UC San Diego
JACOBS SCHOOL OF ENGINEERING
Electrical and Computer Engineering

ScatterMIMO: Enabling Virtual MIMO with Smart Surfaces

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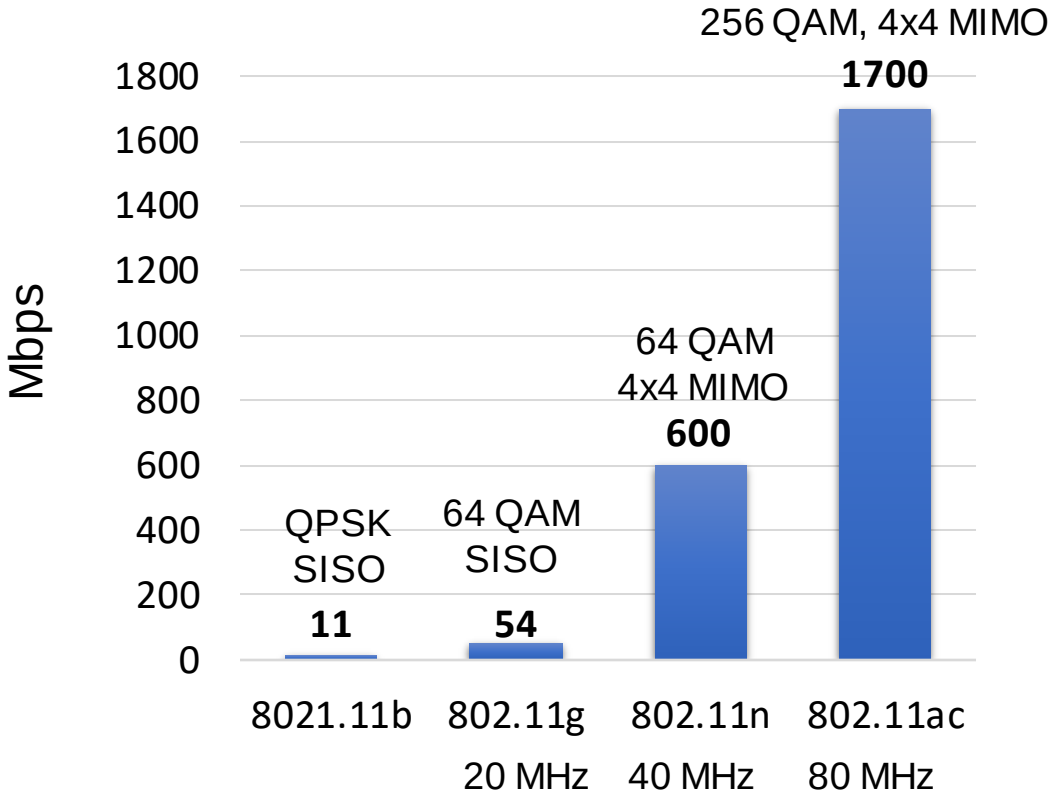
Mobicom 2020

