

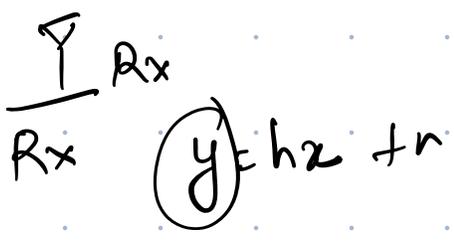
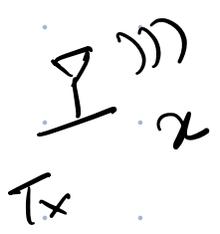
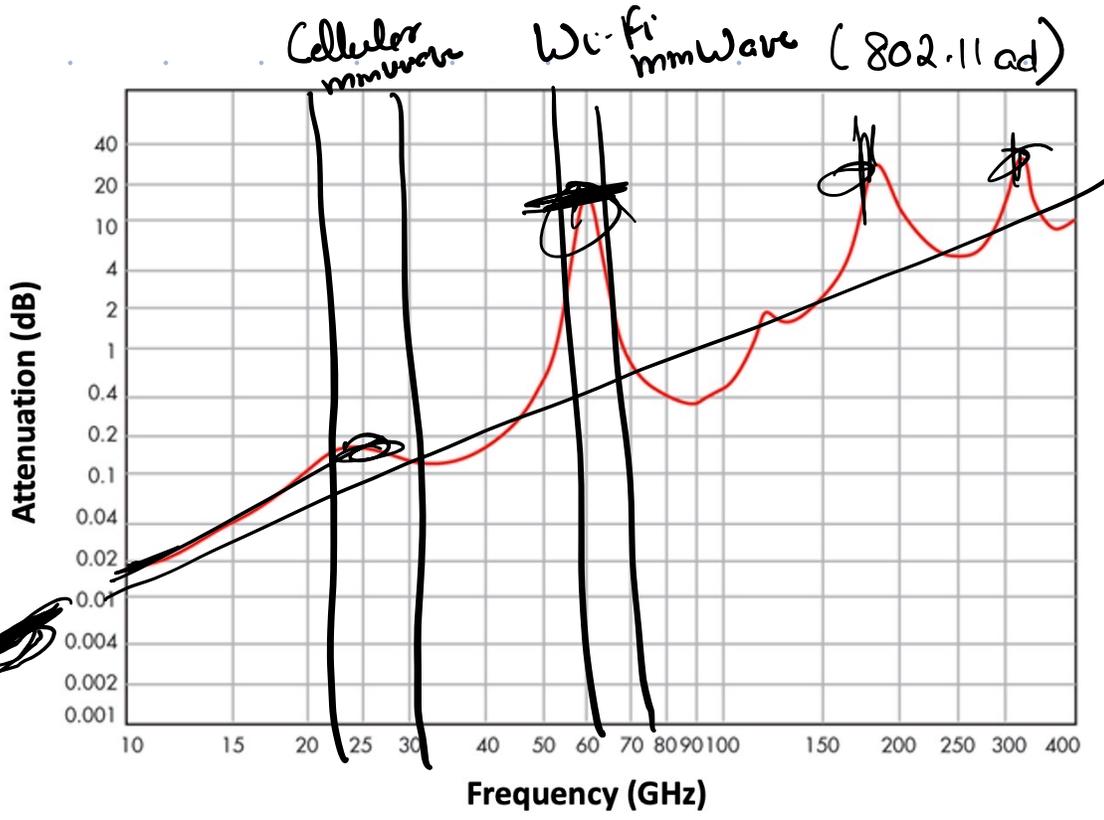
LECTURE 19

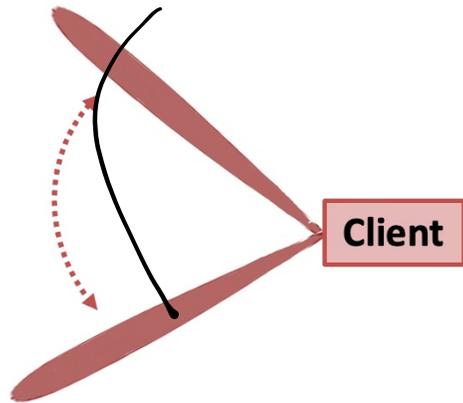
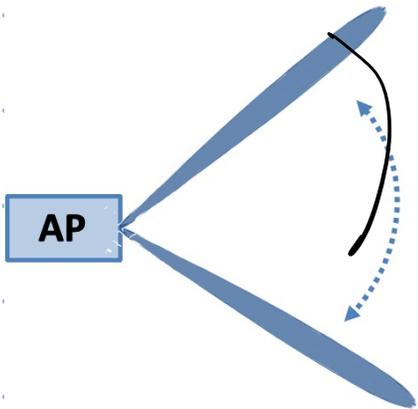
- mmWave Characteristics
- Phased array
- Beam Alignment Challenge
- Agile Link.

mmWave Characteristics

Wi-Fi → 2.4 GHz
 → 5 GHz

Cellular → Low-band (< 1 GHz)
 → Midband (1-7 GHz)
 → mmWave (> 7 GHz)





BEAMS

How do you create beams?

