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

Yu-Lin Wei

Romit Roy Choudhury

ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

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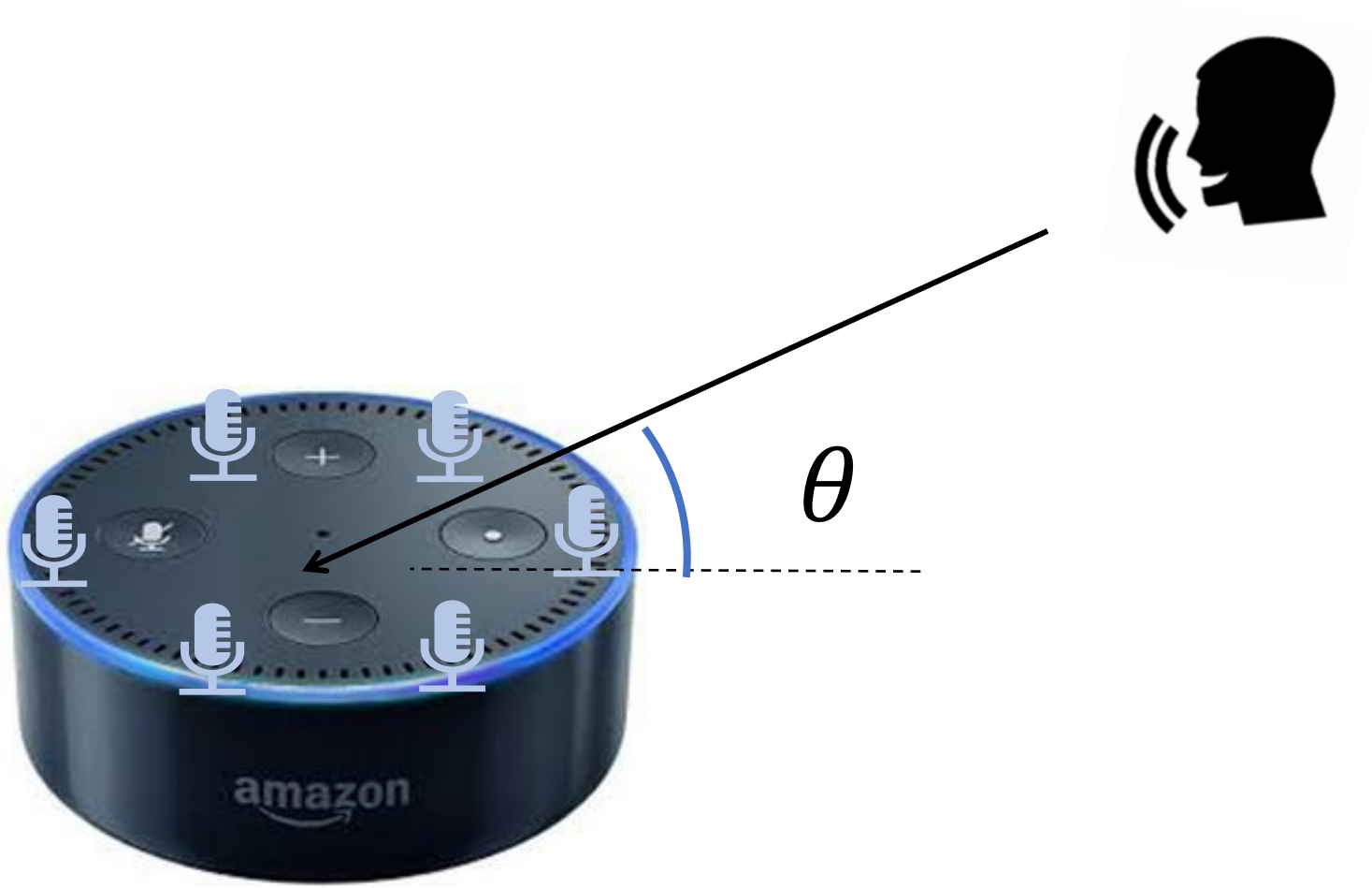
AoA (Angle of Arrival) = angle θ in which a signal arrives



Microphone array can estimate AoA

Different AoA difficulties

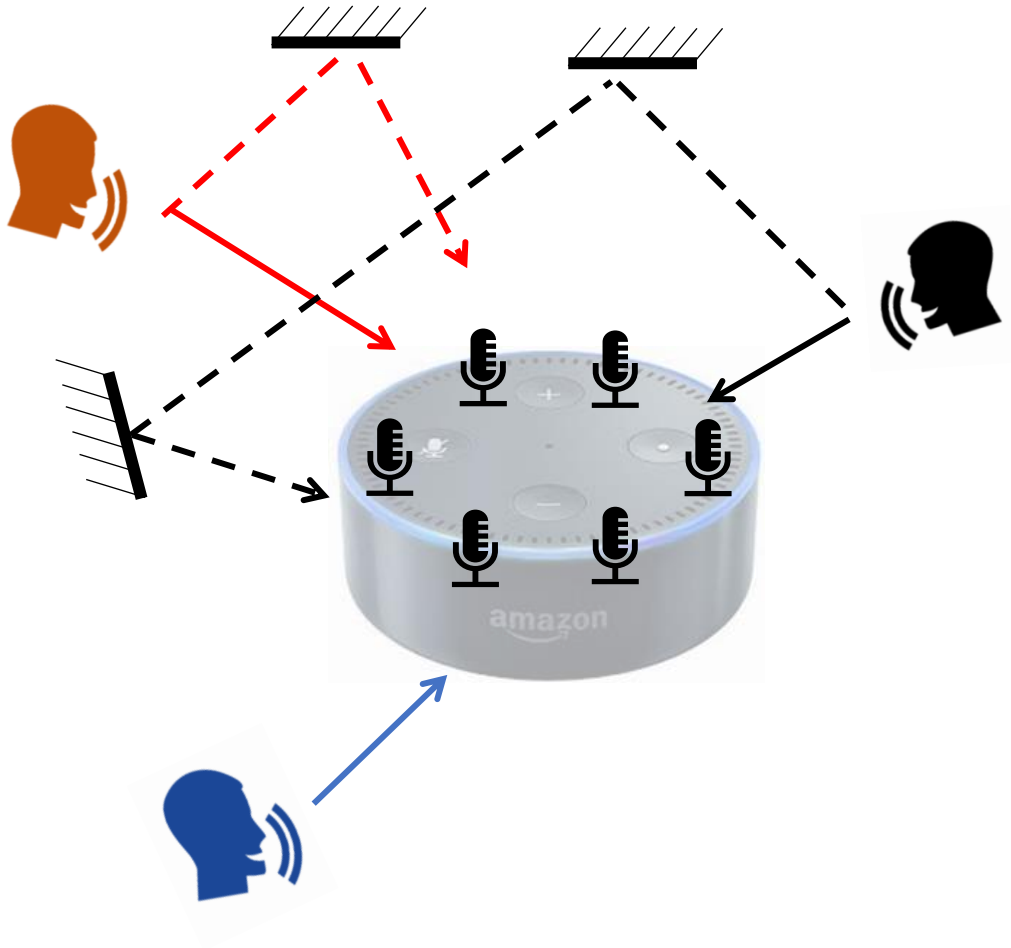
Easy

1 source

Uncorrelated sources

Hard

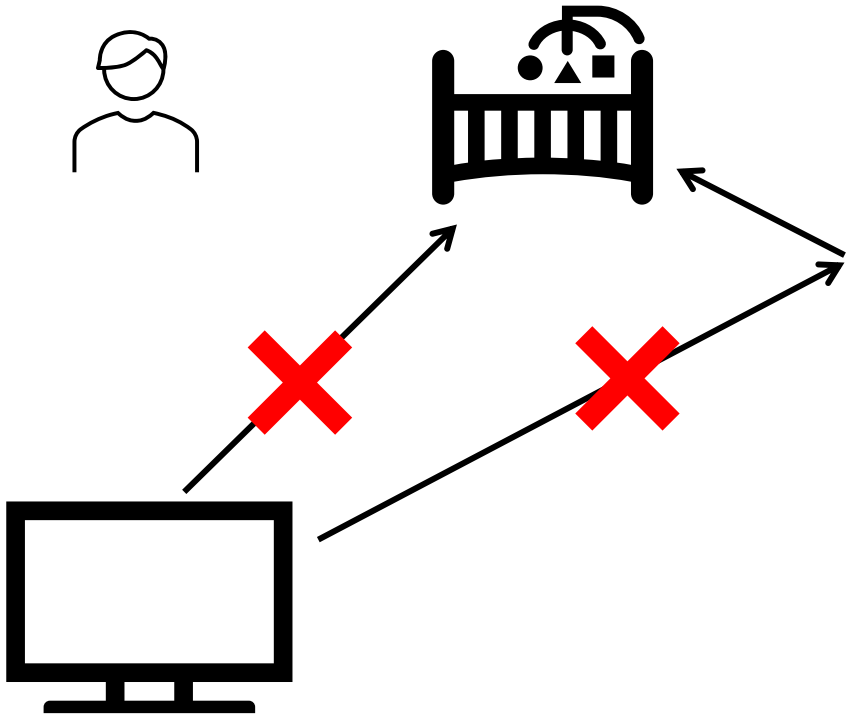
This paper:
Correlated or
uncorrelated sources



Why do we want to estimate echo AoA?

