Wireless Communication Systems
@CS.NCTU

Lecture 12: mmWave

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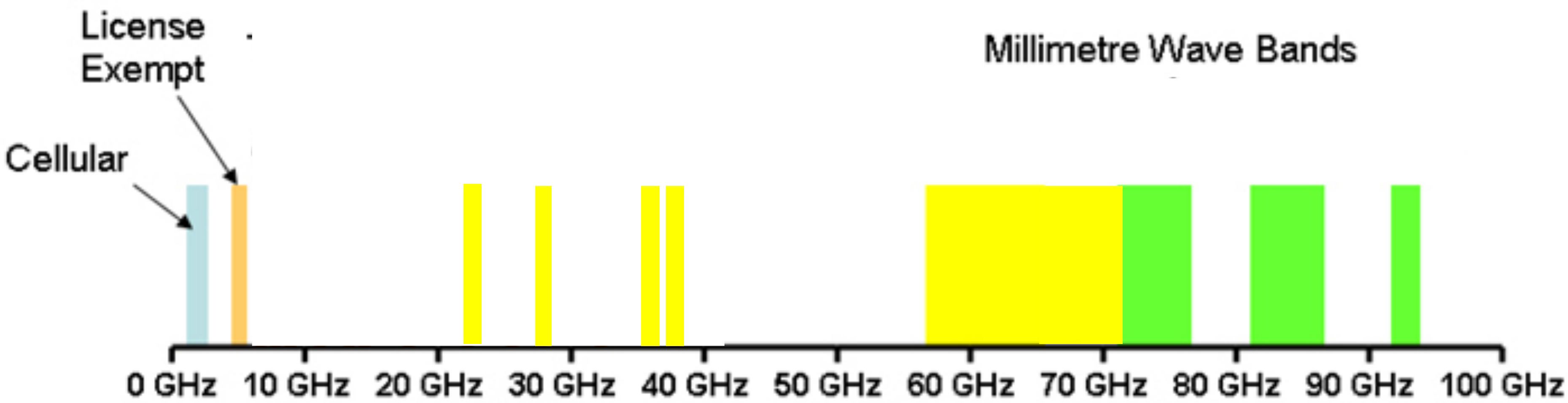
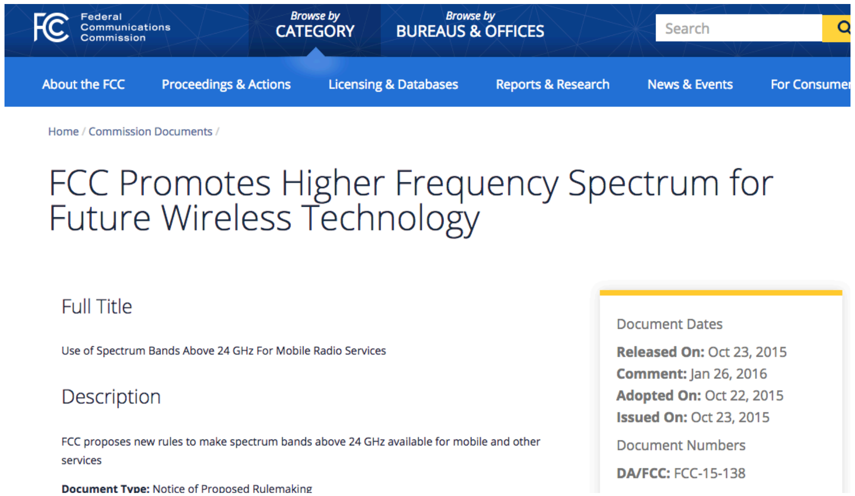
Millimeter Wave Bands

- Huge amount of available bandwidth (λ=C/f)





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FCC Promotes Higher Frequency Spectrum for Future Wireless Technology

Full Title

Use of Spectrum Bands Above 24 GHz For Mobile Radio Services

Description

FCC proposes new rules to make spectrum bands above 24 GHz available for mobile and other services

Document Type: Notice of Proposed Rulemaking

Document Dates

Released On: Oct 23, 2015
Comment: Jan 26, 2016
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Issued On: Oct 23, 2015

Document Numbers

DA/FCC: FCC-15-138

National Science Foundation
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Advanced Wireless Research Initiative @ NSF

The Advanced Wireless Research Initiative will sustain United States leadership in wireless communications and tech and development.

