Communication Using Reconfigurable Intelligent Surfaces

Fundamentals and Recent Insights

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Imagine a world full of mirrors…

RIS =

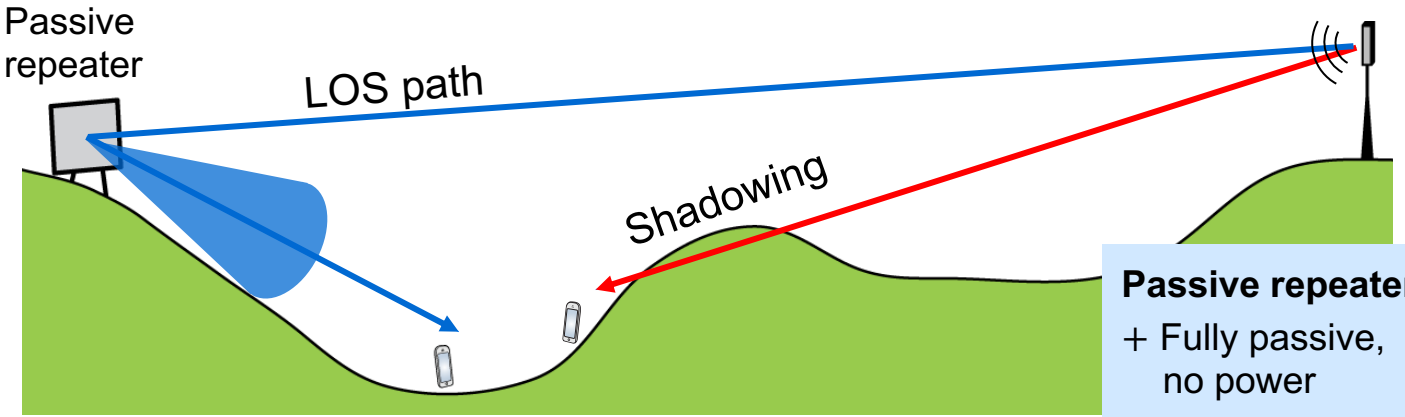
Reconfigurable: Changeable properties

Intelligent: Real-time controllable

Surface: Two-dimensional array

Photo: Myrabella, Wikimedia Commons

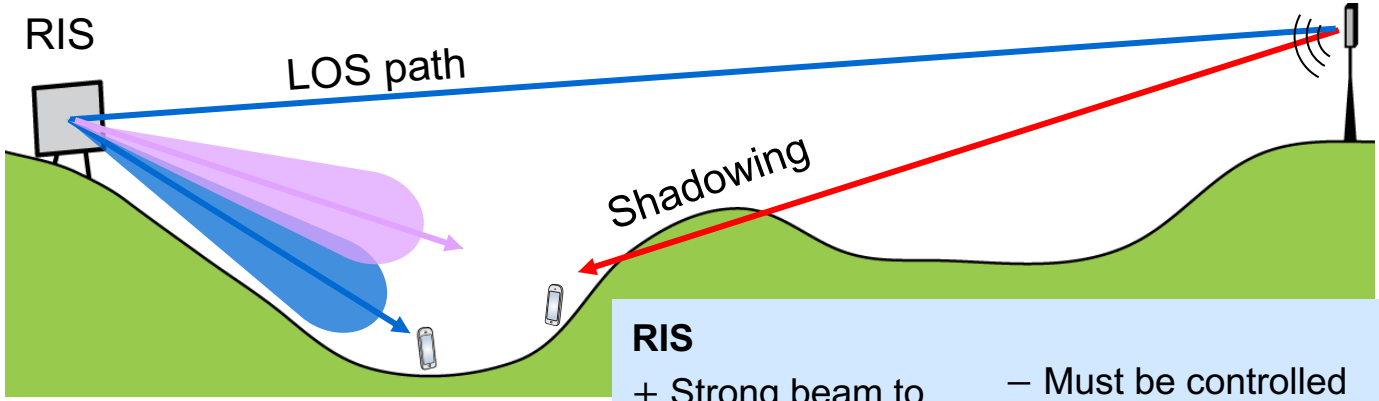
Passive Repeaters & Reconfigurable Intelligent Surfaces (RIS)



Passive repeater

+ Fully passive, no power

– Fixed beam pattern: wide or strong?



