Today

- mmWave
  - Attenuation
  - Phased Array
  - Alignment
  - Sparse Recovery.

Wi-Fi → 2.4 GHz or 5 GHz

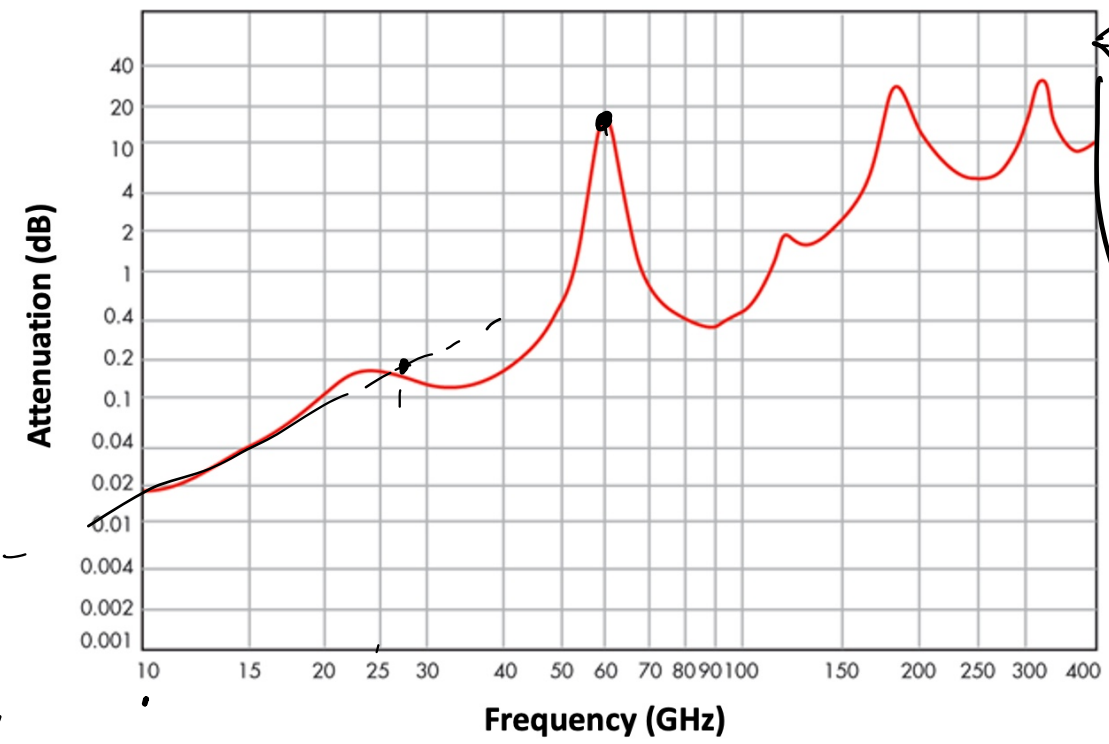
3G/4G → < 2GH, or < 4GHz

mmWave → 28GHz or 60GHz

