IEEE Vehicular Technology Conference: VTC2021-Spring

On The Energy-Efficiency Fairness of Reconfigurable Intelligent Surface-Aided Cell-Free Network

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Overview

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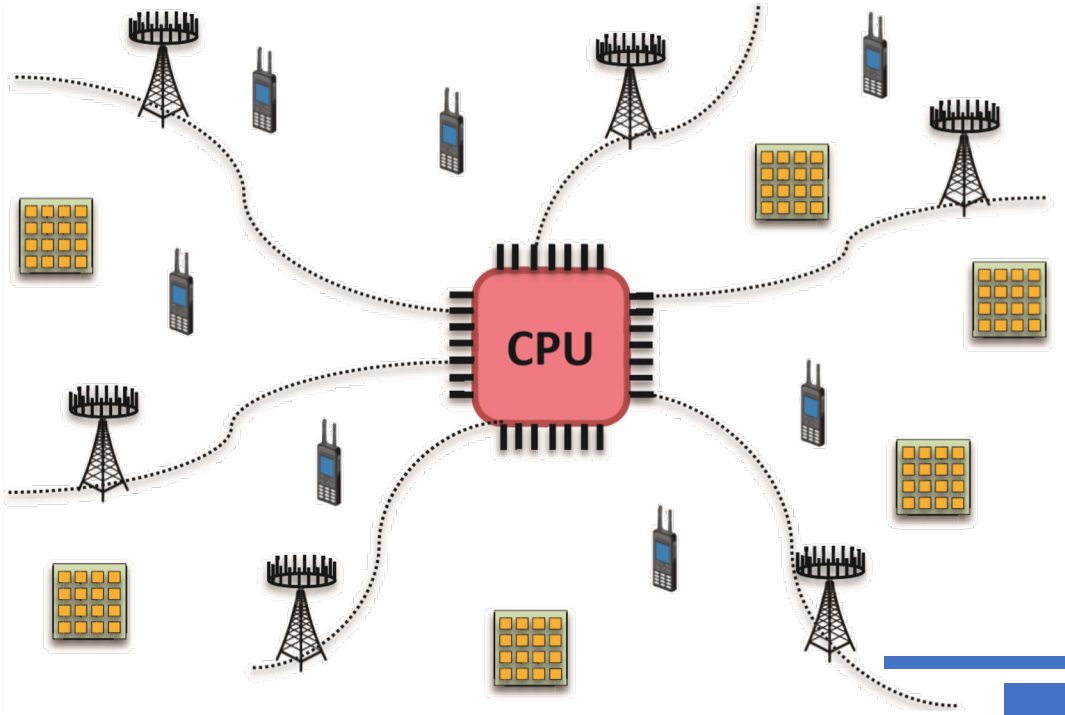
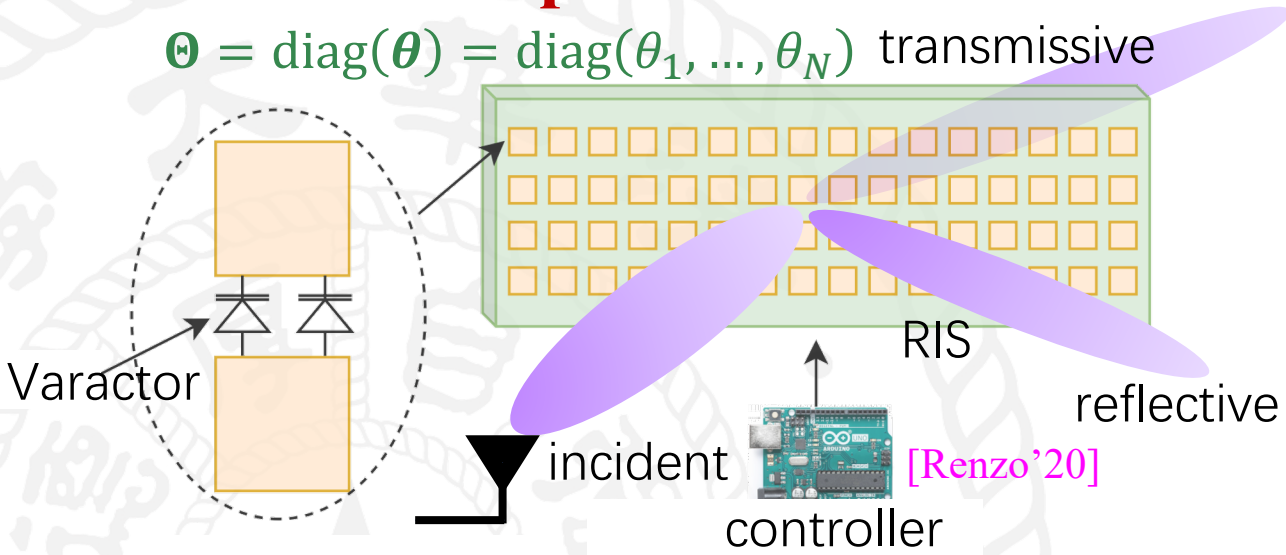
On The Energy-Efficiency Fairness of Reconfigurable Intelligent Surface-Aided Cell-Free Network