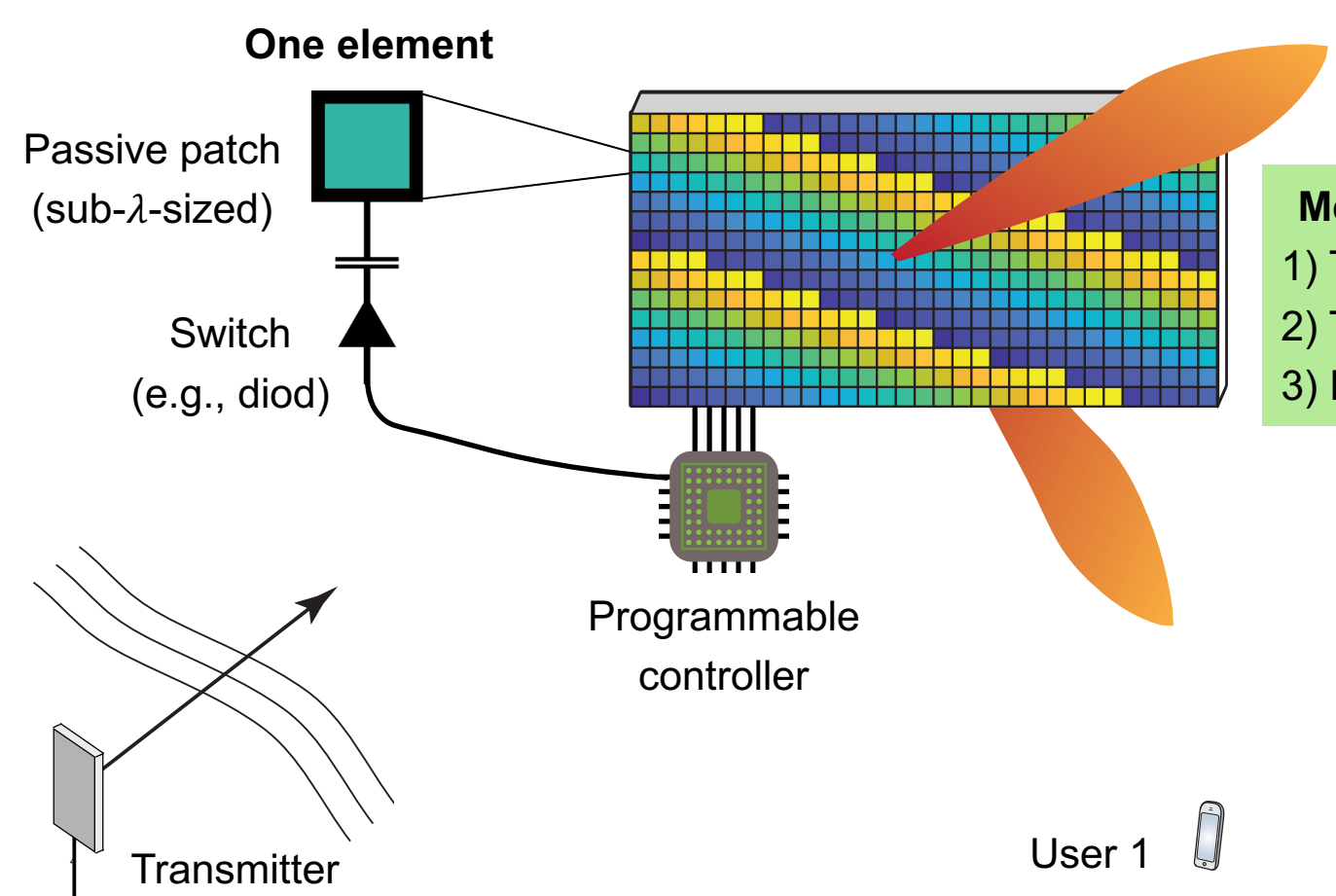
RIS

+ Strong beam to desired location

– Must be controlled

– Requires power

RIS Operation in a Nutshell



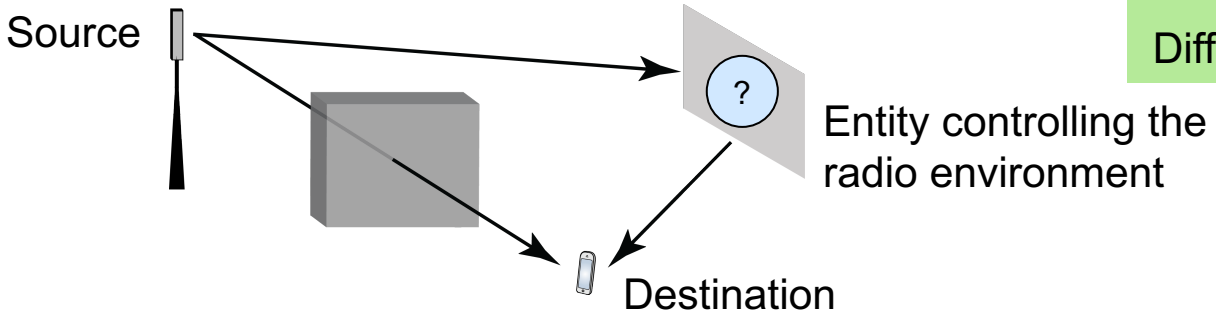
Means of reconfigurability

1) Tuning impedances
2) Tuning length of delay lines
3) Phase-shifters

Taxonomy of “Cooperative Communications”

Not one or the other!

Different choice in different setups



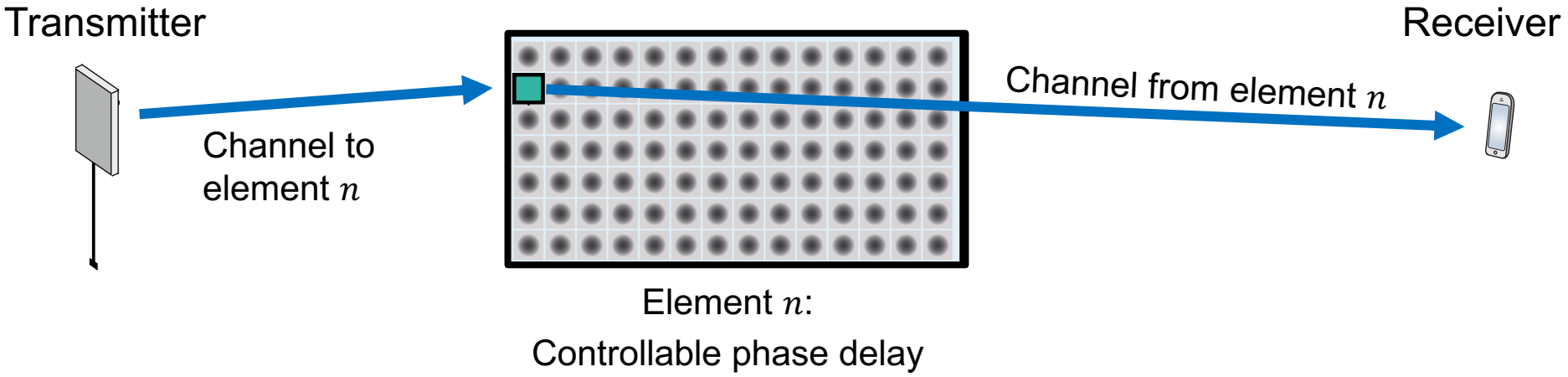
