



# User-Side RIS: Realizing Large-Scale Array at User Side

Kunzan Liu

*Dept. EE, Tsinghua Univ.*

Email: lkz18@mails.tsinghua.edu.cn

Co-authors: Zijian Zhang and Linglong Dai

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# Outline

**Introduction**

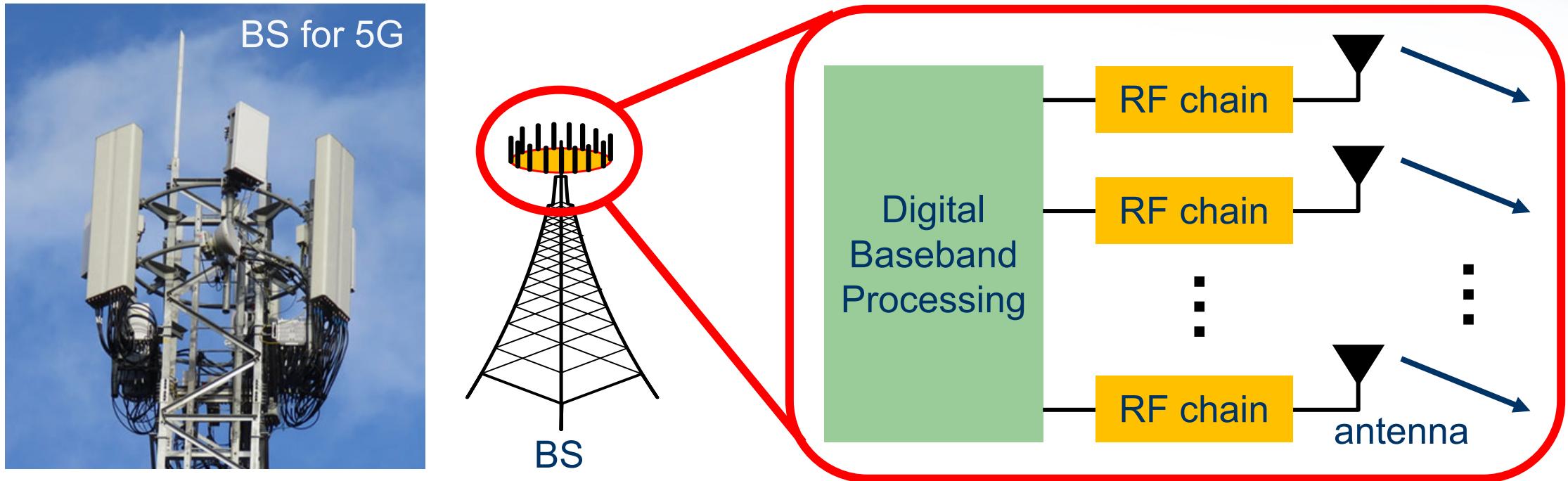
**Concept & Architecture**

**System model & Precoding design**

**Simulation results**

# Massive MIMO

- **Massive MIMO: Deploying large-scale antenna array at the BS side for low-power communications**
- By serving users with precoding and combining operations, orders of magnitude increase in the spectral efficiency can be achieved

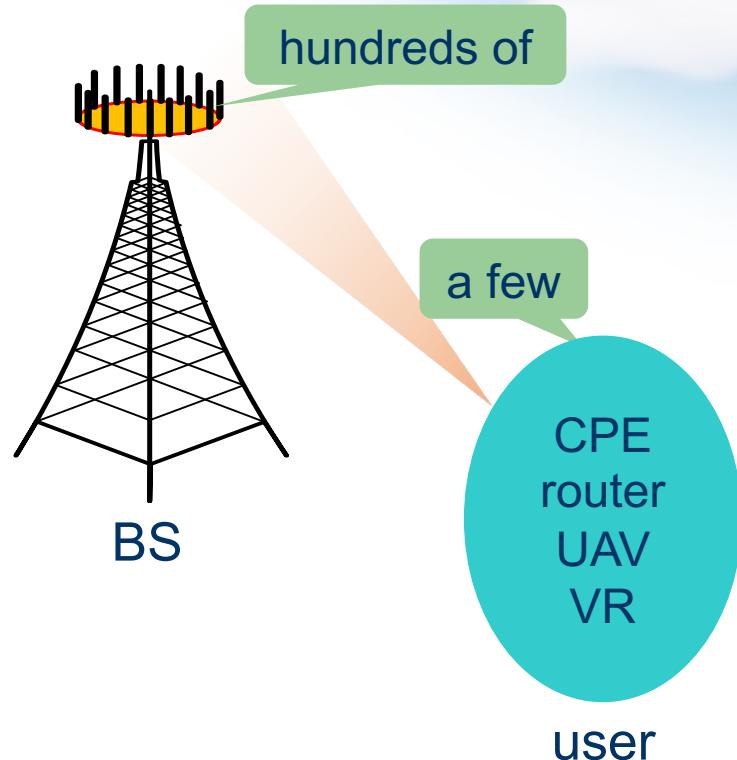


# Massive MIMO

Q: Can user employ a **large-scale array**?

## Pros

1. Save the **power consumption** for users, and prolong the stand-by time.
2. Enhance the **wireless coverage**, and enable the communications in the basement.



