Structured Massive Access for Scalable Cell-Free Massive MIMO Systems

Shuaifei Chen*, Jiayi Zhang, Jing Zhang, Emil Björnson, Bo Ai

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BEIJING JIAOTONG UNIVERSITY

Outline

- Introduction
- Scalable Access
- Numerical Results
- Conclusions

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Index Terms— Beyond 5G network, cell-free massive MIMO, massive access, AP selection, pilot assignment, user-centric network.

I. Introduction

CELLULAR massive multiple-input multiple-output (MIMO) is recognized as a component of the fifth-generation (5G) networks [1]–[5]. Looking into the future, beyond 5G networks are expected to handle a significantly larger number of accessing users and deliver higher data rates, while providing a more uniform quality-of-service (QoS) throughout the entire network [6]. These goals can be potentially be achieved by cell-free massive MIMO [7]–[10], which inherits several virtues from cellular massive MIMO (in particularly *favorable propagation*) while being capable of reaching the beyond 5G requirements.

The basic idea of cell-free massive MIMO is to deploy a large number of access points (APs), which are arbitrarily distributed in the coverage area and connected to a central processing unit (CPU). Under the coordination and computational assistance from the CPU, the APs jointly serve all user equipments (UEs) on the same time-frequency resource by coherent joint transmission and reception [11]–[13]. Hence, cell-free massive MIMO can be viewed as a structured approach to massive access. Firstly, its macro-diversity can greatly improve the coverage probability compared to cellular

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1. Why Do We Fail to Access?

Spectral Efficiency (SE) [bit/s/Hz]

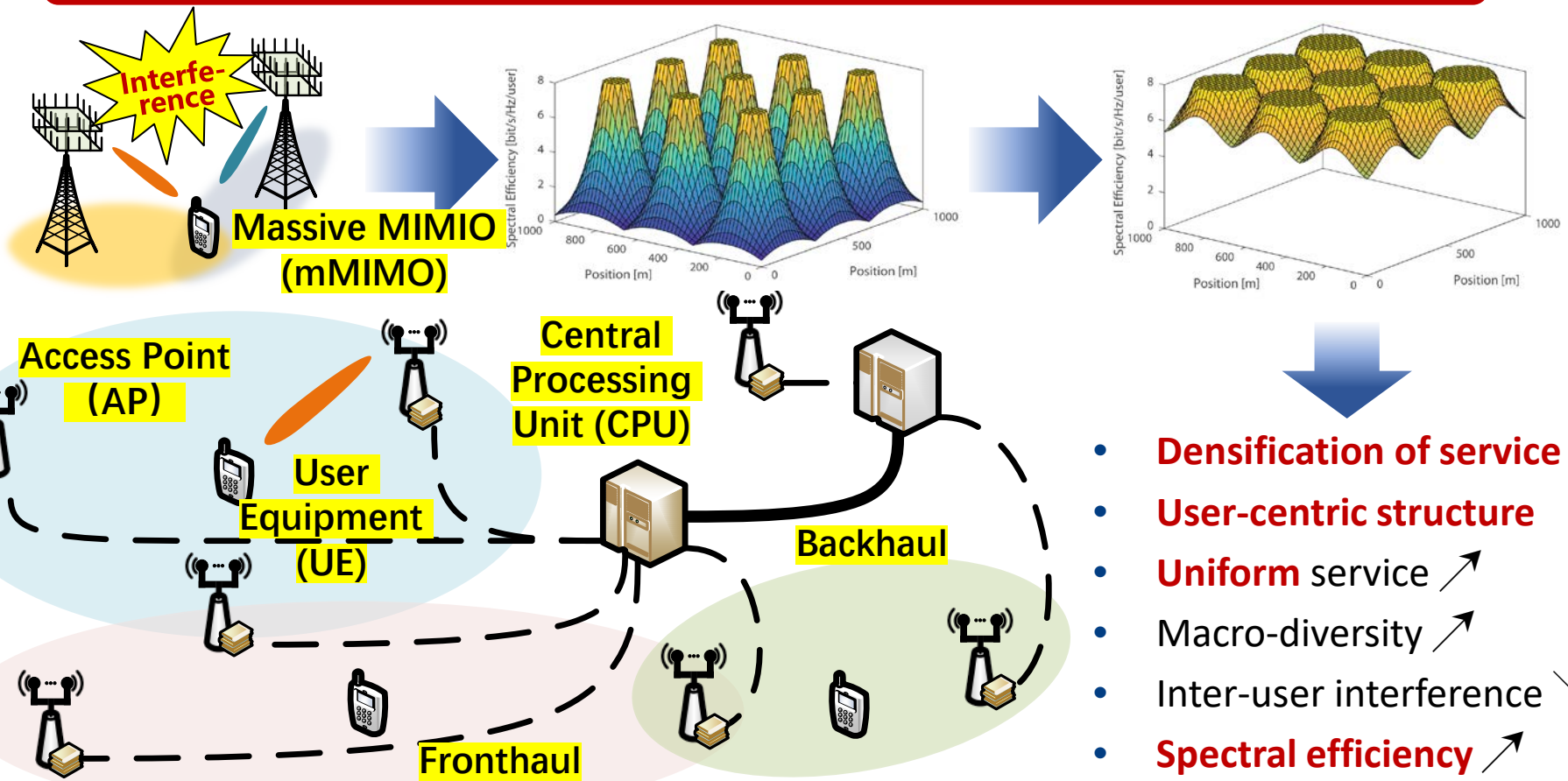
SE indicates how **FAST** it can reliably transmit over the wireless channel [1].

