High-Accuracy Indoor Localization: A WiFi-based Approach

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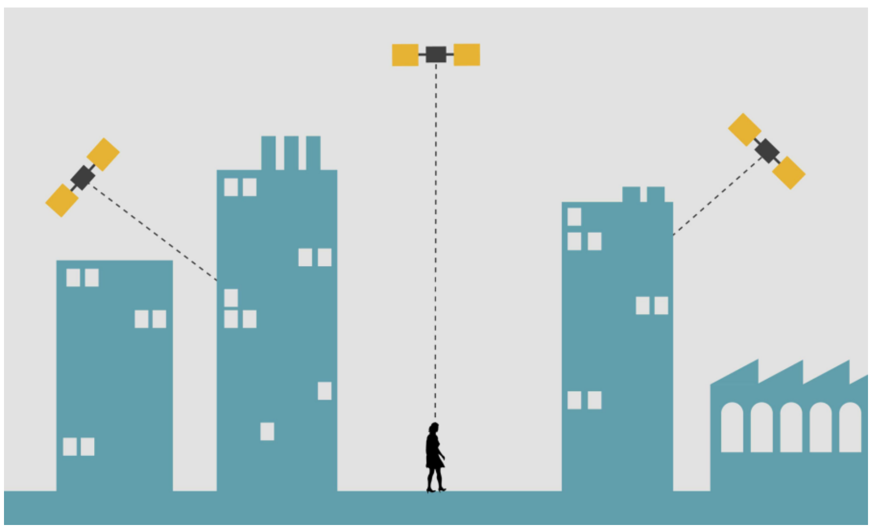
GPS Fails Indoors

- Signal blockage leads to severe attenuation.
- Multipath environment causes error in timing.



Indoor Positioning

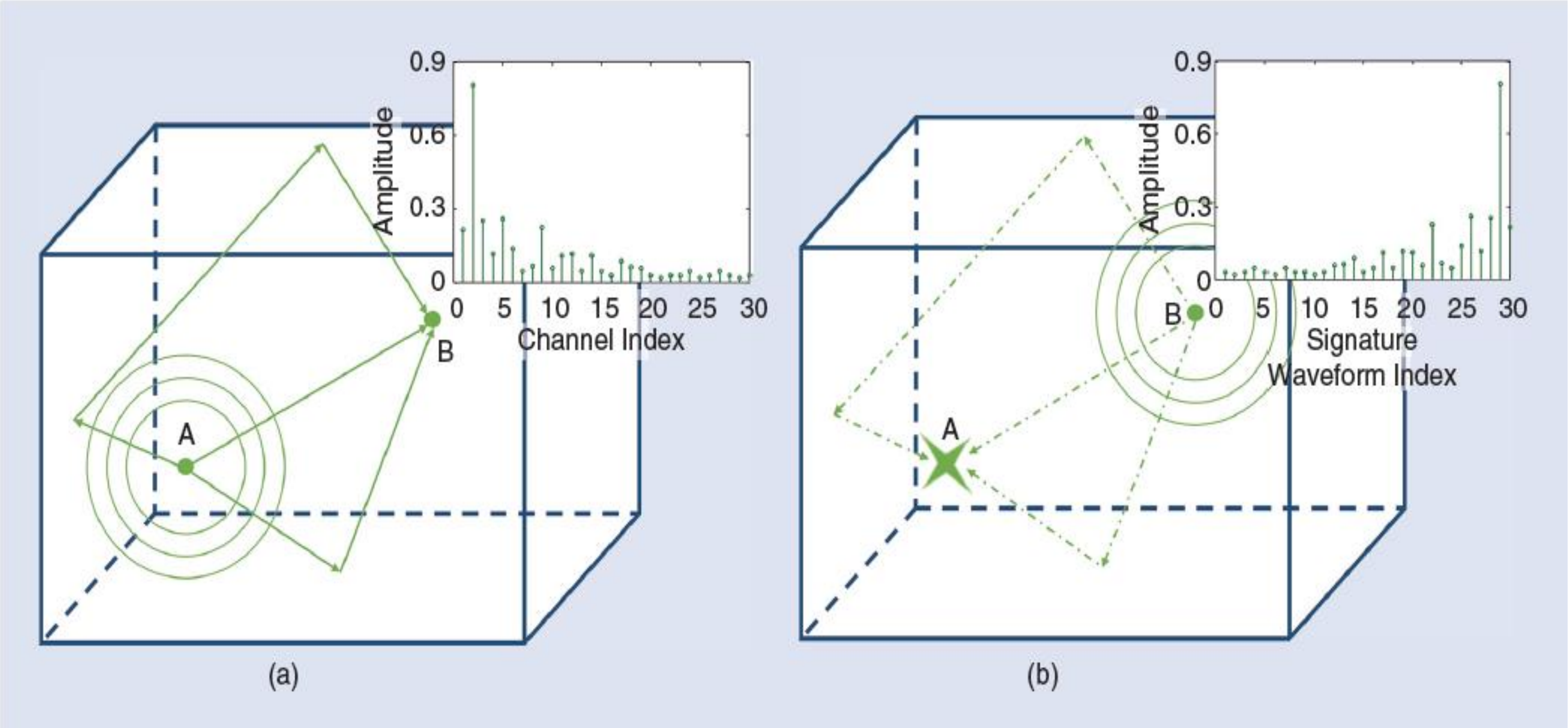
- Indoor positioning systems have been developed for two decades with many approaches
  - RFID
  - Received Signal Strength
  - Time-of-Arrival
  - Angle-of-Arrival
  - Magnetic Field