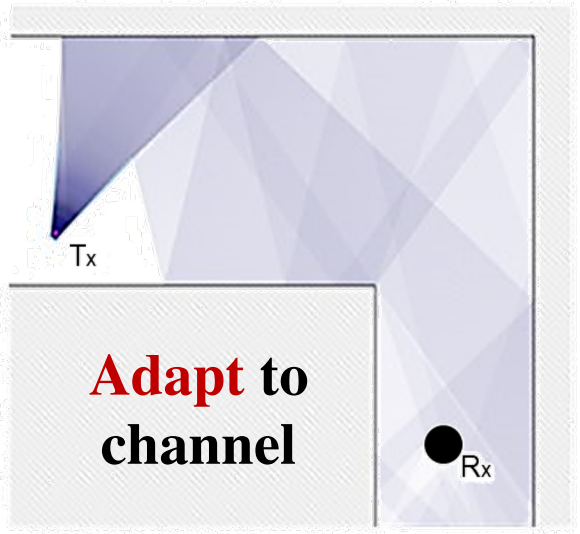
We formulate the energy-efficiency fairness problem in the RIS-aided cell-free network and propose a resource allocation algorithm that gives the optimal solution.

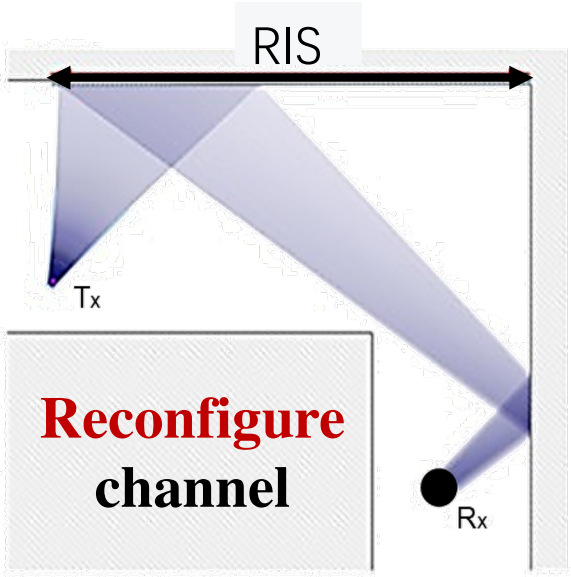


RIS

- RIS is an array composed by passive and controllable materials
- RIS has low cost and low power consumption
- RIS can reflect or penetrate signals to desired directions, with a controlled phase shift





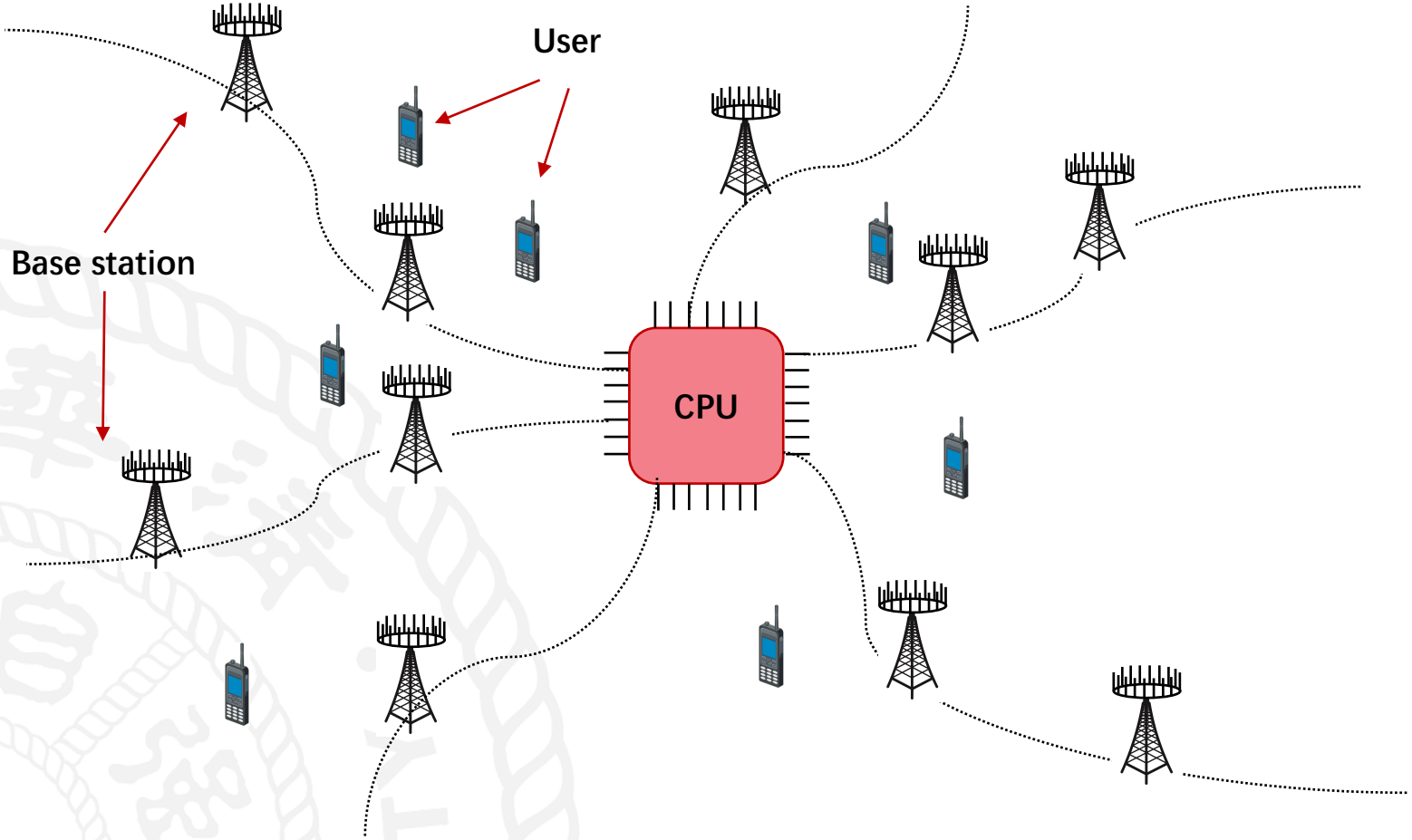


[Zhao'19]

RIS is the most revolutionary technique for future 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.