$$SE \propto \log_2\left(1+\frac{\text{Signal}}{\text{Interference}+\text{Noise}}\right)$$

[1] E. Björnson, *et al*, "Massive MIMO networks: Spectral, energy, and hardware efficiency, " *Foundations and Trends® in Signal Processing*, 2017.

1. Cell-free versus Small Cells

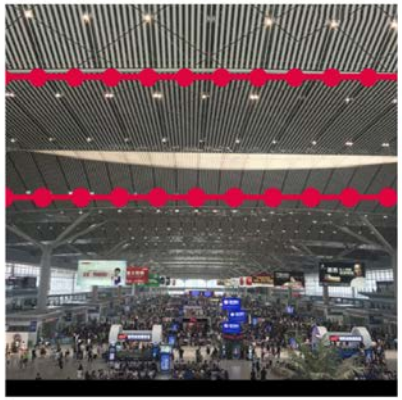
Cell-free Massive MIMIO (CF mMIMO) is recognized as one of the key enablers for 6G [2]

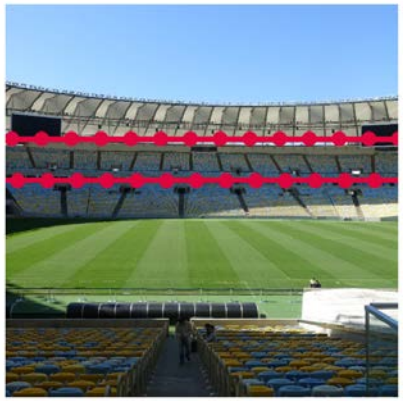


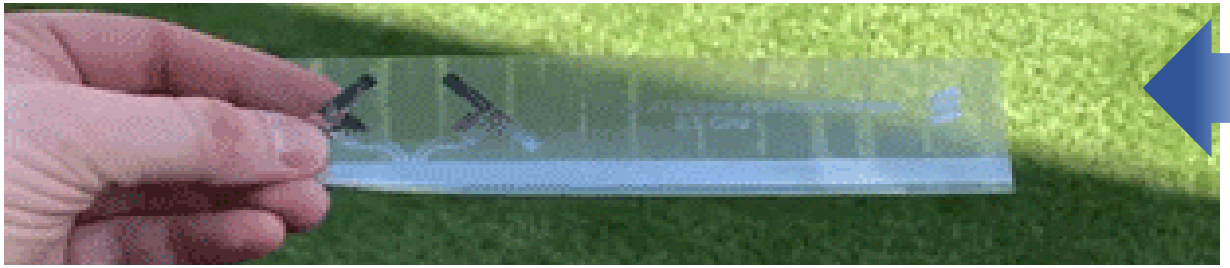
- **Densification of service**
- **User-centric structure**
- **Uniform** service ↗
- Macro-diversity ↗
- Inter-user interference ↘
- **Spectral efficiency** ↗

