Simulation of optimal methodologies for channel estimation in a MISO RIS-aided system

Stamatia, F., Drampalou*
Department of Informatics and Computer Engineering, University of West Attica, 250 Thivon Av., 12244 Athens, Greece
sdrampalou@uniwa.gr

Nikolaos, I., Miridakis
Department of Informatics and Computer Engineering, University of West Attica, 250 Thivon Av., 12244 Athens, Greece
nikozm@uniwa.gr

Panagiotis, A., Karkazis
Department of Informatics and Computer Engineering, University of West Attica, 250 Thivon Av., 12244 Athens, Greece
p.karkazis@uniwa.gr

ABSTRACT

Extensive research in telecommunications and especially in wireless systems assisted by reconfigurable intelligent surfaces (RIS) has emerged at the forefront of cutting-edge wireless communications nowadays. RISs are composed of several arrays of passive elements, where their purpose is to receive the transmitted signal and send it to the corresponding receiver. One of the main disadvantages of RIS, due to the various processes performed in the RIS controller, is the channel estimation time. Therefore, research has focused on optimized channel estimation algorithms in multiple input- multiple output (MIMO) systems to reduce channel overhead and estimation time. In a previous publication, we presented the methodologies that have been used for channel estimation and our goal in this research is to simulate the proposed algorithms on a common system and common parameters. The presentation of the operation mode of the optimal channel estimation methodologies is implemented in a multiple input- single output (MISO) system and in a Base Station (BS) -RIS-user channel. Then we will present in detail the results of the comparison of the methods and mention future scenarios that can be tested.

CCS CONCEPTS

• **Reconfigurable Intelligent Surface**; • **channel estimation**; • **optimized methodologies**;

KEYWORDS

MISO systems, Least Square Method, Katri-Rao product, Kronecker product

ACM Reference Format:
Stamatia, F., Drampalou, Nikolaos, I., Miridakis, and Panagiotis, A., Karkazis. 2023. Simulation of optimal methodologies for channel estimation in a MISO RIS-aided system. In *27th Pan-Hellenic Conference on Progress in Computing and Informatics (PCI 2023), November 24–26, 2023, Lamia, Greece.* ACM, New York, NY, USA, 3 pages. https://doi.org/10.1145/3635059.3635101

*sdrampalou@uniwa.gr

PCI 2023, November 24–26, 2023, Lamia, Greece

ACM ISBN 979-8-4007-1626-3/23/11.
https://doi.org/10.1145/3635059.3635101

1 INTRODUCTION

The reconfigurable intelligent surface (RIS) comprising a large number of passive reflective elements is emerging as a promising technology to realize an intelligent and programmable wireless propagation environment through software-controlled reflection [1]. That is, RIS with reconfigurable reflection arrays can direct beams to intended users to achieve similar energy beamforming (EB) gains as massive MISO systems involving active arrays [2]. Each element in an active array [3] has its own radio frequency (RF) chain that includes multiple active elements and these can operate in receive mode so that they can receive incident signals to help estimate the base station (BS)-RIS channel and the RIS-user channel. Furthermore, by properly adjusting the phase shifts of the passive elements, the reflected signals can be consistently added to the desired receiver to improve the signal strength [1].

The transmitted signal, due to the two different paths it follows, creates losses in the signal and delays in the time the user receives the signal. To mitigate the phenomenon, as we analyzed in a previous publication [4] and as resolved in [5], different methods have been developed for MISO RIS-aided systems. Also, in [6] the strategies for mapping computational and network requirements in virtual telecommunication systems have been analyzed. For single-user narrowband MISO RIS-aided systems, as reported in [1], [2] and [7] use well-known mathematical models for channel estimation in the ON/OFF method. Therefore, in this paper we will assume a MISO RIS-aided system with minimal channel losses and attenuate the final received signal with different techniques. The techniques that will be used to mitigate the signals are the Least Square (LS) Method, the Kronecker product and the Khatri-Rao product.

The rest of the paper is organized as follows: Section 2 presents system model for channel estimation in MISO RIS-aided system and presents the proposed algorithm for simulating methods. Section 3 presents the simulated results, and some concluding remarks are drawn in Section 4.

