

Statistical-CSI-Based RIS User Clustering: From Interference-Free TDMA to Simultaneous Multiuser Transmission

Pedro Lucas Teixeira Segal, José Carlos Marinello Filho

Abstract—Reconfigurable intelligent surfaces (RISs) can improve wireless coverage and spectral efficiency, but practical deployments are limited by channel estimation overhead and by the number of RIS reconfigurations within a transmission frame. Statistical channel state information (S-CSI) is a low-overhead alternative for RIS phase-shift design and user clustering. Previous work showed that S-CSI-based minimum-distance (minD) clustering performs close to perfect CSI (P-CSI)-based methods in interference-free time division multiple access (TDMA) operation. This paper investigates the extension of that framework to simultaneous multiuser transmission, where users assigned to the same cluster are served in the same time slot under a common RIS configuration. The analysis is reformulated from signal-to-noise ratio (SNR) to signal-to-interference-plus-noise ratio (SINR), accounting for multiuser interference and spatial correlation. Numerical results show that, for the considered setup, the prelog gain obtained by reducing the number of time slots does not compensate for the interference penalty. Thus, the analysis identifies an operational boundary for the S-CSI/minD framework: it is effective for sharing RIS configurations among temporally multiplexed users, but serving one user per slot remains the most effective strategy when multiuser interference is significant.

Keywords—Reconfigurable intelligent surface, statistical CSI, user clustering, TDMA, multiuser interference, SINR.

I. INTRODUCTION

Reconfigurable intelligent surfaces (RISs) have emerged as a promising technology for beyond-fifth-generation (B5G) and sixth-generation (6G) wireless networks, since they can reshape the wireless propagation environment through nearly passive reflecting elements [1], [2], [3]. By adjusting their phase shifts, RISs can enhance coverage and spectral efficiency, especially when the direct link between the base station (BS) and the users is severely blocked.

Practical RIS-assisted systems are constrained by channel estimation overhead, hardware limitations, and the finite rate and latency of the RIS control link. Since instantaneous or perfect CSI (P-CSI) acquisition becomes increasingly costly as the number of reflecting elements grows, large-scale RIS deployments require strategies that reduce channel acquisition and reconfiguration overhead [4]. In addition, RIS prototypes show that reconfiguration time and control signaling must be considered in practical designs [5]. A natural approach is to

limit the number of RIS configurations within a frame and group users that can share the same phase shifts [6], [7].

Statistical CSI (S-CSI) provides a low-overhead alternative for RIS phase-shift design and user clustering, since it relies on long-term propagation features rather than instantaneous channel realizations [8], [9]. In [10], an S-CSI-based minimum-distance (minD) clustering method was proposed for RIS-assisted TDMA systems with limited RIS reconfiguration. In that interference-free regime, users sharing the same RIS configuration are still served orthogonally in time, and the method achieves performance close to P-CSI-based approaches while reducing CSI acquisition overhead.

However, the interference-free TDMA formulation also imposes a temporal resource penalty, since users are served one at a time. A natural but nontrivial extension is to serve multiple users assigned to the same cluster simultaneously under the same RIS configuration, reducing the number of required time slots from the number of users to the number of clusters. In this case, the gain in the prelog factor must be weighed against the additional multiuser interference introduced by resource sharing. Therefore, unlike the interference-free formulation in [10], performance must be evaluated through a signal-to-interference-plus-noise ratio (SINR)-based analysis that accounts for channel covariance and spatial correlation among users.

This paper investigates the extension of the S-CSI-based minD framework of [10] from interference-free TDMA operation to simultaneous multiuser transmission. The main contribution is to analyze this operational transition by reformulating the SNR-based analysis into an SINR-based framework that incorporates equivalent channel covariance, intra-cluster interference, and spatial correlation. The objective is to assess whether the reduction in the number of transmission time slots can compensate for the additional interference introduced by simultaneous service. The results show that, for the considered setup, the prelog gain obtained from simultaneous transmission does not compensate for the interference penalty, and serving one user per time slot remains the most effective strategy. This analysis identifies an operational boundary for the S-CSI/minD framework under limited RIS reconfiguration.