[2] Z. Pan, et al, "Towards 6G wireless communication networks: Vision, enabling technologies, and new paradigm shifts, " *SCIC*, 2020.

1. Flexible Application and Deployment







Can be implemented at

- **Campuses**
- **Railway stations**
- **Stadiums, etc.**

Prof. Emil Björnson (IEEE Fellow) demonstrating a prototype

[3] **Shuaifei Chen**, Jiayi Zhang, Jing Zhang, E. Björnson, Bo Ai, "A Survey on User-Centric Cell-Free Massive MIMO Systems," *DCN*, 2021.

1. Structured Massive Access for CF mMIMO

- **Scientific issues**
  - **Limited access resources vs. numerous UEs**
  - UEs reuse pilot sequences and cause **pilot contamination**
- **Challenges**
  - **Interferences** among different AP-UE pairs are **coupled**
  - Conventional distributed schemes **cannot suppress interference** effectively
  - Centralized schemes are with **heavy computation complexities**, which increase as the network scales, and thus are **not scalable**
- **Contributions**
  - **Quantify interferences** among the UEs by considering the **spatial differences** of the communication devices in the network
  - Propose a novel access scheme for **joint AP selection and pilot assignment** by exploiting the **sparsity of the AP-UE association**

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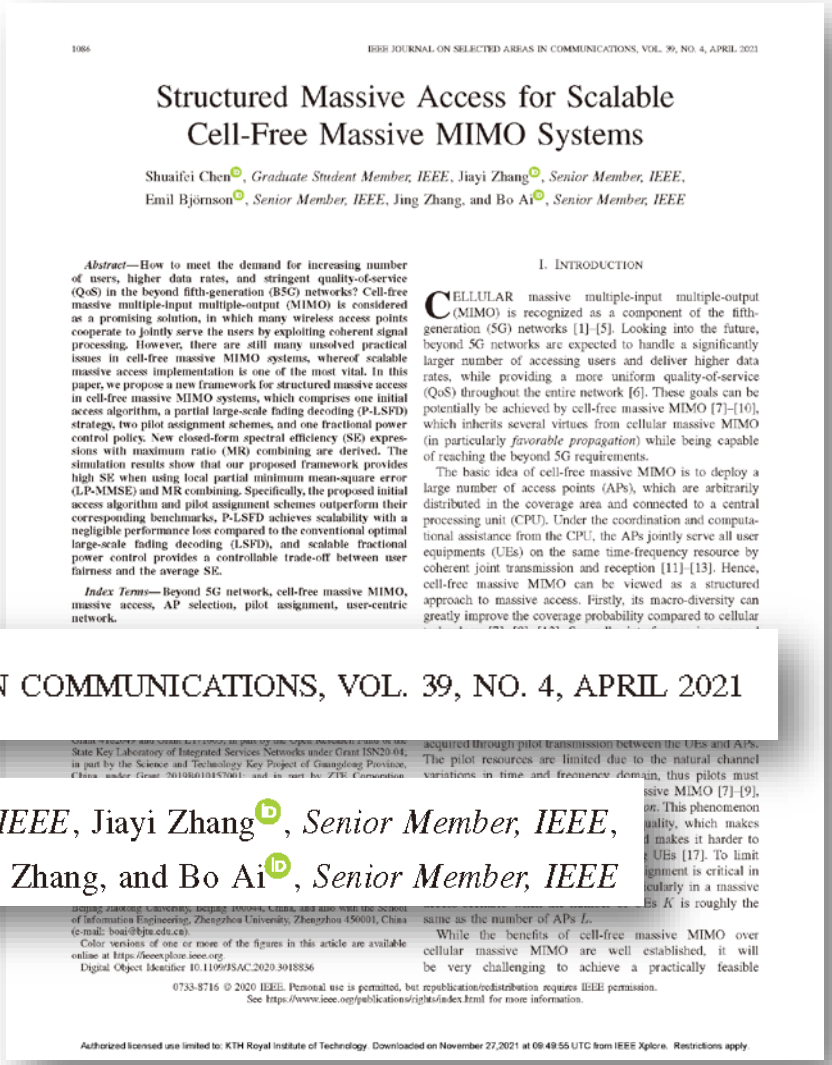