Indoor localization

Silent zone



More information -> more applications

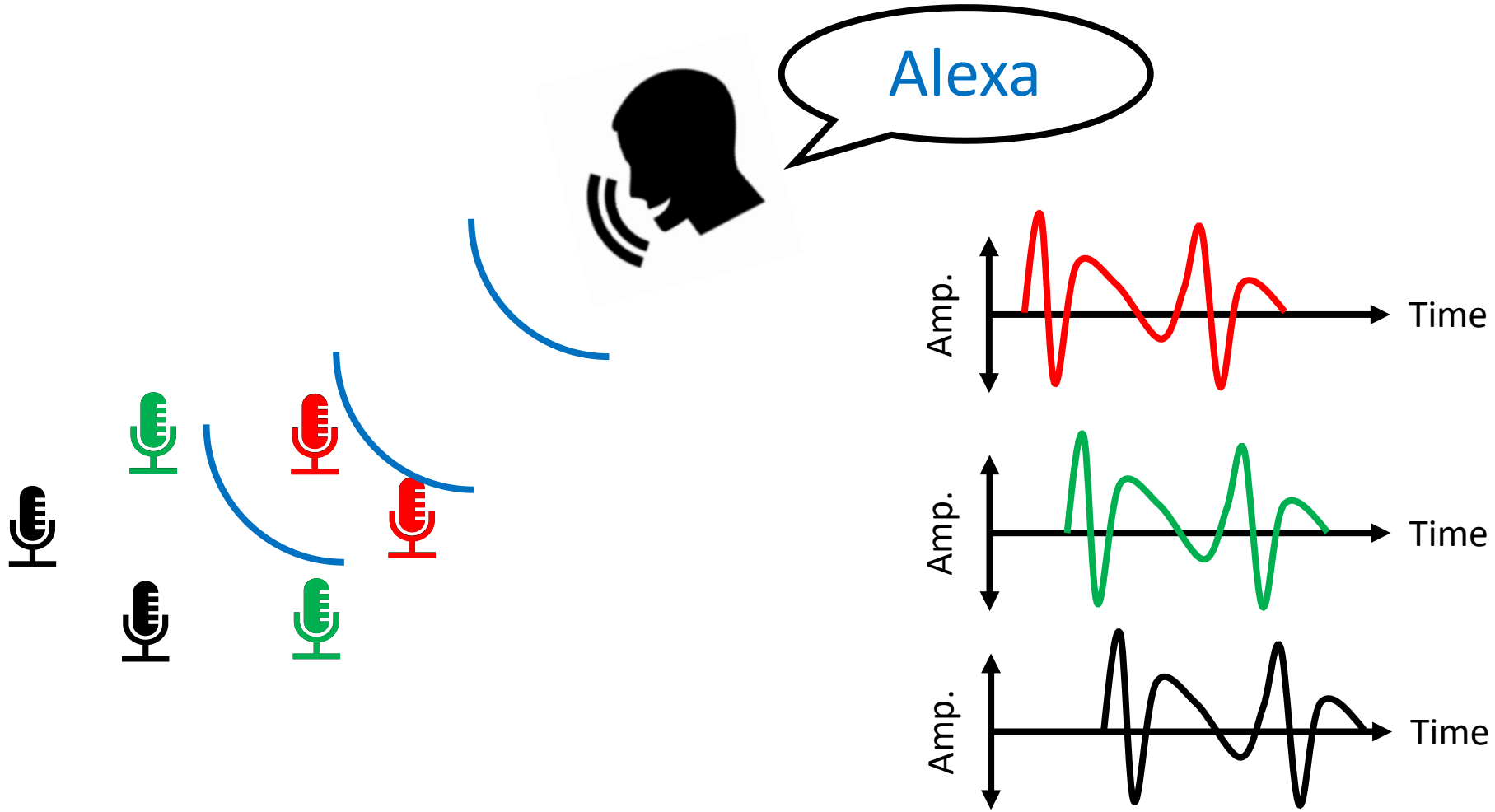
This presentation

AoA Primer & Challenge

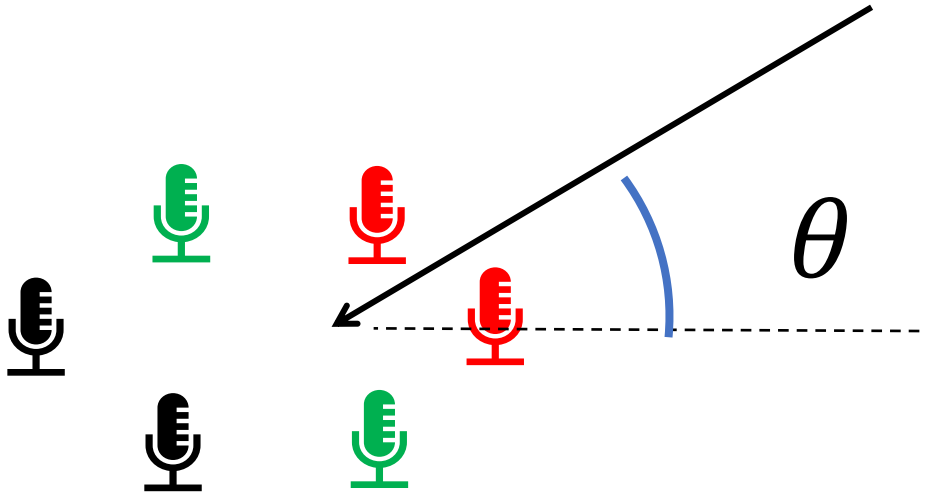
New AoA Algorithm

Results

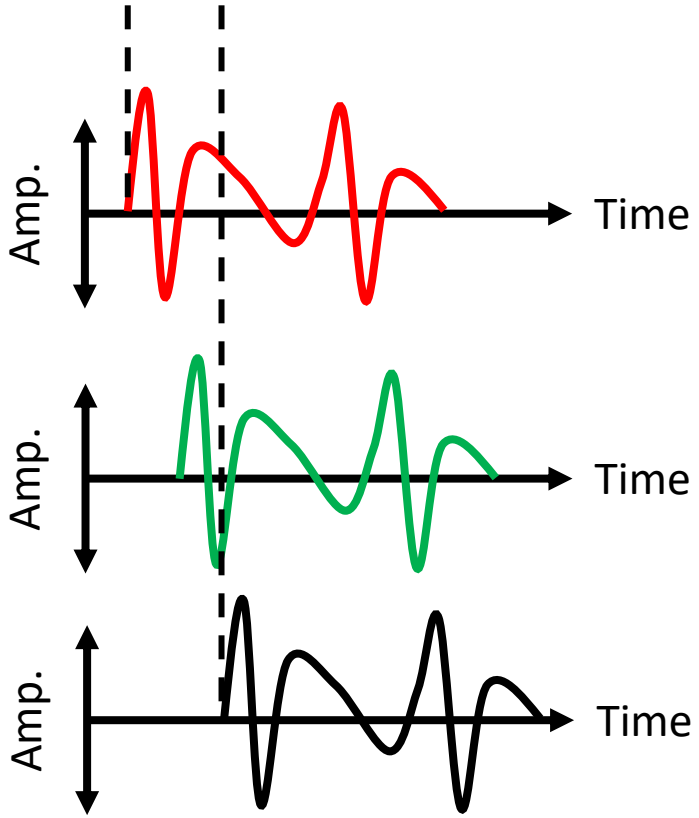
1 Speaker & 1 path



1 Speaker & 1 path



Per microphone pair delay τ_{ij}



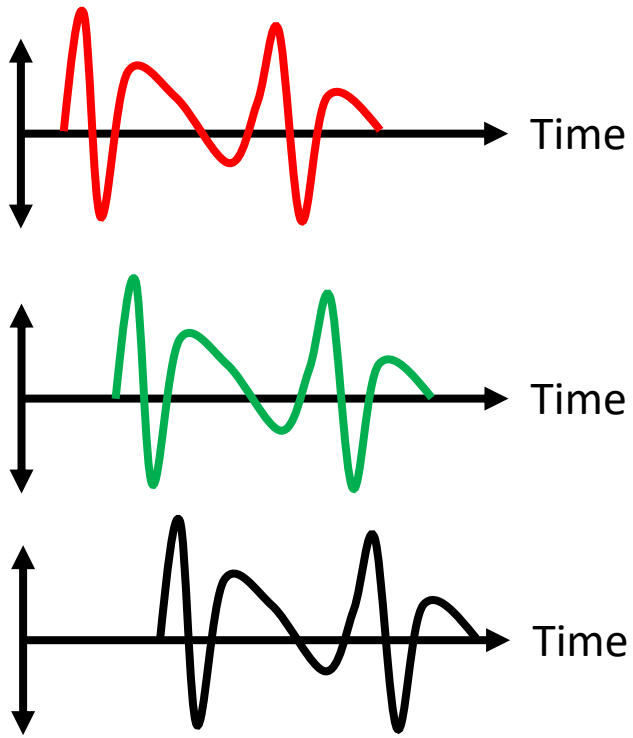
Estimating $\tau_{ij} \leftrightarrow AoA\ \theta$

Estimating τ_{ij}: Align & Cancel

