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A Novel Channel Estimation Method for RIS Assisted Wireless Communication Systems

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***Abstract*—Channel estimation (CE) can be challenging in reconfigurable intelligent surface (RIS)-assisted wireless communication systems. On the one hand, the dimensionality of the cascaded base station-RIS-user equipment (BS-RIS-UE) channel is exceedingly large. On the other hand, the currently available RIS hardware cannot arbitrarily switch between the active (reflection with configurable phase) and deactivate (absorption) modes, thereby resulting in a perpetual coupling between the BS-RIS-UE channel and BS-UE channel. To address the challenges above, we introduce a novel CE method that leverages the spatial modulation capabilities of RIS. The proposed CE strategy is bifurcated into two distinct phases: the BS-UE CE and the RIS-UE CE. In the BS-UE CE phase, the RIS is strategically configured to steer the incoming signals from the UEs away from the BS. This maneuver significantly suppresses the signal through the cascaded BS-RIS-UE channel, allowing it to be effectively disregarded. Consequently, this facilitates a separate BS-UE CE process using the conventional least squares (LS) algorithm. Armed with the estimated BS-UE channels, the RIS-UE channels can then be readily estimated. Simulation results show that, compared to the existing CE schemes, the proposed CE method can improve the estimation accuracy and reduce the computational complexity.**

***Keywords*—Reconfigurable intelligent surface, channel estimation, spatial modulation, channel decoupling.**

I. INTRODUCTION

Reconfigurable intelligent surface (RIS) has been recognized as a potential technology for future wireless communication systems, due to its capability of manipulating the wireless propagation environment by controlling the reflection coefficients of RIS elements [1], [2]. In RIS-aided wireless communication systems, it's of great importance to perform channel estimation (CE), to obtain the channel state information (CSI) that is required for the design of the precoding matrix of the base station (BS) and the reflection coefficients of the RIS [3]. Due to the large number of RIS elements, the dimensionality of the cascaded BS-RIS-UE channel is practically very large, making the pilot overhead during CE prohibitively high.

Many works have been done to address the CE problem in RIS-aided wireless communication systems. Specifically, by exploiting the quasi-static nature of the BS-RIS channel, the authors in [4] proposed a coordinate descent-based algorithm to realize a separate estimation of the BS-RIS channel. With this strategy in [4], the BS-RIS channel can be assumed as a prior information and only the BS-UE and RIS-UE channels remain to be estimated. Further, by exploiting the sparse feature of the wireless channel, especially for the high-frequency band, the authors in [5] adopted the compressed sensing technology for the CE in RIS-aided wireless communication systems, which effectively reduced the pilot overhead.

However, the channel estimation for RIS-aided wireless communication systems is still challenging due to the following two difficulties [6]. Firstly, the existing schemes that directly estimate the coupled direct BS-UE and cascade BS-RIS-UE channels usually have a high algorithmic complexity and may cause error propagation [7]. Secondly, in order to decouple the direct BS-UE channel and the cascaded BS-RIS-UE channel and thus simplify the CE procedure, existing works assumed that the RIS element can be turned off, or just assumed the absence of the BS-UE channel [4]–[6], [8], [9]. However, it's actually unrealistic to ideally assume that the BS-UE channel does not exist. Besides, the "off" mode of RIS cannot be directly achieved due to the practical hardware characteristics, since the currently available RIS hardware cannot arbitrarily switch between the active (reflection with configurable phase shifts) and deactivate (absorption) modes [8]. Therefore, a perpetual coupling exists between the BS-RIS-UE channel and the BS-UE channel. To address the above challenges, we propose a novel CE method that leverages the spatial modulation capabilities of the RIS to decouple the BS-RIS-UE and BS-UE channels during the CE process. The contributions of this paper are summarized as follows.

- A novel CE method is proposed for RIS-aided wireless systems, which includes two sequential phases, namely the BS-UE CE and the RIS-UE CE.
- The spatial modulation capability of RIS is exploited to effectively decouple the BS-RIS-UE channel and BS-UE channel, which facilitates a separate BS-UE CE and the subsequent RIS-UE CE.
- Simulation results show that, compared to the existing CE schemes, the proposed CE method can improve the estimation accuracy and reduce the computational complexity.