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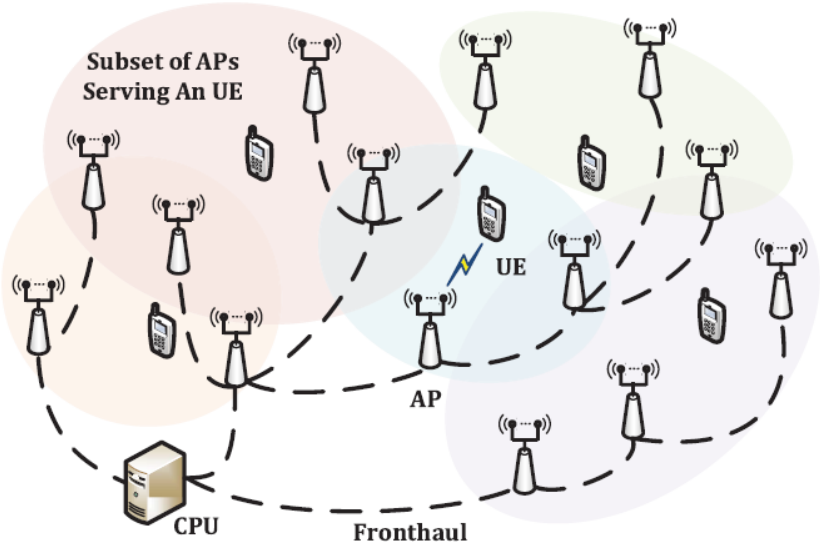
2. Initial Access and AP Selection

- **Constraints should be met**
  - Each UE is associated with **at least one AP**
  - Each AP serves **at most one UE per pilot**
- **Basic Ideas**
  - Each UE accesses more APs as possible
  - UEs **compete** when an AP is about to serve more than one UE per pilot
  - UE with **strong channel condition** wins the competition
  - A UE is **protected from competition** when it has lost all competitions it participated