Used in cellular networks

Old-school analog repeater

	Regenerative	Transparent
Half duplex	Decode-and-forward (DF) relay	Amplify-and-forward (AF) relay
Full duplex	**AF and DF relay**	Passive repeater, **RIS**

Emerging technologies

Phase-Shift Optimization

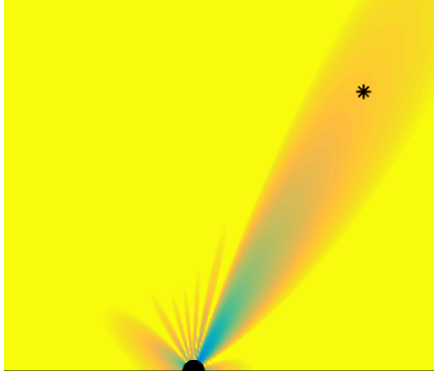


- Received signal:

$$\sum_{n=1}^{N} [\text{Signal via element } n] + \text{Noise}$$

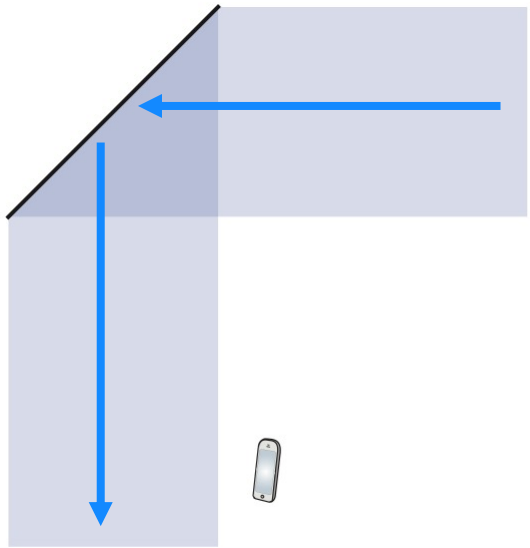
Controllable properties:

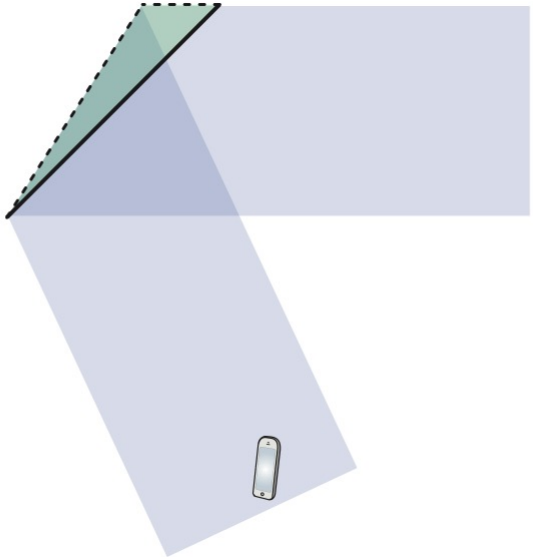
Adapt to channels

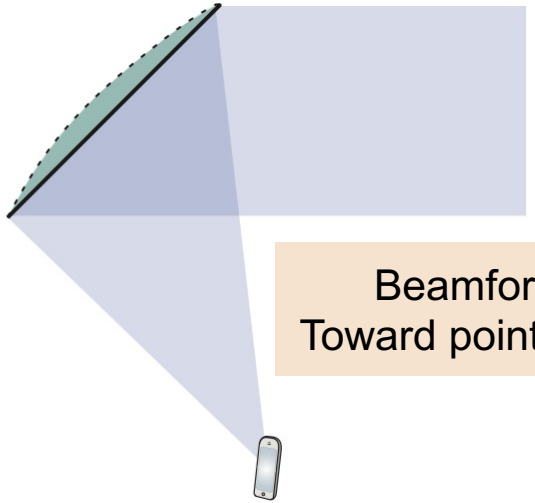


Example: Synthesizing Surface Shapes

3: Signal focusing
(closer than infinity)







