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# Performance tradeoff in a unified system of communications and passive radar: A secrecy capacity approach

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ABSTRACT

In a unified system of passive radar and communication systems of joint transmitter platform, information intended for a communication receiver may be eavesdropped by a passive radar receiver (RR), thereby undermining the security of communications system. To minimize this information security risk, in this paper, we propose a unified passive radar and communications system wherein the signal-to-interference and noise ratio (SINR) at the RR is maximized while ensuring that the information secrecy rate is above a certain threshold value. We consider both scenarios wherein transmissions of the radar waveform and information signals are scheduled with the disjoint (non-overlapping case) as well as with the same set of resources (overlapping case). In both cases, the underlying optimization problems are non-convex. In the former case, we propose alternating optimization (AO) techniques that employ semidefinite programming and computationally efficient semi-analytical approaches. In the latter case, AO method based on semi-definite relaxation approach is proposed to solve the optimization problem. By changing the threshold value of the information secrecy rate, we then characterize the performance tradeoff between passive radar and communication systems with the boundaries of the SINR-secrecy capacity regions. The performance comparison of the proposed optimization methods demonstrate the importance of the semi-analytical approach and the advantage of overlapping case over non-overlapping one.

## 1. Introduction

Radar sensing and wireless communications are the two most prominent techniques that are based on similar radio frequency phenomena and can be characterized with similar signal processing techniques [1]. However, a radar system's typical goal is to detect, localize, and track targets, whereas the goal of communication systems is to maximize information transfer and enhance its reliability. Due to different objectives, hardware configurations, power and bandwidth requirements, and frequency bands of operations, these two systems have been independently considered and developed as two separate entities. However, due to an ever increasing number of wireless devices and networks as well as demand for high speed multimedia data services, it is important for the two systems to share common spectrum and enhance bandwidth utilization via improved spectrum congestion techniques. In this regard, some frequency spectrum, e.g., 2–4 GHz range, has been allocated for both radar and communication systems, such as Long Term Evolution (LTE) [2]. When two systems share the same frequency band, techniques such as opportunistic spectrum sharing [3], dual-function radar-communications (DFRC) [4], [5], and cooperation between radar and communication systems [6], [7] have been proposed to minimize the inter-system interference and enhance the performance of both systems.

On the other hand, passive radar systems (PRS) have received significant research interests due to their low cost, covertness, and availability of a large number of illumination sources, such as cellular base stations and television stations [8], [9]. To this end, the authors of [10–12] have proposed several algorithms for detecting, localizing, and tracking targets in PRS. In [13], the detector based on the generalized likelihood ratio test (GLRT) has been proposed for PRS consisting of a single transmitter and a single receiver, whereas the corresponding GLRT detectors for multiple-input multiple-output (MIMO) PRS have been developed in [14,15]. While these papers assume multi-frequency networks, an extension to single-frequency multi-static PRS has been proposed in [16].

Recent advancements in PRS (especially in the case of single-frequency multi-static scenario) demonstrate that the estimation

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of the non-cooperative transmitters' waveforms is challenging and significantly affects the performance of the PRS. In particular, the performance of the PRS approaches that of active radars [16], if the waveform estimation is sufficiently accurate. Motivated from this fact, the authors in [17] propose to develop PRS as a part of a bandwidth-flexible communication system [17], where the transmitters no longer remain completely non-cooperative, and in fact, assist the radar receiver in estimating the broadcast signals more efficiently through improved resource allocations. The single joint radar and communications transmitter proposed in [17] is recently extended to a scenario of multiple transmitters in [18]. However, in both papers, information security is not considered, each transmitter is equipped with only a single antenna, and the radar and information signals are transmitted through orthogonal channels (non-overlapping case).

Security in wireless communications is a critical issue, since wireless channels are often prone to eavesdropping. To this end, based on the seminal work of [19], information theoretic physical layer design approaches for enhancing security in wireless systems have been widely studied in the literature [20–22]. Physical layer security approach aims to prevent unintended users from decoding information transmitted to the intended users by maximizing information *secrecy rate*. The advantage of this approach is that secrecy can be achieved without using an encryption key. On the other hand, information theoretic metrics have been also used in the design and analysis of radar systems [23], [24]. To this end, the authors in [25] consider a monostatic MIMO radar system, wherein the objective is to enhance radar performance and secure information transmitted to a legitimate communication receiver from an eavesdropper-target. For this purpose, beamforming vectors, applied to communication and distortion signals, are jointly optimized. A Taylor series approximation approach [26] is proposed to convexify the non-convex function of secrecy rate. However, to the best of our knowledge, the problem of designing algorithms for a unified system of passive radar and communications, while emphasizing information security has not been investigated in the literature. This problem is important in a unified system since information signals intended for a communication receiver (CR) may be eavesdropped by a passive radar receiver (RR), thereby undermining information security. Moreover, in contrast to [25], our objective is to jointly optimize radar waveforms and covariance matrix of information signals without additionally transmitting distortion signal.