2 SYSTEM MODEL

In this section we will present the MISO system model that we used to implement the simulation.

The notations will be followed is, $\otimes$ is the Kronecker product. The notation $(\cdot)^T$ each stands for the transpose operator. The diag (a) denotes an $n \times n$ diagonal matrix that consists of the elements of vector a. $b \sim \mathcal{CN}(0, \Sigma)$ is the symbol for a circularly symmetric complex Gaussian vector with zero mean and covariance matrix Σ, λ is the wavelength.

2.1 MISO Channel Model

The system and channel models for the considered RIS-aided MISO communication systems are like those in [1], [2] and [8]. We consider a RIS- aided MISO system with N antennas at the BS, communicating with a user. RIS is equipped with M reflecting elements for signal transmission. Each m-th reflective element of the RIS has a reflective coefficient ξ_m. The reflectance matrix of the RIS panel can is depicted as $\Theta = \text{diag}(a_1\xi_1, \ldots, a_m\xi_m)$, where a_m denotes the amplitude reflection coefficient and $\xi_m = e^{j\theta j}$ with θ_m denoting the phase shift of m-th element of RIS. The reflection amplitude and phase shift coefficients are changed by a PIS-controller, which is connected and programmed by the BS. All channel models follow the Rician distribution. Researchers use different methods to calculate BS-RIS-user channels for the MISO system. RIS is considered by some as a large vector like [2], [7], [9] and others consider it as a uniform planar array (UPA) like [1], [10].

$h_{SU} \in \mathbb{C}^{N\times 1}$ is the direct channel from BS to the UE, $H_{SI} \in \mathbb{C}^{N\times M}$ that from BS to RIS and $h_{IU} \in \mathbb{C}^{M\times 1}$ that from RIS to the UE. The corresponding effective channel from the transmitter to the UE would be $h^T \triangleq h_{SU}^T + h_{IU}^T \Theta \mathrm{H}_{\mathrm{SI}}$.

The channels matrix h_{IU}, h_{SU} between the RIS-user and BS-user, respectively are donated as

$$h_{ik} = \sqrt{\frac{\delta_{ik}\mathrm{K}_{ik}}{1+\mathrm{K}_{ik}}} h_{D_{ik}} + |\sqrt{\frac{\delta_{ik}}{1+\mathrm{K}_{ik}}} h_{S_{ik}} \tag{1}$$

$\forall\ i \in \{S, I\},\ k \in U$, where δ_{ik} is the distance dependent path-loss factor and shadowing based large-scale fading, K_{ik} is the Rician factor. $h_{D_{ik}}$ are deterministic vectors containing specular components and $h_{S_{ik}}$ are complex Gaussian random vectors with independent and identically distributed (IID) zero-mean unit-variance entries. Similarly, the baseband equivalent of Rician fading for BS-to-RIS channel is represented by $H_{SI} \in \mathbb{C}^{N\times M}$. For more information see [2], [7], [9].

Suppose that the RIS is an $M_x \times M_y$ UPA. H_{SI} the BS- RIS channel can be modeled as

$$H_{SI} = \sqrt{\frac{NM}{\delta_{SI}}} \sum_{l=1}^{L} \rho_l a_r(\theta_l, \gamma_l)\, \alpha_t^h(\varphi_l) \tag{2}$$

where δ_{SI} denotes the path-loss between the BS and RIS, L is the number of paths, ρ_l denotes the complex gain associated with the l-th path, θ_l (γ_l) denotes the azimuth (elevation) angle of arrival (AoA), φ_l is the angle of departure (AoD), a_r and a_t represent the receive and transmit array response vectors, respectively.