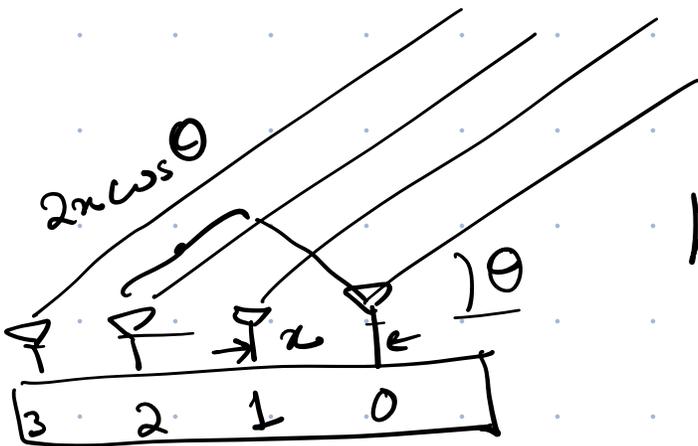
↳ Directional antennas to create beams.

↳ point to each other using mechanical motion

Problem: Does not support mobility.

Phased arrays! can create beams and steer them electronically.

RECAP: ANTENNA ARRAYS



$$h_i = h_0 e^{-j \frac{2\pi x_i \cos \theta}{\lambda}}$$

λ ← wavelength

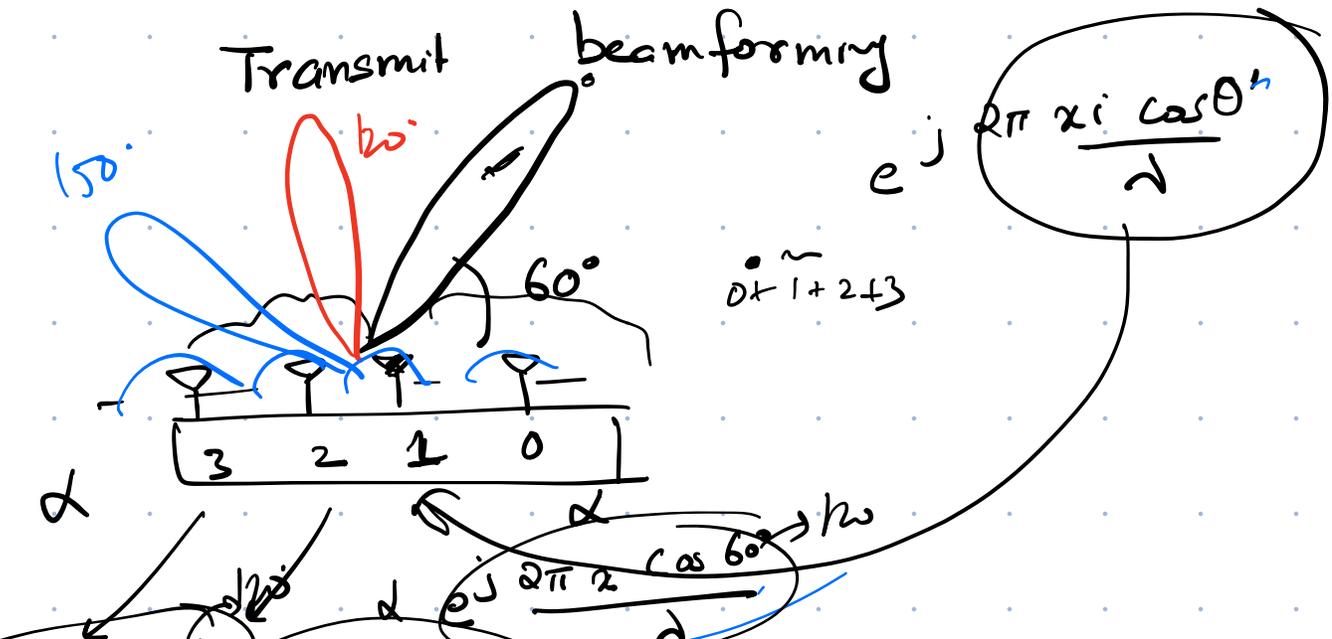
$$P(\theta) = \left| \sum h_i e^{j \frac{2\pi x_i \cos \theta'}{\lambda}} \right|^2$$

$\theta = \theta'$, $P(\theta') \uparrow$

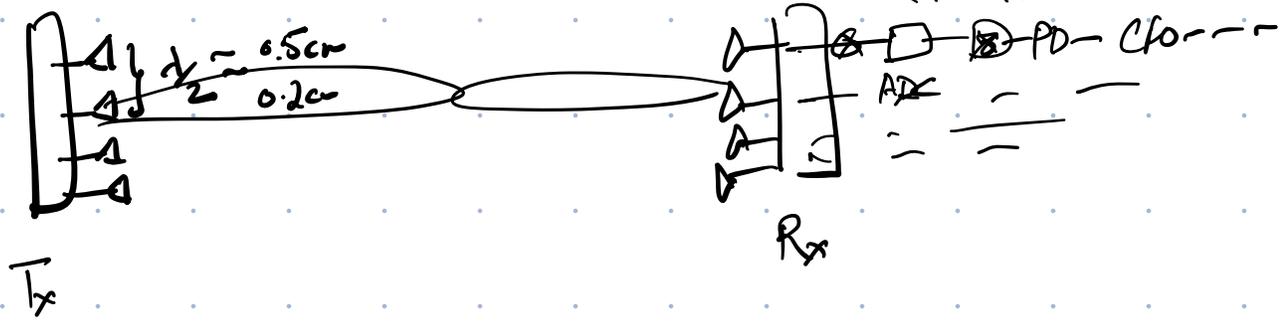
$\theta \neq \theta'$, $P(\theta') \downarrow$