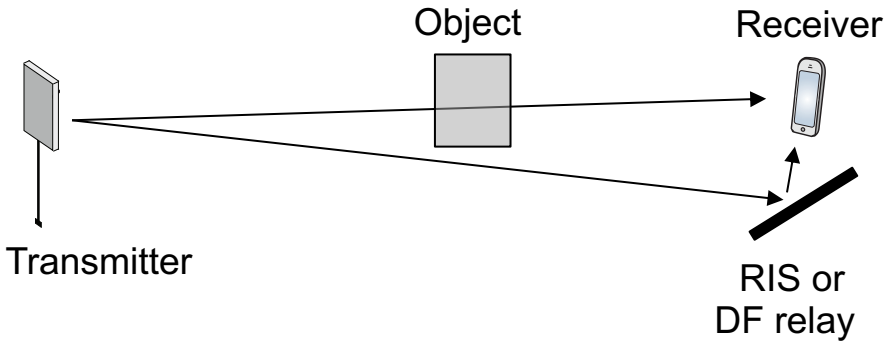
Beamforming:
Toward point/direction

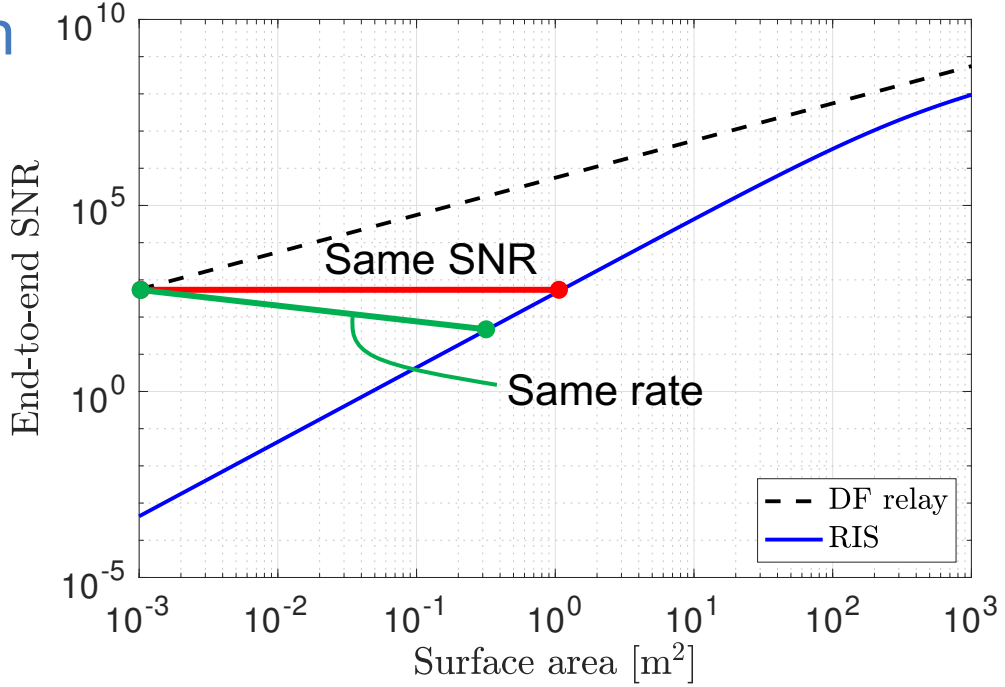
1: Normal reflection

2: Anamolous reflection
(focus at infinity)

Varying phase delay profile
along the surface

Use Case: SNR Maximization



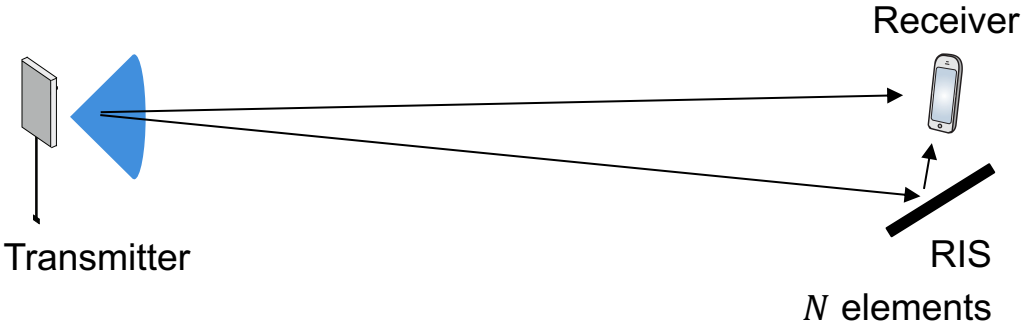


Large surfaces are needed
to beat an elementary DF relay

Reference:

[R1] Ö. Özdogan, E. Björnson, E. G. Larsson, "Reconfigurable Intelligent Surfaces: Three Myths and Two Critical Questions"

Improving Channel Properties

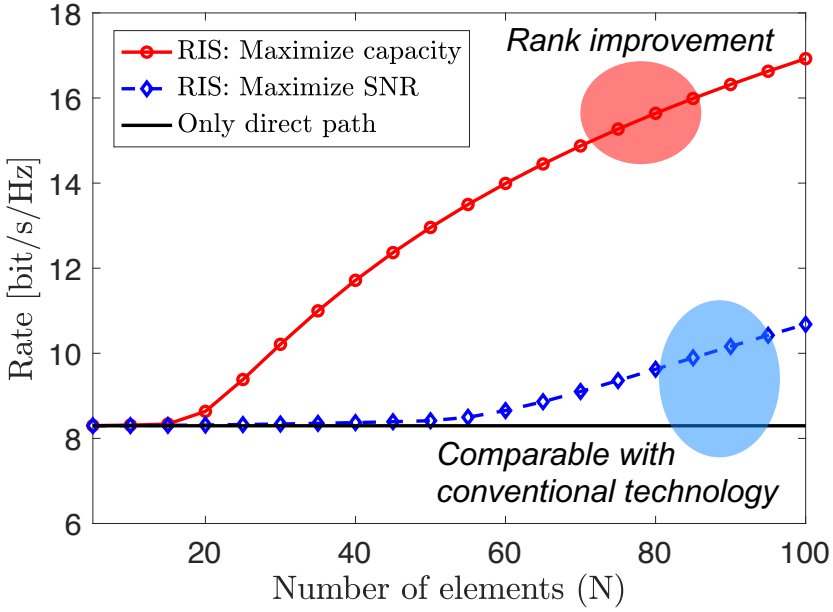


Two antennas at each device

Line-of-sight channels: Rank 1

Improve propagation conditions

More than just SNR gain!