The National Science Foundation's (NSF) leadership of this Initiative has three intertwined components:

- Establishing **platforms for advanced wireless research** enabled by a new industry consortium and engagem
- Supporting **fundamental research enabling advanced wireless technologies**; and
- Catalyzing **academic, industry, and community leaders** to work together to prototype innovative wireless ap

These efforts will provide new insights capable of making wireless communication faster, smarter, more responsive, a

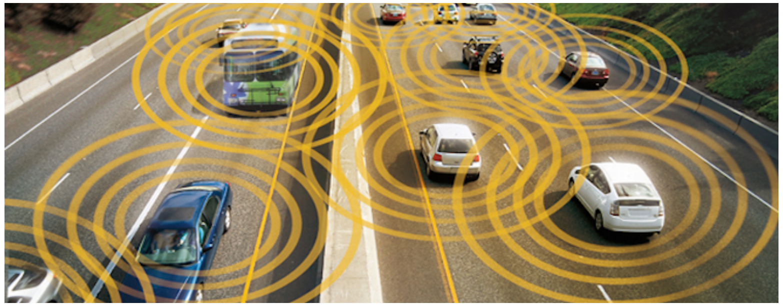
mmWave Wireless Applications

5G Cellular Networks

Wireless Data Centers

Wireless LANs 802.11ad

Wireless Virtual/ Augmented Reality



Connected Vehicles

Gesture Recognition

- Between 30GHz and 300GHz
- Offers much greater bandwidths combined with further gains via beamforming and spatial multiplexing
- Antenna arrays: Enable large numbers (32 elements) of miniaturized antennas placed in small dimensions
- Increasing omnidirectional path loss due to the higher frequencies of mmWave transmissions
  - Compensated through suitable beamforming and directional transmissions
  - Severely vulnerable to shadowing (blockage)

Challenges

- Directional communications
- Shadowing
- Channel fluctuation
- Multiuser coordination
- Power consumption

Directional Transmissions

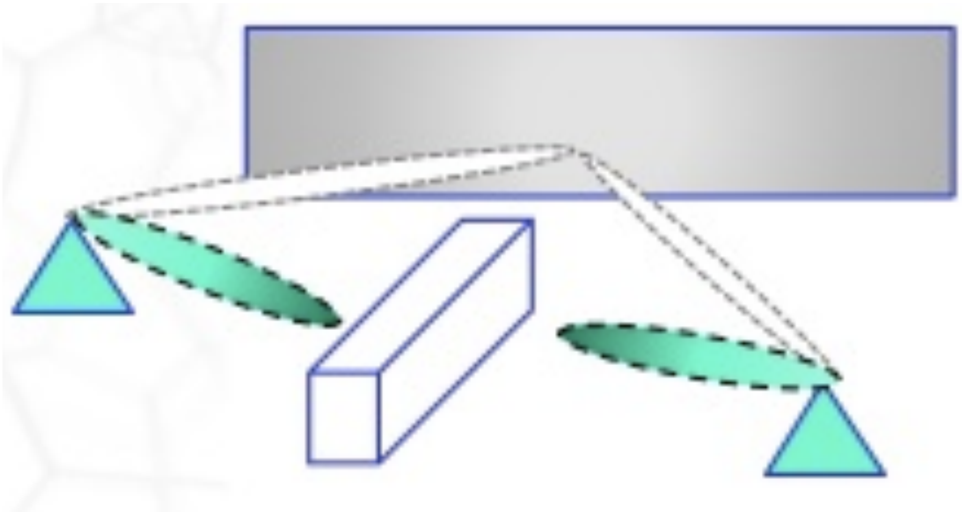
- Path loss grows with the square of the frequency

$$\frac{P_r}{P_t} = G_t G_r \left(\frac{\lambda}{4\pi R}\right)^2$$

- Small wavelength → Large path loss → Short transmission range
- Leverage antenna array and beamforming to steer directional beam with a stronger power
- Deafness occurs when the main lobes at both Tx and Rx do not point to each other

Shadowing

- mmWave signals are extremely susceptible to shadowing
  - High penetration loss due to obstacles
  - Brick can attenuate signals by as much as 40–80 dB

