

Yingliang XIAN, Yaqian YI, Guangchi ZHANG, Miao CUI, Qingqing WU, Xiaoli XU, Yong ZENG, 2025. QoS-aware multi-user scheduling and power control for modular XL-MIMO communications. *Frontiers of Information Technology & Electronic Engineering*, 26(11):2353-2364. <https://doi.org/10.1631/FITEE.2500333>

QoS-aware multi-user scheduling and power control for modular XL-MIMO communications

Key words: Extremely large-scale multiple-input multiple-output (XL-MIMO); User scheduling; Power control; Near-field communication; Modular array; Interference suppression

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Motivation

Targeting the inadequacy of conventional far-field-based user scheduling methods in near-field extremely large-scale multiple-input multiple-output (XL-MIMO) systems, where inter-user interference depends jointly on angular and distance domains, a quality-of-service (QoS)-aware joint user scheduling and power control framework is proposed to effectively suppress near-field interference and support dense-user communications.

Main idea

- A QoS-aware joint user scheduling and power control framework for near-field XL-MIMO systems is proposed, which maximizes the sum spectral efficiency while satisfying users' QoS requirements.
- A spatial correlation-based scheduling (SCS) algorithm is developed by exploiting the angular–distance dual-domain characteristics of near-field beam focusing, effectively suppressing inter-user interference.
- The proposed framework is further extended to modular XL-MIMO systems, where an adapted SCS-mod algorithm leverages modular array deployment to enhance spatial resolution and multi-user multiplexing capability.

Method

- A near-field XL-MIMO downlink system is modeled using the uniform spherical wave channel.
- A user scheduling algorithm based on spatial correlation is designed, which selects users according to angular resolution and range domain discrimination criteria.
- Zero-forcing precoding is employed to eliminate inter-user interference, and a dynamic power allocation strategy is applied under QoS and transmit power constraints.
- An iterative user deletion process is introduced to ensure feasibility, and the proposed method is extended to a modular XL-MIMO architecture.

Method

Algorithm 3 Proposed algorithm for P0

Input: The set of all users \mathcal{S} ; the spatial angular resolution $\Delta_{\theta, \text{res}}$; the distance threshold parameter Z_{Δ} ; the maximum transmit power P_{\max} ; the minimum spectral efficiency requirements $\{\bar{R}_k\}_{k \in \mathcal{K}'}$

Output: The feasible set of scheduled users \mathcal{K}^* ; the allocated powers $\{p_k^*\}_{k \in \mathcal{K}^*}$

- 1: Generate the initial scheduled user set \mathcal{K}' by using Algorithm 1
 - 2: Construct the channel coefficient matrix $\mathbf{H} \in \mathbb{C}^{N \times |\mathcal{K}'|}$, and compute the minimum required total power $\sum_{k \in \mathcal{K}'} \bar{p}_k$
 - 3: **while** $\sum_{k \in \mathcal{K}'} \bar{p}_k > P_{\max}$ **do**
 - 4: Update the scheduled user set \mathcal{K}^* by deleting users according to Algorithm 2, and recompute $\sum_{k \in \mathcal{K}^*} \bar{p}_k$
 - 5: **end while**
 - 6: Obtain a feasible scheduled user set \mathcal{K}^*
 - 7: For all $k \in \mathcal{K}^*$, obtain p_k^* according to Eq. (18)
 - 8: **return:** \mathcal{K}^* ; $\{p_k^*\}_{k \in \mathcal{K}^*}$
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The optimization problem P0:

$$\max_{\mathcal{K}, \{\mathbf{f}_k\}_{k \in \mathcal{K}}} \sum_{k \in \mathcal{K}} R_k \quad (6a)$$

$$\text{s.t.} \quad R_k \geq \bar{R}_k, \quad \forall k \in \mathcal{K}, \quad (6b)$$