The rest of this paper is organized as follows. The system model of the RIS-aided wireless communication systems is illustrated in Section II. The prior works are introduced

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in Section III. The decoupled two-stage channel estimation scheme is introduced in Section IV. Simulation results are shown in Section V. Finally, conclusions are given in Section VI.

Notations:Throughout this paper, scalar variables, vectors and matrices are denoted by normal-face letters, boldface lower letters, and boldface upper-case letters. $\mathbf{I}_d$ denote an $d \times d$ identity matrix. $\odot$ denotes the Hadamard product. vec$(.)$ denotes the vectorization operation. $(.)^{\mathrm{T}}$ and $(.)^{\mathrm{H}}$ denote the transpose and the conjugate transpose operations. $(.)^*$ and $|.|$ denote the conjugate and the amplitude. Finally, diag$(\mathbf{x})$ denotes the diagonal matrix of $\mathbf{x}$.

II. SYSTEM MODEL

We consider the uplink channel estimation of a RIS-aided wireless communication system as shown in Fig. 1, where K single-antenna user equipments (UEs) are served simultaneously by a base station (BS) with M antennas and a RIS with N elements. We adopt the classical Saleh-Valenzuela (SV) channel model. Suppose uniform linear arrays (ULAs) are employed at the BS, and uniform planar arrays (UPAs) are employed at the RIS. The BS-RIS channel $\mathbf{G} \in \mathbb{C}^{M\times N}$, the RIS-UE$_k$ channel $\mathbf{f}_k \in \mathbb{C}^{N\times 1}$ and BS-UE$_k$ channel $\mathbf{h}_k \in \mathbb{C}^{M\times 1}$ can be given as:

$$\mathbf{G} = \sqrt{\frac{MN}{P}} \sum_{i=1}^{P} \tilde{\alpha}_i \mathbf{a}_{\mathrm{R}_{\mathrm{BS}}}(\gamma_i^r) \mathbf{a}^{\mathrm{H}}_{\mathrm{T}_{\mathrm{RIS}}}\left(\theta_i^t, \eta_i^t\right), \tag{1}$$

$$\mathbf{f}_k = \sqrt{\frac{NK}{L}} \sum_{i=1}^{L} \tilde{\beta}_i \mathbf{a}_{\mathrm{R}_{\mathrm{RIS}}}\left(\theta_i^r, \eta_i^r\right), \tag{2}$$

$$\mathbf{h}_k = \sqrt{\frac{KM}{Q}} \sum_{i=1}^{Q} \tilde{\delta}_i \mathbf{a}_{\mathrm{R}_{\mathrm{BS}}}(\gamma_i^r), \tag{3}$$

where P, L and Q denote the total number of BS-RIS, RIS-UE, and BS-UE channel. $\theta_i^r, \eta_i^r (\theta_i^t, \eta_i^t)$ denotes the azimuth and elevation angles of arrival (departure) associated with the RIS. $\gamma_i^r (\gamma_i^t)$ represents the angle of arrival (departure) associated with the BS. $\alpha_i, \beta_i, \delta_i$ are the complex channel gains, $\mathbf{a}_{\mathrm{R}_{\mathrm{j}}}$ and $\mathbf{a}_{\mathrm{T}_{\mathrm{j}}}$ denote the normalized array response vectors associated with the receiver and the transmitter [10], respectively. Specifically, for UPA with $M = M_y M_z$ elements, the normalized array response vector can be written as

$$\mathbf{a}(\theta, \eta) = \frac{1}{\sqrt{M}}[1, \cdots, e^{j\frac{2\pi d}{\lambda}((m_1-1)\cos(\eta)\sin(\theta)+(m_2-1)\sin(\eta))} \tag{4}$$

$$\cdots, e^{j\frac{2\pi d}{\lambda}((M_y-1)\cos(\eta)\sin(\theta)+(M_z-1)\sin(\eta))}\Big]^{\mathrm{T}}, \tag{5}$$

for ULA with N antennas, the normalized array response vector is given by

$$\mathbf{a}(\gamma) = \frac{1}{\sqrt{N}}[1, \cdots, e^{j\frac{2\pi d}{\lambda}(n-1)\sin(\gamma)} \cdots, e^{j\frac{2\pi d}{\lambda}(N-1)\sin(\gamma)}]^{\mathrm{T}}, \tag{6}$$

