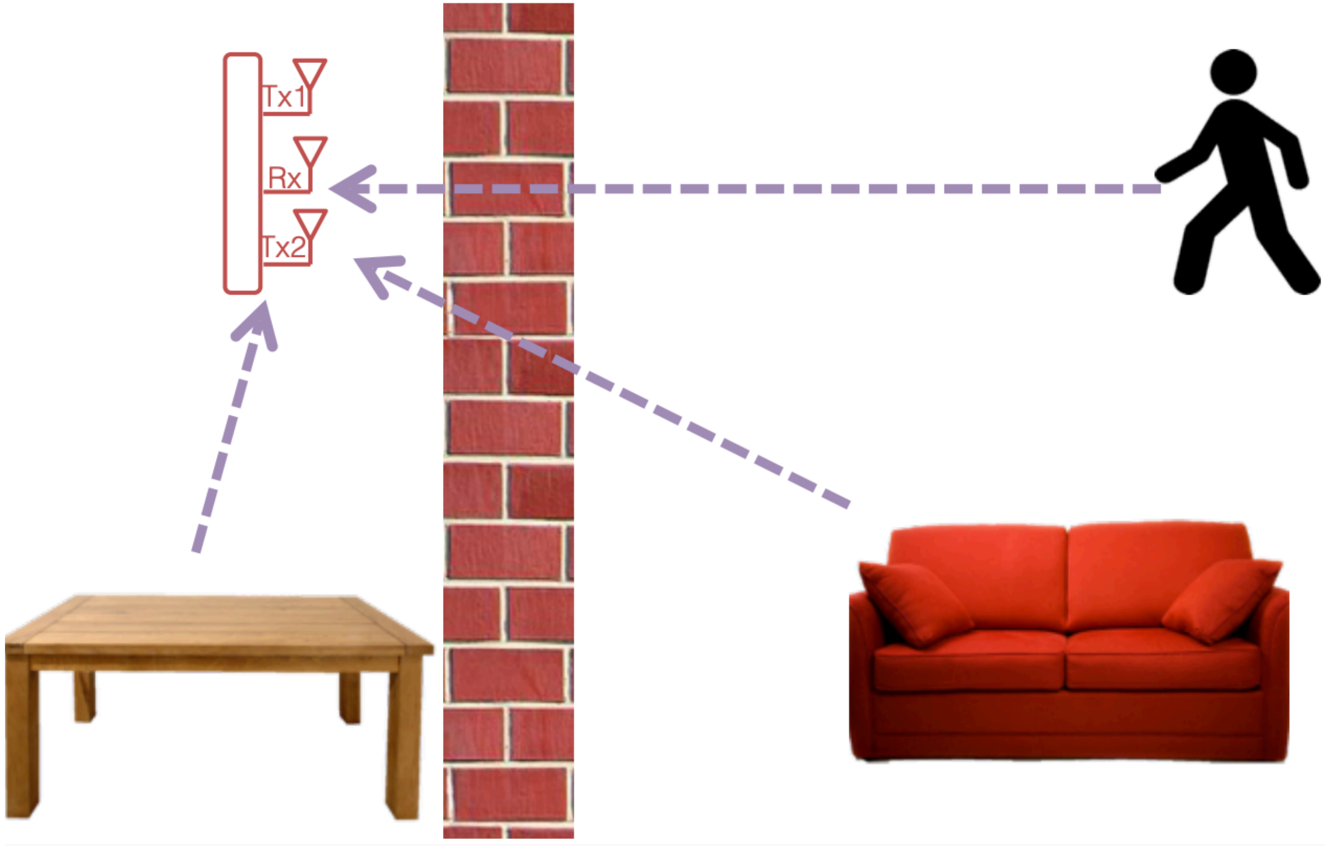
People tend to move → detectable

How to eliminate the Wall's reflection?