II. SYSTEM MODEL

We consider a downlink RIS-assisted wireless communication system composed of a BS, an RIS, and K single-antenna users. The BS is equipped with M antennas arranged as a

Pedro Lucas Teixeira Segal and José Carlos Marinello Filho are with the Department of Electrical Engineering, Federal University of Technology – Paraná (UTFPR), Cornélio Procopio, PR, Brazil, e-mails: pedrosegal@alunos.utfpr.edu.br, jcmarinello@utfpr.edu.br. This work was partially supported by CNPq through Grant No. 310996/2025-2.

uniform linear array (ULA), while the RIS has $N = N_h N_v$ passive reflecting elements arranged as a uniform planar array (UPA). The set of users is denoted by $\mathcal{K} = \{1, \dots, K\}$.

The direct BS–user links are assumed to be blocked, so that communication occurs through the RIS-assisted cascaded channel. Each RIS element applies an independently controllable unit-modulus phase shift. The RIS configuration associated with the z -th transmission interval is denoted by

$$\phi_z = [e^{j\theta_{z,1}}, e^{j\theta_{z,2}}, \dots, e^{j\theta_{z,N}}]^T. \quad (1)$$

Let $\mathbf{H}_r \in \mathbb{C}^{M \times N}$ denote the BS–RIS channel matrix and $\mathbf{h}_{r,k} \in \mathbb{C}^{N \times 1}$ denote the RIS–user channel vector of user k . When user k is served under the RIS configuration ϕ_z , the equivalent cascaded channel is

$$\mathbf{h}_{eq,k}(\phi_z) = \mathbf{H}_r \text{diag}(\phi_z) \mathbf{h}_{r,k}. \quad (2)$$

The received baseband signal at user k in an interference-free transmission interval is

$$y_k = \sqrt{\rho_k} (\mathbf{H}_r \text{diag}(\phi_k) \mathbf{h}_{r,k})^H \mathbf{w}_k x_k + n_k, \quad (3)$$

where ρ_k is the downlink transmit power, $\mathbf{w}_k \in \mathbb{C}^{M \times 1}$ is the BS precoding vector with $\|\mathbf{w}_k\| = 1$, x_k is the transmitted symbol with $\mathbb{E}\{|x_k|^2\} = 1$, and $n_k \sim \mathcal{CN}(0, \sigma_n^2)$ is additive white Gaussian noise.

A. Channel Model

The BS–RIS link is modeled as a Rician fading channel,

$$\mathbf{H}_r = \sqrt{\beta_r^{BR}} \left(\sqrt{\frac{\alpha_r^{BR}}{1 + \alpha_r^{BR}}} \mathbf{H}_r^{\text{LoS}} + \sqrt{\frac{1}{1 + \alpha_r^{BR}}} \mathbf{H}_r^{\text{NLoS}} \right), \quad (4)$$

where β_r^{BR} is the large-scale fading coefficient, α_r^{BR} is the BS–RIS Rician factor, and $\mathbf{H}_r^{\text{NLoS}}$ is the random scattering component with independent entries distributed as $\mathcal{CN}(0, 1)$.

The deterministic LoS component of the BS–RIS channel is

$$\mathbf{H}_r^{\text{LoS}} = \mathbf{a}_B(\vartheta_r^B) \mathbf{a}_R(\vartheta_r^R, \varphi_r^R)^H, \quad (5)$$

where ϑ_r^B is the azimuth angle of departure from the BS toward the RIS, while ϑ_r^R and φ_r^R are the azimuth and elevation angles of arrival at the RIS, respectively.