"The Indoor Location Problem is NOT Solved"
Microsoft Indoor Localization Competition: Experiences and Lessons Learned, 2014

Motivations

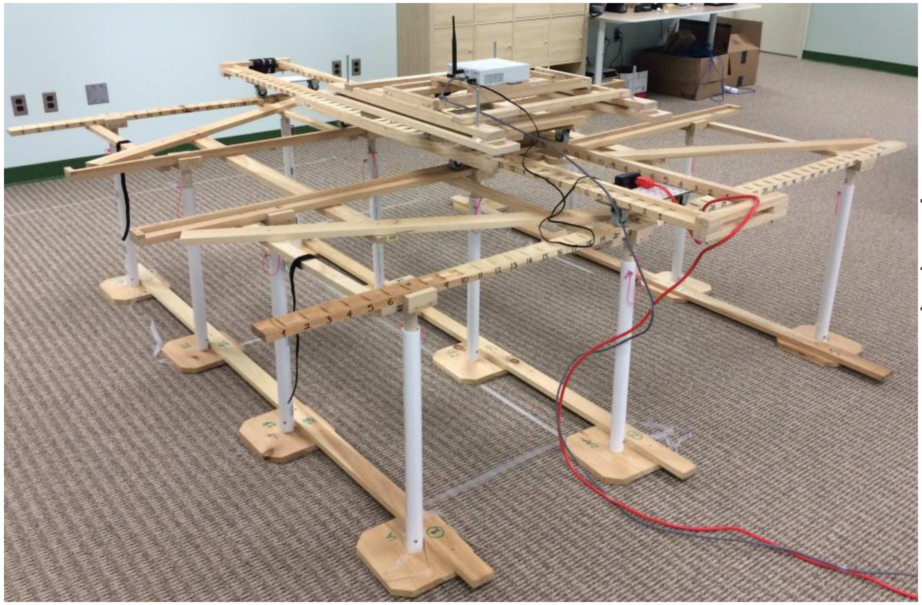
- None of the existing positioning systems can
  - achieve centimeter-level accuracy
  - under non-line-of-sight (NLOS) conditions
  - most with accuracy of 1m or more
- Is there any way that we can achieve centimeter-level accuracy under NLOS conditions?
- We propose to use the fundamental physical principle of time-reversal to answer this question.