Received signal: $y = h_1 x + h_2 \alpha x \rightarrow 0$



Eliminating all static reflections



Eliminating all static reflections

$$y = h_1 x + h_2 \alpha x$$

Reflections linearly combine over the wireless medium

$$y = \left(\sum_i h_{1i}\right) x + \left(\sum_i h_{2i}\right) \alpha x$$

reflector i

Static objects (wall, furniture, etc.) have constant channels

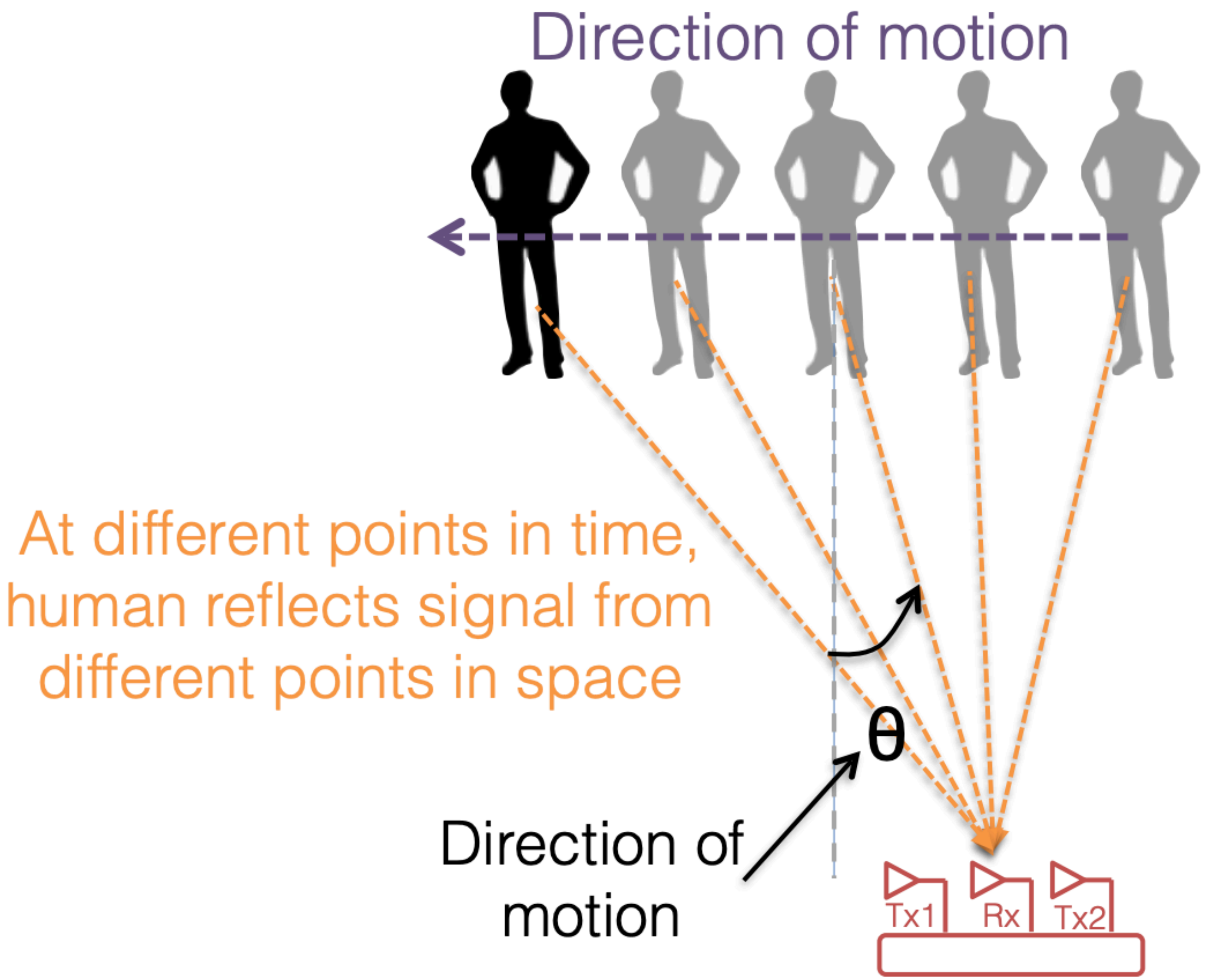
~~$y_i = h_{1i}\, x + h_{2i}(- h_{1i}/ h_{2i})x$~~ → 0