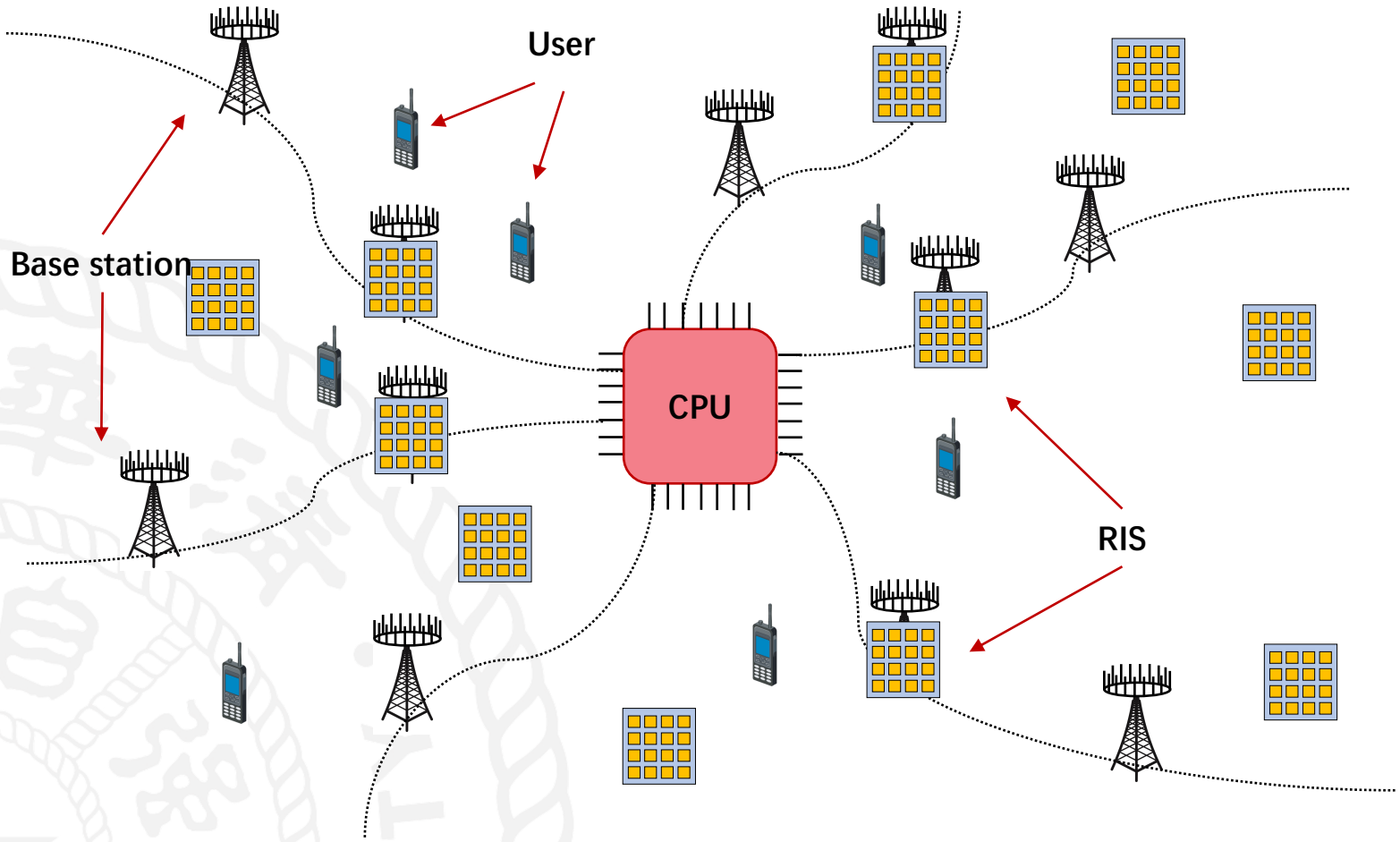
Traditional Network



How to increase capacity with limited consumption and cost?

[Nayebi'15] E. Nayebi, A. Ashikhmin, T. L. Marzetta, and H. Yang, "Cell-free massive MIMO systems," in *Proc. 2015 49th Asilomar Conference on Signals, Systems and Computers*, Nov. 2015, pp. 695–699.

