Multi-Beam Methods for Increased Throughput and Reliability

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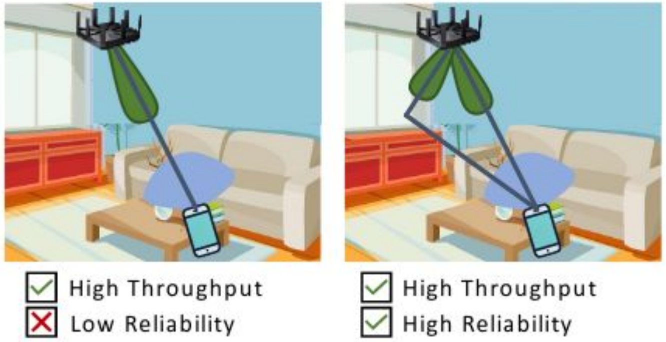
Motivation

Two beams are better than one: Towards Reliable and High Throughput mmWave Links: Ish Kumar Jain et al.

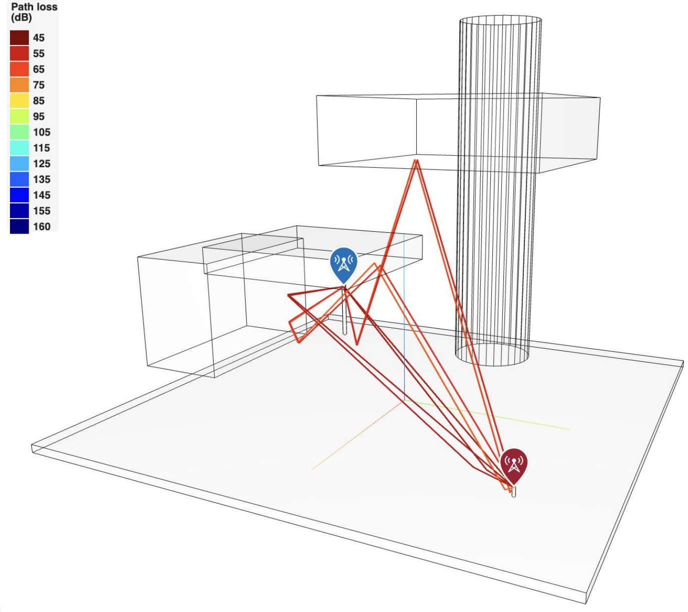
- mmWave links have low reliability due to blockages
- Sending multiple beams improves reliability
- Sending multiple beams increases signal strength at the receiver



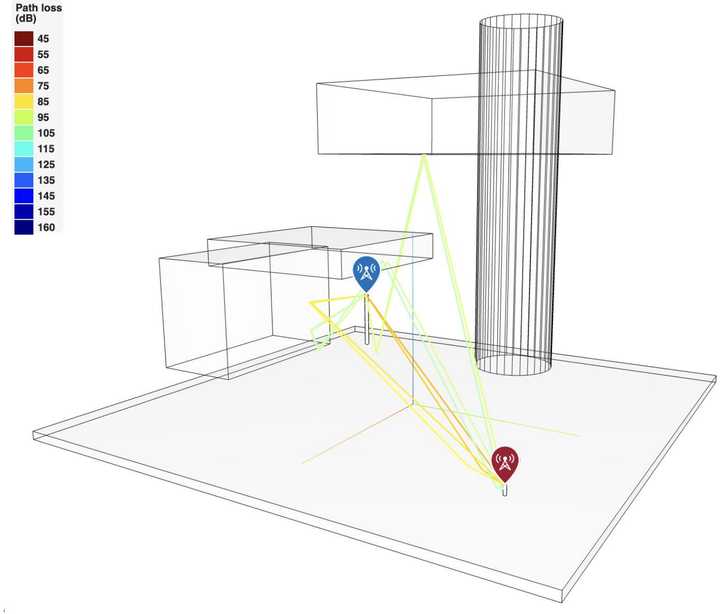
(a) Conventional (b) mmReliable

Theoretical Overview: Path Loss

300 MHz



30 GHz



Path Loss is Much Greater at mmWave range

Theoretical Overview: Constructive Multipath Gain

For n beams:

- Normalized transmit power gives per beam gain = $\frac{1}{\sqrt{n}}$
- Lossless constructive gain at the receiver = $\frac{n}{\sqrt{n}}$