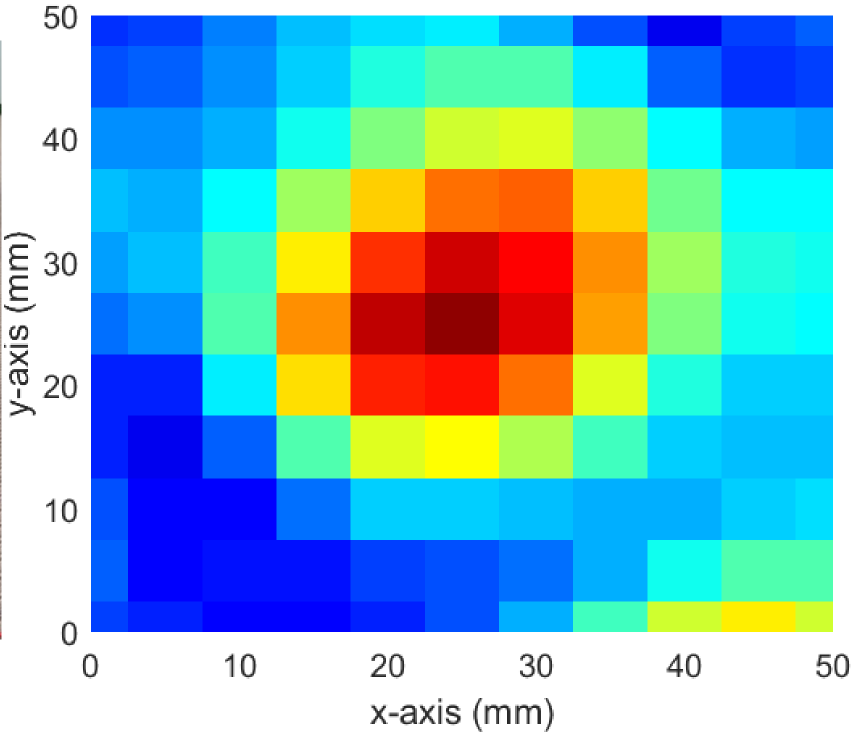
What is Time-Reversal?



Time-Reversal Focusing Effect

- Experiment results show that the time-reversal can achieve 1-2cm accuracy in indoor localization.