The promise of MIMO 802.11ac



High data rate: Cornerstone of modern applications

Virtual Reality

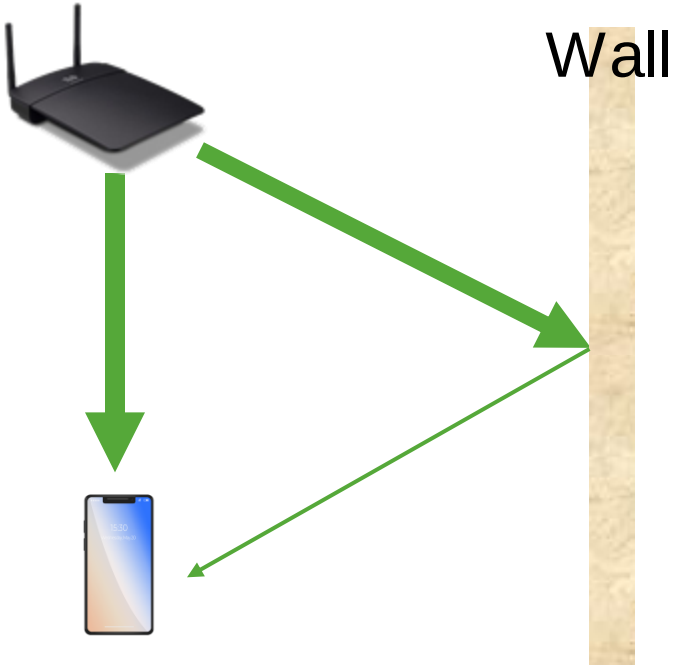
Online Gaming

The Reality

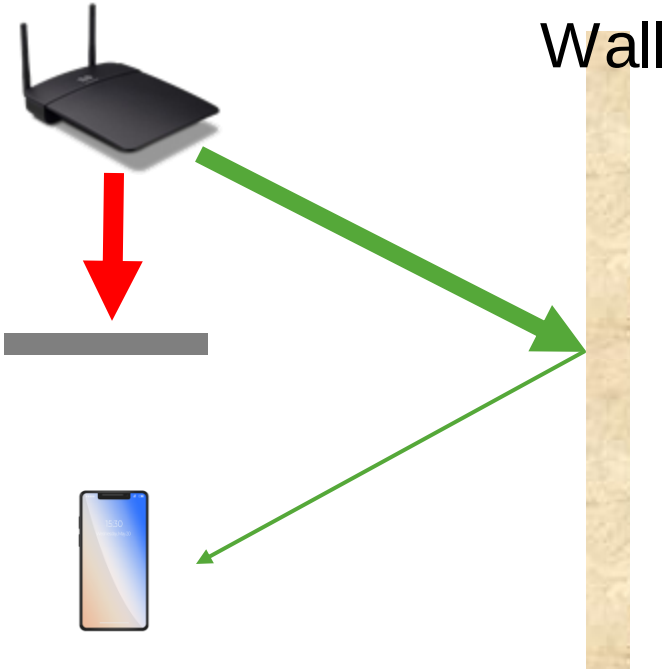
Poor Speed

Poor Coverage

Why don't we get advertised Gbps data-rates?

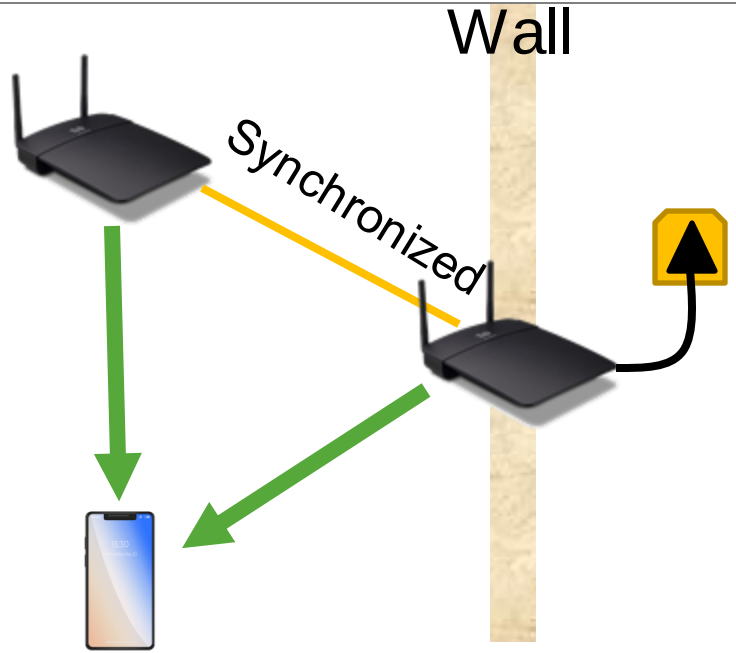


Weak Multipath (Low MIMO rank)



LOS path blockage

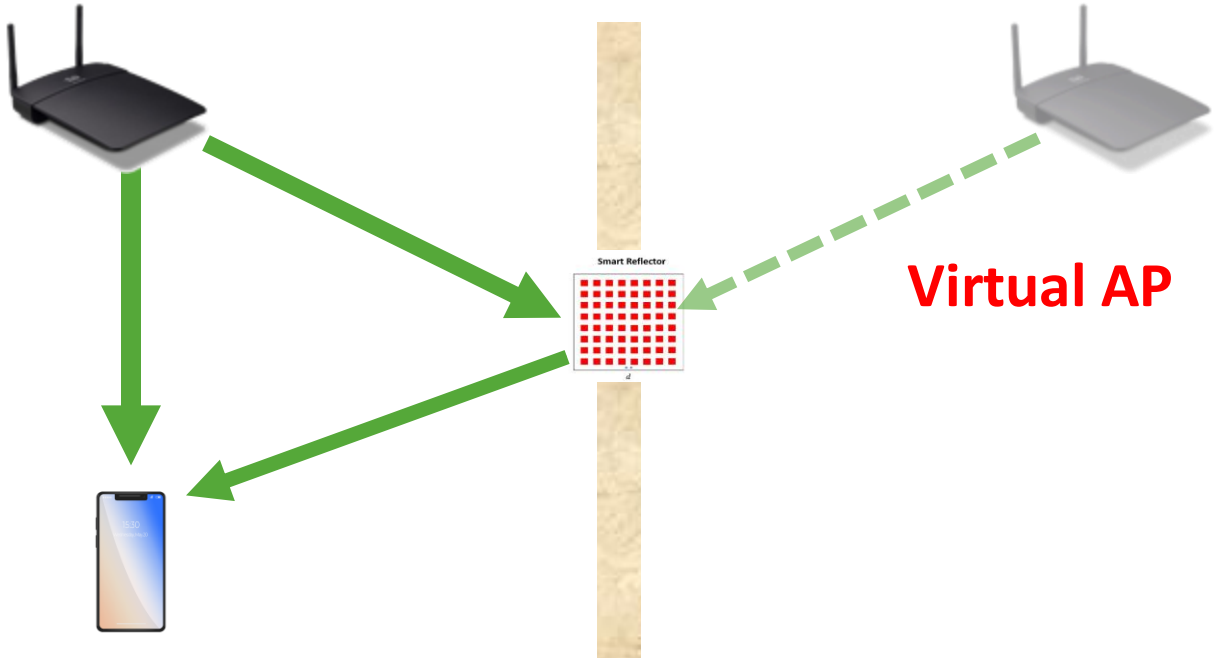
Distributed MIMO



Can we do it passively??

