Fundamentals of Intelligent Reflecting Surfaces

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Massive MIMO is a Reality

Sprint deployed 1000 sites in 2019

- 64-antenna TDD active arrays
- Compact arrays (2.5 GHz band)

Improves sum rates with 4-20x

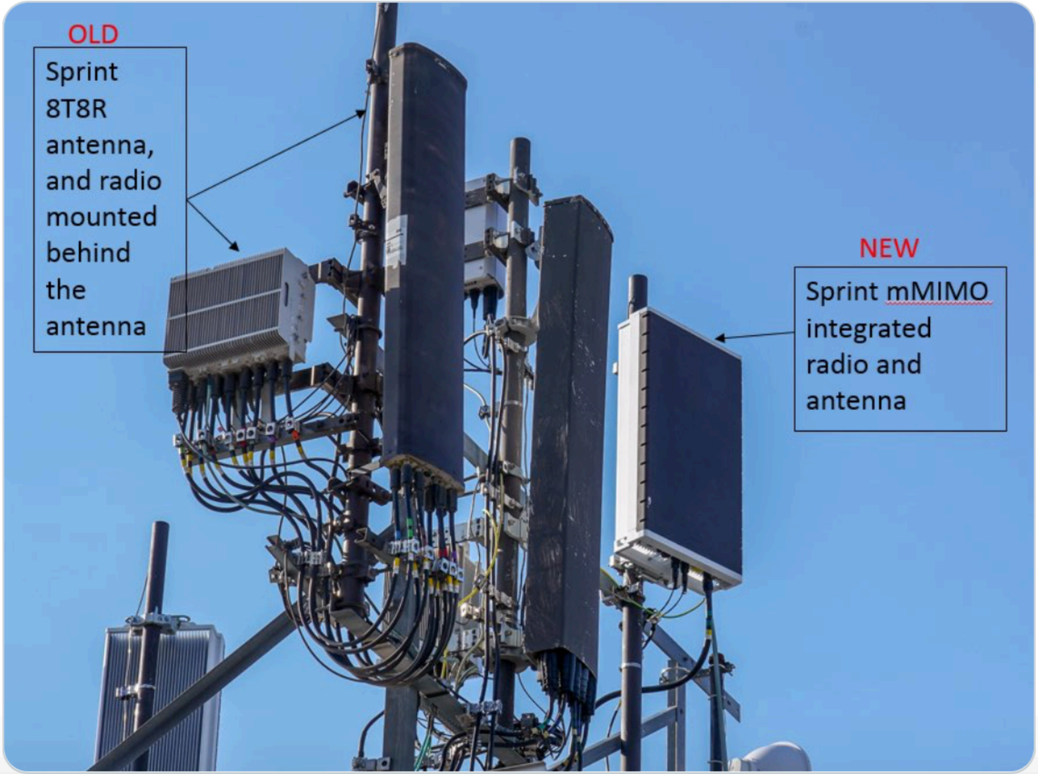
What is next? Larger arrays!

1) Metasurfaces
(Intelligent reflecting surface)