RIS-Aided Cell-Free Network



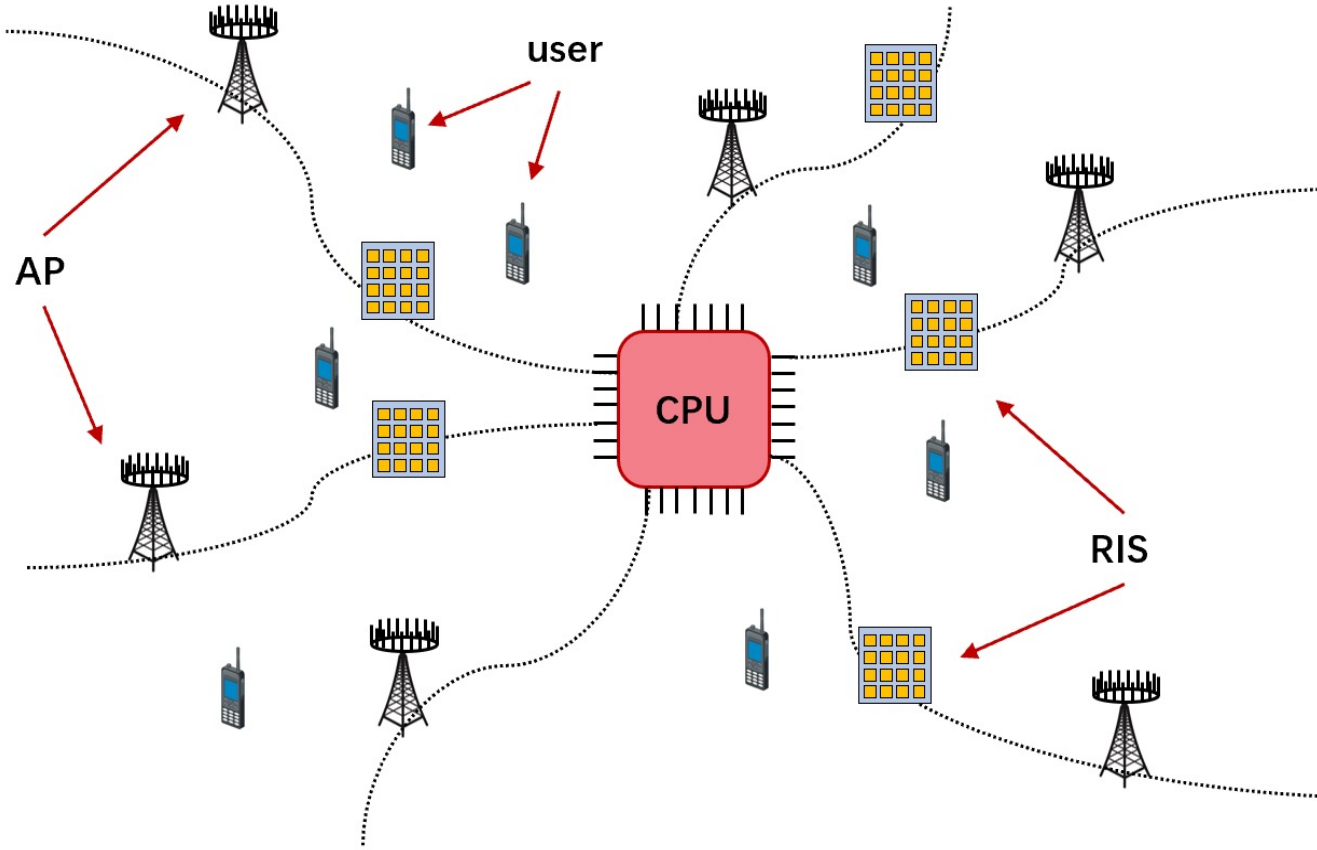
RIS-aided cell-free network: increase capacity with low consumption and cost

[Zhang'20] Z. Zhang and L. Dai, "Capacity improvement in wideband reconfigurable intelligent surface-aided cell-free network," *International Workshop on Signal Processing Advances in Wireless Communications (SPAWC)*, 2020.