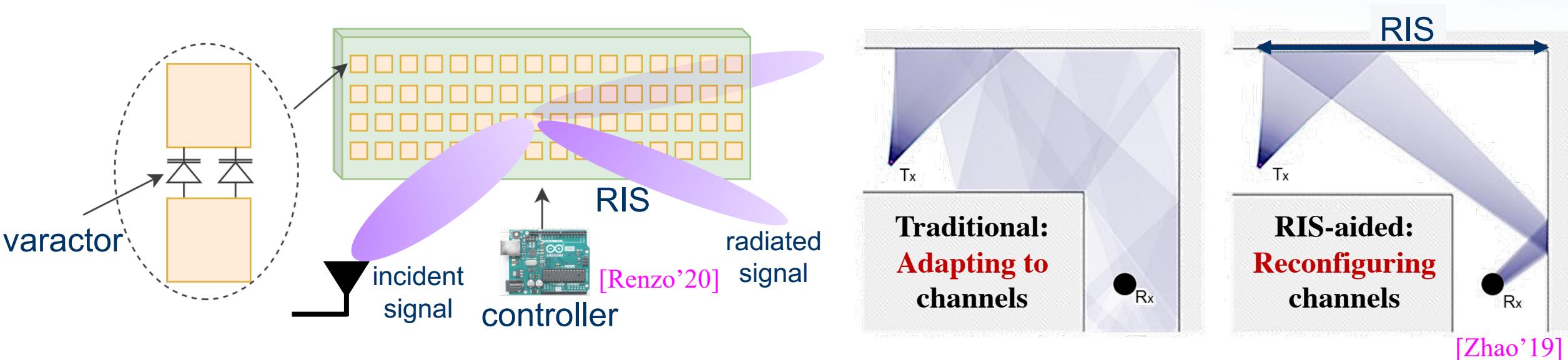
## Cons

1. Every antenna has a dedicated **high-cost RF chain**.
2. Mismatch of the large-scale array and the user in **dimensions**.

It is almost **impossible** to employ a **large-scale array** at the user side.

# RIS (Reconfigurable Intelligent Surfaces)

- A **large-scale array** composed of **passive controllable meta-materials**
- **Cost- and energy-efficient**, do not introduce additive noise
- Control the phase of the **reflected/penetrated** signal, and thus improve the environment of communications