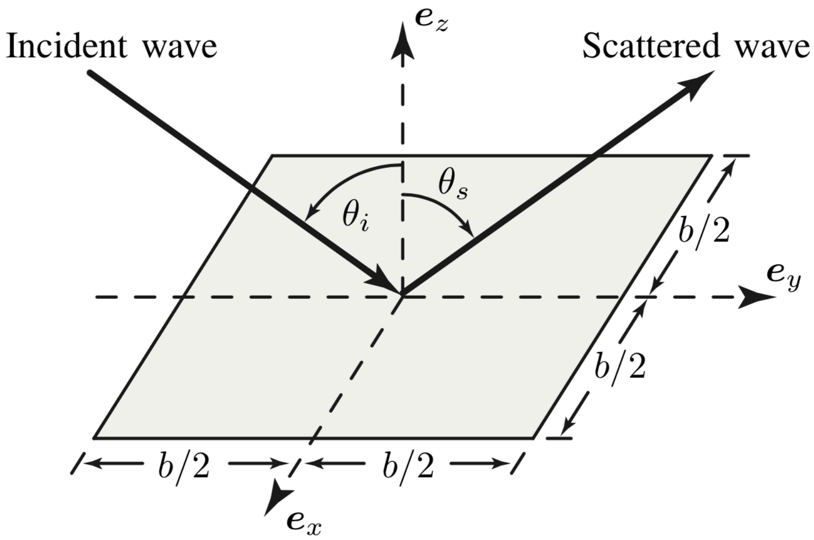
2) Holographic beamforming

John Saw
@SprintCTO

Sprint Massive MIMO unit Vs legacy 8T8R antenna+RRH +coax cables



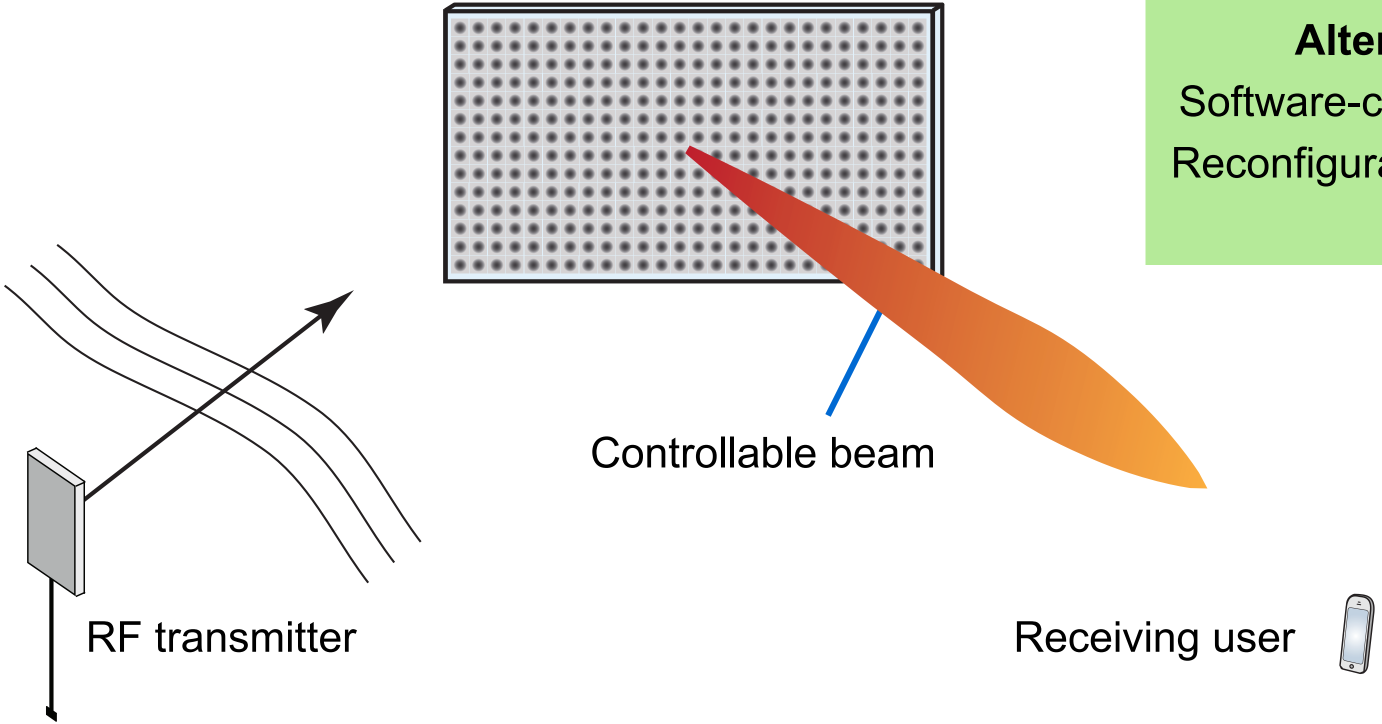
What is a Reflecting Surface?



Snell's law:

Scattered wave strongest for $\theta_i = \theta_r$

Intelligent Reflecting Surface



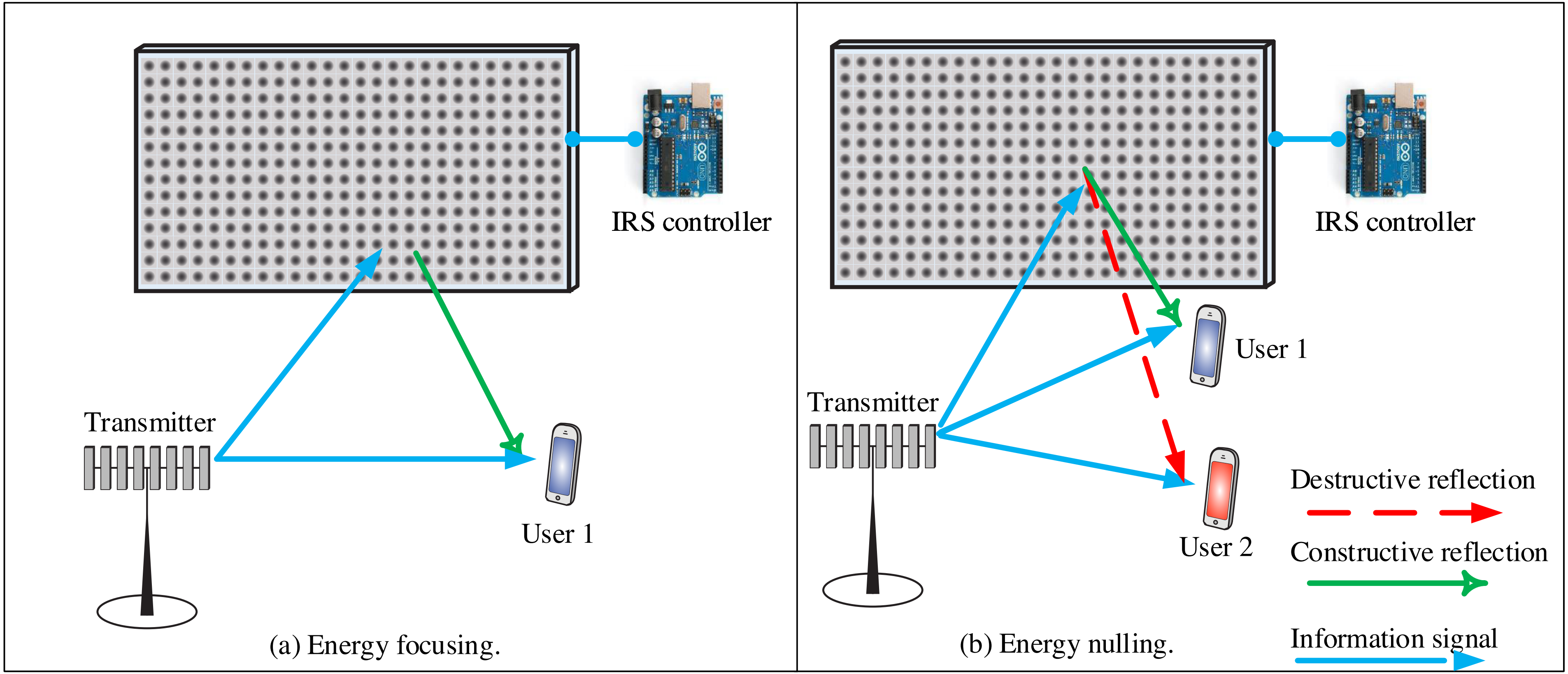
Alternative names:

Software-controlled metasurface

Reconfigurable intelligent surface

…

Two Prospective Use Cases



Origin: Reflectarray Antennas

IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 45, NO. 2, FEBRUARY 1997 287

Design of Millimeter Wave Microstrip Reflectarrays

David M. Pozar, *Fellow, IEEE*, Stephen D. Targonski, and H. D. Syrigos, *Senior Member, IEEE*

AS its name implies, a reflectarray antenna combines some of the best features of reflector and array antennas. In its basic form, a microstrip reflectarray consists of a flat array of microstrip patches or dipoles printed on a thin dielectric substrate. A feed antenna illuminates the array whose individual elements are designed to scatter the incident field with the proper phase required to form a planar phase surface in front of the aperture, as suggested in Fig. 1. This operation is similar in concept to a parabolic reflector that naturally forms a planar phase front when a feed is placed at its focus, thus, the term *flat reflector* is sometimes used to describe the reflectarray.

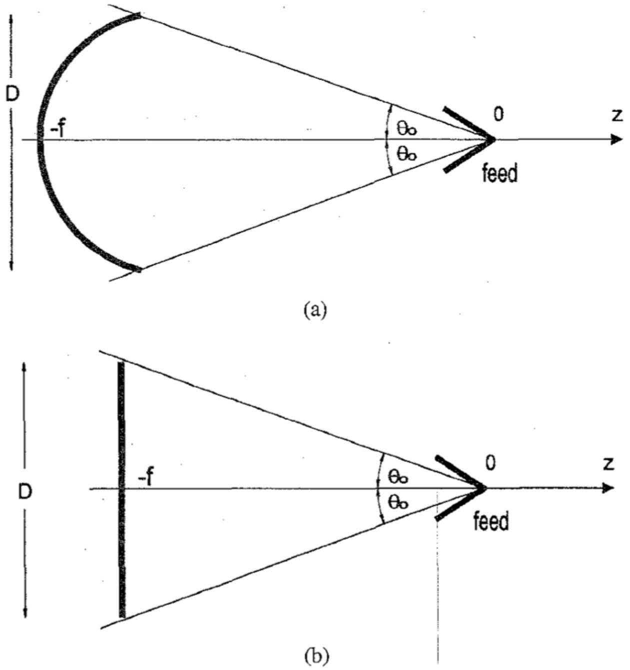
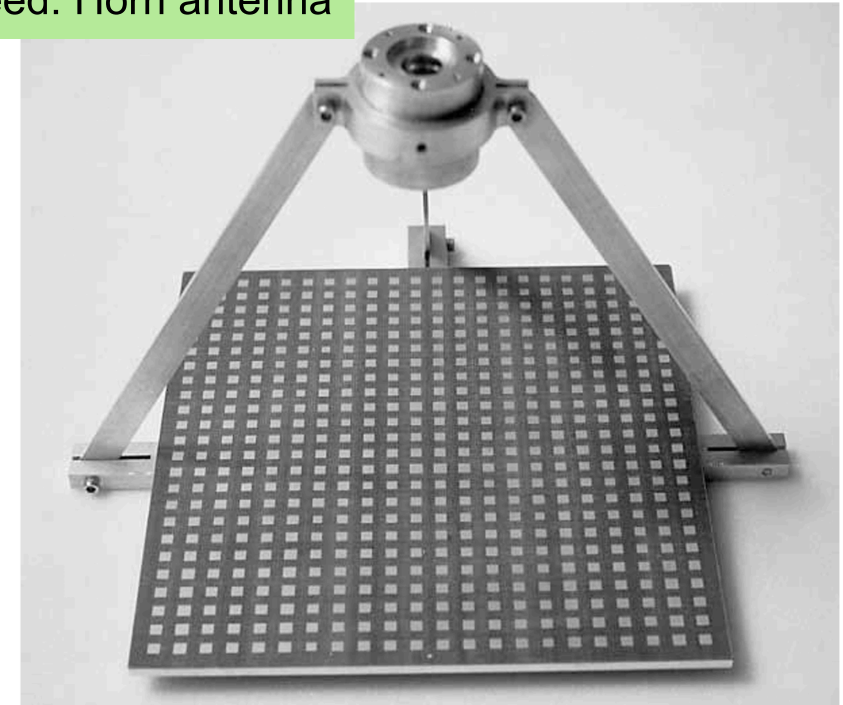


Fig. 2. Subtended angles of (a) a prime focus parabolic reflector and (b) a reflectarray.

Experimental setup

Feed: Horn antenna



Photograph of a 6-inch reflectarray with an operating frequency of 28 GHz.