The RIS–user channel also follows a Rician fading model,

$$\mathbf{h}_{r,k} = \sqrt{\beta_k^{RU}} \left[\sqrt{\frac{\alpha_k^{RU}}{1 + \alpha_k^{RU}}} \mathbf{h}_k^{\text{LoS}} + \sqrt{\frac{1}{1 + \alpha_k^{RU}}} \mathbf{h}_k^{\text{NLoS}} \right], \quad (6)$$

where β_k^{RU} is the large-scale fading coefficient, α_k^{RU} is the RIS–user Rician factor, and $\mathbf{h}_k^{\text{NLoS}} \sim \mathcal{CN}(\mathbf{0}_N, \mathbf{I}_N)$.

The deterministic LoS component of the RIS–user channel is

$$\mathbf{h}_k^{\text{LoS}} = \mathbf{a}_R(\vartheta_k^R, \varphi_k^R), \quad (7)$$

where ϑ_k^R and φ_k^R are the azimuth and elevation angles of departure from the RIS toward user k , respectively.

The vectors $\mathbf{a}_B(\cdot)$ and $\mathbf{a}_R(\cdot, \cdot)$ denote the standard ULA and UPA array responses, respectively. The large-scale fading coefficients follow the power-law model $\beta = \beta_0 d^{-\kappa}$, with

link-dependent distance d , path loss exponent κ , and path loss at a reference distance of 1m β_0 .

Given the downlink signal model in (3), the SNR of user k under RIS configuration ϕ_k is

$$\gamma_k(\phi_k) = \frac{\rho_k}{\sigma_n^2} \left| (\mathbf{H}_r \text{diag}(\phi_k) \mathbf{h}_{r,k})^H \mathbf{w}_k \right|^2. \quad (8)$$

B. Limited RIS Reconfiguration

We assume that only Z distinct RIS configurations are available within a transmission frame, with $Z \leq K$. The users are divided into Z disjoint clusters $\mathcal{U}_1, \dots, \mathcal{U}_Z$, such that

$$\bigcup_{z=1}^Z \mathcal{U}_z = \mathcal{K}, \quad \mathcal{U}_i \cap \mathcal{U}_j = \emptyset, \quad i \neq j. \quad (9)$$

Each cluster $\mathcal{U}_z$ is associated with a single RIS configuration ϕ^z , which remains fixed during the corresponding transmission interval. Thus, $\phi_k = \phi^z$ for all $k \in \mathcal{U}_z$.

In the strict TDMA formulation, each user is served individually in time. The sum spectral efficiency is

$$SE_{\text{TDMA}} = \frac{\tau_c - \tau_p}{K \tau_c} \sum_{z=1}^Z \sum_{k \in \mathcal{U}_z} \log_2(1 + \gamma_k(\phi^z)), \quad (10)$$

where τ_c is the channel coherence block and τ_p is the pilot sequence length.

III. S-CSI-BASED RIS CONFIGURATION AND USER CLUSTERING

The S-CSI-based RIS phase-shift design and minD user clustering method adopted in this paper were originally proposed in [10] for RIS-assisted TDMA systems with a limited number of RIS reconfigurations. In that interference-free regime, users sharing the same RIS configuration are still served orthogonally in time. Here, we use this method as a starting point to investigate whether users assigned to the same cluster can be served simultaneously under a common RIS configuration, making better use of temporal resources.

A. S-CSI-Based RIS Phase-Shift Design

The use of P-CSI for RIS phase-shift design requires estimating the BS–RIS and RIS–user channels, which leads to high overhead and frequent updates. To reduce this burden, the S-CSI-based design in [10] relies on long-term propagation features, especially the deterministic LoS components of the cascaded channel.

For user k , the RIS configuration is obtained by aligning the LoS components of the BS–RIS and RIS–user links. Thus, the RIS phase-shift vector and the BS precoder are selected as

$$\phi_k = \mathbf{a}_R(\vartheta_k^R, \varphi_k^R)^* \odot \mathbf{a}_R(\vartheta_r^R, \varphi_r^R), \quad \mathbf{w}_k = \frac{\mathbf{a}_B(\vartheta_r^B)}{\sqrt{M}}, \quad (11)$$

where $\odot$ denotes the Hadamard product.