1. compute $\widehat{\tau_{ij}}(\theta)$ $\forall\theta \in [0°, 360°)$
2. Delay received signal y_i by $-\widehat{\tau_{ij}}(\theta)$
3. Find the delay $\widehat{\tau_{ij}(\theta)}$ matching signals

$$\theta = argmin_\theta \sum_{ij} \left| Delay\left(y_i, -\widehat{\tau_{ij}}(\theta)\right) - y_j \right|$$

$\widehat{\boldsymbol{\theta}} =$



But what if there are two paths?

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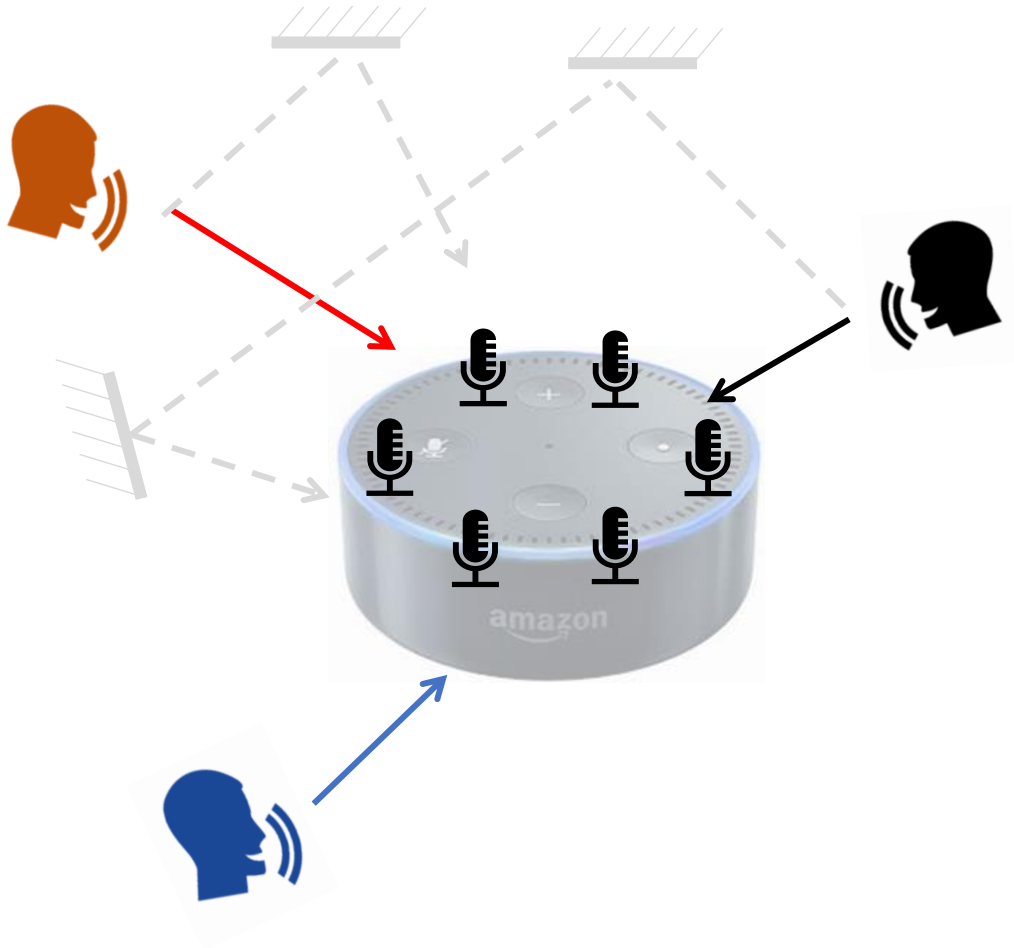
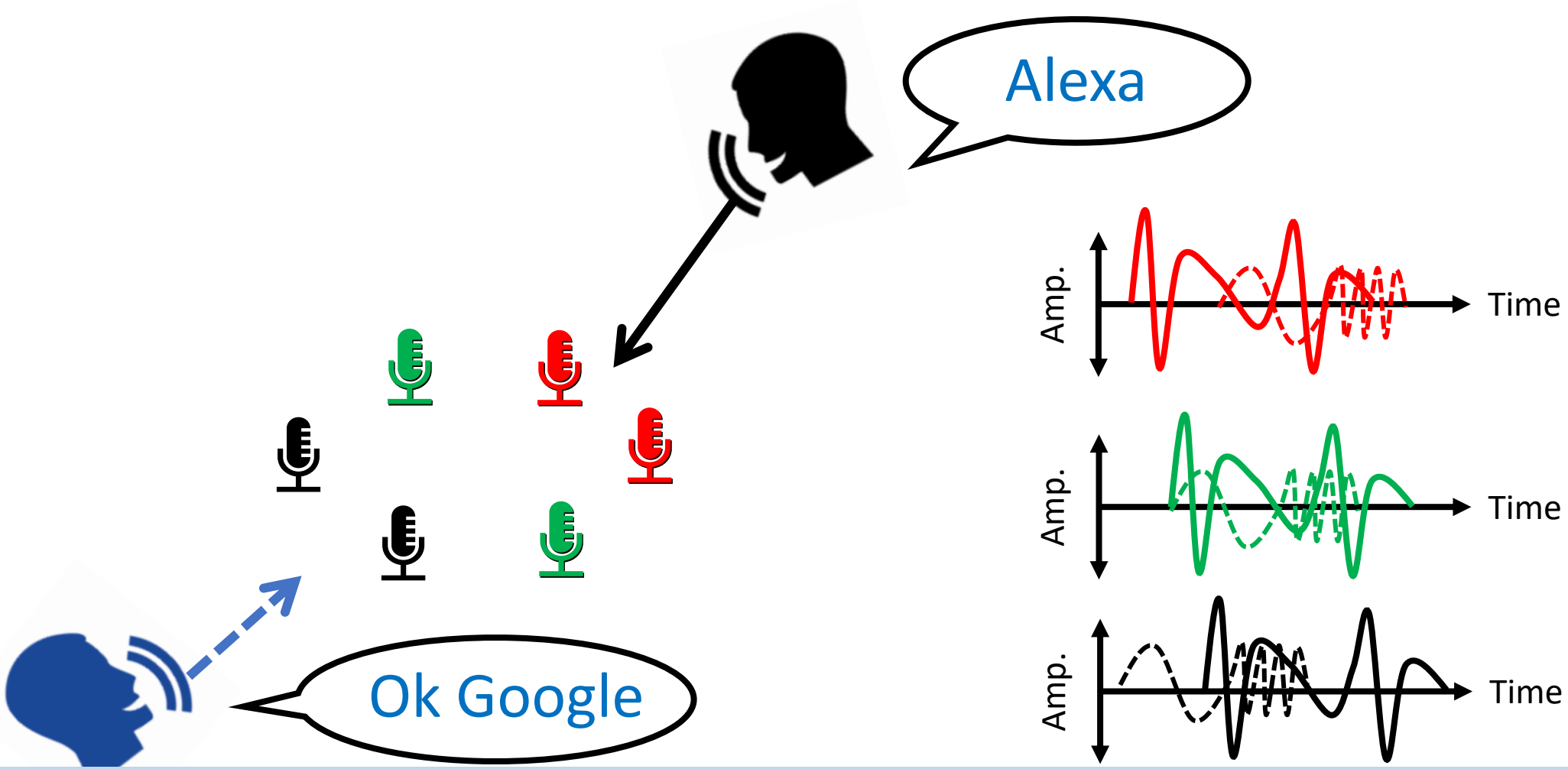