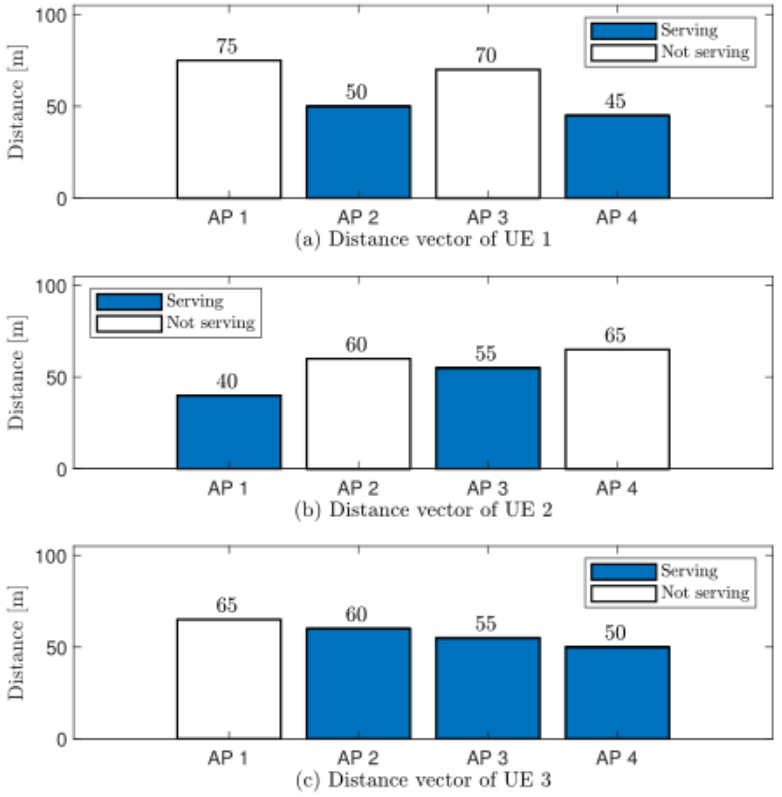
2. Pilot assignment



	UE_1	UE_2	UE_3	UE_4	UE_5
AP_1	1	1	0	0	0
AP_2	0	1	0	1	0
AP_3	0	0	1	0	0
AP_4	0	0	0	1	1
AP_5	1	1	0	0	0
AP_6	0	0	1	0	0
AP_7	0	1	0	0	1
AP_8	0	0	1	0	1
AP_9	1	0	0	0	0

Sparse AP-UE association

- Each AP serves **at most one UE per pilot**

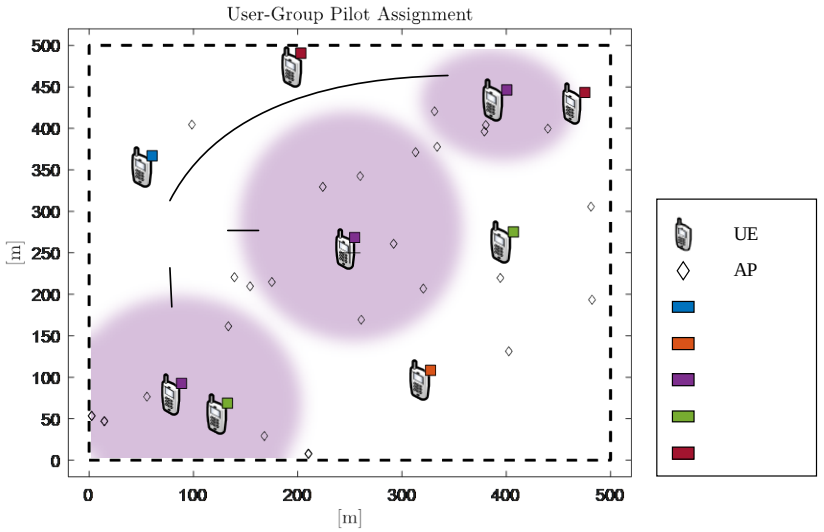


- **Metric for mutual interference**

$$\mathrm{Dis}_{ik} = \left\| \mathrm{diag}\left(\mathbf{d}_i\right) \mathbf{A}_{\cdot i} - \mathrm{diag}\left(\mathbf{d}_k\right) \mathbf{A}_{\cdot k} \right\|_2^2 ;$$

2. Pilot assignment

- **Constraints should be met**
  - Each AP serves **at most one UE per pilot**
- **Basic Ideas**
  - UEs **unlikely** generate interference are clustered and **share the same pilot**
  - Pilots are **reused across the clusters**
  - UEs with the **minimum intersections of serving APs** will generate least interference if the share one pilot
  - **Dynamically** form UE clusters



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AP_8	0	0	1	0	1
AP_9	1	0	0	0	0

Sparse AP-UE association

[4] **Shuaifei Chen**, Jiayi Zhang , E. Björnson, Jing Zhang, Bo Ai, " Structured massive access for scalable cell-free massive MIMO systems," *IEEE JSAC*, 2021.