$$\sum_{k \in \mathcal{K}} \|\mathbf{f}_k\|_2^2 \leq P_{\max}, \quad (6c)$$

$$\mathcal{K} \subseteq \mathcal{S}, \quad (6d)$$

Results

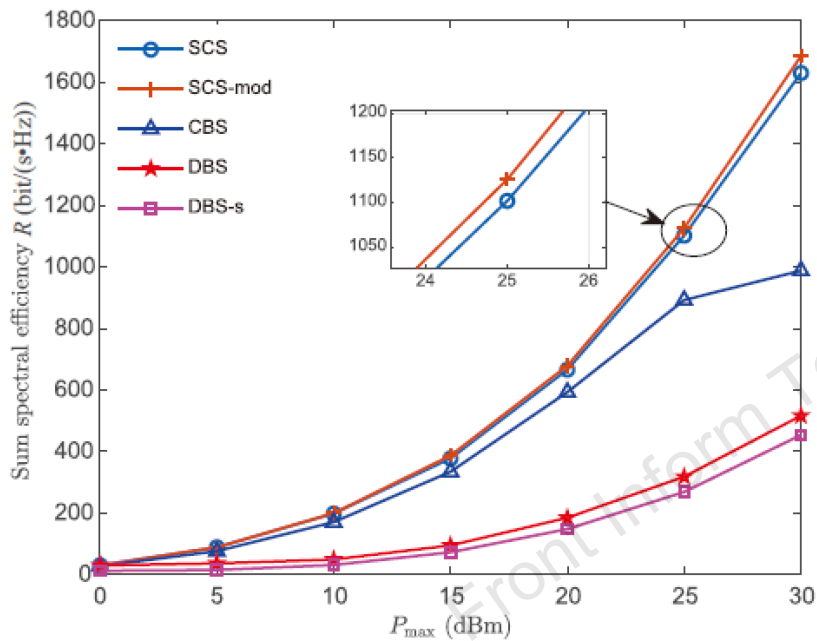


Fig. 3 Sum spectral efficiency vs. transmit power P_{\max} for $\bar{R}_k = 15$ bit/(s·Hz)

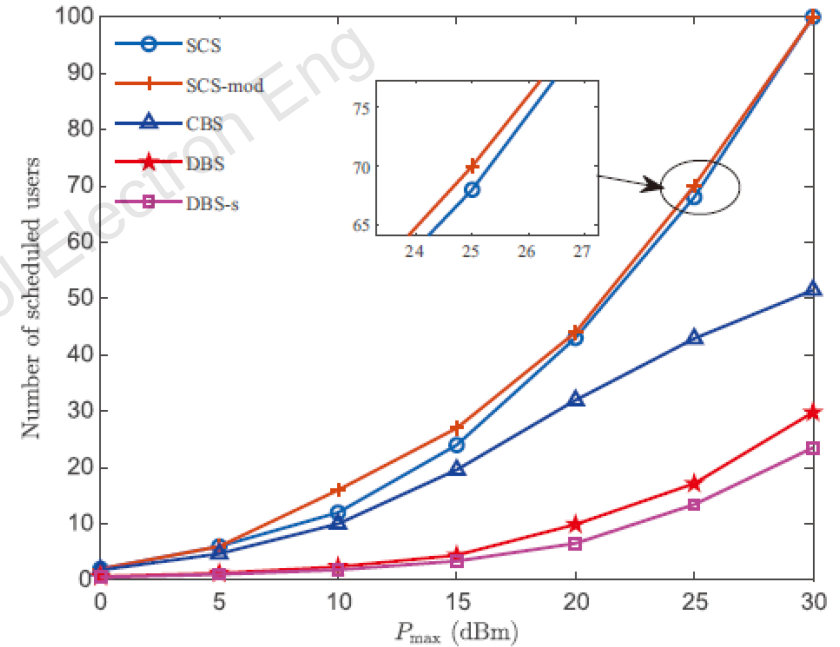


Fig. 4 Number of scheduled users vs. transmit power P_{\max} for $\bar{R}_k = 15$ bit/(s·Hz)

Results

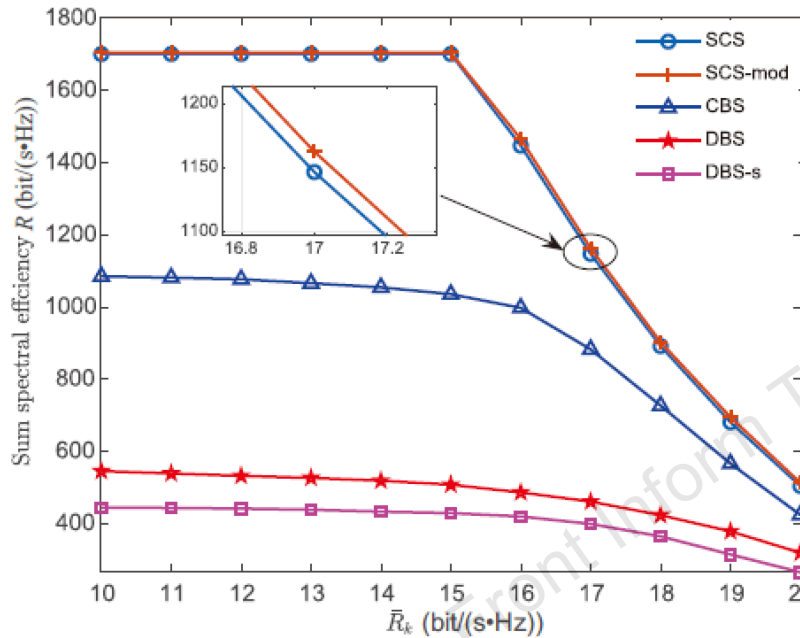


Fig. 5 Sum spectral efficiency vs. minimum spectral efficiency requirement \bar{R}_k for $P_{\max} = 30$ dBm