N Speaker & 1 path



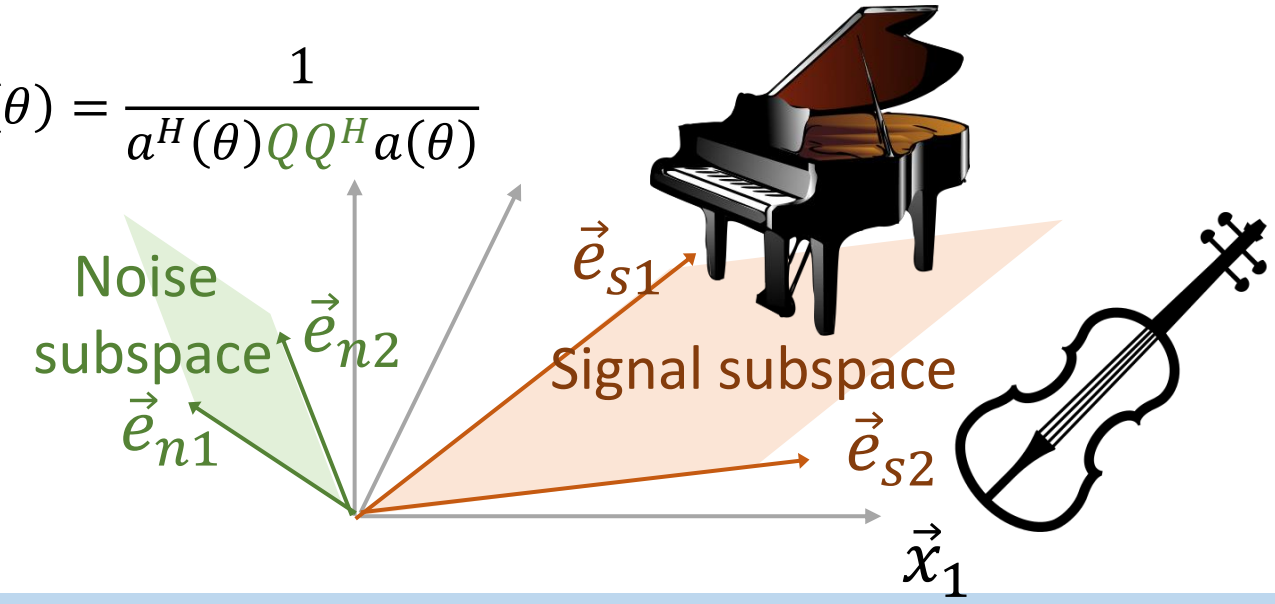
No single microphone delay τ_{ij}

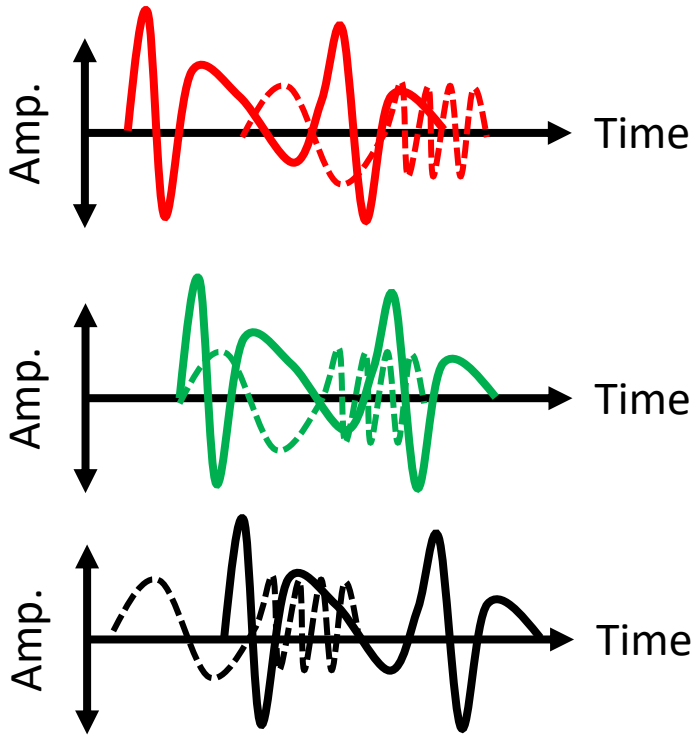
State-of-the-art

MUSIC[R. Schmidt 1986], ESPRIT[R. Roy 1989]

- Separate only "**uncorrelated**" sources
- Human can separate violin from piano

$$P(\theta) = \frac{1}{a^H(\theta) Q Q^H a(\theta)}$$





But echoes are strongly correlated

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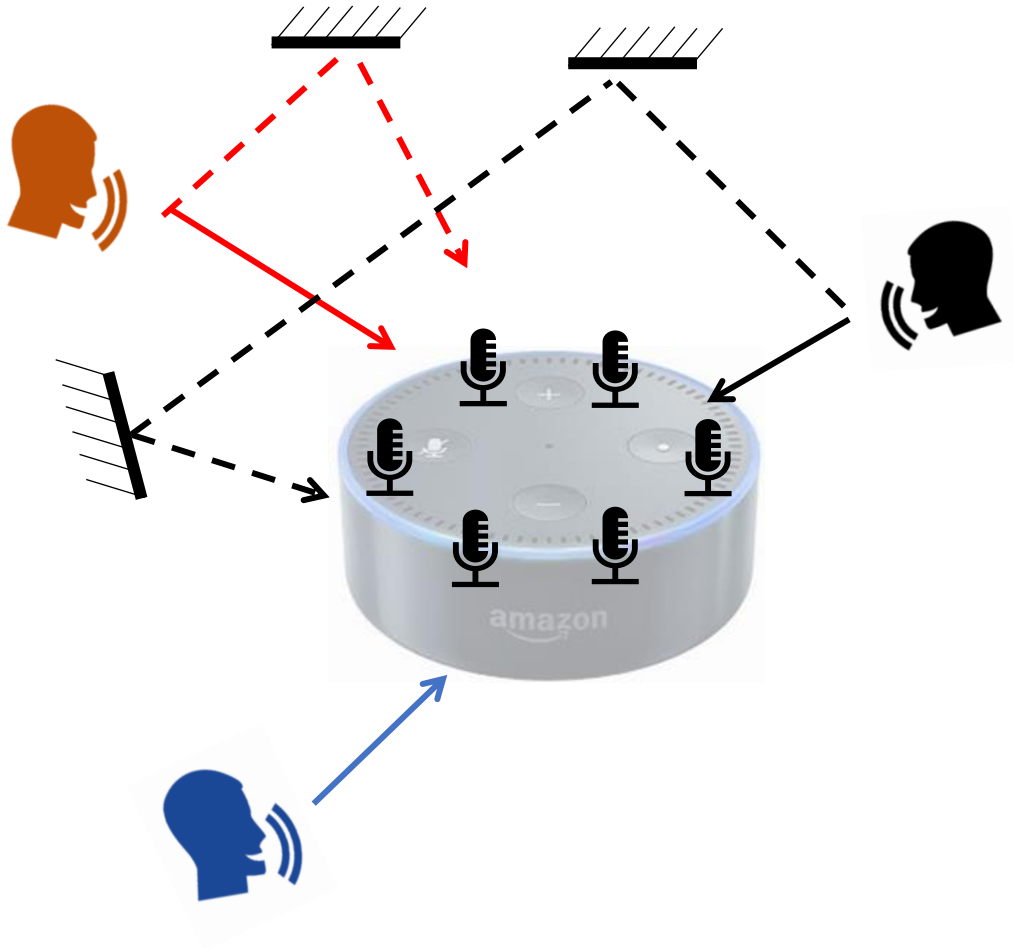