The channel matrix h_{IU}, between the RIS-user is donated as

$$h_{IU} = \sqrt{\frac{M}{\delta_{IU}}} \sum_{l=1}^{L} a_l a_r(\theta_l, \gamma_l) \tag{3}$$

where δ_{IU} denotes the average path-loss between the IRS and the user, a_l denotes the complex gain associated with the l-th path, and θ_l (γ_l) denotes the azimuth (elevation) AoD [1].

$$a_r(\theta_l, \gamma_l) = a_x(u) \otimes a_y(v) \tag{4}$$

where $u = 2\pi d \cos\gamma_l/\lambda$, $v = 2\pi d \sin\gamma_l \cos\theta_l/\lambda$, d denotes the antenna spacing, and

$$\begin{aligned} a_x(u) &= \frac{1}{\sqrt{M_x}} \begin{bmatrix} 1, e^{ju}, \ldots, \\ e^{j(M_x-1)u} \end{bmatrix}^T, \\ a_y(v) &= \frac{1}{\sqrt{M_y}} \begin{bmatrix} 1, e^{jv}, \ldots, \\ e^{j(M_y-1)v} \end{bmatrix}^T \end{aligned} \tag{5}$$

For more information see [1], [10].

2.2 Proposed Methods

Although researchers use different mathematical models to analyze how to calculate the received signal to the user and the estimation of this channel, the form of the equation is shown below. The received signal y_u to user k is

$$y_u = \left(h_{SU}^T + h_{IU}^T \Theta H_{SI}^T\right) f_a x_e + w_u, \tag{6}$$

where representing the unit-norm linear precoder or active energy beamforming vector at BS by $f_a \in \mathbb{C}^{N\times 1}$, with its transmit energy signal being $x_e \in \mathbb{C}$, having power $|x_e|^2 = p_e$ and w_u is the received additive white Gaussian noise (AWGN) with zero-mean and variance σ_{wu}^2.

The details of the proposed algorithm for simulating the different methods, which are optimized by LS Method, Kronecker and Khatri-Rao product are presented in Algorithm 1.

Algorithm 1 simulating methods

Initialization number of BS antennas, number of passive RIS elements, fixed variables, distances between BS antennas, distance between BS-RIS-user
Iteration T: for t = 0, 1, . . . , do
  Compute channels h_{IU}, h_{SU} and H_{SI}
  Compute Θ reflectance matrix of the RIS
  Compute f_a beamforming vector, x_e tran smit energy signal
  for each received signal in user, do
    use of methods LS Method, Kronecker and Khatri-Rao product
  end
  final received signal in user
end
  creating diagram
end

3 SIMULATION RESULTS

In this section, we present simulation results to evaluate the performance in the algorithm proposed in [1], [2]. We assume that the BS employs a uniform linear array (ULA) with N = 10 antennas and the RIS is a UPA consisting of M = 10×10 passive reflecting elements. In our simulations, we set $\mathrm{N_G} = 64$, $\mathrm{M_{G,x}} = 20$ and $\mathrm{M_{G,y}} = 20$. The number of paths for mmWave channels H_{SI} and h_{IU} are respectively set to L = 3, where the AoA and AoD parameters are uniformly generated from $[0, 2\pi]$. Also, p_e = 30dBm, $\sigma_{ws}^2 = \sigma_{w_u}^2 = \sigma^2 = 10^{-20}$ Joule (J), $\eta = 0.7$, $\delta = \frac{3\times 10^8}{2f}$ with δ being the inter-element separation at PIS and PB, f = 915 MHz being transmit frequency and ρ=2 is the path loss exponent [1].

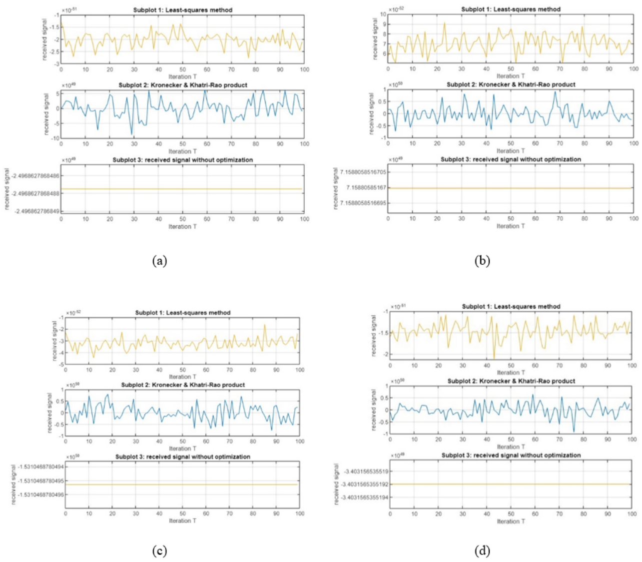

Figure 1: Validating the performance of the proposed algorithms for t=100 iterations for 4 simulations