Upper bound for revier gain for n beams:

$$\sqrt{n}$$

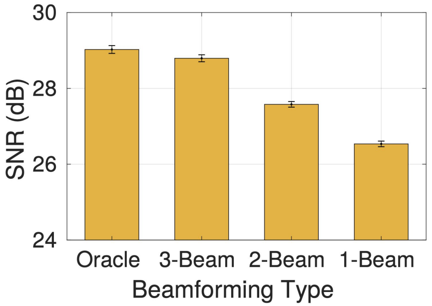
Paper Results

Highlights gain upper bound of $\sqrt{2}$ for dual beam

Experimental results

- Dual-beam gives 1.04 dB SNR gain compared to single
- Three-beam gives 2.27 dB SNR gain compared to single

Also analyzes and evaluates reliability and tracking for moving user



Our Work

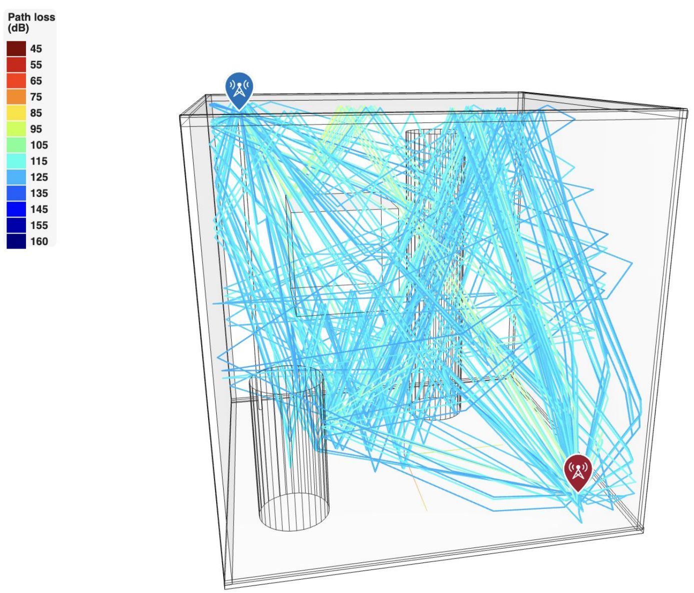
- Model the COSMOS phased array in MATLAB
- Simulate the multipath profile of 3D scene at mmWave frequencies
- Scan multipath profile for constructive channels
- Simulate phased array implementation at constructive beams
- **Evaluate SNR gain across varying number of beams and 3D scenes**
- Re-create beam tracking for user movement

Research Question:

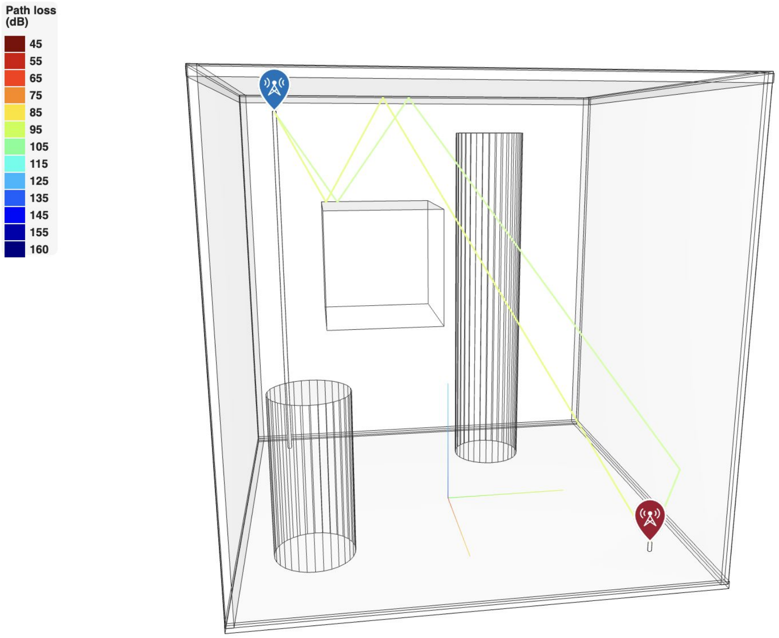
How does the number of beams and the type of environment affect the SNR gain for multi-beamforming?