System Model

System Model

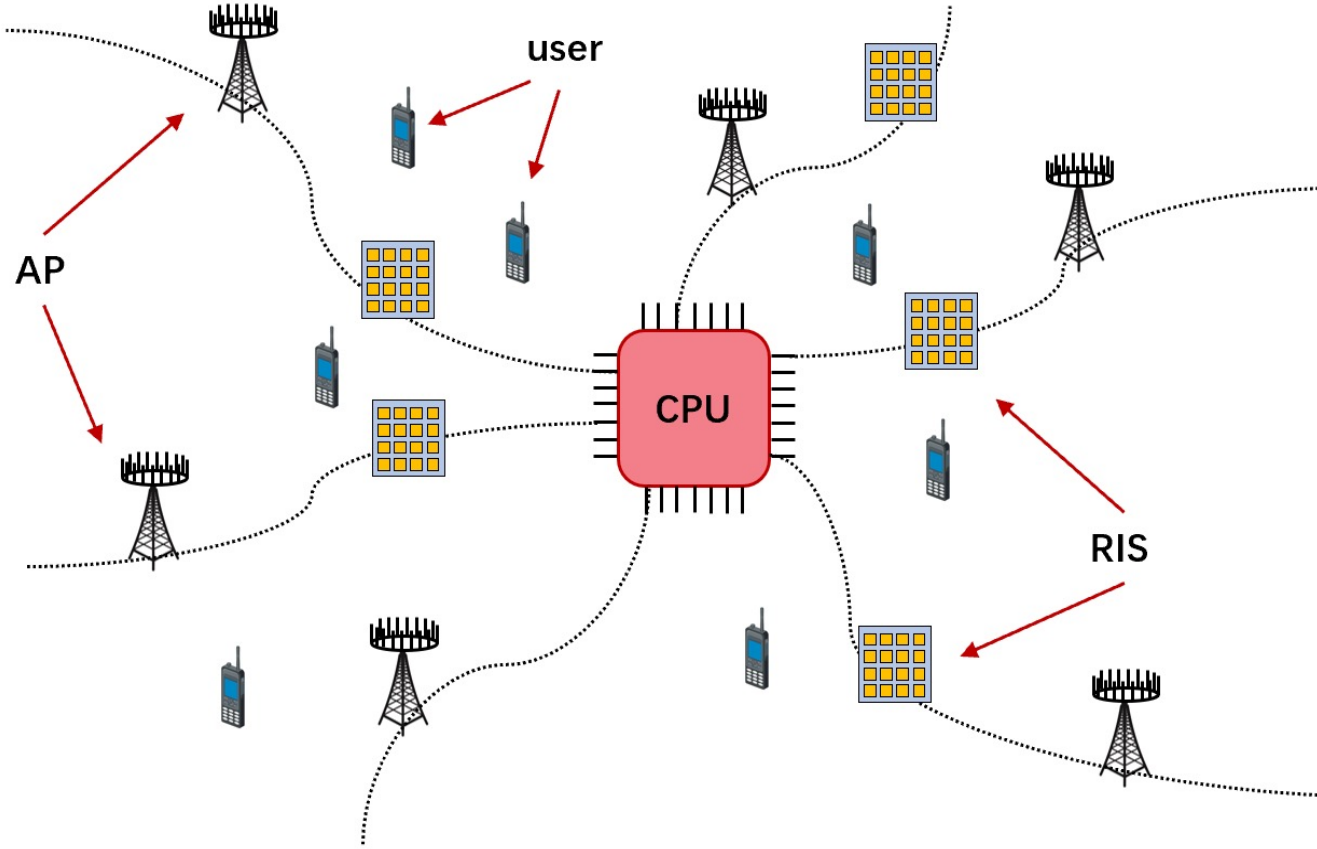
- B base stations, M antennas
- K users, 1 antenna
- Q RISs, N units
- P subcarriers OFDMA



System Model

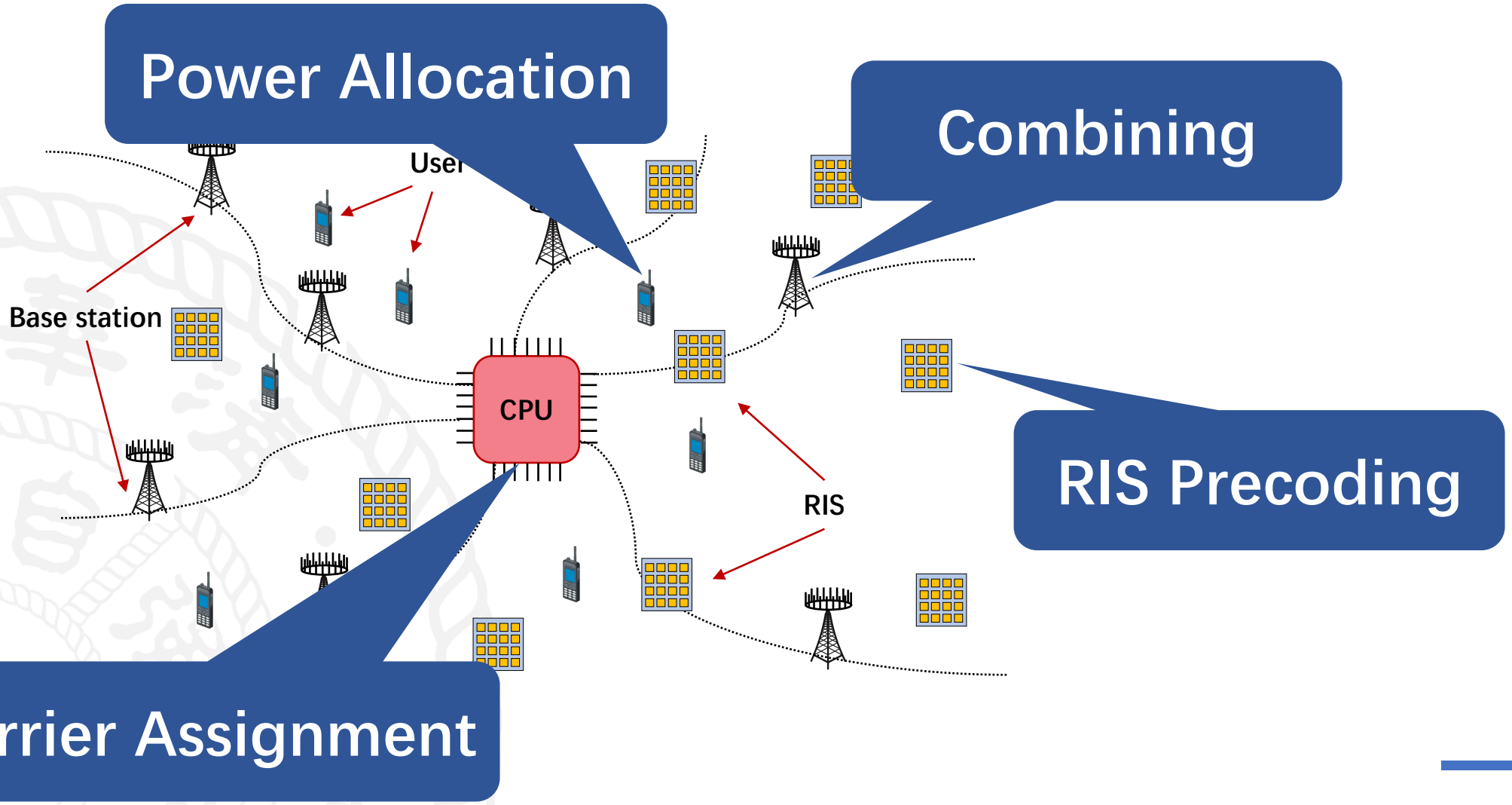
Prior Work

- Only one work study the spectrum efficiency of this network
- Energy efficiency is still a blank