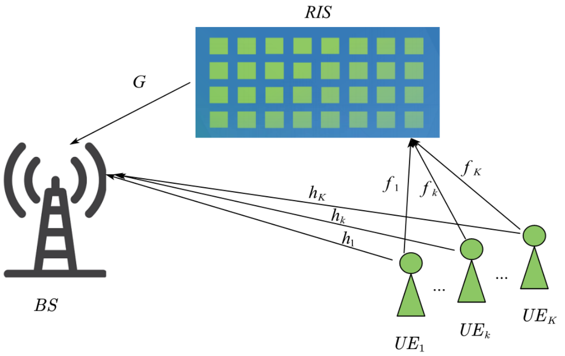

Fig. 1. The RIS-aided wireless communication system.

where d and λ are the antenna spacing and the carrier central wavelength. The received signal of the BS is given by

$$\mathbf{y} = \sum_{k=1}^{K} [\mathbf{G}(\boldsymbol{\varphi} \odot \mathbf{f}_k) + \mathbf{h}_k] x_k + \mathbf{n}, \tag{7}$$

where $x_k \in \mathbb{C}$ denotes the transmitted pilot symbol from the UE$_K$, and $\mathbf{n} \in \mathbb{C}^{M\times 1}$ denotes the noise followed the Gaussian distribution.

Let us revisit (7), which can be equivalently rewritten as

$$\mathbf{y} = \sum_{k=1}^{K} \left[\mathbf{G}\mathrm{diag}(\mathbf{f}_k)\boldsymbol{\varphi} + \mathbf{h}_k\right] x_k + \mathbf{n} \tag{8}$$

$$= \sum_{k=1}^{K} \left[\mathbf{C}_k \boldsymbol{\varphi} + \mathbf{h}_k\right] x_k + \mathbf{n}, \tag{9}$$

where $\mathbf{C}_k \triangleq \mathbf{G}\mathrm{diag}(\mathbf{f}_k)$ represents the compound of the BS-RIS channel and the RIS-UE channel. The uplink pilot transmission scheme has been adopted to estimate channels. In order to distinguish the pilots from different UEs, we assign orthogonal pilot sequences to different UEs as

$$\mathbf{x}^{\mathrm{H}}_{k1}\mathbf{x}_{k2} = \begin{cases} KP_{\mathrm{UE}} & \text{if } k_1 = k_2, \\ 0 & \text{else } k_1 \neq k_2, \end{cases} \tag{10}$$

where P_{UE} is the transmitted power of each UE.

III. PRIOR WORKS

In [11], the authors consider the problem of channel estimation for RIS-assisted mmWave systems. To reduce the training overhead, sparsity inherent in mmWave channels is exploited. By utilizing properties of the Khatri-Rao and Kronecker products, they find a sparse representation of the concatenated BS-RIS-user (cascade) channel. Channel estimation can then be cast as a sparse signal recovery problem and existing compressed-sensing methods can be employed.

In [5], the authors propose a two-timescale channel estimation framework which can jointly estimate the BS-UE channel and RIS-UE channel. They exploit the property that the BS-RIS channel is high-dimensional but quasi-static, while the RIS-UE channel is mobile but low-dimensional. To estimate the BS-RIS channel, they propose a dual-link pilot transmission scheme, where the BS transmits downlink pilots and receives uplink pilots reflected by the RIS. Then, they propose a coordinate descent-based algorithm to recover the BS-RIS channel. For the mobile RIS-UE and the BS-UE channels, they can be estimated by the least square algorithm.

Specifically, the transmission frame consists of τ_0 sub-frames. In the t-th sub-frame $(t = 1, \cdots, \tau_0)$, the reflection coefficient vector at the RIS is $\boldsymbol{\varphi} \in \mathbb{C}^{N\times 1}$. The elements of the reflection coefficient vector are randomly drawn from $\{+1, -1\}$. The UEs transmit uplink pilot sequences, i.e., $\mathbf{d}_k \in \mathbb{C}^{K\times 1}, k = 1, 2, \cdots, K$. In the t-th sub-frame, based on (7), the multi-slot pilot transmission model is given by