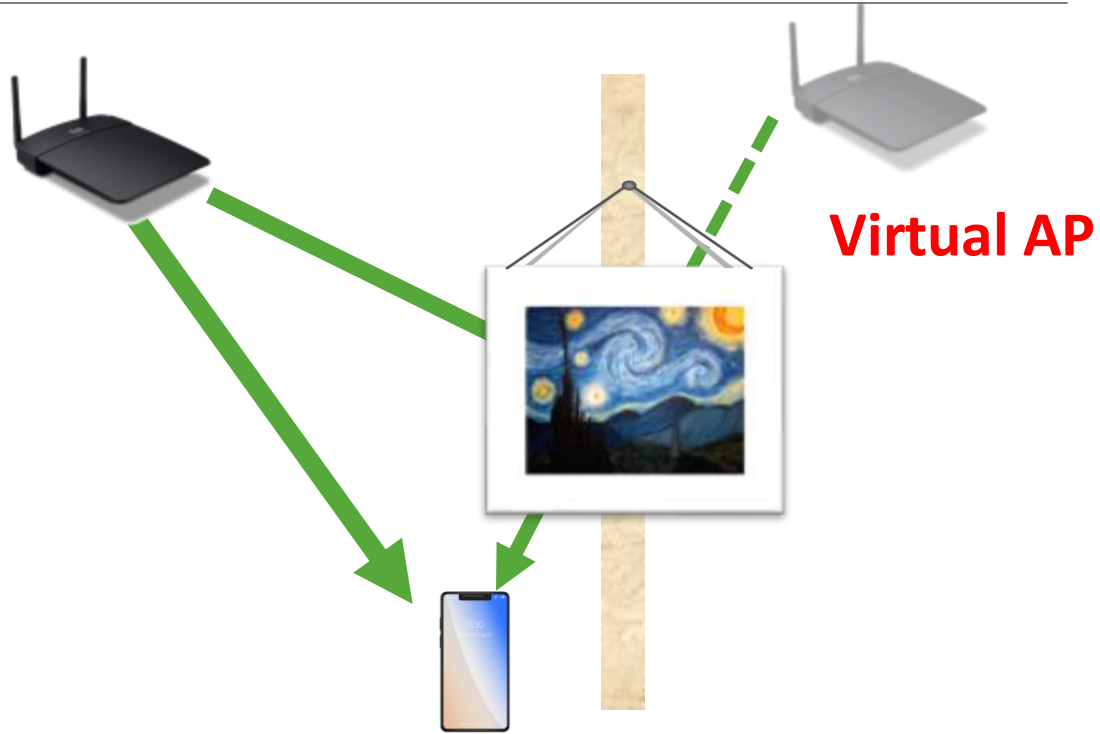
ScatterMIMO: Overview

- Passive
- 2x throughput gain
- 1.5x coverage improvement

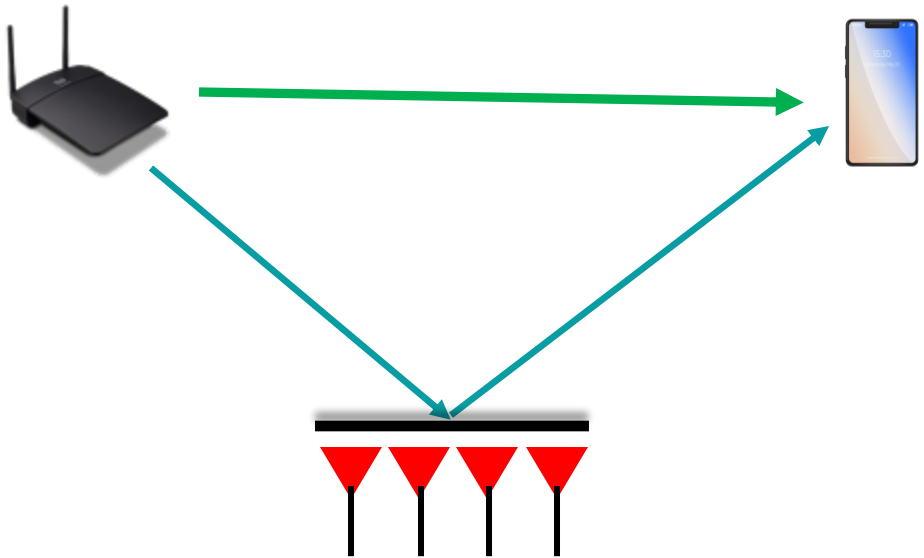


ScatterMIMO: Overview

- Passive
- 2x throughput gain
- 1.5x coverage improvement
- Supports user mobility
- Seamless integration



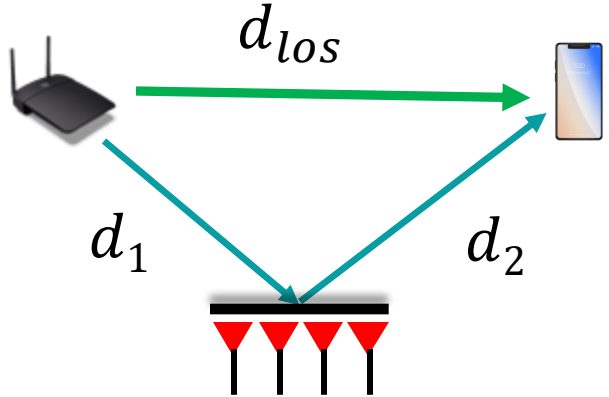
How does the smart surface work?

