Signal Processing for Environment-Invariant WiFi Human Sensing

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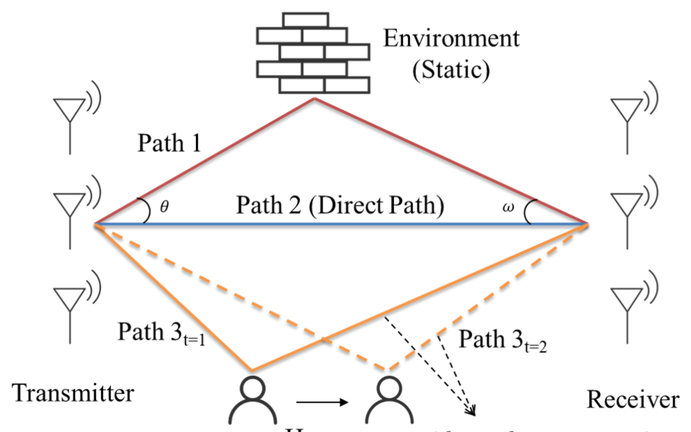
Motivation

- 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

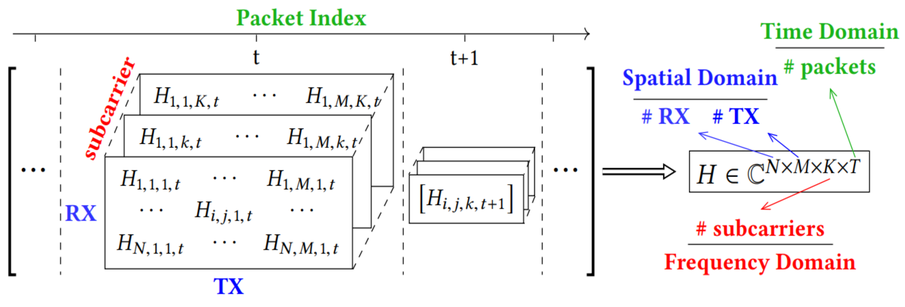
CSI: Channel State Information



$\Delta length_{path_k} = v_k \Delta t$

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

$$H(t;\ f)\ = \sum_l \gamma_l(t) e^{-j2\pi\, f \tau_l(t)}$$

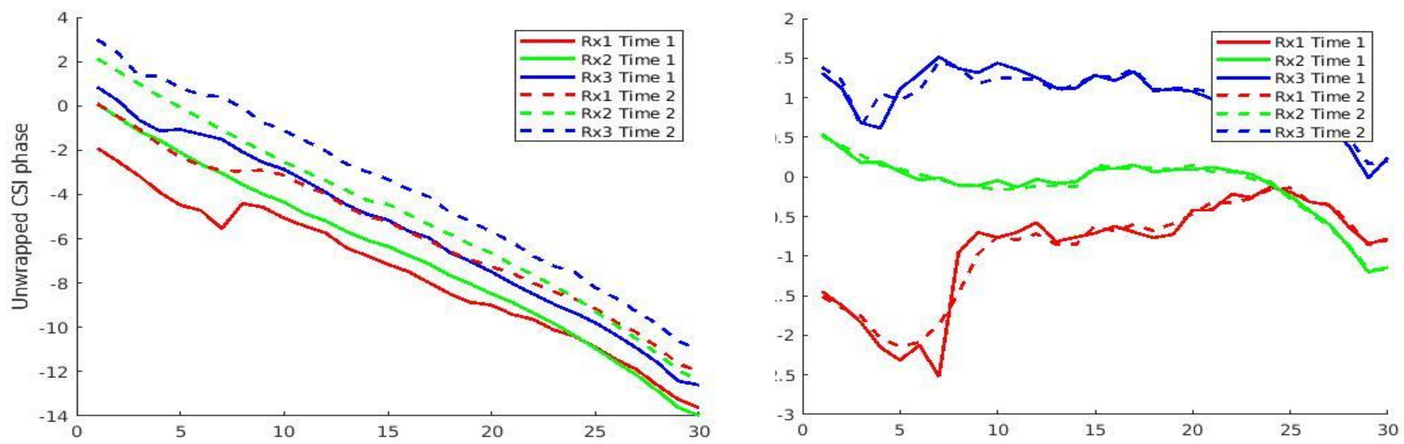


Phase Offsets Removal

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]