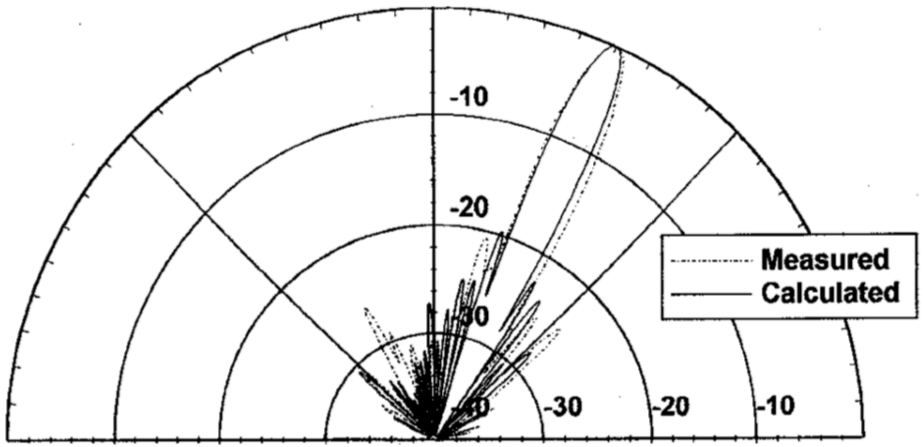
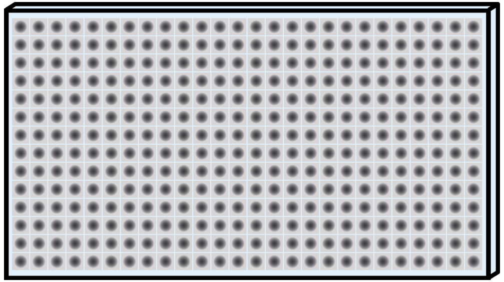


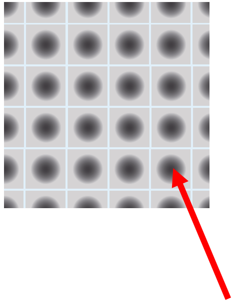
Fig. 8. Measured and calculated E-plane patterns for the 28 GHz 6″-square reflectarray.

22 x 24 = 528 element (~27 dB array gain)

