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Redefining Connectivity with Next-Gen Strategies in Design and Tactical Deployment of Interference-Resolving Models for Millimeter Wave Networks

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Abstract

In this paper, we investigate an Intelligent Reflecting Surface (IRS)-aided radar-communication (Radcom) system, where the IRS plays a crucial role in assisting the Radcom base station (BS) in simultaneously transmitting communication signals and radar signals. The main objective is to minimize the total transmit power at the Radcom BS by optimizing the active beam formers, which include both communication and radar beam formers at the Radcom BS, along with the phase shifts at the IRS. This optimization is subject to constraints such as the minimum Signal-to-Interference-plus-Noise Ratio (SINR) required by communication users, the minimum SINR required by the radar, and the design of cross-correlation patterns. The paper considers two cases: case I and case II. Case I does not take into account cross-correlation design and interference introduced by the IRS on the Radcom BS. It is proven that dedicated radar signals are not necessary in this case, significantly reducing implementation complexity and simplifying algorithm design. A penalty-based algorithm is proposed to solve the resulting no convex optimization problem. On the other hand, for case II, which considers cross-correlation design and interference, the paper reveals that dedicated radar signals are generally needed to enhance system performance. As the optimization problem in case II is more challenging, a Semi definite Relaxation (SDR) based Alternating Optimization (AO) algorithm is proposed. Notably, instead of relying on the Gaussian randomization technique, the proposed algorithm aims to achieve tight optimization.

Keywords: IRS-aided Radcom Systems, Semidefinite Relaxation (SDR), Alternating Optimization (AO) Algorithm, Spectrum Sharing, Cross-correlation Design.

1. Introduction

The paper investigates the challenges posed by the exponential growth of mobile data and the proliferation of Internet of Things (IoT) devices, which are straining wireless service providers to deliver high data rates and ultra-reliable low-latency communication. This is particularly challenging due to the limited frequency spectrum available, ranging from 700 MHz to 2.6 GHz in existing communication networks. In contrast, radar systems operate across a more extensive spectrum, typically from 0.3-100 GHz, providing an opportunity for spectrum sharing between radar and wireless communication systems.

The study focuses on a radar-communication (Radcom) system, aiming to concurrently serve communication users and track targets. To enhance the capabilities of the Radcom system, the paper explores the integration of Intelligent Reflecting Surfaces (IRS). IRSs consist of passive reflecting elements capable of adjusting phase shift and/or amplitude on incoming electromagnetic signals. Leveraging IRS in Radcom systems presents an avenue for joint optimization of communication and radar signals. The paper introduces two cases, denoted as Case I and Case II, based on the presence or absence of radar cross-correlation design and interference introduced by the IRS on the Radcom base station (BS). The primary objective is to minimize the total transmit power at the Radcom BS through the joint optimization of active beamformers and phase shifts at the IRS. Constraints include ensuring minimum Signal-to-Interference-Plus-Noise Ratio (SINR) for communication users, minimum SINR for radar, and the design of cross-correlation patterns. In Case I, where interference introduced by the IRS is perfectly canceled, and cross-correlation design is ignored, the paper discusses the resulting optimization problem and proposes a solution. Case II, considering interference introduced by the IRS and including cross-correlation design, poses a more complex optimization problem. The paper introduces a Semidefinite Relaxation (SDR) based Alternating Optimization (AO) algorithm to address this challenge. The comparison between Case I and Case II sheds light on the necessity of dedicated radar signals under various design criteria, channel conditions, and receiver types. The study provides insights into the implications of interference and the importance of cross-correlation patterns in IRS-aided Radcom systems. The paper also delves into the integration of IRS into Radcom systems, highlighting the potential benefits of passive reflecting elements in enhancing both communication and radar sensing performance. Various applications of IRS in wireless communication, such as information transmission, wireless-powered communication networks, and non-orthogonal multiple access, are discussed.

Furthermore, the study considers multi-user and multi-target scenarios, extending its analysis to more realistic and complex deployment scenarios. By addressing the challenges and opportunities in IRS-aided Radcom systems, the paper contributes to the understanding of joint optimization strategies for communication and radar signals in the context of evolving wireless communication technologies. In conclusion, the paper navigates the intricate landscape of spectrum sharing between radar and wireless communication systems, proposing solutions and insights for optimizing Radcom systems with the integration of IRS. The findings contribute to the ongoing discourse on the future of wireless communication, particularly in the context of 6G paradigms, shedding light on potential advancements and challenges in this rapidly evolving field.

2. Intelligent Reflecting Surface

In addressing the non-convex optimization problem associated with an Intelligent Reflecting Surface (IRS)-aided Radar-Communication (Radcom) system, the paper presents a comprehensive approach divided into two cases: Case I, where cross-correlation design and interference from the IRS are not considered, and Case II, where both factors are taken into account.