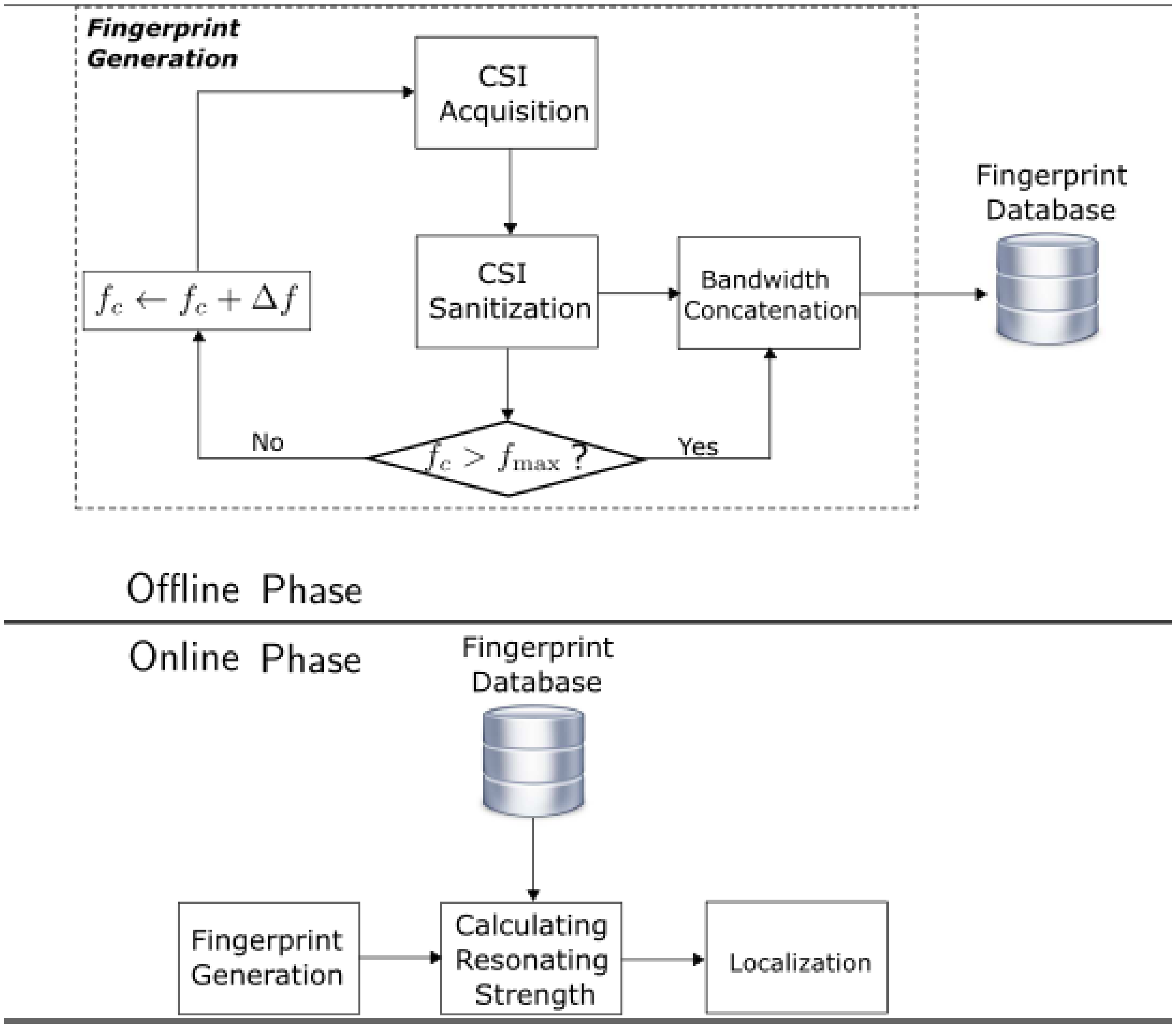




Large Effective Bandwidth

- Time-Reversal requires a large bandwidth for resolving the multipaths in the environment.
- Existing WiFi-based methods cannot achieve centimeter-level accuracy due to bandwidth limit.
  - Only 20MHz or 40MHz per channel
- We propose to create a large effective bandwidth by concatenating bandwidths from multiple channels.

Overview of Algorithm



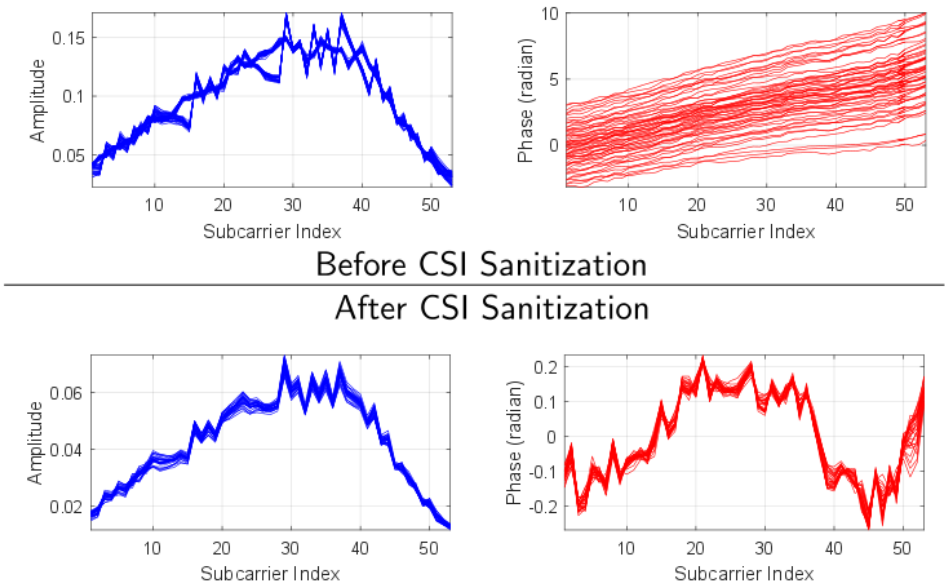
CSI Sanitization

- Channel State Information (CSI) is corrupted by
  - Carrier frequency offset: additional initial phase shift
  - Timing offset: additional linear phase shift

Input: CSI on channel d and subcarrier k for the first and second long trainir sequence, denoted as $H_d[k]$ and $H'_d[k]$ respectively.