In this paper, we consider a unified system consisting of a transmitter, a passive RR, and a CR, each equipped with multiple antennas. The performance tradeoff between radar and communications is characterized by obtaining the boundaries of the signal-to-interference-and-noise ratio (SINR) for the RR versus information secrecy rate region, when considering the same RR as an eavesdropper.[1] To this end, joint optimization of radar waveforms and transmit covariance matrix of information signals is proposed with the objective of maximizing the SINR at the RR, while ensuring that the information secrecy rate is above a certain threshold. We formulate the underlying non-convex optimization problems and provide corresponding solutions when the radar and information signals use both orthogonal and non-orthogonal (overlapping) sets of resources. In both cases, iterative alternating optimization (AO) methods that employ semi-definite programming (SDP)/semi-definite relaxation (SDR) are proposed for optimizing radar waveforms and transmit covariance matrices.[2] However, in the former case, a computationally efficient semi-analytical approach is also proposed. Simulation results show that this approach provides significant performance gains over the SDP-based approach. Moreover, in spite of interference caused in the overlapping method, due to joint optimization of radar waveforms and transmit covariance matrix, results show that the overlapping method provides better performance than the non-overlapping one.

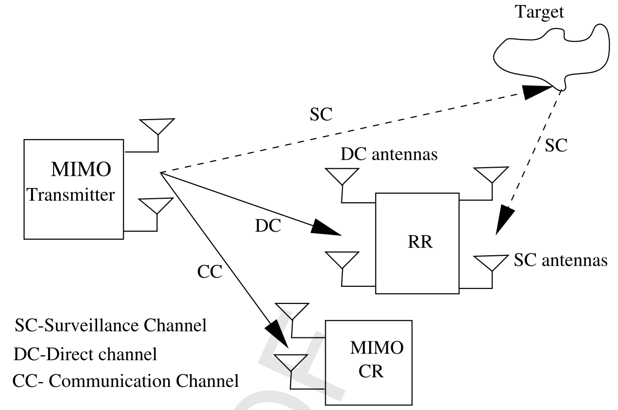

**Fig. 1.** A unified system with a transmitter, a RR and a CR, all equipped with multiple antennas.

The remainder of this paper is organized as follows: Section 2 presents the system model of unified passive radar and communications. Section 3 provides problem formulations and corresponding solutions for the optimization problems of the non-overlapping case. The problem formulation and optimization method for the overlapping case are presented in Section 4. Numerical results are provided in Section 5. Finally, Section 6 concludes the paper and summarizes the key findings.

*Notations:* Upper (lower) bold face letters will be used for matrices (vectors); $(\cdot)^H$, $\mathbf{I}_N$, $||\cdot||$, and $\otimes$ denote Hermitian transpose, $N \times N$ identity matrix, Euclidean norm for vector/Frobenius norm for matrix, and Kronecker product operator, respectively. $\mathrm{tr}(\mathbf{X})$ and $\det(\mathbf{X})$ denote trace and determinant of a matrix $\mathbf{X}$, respectively, $\mathbf{X} \succeq 0$ denotes that $\mathbf{X}$ is a positive semi-definite matrix, and $\mathrm{vec}(\mathbf{X})$ denote the vectorization of $\mathbf{X}$. $\mathcal{C}^{N \times M}$ stands for a space of complex matrix of dimension $N \times M$, and $\mathcal{N}_C(\mu, \sigma^2)$ and $\mathbb{E}\{\}$ denote circularly symmetric complex Gaussian distribution with mean $\mu$ and variance $\sigma^2$ and expectation operation, respectively.

## 2. System model

Consider a system that supports both communications and radar receivers, as shown in Fig. 1. The transmitter and CR are equipped with $N_t$ and $M$ antennas, respectively. The antennas of the RR are divided into groups of direct channel (DC) antennas and surveillance channel (SC) antennas. Without loss of generality, we assume that the same, i.e., $N$ antennas are used for the DC and SC. The DC antennas receive signals via direct path from the transmitter, whereas the SC antennas receive signals originating from the transmitter but reflected by a target. The direct path signal is used at the RR for estimating the radar waveform as in the case of PRS. Although the transmitter is not non-cooperative to the RR (in contrast to the conventional PRS), signal transmissions to the radar and communication receivers may be scheduled using

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[1] In general, information security should be achieved against all eavesdroppers, including the RR. While such design approach will be reported in our future work, it is worthwhile to mention that the RR's eavesdropping capability is higher than that of any other eavesdropper, since, as a part of the unified system, the RR has more knowledge about the settings, parameters, and protocols of the unified system.

[2] These optimization techniques form the basis for solving several problems in other contexts, primarily in the design of communication only systems (see [22], [27], and references therein). We propose to leverage these techniques for the joint transmitter design in a unified system of passive radar and communications.

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