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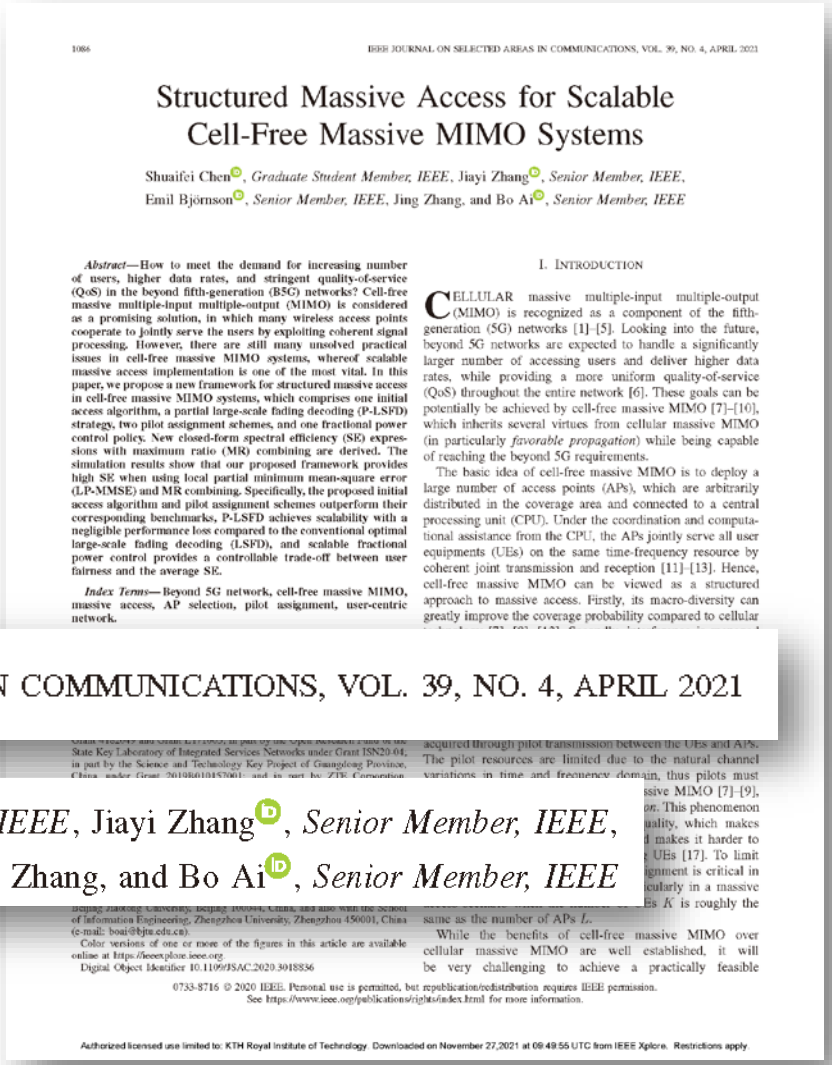

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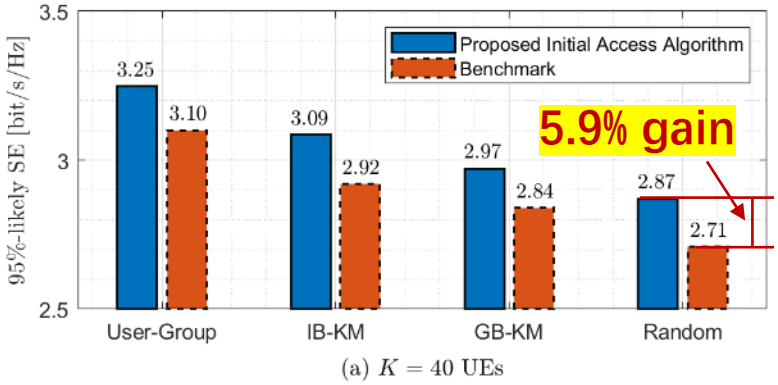
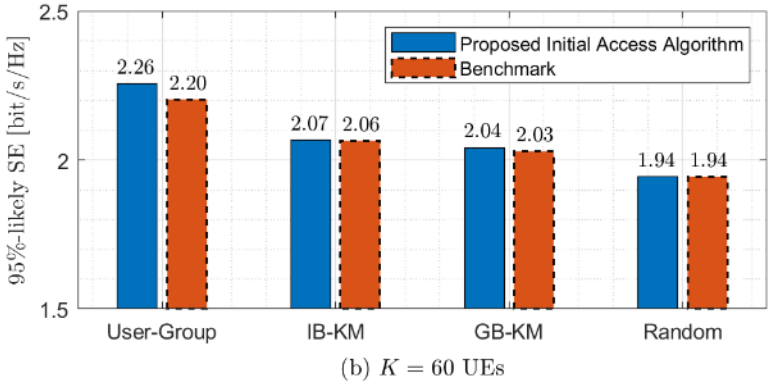
3. Proposed Access Scheme Increases SE

