Multiobjective optimal waveform design for OFDM integrated radar and communication systems

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Abstract

To improve the availability of limited spectral resources and construct a cost-efficient platform simultaneously performing both radar and communication functions, the orthogonal frequency division multiplexing (OFDM) integrated radar and communication system (IRCS), which is referred to as OFDM-IRCS, is provided. For the frequency sensitive target and frequency selective fading channel, it is able to improve the radar and communication performance by efficiently employing the limited transmit power in the OFDM-IRCS. To this end, we propose two optimal waveform design methods that meet different users' demands. First, the Cramer-Rao bounds (CRBs) for estimating range, velocity and target scattering coefficients with integrated OFDM waveform are derived. And the channel capacity in communication is formulated. Then, the multiobjective optimization problem is devised, and the adaptive weighted-optimal and Pareto-optimal waveform design approaches are proposed to simultaneously improve the estimation accuracy of range and velocity in radar and the channel capacity in communication. Finally, several numerical examples are presented to demonstrate the effectiveness of the proposed design methods.

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1. Introduction

With the development of electronic technique, multimission and multifunction systems have become a development tendency. The traditional approach that accumulates the devices of different functions, such as radar and communication, in the same platform will cause the increase of size, weight, energy cost, electromagnetic interference, radar cross section, and complexity in operating the whole system. A typical solution that comes from the advanced multifunction radio frequency concept (AMRFC) integrates radar, electronic warfare, and communication in an identical platform with the array antennas, signal processing, and display hardware shared [1]. However, the waveforms corresponding to different functions are independent. In the intelligent transportation system (ITS) [2–4], it is imperative to utilize the radar device to sense the surrounding traffic circumstance and exploit the communication device to mutually convey information with others, which brings about the requirement for their integration to decrease the system size, energy consumption and complexity (Fig. 1).

Except for the integration of radar and communication in hardware, many researchers are concerning about their integration in waveform (i.e., integrated waveform) to improve the availability of limited spectral resources [5,6]. These investigations are motivated by the potential scenarios in which the integrated radar and communication system (IRCS) with integrated waveform would be used. Two illustrative examples are shown in Fig. 2 [6]. In Fig. 2, the IRCS transmits the integrated waveform to convey the communication information to the communication receiver and detect the target, simultaneously.

The integration of radar and communication in hardware platform is easily performed, since there are many similar hardware configurations in the radar and communication systems [6]. At present, it is more significant to explore the integrated waveform to improve the spectral efficiency. Due to this, various integrated waveform design approaches are proposed, and they can be classified into two major groups: multiplexing-waveforms and identical-waveforms. The multiplexing-waveforms perform the multiplexing of the radar and communication waveforms by employing space division multiplexing (SDM) [7], time division multiplexing (TDM) [8], frequency division multiplexing (FDM) [9], or code division multiplexing (CDM) [10]. Such type of methods is prone to be implemented but has limited availability of system resources. For example, the multiplexing-waveform exploiting TDM cannot carry out the radar and communication functions at the same time. The identical-waveforms are shared by radar and communication and they are either proceeded from the conventional radar waveforms [11,12], or rested on the classical communication waveforms [13]. The resource utilization of this kind of waveforms is high effi-

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it has been revealed that the total power of the IRCS is limited. Performing the equal transmit power allocation in each subcarrier, the OFDM-IRCS performance will be degraded. To simultaneously improve the radar and communication performance of the OFDM-IRCS, the transmit power allocated in different subcarriers is optimized under the total power constraint.

Generally, it is potential to improve the range and velocity estimation accuracy by minimizing the corresponding Cramér-Rao bounds (CRBs), since the CRB is the lower bound on the variance of the unbiased estimators [50]. The CRBs on range and velocity is associated with the target scattering coefficients which are unknown but can be estimated in practical applications. Therefore, improving the estimation accuracy of the target scattering coefficients by minimizing the corresponding CRBs is essential for minimizing the CRBs on range and velocity. Moreover, the communication performance can be improved by maximizing the channel capacity. Hence, under the total transmit power constraint, the multiobjective optimization problem is devised to improve the radar and communication performance of the OFDM-IRCS. It contains four objective functions: 1) maximize the channel capacity; 2) minimize the CRB on range; 3) minimize the CRB on velocity; and 4) minimize the trace of the CRB matrix on the target scattering coefficients.

In this paper, the multiobjective function is solved by two methods. One method is that the devised multiobjective optimization problem is transformed into a single objective optimization problem by specifying a weight for each objective function according to the user’s demand, which is referred to as weighted-optimal waveform design method. The other method directly settles the multiobjective optimization problem by employing the distinguished nondominated sorting genetic algorithm II (NSGA-II) [51] and achieves the Pareto-optimal solutions, which is defined as Pareto-optimal waveform design method. The Pareto-optimal waveform design method in this paper is to improve the radar and communication performance of the IRCS, while the adaptive waveform design method in [42] is to improve the detection performance of the OFDM-STAP radar, although both of them utilize the well-known NSGA-II optimization technique and include the objective functions of the CRB on velocity and the trace of CRB matrix on target scattering.

Moreover, in this paper the peak-to-average power ratio (PAPR) of the designed waveforms are investigated, since it is an important feature of OFDM. The potential high PAPR due to the time-varying envelop of OFDM is able to cause the nonlinear distortion of the signal. For this reason, various methods are proposed to reduce the PAPR [31,52,53].

The residual of this paper is organized as follows. In Section II, the integrated signal and radar measurement models are established. Two adaptive waveform design methods are proposed in Section III. In Section IV, several numerical simulations are pre-

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**Fig. 1.** The application scenarios of integrated radar and communication system. (a) ITS. (b) Avionics.

**Fig. 2.** The transmitted OFDM waveform in (a) OFDM-IRCS, (b) OFDM-STAP, and (c) communication system.
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