Reflection in a *wide meaning*

Today: Metasurface

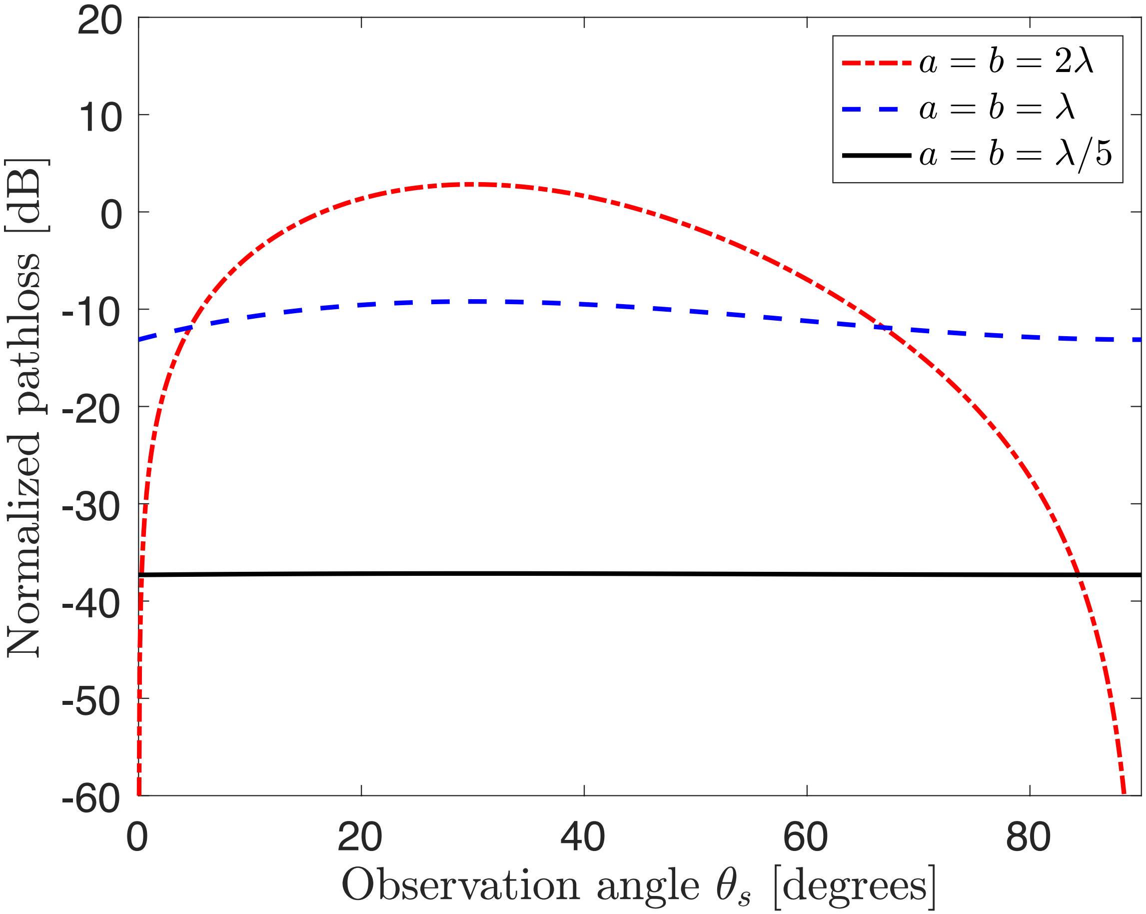




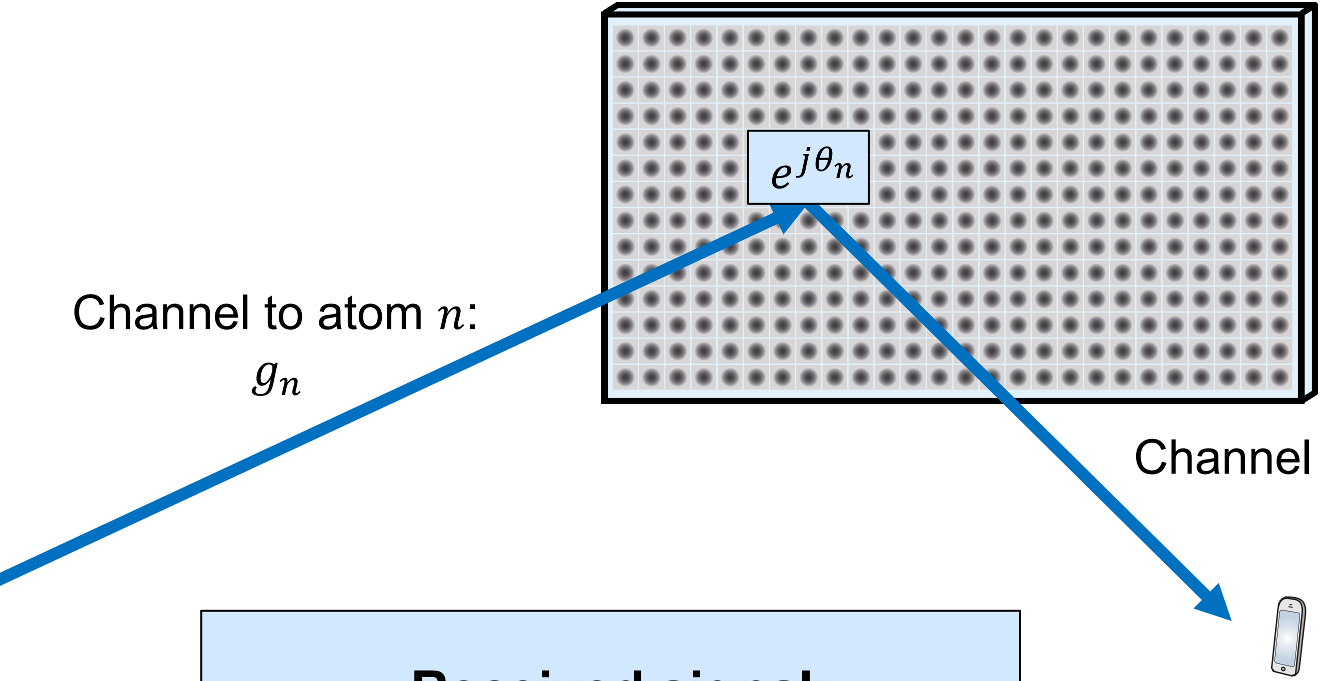
“Meta-atom”

Sub-λ-sized

Scatters incoming wave with controllable delay/phase, polarization



Communication System Model

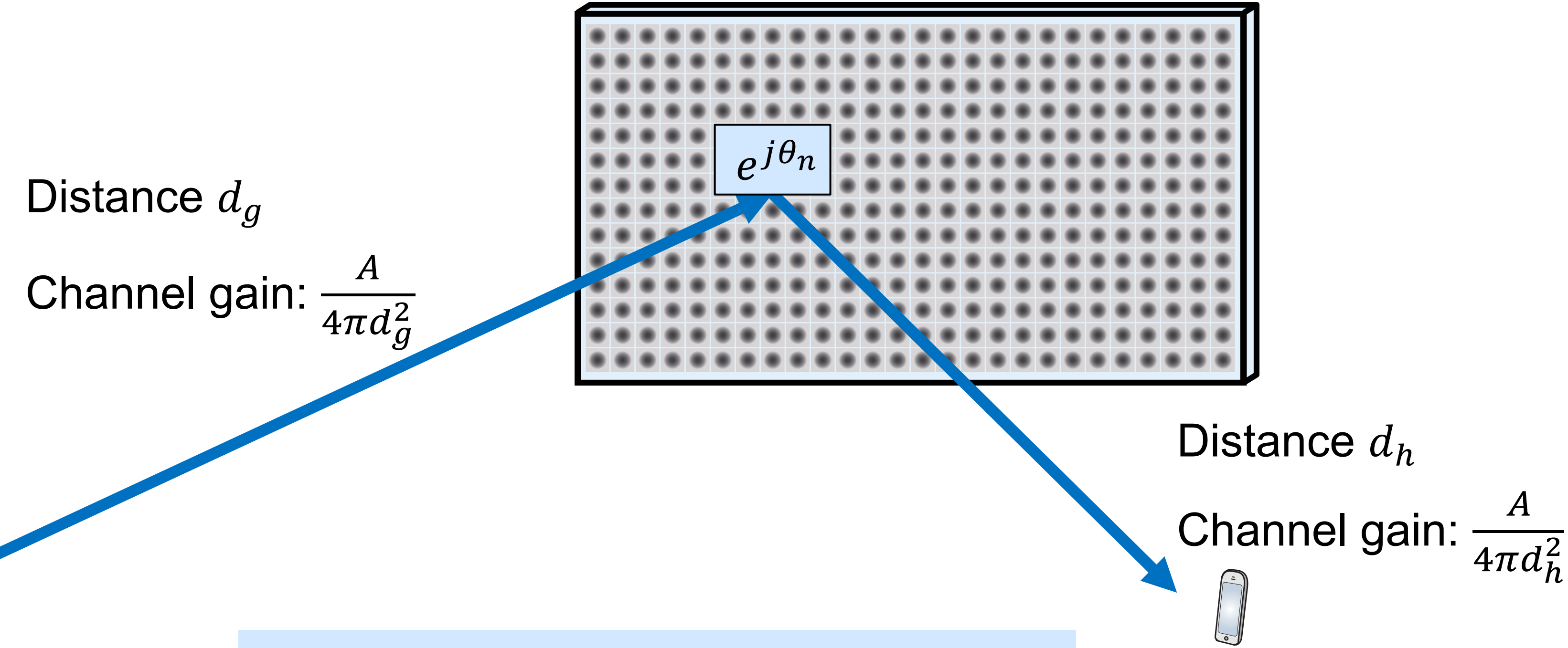


Received signal:

$$y = \sum_{n=1}^{N} g_n e^{j\theta_n} h_n \cdot \text{signal} + \text{noise}$$

End-to-end channel
$g_n e^{j\theta_n} h_n$

Channel Gain With Line-of-Sight to IRS



End-to-end channel gain:

$$\left|g_n e^{j\theta_n} h_n\right|^2 = |g_n|^2 |h_n|^2 = \frac{A^2}{\left(4\pi d_g d_h\right)^2}$$

Optimizing the Phase Shifts: Coherent Beamforming

Received signal:

$$y = \sum_{n=1}^{N} g_n e^{j\theta_n} h_n \cdot \text{signal} + \text{noise}$$

Channel gain:

$$\left| \sum_{n=1}^{N} g_n e^{j\theta_n} h_n \right|^2 \leq \left| \sum_{n=1}^{N} |g_n||h_n| \right|^2$$

Equality for $\theta_n = -\arg(g_n) - \arg(h_n)$

Less trivial optimization:

Multiple antennas

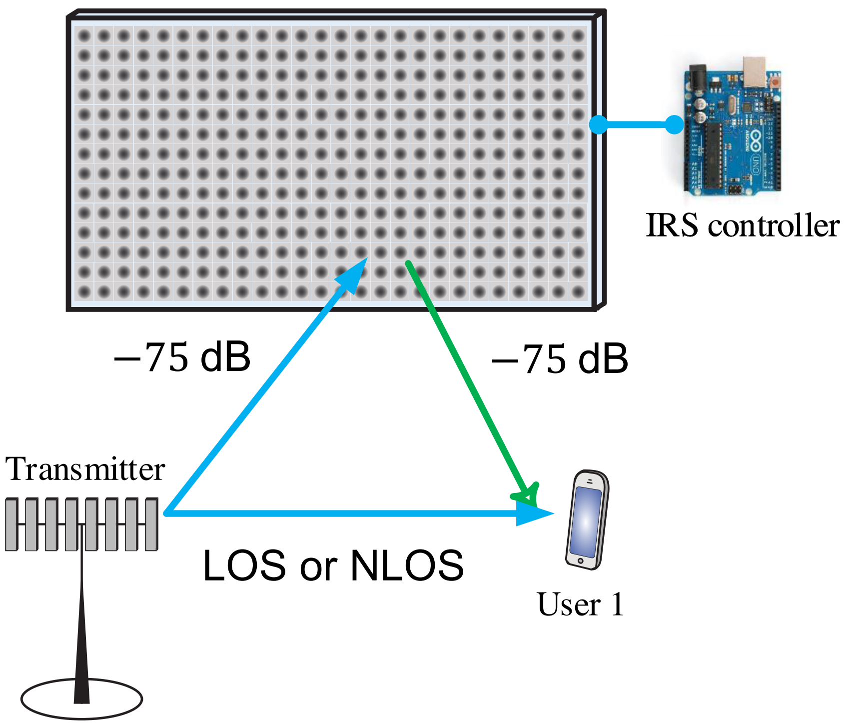
Multiple devices

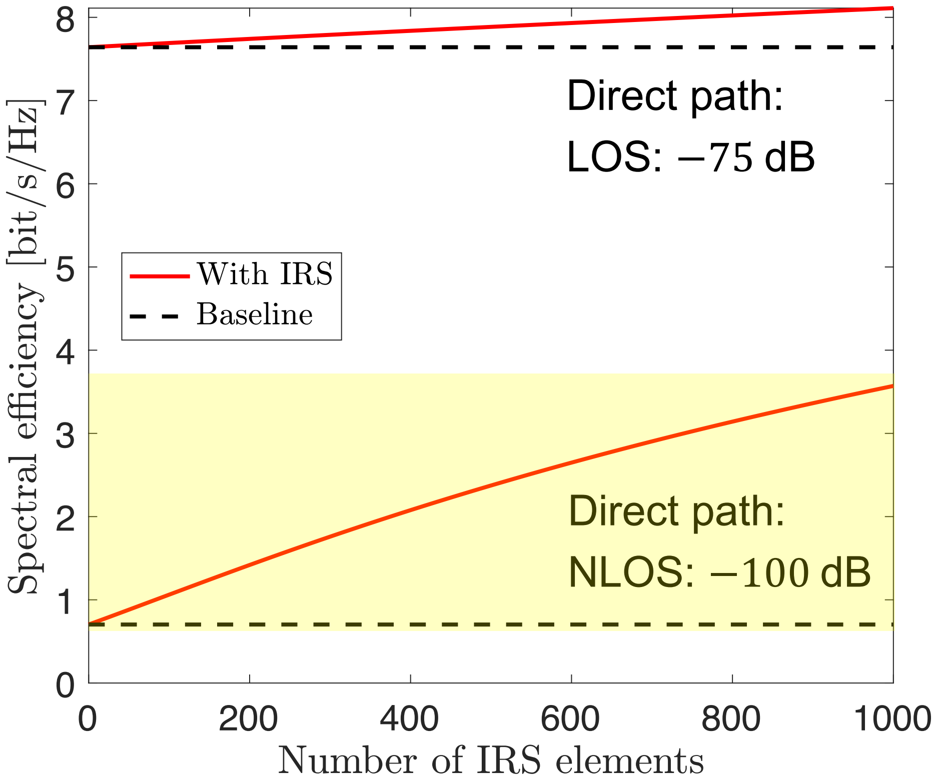
…

Continuing the previous example:

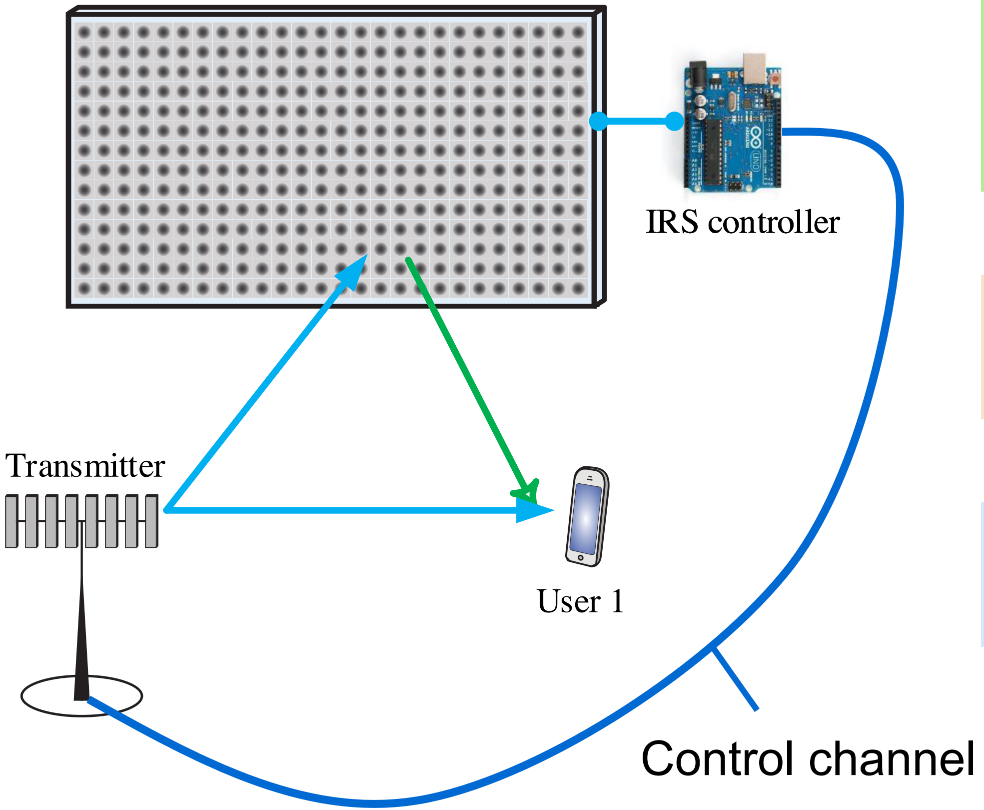
$$\left| \sum_{n=1}^{N} |g_n||h_n| \right|^2 = \left| N \frac{A}{4\pi d_g d_h} \right|^2 = N^2 \frac{A^2}{(4\pi d_g d_h)^2}$$

Simulation Example: Signal Focusing





How to Learn the Channel?



Send pilot signals via IRS?

Change the IRS simultaneously to achieve more information

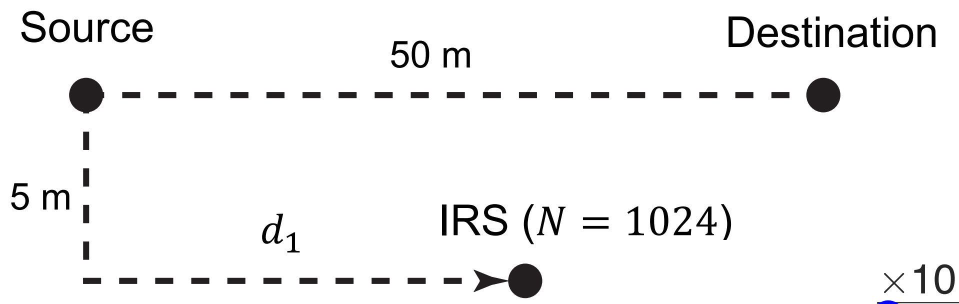
Use parameteric models?

Estimate position or angle to the user

Have a few active elements in the IRS?