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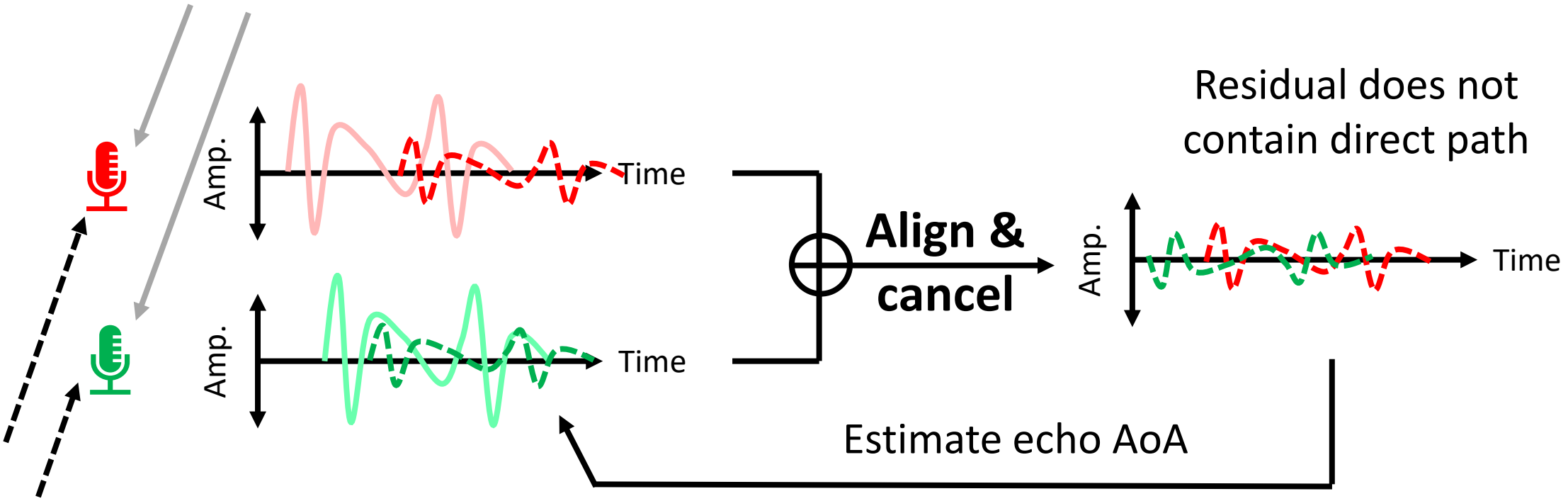
AoA Primer & Challenge

New AoA Algorithm

Results

Insight

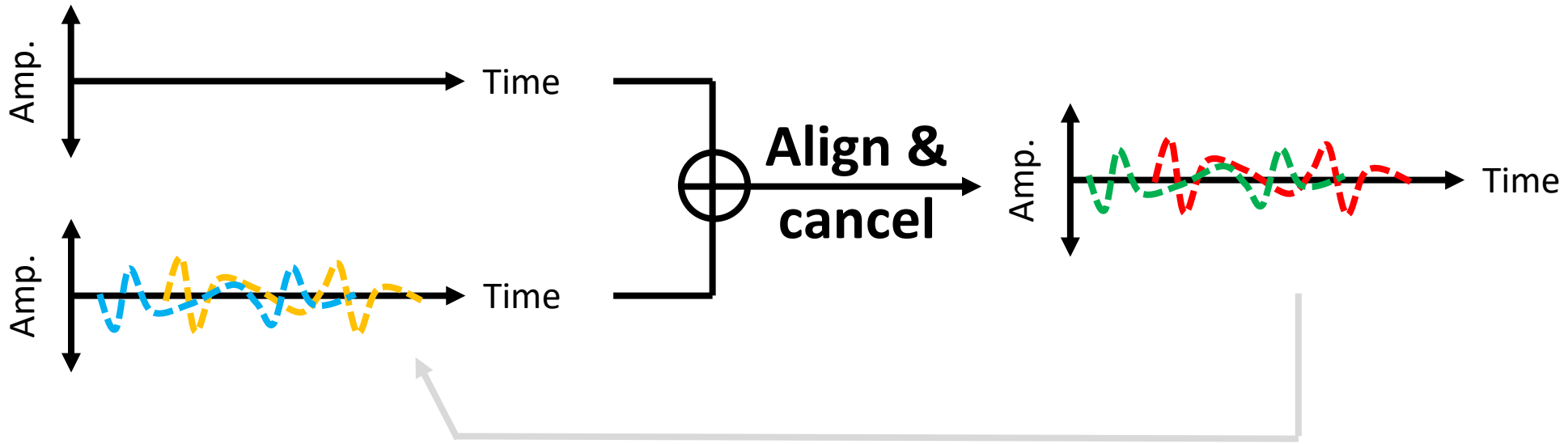
Cancel the **known** path iteratively



How to cancel the mixed echoes in the residual?