In Case I, the paper provides a rigorous proof that dedicated radar signals are unnecessary under certain assumptions, including the independence of complex amplitudes of targets and the lack of correlation between amplitudes of targets and user channels. This proof significantly reduces implementation complexity and guides subsequent algorithm design. The proposed solution involves a novel penalty-based algorithm, featuring a two-layer iteration – an inner layer solving the penalized optimization problem and an outer layer updating the penalty coefficient to ensure convergence. Importantly, the inner layer employs either closed-form or semi-closed-form expressions to solve each subproblem.

For Case II, where both cross-correlation pattern design and IRS-induced interference are considered, the paper acknowledges the increased complexity compared to Case I. Consequently, the penalty-based algorithm from Case I is deemed inadequate, and a Semidefinite Relaxation (SDR)-based Alternating Optimization (AO) algorithm is proposed. This algorithm overcomes the difficulty by achieving tightness through a novel reconstruction strategy, eliminating the need for the Gaussian randomization technique for obtaining an approximate solution. Furthermore, the paper reveals that dedicated radar signals are generally required in Case II to enhance overall system performance. Simulation results presented in the paper demonstrate the benefits of IRS in reducing transmit power for Case I. Additionally, for Case II, the deployment distance between the IRS and the Radcom BS plays a crucial role: when the IRS is farther away, it aids in power reduction, but proximity may lead to interference, potentially deteriorating system performance. The adoption of dedicated radar signals at the Radcom BS is shown to significantly reduce system outage probability in Case II compared to scenarios without such signals.

The subsequent sections of the paper are organized as follows: Section II introduces the system model and formulates the problem for the IRS-aided Radcom system. Section III proposes a penalty-based algorithm for solving Case I, while Section IV presents an SDR-based AO algorithm for Case II. Numerical results are discussed in Section V, and the paper concludes in Section VI. Various notations are employed throughout the paper to denote matrices, vectors, and other mathematical entities, and the relevant definitions and symbols are provided. The paper concludes with acknowledgments and references.

3. Case Studies

Case I:

In Case I, the paper rigorously establishes that dedicated radar signals are unnecessary under specific assumptions, reducing implementation complexity. The proposed penalty-based algorithm, featuring a two-layer iteration, provides an efficient solution with closed-form or semi-closed-form expressions for each subproblem. The proof emphasizes the independence of complex amplitudes of targets and the lack of correlation between amplitudes of targets and user channels. Simulation results demonstrate the feasibility of this approach, showcasing reduced implementation complexity and optimized system performance without the need for dedicated radar signals.

Case II:

Case II introduces increased complexity by considering both cross-correlation pattern design and IRS-induced interference. The inadequacy of the penalty-based algorithm in this scenario prompts the introduction of an SDR-based AO algorithm. This novel approach overcomes the challenges by achieving tightness through a unique reconstruction strategy, eliminating the reliance on the Gaussian randomization technique. Simulation results highlight the necessity of dedicated radar signals in Case II, emphasizing their role in enhancing system performance. The analysis underscores the critical impact of the deployment distance between the IRS and Radcom BS, providing practical insights for optimizing power reduction and minimizing interference for improved overall system reliability.

4. Conclusion

In conclusion, the paper provides a comprehensive exploration of the optimization challenges associated with Intelligent Reflecting Surface (IRS)-aided Radar-Communication (Radcom) systems. By dividing the analysis into two distinct cases, the study elucidates the intricate dynamics involved in spectrum sharing between radar and wireless communication systems, offering valuable insights for the joint optimization of communication and radar signals. The introduction of Semidefinite Relaxation (SDR)-based Alternating Optimization (AO) algorithms proves to be a pivotal contribution in addressing the increased complexity arising from interference introduced by the IRS and the inclusion of cross-correlation design.

The comparison between Case I and Case II underscores the significance of dedicated radar signals under diverse design criteria, channel conditions, and receiver types. The findings emphasize the necessity of tailored radar signal strategies to enhance system performance, especially in scenarios where interference and cross-correlation patterns are critical considerations. The study further extends its analysis to multi-user and multi-target scenarios, presenting a more realistic depiction of deployment scenarios and offering practical implications for real-world applications. Additionally, the paper delves into the integration of IRS into Radcom systems, shedding light on the potential benefits of passive reflecting elements in augmenting both communication and radar sensing capabilities. The discussions on various applications of IRS in wireless communication broaden the scope of the study, touching upon information transmission, wireless-powered communication networks, and non-orthogonal multiple access. By addressing the non-convex optimization problem associated with IRS-aided Radcom systems, the paper not only contributes to the current understanding of joint optimization strategies but also paves the way for future advancements in wireless communication technologies, particularly in the context of emerging 6G paradigms. The comprehensive approach presented in the paper, along with the proposed algorithms, offers a valuable framework for navigating the challenges and opportunities in the evolving landscape of spectrum sharing.

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