28GHz → 1cm

60GHz → < 1cm

mm Wave Attenuation

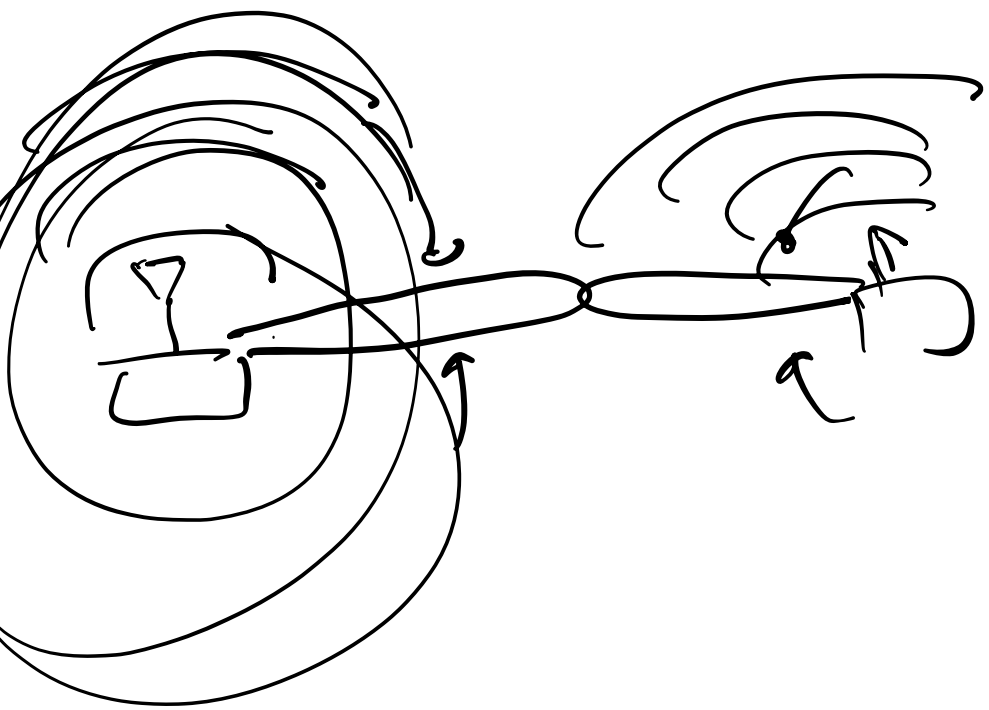


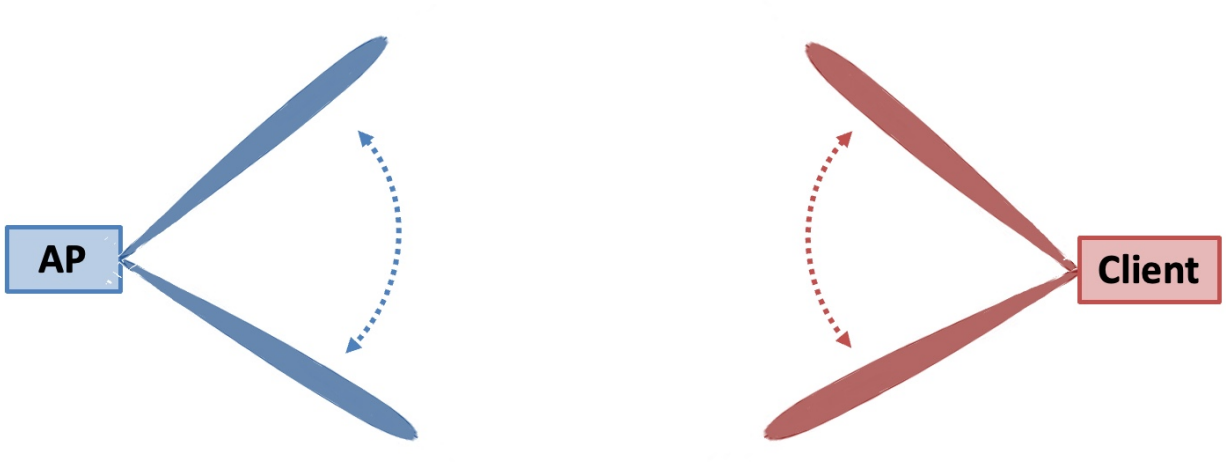
→ Low range

→ More power

→ Beamforming

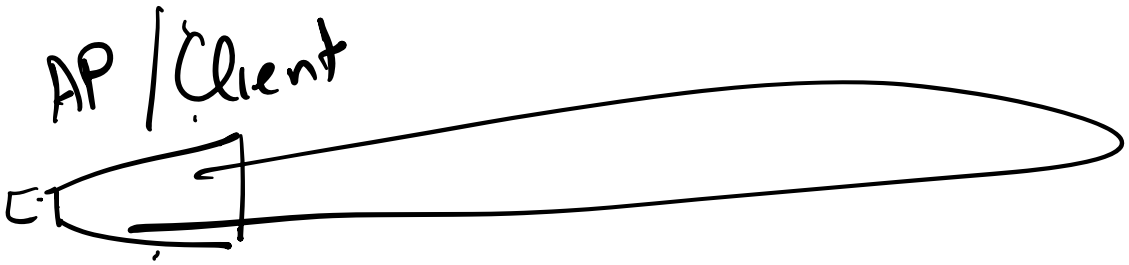