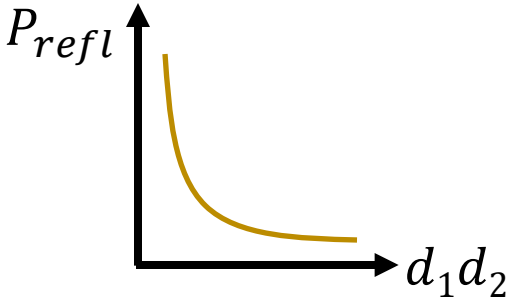


Challenge 1: How to achieve comparable power?

$$P_{los} \propto \frac{1}{(d_{los})^2}$$

$$P_{refl} \propto \frac{1}{(d_1)^2}\ \frac{1}{(d_2)^2}$$

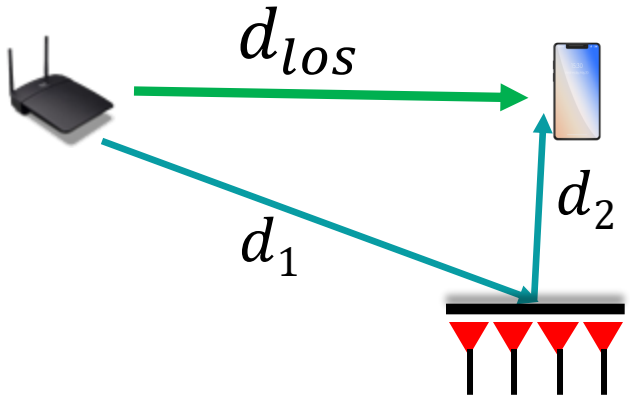




- Minimize the product $d_1 d_2$ (i.e., $d_1 d_2 \to 0$)

Challenge 1: How to achieve comparable power?

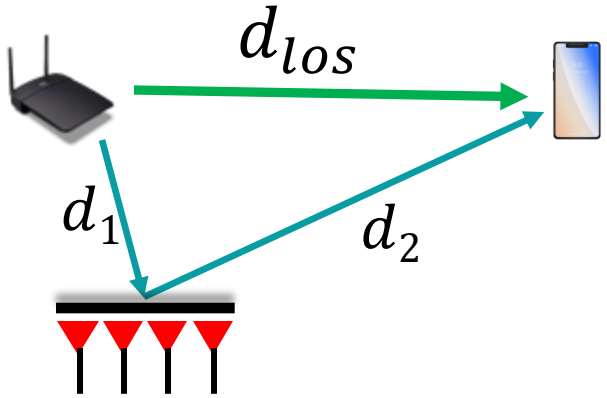
- Make $d_2 \rightarrow 0$
- Keep smart surface close to the user
- But if the user moves, the smart surface must move



Impractical to move smart surface with mobile user

Challenge 1: How to achieve comparable power?

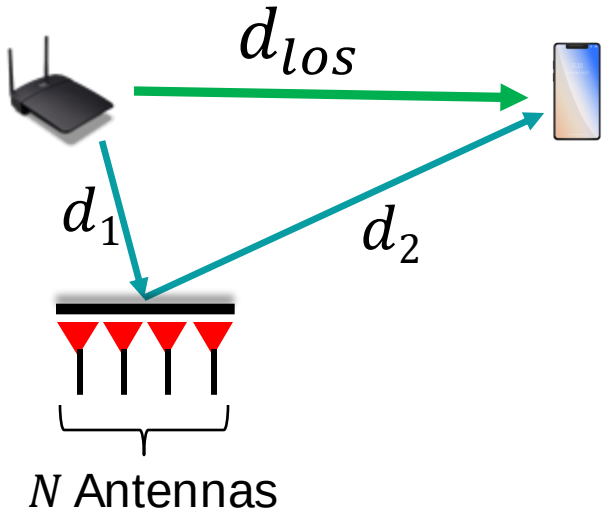
- Make $d_1 \to 0$
- Keep the smart surface close to the access point
- To have good spatial diversity, place the smart surface in the far field.



Challenge 1: How to achieve comparable power?

- For d_1 equal to one wavelength, path loss from AP to the smart surface is 20 dB.

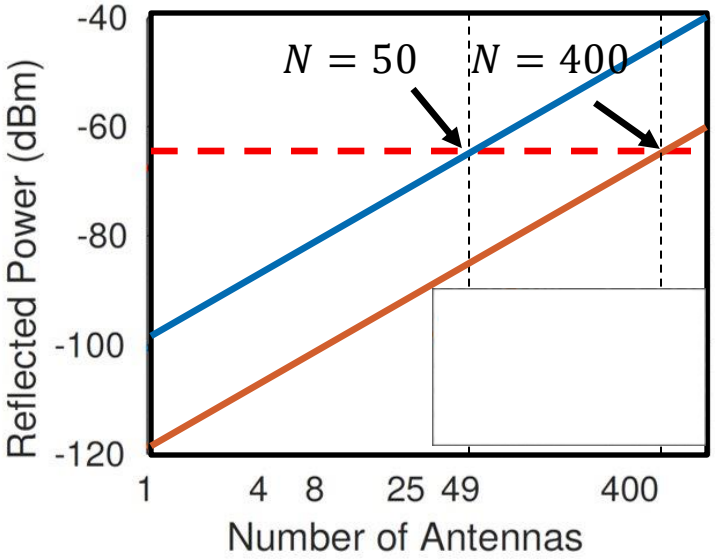
$$P_{refl} \propto \frac{1}{(d_1)^2}\frac{1}{(d_2)^2} \times N^2$$



Challenge 1: How to achieve comparable power?