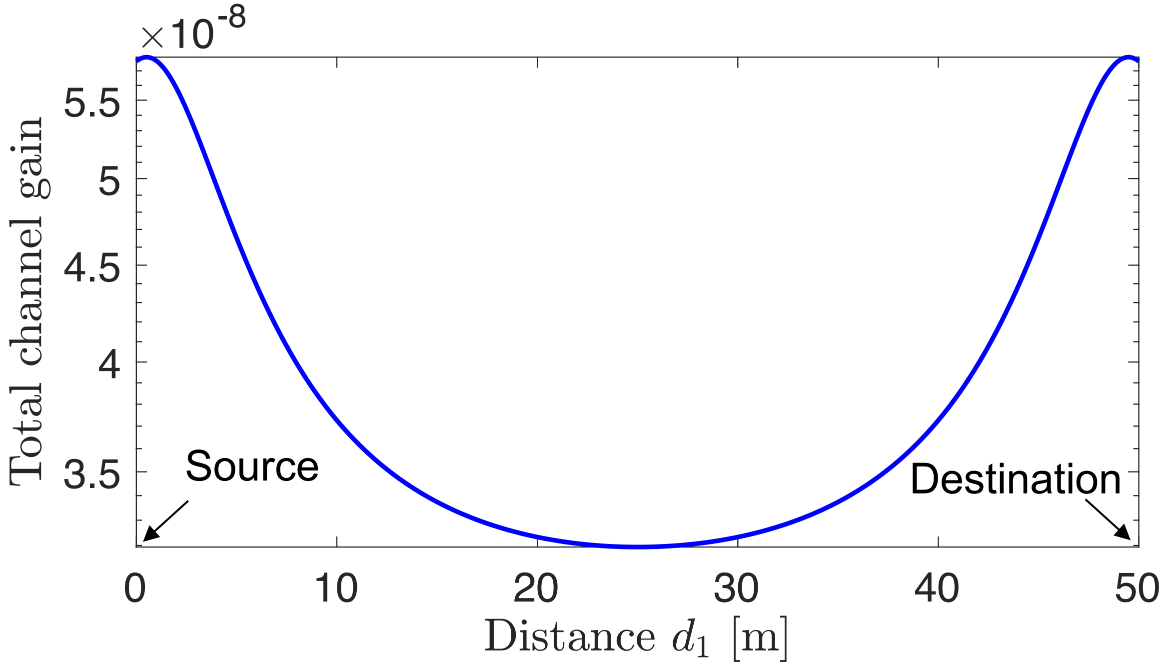
Anyway convenient for control channel

Where Shall We Place the Metasurface?



Preferred choice:
Close to source or destination

What if they are co-located?



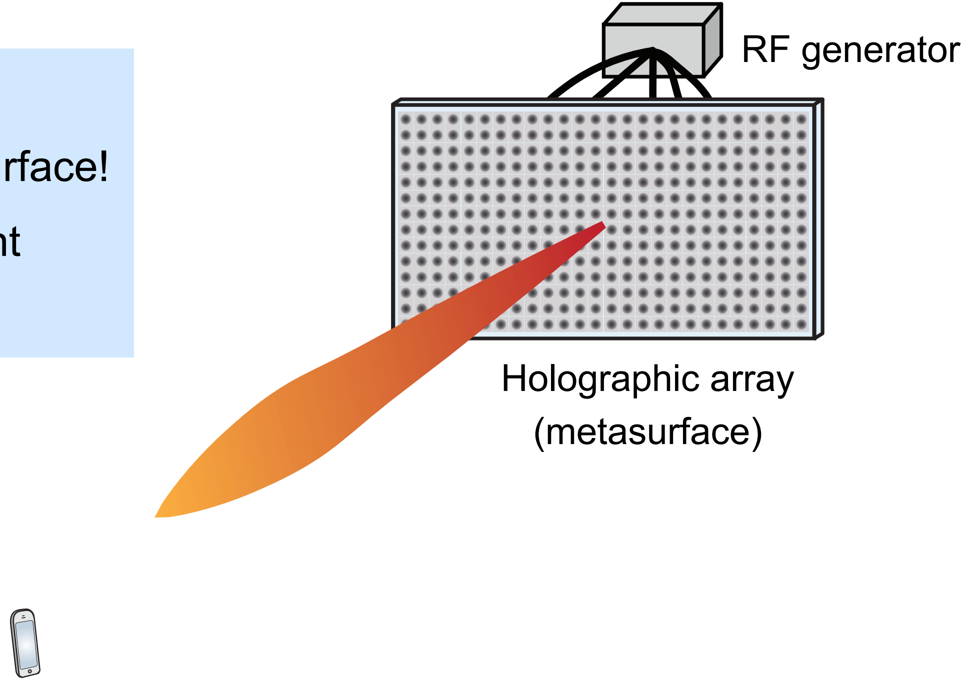
Holographic Beamforming

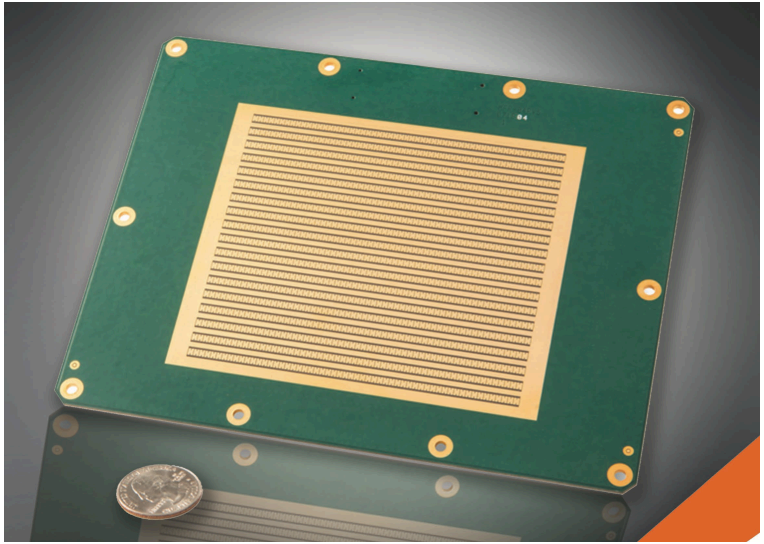
Metasurface with built-in source

No pathloss between RF generator and surface!

Thin form factor – invisible deployment

Ideally a contiguous surface





PIVOTAL
COMMWARE

28 GHz, Small array,
one RF chain

Do You Want to Learn More?