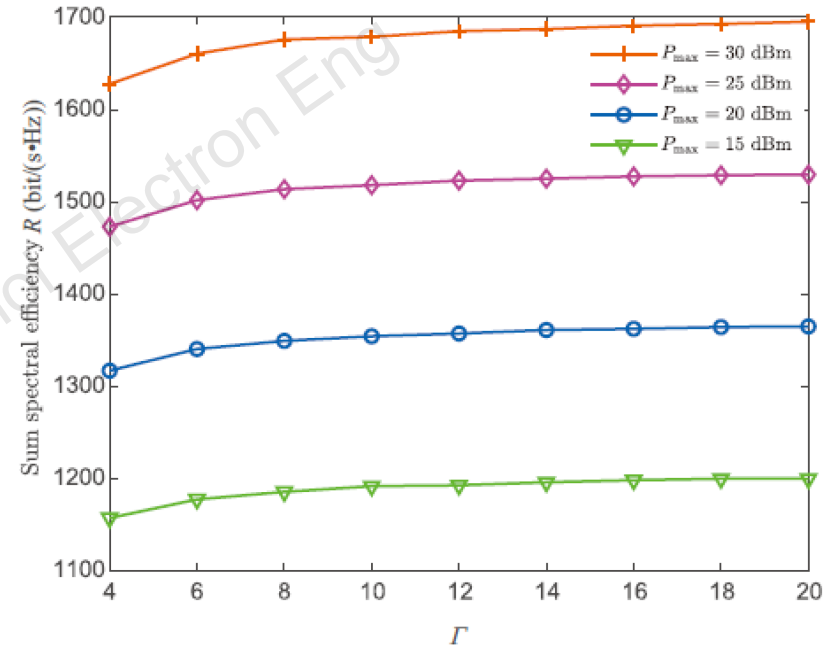


Fig. 6 Sum spectral efficiency vs. different module spacings for $\bar{R}_k = 10$ bit/(s·Hz)

Results

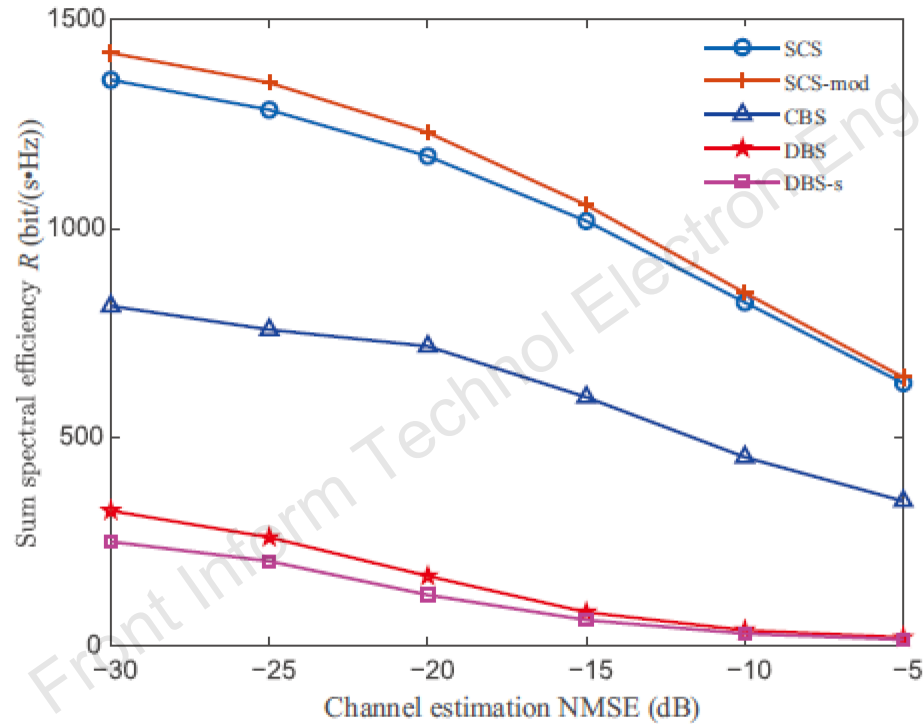


Fig. 7 Sum spectral efficiency vs. channel estimation NMSE for $P_{\max} = 30$ dBm

Conclusions

In this work, we proposed a QoS-aware joint user scheduling and power control algorithm (SCS) that maximizes sum spectral efficiency while meeting user QoS. The SCS algorithm employed a spatial correlation-based selection strategy, considering both angular and distance domains, to mitigate IUI. We further extended this framework to modular XL-MIMO architectures with an adapted algorithm (SCS-mod). This SCS-mod algorithm leveraged the distinct spatial characteristics of modular uniform linear arrays (mULAs), to enhance user discrimination and interference suppression.



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