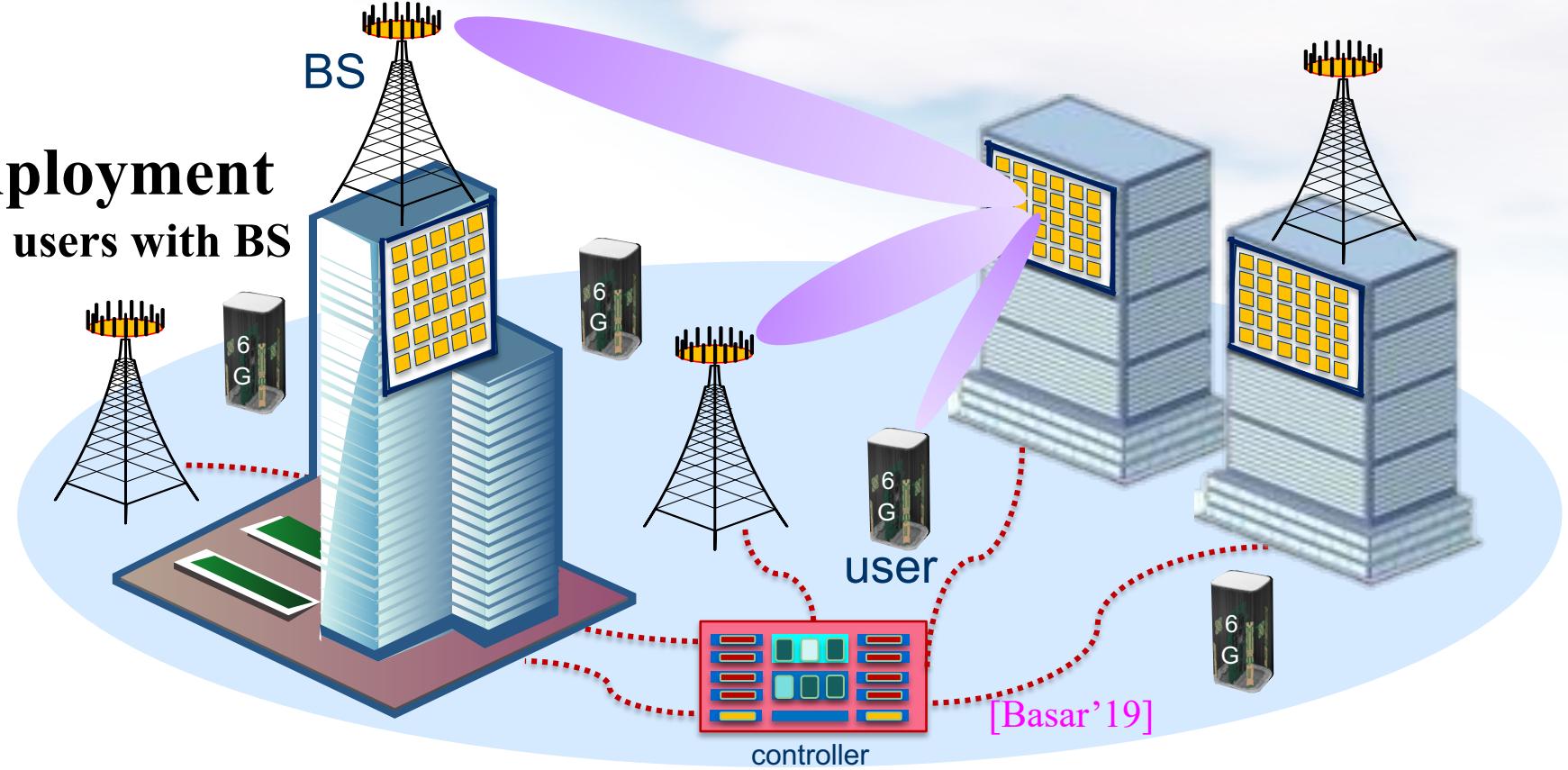


[Renzo'20] M. Di Renzo *et al.*, "RIS vs. Relaying: Differences, Similarities, and Performance Comparison," *IEEE Open J. Commun. Society*, vol. 1, pp. 798-807, Jun. 2020.

[Zhao'19] J. Zhao and Y. Liu, "A Survey of Intelligent Reflecting Surfaces (IRSs): Towards 6G Wireless Communication Networks," *arXiv preprint arXiv:1905.00152*, Jun. 2019.