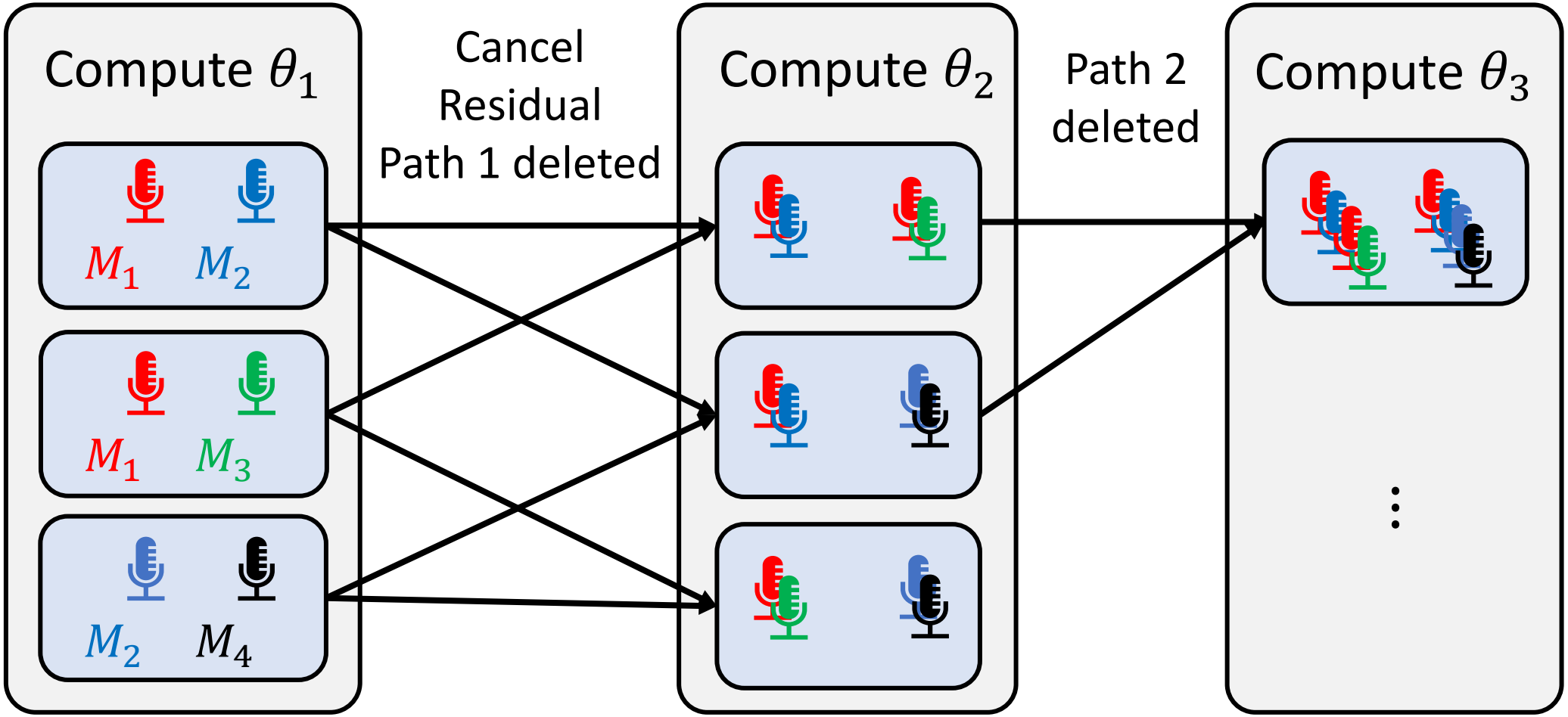
Algorithm challenge

Align and cancel with **another** residual



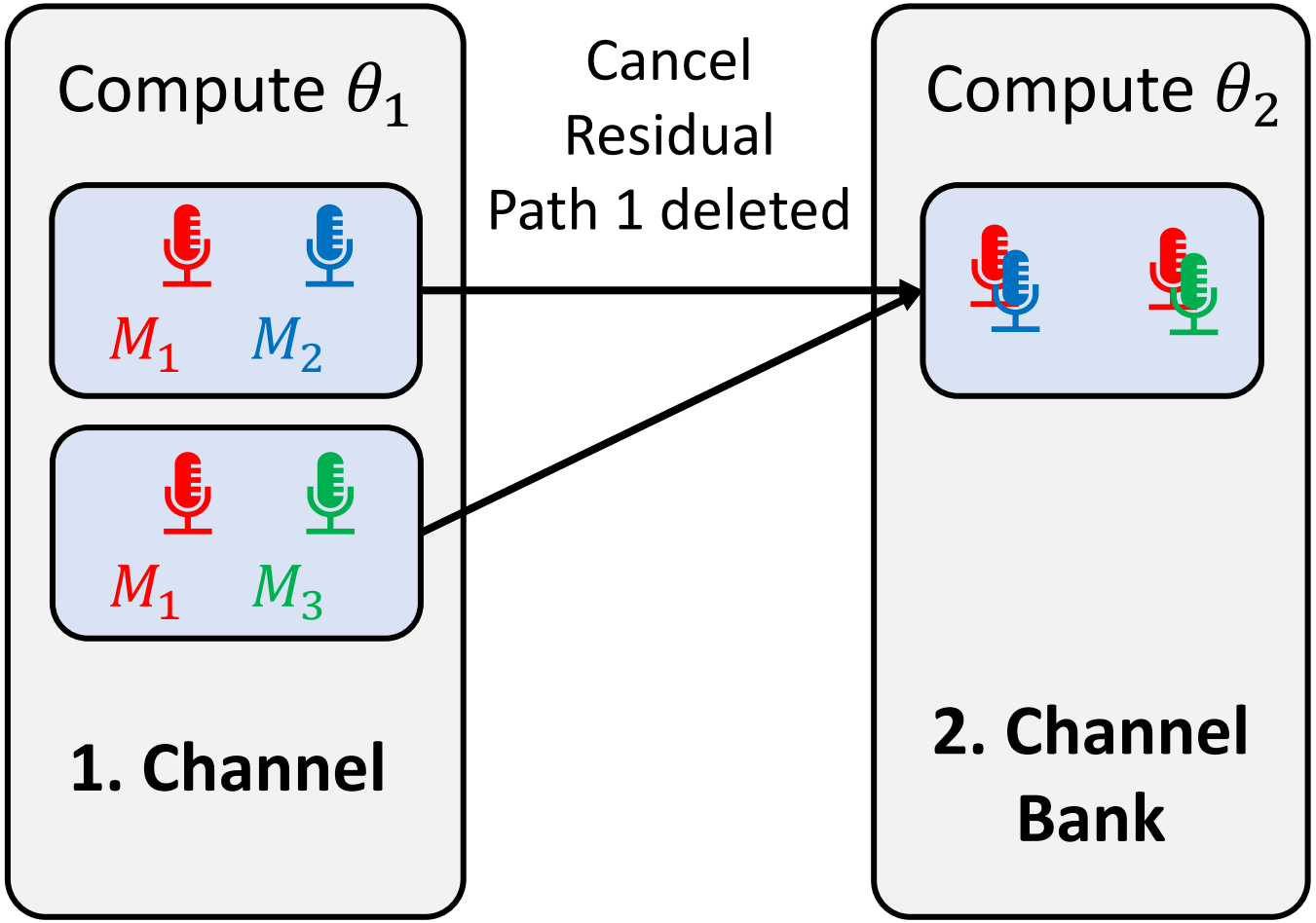
Residual pair to estimate the echo AoA

This paper: IAoA - Iterative AoA



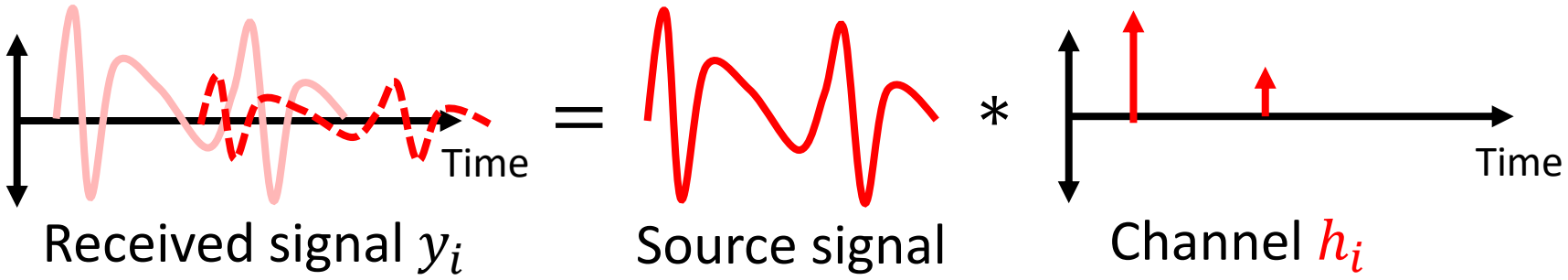
We can solve N echoes one by one

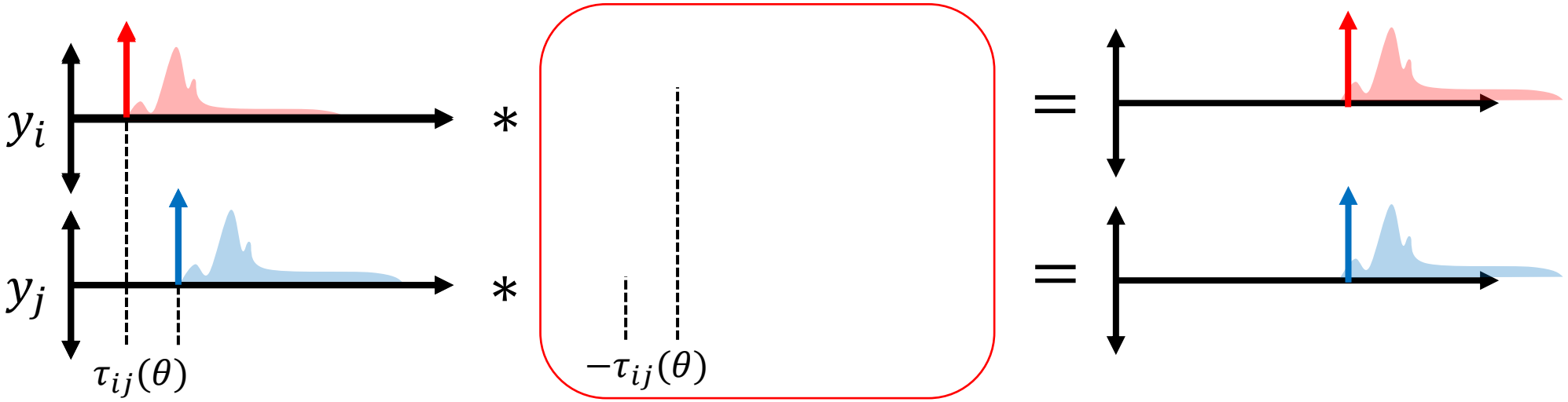
IAoA – Technical zoom in



1. Align & cancel using **channel**
2. Cancel residual using **channel bank**

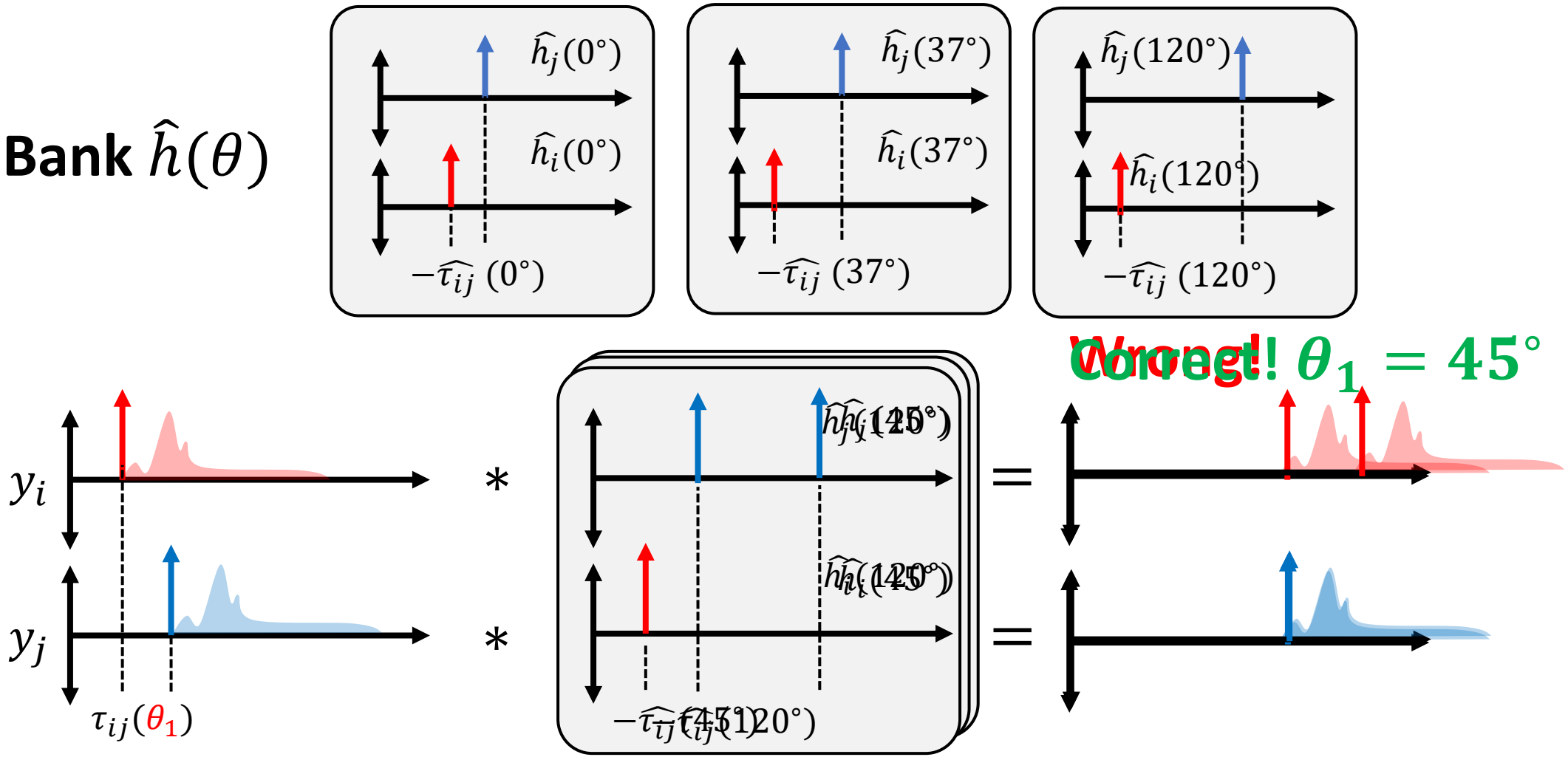
Channel