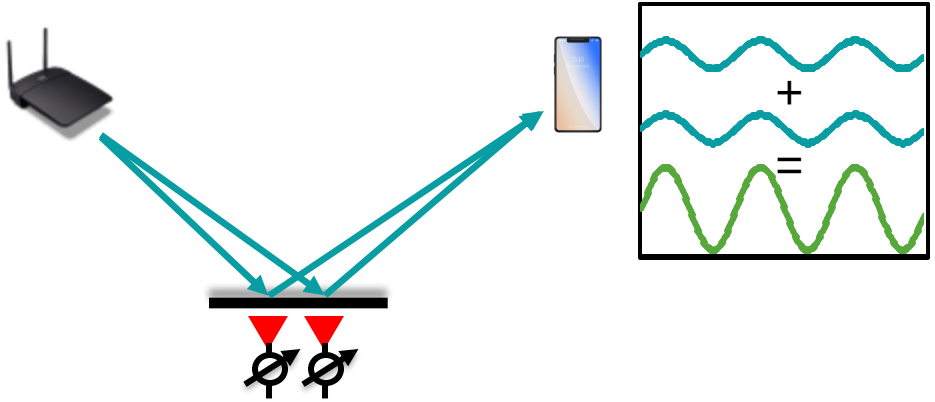
- d_1= 50 cm is in far-field.
- $N = 50$ provides comparable reflected power.

$$P_{refl} \propto \frac{1}{(d_1)^2}\frac{1}{(d_2)^2} \text{ x } N^2$$



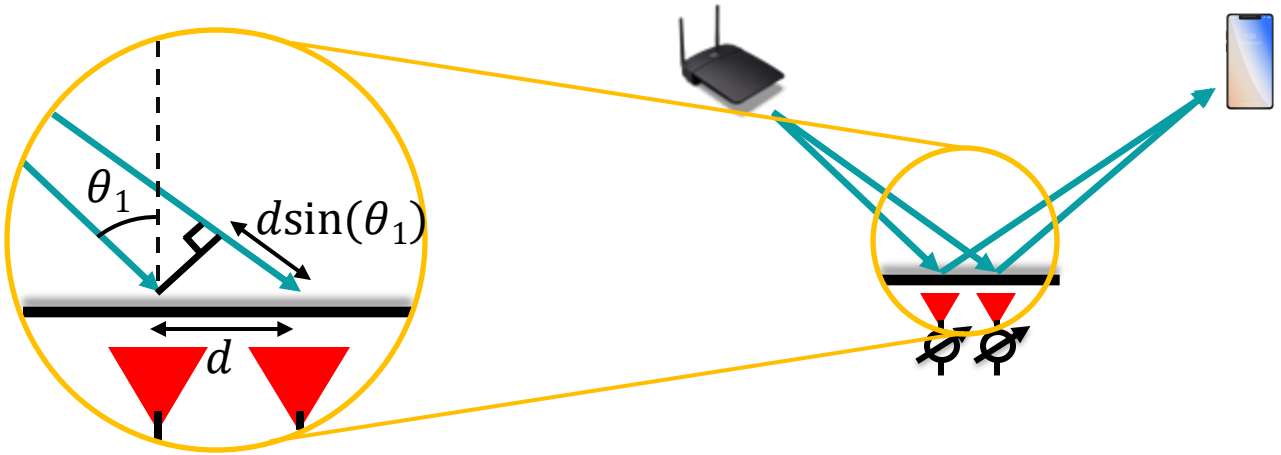
Challenge2: How to constructively combine?

- 50 antennas =>
  4^{50} phase combinations



2-bit phase shifters

Novel approach: Geometric channel model



Novel approach: geometric channel model

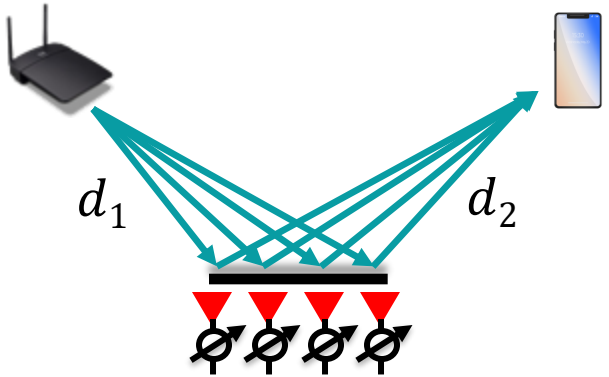
- Path lengths:

$d_1 + d_2$

$d_1 + d_2 + d\sin(\theta_1) - d\sin(\theta_2)$

$d_1 + d_2 + 2d\sin(\theta_1) - 2d\sin(\theta_2)$

$d_1 + d_2 + 3d\sin(\theta_1) - 3d\sin(\theta_2)$



- For n[th] antenna, path length =

$d_1 + d_2 + n(dsin(\theta_1) - dsin(\theta_2))$

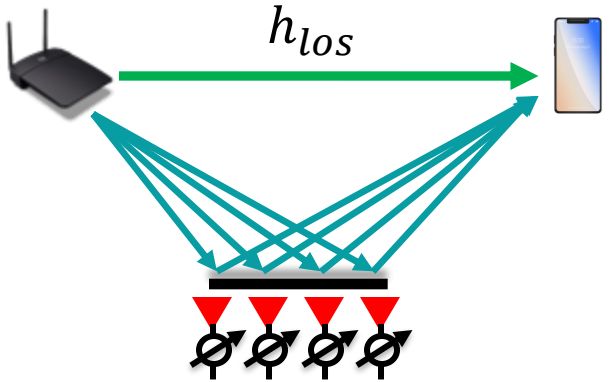
Optimal phase for constructive combining

- Phase difference

$$\alpha = \frac{2\pi}{\lambda}[d\sin(\theta_1) - d\sin(\theta_2)]$$

- Channel response

$$h = h_{los} + h_{refl}\sum_{n=0}^{3} a_n \exp(-jn\alpha)$$



Finding α in 3 easy steps

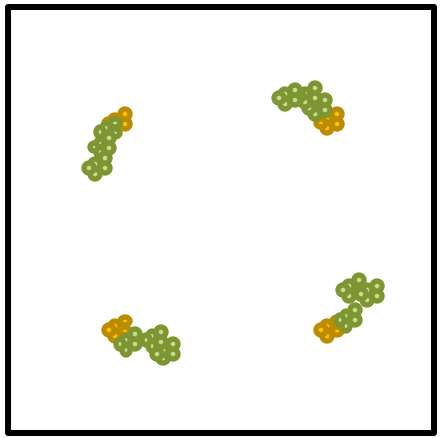
	Applied Phases	Channel Response
1.	$[1 \quad 1 \quad 1 \quad 1]$	$h_1 = h_{los} + h_{refl}\left(1 + e^{-j\alpha} + e^{-2j\alpha} + e^{-3j\alpha}\right)$
2.	$[1 \quad -1 \quad 1 \quad -1]$	$h_2 = h_{los} + h_{refl}\left(1 - e^{-j\alpha} + e^{-2j\alpha} - e^{-3j\alpha}\right)$
3.	$[-1 \quad 1 \quad -1 \quad 1]$	$h_3 = h_{los} + h_{refl}\left(-1 + e^{-j\alpha} - e^{-2j\alpha} + e^{-3j\alpha}\right)$

$$(h_1 - h_3)\overline{(h_1 - h_2)} = 4e^{j\alpha}\left|1 + e^{-2j\alpha}\right|^2\left|h_{refl}\right|^2$$

- Just 3 CSI measurements sufficient to optimize the surface.

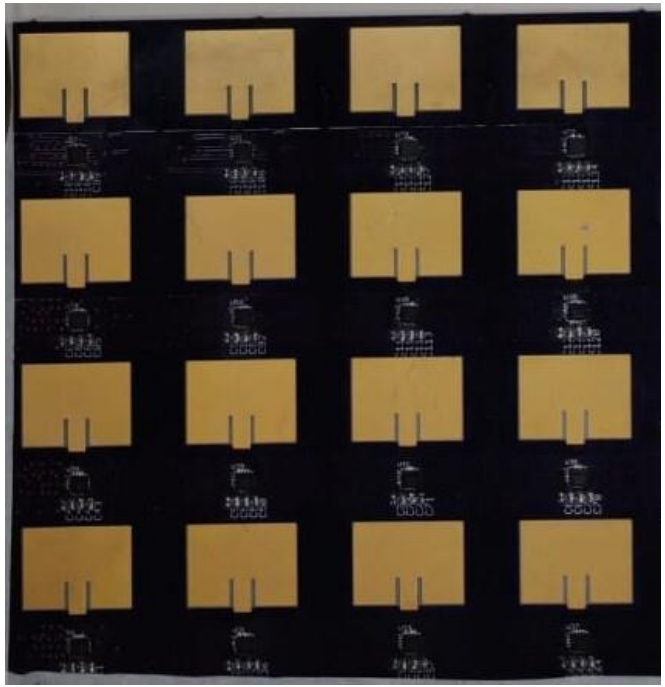
Challenge 3: Working with off-the-shelf devices

COTS device



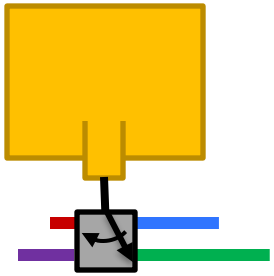
- ScatterMIMO requires only one additional channel measurement to solve for hardware impairments