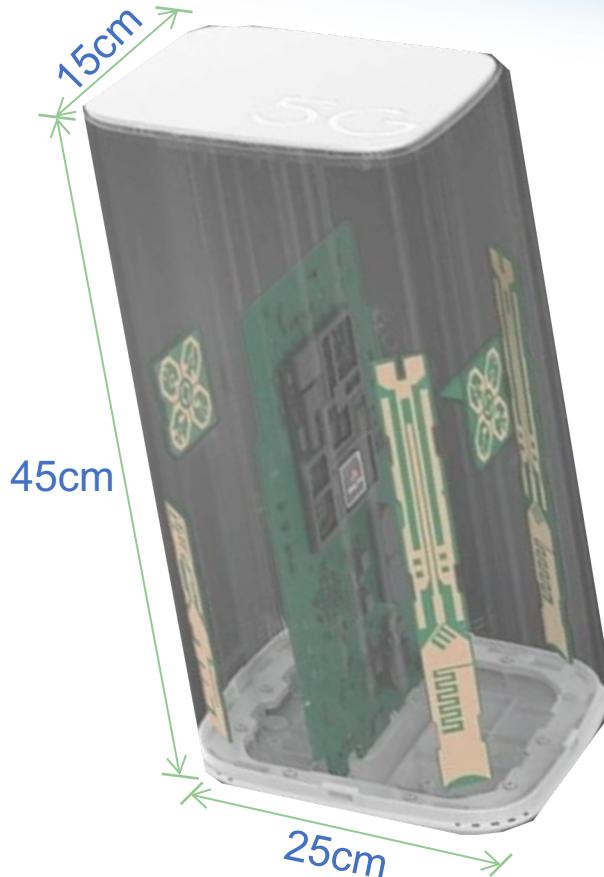
# RIS-aided communications

**Relay-like employment**  
Cooperatively serve users with BS

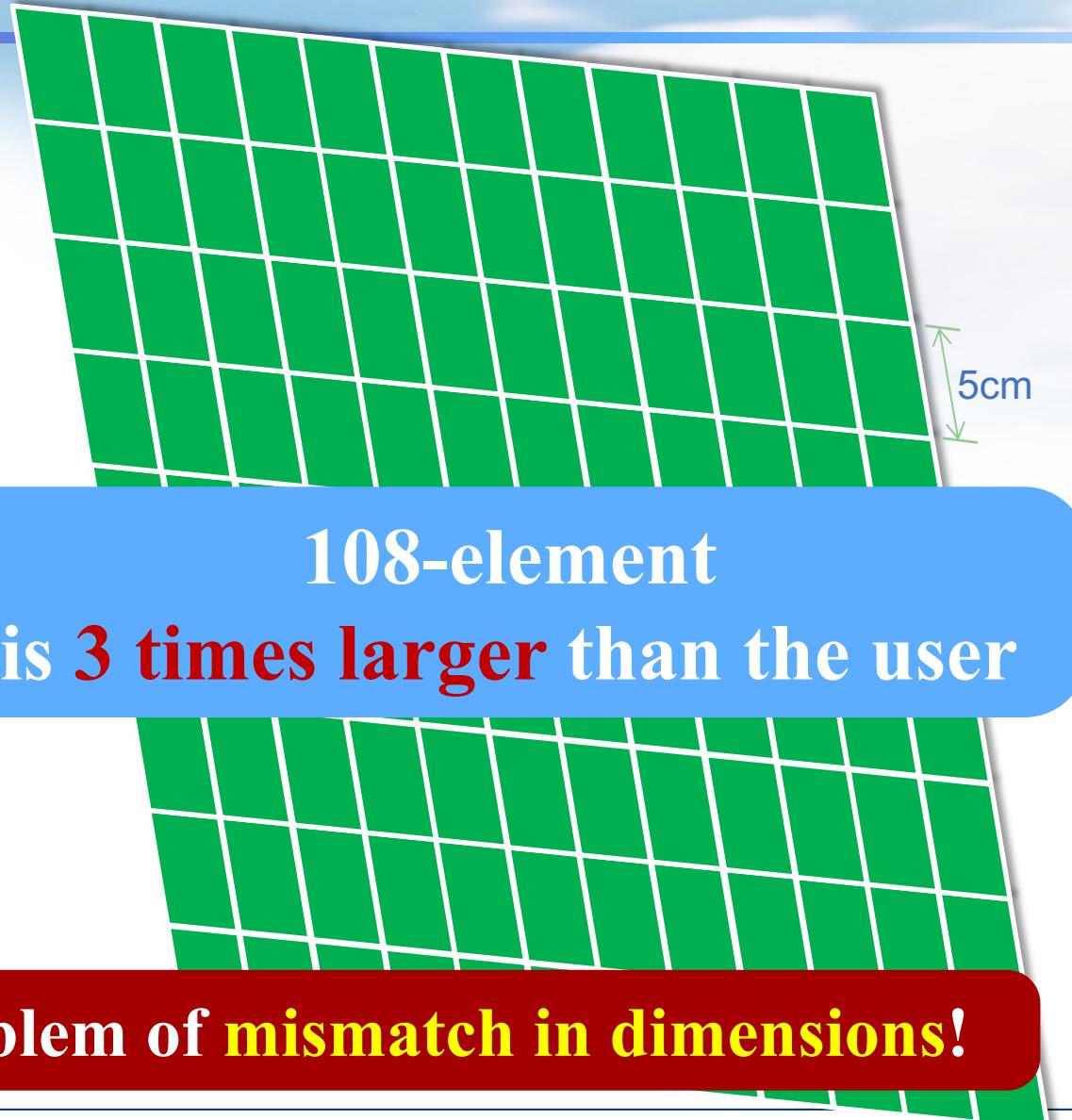


[Basar'19] E. Basar *et al.*, "Wireless communications through reconfigurable intelligent surfaces," *IEEE Access*, vol. 7, pp. 116753-116773, Jul. 2019.

# Can we employ RIS at the user side?



CPE (Customer-Premises Equipment)



Still cannot solve the problem of **mismatch in dimensions!**

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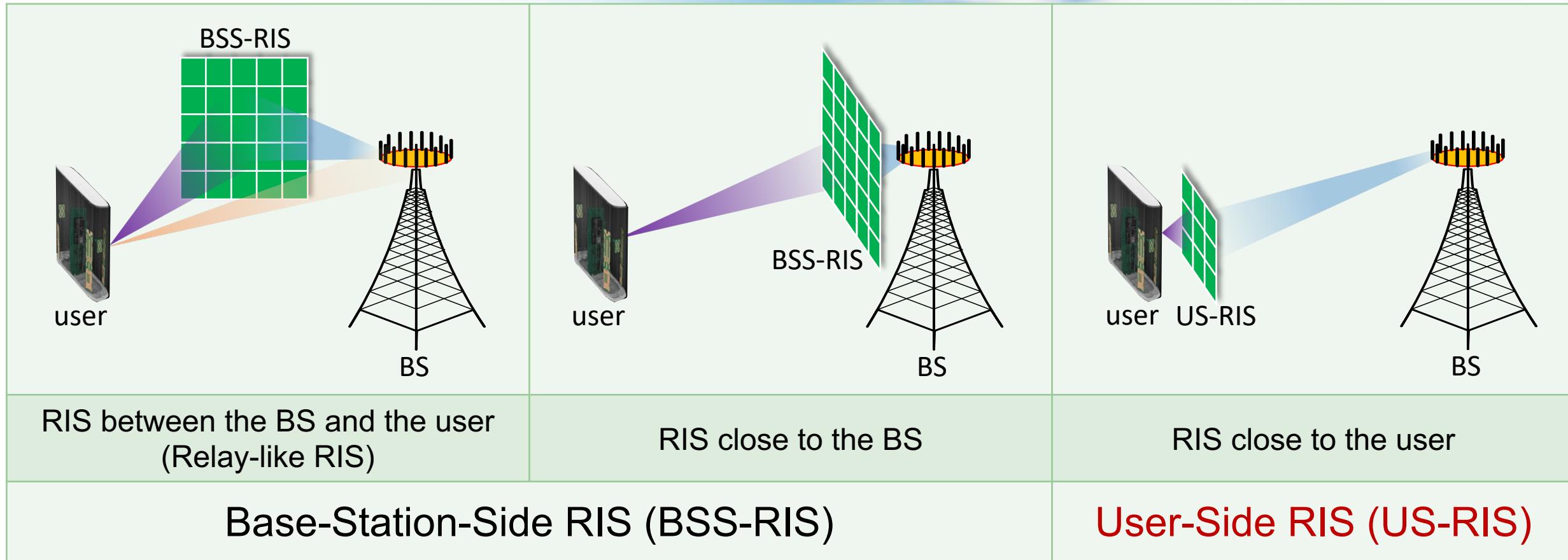
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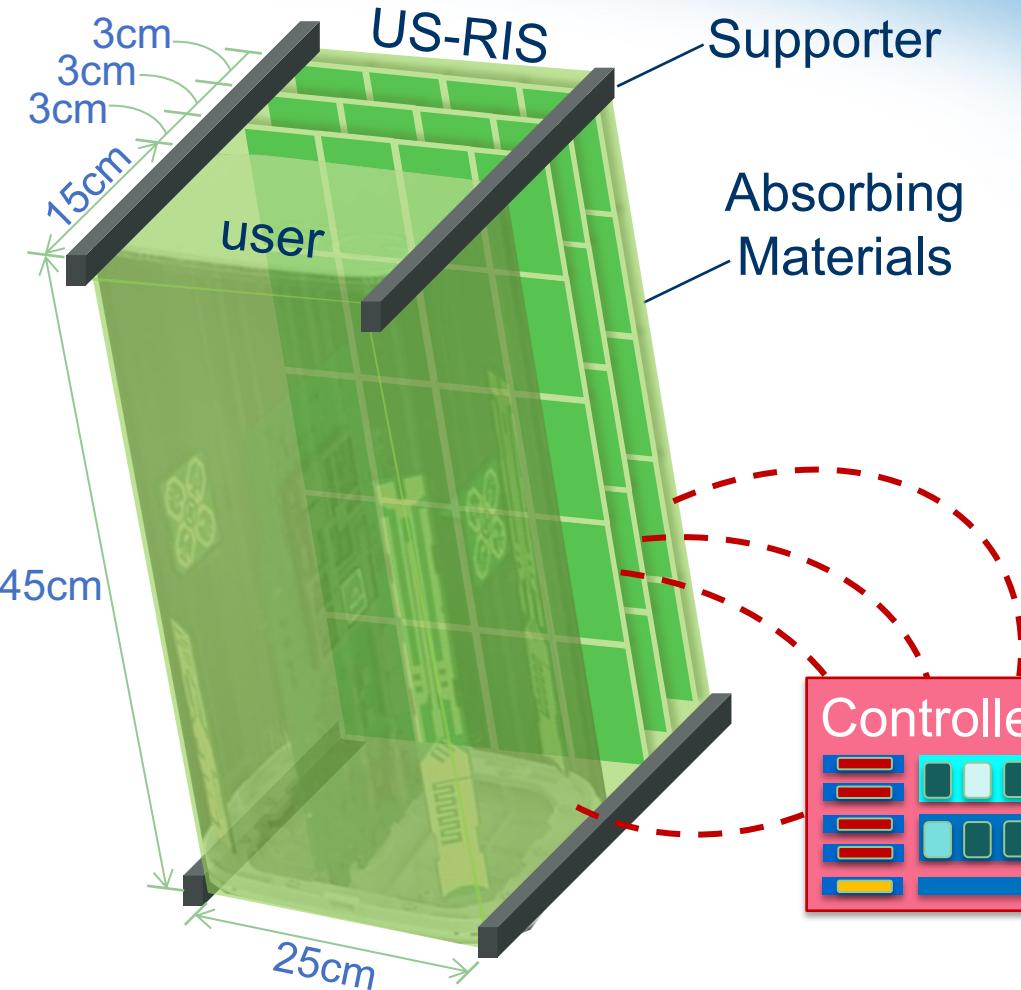
Simulation results