$$\mathbf{B}_t = \sum_{k=1}^{K} \left[\mathbf{Q}\,\mathrm{diag}\left(\mathbf{W}_k\right)\tilde{\boldsymbol{\varphi}}_t + \mathbf{l}_k\right]\mathbf{d}_k^{\mathrm{T}} + \mathbf{N}_t, \tag{11}$$

where $\mathbf{B}_t \in \mathbb{C}^{M\times K}$ is the matrix of received pilots at the BS. $\mathbf{Q}$ denotes the BS-RIS channel, $\mathbf{W}_k$ denotes the RIS-UE$_k$ channel, $\mathbf{l}_k$ denotes the RIS-UE$_k$ channel, Each column of $\mathbf{B}_t$ is the received pilots in a single time slot. $\mathbf{N}_t \in \mathbb{C}^{M\times k}$ is the noise. Then, by right-multiplying the conjugate of the pilot sequences, we can distinguish the channels of different UEs as

$$\widetilde{\mathbf{b}}_{k,t} = \frac{1}{KP_{\mathrm{UE}}}\mathbf{B}_t\overset{*}{\mathbf{d}}_k \tag{12}$$

$$= \frac{1}{KP_{\mathrm{UE}}}\sum_{k'=1}^{K}[\mathbf{Q}\mathrm{diag}(\tilde{\boldsymbol{\varphi}}_t)\mathbf{w}_{k'} + \mathbf{l}_{\mathbf{k}'}]\overset{\mathrm{T}}{\mathbf{d}}_{k'}\overset{*}{\mathbf{d}}_k + \frac{\mathbf{N}\overset{*}{\mathbf{d}}_k}{KP_{\mathrm{UE}}} \tag{13}$$

$$= [\mathbf{Q}\mathrm{diag}(\tilde{\boldsymbol{\varphi}}_t)\mathbf{w}_k + \mathbf{l}_{\mathbf{k}}] + \widetilde{\mathbf{n}}_{k,t} \tag{14}$$

$$= \mathbf{A}_t\begin{bmatrix}\mathbf{w}_k\\ \mathbf{l}_k\end{bmatrix} + \widetilde{\mathbf{n}}_{k,t}k = 1, 2, \cdots, K, \tag{15}$$

where $\widetilde{\mathbf{n}}_k$ is equal to $\frac{\mathbf{N}\overset{*}{\mathbf{d}}_k}{KP_{\mathrm{UE}}}$, and

$$\mathbf{A}_t = [\mathbf{Q}\mathrm{diag}(\tilde{\boldsymbol{\varphi}}_t)\mathbf{I}_M]. \tag{16}$$

Finally, they have the least square (LS) estimate of the RIS-UE channel and the BS-UE channel of the UE$_k$ as

$$\begin{bmatrix}\hat{\mathbf{w}}_k\\ \hat{\mathbf{l}}_k\end{bmatrix} = \mathbf{A}^{\dagger}\widetilde{b}_k \tag{17}$$

$$= (\mathbf{A}^{\mathrm{H}}\mathbf{A})^{-1}\mathbf{A}^{\mathrm{H}}\widetilde{b}_k, \quad k = 1, 2, 3, \ldots, K, \tag{18}$$

where $\hat{\mathbf{w}}_k$ and $\hat{\mathbf{l}}_k$ are the estimates of the RIS-UE channel and the BS-UE channel of the UE$_k$, respectively.

Based on the existing estimation of the coupling between channels, we have identified that it may increase the computational complexity and also may cause error propagation during channel estimation.

To reduce system complexity and ensure the accuracy of channel estimation, we propose a novel scheme, which decouples the BS-UE channel estimation and the BS-RIS channel estimation, achieving a reduced computing complexity and a higher channel estimation accuracy, compared with the existing baselines.

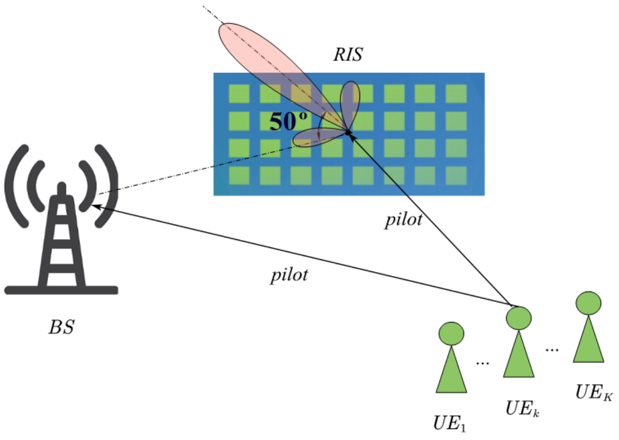

Fig. 2. The proposed channel decoupling method.

