Angle-of-Arrival (AoA) Factorization in Multipath Channels

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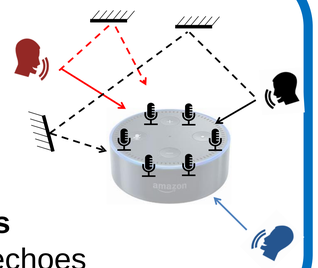
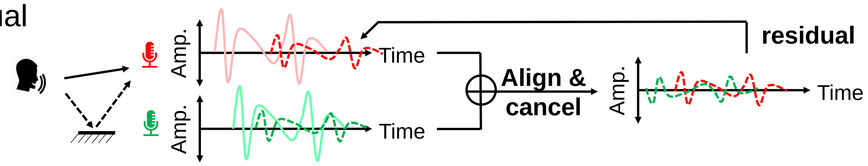
Problem Statement

- Users are speaking to a microphone array simultaneously
  - **Input**: Received signal from each microphone
  - **Output**: Estimate K AoAs of direct path and echoes
  - **Note**: The source signals are unknown
- Status quo
  - MUSIC can estimate AoAs of **uncorrelated sources**
- Can we estimate **AoA of every path,** including correlated echoes



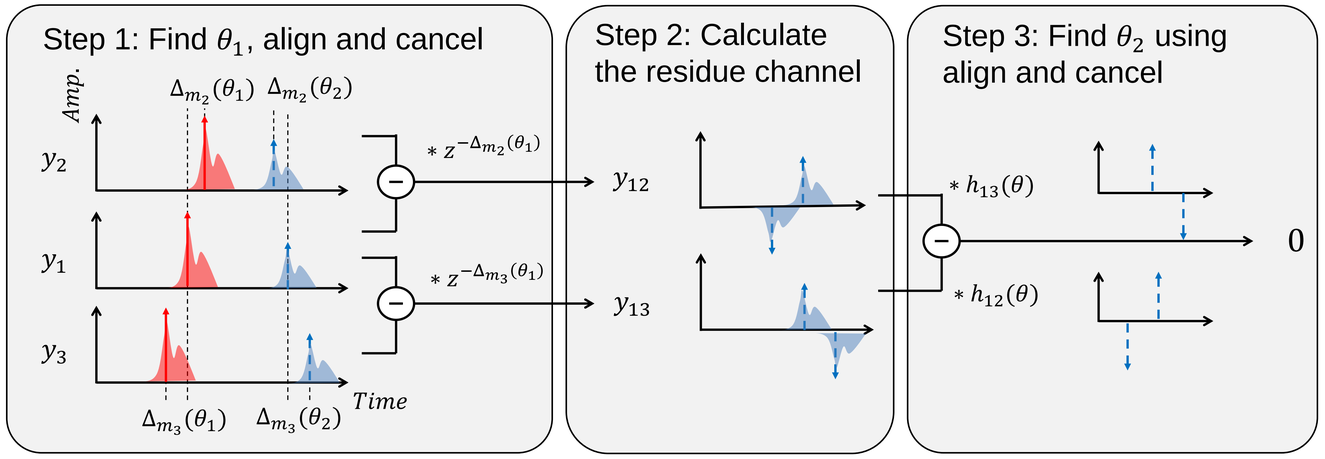
Key Insight

- Iteratively align and cancel each signal path to decode subsequent AoA
  - Strong path can be estimated, but pollutes weak path AoA estimation
  - Align and cancel strong path after estimating its AoA, then iterate on the residual



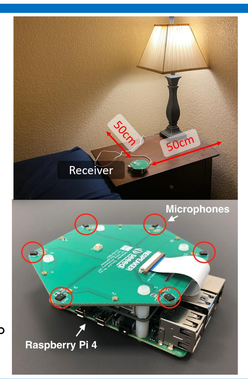
Main Steps

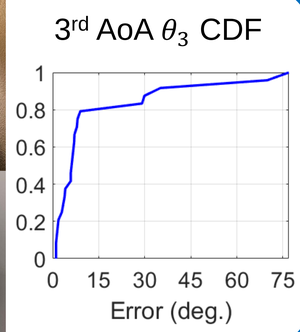
1. Align and cancel (A&C) on received signal y_i for θ_1 and keep the residual
   - $\theta_1 = argmin_\theta(y_i * h_j(\theta) - y_j * h_i(\theta))$
   - $y_{ij} = y_i * h_j(\theta_1) - y_j * h_i(\theta_1)$
2. Construct residual channel bank
   - $h_{ij}(\theta) = h_i(\theta) * h_j(\theta_1) - h_j(\theta) * h_i(\theta_1)$
3. A&C on residual pairs for θ_2 using the residual channel bank
   - $\theta_2 = argmin_\theta(y_{ij} * h_{mn}(\theta) - y_{mn} * h_{ij}(\theta))$
4. Keep the residual and go to Step 2.
   - $y_{ij,mn} = y_{ij} * h_{mn}(\theta_2) - y_{mn} * h_{ij}(\theta_2)$



Results

- Real-world experiment
  - Raspberry Pi 4 microphone array
  - Placed at bedroom corner
  - source signal ~1 meter away
  - 24 test cases
- Performance
  - Can estimate up to **3 paths**
  - θ_3 error: 80th percentile error **<10°**





Takeaways

- We proposed IAoA that estimates the **AoA of each path (including correlated echoes)** using signals received from a **microphone array**
- The core idea is to align and cancel **already estimated paths**
- **6-mic** array can accurately estimate AoA up to **3** paths (error grows thereafter)
- Works for both **correlated or uncorrelated** sources