Receive beamforming

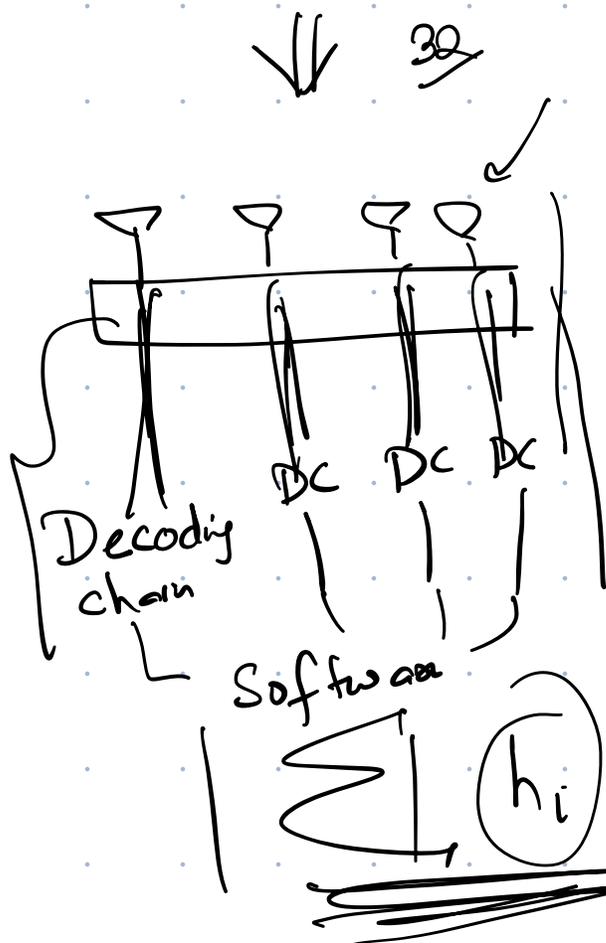
Transmit beamforming



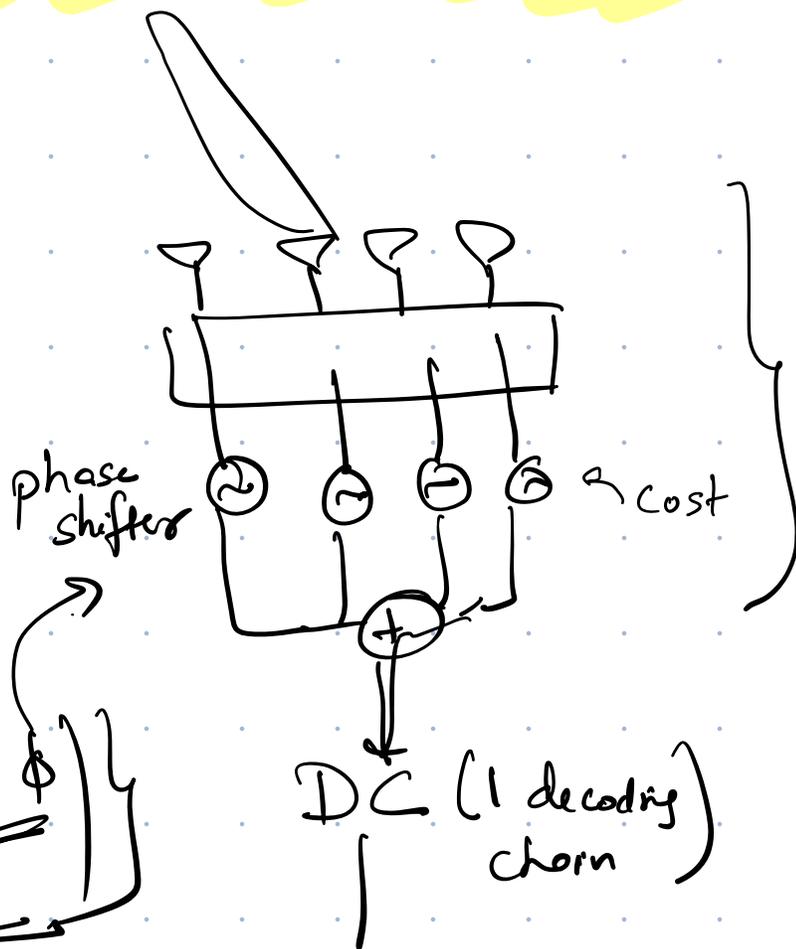
$\alpha e^{j2\pi(3x) \cos \theta}$
 $\frac{2\pi(2x) \cos 56^\circ}{\lambda}$
 $\frac{4}{8} / 16 / 32$



