MmWave Beam Training

Ish Jain
Networks Reading Group

https://nrgucsd.github.io/

[MobiCom'18] Multi-Stream Beam-Training for mmWave MIMO Networks

- Motivation
  - Searching for spatial beams has a high overhead (N^{2m} for N beams in codebook and m streams).
- Observation
  - Channel is sparse at high frequencies.
  - It allows GHz-scale sampling
  - There are irregular beam patterns (significant side lobes), but the patterns are known a-priori
- Contribution
  - Estimated power-delay profile (PDP) for each beam by utilizing 802.11ad beam training procedure
  - Obtained angular direction of reflectors by combining the obtained PDPs
  - Used these direction inferences to transmit multiple stream along diverse paths
- Results
  - Achieves 90% of the maximum achievable aggregate rate while incurring only 0.04% of exhaustive search's training overhead
- Analysis/Criticism
  - Some paths may cause destructive interference at the receiver
  - Channel power in PDP is ignored
  - No tracking of reflectors over time
  - May not establish a reliable link
  - Does not talk about mitigating blockages

Why Analog beamforming?

Hybrid beamforming (Digital + Analog)

Analog beamforming requires setting appropriate phase and amplitude values at each phased array antenna.

It is critical to provide diverse/orthogonal paths for each stream to obtain full rank channel matrix.

See Fig 2: Some patterns are preferred over the other to avoid interference from side lobes.

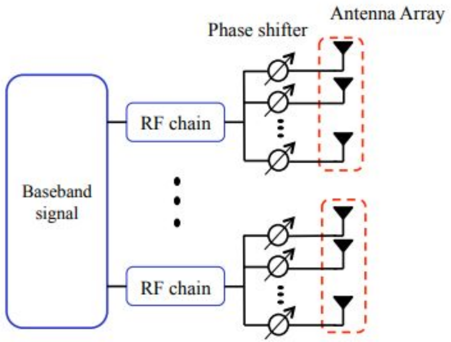
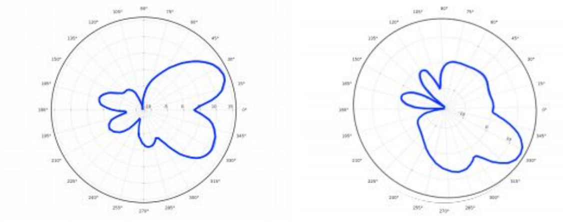


Figure 1: Node architecture.



(a) Example 1 **(b) Example 2**

Figure 2: Irregular beam pattern examples from X60 platform [18].

Getting PDP for mmWave is not trivial!

GHz sampling rate provides fine grained PDP. But,

- We get different PDP for different beam patterns
    - The power along a path depends on the antenna gain in that direction (which can be very low)
    - Not all patterns capture the same multi-path component

Procedure

- Get PDP for each beam patterns used during IEEE 802.11ad beam training
- Obtain a cluster of beam patterns for each path (identified by same delay e.g. τ_1)
- Obtain aggregate PDP by combining these clusters

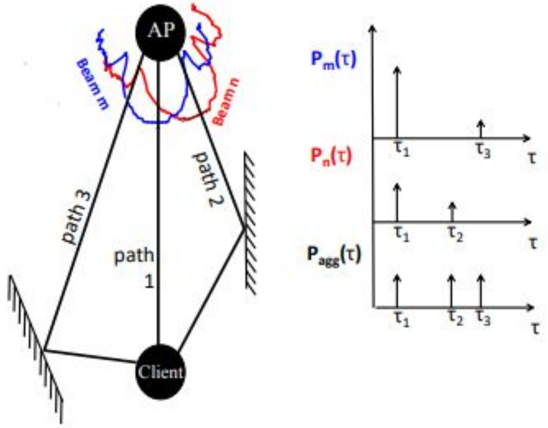


Figure 4: An example scenario with 3 dominant physical paths between the AP and client.

How to use PDP to infer path directions?