# From Base-Station-Side to User-Side



**User-side RIS employs RIS at the user side for the first time**

# User-Side RIS: Architecture



User architecture based on **US-RIS**

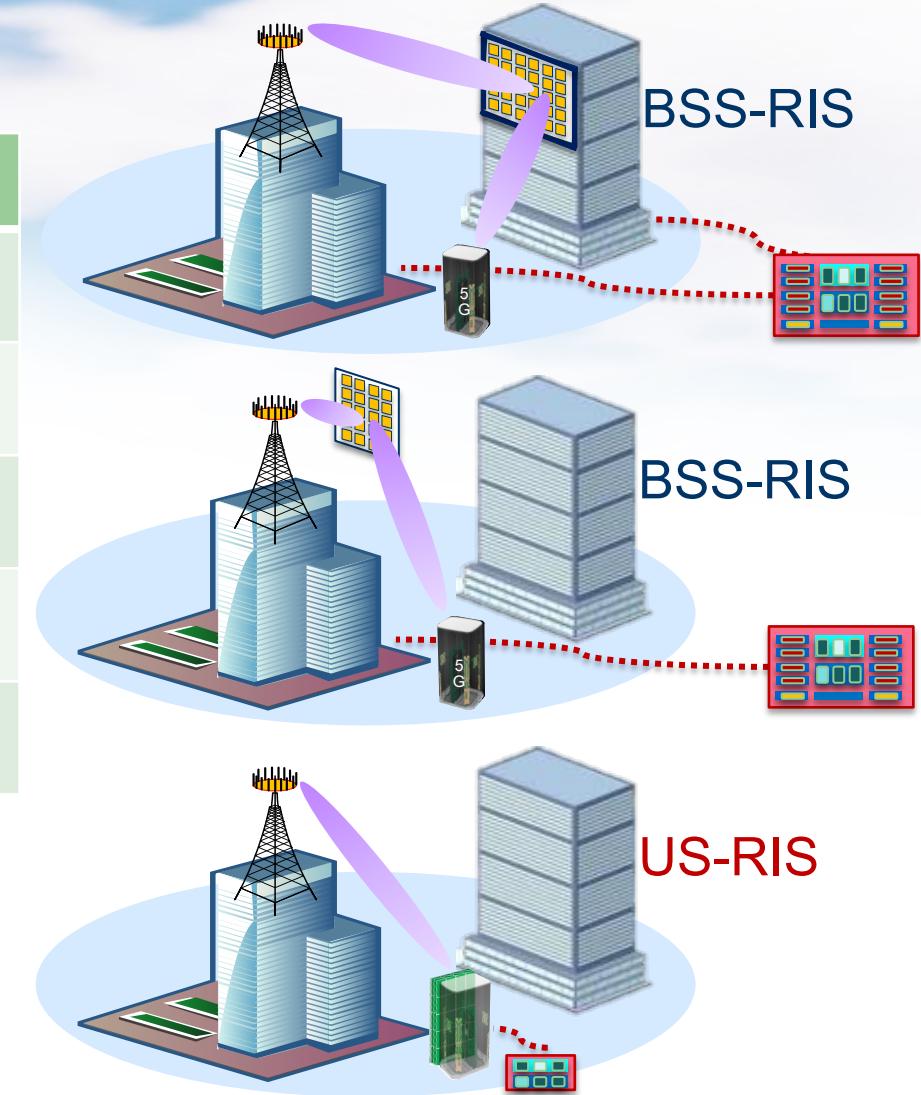
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2. Mismatch of the large-scale array and the user in **dimensions**.