ANTENNA ARRAY VS PHASED ARRAY



- Multiple decoders



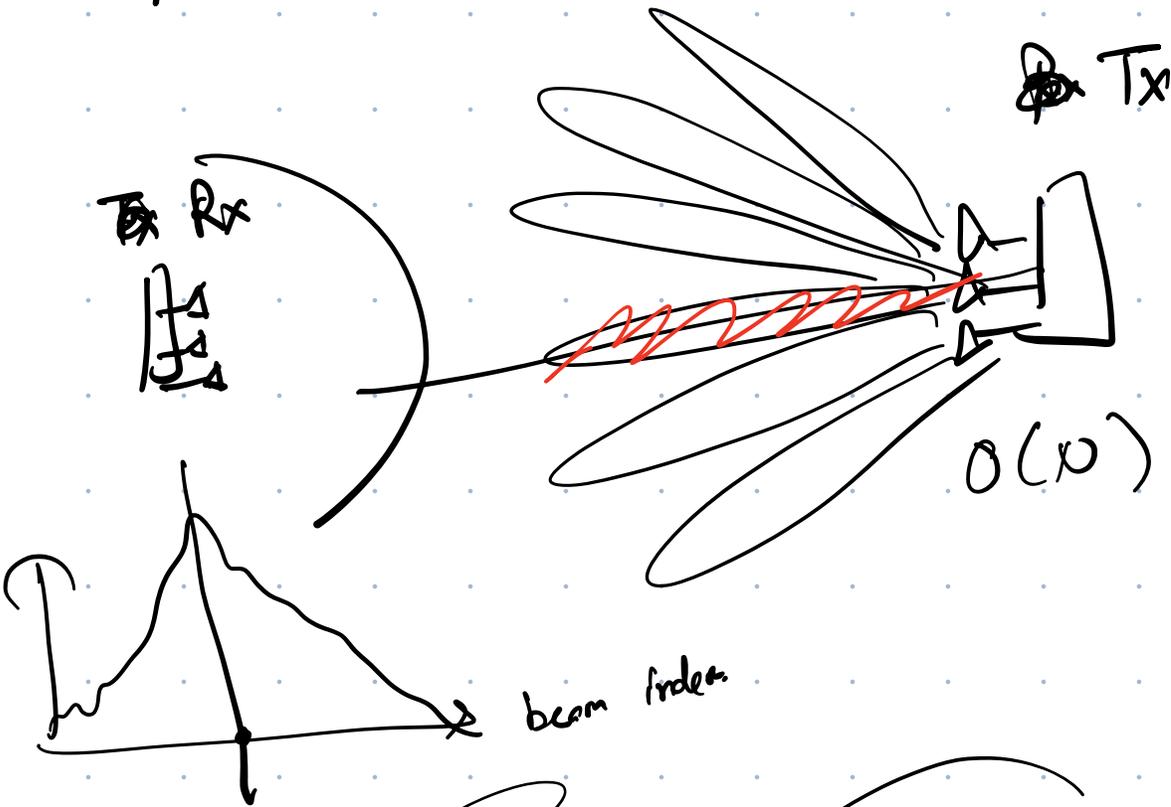
- 1 decoder.
- can only beam in 1 direction.
- SNR is high, when the direction is correct

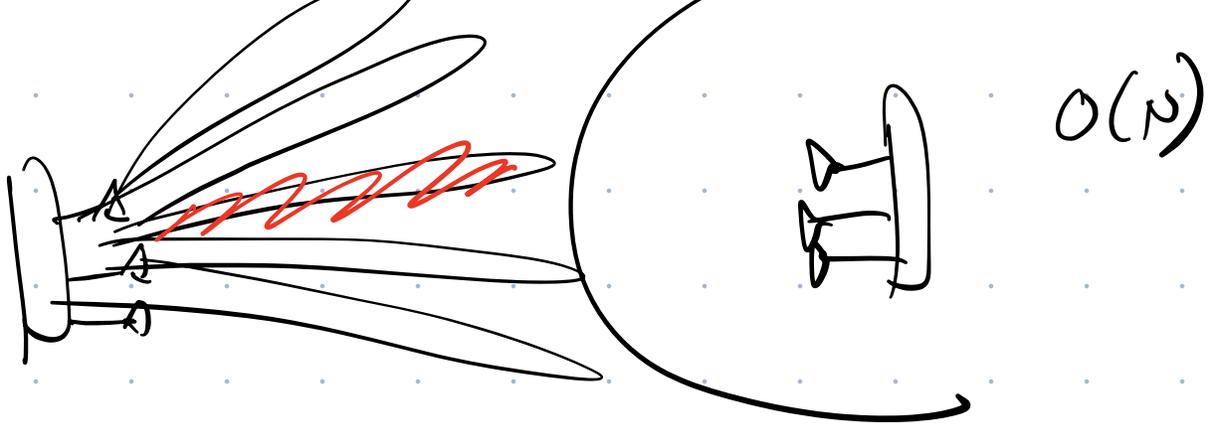
BEAM ALIGNMENT



$$18 \times 18 = 0 \text{ (N}^2) \text{ options}$$

- Setup is slow
- Response to mobility is slow.