Integrate PDP with the knowledge of beam patterns.
Set of beam patterns that provide delay of say τ_1 will have a high antenna gain along the path corresponding to delay τ_1

$$score(\theta) = \sum_{c_b \in C_{AP}} I(b,p)\left(\frac{|c_b(\theta) - \bar{c}_b| + c_b(\theta) - \bar{c}_b}{2}\right)$$

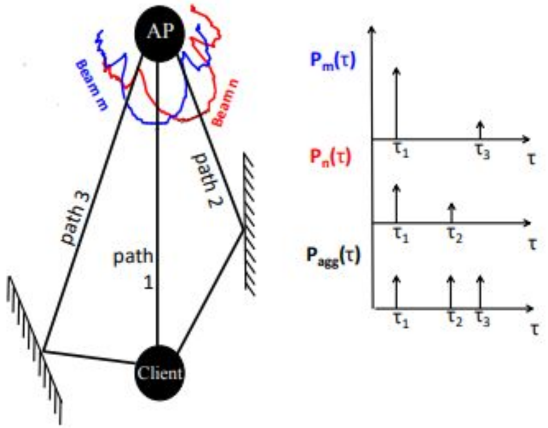
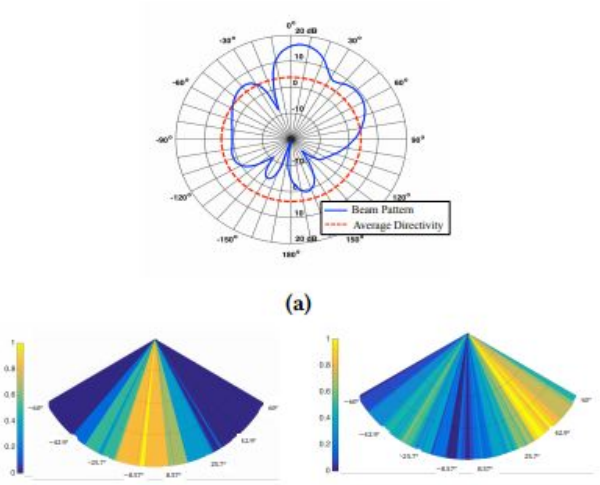


Figure 4: An example scenario with 3 dominant physical paths between the AP and client.



(a)

(b) *score* (θ) for path 1

(c) *score* (θ) for path 2

Figure 5: (a) An example irregular beam pattern and its average directivity, (b) *score* (θ) for path 1, and (c) *score* (θ) for path 2 in Fig. 4.

Utilize path inference to select candidate beams

In Fig 6, U1 and U2 should not be served by LOS path to avoid interference.

Select beam pattern for user u to maximize the signal-to-leckage-power ratio.

$$B_u(G) = \{\arg\max_b \frac{c_b(\theta_{u,i})}{\sum_{\substack{v \in G \\ v \neq u}} \sum_{\substack{\theta_{v,x} \in A_v \\ \theta_{v,x} \neq \theta_{u,i}}} c_b(\theta_{v,x})}, \forall \theta_{u,i} \in A_u(\Theta)\}$$

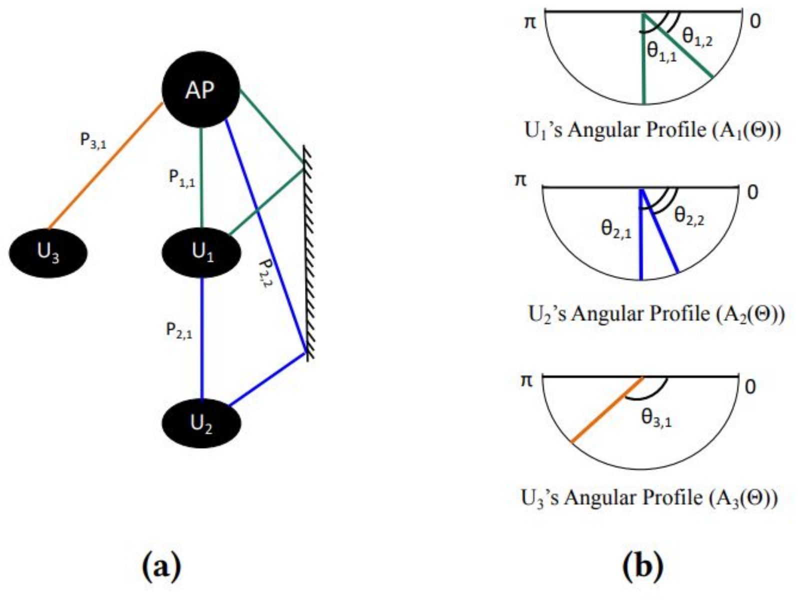


Figure 6: Candidate selection example.