IV. DECOUPLING SCHEME FOR CHANNEL ESTIMATION

A. The Proposed Channel Decoupling Method And The Proposed CE Procedure

By dynamically adjusting the individual elements on the RIS, RIS can direct the signal beam towards specific direction [12]. When estimating the direct channel between the BS and the k-th UE, The phases of RIS are configured to beamform the UEs' incident signal in the direction away from the BS, as illustrated in Fig. 2. For example, in Fig. 3, the BS is positioned at an angle of -30 degrees relative to the RIS. As the RIS adjusts its beamforming to direct the signal towards 20 degrees, the signal power through the UE-RIS-BS link is more than 45 dB less than its maximum value (when the RIS beamforms towards the angle of the BS). In this case, it can be readily assumed that the influence of the cascaded BS-RIS-UE channel can be ignored. In other words, the decoupling of the cascade channel and direct channel is realized.

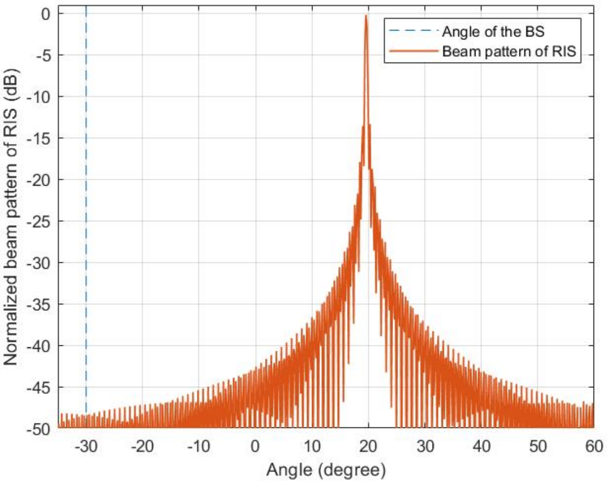

Fig. 3. A case for the proposed channel decoupling method.

In the proposed pilot transmission scheme, We assume that the BS-RIS channel is known. Fig. 4 is the proposed channel estimation frame structure.

Fig. 4. The proposed channel estimation frame structure.

The process is divided into three stages, which are BS-UE channel estimation, RIS-UE channels estimation, and data transmission.

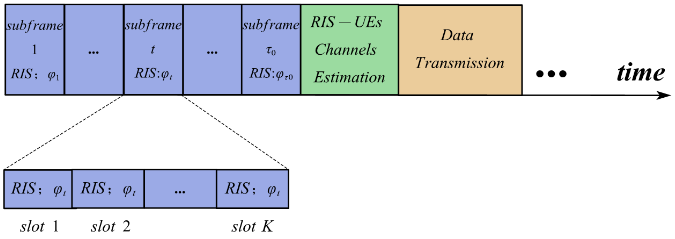

Fig. 5. The BS-UE channels estimation frame structure.

To make sure that the number of received pilots is larger than the number of channel coefficients, we can calculate τ_0 by coefficients in the channel. In the BS-UE channel estimation stage shown as Fig. 5, there are MK coefficients in the channel that need to be estimated. Since the BS gets MK pilot measurements in one sub-frame of K time slots, there are K time slots in one sub-frame, so we can calculate τ_0 by $MK\tau_0 \geq MK$. Thus, $\tau_0 = 1$. The pilot overhead for the small-timescale channel estimation is K.

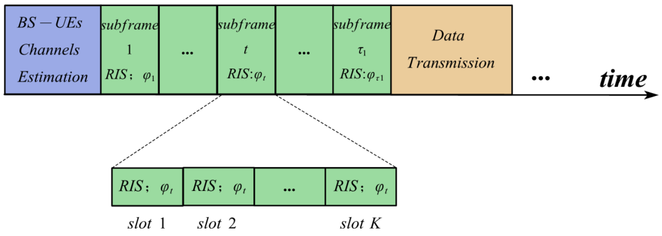

Fig. 6. The RIS-UE channels estimation frame structure.

