Reconfigurable Intelligent Surface-Assisted Channel Estimation for Indoor mmWave Communication Systems

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Abstract

This paper presents the reconfigurable intelligent surface-assisted channel estimation for indoor millimeter wave communication systems to increase the coverage and the channel performance. In the conventional wireless systems, beamforming cannot lead the accurate channel state information due to the unwanted obstacles. Hence, we propose a RIS-assisted channel estimation scheme to improve the quality of the transmission channel. To achieve a good normalized mean square error (NMSE) performance, we consider an orthogonal matching pursuit (OMP)-based channel estimation algorithm in this paper. The effectiveness of the proposed RIS-assisted OMP algorithms outperform the conventional RIS-assisted algorithms and are verified in terms of the NMSE performance through computer simulation.

I. Introduction

Recently, reconfigurable intelligent surface (RIS) has been considered as one of the key technologies of fifth generation (5G) communication systems to extend coverage, increase link capacity and add new degrees of freedom to intelligently control wireless channels for improved communications [1-3]. The authors investigated the RIS-assisted large antenna systems to reduce the normalized mean-square-error by changing the phase matrix of the RIS systems [4].

However, we propose a RIS-assisted OMP channel estimation algorithm in this paper to reduce the pilot overhead. We consider an indoor RIS-assisted communication model such as a shopping mall. The proposed RIS-assisted OMP algorithm outperforms the conventional iterative RIS-assisted algorithm through computer simulation.

II. System Model

Consider a multiuser indoor reconfigurable intelligent surface (RIS)-assisted communication model where an access point (AP) is operating a millimeter wave (mmWave) frequency bands and communicating with M -reflecting elements and K single antenna users. The uplink RIS-assisted system model is illustrated in Fig.1, where the AP is equipped with N_t-element antenna array. Thus, the received signal vector, $\mathbf{r} \in \mathbb{C}^{M\times 1}$ can be modeled as

$$\mathbf{r} = \sum_{k=1}^{K} (\mathbf{d}_k + \mathbf{g}^T \boldsymbol{\Theta} \mathbf{h}_k^{ris})\, x_k + \mathbf{z}, \tag{1}$$

where $\mathbf{d}_k \in \mathbb{C}^{N_t\times 1}$ denotes the channel between the k-th user and access point, $\mathbf{g} \in \mathbb{C}^{M\times 1}$ denotes the vector of line-of-sight channel coefficients between the RIS and the user, $\mathbf{h}_k^{ris} \in \mathbb{C}^{M\times 1}$ can be represented as

$$\mathbf{h}_k^{ris} = \sqrt{\frac{N_t}{L_k^{ris}}} \sum_{l_2}^{L_k^{ris}} \alpha_{l_2,k}^{ris}\, \mathbf{a}\left(\vartheta_{l_2,k}^{ris}, \varphi_{l_2,k}^{ris}\right) \tag{2}$$

where L_k^{ris} denotes the number of paths between the k -th user and the RIS, $\alpha_{l_2,k}^{ris}$ represent the complex channel gain, x_k is the transmitted signal, $\mathbf{z}$ is the Gaussian noise vector. For typical, we assume uniform planer array, which is given by [xx]

$$\mathbf{a}(\vartheta,\varphi) = \frac{1}{\sqrt{N_t}}\left[e^{-j2\pi d \sin(\vartheta)\cos(\varphi)\mathbf{n}_1/\lambda}\right] \otimes \left[e^{-j2\pi d \sin(\vartheta)\mathbf{n}_2/\lambda}\right] \tag{3}$$

where d is the antenna spacing distance, λ is the wavelength, $\mathbf{n}_1 = [0,1,\ldots N_{t,1}-1]$ and $\mathbf{n}_2 = [0,1,\ldots N_{t,2}-1]$. The RIS element response matrix $\Theta = \mathrm{diag}(vec(\boldsymbol{\theta}))$ where the reflection coefficient of the RIS elements is reflected by

$$\boldsymbol{\theta} = \begin{bmatrix} \theta_{1,1} & \theta_{1,2} & \cdots & \theta_{1,M} \\ \vdots & \ddots & \cdots & \vdots \\ \theta_{M,1} & \theta_{M,2} & \cdots & \theta_{M,M} \end{bmatrix}. \tag{4}$$

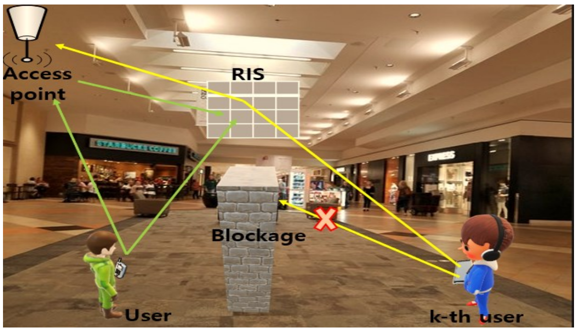

Fig.1 RIS-assisted indoor communication model.