Smart surface implementation



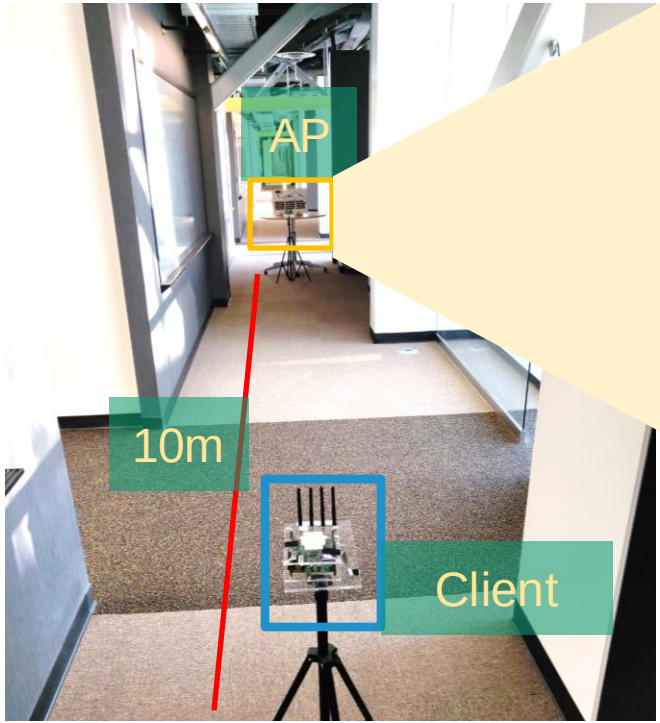
4 x 4 scatterMIMO tile

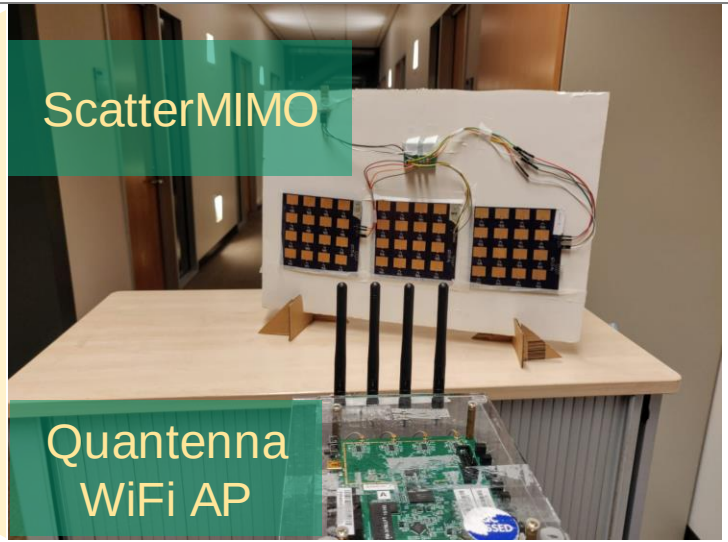
- Array of 5 GHz patch antennas on a PCB.



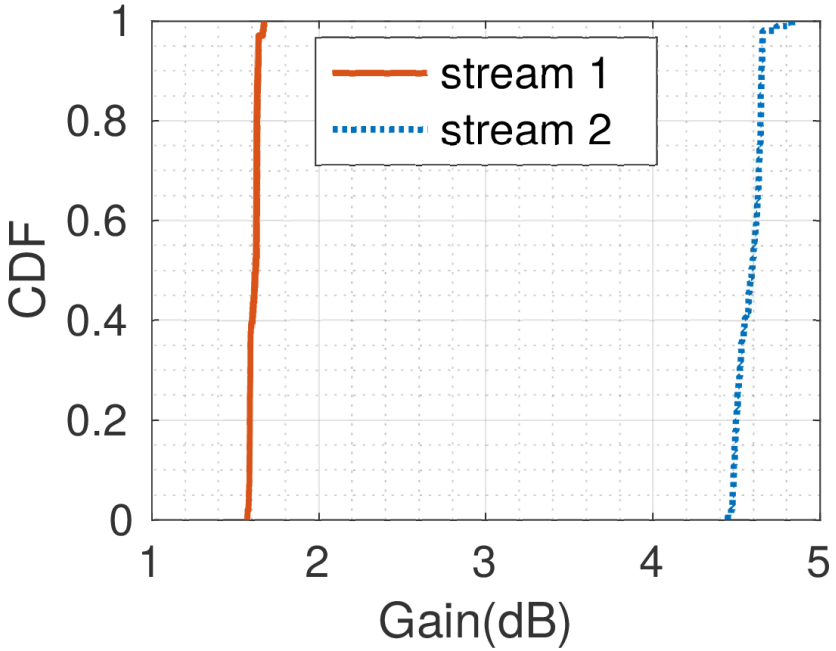
- 2-bit phase shifter – 4:1 RF switch to select one of the $0^{\circ}, 90^{\circ}, 180^{\circ}, 270^{\circ}$ transmission lines.
- Smart surface costs less than $5