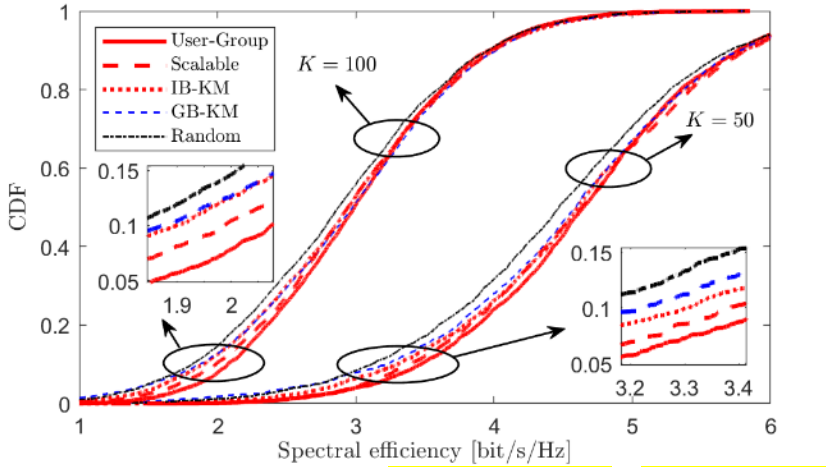


(a) $K = 40$ UEs



(b) $K = 60$ UEs

Competition-based initial access increases SE



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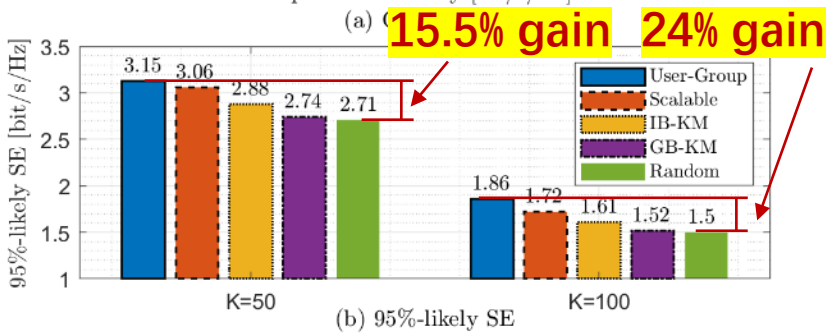

(b) 95%-likely SE

Cluster-based pilot assignment increases SE

[5] E. Björnson, et al, " Scalable cell-free massive MIMO systems," *IEEE TCOM*, 2020.

[6] M. Attarifar, et al, " Random vs structured pilot assignment in cell-free massive MIMO wireless networks," *IEEE ICC*, 2018.