III. RIS-Assisted Channel estimation

For simplicity, we consider the RIS over T time slots for the uplink channel estimation. The effective received signal can be written as

$$\mathbf{r}_{k,t} = \mathbf{H}_k \boldsymbol{\theta}_t x_{k,t} + z_{k,t} \tag{5}$$

Now, we can get the $M \times T$ measurement matrix as

$$\begin{aligned} \mathbf{R}_k &= \mathbf{H}_k \Theta x_{k,t} + \mathbf{Z}_k \\ &= \mathbf{V}_M \tilde{\mathbf{H}}_k^H \mathbf{V}_{N_t}^T \Theta + \mathbf{Z}_k \end{aligned}, \tag{6}$$

where $x_{k,t} = 1$. However, we can measure the compressive sensing model as follows.

$$\tilde{\mathbf{R}}_k = \tilde{\Theta}\tilde{\mathbf{H}}_k^H + \tilde{\mathbf{Z}}_k , \quad (7)$$

where $\tilde{\mathbf{R}}_k = (\mathbf{V}_M^H \mathbf{R}_k)^H$ and $\tilde{\mathbf{Z}}_k = (\mathbf{V}_M^H \mathbf{Z}_k)^H$.
The proposed RIS-assisted OMP-based channel estimation algorithm is given in **Algorithm 1**.

Algorithm 1: RIS-assisted OMP algorithm

1. Input: $\tilde{\mathbf{R}}_k$ and $\tilde{\Theta}$.
2. Begin $\hat{\tilde{\mathbf{H}}}_k^H = 0_{M \times N_t}$.
3. for $k = 1, 2, ..., K$ do
4. $\hat{\tilde{\mathbf{H}}}_k = \arg\min_{\tilde{\mathbf{H}}_k^H} \left\| \tilde{\mathbf{R}}_k - \tilde{\Theta}\tilde{\mathbf{H}}_k^H \right\|$
6. end for
7. $\hat{\mathbf{H}}_k = \mathbf{V}_M^H \hat{\tilde{\mathbf{H}}}_k \mathbf{V}_{N_t}, \forall_k$
8. Output: estimated channel matrices $\hat{\mathbf{H}}_k$.

Table 1: Summary of simulation parameters

Number of transmit antennas	256
Number of receive antennas	16
RIS elements	64
Antenna spacing distance	0.5
Channel path	8
Carrier frequency	28GHz
RIS path	5

IV. Result and Discussion.

In computer simulation, a RIS-assisted channel model is considered for indoor mmWave massive MIMO systems. We use a RIS-assisted OMP algorithm and show the effectiveness of pilot overhead in **Algorithm 1**. Throughout the computer simulation, we assume the parameters in Table 1. We evaluate the normalized mean square error (NMSE) to quantify the accuracy of channel estimation for each user, which is expressed as

$$NMSE = \mathbb{E}\left[\frac{\|\mathbf{H}_k - \widehat{\mathbf{H}}_k\|^2}{\|\mathbf{H}_k\|^2}\right], \quad (8)$$

where $\mathbf{H}_k$ is ideal in the initial channel estimation. We consider RIS reflecting matrix $\mathbf{\Theta} \in \{-\frac{1}{\sqrt{N}}, \frac{1}{\sqrt{N}}\}$ by considering discrete phase shift of the RIS [3]. The access point to RIS distance is 10 meters.

Fig.2 illustrates the normalized mean square error performance for both the proposed RIS-assisted OMP-based channel estimation and the conventional iterative RIS-assisted channel estimation algorithm. We observe that in Fig.2, the estimation accuracy is improved due to increase the number of pilot transmission in the system. Thus, the proposed RIS-assisted OMP algorithm performs satisfactorily with the conventional iterative RIS-assisted channel estimation algorithm in [4].

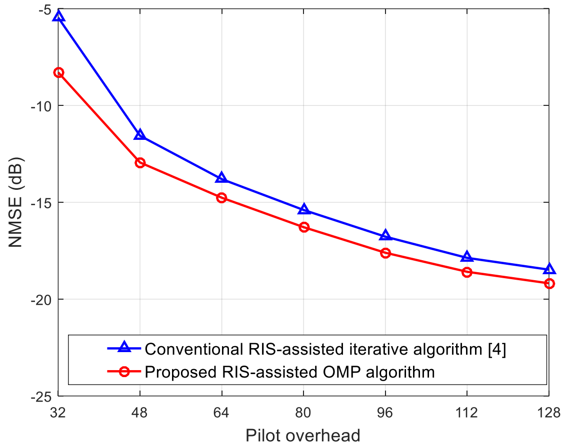

Fig.2 Normalized mean square error performance versus pilot overhead.

Conclusion

In this paper, we proposed a RIS scheme to reduce the signaling overhead and improve the channel NMSE performance. Simulation result confirms that the proposed RIS-based OMP algorithm significantly outperforms the RIS-assisted iterative channel estimation algorithm, in terms of normalized mean square error. This work can be extended further to apply more scenarios in the outdoor approach wireless communications.

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