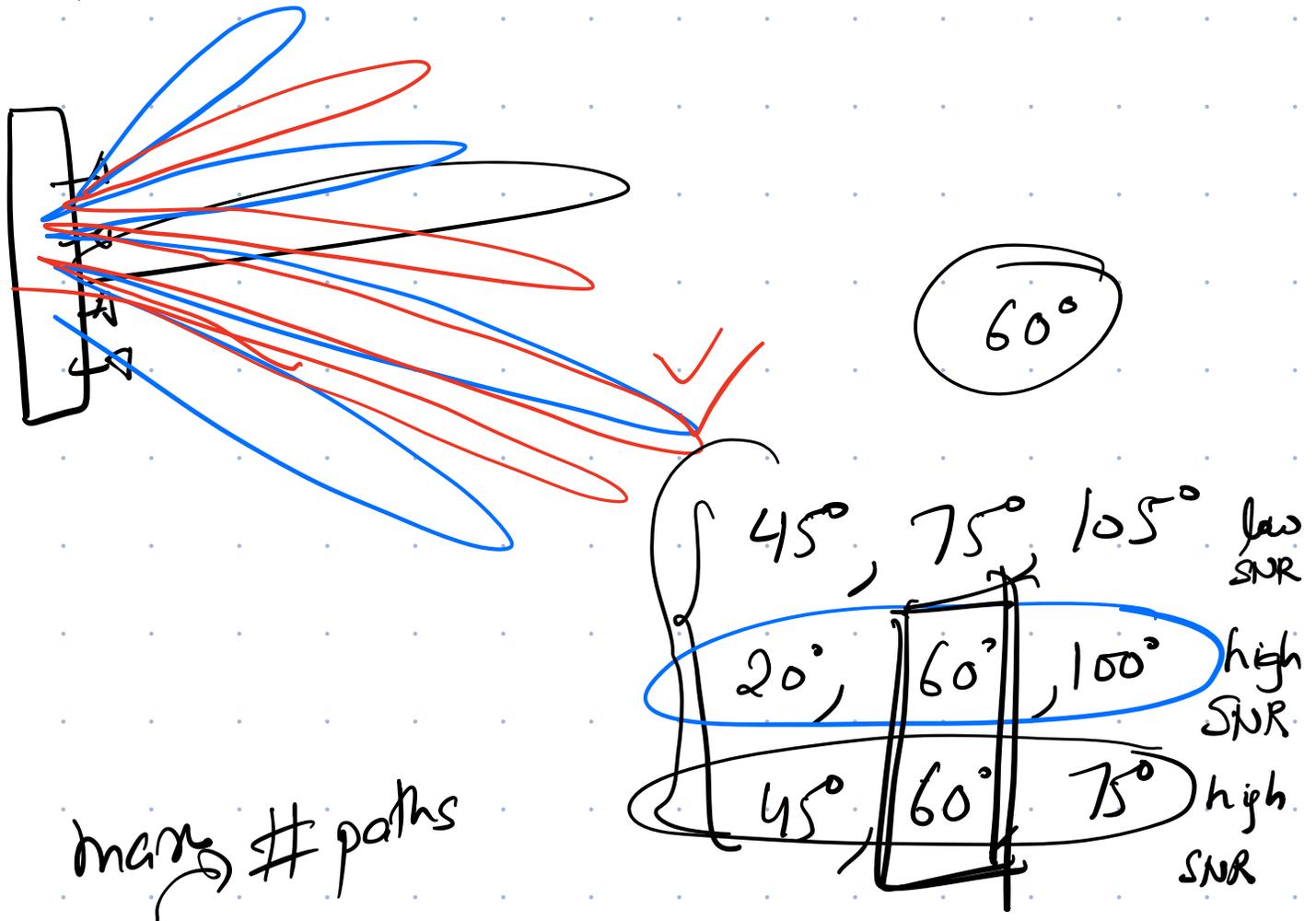
Lose some range.

Agde Link: Can we do this in
 $O(\log N)$

Intuition: Multipath is sparse.