Experimental Setup



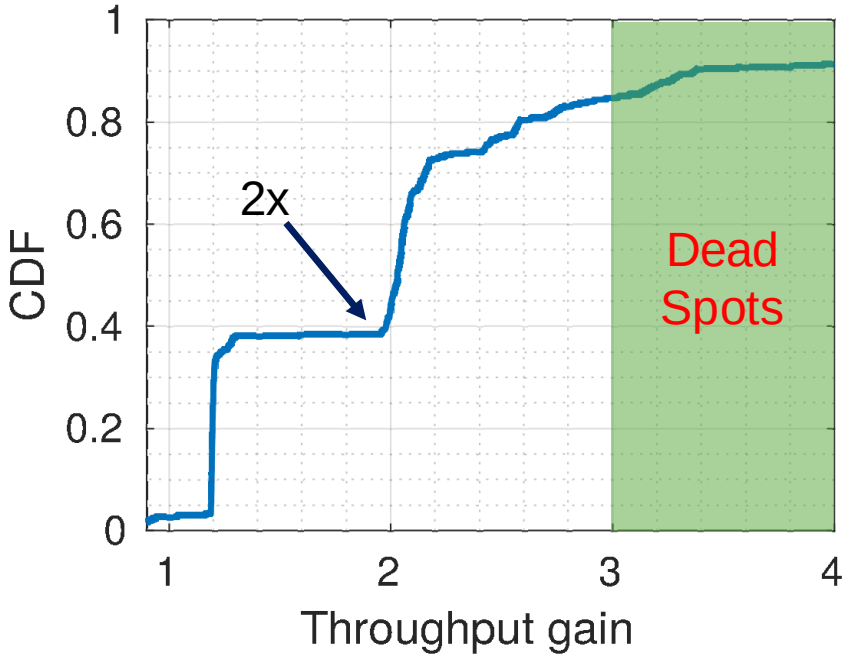


SNR improvement of spatial streams



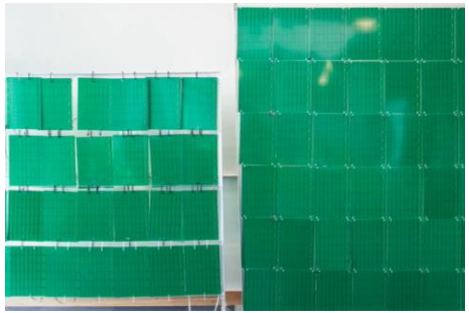
- Improves signal power of both primary and secondary streams
- Secondary stream's SNR improved by **4.5 dB**

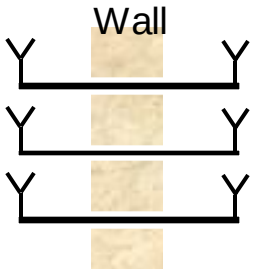
Throughput Improvement over baseline

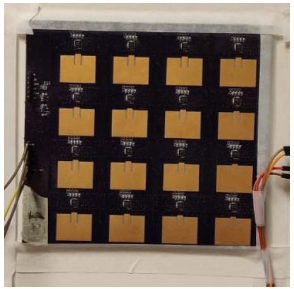


Related Work

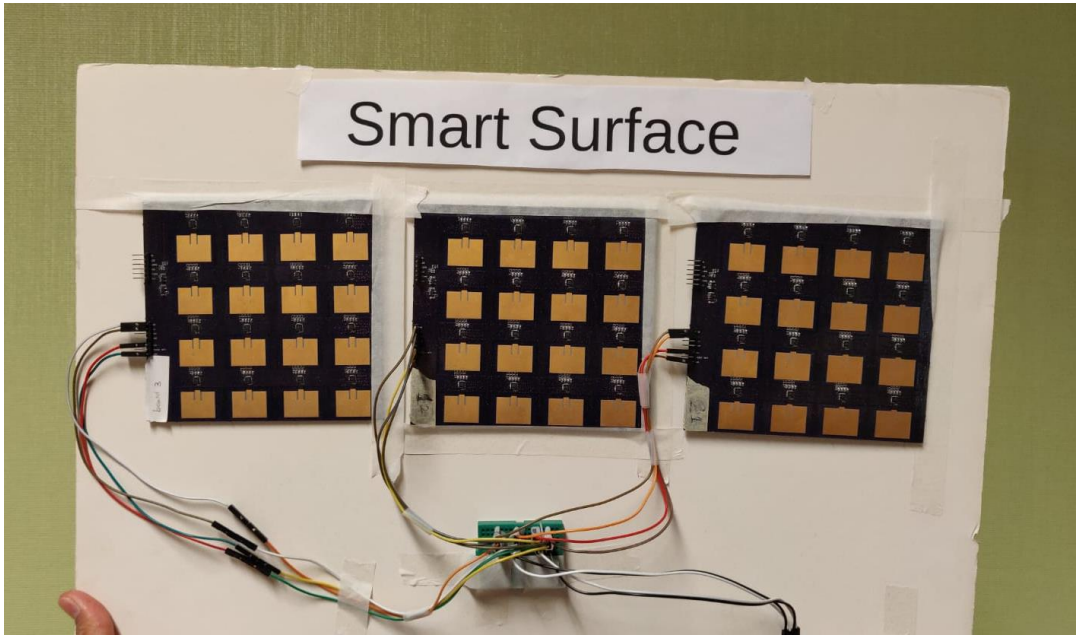
	Rfocus [NSDI'20]	LAIA [NSDI'19]	ScatterMIMO
#Antenna elements	3720	36	**48**
Algorithm Latency	4000 packets	72 packets	**4 packets**
Coverage	30 m	8 m	**45 m**







Thanks for listening



https://wcsng.ucsd.edu/scattermimo/