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

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

$$\Delta f = \frac{v \cos \alpha}{\lambda},$$

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

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?
<table>
<thead>
<tr>
<th>Signal</th>
<th>Protocol</th>
<th>Frequency</th>
<th>Bandwidth</th>
<th>Max. data rate (theoretical)</th>
<th>Approximate indoor rage</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>WiFi</td>
<td>802.11a/b/g/n/ac</td>
<td>11–2.4 GHz 11a–3.7/5 GHz 11b–2.4 GHz 11g–2.4 GHz 11n–20/40 MHz 11ac–5 GHz</td>
<td>11–22 MHz 11a–20 MHz 11b–20 MHz 11g–20 MHz 11n–20/40 MHz 11ac–20/40/80/160 MHz</td>
<td>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</td>
<td>11–20 m 11a–35 m 11b–35 m 11g–35 m 11n–70 m 11ac–35 m</td>
<td>1. Low cost 2. Ubiquitousness 3. Large coverage</td>
<td>1. Susceptible to environmental influence</td>
</tr>
<tr>
<td>RFID</td>
<td>ISO11784/85 ISO15693 ISO14443 EPCglobal</td>
<td>LF: 125–134 kHz HF: 13.553–13.567 MHz UHF: 868 MHz, 915 MHz</td>
<td>LF: 10 kHz HF: 15 kHz UHF: 500 kHz (North America)</td>
<td>26.7 kb/s up to 640 kb/s</td>
<td>LF: 0.2 m–1 m HF: 0.1 m–0.7 m UHF: 3 m–10 m</td>
<td>1. Directional performance 2. Privacy</td>
<td>1. Signal collision and data loss 2. Security concerns</td>
</tr>
<tr>
<td>UWB</td>
<td>802.15.7</td>
<td>3.1–10.6 GHz</td>
<td>&gt;500 MHz</td>
<td>480 Mb/s up to 1.6 Gb/s</td>
<td>10 m</td>
<td>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</td>
<td>1. Hardware dependency</td>
</tr>
<tr>
<td>Acoustics</td>
<td>N/A</td>
<td>20 to 20 kHz</td>
<td>N/A</td>
<td>N/A</td>
<td>Several meters</td>
<td>1. Ubiquitousness 2. High speed resolution 3. High resolution in detecting phase shift</td>
<td>1. Susceptible to environment 2. Small coverage 3. Bad user experience</td>
</tr>
</tbody>
</table>
RF Sensing: Applications

• Localization
• Gesture recognition
• Motion detection
• Activity detection
• More general applications (e.g., Healthcare, VR/AR, Security)
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Wireless and Mobile Networks

RF Sensing – II (Applications)

Mallesham Dasari
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
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.

\[ \Delta f_n = \frac{v}{\lambda} \cos \alpha_n \]

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

(a) Push  (d) Dodge  (g) Strike
(b) Pull  (e) Drag  (h) Kick
(c) Circle  (f) Punch X2  (i) Bowling
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-txrfar

(d) Through-the-Wall
(e) Through-the-Corridor
(f) Through-the-Room
WiSee Results

Detection + Classification Accuracy (%)

Number of Interfering Users

Doppler Energy of Target User (in dB)

Distance of Interfering User from Receiver (in feet)
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: \( y = h_1 x + h_2 \alpha x \)

\[ \alpha = -h_1 / h_2 \]
Eliminating all static reflections
Eliminating all static reflections

\[ y = h_1x + h_2\alpha x \]

Reflections linearly combine over the wireless medium

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

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

\[ y_i = h_{1i}x + h_{2i}(\alpha - h_{1i}/h_{2i})x \]

People move, therefore their channels change

\[ y_i = h_{1'i}x + h_{2'i}(\alpha - h_{1'i}/h_{2'i})x \]

Not Zero
How to track human motion?

At different points in time, human reflects signal from different points in space.
WiVi Results

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

Two Humans

Three Humans
3D Motion Tracking: WiTrack

Measuring Distances

Distance = Reflection time × 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?

Emotion recognition using wireless signals

Smart Homes that adapt to our mood

Did I get the Job? …. No

Respiration Signal

Reflection

Heartbeat Signal

Does my advisor like my work?

Graduate student
Advisor

Combating Depression

Is the date going well!

that is what
Sad

this is what
expression

Learn the difference.