Fig. 6 is the RIS-UE channel estimation frame structure. We can use the common method to calculate τ_1. In the RIS-UE channel estimation stage, there are NK coefficients in the channel that need to be estimated. There are K time slots in one sub-frame, so we can calculate τ_1 by $MK\tau_1 \geq NK$. Thus, $\tau_1 = [\frac{NK}{M}]$. So the pilot overhead is $K + [\frac{NK}{M}] + K$.

B. BS-UE Channel Estimation

According to IV-A, the signal power of the BS-RIS-UE link can be significantly suppressed by properly configuring the RIS beamforming. Therefore, the BS-UE channel can be independently estimated by ignoring the impact of the BS-RIS-UE link, which is elaborated as below. In the t-th sub-frame, we write the multi-slot pilot transmission model by

$$\mathbf{Y_t} = \sum_{k=1}^{K} \left[\mathbf{G}\mathrm{diag}(\mathbf{f}_k)\boldsymbol{\varphi} + \mathbf{h}_k\right] \mathbf{x}_k^{\mathrm{T}} + \mathbf{N}, \tag{19}$$

which can be simplified to

$$\mathbf{Y}_t = \sum_{k=1}^{K} \mathbf{h}_k \mathbf{x}_k^{\mathrm{T}} + \mathbf{N}, \tag{20}$$

where $\mathbf{Y}_t \in \mathbb{C}^{M\times K}$ denotes the matrix of received pilots at the BS, $\mathbf{N} \in \mathbb{C}^{M\times K}$ denotes the noise. Then, by right-multiplying the conjugate of the pilot sequences, we can distinguish the channels of different UEs as

$$\widetilde{\mathbf{y}}_{k,t} = \frac{1}{KP_{\mathrm{UE}}} \mathbf{Y}_t \mathbf{x}_k^{*} \tag{21}$$

$$= \frac{1}{KP_{\mathrm{UE}}} \sum_{k'=1}^{K} \mathbf{h}_{k'} \mathbf{x}_{k'}^{\mathrm{T}} \mathbf{x}_k^{*} + \frac{\mathbf{N}\mathbf{x}_k^{*}}{KP_{\mathrm{UE}}} \tag{22}$$

$$= \mathbf{h}_k + \widetilde{\mathbf{n}}_k, \tag{23}$$

where $\widetilde{\mathbf{n}}_k$ is equal to $\frac{\mathbf{N}\mathbf{x}_k^{*}}{KP_{\mathrm{UE}}}$. The direct channel between the BS and the UE is defined by

$$\hat{\mathbf{h}}_{\mathbf{k}} = \widetilde{\mathbf{y}}_{k,t} \;\; k = 1, 2, 3, \cdots, K, \tag{24}$$

C. RIS-UE Channel Estimation

In the RIS-UE CE procedure, the elements of the reflection coefficient vector are randomly drawn from $\{+1, -1\}$. The signal received by the base station is

$$\mathbf{Y} = \sum_{k=1}^{K} \left[\mathbf{G}\mathrm{diag}(\mathbf{f}_k)\boldsymbol{\varphi} + \mathbf{h}_k\right] \mathbf{x}_k^{\mathrm{T}} + \mathbf{n}. \tag{25}$$

Then, by right-multiplying the conjugate of the pilot sequences, we can distinguish the channels of different UEs as

$$\widetilde{\mathbf{y}}_{k,t} = \frac{1}{KP_{\mathrm{UE}}} \sum_{k'=1}^{K} [\mathbf{G}\mathrm{diag}(\boldsymbol{\varphi})\mathbf{f}_{k'} + \mathbf{h}_{\mathbf{k'}}] \mathbf{x}_{k'}^{\mathrm{T}} \mathbf{x}_k^{*} + \frac{\mathbf{N}\mathbf{x}_k^{*}}{KP_{UE}} \tag{26}$$

$$= [\mathbf{G}\mathrm{diag}(\boldsymbol{\varphi})\mathbf{f}_k + \mathbf{h}_{\mathbf{k}}] + \widetilde{\mathbf{n}}_{k,t}. \tag{27}$$