directional antennas



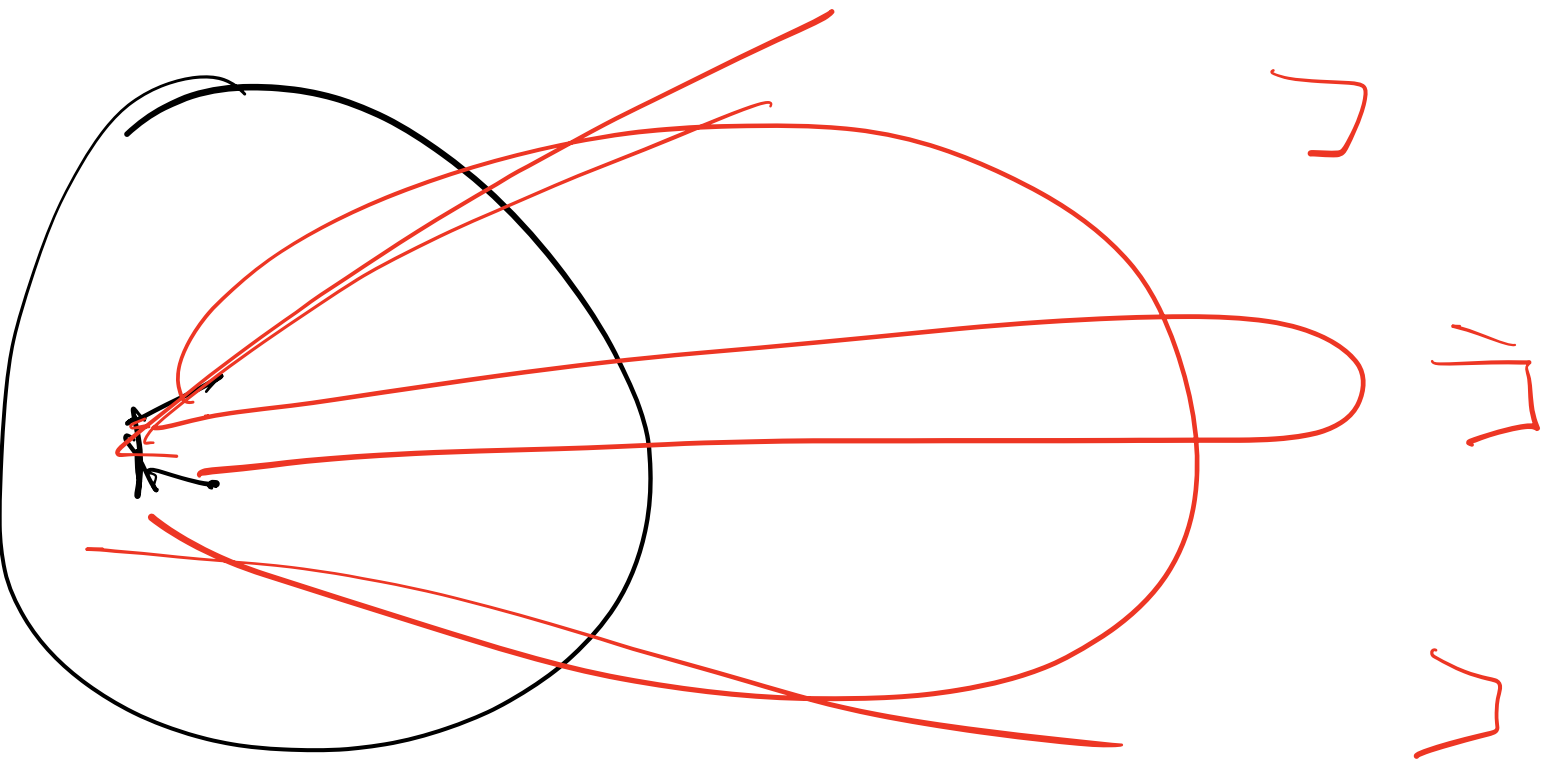

AP
Client

Creating Beams

1) Directional antennas.

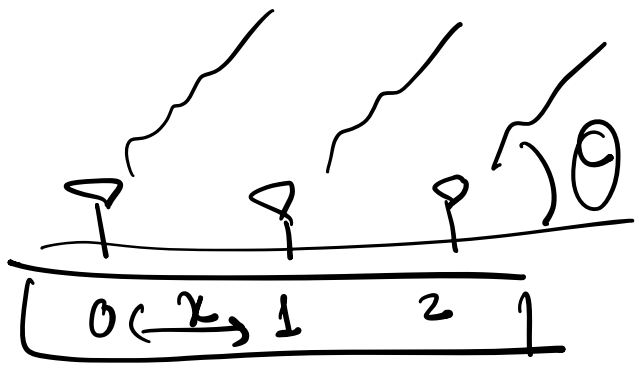


↳ pointing requires mechanical motion.