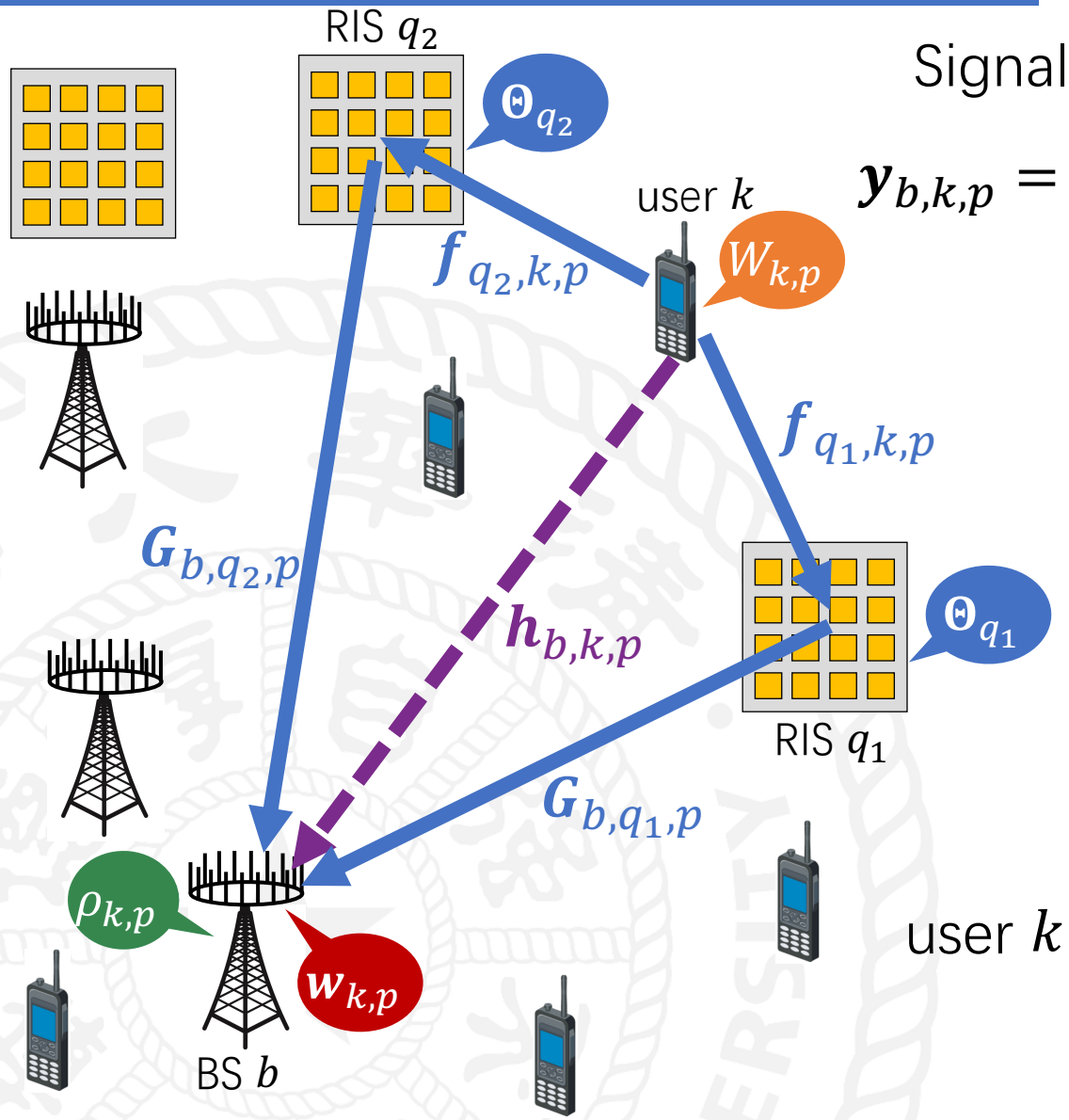


[Zhang'20] Z. Zhang and L. Dai, "Capacity improvement in wideband reconfigurable intelligent surface-aided cell-free network," *International Workshop on Signal Processing Advances in Wireless Communications (SPAWC)*, 2020.