We have calculated the estimated channel of BS-UE, We also assume that the channel from the base station to the RIS is known. Now, we only need to estimate the RIS-UE channel by

$$\mathbf{G}\mathrm{diag}(\boldsymbol{\varphi})\mathbf{f}_k = \widetilde{\mathbf{y}}_k - \hat{\mathbf{h}}_{\mathbf{k}}. \tag{28}$$

It can be overwritten as

$$\widetilde{\mathbf{y}}_k - \hat{\mathbf{h}}_{\mathbf{k}} = \mathbf{A}\mathbf{f}_{\mathbf{k}}, \tag{29}$$

where $\mathbf{A} = \mathbf{G}\mathrm{diag}(\boldsymbol{\varphi})$. Then, we can use the least square(LS) algorithm [13]. The estimated channel is defined by

$$\hat{\mathbf{f}}_{\mathbf{k}} = \mathbf{A}^{\dagger}(\tilde{\mathbf{y}}_k - \hat{\mathbf{h}}_{\mathbf{k}}) \tag{30}$$

$$= (\mathbf{A}^H\mathbf{A})^{-1}\mathbf{A}^H(\tilde{\mathbf{y}}_k - \hat{\mathbf{h}}_{\mathbf{k}}) \; k = 1, 2, 3, \cdots, K. \tag{31}$$

D. Computational Complexity

In the BS-UE channel estimation, the computational complexity is determined by the equation in (21), which is $O(MK^2)$. In the RIS-UE channel estimation, the computational complexity is determined by that of the LS channel estimation in (30), which is $O(MN^2+N^3+MNK)$. So, the total computational complexity is $O(MK^2+MN^2+N^3+MNK)$. Compared to $O((M+N)^3+(M+N)^2K)$ in [5], complexity is reduced.

To further compare the computational complexity between the two schemes, we utilized the execution time in the simulation of section V.

V. SIMULATIONS

In our simulations, $M = 32$, $N = 256$, and $K = 8$. The base station with a ULA array is located on the XZ plane with coordinates of $(2, 0, 10)$. RIS with UPA array is deployed on the YZ plane with coordinates of $(0, 100, 10)$. The eight users are arranged in a linear manner, where the X-axis coordinate is fixed at $100m$ and the Z-axis coordinate is fixed at $1.8m$. Y-axis coordinates are $(80, 85, 90, \cdots)$. When we estimate the direct link channel of BS-UE, we obtain the horizontal angle and elevation Angle of the RIS-BS channel according to the known position information, and add 50 degrees on this basis, by controlling the phase information of RIS, it is beamforming like this angle. When the user's transmission power increases from 0 dBm to 20 dBm, we evaluate the accuracy of the algorithm's channel estimation, and the evaluation parameter used here is the normalized mean square error (NMSE) performance. The NMSE of the direct channel is defined by

$$\mathrm{NMSE}_h \triangleq \frac{\mathbb{E}\left\{\sum_{k=1}^{K}\left\|\hat{\mathbf{h}}_k - \mathbf{h}_k\right\|_F^2\right\}}{\mathbb{E}\left\{\sum_{k=1}^{K}\left\|\mathbf{h}_k\right\|_F^2\right\}}. \tag{32}$$

In Fig. 7, we can see that the NMSE decreases as Tx-power becomes large. Meanwhile, the proposed channel estimation method can achieve lower NMSE than that in [5] and the channel estimation algorithm under the condition of random phase configuration of RIS.

In order to estimate the RIS-UE channel, we have adopted an uplink pilot transmission scheme. The elements of the reflection coefficient vector are randomly drawn from $\{+1, -1\}$. This channel is a part of the whole cascade channel, but if we assume that BS-RIS is a prior known condition, then the estimation of this channel can actually represent the estimation of the cascade channel. We continue to select the power level at which the user transmits the pilot signal as a variable. We averaged 1000 Monte-Carlo trials to analyze the results. The NMSE of the RIS-UE channel is defined by