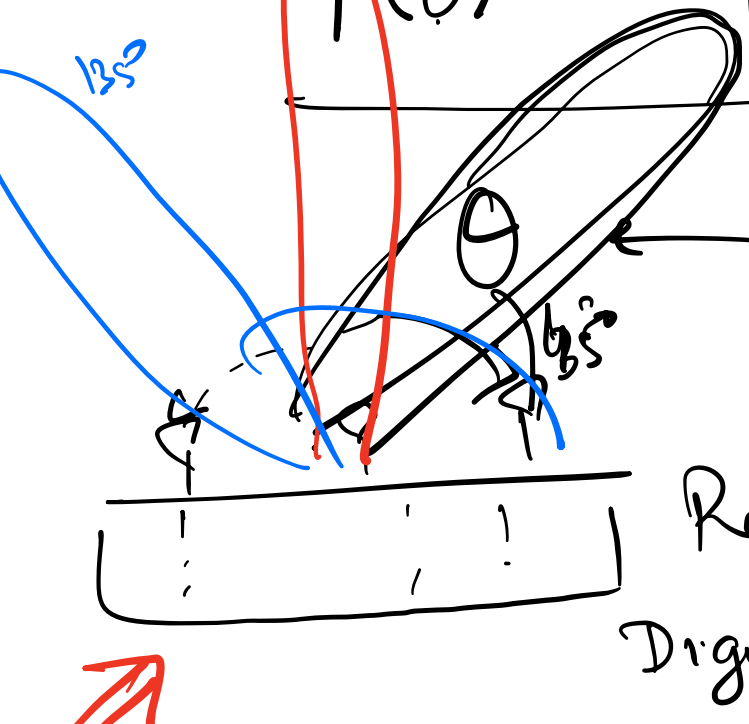


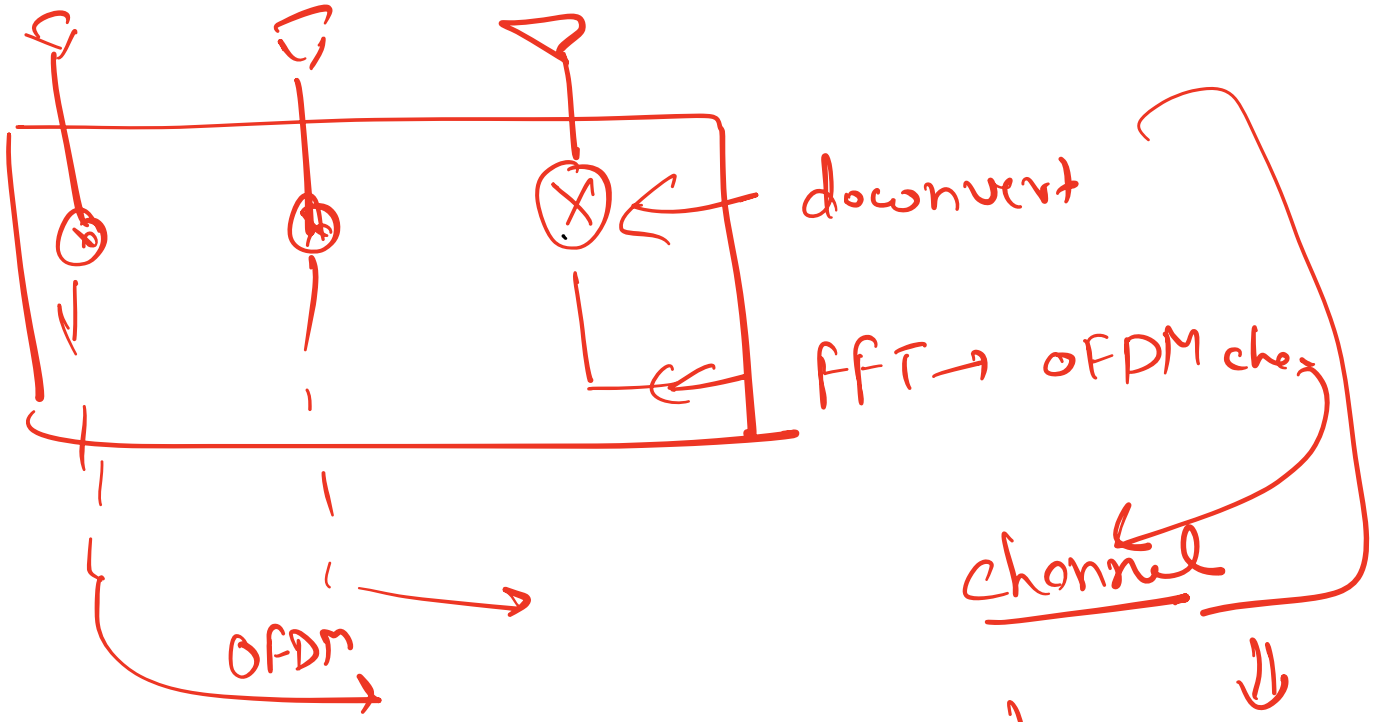
Phased Arrays

Antenna Arrays.



$$P(\theta) = \left| \sum h_i e^{j \frac{2\pi}{\lambda} i x \cos\theta} \right|$$

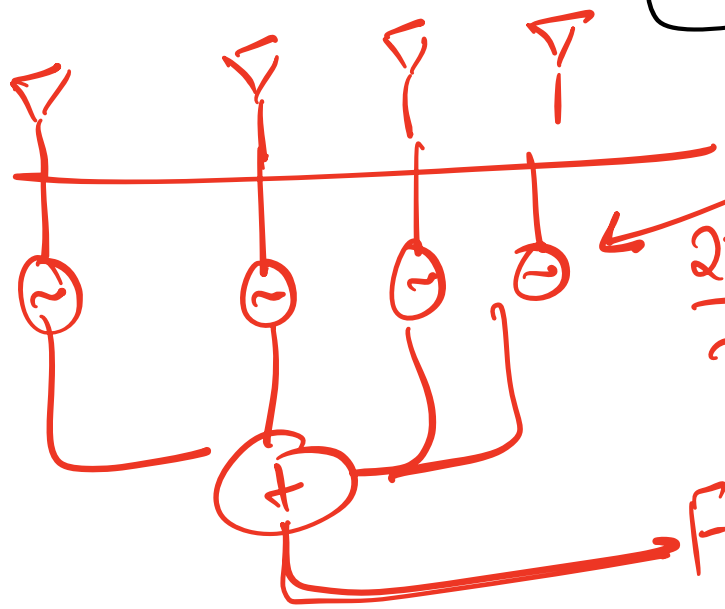




$$P(\theta) = \left| \sum h \right|$$

phase shifter.

$$P(\theta) = \left| \sum h_i \, e^{j \frac{2\pi}{\lambda} i x \cos\theta} \right|$$