Substituting this LoS-based design into the received signal model and retaining the deterministic components yields

$$y_k \approx \sqrt{\rho_k} \zeta_k \sqrt{M} N x_k, \quad (12)$$

where

$$\zeta_k = \sqrt{\beta_r^{BR} \beta_k^{RU} \frac{\alpha_r^{BR}}{1 + \alpha_r^{BR}} \frac{\alpha^{RU}}{1 + \alpha^{RU}}}. \quad (13)$$

To isolate the maximum coherent gain provided by the S-CSI phase alignment, consider the pure LoS condition, *i.e.*, $\alpha_r^{BR}, \alpha^{RU} \rightarrow \infty$. The resulting SNR is

$$\gamma_k(\phi_k) = \frac{\rho_k \beta_r^{BR} \beta_k^{RU} M N^2}{\sigma_n^2}. \quad (14)$$

When NLoS components are present, this S-CSI-based design may suffer some degradation compared with P-CSI-based methods. Nevertheless, it avoids the overhead associated with instantaneous channel acquisition and frequent RIS reconfiguration.

B. Minimum-Distance User Clustering

Since only Z RIS configurations are available within a frame, with $Z \leq K$, multiple users must share the same RIS phase-shift vector. Following the minD criterion in [10], the Z users with the highest individual S-CSI-based SNRs are first selected as cluster representatives. Their individual RIS configurations define the initial set

$$\mathcal{C} = \{\phi^1, \phi^2, \dots, \phi^Z\}. \quad (15)$$

Each remaining user k is assigned to the cluster whose representative RIS configuration is closest to its individual S-CSI-based configuration:

$$z' = \arg \min_{z \in \{1, \dots, Z\}} \|\phi_k - \phi^z\|^2. \quad (16)$$

After the user assignment, the RIS configuration of each cluster is updated by averaging the individual RIS configurations of its users and projecting the result onto the unit-modulus constraint:

$$\phi^z = \exp \left(j \angle \left(\frac{1}{|\mathcal{U}_z|} \sum_{k \in \mathcal{U}_z} \phi_k \right) \right). \quad (17)$$

IV. EXTENSION TO SIMULTANEOUS MULTIUSER TRANSMISSION

In the strict TDMA regime, users are served orthogonally in time and no multiuser interference is observed. However, the prelog factor is penalized by the total number of users K . To reduce this temporal resource penalty, we consider a simultaneous multiuser regime in which all users assigned to the same cluster $\mathcal{U}_z$ are served in the same time slot under the same RIS configuration ϕ_z .

In this case, the transmission frame is divided into Z time slots instead of K individual user slots. Since $Z \leq K$, simultaneous transmission improves the prelog factor. Nevertheless, users sharing the same RIS configuration interfere with each other, and the system performance must be evaluated through SINR rather than SNR.

A. Equivalent RIS-Assisted Channel

Using the Rician decompositions in (4) and (6), the equivalent channel in (2) can be characterized through its first- and second-order moments. Although the S-CSI phase-shift design relies on the dominant LoS components, the Rician characterization accounts for the random scattering components that affect the equivalent channel covariance and the resulting multiuser interference.

The mean equivalent channel is

$$\bar{\mathbf{h}}_k = \mathbb{E}[\mathbf{h}_{eq,k}] = \zeta_k \mathbf{H}_r^{\text{LoS}} \text{diag}(\phi_z) \mathbf{h}_k^{\text{LoS}}. \quad (18)$$

The covariance matrix of the equivalent channel is defined as

$$\mathbf{R}_k = \mathbb{E}[(\mathbf{h}_{eq,k} - \bar{\mathbf{h}}_k)(\mathbf{h}_{eq,k} - \bar{\mathbf{h}}_k)^H]. \quad (19)$$