AGILE LINK

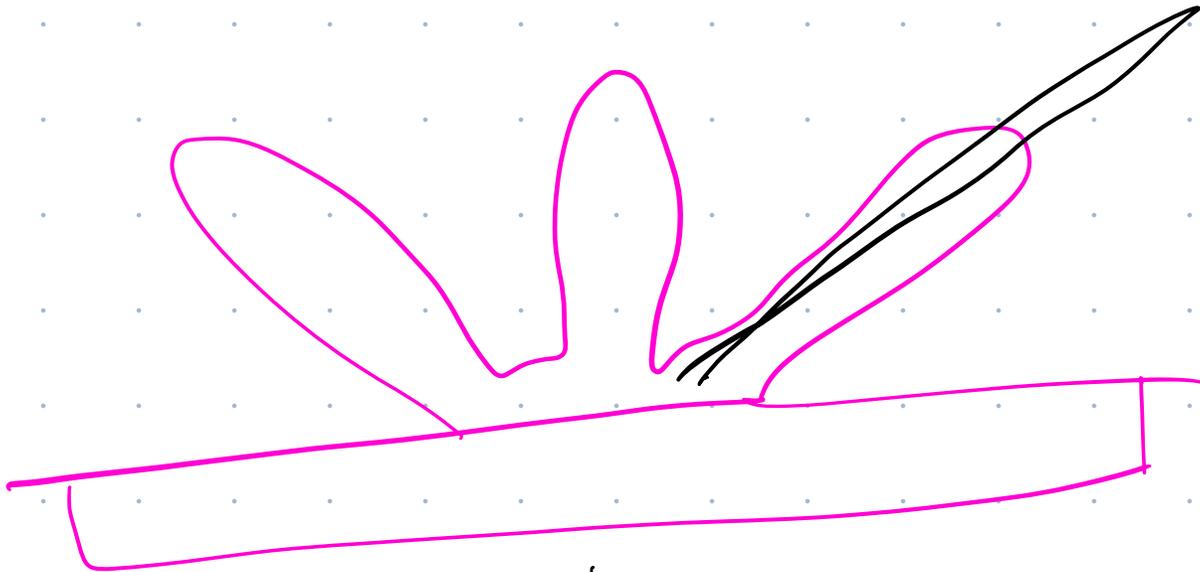
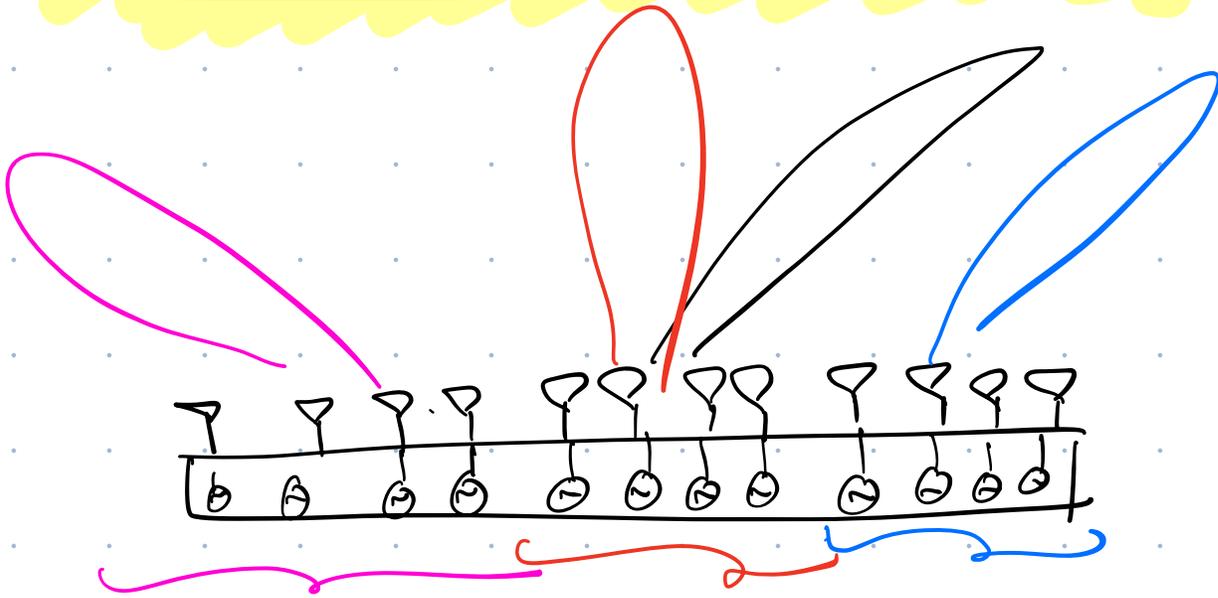
Multi-arm beams.