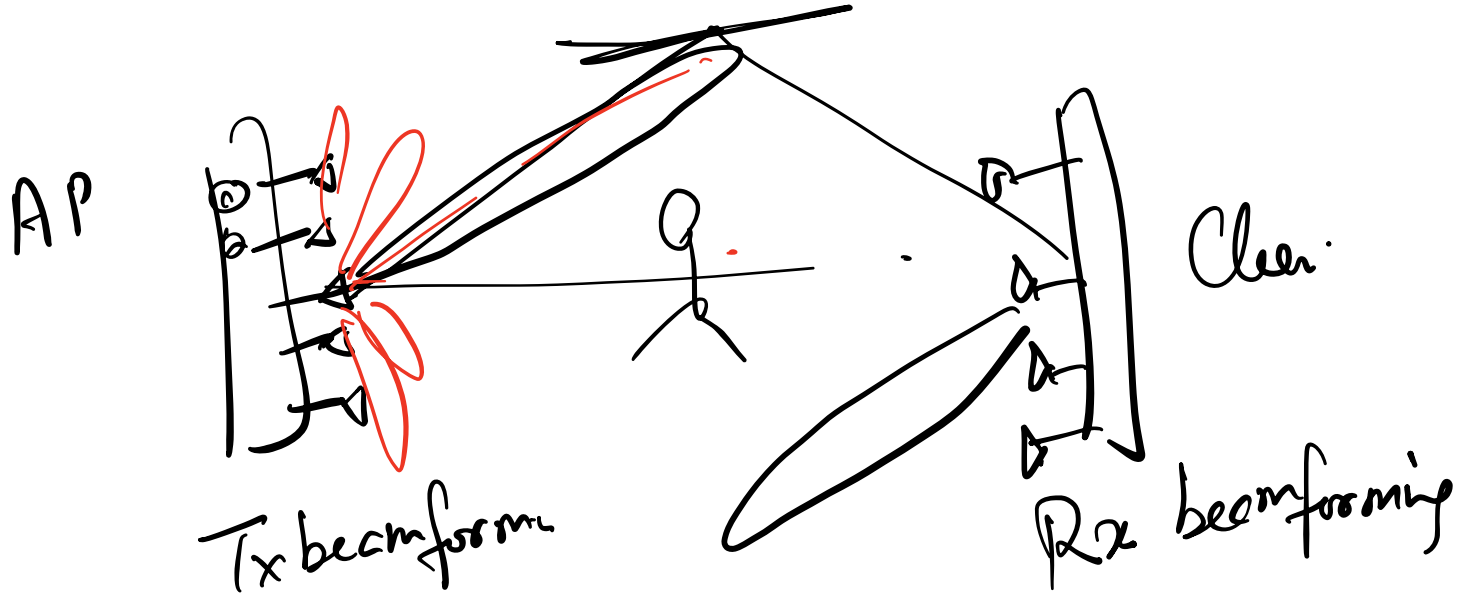


$\frac{2\pi}{\lambda} i x \cos\theta$

by Fourier transform

FFT/OFDM processi

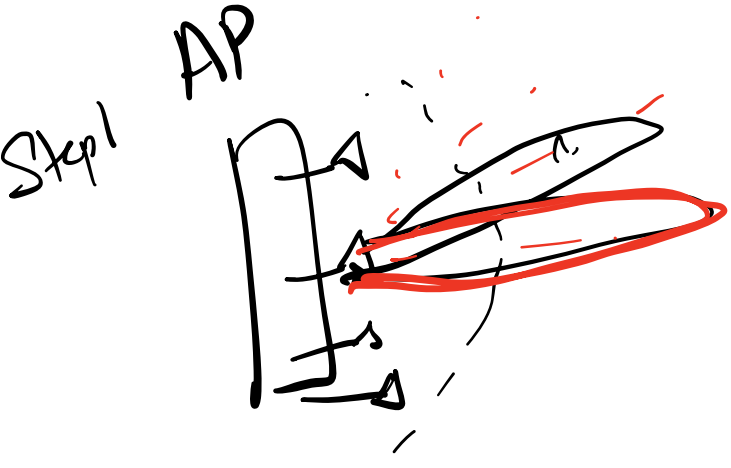
Alignment Options

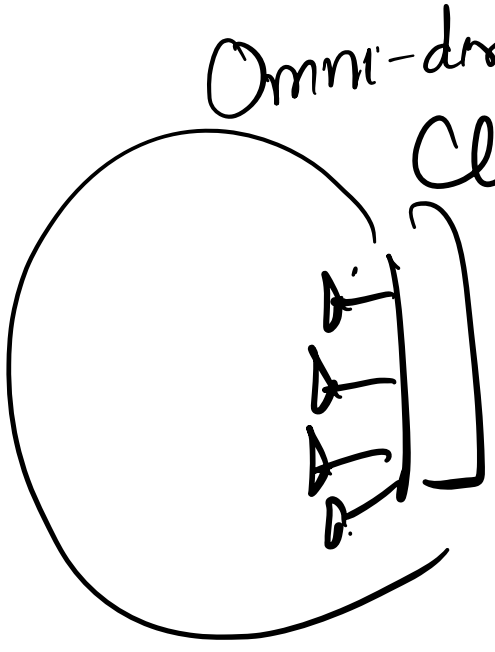


N possible directions

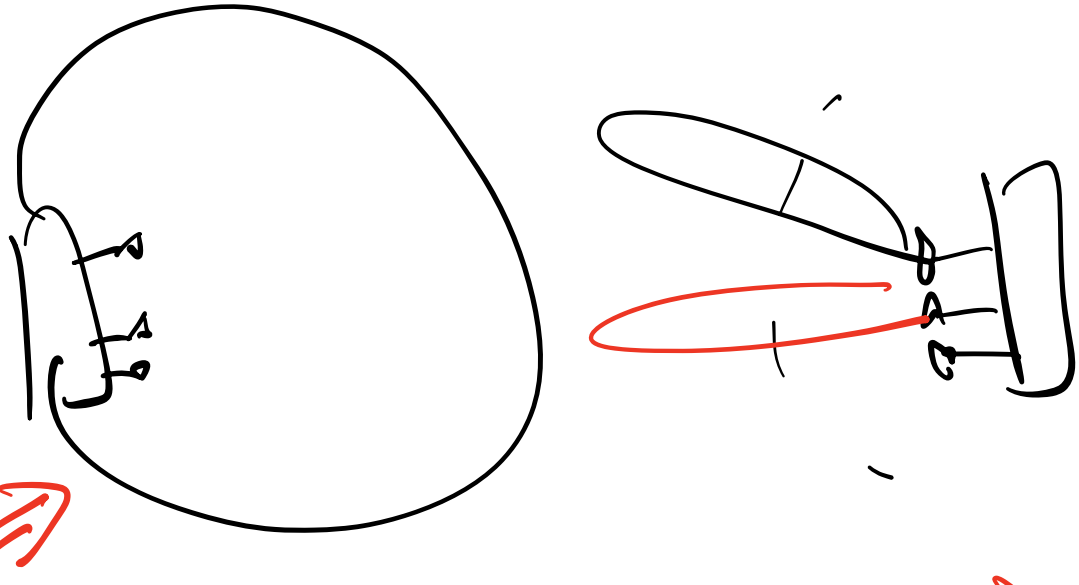
$O(N^2)$

802.11ad $O(N)$





Step2

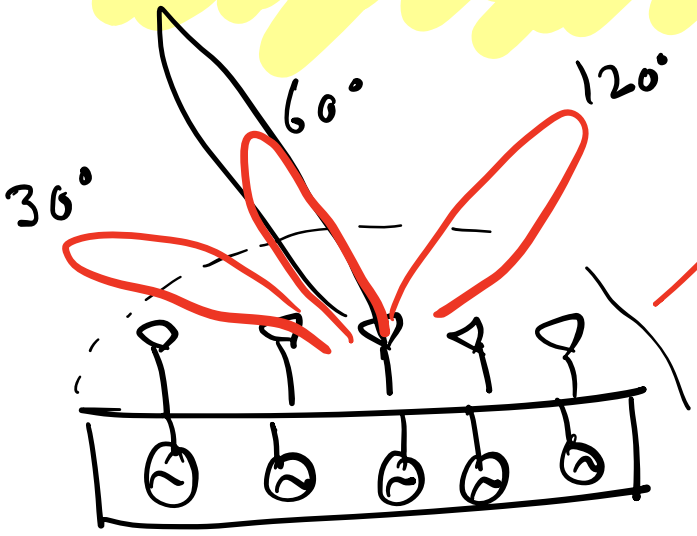


Agile Link $\Rightarrow$ $O(\log N)$