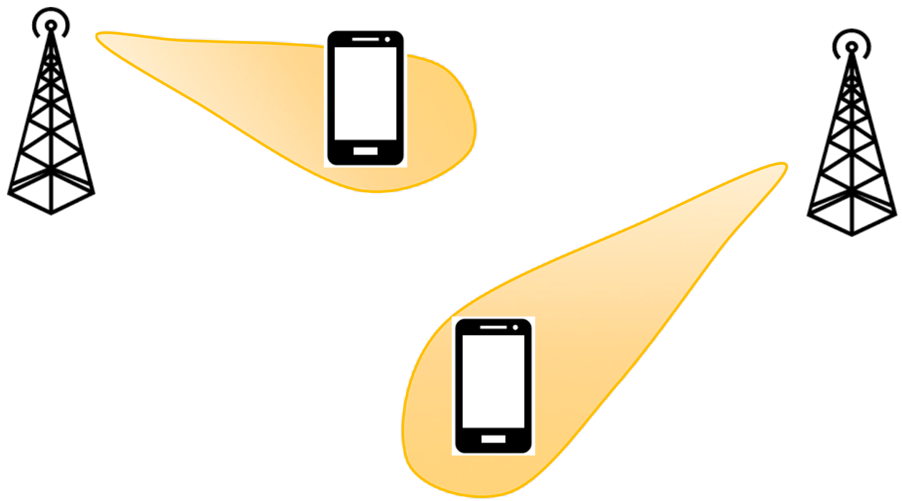


Channel Fluctuation

- For a given mobile velocity, channel coherence time is linear in the carrier frequency → higher frequency, shorter coherence time
  - Connectivity will be highly intermittent and communication will need to be rapidly adaptable
  - Channel estimation should be performed frequently → large overhead

Multiuser Coordination

- Directional transmissions imply more spatial reuse opportunities



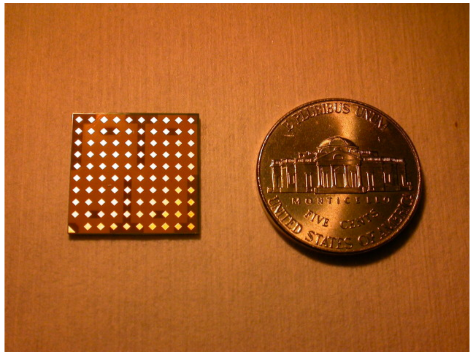
- Challenges
  - How to locate users?
  - How to quickly switch the beam directions and widths?

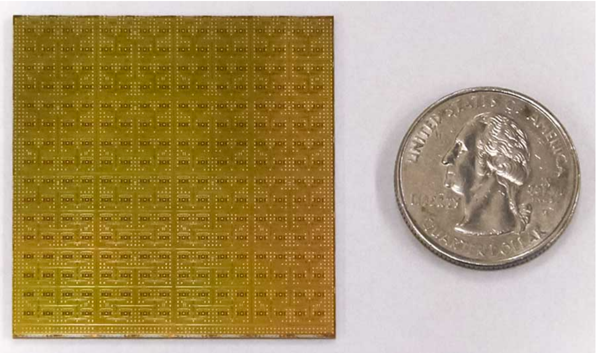
Power Consumption

- Power consumption generally scales
  - linearly in the sampling rate
  - exponentially in the number of bits per samples
- Hard to achieve high-resolution quantization at wide bandwidths and large numbers of antennas
- Efficient RF power amplification and combining will be needed for phased array antennas