The closed-form covariance follows from the LoS/NLoS decomposition of the cascaded Rician channel. Using the independence and zero-mean properties of the NLoS components, the covariance can be written as

$$\mathbf{R}_k = \beta_r^{BR} \beta_k^{RU} \left(\frac{\alpha_r^{BR}}{1 + \alpha_r^{BR}} \frac{1}{1 + \alpha^{RU}} N \mathbf{a}_B(\vartheta_r^B) \mathbf{a}_B(\vartheta_r^B)^H + \frac{N}{1 + \alpha_r^{BR}} \mathbf{I}_M \right). \quad (20)$$

B. SINR-Based Spectral Efficiency

In the simultaneous multiuser regime, the interference generated among users sharing the same time slot becomes one of the main performance-limiting factors. Therefore, the SNR is no longer representative, and the SINR must be used instead.

Following the downlink formulation with LS channel estimation [11] and adapting it to the considered single-cell RIS-assisted scenario, define

$$A_k = |\text{tr}(\mathbf{R}_k) + \|\bar{\mathbf{h}}_k\|^2|^2 \quad (21)$$

and

$$D_k = \tau_p \text{tr}(\Psi_k^{-1}) + \|\bar{\mathbf{y}}_k^p\|^2. \quad (22)$$

For user $k \in \mathcal{U}_z$, the SINR is then given by

$$\eta_k = \frac{\rho_k p_k \tau_p^2 A_k / D_k}{\sum_{i \in \mathcal{U}_z} \rho_i \frac{p_i \tau_p^2 \chi_i^{\text{dl,ls}}}{D_i} - \rho_k \frac{p_k \tau_p^2 A_k}{D_k} + \sigma^2}. \quad (23)$$

In (22),

$$\Psi_k^{-1} = p_k \tau_p \mathbf{R}_k + \sigma^2 \mathbf{I}_M \quad (24)$$

is the matrix associated with the channel estimation precision, while

$$\bar{\mathbf{y}}_k^p = \sqrt{p_k \tau_p} \bar{\mathbf{h}}_k \quad (25)$$

represents the deterministic contribution of the received pilot signal. The term $\chi_i^{\text{dl,ls}}$ accounts for the residual downlink interference associated with LS channel estimation and the corresponding precoding vector.

The sum spectral efficiency in the simultaneous multiuser regime is

$$SE_{\text{MUI}} = \frac{\tau_c - \tau_p}{Z \tau_c} \sum_{z=1}^Z \sum_{k \in \mathcal{U}_z} \log_2(1 + \eta_k). \quad (26)$$

Compared with strict TDMA, the prelog factor in (26) is improved because it depends on the number of clusters Z instead of the total number of users K . However, this gain is counterbalanced by the interference terms included in η_k .

C. Spatial Correlation Among Users

Since the spatial correlation among users in the same cluster directly affects multiuser interference, we use the average intra-cluster correlation to interpret the limits of simultaneous service. For each pair of users $k, l \in \mathcal{U}_z$, define

$$c_{k,l} = \frac{|\mathbf{h}_{eq,k}^H \mathbf{h}_{eq,l}|}{\|\mathbf{h}_{eq,k}\| \|\mathbf{h}_{eq,l}\|}. \quad (27)$$

Clusters with higher correlation tend to present stronger interference, which may reduce the gains obtained from simultaneous transmission. Thus, the average intra-cluster correlation is defined as

$$\text{Corr} = \frac{1}{Z} \sum_{z=1}^Z \begin{cases} \frac{1}{|\mathcal{U}_z|(|\mathcal{U}_z| - 1)} \sum_{\substack{k,l \in \mathcal{U}_z \\ k \neq l}} c_{k,l}, & \text{if } |\mathcal{U}_z| > 1, \\ 0, & \text{if } |\mathcal{U}_z| = 1. \end{cases} \quad (28)$$

This metric helps explain why a clustering strategy that is suitable for sharing RIS configurations in strict TDMA may not be equally effective when users are served simultaneously.