↳ Multipath is sparse.

Past work: Sparse fourier transform.

Agile Link: Multi-arm Beams



Rule out options pretty quickly.

3 true path ⇒ 75°

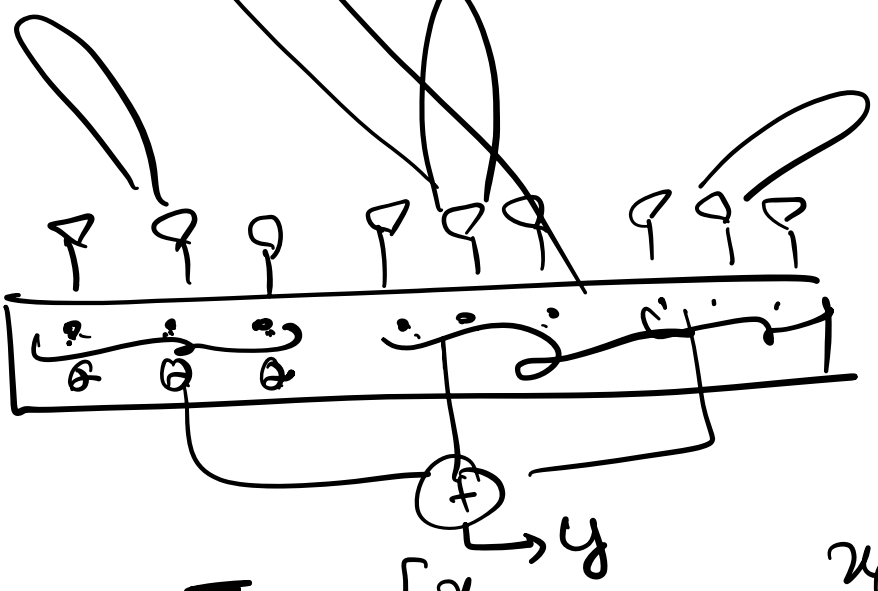
1 0°

30°, 60°, 120°

45, 75, 105 Strong

~~75°~~ 15°, 75, 135° Strong

How to Create Multi-arm Beams



$P(\theta) = \Sigma_1 - 1$

$\bar{x} = [x_1 \ldots \underset{\uparrow}{x_k} \ldots x_N]$

x_k ~ 6:

↑ signal along direction k.