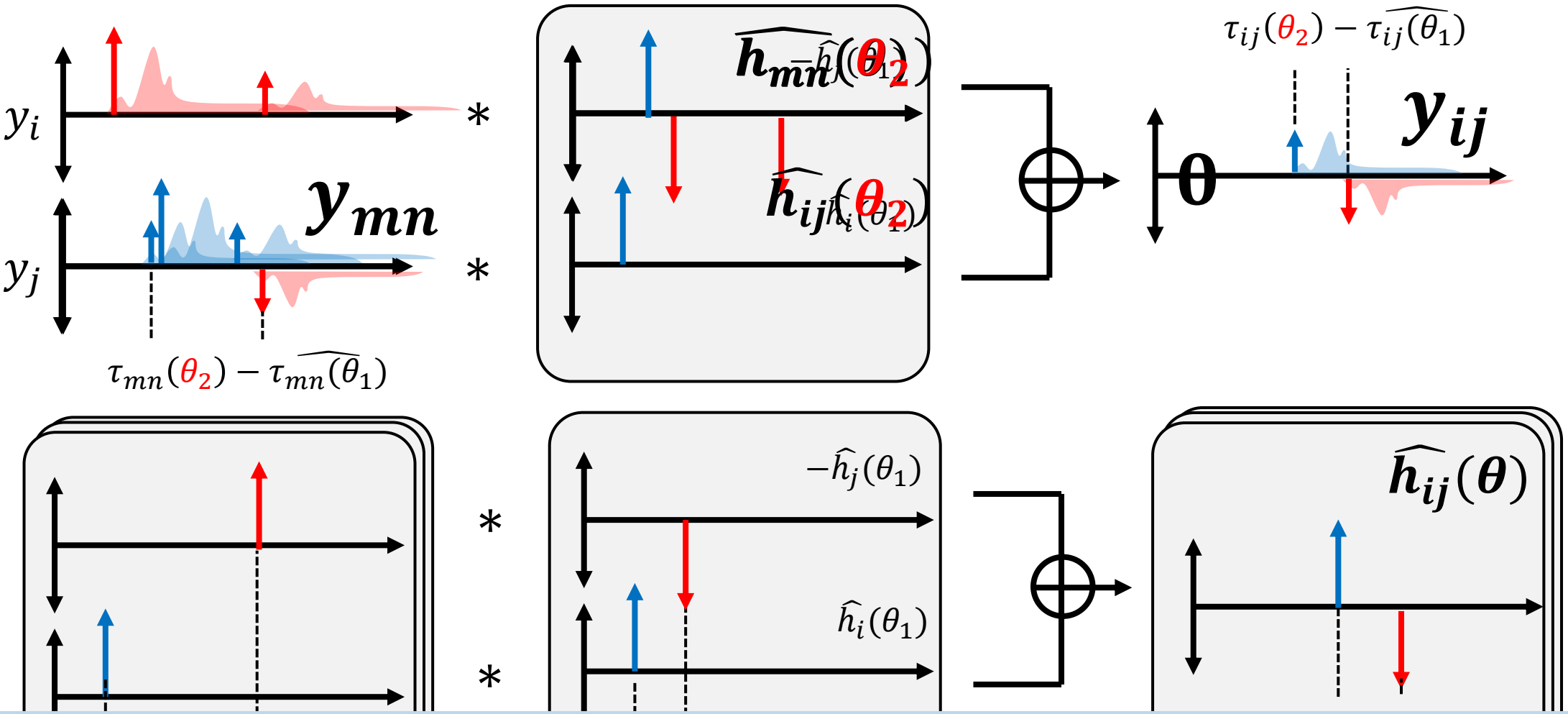
Align = convolve with the other channel

Align using the channel bank $\hat{h}(\theta)$



Align the signal using $\hat{h}(\theta)$

Cancel the second path



We can find θ_k with updated channel banks

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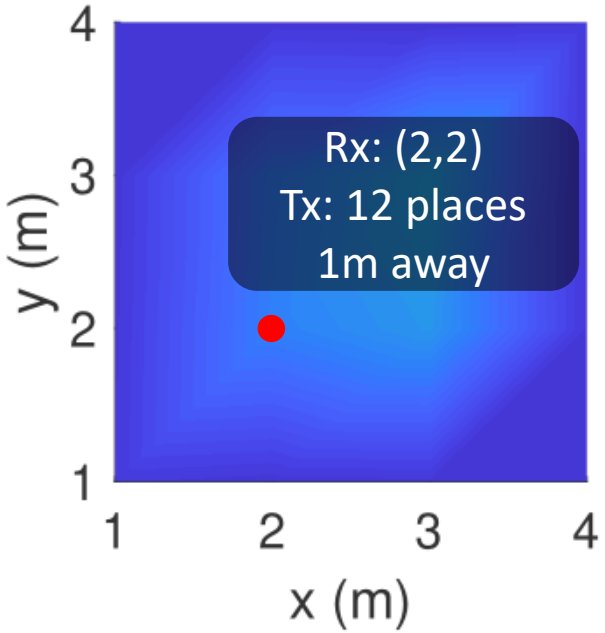
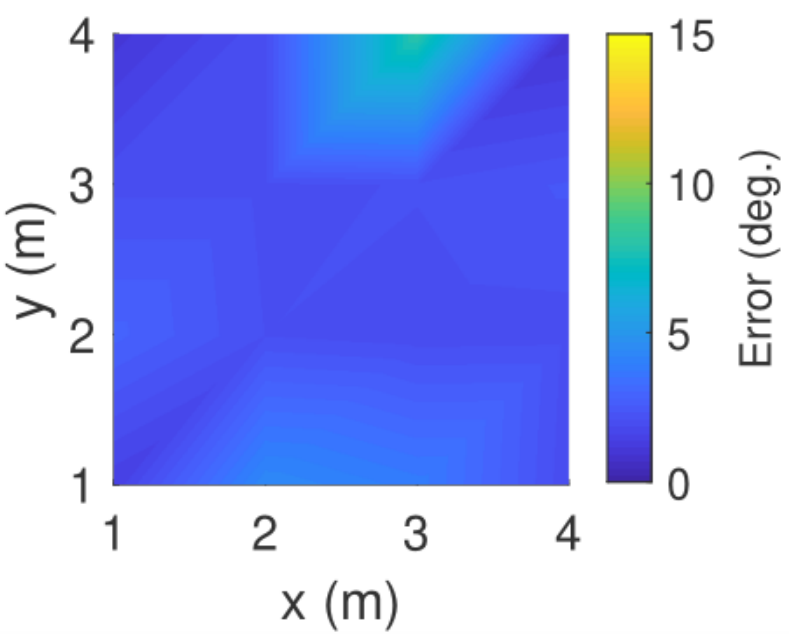
Simulation

2nd AoA θ_2



3rd AoA θ_3

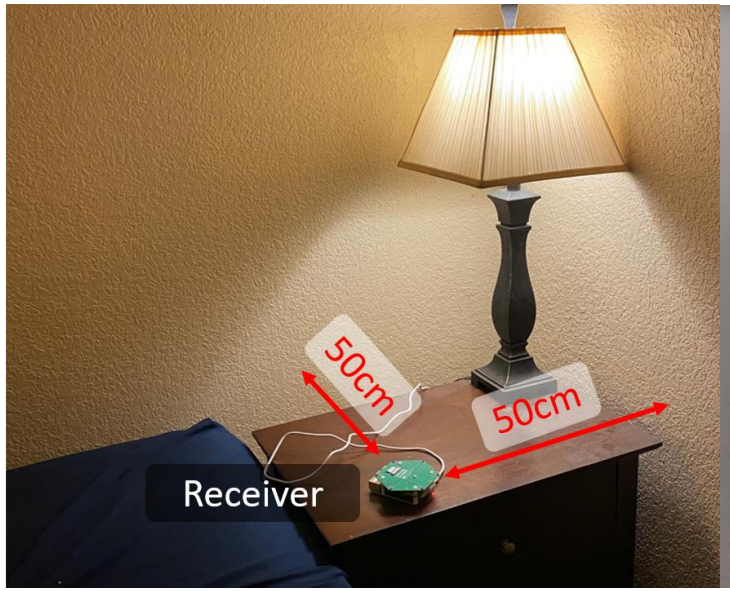


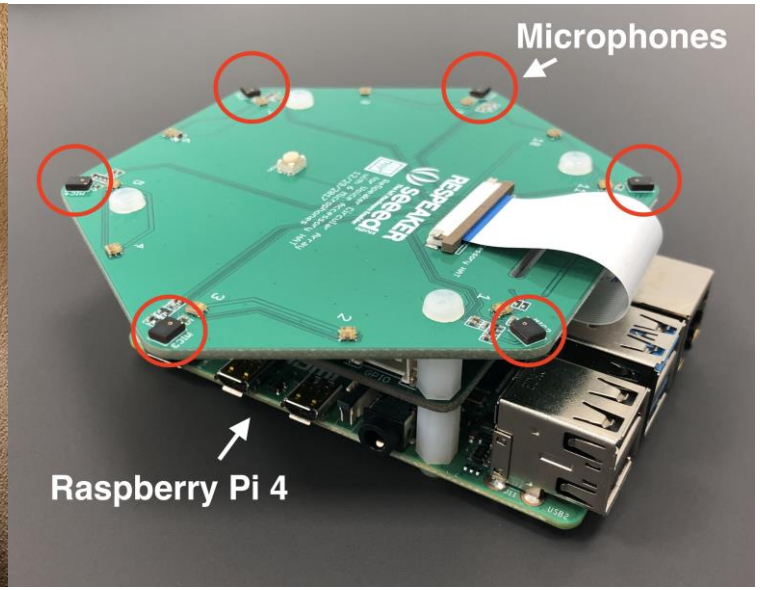