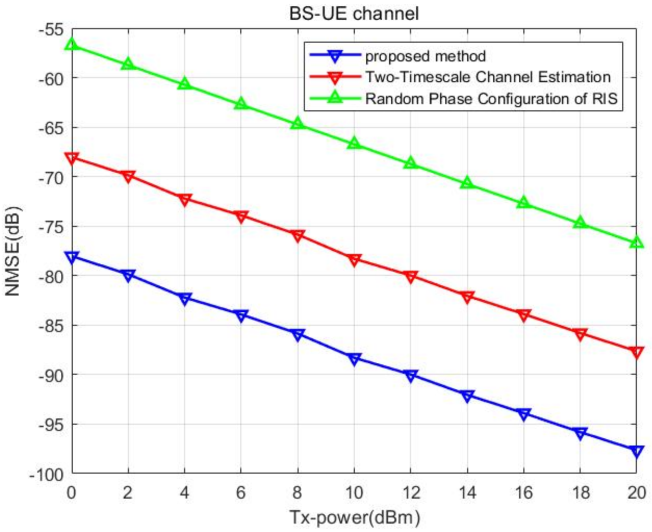

Fig. 7. NMSE of the BS-UE channel.

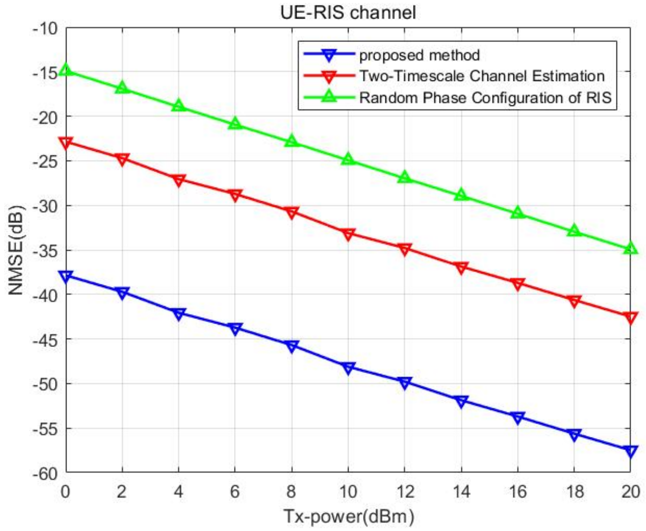

Fig. 8. NMSE of the UE-RIS channel.

$$\mathrm{NMSE}_f \triangleq \frac{\mathbb{E}\left\{\sum_{k=1}^{K}\left\|\hat{\mathbf{f}}_k - \mathbf{f}_k\right\|_F^2\right\}}{\mathbb{E}\left\{\sum_{k=1}^{K}\left\|\mathbf{f}_k\right\|_F^2\right\}}. \tag{33}$$

In Fig. 8, we can see that the NMSE decreases as Tx-power becomes large. Meanwhile, Due to the excellent estimation performance of the direct link channel, the accuracy of the RIS-UE channel estimation results is also better. It is noteworthy that despite this reduced margin, the NMSE for the RIS-UE channel remains more favorable than that of the comparative algorithm. This observation highlights the subtle yet significant advantage in RIS-UEs channel estimation accuracy, even though it is not as pronounced as in the BS-UEs channel. After conducting 1000 experimental trials, the total execution time for the proposed channel estimation algorithm is recorded at 1180 seconds, which is a 5.9% reduction compared to the 1254 seconds observed in the alternative scheme.

VI. CONCLUSION

In this paper, we propose a scheme that is more realistic, considering the existence of the direct link channel and the fact that the RIS unit cannot be turned off. At present, numerous studies assume that RIS-based units can be switched on and off at will [14]. However, this type of RIS unit can achieve an arbitrary "on/off" state, similar to that of a conventional antenna array element, if it can switch between the reflect/transmit and absorption states at will. There are, however, very few hardware RIS implementations that support both the reflect/transmit and absorption modes. As a result, these assumptions are too idealized and do not accord with the actual channel characteristics and hardware conditions. Meanwhile, the channel estimation method using RIS beamforming is proposed to realize the decoupling of the direct channel and cascade channel. The estimation of the coupling between channels may increase the computational complexity and the cost of the pilot and also may cause error propagation between channels. In the end, by analyzing the computational complexity of the model and running code, we can verify that the complexity of the proposed algorithm is lower than the existing scheme. Through 1000 Monte-Carlo test, we found that the proposed scheme can still maintain good performance in the estimation accuracy of the direct link channel and RIS-UE channel.

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