many # paths

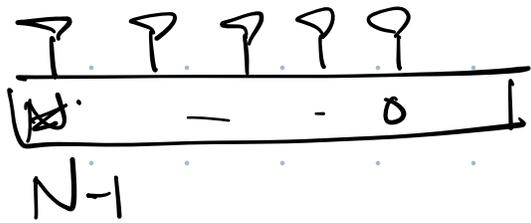
$$O(k \log N)$$

CREATING MULTI ARM BEAMS



$$\text{SNR} \propto \frac{1}{d^2}$$

$$\text{SNR} \propto \frac{N^2}{N}$$



$$P(\theta) = \sum h_i e^{j \frac{2\pi}{\lambda} ix \cos \theta}$$

$$\bar{P} = [P(\theta_1) \quad P(\theta_2) \quad \dots \quad P(\theta_N)]$$

$$\bar{P} = F \vec{h}$$

matrix

$$e^{j \frac{2\pi}{\lambda} ix \cos \theta_1}$$

$$e^{j \frac{2\pi}{\lambda} ix \cos \theta_2}$$

$$F_{\alpha\beta} = e^{j \frac{2\pi}{\lambda} \beta x \cos \theta_\alpha}$$

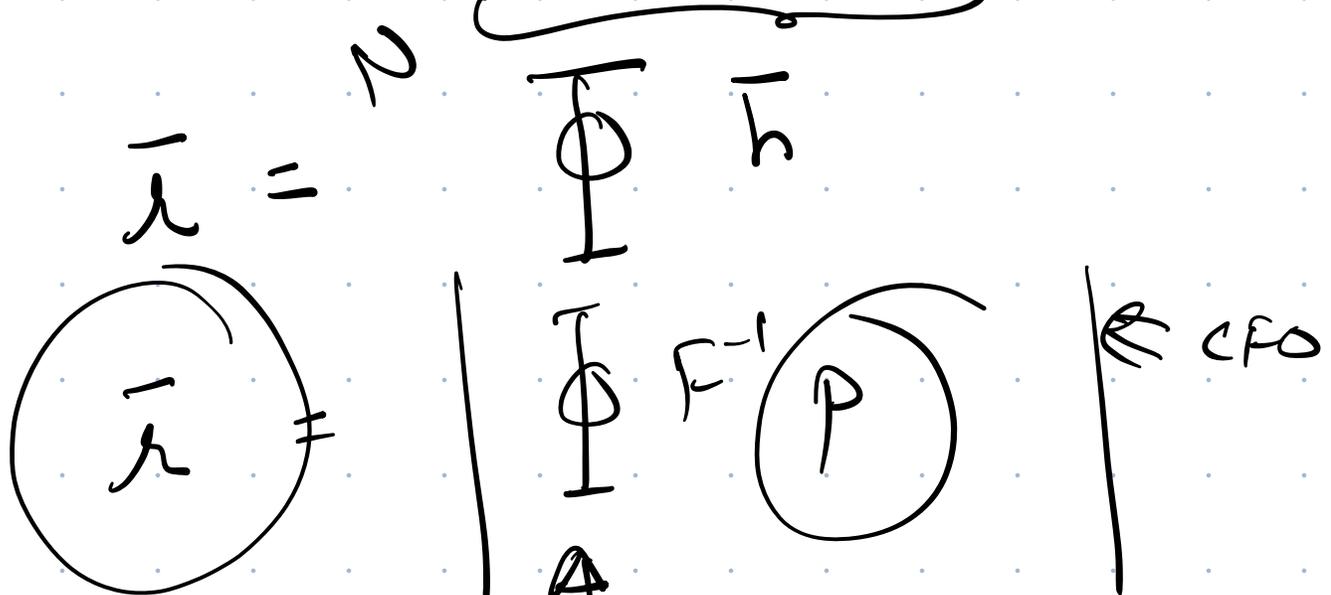
phase shifts

Receiver measures $= \left| \sum e^{j \phi_i} h_i \right|$

$$\vec{h} = F^{-1} \bar{P}$$

true signal values along each direction

$$r_1 = \begin{bmatrix} e^{i\phi_1} & e^{i\phi_2} & \dots & e^{i\phi_n} \\ e^{i\phi_1} & e^{i\phi_2} & \dots & e^{i\phi_n} \\ \vdots & \vdots & \ddots & \vdots \\ e^{i\phi_1} & e^{i\phi_2} & \dots & e^{i\phi_n} \end{bmatrix} \begin{bmatrix} h_1 \\ h_2 \\ \vdots \\ h_n \end{bmatrix}$$



$O(k \log N)$ to a unique customized set of values

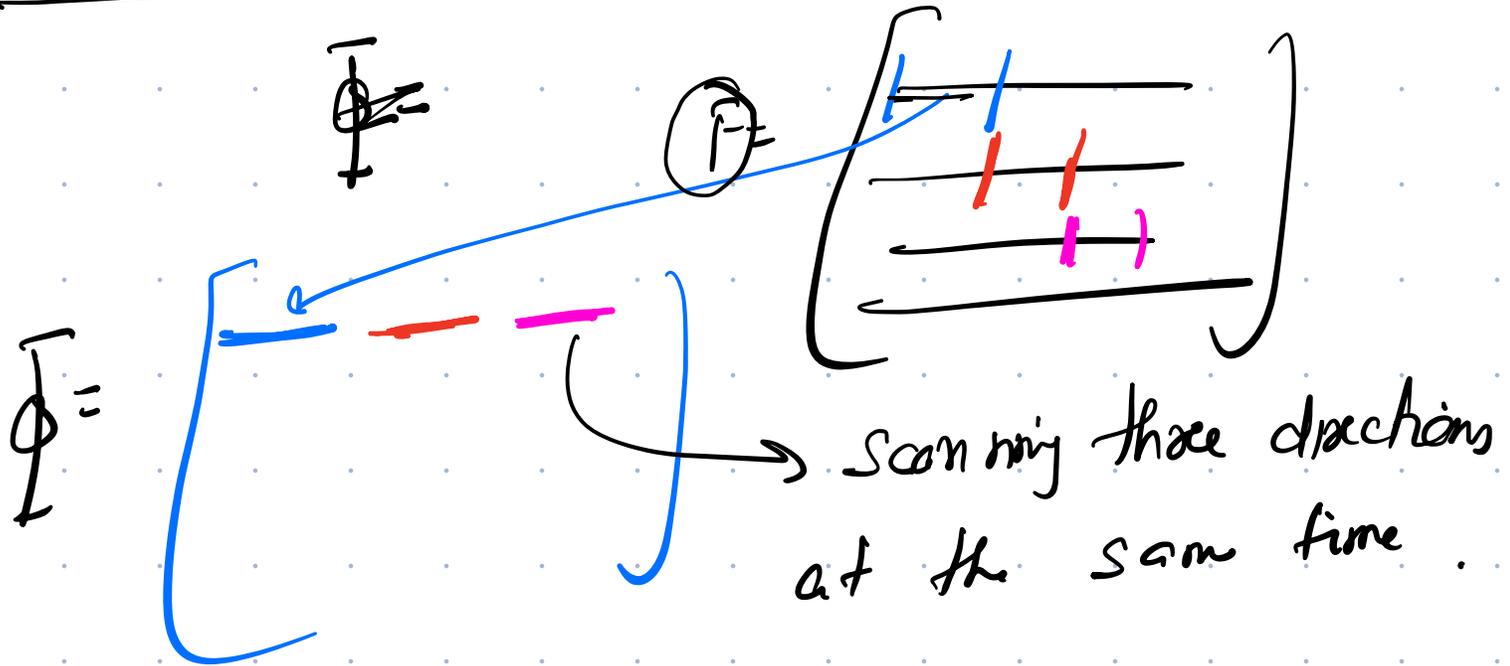
easy thing

$$\phi = F$$

$$\bar{r} = P \quad O(N)$$

$\hookrightarrow P$ is sparse.