Multipath Profile Simulation

Multipath Scattering



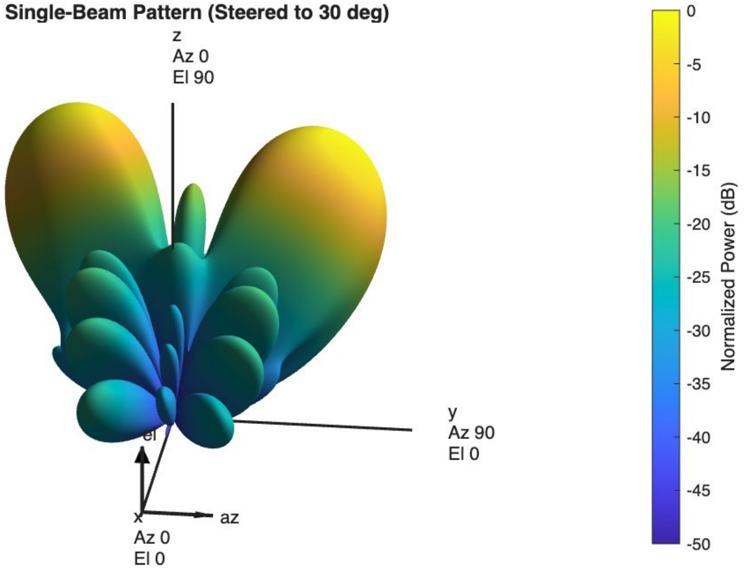
Best Constructive Channels

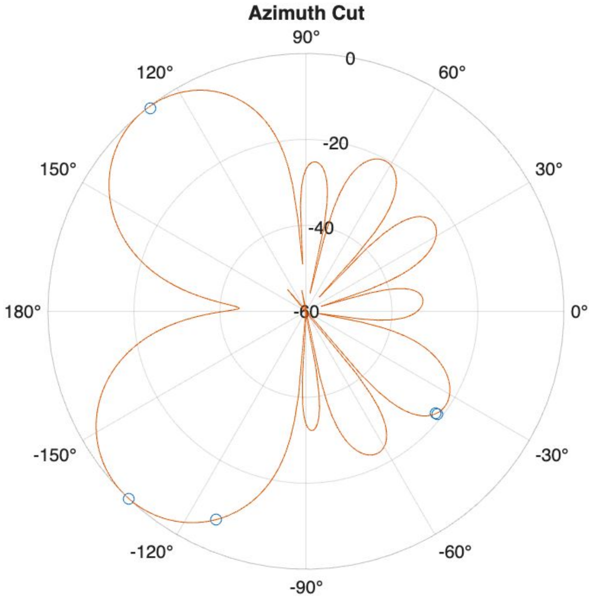


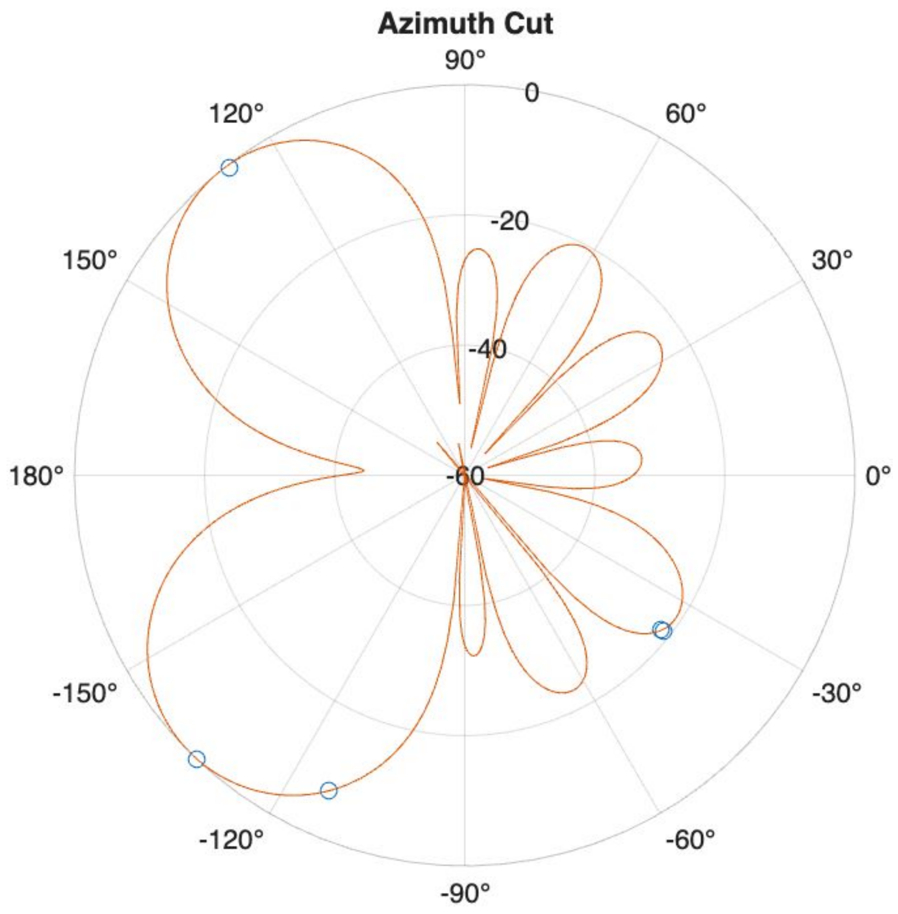
Phased Array Simulation

COSMOS Phased array:

- 28GHz
- 8x8 array
