Signal Processing for Environment-Invariant WiFi Human Sensing

Yutian Lei  Fei Wang  Dong Huang

Motivation

- Raw CSI data contains redundant information from the static environ
- CSI measurements are sensitive to the location and orientation of the antenna
- There are hardware and software estimation errors for CSI

CSI: Channel State Information

CSI characterizes how wireless signals propagate from the transmitter to the receiver at certain carrier frequencies.

\[ H(t; f) = \sum f_1(t) e^{-j2\pi ft_1(t)} \]

 CSI: Channel State Information

Phase Offsets Removal

**Sampling Time Offset (STO):** the receivers and the transmitter are not tightly time synchronized, so their sampling clocks at the DAC and the ADC are not in sync. **Sampling frequency offset (SFO):** between every WiFi sender receiver pair. SFO changes the sampling time offset from packet to packet for the same sender-receiver pair; **Cyclic Shift Diversity (CSD):** caused by Orthogonal Frequency-Division Multiplexing (OFDM). [2]

\[ H_{m,n,k} = \gamma(e^{-j2\pi f_k \tau_{m,n,l}}) e^{-j2\pi a_m f_k} e^{-j2\pi b_k f_k} e^{-j2\pi c(f_k' - f_k)} \]

\[ \angle H_{m,n,k} = \Phi_{m,n,k} - 2\pi f_k(a_i + b + c(f_k' / f_k - 1)) \]

Multipath Feature Estimation

- Angle of Arrival and Angle of Departure; Time of Flight; Doppler velocity [3]
- \( X = AF + N; X: \) Received Signal, \( A: \) Steering Matrix, \( N: \) White Noise

\[ R_X = \frac{1}{N} E(XX^H) = U_S\Sigma_S U_S^H + U_N\Sigma_N U_N^H \]

\[ \theta_{Music} = \arg \min_\theta \frac{1}{\alpha(\theta)U\Sigma U^H(\theta)} \]

Summary of 1-D Estimation of Multi-Path Feature

<table>
<thead>
<tr>
<th>Snapshot Domain</th>
<th>CSI Shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>AoA</td>
<td>Transmitter, Frequency and Time</td>
</tr>
<tr>
<td>AoD</td>
<td>Receiver, Frequency and Time</td>
</tr>
<tr>
<td>ToF</td>
<td>Receiver and Transmitter Time</td>
</tr>
<tr>
<td>Doppler</td>
<td>Receiver and Transmitter Frequency</td>
</tr>
</tbody>
</table>

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