European Commission | Funding & tender opportunities
Single Electronic Data Interchange Area (SEDIA)

H2020-MSCA-IF-2020

Secure Indoor Communication empowered by Intelligent reflecting Surface (SICIS)

D1.1

Report on approaches of acquiring CSI for indoor environments with IRS

Authors(s)	Sai Xu, Jie Zhang
Author(s) Affiliation	University of Sheffield, UK
Editor(s):	Sai Xu
Status-Version:	V1.0
Project Number:	101032170
Project Title:	Secure Indoor Communication empowered by Intelligent reflecting Surface
Project Acronym:	SICIS
Work Package Number	1

Abstract

Channel state information (CSI) plays a pivotal role in modern wireless communication systems, and the integration of IRS introduces novel opportunities for enhancing signal quality, coverage, and spectral efficiency in indoor scenarios. During the project, the channel estimation for intelligent reflecting surfaces (IRS) aided wireless communications has been well investigated. Furthermore, the methodologies and techniques also apply to indoor environments. Thus, the channel estimation for IRS-aided indoor communications is no longer further studied. Instead, we summarize existing works on channel estimation for IRS-aided wireless communications.

The results presented in this deliverable have addressed the requirement of Task 1.1 in the SICIS project.

Keywords: Intelligent reflecting surface, reconfigurable intelligent surface, channel estimation

Summary

In the field of indoor communication, a range of advanced technologies such as massive MIMO, millimeter-wave (mmWave) communication, and ultra-dense networks (UDN) have been extensively studied and proposed to enhance the spectral efficiency of wireless systems [1], [2], in response to the growing demand for high-speed, low-latency data applications. While these technologies have revolutionized fifth-generation (5G) cellular networks, they have simultaneously increased energy consumption and hardware costs due to the large number of active nodes, antennas, and Radio-Frequency (RF) chains.

Intelligent Reflecting Surfaces (IRS) have emerged as a promising solution to address these challenges and improve system performance [3]–[6]. Essentially, an IRS is a man-made flat surface composed of numerous passive and low-cost reflecting elements. Independently controlled through external software, these elements manipulate the amplitude and/or phase of incident signals. Coordination among these elements creates an advantageous environment for wireless signal propagation, substantially enhancing wireless communication coverage, throughput, and energy efficiency.

Unlike half-duplex amplify-and-forward (AF) relays, IRS achieves substantial beamforming gains by adjusting reflection coefficients at various elements in a full-duplex manner, with minimal hardware and energy costs. Consequently, IRS has attracted considerable attention, with studies demonstrating its effectiveness in enhancing system performance [7]–[11]. However, the acquisition of Channel State Information (CSI) becomes crucial for leveraging IRS benefits. As IRS lacks transmit/receive RF chains, intricate baseband signal processing becomes unfeasible, especially with a large number of base station (BS) antennas, IRS reflecting elements, and users, necessitating extensive channel coefficient estimation.

Recent studies have proposed strategies to efficiently estimate channels in IRS-assisted wireless systems [13]–[26]. For single-user systems, binary reflection-controlled channel estimation schemes have been suggested [13], [14]. Initially estimating the user-BS channel (direct channel) with all elements turned off, subsequent time slots activate individual reflecting elements to estimate the cascaded user-IRS-BS channel (reflected channel). Although this may potentially degrade accuracy, activating only a fraction of IRS elements at any time might limit the IRS's large aperture gain. Improved binary reflection strategies have been proposed [15]–[17], leveraging complete IRS reflection across all time slots and designing Discrete Fourier Transform (DFT)-based IRS training reflection matrices. Additionally, studies address practical constraints, such as phase shift constrained to discrete values [19]. For massive MIMO systems, exploitation of low-rank channel matrix structures has been proposed [20], while mmWave MIMO systems explore channel sparsity [21], [22], employing deep learning for compressive channel estimation to reduce training overhead [23].

Multi-user systems adopt compressive sensing (CS)-based methods [24], assuming sparse reflected channels. Meanwhile, more general models introduce innovative frameworks [25], reducing training overhead through a three-phase channel estimation (3PCE). By exploiting correlation among reflected channels, this framework reduces the length of pilot sequences. However, issues of error propagation challenge this framework. Other studies utilize channel correlation to enhance training efficiency and support more users in IRS-assisted systems [26], employing orthogonal frequency division multiple access (OFDMA) for multiuser broadband Single-Input Single-Output (SISO) systems.