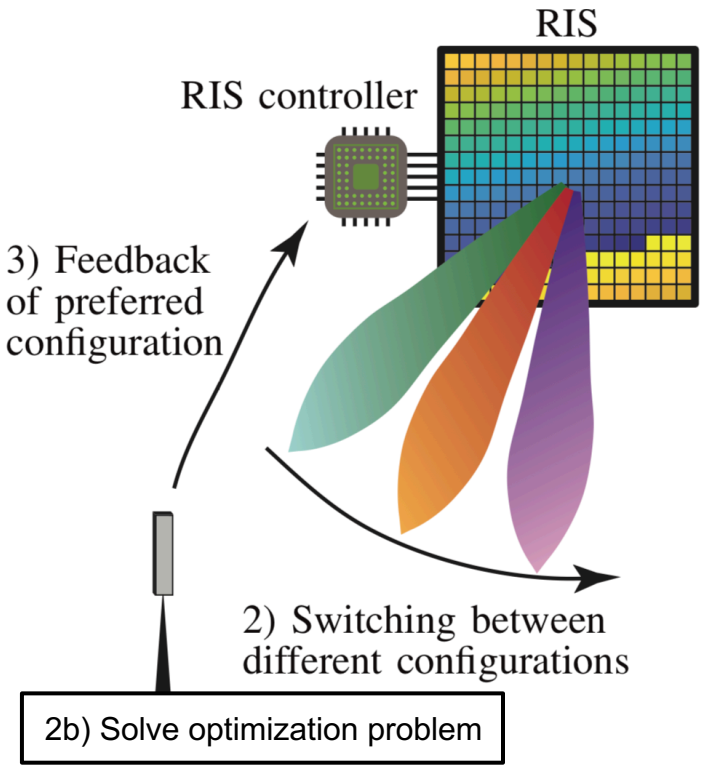


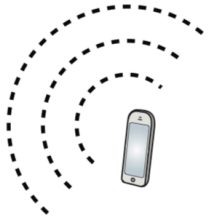
Reference:

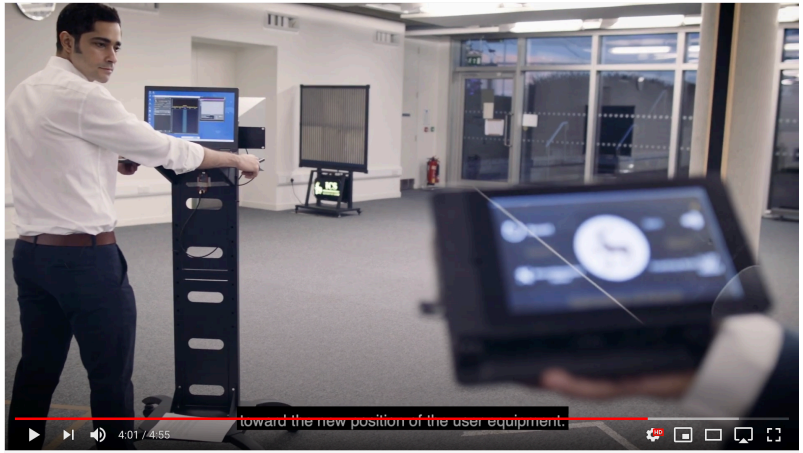
[R2] Ö. Özdogan, E. Björnson, E. G. Larsson, "Using Intelligent Reflecting Surfaces For Rank Improvement in MIMO Communications"

Reconfigurability is Complicated But Doable

An RIS is blind!