People move, therefore their channels change

$y_i = h_{1i}'\, x + h_{2i}'(- h_{1i}/ h_{2i})x$

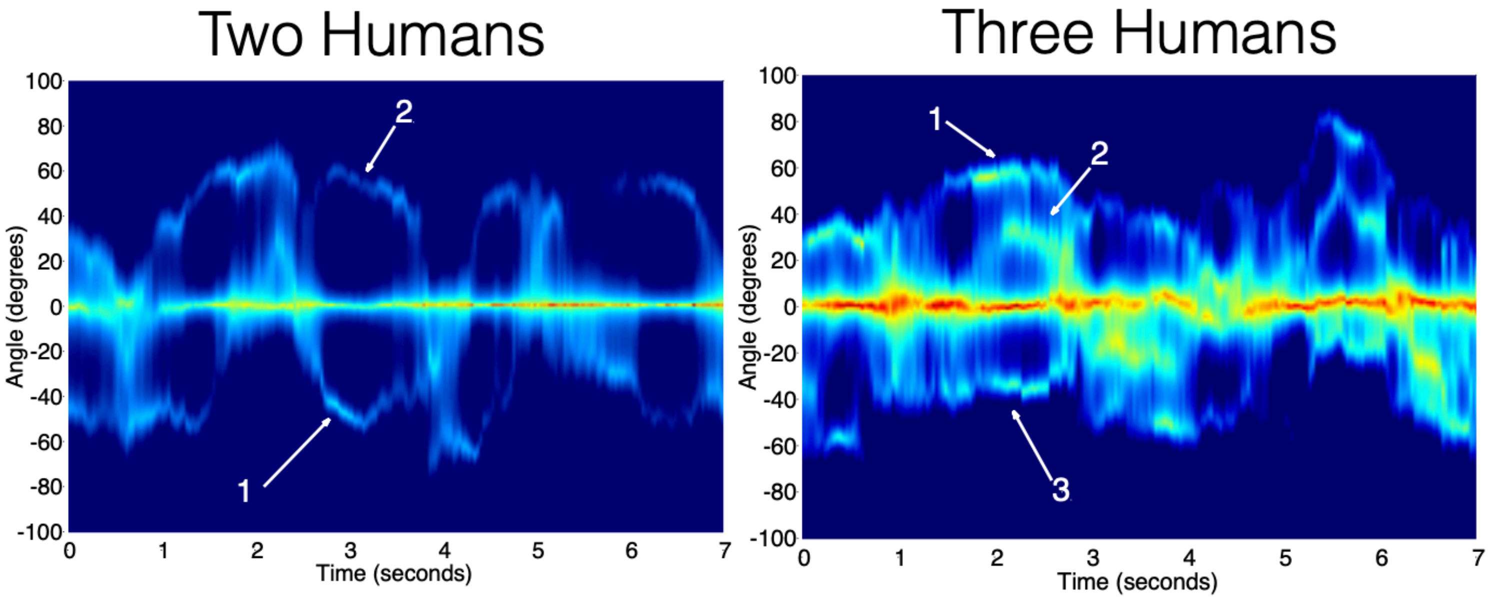
Not Zero

How to track human motion?