V. NUMERICAL RESULTS

This section evaluates the S-CSI-based minD framework in the simultaneous multiuser regime and compares it with the strict interference-free TDMA operation previously considered in [10]. The objective is to determine whether the prelog gain obtained by serving multiple users in the same time slot compensates for the multiuser interference introduced by resource sharing, and thus identify the best approach to serve multiple users in an RIS-assisted cellular network.

A. Simulation Setup

The numerical results consider a single-cell RIS-assisted downlink scenario with blocked direct BS–user links. Unless otherwise stated, the main simulation parameters are summarized in Table I. The RIS is positioned at a distance $d_r^{BR} = 0.7d_c$ from the BS, with BS–RIS azimuth angle of departure $\vartheta_r^B = 0$ and azimuth angle of arrival at the RIS $\vartheta_r^R = \pi/4$. The BS, RIS, and users are assumed to be at the same height; hence, the elevation angles are set to $\varphi_r^R = \varphi_k^R = 0$. The users are distributed over an annular circular sector centered at the RIS, with aperture 120° and RIS–user distances uniformly distributed in $d_{r,k}^{RU} \sim \mathcal{U}[0.1d_c, 0.4d_c]$. The results are averaged over 100 independent Monte Carlo realizations.

B. Simultaneous Multiuser Transmission and Correlation Analysis

In [10], the S-CSI-based minD strategy was evaluated under a strict TDMA regime, where users sharing the same RIS configuration are still served orthogonally in time. In

that interference-free case, the method achieved performance close to P-CSI-based approaches while avoiding the overhead associated with instantaneous CSI acquisition. Here, we use that regime as a reference and focus on the simultaneous multiuser extension, in which all users assigned to the same cluster are served in the same time slot under a common RIS configuration.

Fig. 1a shows the sum spectral efficiency versus the number of RIS configurations Z for the S-CSI- and P-CSI-based minD methods and random user clustering (Random). Increasing Z improves performance because fewer users share the same RIS configuration and time slot, reducing intra-cluster interference. Nevertheless, the spectral efficiency remains strongly interference-limited for smaller Z , where more users coexist under the same RIS state.

An important observation is that the S-CSI-based minD strategy may outperform its P-CSI-based counterpart in this interference-limited regime. This suggests that P-CSI-based clustering, by favoring instantaneous channel gain, may group users with overly similar spatial signatures, increasing intra-cluster correlation and, consequently, multiuser interference.

To support this interpretation, Fig. 1b shows the average intra-cluster channel correlation, which is directly related to the interference experienced by users sharing the same RIS configuration. The results indicate that strategies with higher intra-cluster correlation tend to be more interference-limited, explaining why maximizing instantaneous channel gain does not necessarily yield the highest spectral efficiency under simultaneous transmission. Since correlated equivalent channels are harder to separate spatially, the resulting interference reduces the benefits expected from the improved prelog factor.

C. TDMA versus Simultaneous Multiuser Transmission

Fig. 1c directly compares the strict TDMA reference and the simultaneous multiuser regime. The simultaneous regime reduces the number of required transmission intervals from K user slots to Z cluster slots, which improves the prelog factor and partially mitigates the temporal penalty associated with limited RIS reconfiguration. However, this gain is outweighed by the additional intra-cluster interference introduced when

TABLE I
SIMULATION PARAMETERS

Parameter	Value
Users	$K = 100$
BS antennas	$M = 128$
RIS elements	$N = 256$ (16×16)
Carrier frequency	$f_c = 3$ GHz
Bandwidth	$B = 10$ MHz
Cell radius	$d_c = 150$ m
BS–RIS distance	$d_r^{BR} = 0.7d_c$
Transmit power	$\rho = 2$ W
Path loss at 1 m	$\beta_0 = -35.3$ dB
Path loss exponents	$\kappa_{BR} = \kappa_{RU} = 2.30$
Rician factors	$\alpha_r^{BR} = \alpha_r^{RU} = 5$ dB
Noise PSD / noise figure	-174 dBm/Hz / 10 dB
Coherence block	$\tau_c = 200$
Pilot length	$\tau_p = 100$
Monte Carlo realizations	100