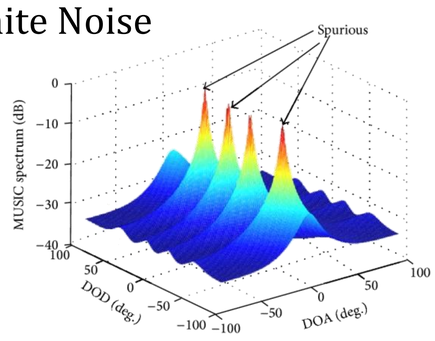
$$H_{m,n,k} = (\sum_l^L \gamma_l e^{-j2\pi f_k \tau_{m,n,l}}) e^{-j2\pi a_m f_k} e^{-j2\pi b f_k} e^{-j2\pi c(f'_k - f_k)}$$

$$\angle H_{m,n,k} = \Phi_{m,n,k} - 2\pi f_\sigma k(a_i + b + c(f'_k/f_k - 1))$$



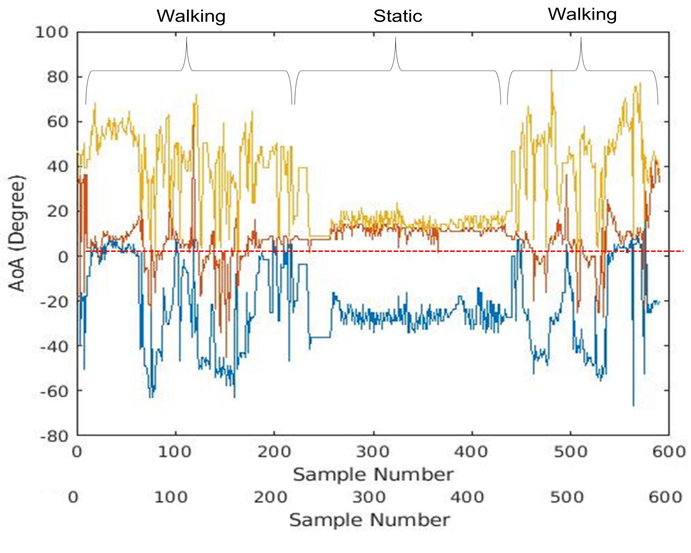
Muiltipath Feature Estimation

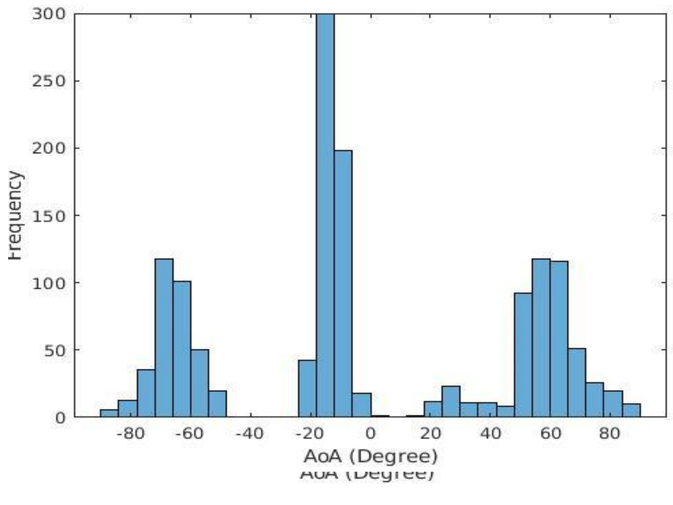
- **Angle of Arrival and Angle of Departure; Time of Flight; Doppler velocity [3]**
- $X = AF + N$, X: Recevied Signal, A: Steering Matrix, N: White Noise
- $\widehat{R_X} = \frac{1}{N} * E(XX^H) = U_S \Sigma_S U_S^H + U_N \Sigma_N U_N^H$
- $\theta_{Music} = \arg\min_\theta \frac{1}{\alpha(\theta)^H U U^H \alpha(\theta)}$



SUMMARY OF 1-D ESTIMATION OF MULTI-PATH FEATURE

	Snapshot Domin	CSI Shape
AoA	Transmitter, Frequency and Time	$(N, M \times K \times T)$
AoD	Recevier, Frequency and Time	$(M, N \times K \times T)$
ToF	Recevierm Transmitter and Time	$(K, M \times N \times T)$
Doppler	Recevierm Transmitter and Frequency	$(T, M \times N \times K)$





Reference

[1] R. Schmidt, “Multiple emitter location and signal parameter estimation,” IEEE Transactions on Antennas and Propagation, vol. 34, no. 3, pp. 276–280, March 1986.
[2] Y. Ma, G. Zhou, and S. Wang, “Wifi sensing with channel state information: A survey,” ACM Comput. Surv., vol. 52, no. 3, pp. 46:1–46:36, Jun. 2019. [Online]. Available: http://doi.acm.org/10.1145/3310194
[3] M. Kotaru, K. Joshi, D. Bharadia, and S. Katti, “Spotfi: Decimeter level localization using wifi,” in ACM SIGCOMM computer communication review, vol. 45, no. 4. ACM, 2015, pp. 269–282

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