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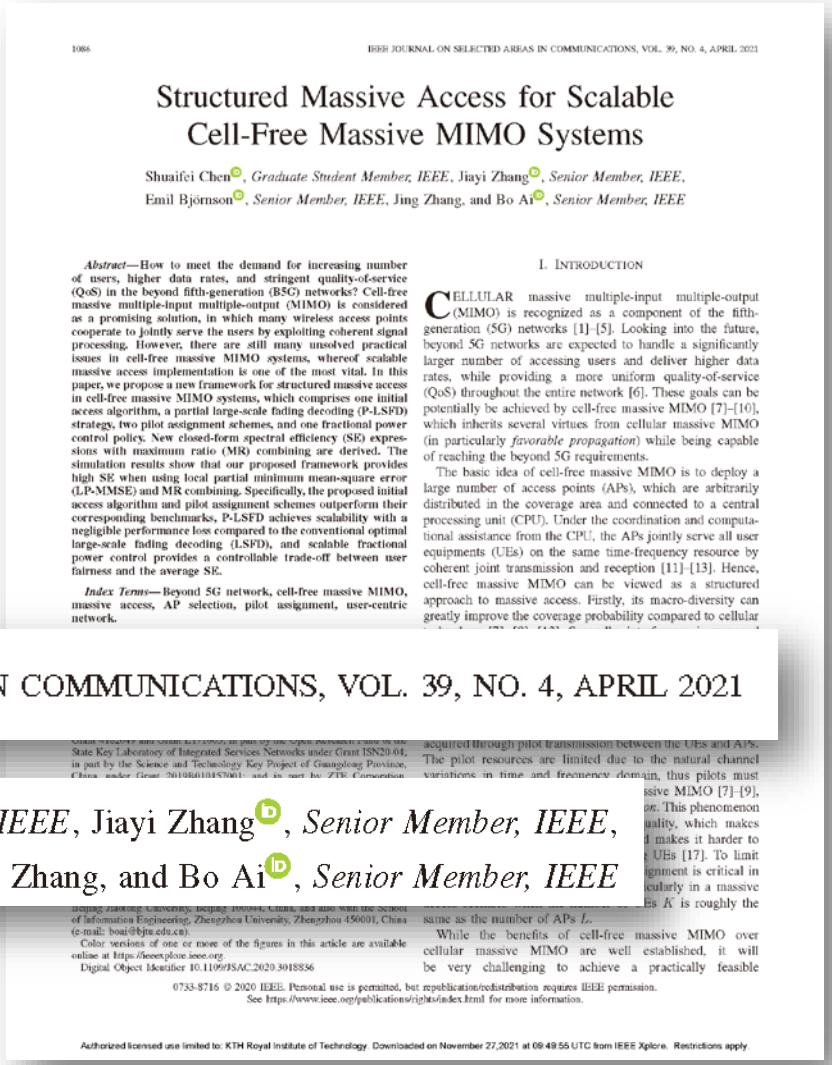

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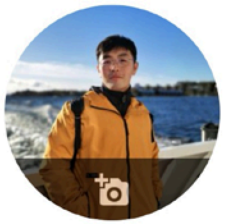
4. Conclusions

In this work, we investigated the massive access in a CF mMIMO system, mainly

- Proposed a massive access scheme for joint AP selection and pilot assignment
- Quantified the interferences among the UEs
- Revealed the sparse feature of the AP-UE association
- Developed algorithms for the AP selection and pilot assignment by exploiting the spatial differences and sparsity feature
- Validated the advantages of our proposed access scheme with numerical results

End



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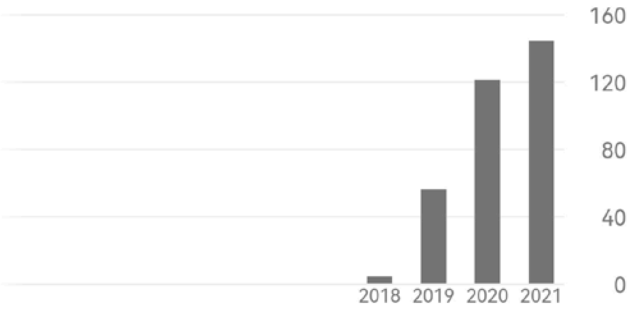
h 指数	7	7
i10 指数	7	7



Google Scholar:

https://scholar.google.com/citations?user=hikpVewAAAAJ&hl=zh-CN

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