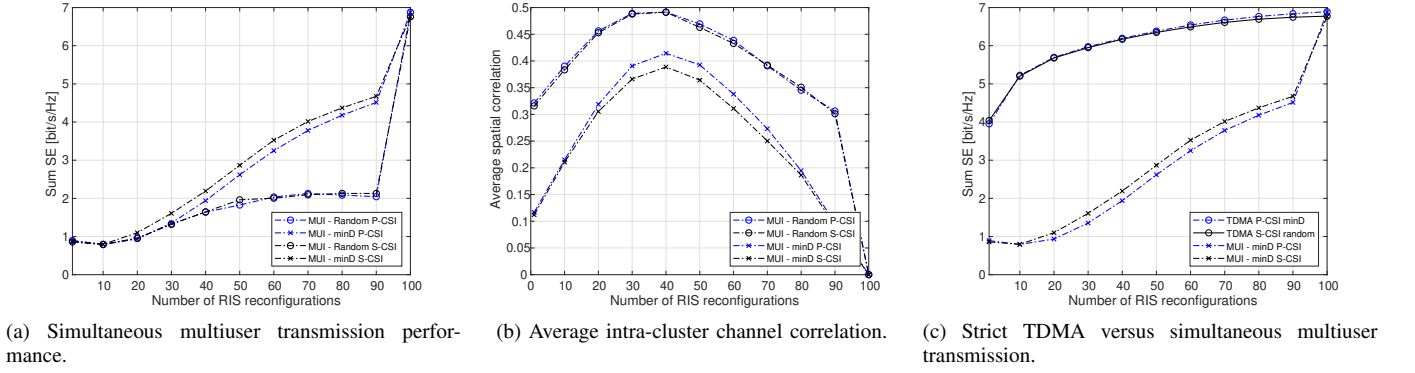


Fig. 1. Performance analysis under limited RIS reconfiguration: (a) sum spectral efficiency in the simultaneous multiuser regime; (b) average intra-cluster channel correlation; and (c) comparison between strict interference-free TDMA and simultaneous multiuser transmission.

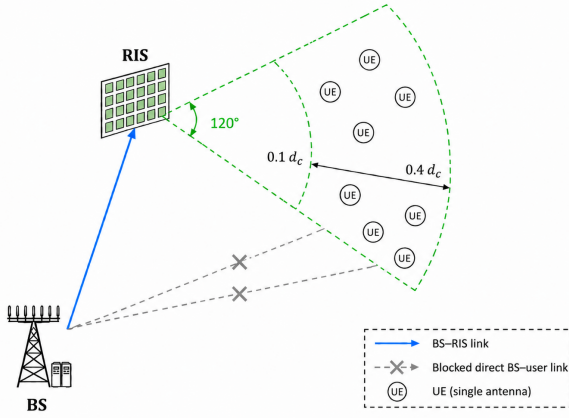


Fig. 2. RIS-assisted downlink simulation scenario with blocked direct BS-user links and users distributed in a circular sector around the RIS.

multiple users are served under the same RIS configuration. Therefore, for the adopted S-CSI/minD framework and simulation setup, the prelog improvement from reducing K user slots to Z cluster slots does not compensate for the increased interference, and serving one user per slot remains the most effective operating strategy. This result establishes an operational boundary for the statistical clustering method proposed in [10].

VI. CONCLUSION

This paper investigated the extension of the S-CSI-based minD RIS phase-shift design and user clustering framework from strict interference-free TDMA to simultaneous multiuser transmission under limited RIS reconfiguration constraints. The analysis was reformulated from SNR to SINR, accounting for equivalent channel covariance, intra-cluster interference, and spatial correlation among users sharing the same RIS configuration.