Phase Array

mmWave radios use phased antenna arrays to focus the power along one direction



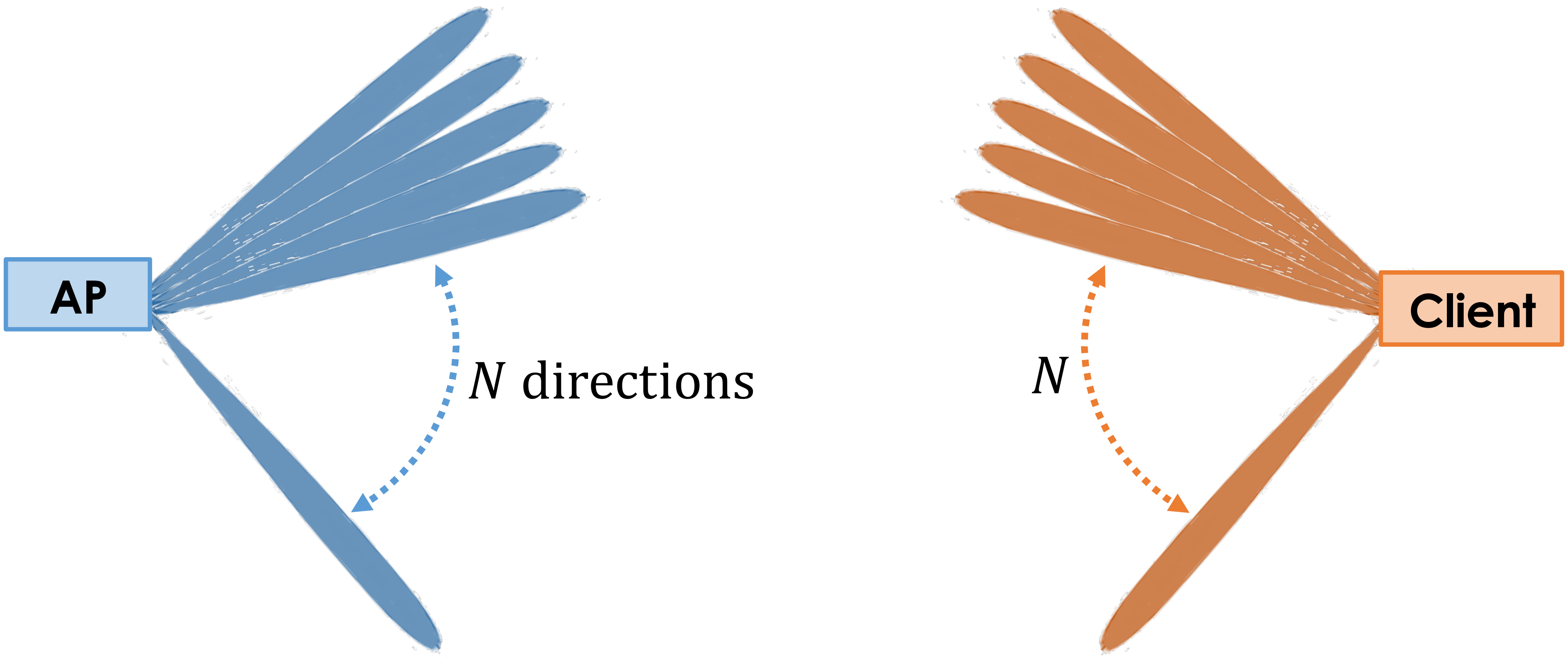


Small Wavelength enables thousands of antennas to be packed into small space

→ Extremely narrow beams

Beam Searching

N : number of possible directions



Naïve solution: Exhaustive search