System Model



Transmission & Consumption



Signal from user k arriving at BS b on subcarrier p

$$\boldsymbol{y}_{b,k,p} = \underbrace{\left(\boldsymbol{h}_{b,k,p} + \sum_{q=1}^{Q} \boldsymbol{G}_{b,q,p}^{H} \boldsymbol{\Theta}_q \boldsymbol{f}_{q,k,p}\right)}_{\boldsymbol{H}_{b,k,p}} \sqrt{W_{k,p}} s_{k,p} + \boldsymbol{z}_{b,p}$$

$$\Downarrow$$

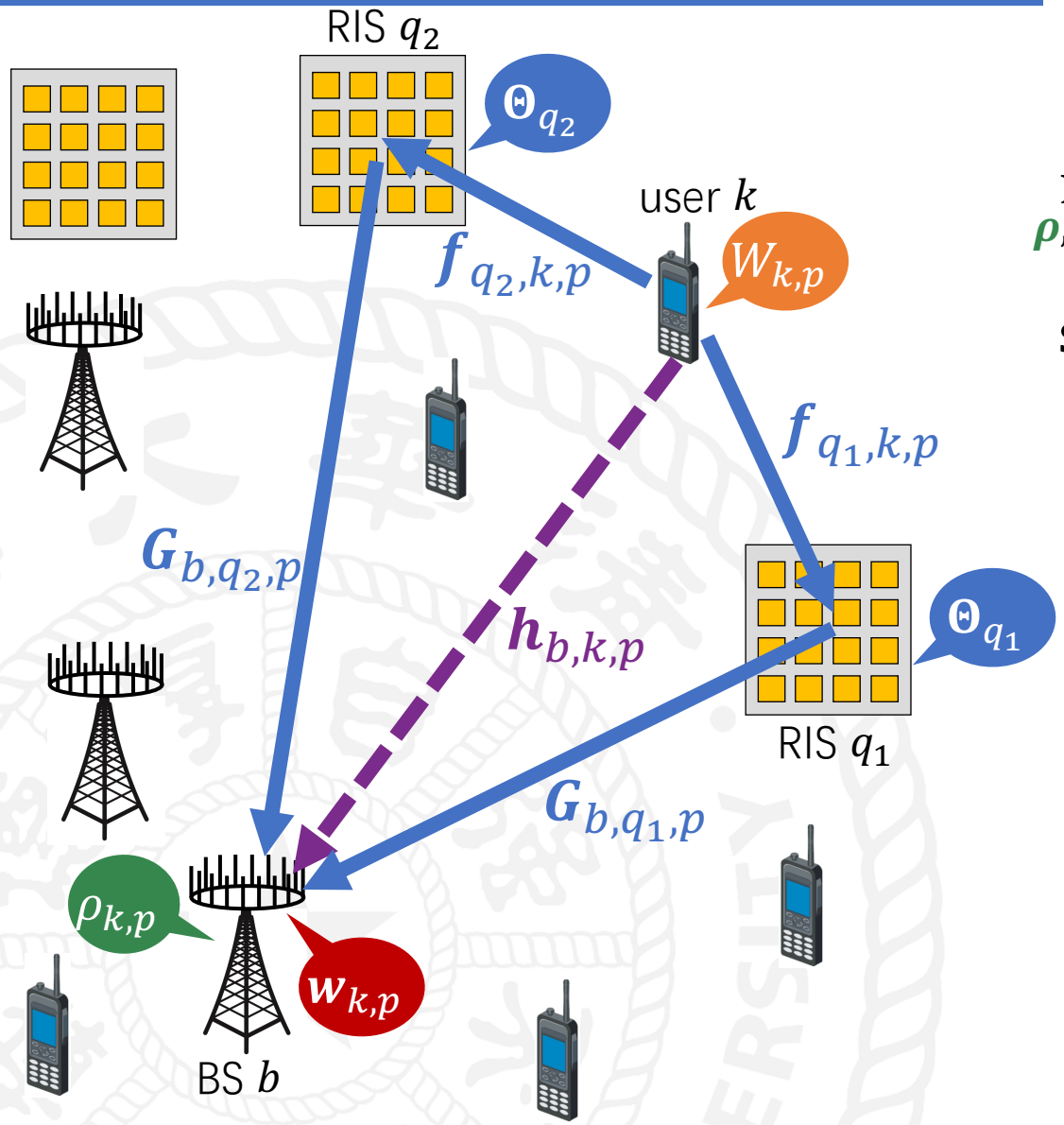
Decoding SNR of symbol $s_{k,p}$

$$\mathrm{SNR}_{k,p} = \frac{W_{k,p} \left| \sum_{b=1}^{B} \boldsymbol{w}_{b,p}^{H} \boldsymbol{H}_{b,k,p} \right|^2}{\sum_{b=1}^{B} \left\| \boldsymbol{w}_{b,p}^{H} \right\|^2 \sigma_0^2}$$

user k

- Transmit rate $R_k = \sum_{p=1}^{P} \rho_{k,p} \log_2\left(1 + \mathrm{SNR}_{k,p}\right)$
- Transmit power $W_k = \sum_{p=1}^{P} \rho_{k,p} W_{k,p}$
- Overall power $\widetilde{W}_k = A_k W_k + \bar{W}_k$

Energy-Efficiency Fairness



$$\max_{\boldsymbol{\rho},\boldsymbol{W},\boldsymbol{w},\boldsymbol{\theta}} \min_{k} \ \eta_k = \frac{R_k}{\widetilde{W}_k} = \frac{\sum_{p=1}^{P} \rho_{k,p} \log_2\left(1+\mathrm{SNR}_{k,p}\right)}{A_k \sum_{p=1}^{P} \rho_{k,p} W_{k,p} + \bar{W}_k}$$

$$\text{s.t. C1: } R_k \geq R_k^{\mathrm{req}}, \forall k$$

$$\text{C2: } W_k \geq W_k^{\max}, \forall k$$

$$\text{C3: } \theta_{q,n} \in \mathcal{F}, \forall q, n$$

$$\text{C4: } \sum_{k=1}^{K} \rho_{k,p} \leq 1, \forall p$$

$$\text{C5: } \rho_{k,p} \in \{0,1\}, \forall k, p$$

A joint optimization problem

Proposed Algorithm

$$\max_{\boldsymbol{\rho},\boldsymbol{W},\boldsymbol{w},\boldsymbol{\theta}} \quad \min_{k} \quad \eta_k = \frac{R_k}{\widetilde{W}_k}$$