1. Calculate $\Phi_d[k] = \measuredangle \{H^*_d[k] H'_d[k]\}$
2. Calculate $\overline{H}_d[k] = H_d[k] \exp(-j\frac{3\pi}{2}\Phi_d[k])$, $\overline{H}'_d[k] = H'_d[k] \exp(-j\frac{5\pi}{2}\Phi_d[k]$
3. Calculate $\tilde{H}_d[k] = \frac{\overline{H}_d[k] + \overline{H}'_d[k]}{2}$
4. Calculate $A_d[k] = \measuredangle \left\{\tilde{H}_d[k]\right\}$
5. Unwrap $\{A_d[k]\}_{k=0,1,\cdots,51}$ into $\{A'_d[k]\}_{k=0,1,\cdots,51}$
6. Calculate $\xi_d = \frac{64 \sum_{k=0}^{51}[k - \frac{51}{2}][A'_d[k] - \overline{A}_d]}{2\pi \sum_{k=0}^{51}[k - \frac{51}{2}]^2}$, where $\overline{A}_d = \frac{\sum_{k=0}^{51} A'_d[k]}{52}$
7. Compensate $\tilde{H}_d[k]$ as $\underline{H}_d[k] = \tilde{H}_d[k] \exp\left(-j\frac{2\pi k}{N}\xi_d\right)$

Output: Sanitized CSI on channel d and subcarrier k $\tilde{H}_d[k]$.



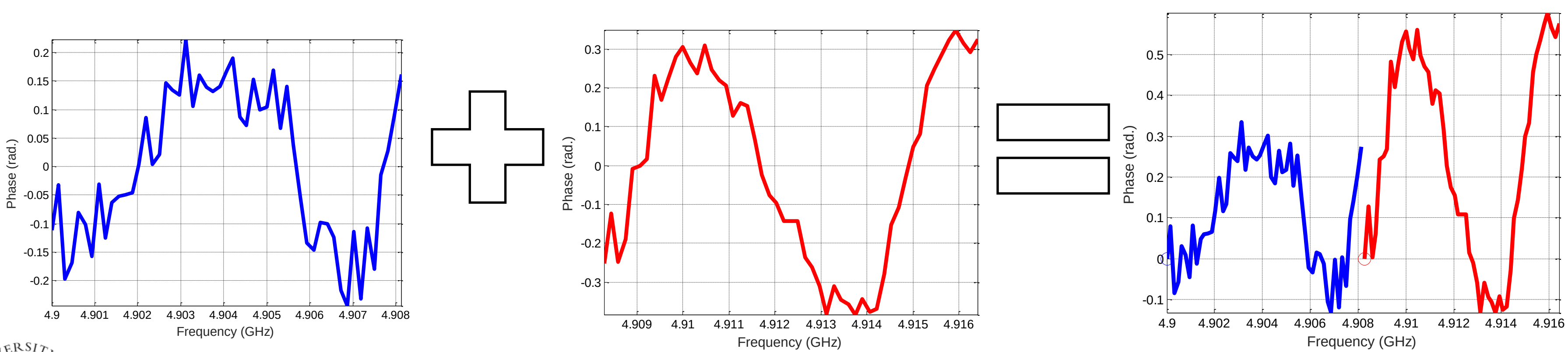
Bandwidth Concatenation

- We form the localization fingerprint by concatenating all sanitized CSIs from different channels.

Input: $\underline{H}_d[k]$ for all channel d and subcarrier k.

1. $G_d[k] = \underline{H}_d[k]\exp(-j\measuredangle\{\underline{H}_d[0]\}),\ \forall d,\ \forall k$
2. $\mathbf{G} = \left[G_1[0] \quad G_1[1]\cdots \quad G_1[51] \quad G_2[0] \quad \cdots \quad G_D[51]\right]^T$

Output: localization fingerprint $\mathbf{G}$.



Localization

Input #1: localization fingerprint $\{\mathbf{G}_\ell\}_{\ell=1,2,\cdots,L}$ from all L locations-of-interest.
Input #2: localization fingerprint $\mathbf{G}_{\ell'}$ from an unknown location ℓ'.