- 5x5m room
- 1 speaker, 6-mic array
- 1m transmission distance

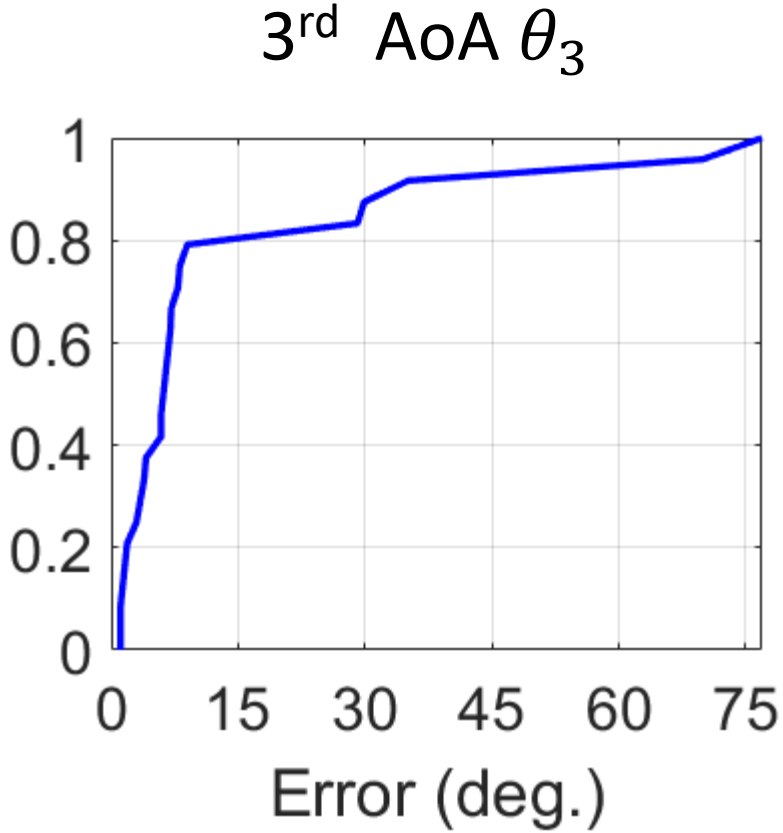
IAoA can accurately estimate θ_1 to θ_3

Real-world experiment

- Corner of a bedroom
- 50cm from the wall
- Speaker placed at 6 places 1m away







Summary

- An algorithm to estimate the **AoA of each echo**
- Align and cancel to **cancel already estimated paths**
- **6-mic** array can accurately estimate AoA up to **3** paths
- Works for any correlated or uncorrelated sources