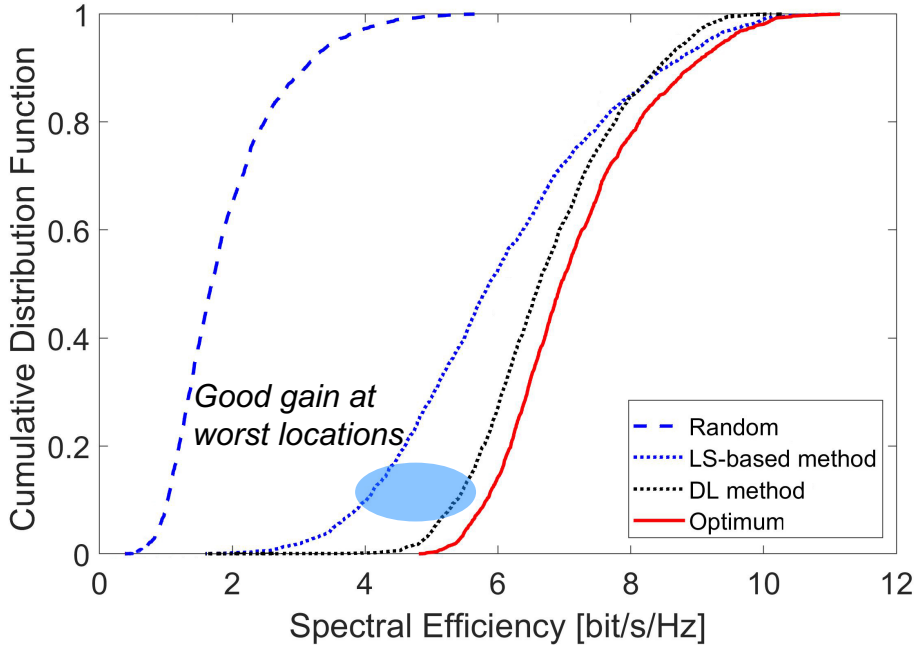
YouTube video from University of Surrey

Machine Learning is Helpful

Channel dimensionality:

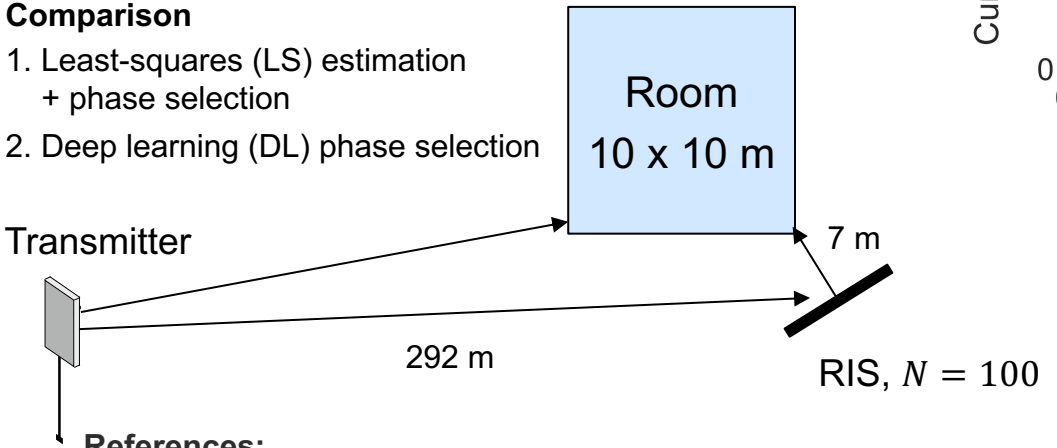
$$\text{Surface area} \cdot \frac{\pi}{\lambda^2}$$

- Example: 79 for 0.5 x 0.5 m, 3 GHz band
- Hard to model hardware properties



Comparison

1. Least-squares (LS) estimation + phase selection
2. Deep learning (DL) phase selection

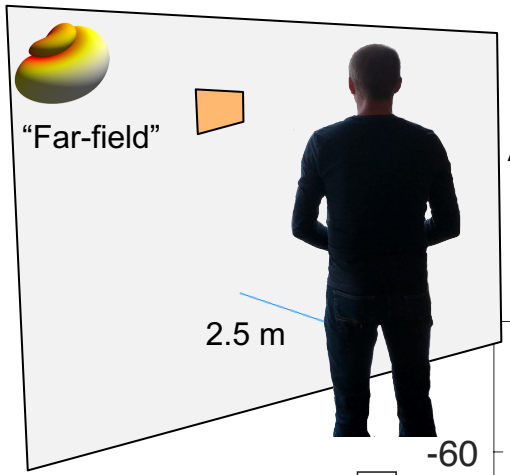


References:

[R3] E. Björnson, L. Sanguinetti, "Rayleigh Fading Modeling and Channel Hardening for Reconfigurable Intelligent Surfaces"