- λ/2 spacing

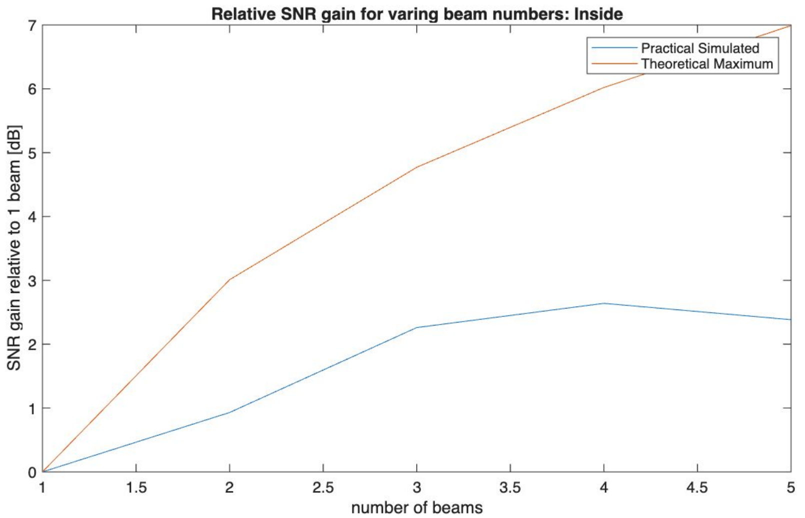


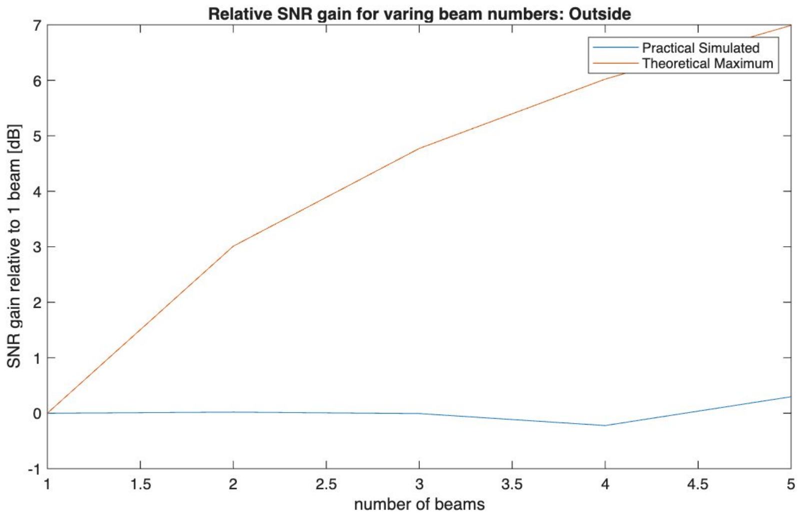


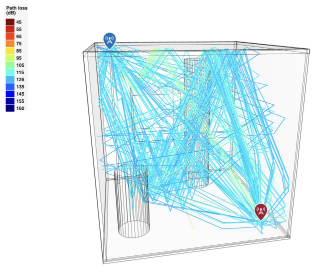


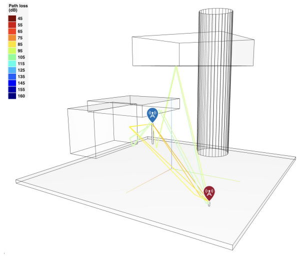
Azimuth Cut
90°
0
60°
120°
-20
30°
150°
-40
180°
-60
0°
-150°
-30°
-120°
-60°
-90°