$O(N^2)$ Beacon Packets → Too expensive

802.11ad: Multi-Stage Scan

- Stage 1: Client uses omni-directional; AP scans directions

802.11ad: Multi-Stage Scan

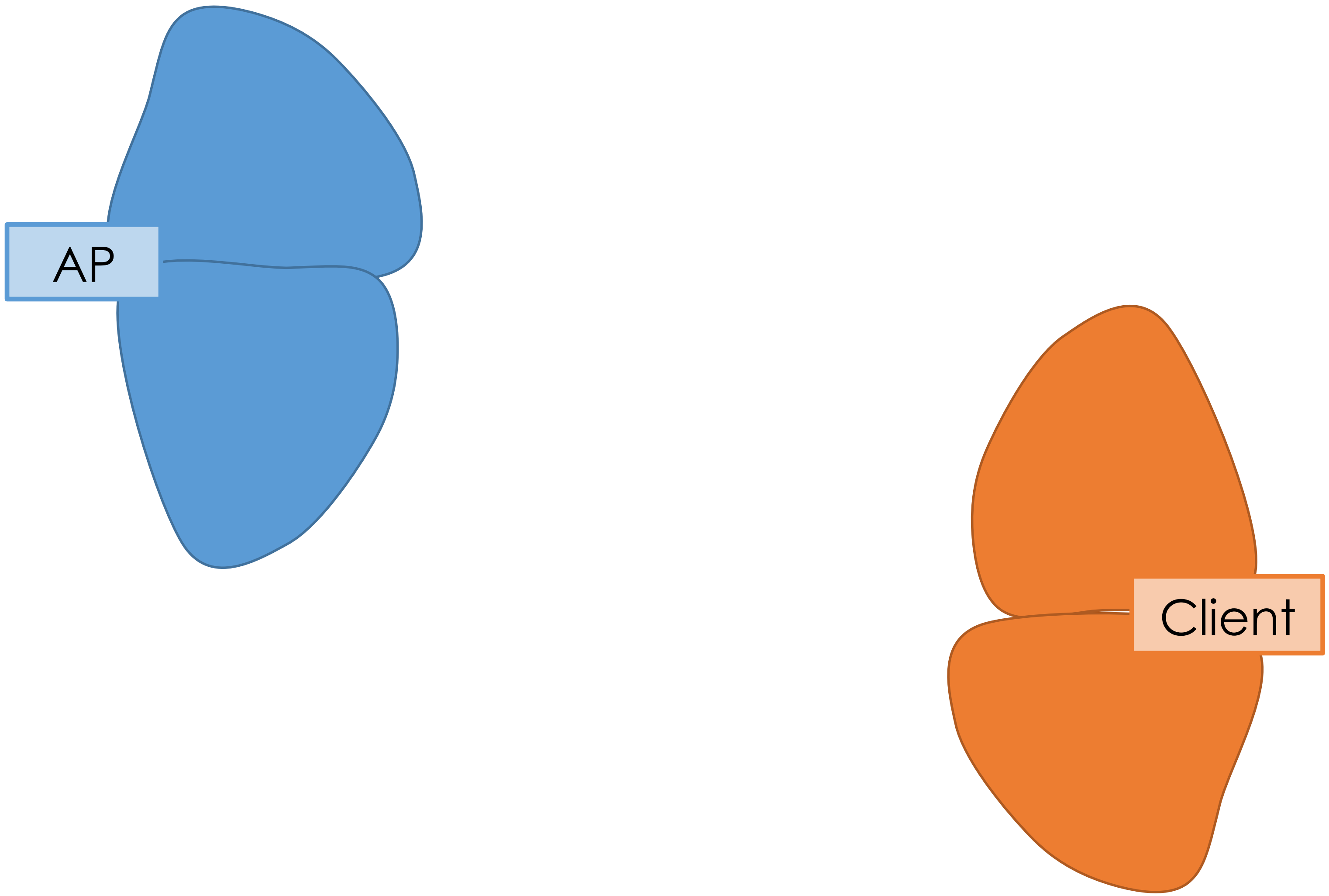
- Stage 2: AP uses omni directional; client scans directions

$O(N)$ Beacon Packets

Still Too Slow [MOBICOM'14, SIGMETRICS'15, NSDI'16]