# Comparisons

	BSS-RIS	US-RIS
<b>Controller</b>	one/multi BS(s)	one user
<b>Beneficiary</b>	one/multi user(s)	one user
<b>Mode</b>	mainly reflective	transmissive
<b>Structure</b>	single-layer	single/multi-layer
<b>Size</b>	very large	small



US-RIS is **essentially different from BSS-RIS**

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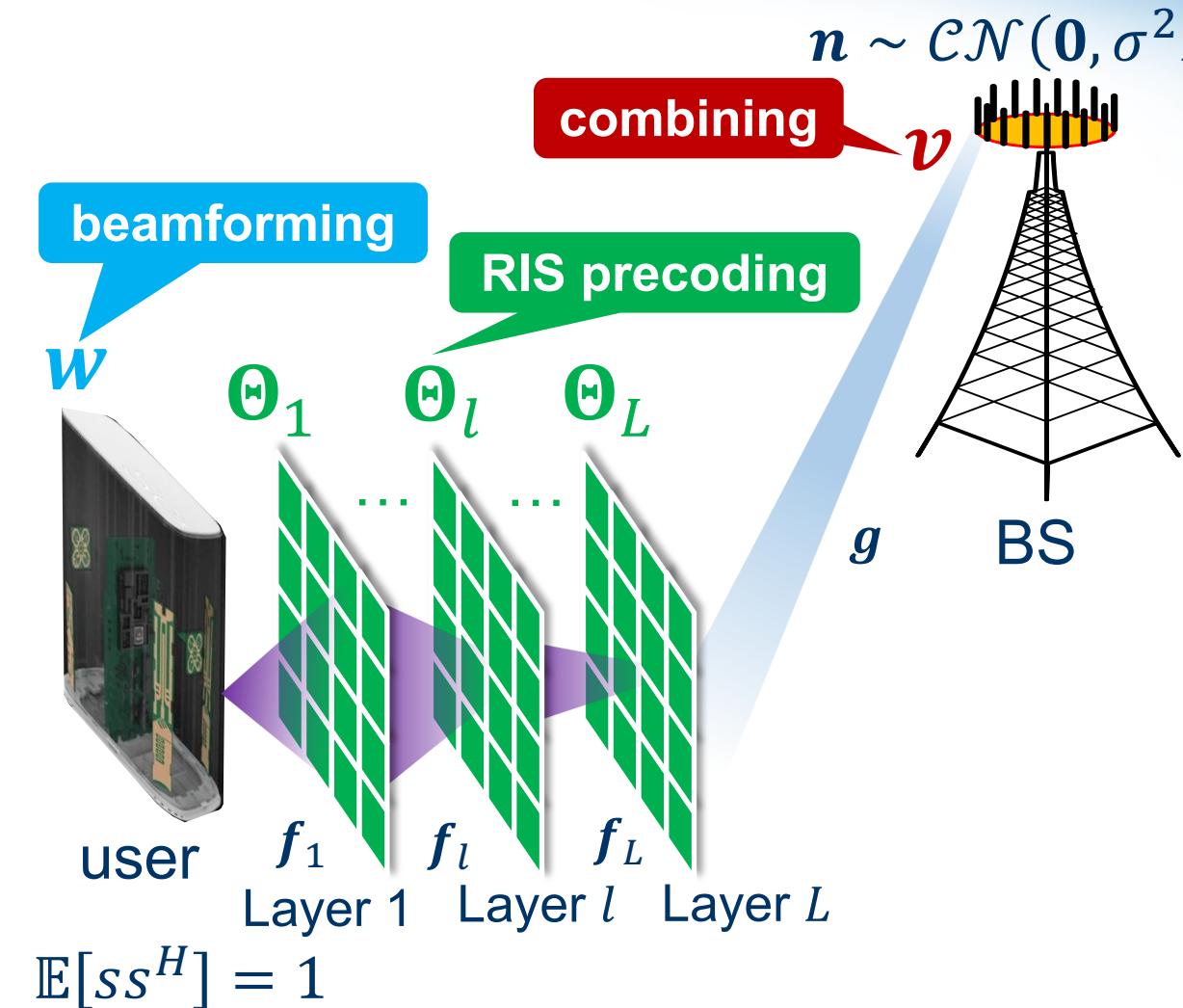
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# System Model & Problem Formulation



$$y = g^H (\prod_{l=1}^L \kappa \Theta_l f_l) w + n.$$
$$z = v^H g^H (\prod_{l=1}^L \kappa \Theta_l f_l) w + v^H n$$