In Figure 1, we plot the received signals of respective algorithms in [1], [2] as a function of T, where the signal-to-noise ratio (SNR) is set as 10dB. In Figure 1 in subplot 1, we see that LS method does not have large exclusions from the received signal without optimization. Also, the signal is more resistant to interference and losses that can affect the signal. In contrast, the signal in subplot 2 using the Kronecker and Khatri-Rao product exhibits larger outliers than the unoptimized signal is more susceptible to interference. The amplitude of the signal using the Kronecker and the Khatri-Rao product is constant around 0, while the signal with the LS method varies at each iteration.

4 CONCLUSION

In the above research we studied the optimized algorithms presented in [4] and conducted simulation experiments on a common MISO RIS-aided system and with common parameters such as antennas and specific constants. From the simulation results we observe that minor differences that exist between the main proposed models. In our future research we will study more methods for estimating channels and focus on methods that use artificial intelligence. Also, in our own MIMO system we will implement and study the channel estimation and the way the signal is transmitted.

ACKNOWLEDGMENTS

This work is partially supported by University of West Attica

REFERENCES

[1] P. Wang, J. Fang, H. Duan and H. Li, "Compressed Channel Estimation and Joint Beamforming for Intelligent Reflecting Surface-Assisted Millimeter Wave Systems," 29 May 2020. [Online]. Available: https://arxiv.org/abs/1911.07202v3.

[2] D. Mishra and H. Johansson, "Channel Estimation and Low-complexity Beamforming Design for Passive Intelligent Surface Assisted MISO Wireless Energy Transfer," ICASSP 2019 - 2019 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), Brighton, UK, pp. 4659-4663, 2019.

[3] A. Yazdan, J. Park, S. Park, T. A. Khan and R. W. Heath, "Energy-efficient massive MIMO: Wireless-powered communication,multiuser MIMO with hybrid precoding, and cloud radio access network with variable-resolution ADCs," IEEE Microw. Mag., vol. 18, no. 5, pp. 18–30 July 2017.

[4] S. Drampalou, N. Miridakis, H. Leligou and P. Karkazis, "A Survey on Optimal Channel Estimation Methods for RIS-Aided Communication Systems," 2023. [Online]. Available: https://doi.org/10.3390/signals4010012.

[5] S. Prekas, P. Karkazis and P. Trakadas, "An Energy-Aware Path Enumeration Solution Based on the Path Algebra Framework.," IEEE IT Professional, vol. 25, no. 4, pp. 29-35, 2023.

[6] S. Prekas, P. Karkazis, V. Nikolakakis and P. Trakadas, "Comprehensive comparison of vne solutions based on different coordination approaches," Telecom, vol. 2, no. 4, pp. 390-412, 2021.

[7] T. Jensen and E. Carvalho, "An optimal channel estimation scheme for intelligent reflecting surfaces based on a minimum variance unbiased estimator," In Proceedings of the IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP), Barcelona, Spain, p. 5000–5004, 4–8 May 2020.

[8] M. Eskandari, H. Zhu, A. Shojaeifard and A. Wang, "Statistical CSI-based Beamforming for RIS-Aided Multiuser MISO Systems using Deep Reinforcement Learning," 1 January 2023. [Online]. Available: https://arxiv.org/abs/2209.09856v1.

[9] Z. Mao, M. Peng and X. Liu, "Channel estimation for reconfigurable intelligent surface assisted wireless communication systems in mobility scenarios," China Commun, vol. 18, p. 29–38, 2021.

[10] M. Xu, S. Zhang, C. Zhong, J. Ma and O. Dobre, "Ordinary differential equation-based CNN for channel extrapolation over RIS-assisted," IEEE Commun. Lett, vol. 25, p. 1921–1925, 2021.