The results show that S-CSI/minD remains effective for sharing RIS configurations among temporally multiplexed users. However, when users in the same cluster are served simultaneously, the prelog improvement from reducing K

user slots to Z cluster slots does not compensate for the increased intra-cluster interference. Thus, for the considered setup, serving one user per slot remains the most effective strategy, suggesting that simultaneous transmission requires interference-aware clustering and joint BS-RIS beamforming.

REFERENCES

- [1] Q. Wu, S. Zhang, B. Zheng, C. You, and R. Zhang, "Intelligent Reflecting Surface-Aided Wireless Communications: A Tutorial," *IEEE Transactions on Communications*, vol. 69, no. 5, pp. 3313–3351, 2021.
- [2] Y. Liu, X. Liu, X. Mu, T. Hou, J. Xu, M. Di Renzo, and N. Al-Dhahir, "Reconfigurable Intelligent Surfaces: Principles and Opportunities," *IEEE Communications Surveys & Tutorials*, vol. 23, no. 3, pp. 1546–1577, 2021.
- [3] E. Basar, M. Di Renzo, J. De Rosny, M. Debbah, M.-S. Alouini, and R. Zhang, "Wireless Communications Through Reconfigurable Intelligent Surfaces," *IEEE Access*, vol. 7, pp. 116 753–116 773, 2019.
- [4] S. Basharat, S. A. Hassan, H. Pervaiz, A. Mahmood, Z. Ding, and M. Gidlund, "Reconfigurable Intelligent Surfaces: Potentials, Applications, and Challenges for 6G Wireless Networks," *IEEE Wireless Communications*, vol. 28, no. 6, pp. 184–191, 2021.
- [5] M. Rossanese, P. Mursia, A. Garcia-Saavedra, V. Sciancalepore, A. Asadi, and X. Costa-Perez, "Designing, Building, and Characterizing RF Switch-Based Reconfigurable Intelligent Surfaces," in *Proceedings of the 16th ACM Workshop on Wireless Network Testbeds*. New York, NY, USA: Association for Computing Machinery, 2022, pp. 69–76.
- [6] A. Rech, M. Pagin, S. Tomasin, F. Moretto, L. Badia, M. Giordani, J. Gambini, and M. Zorzi, "Downlink TDMA Scheduling for IRS-Aided Communications with Block-Static Constraints," in *2023 IEEE Wireless Communications and Networking Conference (WCNC)*, 2023, pp. 1–6.
- [7] A. Rech, L. Badia, S. Tomasin, M. Pagin, M. Giordani, J. Gambini, and M. Zorzi, "Downlink Clustering-Based Scheduling of IRS-Assisted Communications with Reconfiguration Constraints," *arXiv preprint arXiv:2305.14051*, 2023.
- [8] Y. Han, W. Tang, S. Jin, C.-K. Wen, and X. Ma, "Large Intelligent Surface-Assisted Wireless Communication Exploiting Statistical CSI," *IEEE Transactions on Vehicular Technology*, vol. 68, no. 8, pp. 8238–8242, 2019.
- [9] V. D. P. Souto, R. D. Souza, B. F. Uchôa-Filho, and Y. Li, "Intelligent Reflecting Surfaces Beamforming Optimization with Statistical Channel Knowledge," *Sensors*, vol. 22, no. 6, p. 2390, 2022.
- [10] P. L. Teixeira Segal and J. C. Marinello Filho, "User Clustering and Phase-Shift Design for RIS-Aided Systems Based on Statistical CSI," in *2024 19th International Symposium on Wireless Communication Systems (ISWCS)*, Rio de Janeiro, Brazil, 2024, pp. 1–6.
- [11] E. Björnson, J. Hoydis, and L. Sanguinetti, *Massive MIMO Networks: Spectral, Energy, and Hardware Efficiency*. Now Foundations and Trends, 2017.