## SNR Maximization

$$\max_{w, \Theta_1, \dots, \Theta_L, v}$$
$$\text{SNR} = \frac{|v^H g^H (\prod_{l=1}^L \kappa \Theta_l f_l) w|^2}{\|v^H\|_2^2 \sigma^2}$$

$$\text{s. t. } \|w\|_2^2 \leq P_{\max}$$

$$|\theta_{l,n}| = 1, \forall l, n$$

# Precoding Design

$$\max_{\mathbf{v}, \Theta_1, \dots, \Theta_L, \mathbf{w}} \text{SNR} = \frac{\left| \mathbf{v}^H \mathbf{g}^H \left( \prod_{l=1}^L \kappa \Theta_l \mathbf{f}_l \right) \mathbf{w} \right|^2}{\|\mathbf{v}^H\|_2^2 \sigma^2}$$

$$\begin{aligned} \text{s.t. } & \mathbf{C}_1 : \|\mathbf{w}\|_2^2 \leq P_{\max} \\ & \mathbf{C}_2 : |\theta_{l,n}| = 1, \forall l, n \end{aligned}$$

$$(9) \quad \mathbf{v}^{\text{opt}} = \psi_{\max} \left( \mathbf{g}^H \boldsymbol{\xi}_{(L,1)} \mathbf{w} \mathbf{w}^H \boldsymbol{\xi}_{(L,1)}^H \mathbf{g} \right).$$

$$(12) \quad \theta_l^{\text{opt}} = \exp \left( j \arg \left( \text{diag} \left( \mathbf{f}_l \boldsymbol{\xi}_{(l-1,1)} \mathbf{w} \right)^H \boldsymbol{\xi}_{(L,l+1)}^H \mathbf{g} \mathbf{v} \right) \right).$$

$$(15) \quad \mathbf{w}^{\text{opt}} = \sqrt{P_{\max}} \langle \mathbf{w} \rangle^{\text{opt}} = \sqrt{P_{\max}} \left\langle \boldsymbol{\xi}_{(L,1)}^H \mathbf{g} \mathbf{v} \right\rangle.$$

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**Algorithm 1** Multi-layer Precoding Design for US-RIS-Aided Communications

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**Input:** Channel matrices  $\mathbf{f}_1, \dots, \mathbf{f}_L$ , and  $\mathbf{g}$ ; maximum transmit power  $P_{\max}$ ; noise power  $\sigma^2$ ; loss factor  $\kappa$ .

**Output:** Optimized combining vector  $\mathbf{v}$ ; optimized US-RIS precoding matrix  $\Theta_1, \dots, \Theta_L$ ; optimized beamforming vector  $\mathbf{w}$ ; maximized SNR.