Multi-armed bandit



Evaluation

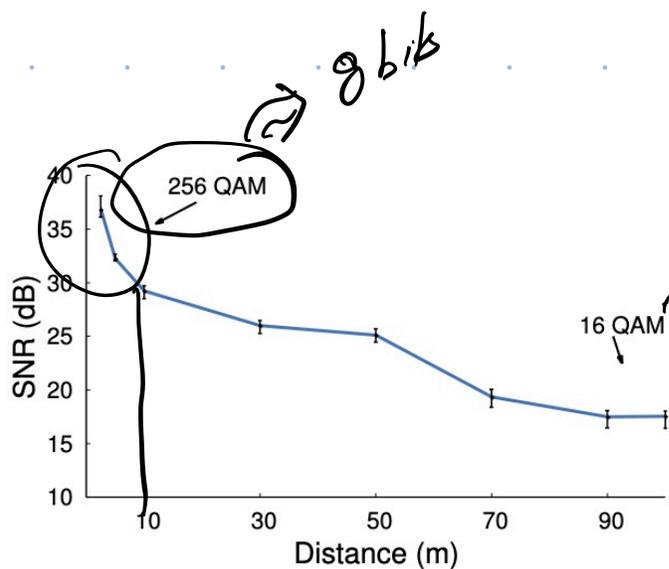


Figure 7: Agile-Link Coverage. SNR at the receiver versus distance between the receiver and the transmitter.

$4 \text{ bits/symbol} \times 100 \times 10^6$

$4 \times 10^8 \text{ b/s}$

400 Mbps

$400 \text{ MHz} \rightarrow 1.6 \text{ Gbps}$

40 MHz \rightarrow 160 Mbps

Bandwidth

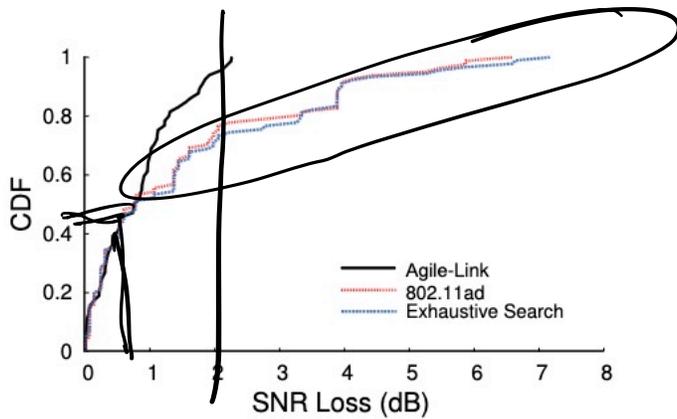
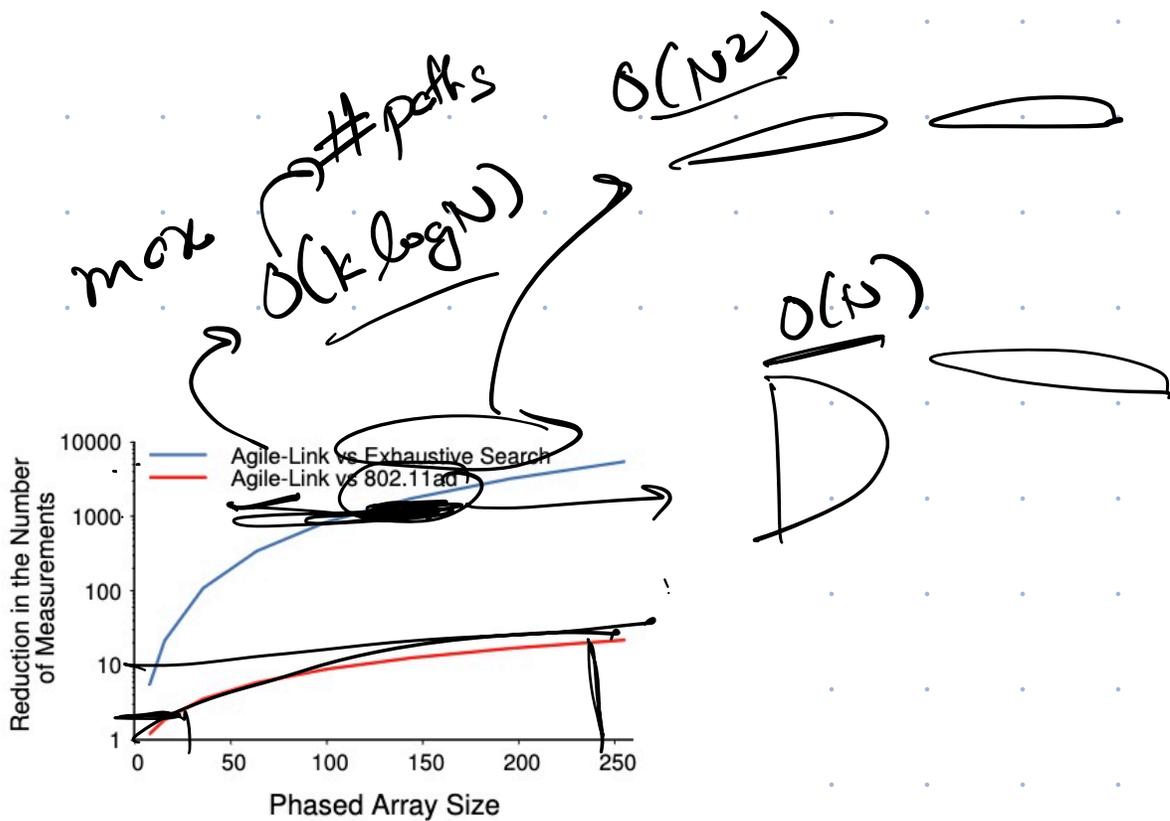


Figure 8: Beam Accuracy with a Single Path: SNR loss due to beam misalignment for Agile-Link, the 802.11ad standard, and exhaustive search.



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