SNR Gain Experiments







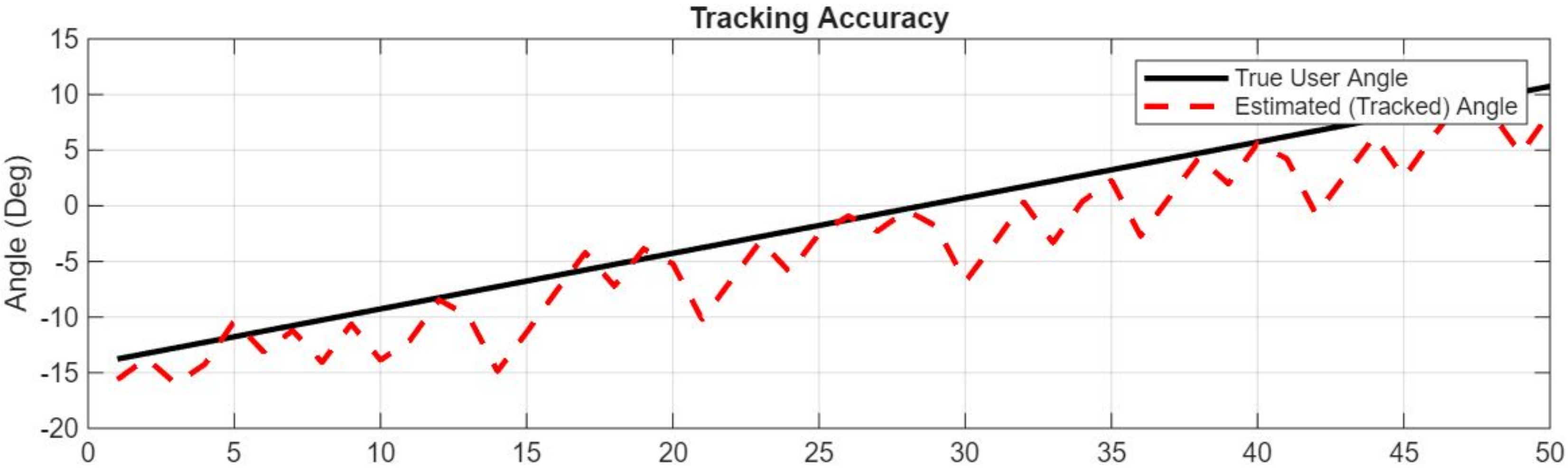


Per-Beam Tracking & Simulation

- Parameters:
  - 28 GHz (mmWave Band)
  - 64 element Uniform Linear Array
  - Transmit Power: 20 dBm
- Environment:
  - 2 Paths: 1 Line of Sight (LOS) & 1 Reflected
  - LOS is randomized between [-30, 30]°
  - Reflection is offset by at least 20°
- Simulated Target Motion
  - 50 steps (time steps)
  - 0.5° per step (Rigid Motion)