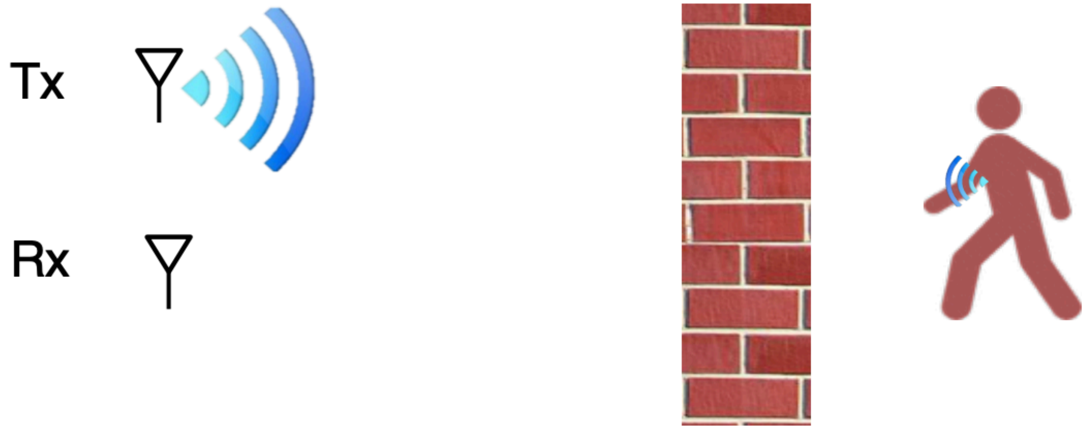
WiVi Results

Number of distinct curves at the same time corresponds to the number of humans



3D Motion Tracking: WiTrack

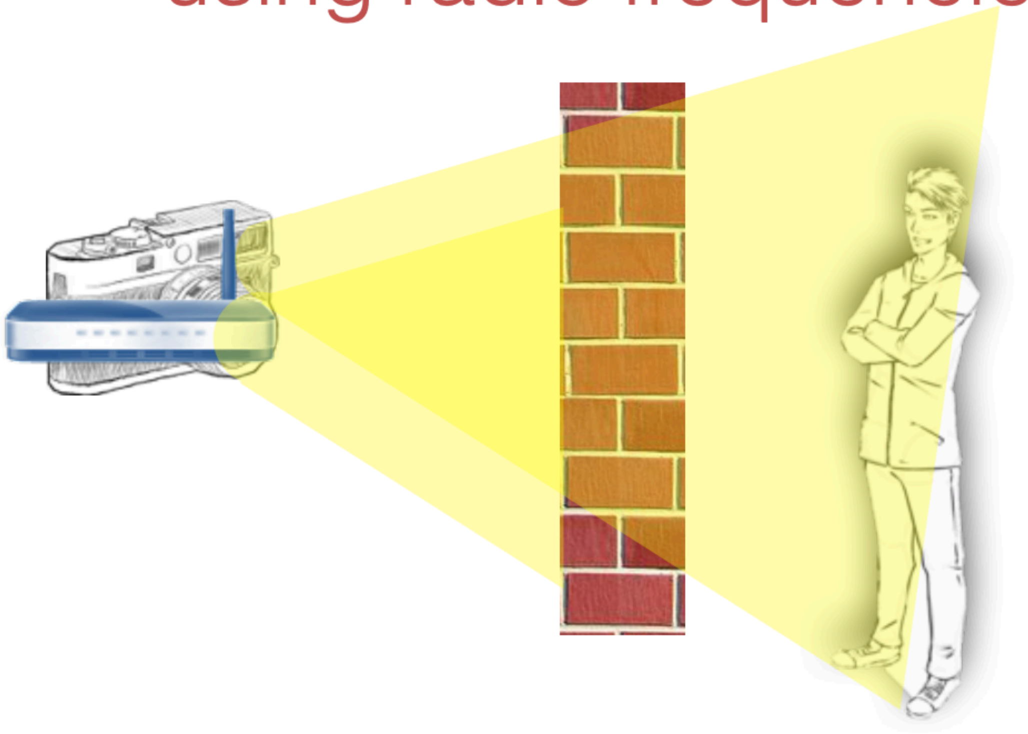
Measuring Distances



Distance = Reflection time x speed of light

RF Imaging

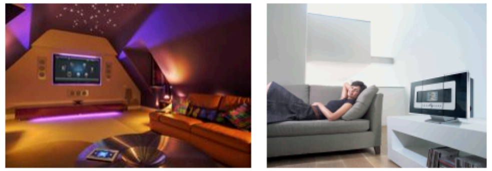
Imaging through occlusions
using radio frequencies



Emotion Recognition

Can you tell people's emotions even if they don't show up on their faces?

Smart Homes that adapt to our mood



Did I get the Job? …. No

Does my advisor like my work?

Graduate student

Advisor

Combating Depression

Is the date going well!

Emotion recognition using wireless signals