Results

Trace driven emulation on NI X60 SDR platform with phased array

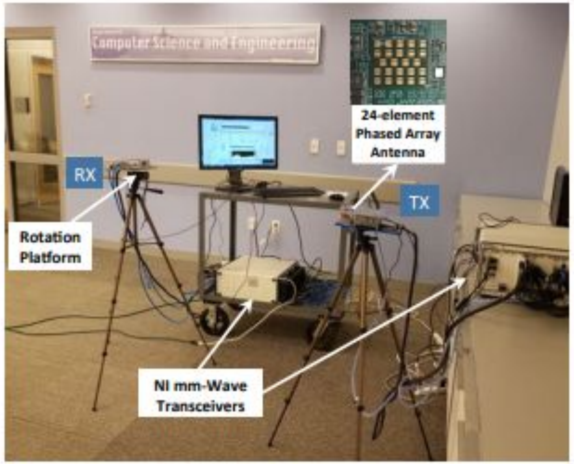


Figure 7: The *X*60 platform for 60 GHz band.

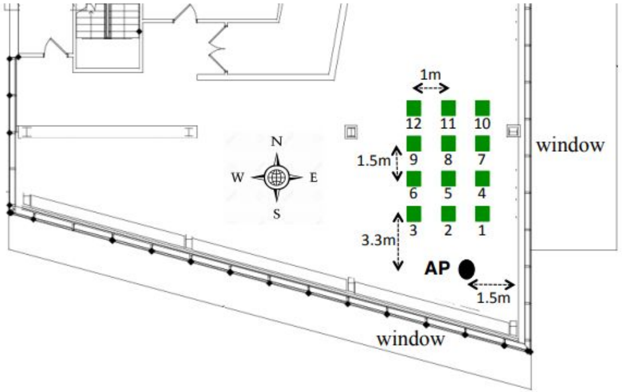


Figure 8: Experimental floorplan. Square boxes represent client positions.

Results

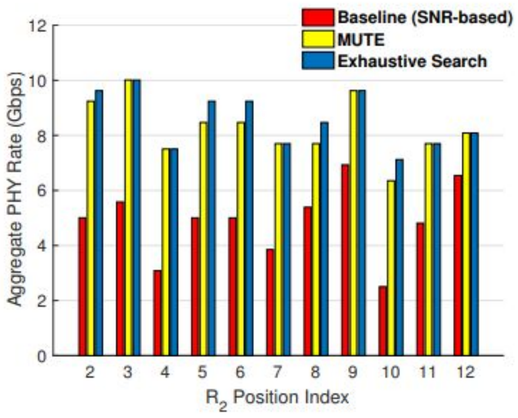


Figure 9: Aggregate PHY rate of a two-user MIMO transmission to R_1 (fixed at position index 1) and R_2 when placed at other 11 positions.

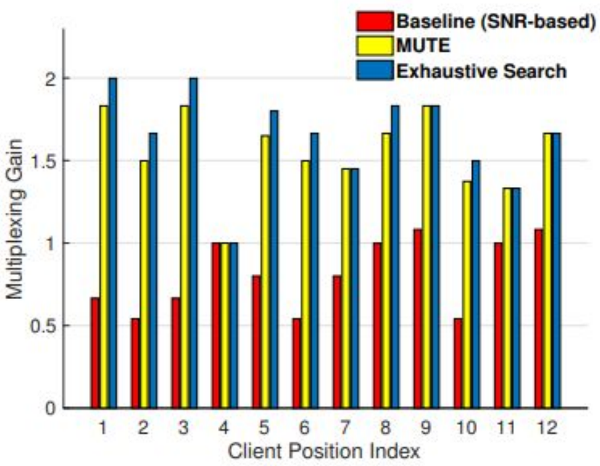


Figure 10: Multiplexing gain of 2×2 single-user MIMO as a function of client position.

Multi-Stream Beam-Training for mmWave MIMO Networks

- Motivation
  - Searching for spatial beams has a high overhead (N^{2m} for N beams in codebook and m streams).
- Observation
  - Channel is sparse at high frequencies.
  - It allows GHz-scale sampling
  - There are irregular beam patterns (significant side lobes), but the patterns are known a-priori
- Contribution
  - Estimated power-delay profile (PDP) for each beam by utilizing 802.11ad beam training procedure
  - Obtained angular direction of reflectors by combining the obtained PDPs
  - Used these direction inferences to transmit multiple stream along diverse paths

- Results
  - Achieves 90% of the maximum achievable aggregate rate while incurring only 0.04% of exhaustive search's training overhead
- Analysis/Criticism
  - Some paths may cause destructive interference at the receiver
  - Channel power in PDP is ignored
  - No tracking of reflectors over time
  - May not establish a reliable link
  - Does not talk about mitigating blockages