$$s.t. \quad \text{C1}: R_k \geq R_k^{\text{req}}, \forall k$$

$$\text{C2}: W_k \leq W_k^{\max}, \forall k$$

$$\text{C3}: \sum_{k=1}^{K} \rho_{k,p} \leq 1, \forall p$$

$$\text{C4}: \rho_{k,p} \in \{0,1\}, \forall k,p$$

$$\text{C5}: \theta_{q,n} \in \mathcal{F}, \forall q,n$$

η_k → Nonconvex Obj. → Lagrangian Dual

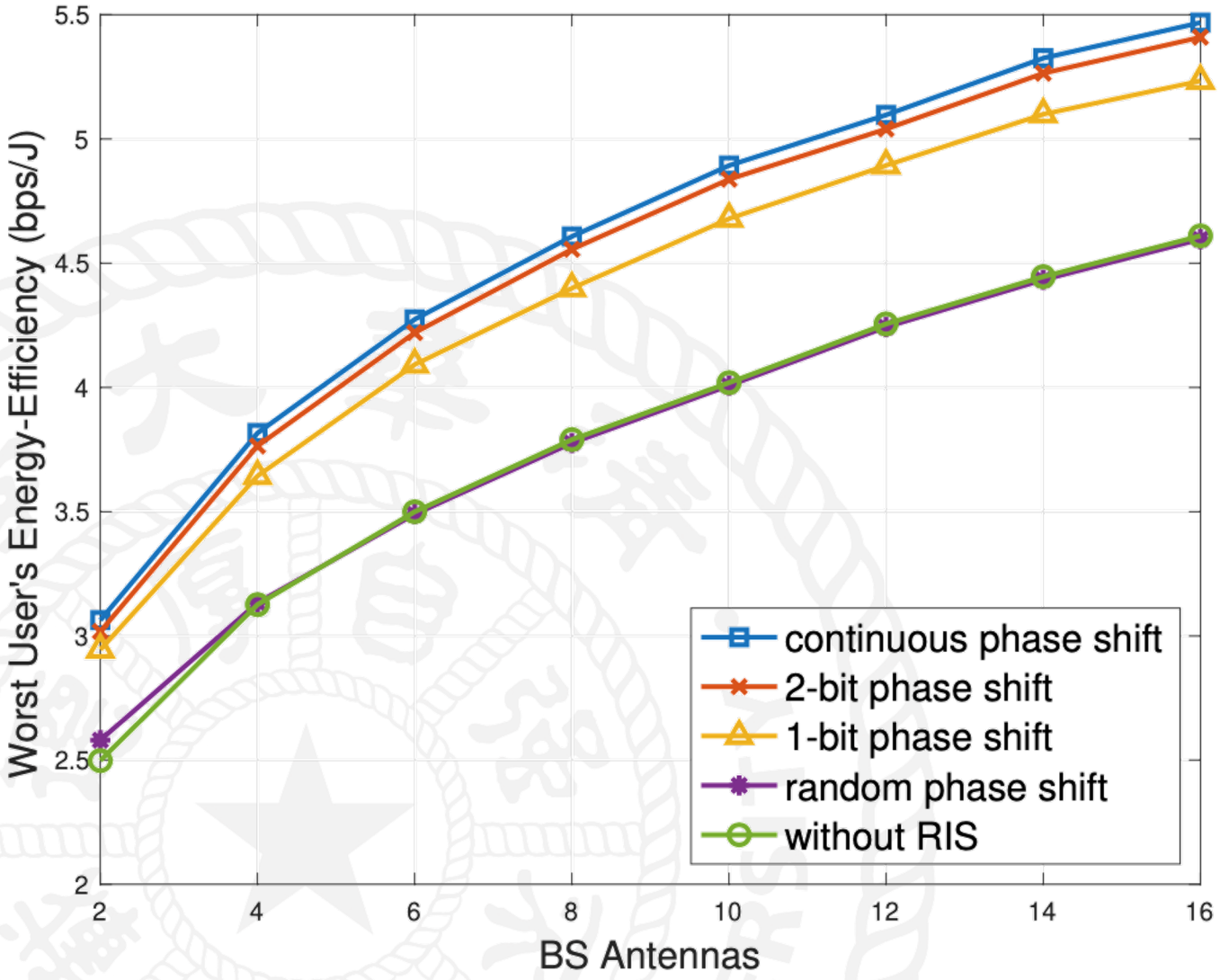
η_k → Fractional Prg. → DinkelBach Alg.

C4 → Mixed-Integer → Relaxation

C5 → Nonconvex Con. → MM Alg.

The optimal solution gives a resource allocation algorithm

Simulation Results



Con 1. **Inputting hardware or software resources can enhance the system.**

Con 2. **The RIS-aided network performs better even when the RIS hardware is not ideal.**

Con 3. **RIS precoding is essential to the performance of the RIS-aided network.**

Wrap Up

- **RIS:** Increasing network capacity with low cost and consumption
- **Energy-Efficiency Fairness Network:**
- **Proposed Algorithm:** Decouple the optimization problem
- **Simulations:** Better performance compared to traditional network

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