- Calculate the maximum of the resonating strength given by

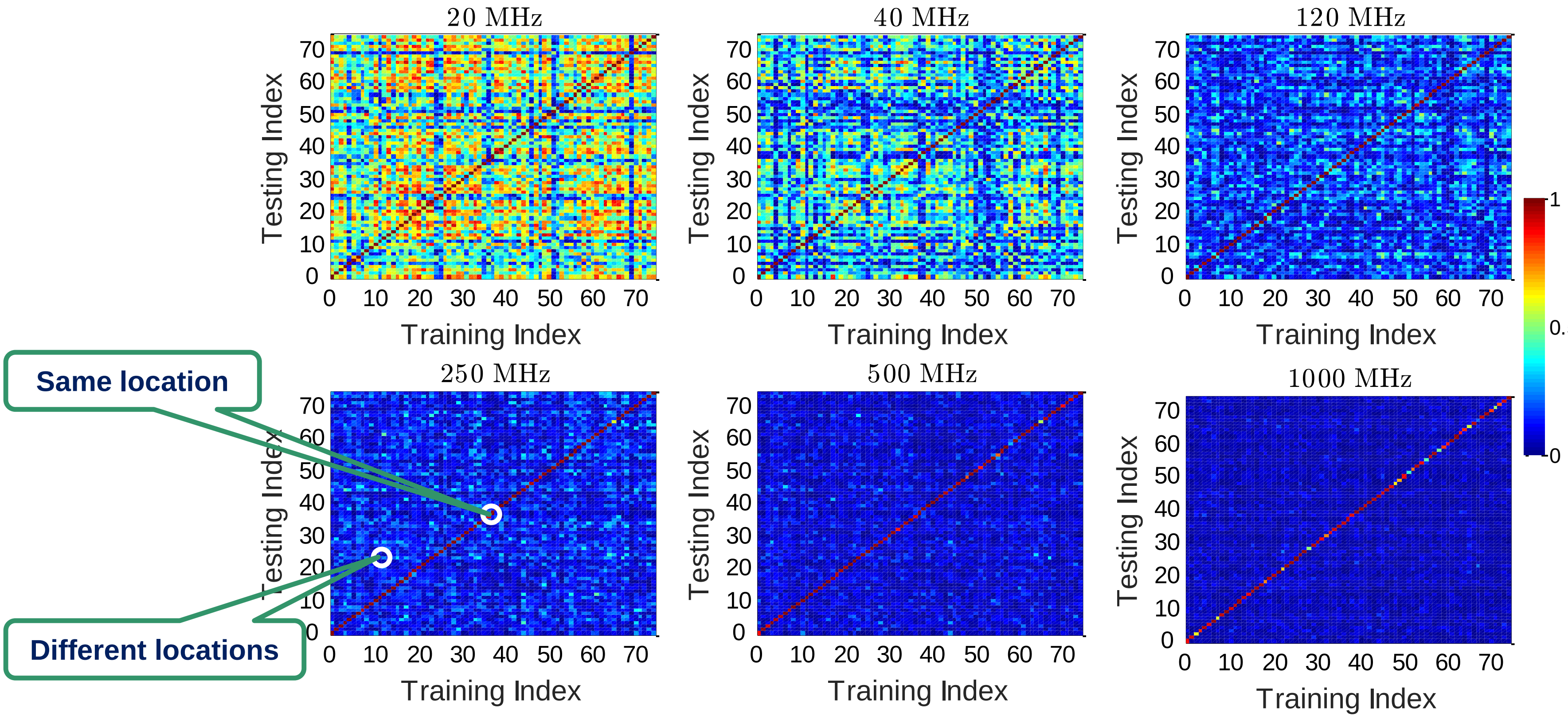
$$\Phi[\ell'] = \max_{\ell=1,2,\cdots,L} \left| \frac{\mathbf{G}_\ell^\dagger \mathbf{G}_{\ell'}}{||\mathbf{G}_\ell||_2 ||\mathbf{G}_{\ell'}||_2} \right|^2$$

- If $\Phi[\ell'] \geq \gamma$ where γ is a threshold, then localize ℓ' to the ℓ that maximizes $\Phi[\ell']$.

- If $\Phi[\ell'] < \gamma$, then consider ℓ' as an unmapped location.

Output: Estimated location ℓ'.

Experiment Results



The confusion matrices (with resonating strengths as elements) of 5cm sampling from the testbed.

Conclusion

- This work is the first to
  - use time-reversal for indoor localization, and
  - achieve centimeter-level accuracy under NLOS conditions.
- The proposed novel bandwidth concatenation algorithm forms a large effective bandwidth to enable centimeter-accuracy.
- It is based on standard WiFi devices, therefore with ubiquitous applications potential.