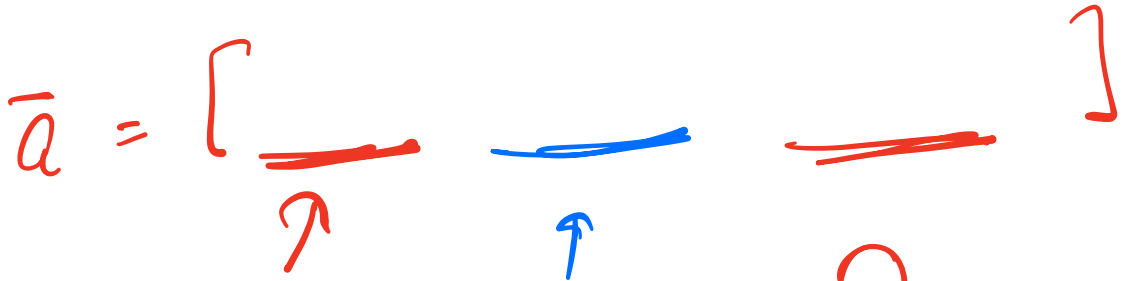
$y = \bar{a} \, F \, \bar{x}$

- $\bar{a}$: phase shifts. → receive beamform.
- F: matrix → fourier matrix
- $\bar{x}$: direction vector → true direction

phase shifts

$\vec{a} =$ 

↳ to point to direction Θ.

$\vec{a} =$ 

θ_1 θ_2 θ_3

$$p(\theta_i) = \sum_k h_k \, e^{j \frac{2\pi}{\lambda} d_k \cos\theta_i}$$

k: antenna k

$$\begin{bmatrix} p_{\theta_1} \\ p_{\theta_2} \\ \vdots \end{bmatrix} = \begin{bmatrix} & \\ & \end{bmatrix} \begin{bmatrix} h_1 \\ \vdots \\ h_N \end{bmatrix}$$

$$\bar{p} = F \bar{h}$$

$$\bar{x}_{\text{ground truth}} = F \bar{h}.$$

$\bar{h} = F^{-1}\,\bar{x}$ ground truth.

$$\sum_i \alpha\, e^{j\phi_i}\, \phi h_i$$

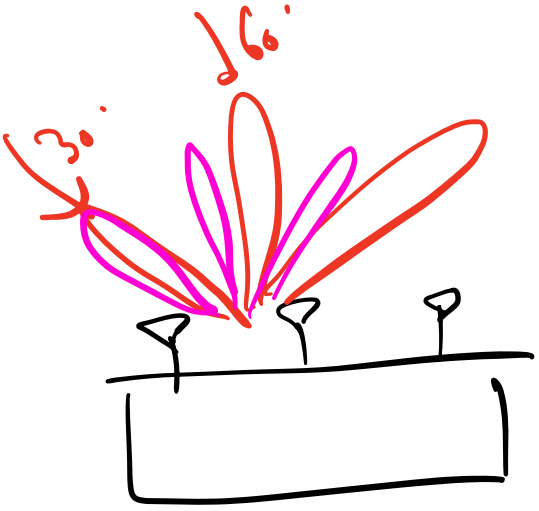
$$= \begin{bmatrix} a \end{bmatrix} \begin{pmatrix} h \end{pmatrix} = F^{-1}x$$

$$y = \left(\underline{\underline{a}}\, F^{-1}x\right)$$

(change; x recovers)

↳ measure

Q. what beams to sample?



$30°, 60°, 120° \rightarrow$ No signal

$\Downarrow$

{ the signal is not coming from $30°, 60°, 120°$

Truepath: $75°$

$$y_1 = |a_1 F^{-1} x|$$

$$y_2 = |a_2 F^{-1} x|$$

Evaluation

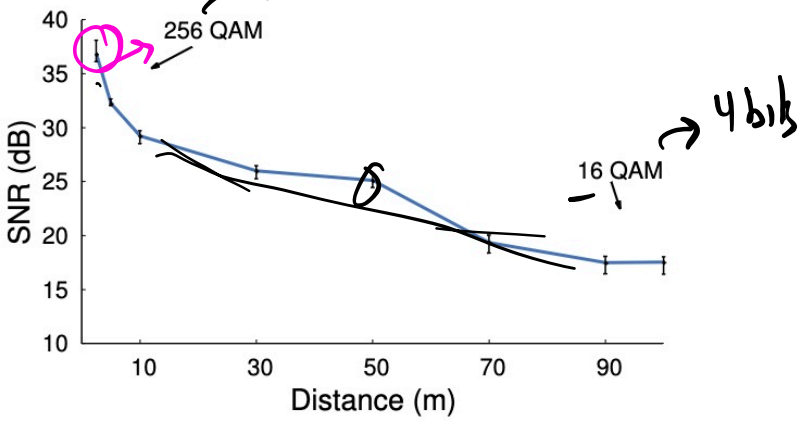


Figure 7: Agile-Link Coverage. SNR at the receiver versus distance between the receiver and the transmitter.

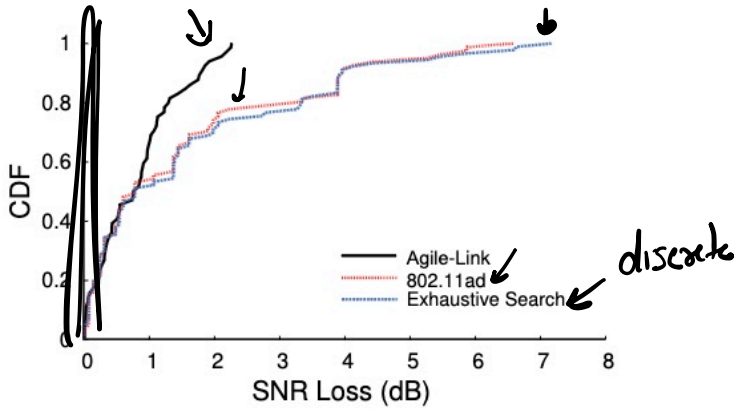


Figure 8: Beam Accuracy with a Single Path: SNR loss due to beam misalignment for Agile-Link, the 802.11ad standard, and exhaustive search.