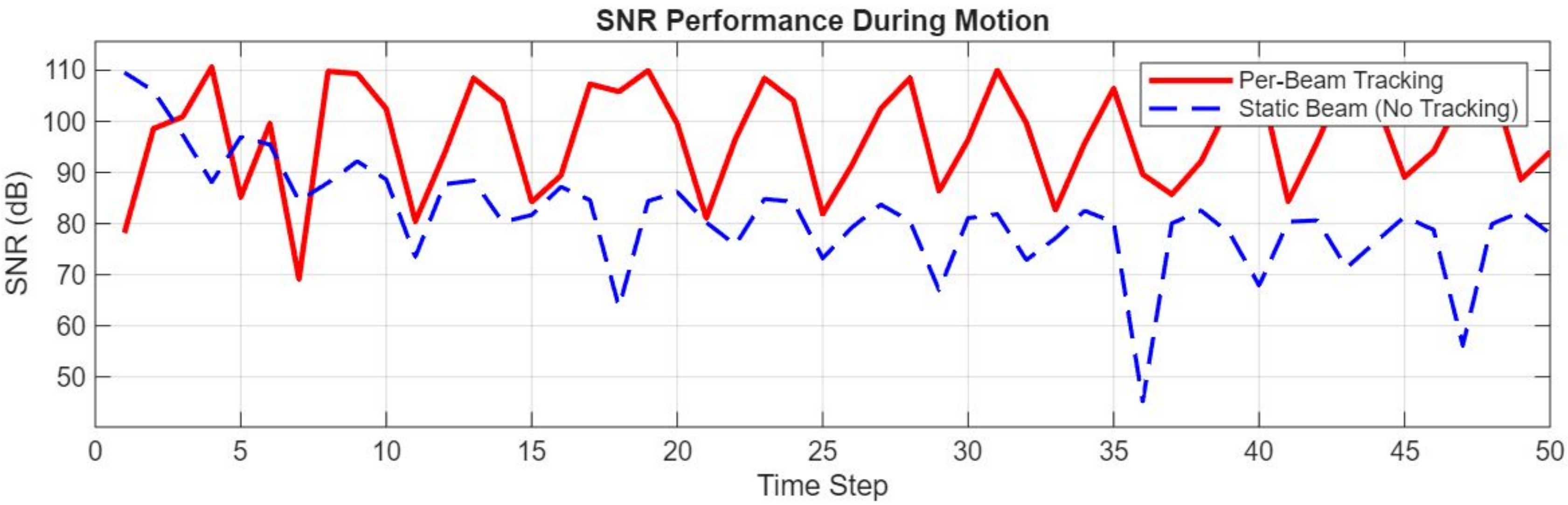
Per-Beam Tracking - Results

Tracking Accuracy



Per-Beam Tracking - Results

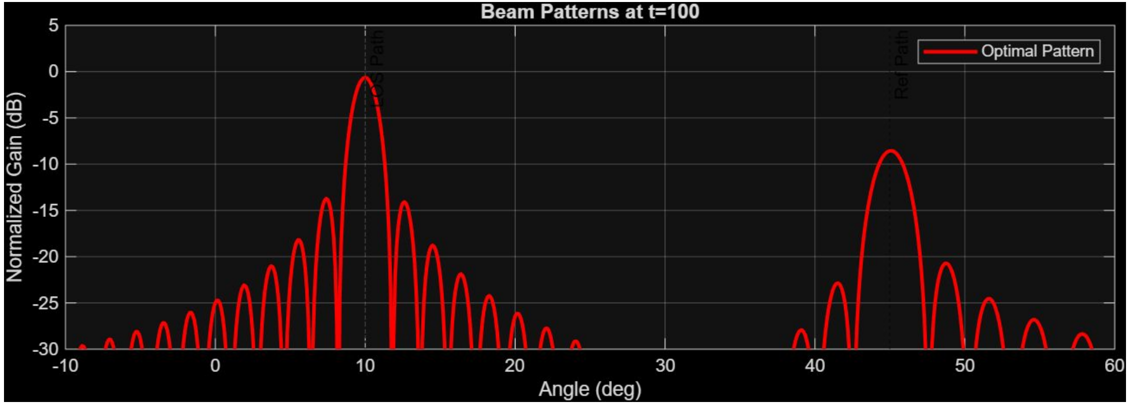
SNR Comparison



Per-Beam Tracking & Optimal Beamforming - Simplified

- Controlling beam power is crucial to maximizing SNR
- Given a fixed power budget, maximizing received signal strength requires that transmit beam weights be aligned with the channel vectors
    - Transmit power allocated to a specific path should be proportional to the path's channel strength

- Using a simplified simulation (assuming gain values for LOS and ref path):



Conclusions

- Multiple beams can provide both reliability and increased throughputs
- mmWave frequencies pose challenges
  - Greater path attenuation: fewer strong beams
  - The few strong beams may not always sum constructively
- Accurate target tracking and beamforming guarantees a high-SNR link
- Using Channel Impulse Response to estimate the amplitude (and power) of each beam would result in a more scalable implementation
  - use in a full multipath environment

Q&A