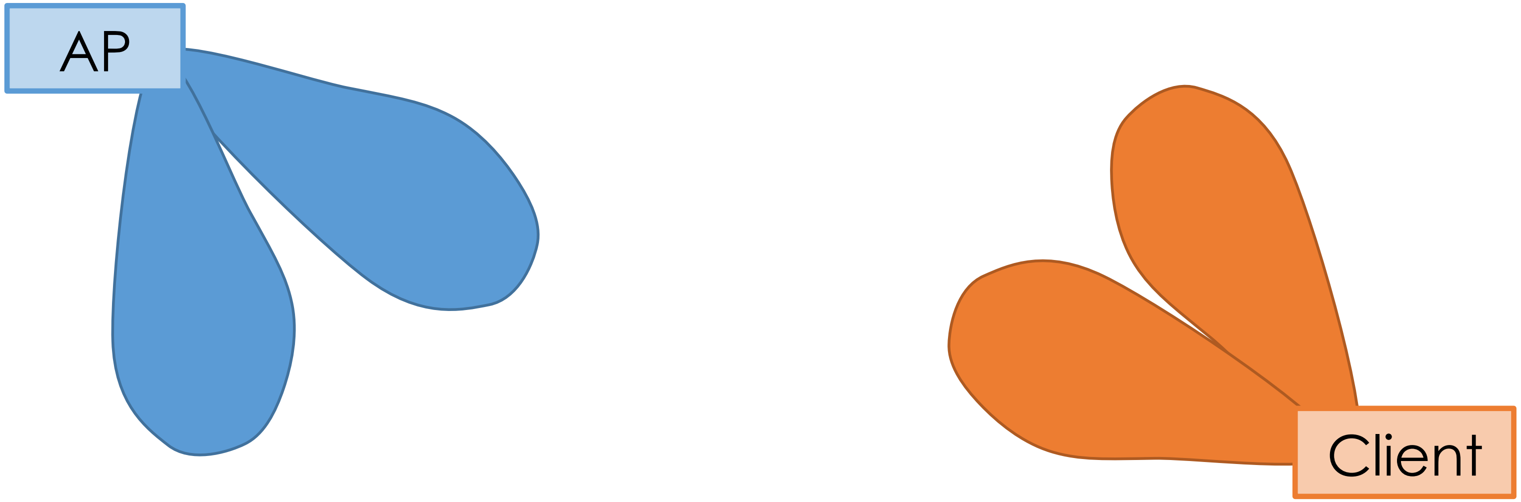
Hybrid Precoding

- Iteratively reduce the size of lobes as scanning



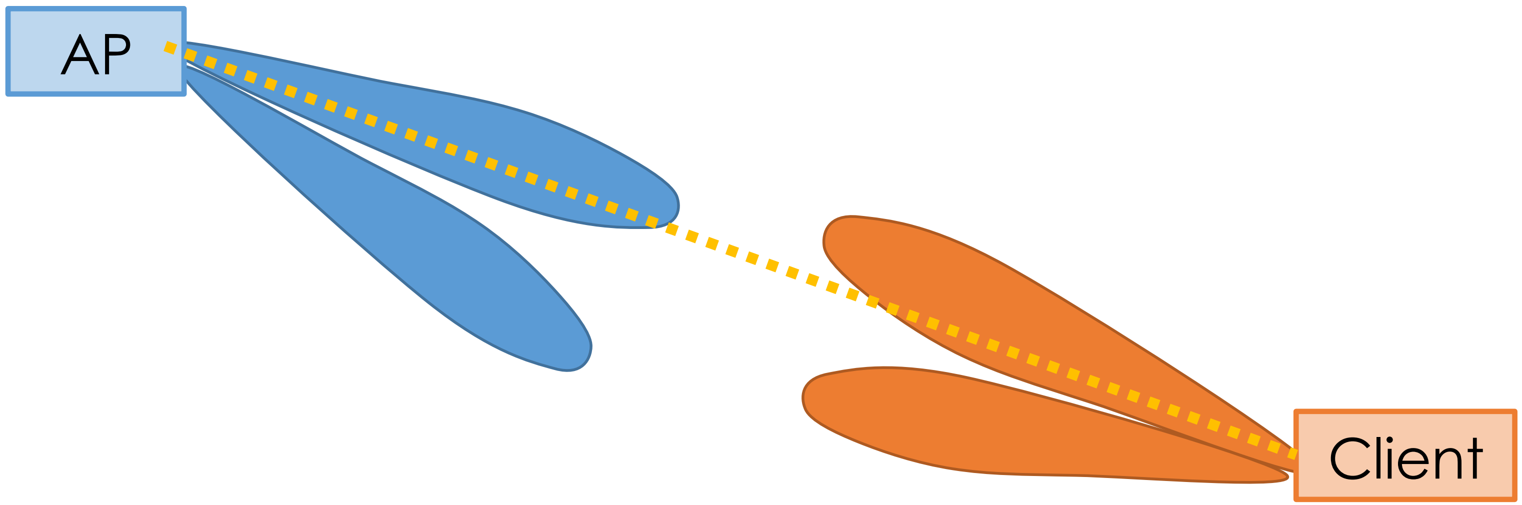
Hybrid Precoding

- Iteratively reduce the size of lobes as scanning



Hybrid Precoding

- Iteratively reduce the size of lobes as scanning
- Until the narrowest beam pointing to each other



Open problem: wider beam → shorter range

How to avoid misdetection in the beginning?