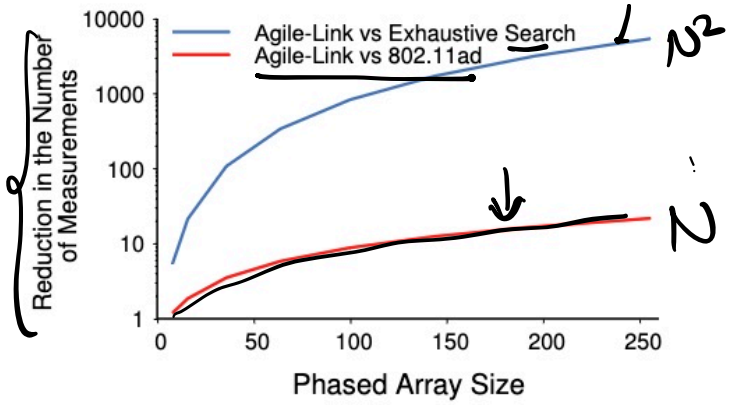
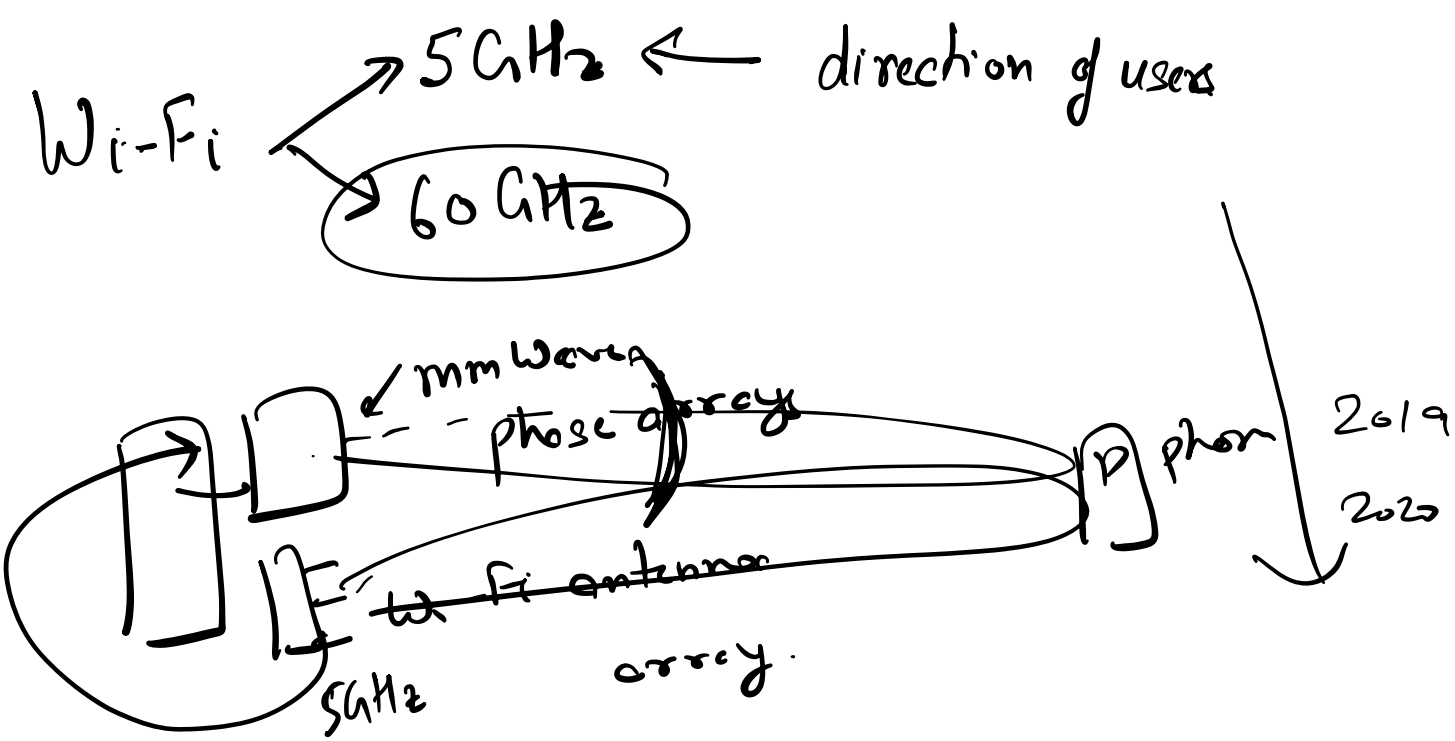


Figure 10: Beam Alignment Latency: Reduction in the number of measurements for Agile-Link versus the 802.11ad standard and exhaustive search.


Wi-Fi
5 GHz
direction of users
60 GHz
mm Wave
phase array
2019
2020
5GHz
array.