- 1: Initialize  $\mathbf{v}$ ,  $\Theta_1, \dots, \Theta_L$ , and  $\mathbf{w}$ ;
  - 2: **while** no convergence of SNR **do**
  - 3:   Update  $\mathbf{v}^{\text{opt}}$  by (9);
  - 4:   Update  $\Theta_1^{\text{opt}}, \dots, \Theta_L^{\text{opt}}$  in term by (12);
  - 5:   Update  $\mathbf{w}^{\text{opt}}$  by (15);
  - 6:   Update SNR by (5);
  - 7: **end while**
  - 8: **return**  $\mathbf{v}$ ,  $\Theta_1, \dots, \Theta_L$ ,  $\mathbf{w}$ , and SNR.
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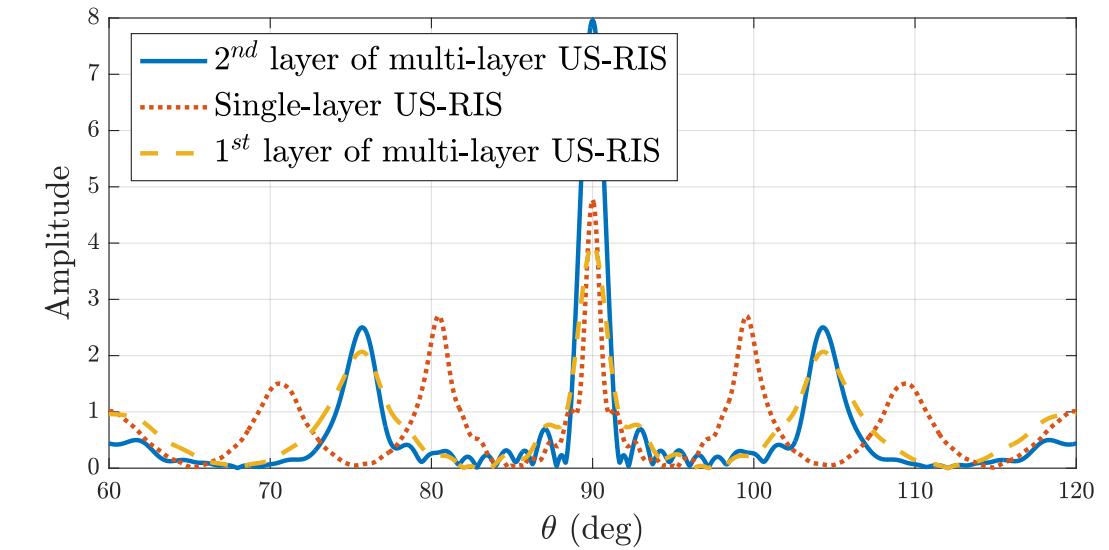
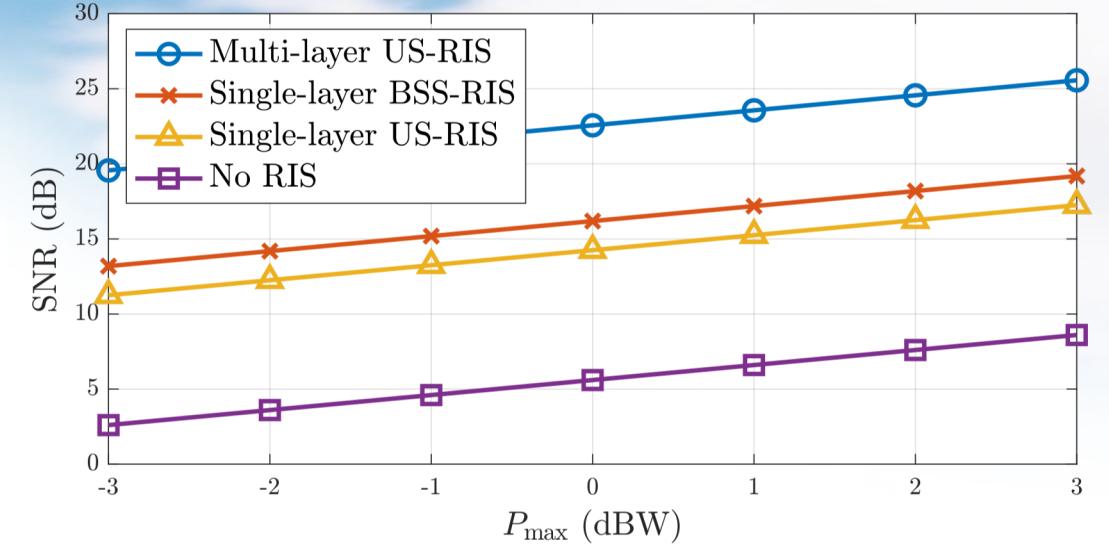
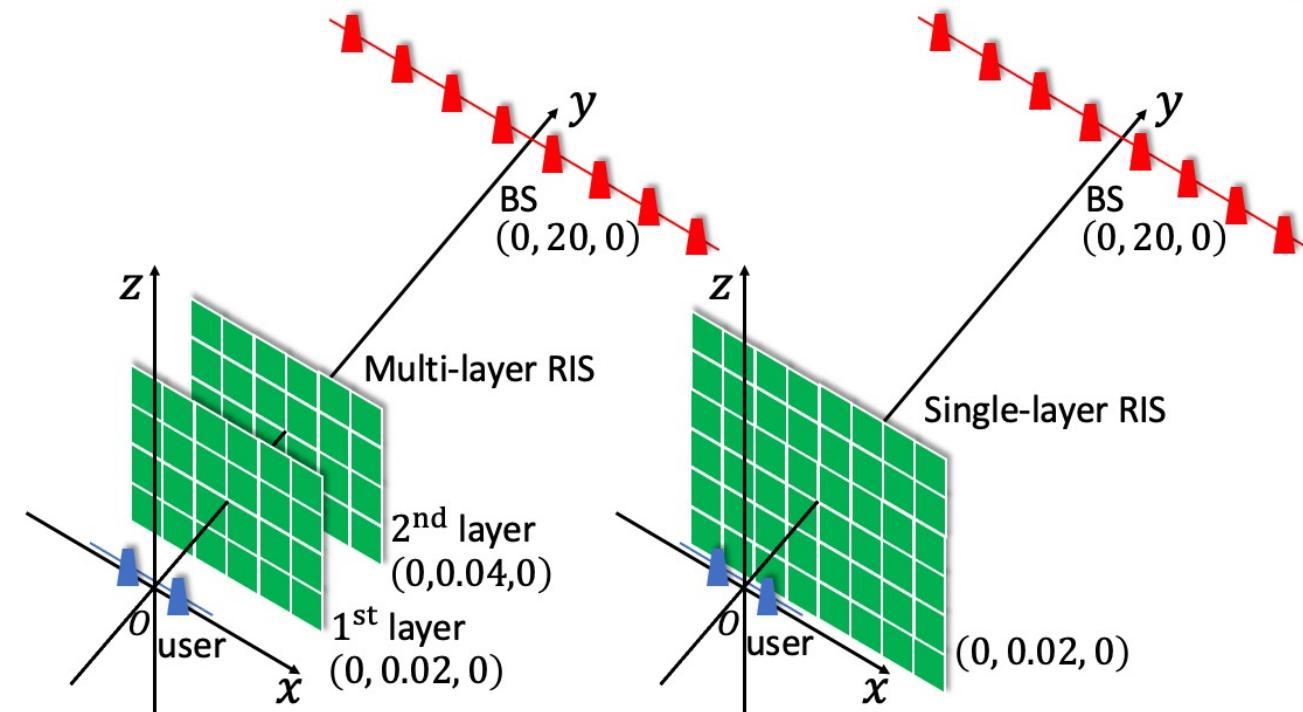
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# Simulation Results



# Wrap Up

- Concept

- **BSS-RIS:** Relay-like RIS or RIS employed close to the BS
- **US-RIS:** A component of the novel user architecture

- Precoding Design

- A user-BS communication with the aid of a **multi-layer US-RIS**
- **Non-convex** problem with **iterative** optimization

- Simulation Results

- **Higher** decoding SNR by multi-layer RIS
- **Higher** mainlobe and lower sidelobes by multi-layer RIS



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