References

1. F. Boccardi, R. W. Heath, Jr., A. Lozano, T. L. Marzetta, and P. Popovski, "Five disruptive technology directions for 5G," *IEEE Commun. Mag.*, vol. 52, no. 2, pp. 74–80, Feb. 2014.
2. M. Shafi et al., "5G: A tutorial overview of standards, trials, challenges, deployment, and practice," *IEEE J. Sel. Areas Commun.*, vol. 35, no. 6, pp. 1201–1221, Jun. 2017.
3. Q. Wu and R. Zhang, "Towards smart and reconfigurable environment: Intelligent reflecting surface aided wireless network," *IEEE Commun. Mag.*, vol. 58, no. 1, pp. 106–112, Jan. 2020.
4. 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. 116753–116773, 2019.
5. Q. Wu, S. Zhang, B. Zheng, C. You, and R. Zhang, "Intelligent reflecting surface-aided wireless communications: A tutorial," *IEEE Trans. Commun.*, vol. 69, no. 5, pp. 3313–3351, May 2021.
6. X. Tan, Z. Sun, D. Koutsonikolas, and J. M. Jornet, "Enabling indoor mobile millimeter-wave networks based on smart reflect-arrays," in *Proc. IEEE INFOCOM*, Apr. 2018, pp. 270–278.
7. M.-M. Zhao, Q. Wu, M.-J. Zhao, and R. Zhang, "Exploiting amplitude control in intelligent reflecting surface aided wireless communication with imperfect CSI," *IEEE Trans. Commun.*, vol. 69, no. 6, pp. 4216–4231, Jun. 2021.
8. H. Guo, Y.-C. Liang, J. Chen, and E. G. Larsson, "Weighted sum-rate maximization for reconfigurable intelligent surface aided wireless networks," *IEEE Trans. Wireless Commun.*, vol. 19, no. 5, pp. 3064–3076, May 2020.
9. M.-M. Zhao, A. Liu, Y. Wan, and R. Zhang, "Two-timescale beamforming optimization for intelligent reflecting surface aided multiuser communication with QoS constraints," *IEEE Trans. Wireless Commun.*, vol. 20, no. 9, pp. 6179–6194, Sep. 2021.
10. Q. Wu and R. Zhang, "Intelligent reflecting surface enhanced wireless network via joint active and passive beamforming," *IEEE Trans. Wireless Commun.*, vol. 18, no. 11, pp. 5394–5409
11. C. You, B. Zheng, and R. Zhang, "Wireless communication via double IRS: Channel estimation and passive beamforming designs," *IEEE Wireless Commun. Lett.*, vol. 10, no. 2, pp. 431–435, Feb. 2021.
12. M.-M. Zhao, Q. Wu, M.-J. Zhao, and R. Zhang, "Intelligent reflecting surface enhanced wireless network: Two-timescale beamforming optimization," I*EEE Trans. Wireless Commun.*, vol. 20, no. 1, pp. 2–17, Jan. 2021.
13. D. Mishra and H. Johansson, "Channel estimation and low-complexity beamforming design for passive intelligent surface assisted MISO wireless energy transfer," in *Proc. IEEE ICASSP*, May 2019, pp. 4659–4663.
14. Y. Yang, B. Zheng, S. Zhang, and R. Zhang, "Intelligent reflecting surface meets OFDM: Protocol design and rate maximization," *IEEE Trans. Commun.*, vol. 68, no. 7, pp. 4522–4535, Mar. 2020.
15. T. L. Jensen and E. De Carvalho, "An optimal channel estimation scheme for intelligent reflecting surfaces based on a minimum variance unbiased estimator," in *Proc. IEEE ICASSP*, May 2020, pp. 5000–5004.
16. B. Zheng and R. Zhang, "Intelligent reflecting surface-enhanced OFDM: Channel estimation and reflection optimization," *IEEE Wireless Commun. Lett.*, vol. 9, no. 4, pp. 512–522, Apr. 2020.
17. Q.-U.-A. Nadeem, H. Alwazani, A. Kammoun, A. Chaaban, M. Debbahs, and M.-S. Alouini, "Intelligent reflecting surface-assisted multi-user MISO communication: Channel estimation and beamforming design," *IEEE Open J. Commun. Soc.*, vol. 1, pp. 661–680, 2020.
18. J. Lin, G. Wang, R. Fan, T. A. Tsiftsis, and C. Tellambura, "Channel estimation for wireless communication systems assisted by large intelligent surfaces," 2019, arXiv:1911.02158. [Online]. Available: http://arxiv.org/abs/1911.02158
19. C. You, B. Zheng, and R. Zhang, "Channel estimation and passive beamforming for intelligent reflecting surface: Discrete phase shift and progressive refinement," *IEEE J. Sel. Areas Commun.*, vol. 38, no. 11, pp. 2604–2620, Nov. 2020.
20. Z.-Q. He and X. Yuan, "Cascaded channel estimation for large intelligent metasurface assisted massive MIMO," IEEE Wireless Commun. Lett., vol. 9, no. 2, pp. 210–214, Feb. 2020.
21. Z. Wan, Z. Gao, and M. Alouini, "Broadband channel estimation for intelligent reflecting surface aided mmWave massive MIMO systems," in *Proc. IEEE ICC*, Jun. 2020, pp. 1–6.
22. W. Zhang, J. Xu, W. Xu, D. W. K. Ng, and H. Sun, "Cascaded channel estimation for IRS-assisted mmWave multi-antenna with quantized beamforming," *IEEE Commun. Lett.*, vol. 25, no. 2, pp. 593–597, Feb. 2021.
23. S. Liu, Z. Gao, J. Zhang, M. D. Renzo, and M.-S. Alouini, "Deep denoising neural network assisted compressive channel estimation for mmWave intelligent reflecting surfaces," *IEEE Trans. Veh. Technol.*, vol. 69, no. 8, pp. 9223–9228, Aug. 2020
24. J. Chen, Y.-C. Liang, H. V. Cheng, and W. Yu, "Channel estimation for reconfigurable intelligent surface aided multi-user MIMO systems," 2019, arXiv:1912.03619. [Online]. Available: http://arxiv.org/abs/1912.03619
25. Z. Wang, L. Liu, and S. Cui, "Channel estimation for intelligent reflecting surface assisted multiuser communications: Framework, algorithms, and analysis," *IEEE Trans. Wireless Commun.*, vol. 19, no. 10, pp. 6607–6620, Oct. 2020.

26. B. Zheng et al., "Intelligent reflecting surface assisted multi-user OFDMA: Channel estimation and training design," *IEEE Trans. Wireless Commun.*, vol. 19, no. 12, pp. 8315–8329, Dec. 2020.