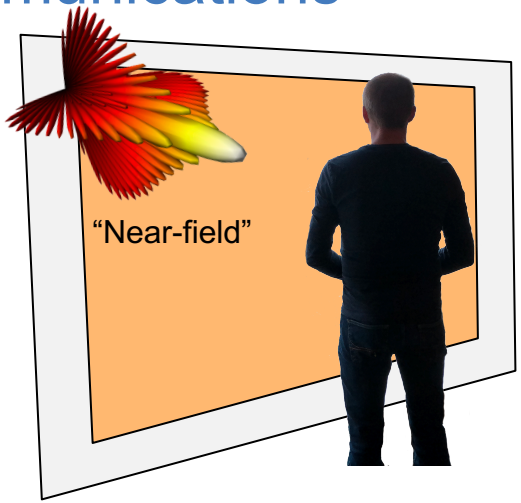
[R4] Ö. Özdogan, E. Björnson, "Deep Learning-based Phase Reconfiguration for Intelligent Reflecting Surfaces"

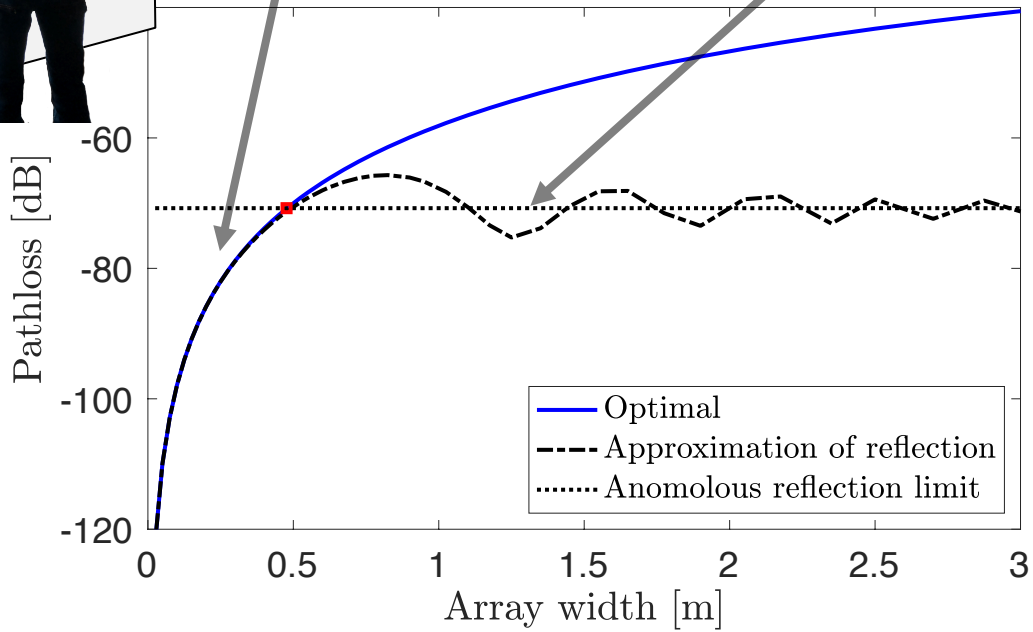
Anamolous Reflection is Not Preferred in Communications



Small RIS:
Acts as a directive *scatterer*

Large RIS:
Can act as a *true reflector*
Vastly suboptimal to do so





Assumptions:
25 m from transmitter
2.5 m to receiver
Isotropic antennas

Summary

RIS a new type of relay

- Not good at beating other relays in terms of SNR
- Well suited to improve other channel properties:
  - Increased MIMO rank
  - Macro diversity (large surface)
  - Mitigate polarization losses
  - …?

Concluding words about RIS

Excellent opportunity for PhD students to explore a new field!

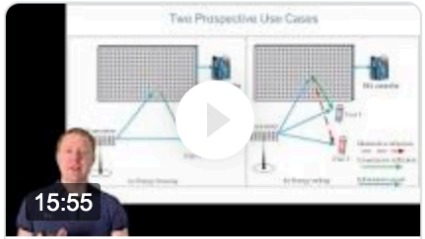
Useful above 100 GHz: Add paths, give diversity, low mobility

To hear me talk more about this…

Listen to my podcast:

WIRELESS FUTURE

Check out my YouTube channel:



Fundamentals of Intelligent Reflecting Surfaces

Towards 6G: Massive MIMO is a Reality—What is Next?

ACCEPTED FROM OPEN CALL

Reconfigurable Intelligent Surfaces: Three Myths and Two Critical Questions

Emil Björnson, Özgecan Özdogan, and Erik G. Larsson

The authors take a neutral look at the RIS technol-

ABSTRACT

The search for physical layer technologies that

riences minor losses. Inside the window, an RIS is deployed to capture signal energy proportion-al to its area and re-radiate it in the shape of a