Optimization of Multistatic Passive Radar Geometry Based on CRLB with Uncertain Observations

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***Abstract*— In the present paper, we derive the Cramer-Rao Lower Bound (CRLB) with uncertain observations, namely for P_d<1, for the 2D position measurements of a multistatic passive radar, to optimize the geometry of the system. This is an extension of the enumeration method CRLB [1-3] to the multisensor case, where it is considered that the multiple receivers could detect or miss the target independently of one another. This version of the CRLB with uncertain observations is the correct measure for the realistic performance assessment of a passive radar, since typically passive radars show low values of P_d and neglecting the target miss probability, in the standard evaluation of the CRLB, provides unreliable performance assessments.**

The obtained CRLB is then used inside the multistatic passive radar optimization scheme derived by the authors in [4], to select the broadcast transmitters and the receiver locations providing the highest accuracy. The proposed approach is illustrated by means of a case study: a multistatic passive radar based on two transmitters of opportunity and a single receiver. For this case, we analyse how the Signal to Noise Ratio and the detection probability affect the measurement accuracy and the estimation accuracy and, finally, we use the theoretical CRLB to select the two transmitters among the available ones and choose the receiver location, for a target flying a specific trajectory.

I. INTRODUCTION

Multistatic passive radar performance in terms of positioning accuracy is largely dependent on the geometry, and can be to optimised by: (i) selecting the most appropriate transmitters of opportunity among the available ones, and (ii) identifying the optimal receiver location. These steps are clearly not independent so that a joint optimization is required. In [4] we introduced a procedure to obtain a multistatic system which is effective for the surveillance of aircrafts flying a specific assigned trajectory, as it is for example the case of an approach path or a portion of an air route.

The optimization procedure presented in [4] was obtained by using a simplifying hypothesis on the range accuracy, that was set coincident with the range resolution and independent of the actual SNR (Signal to Noise Ratio). The resulting performance parameter, represented by the CRLB, depends on the geometry only in terms of relative angular values. In contrast, the SNR affects largely both detection probability and range accuracy and, in the specific case of a passive radar, it rapidly changes from a very high value, very close to the transmitter, to low values, causing a drop of the probability of detection up to values between 0.8 and 0.6. Therefore, for passive radar performance assessment, the SNR value must be carefully included into the evaluation. This is done by both (a) considering a range accuracy dependent on the SNR in the evaluation of the CRLB, (b) removing the assumption of P_d=1, intrinsically made when evaluating the standard CRLB.

The CRLB plays an important role in the estimation theory, because it theoretically predicts the best achievable second-order estimation error performance, however, when operating after a detection test, it must be modified accordingly. In [1], the theoretical CRLB for P_d < 1 and P_{fa}=0 (i.e. absence of false alarms) has been calculated via the enumeration of all possible sequences of detections and miss detections, given a certain scan number, for a conventional active radar. In this paper, we provide an extension of this approach to a multistatic passive radar, where for each bistatic TX-RX couple, an independent detection test is applied, so that there are multiple independent decisions for each set of measurements.

The paper is organized as follows. In Section II we derive the CRLB with uncertain measurements for the multistatic passive radar, by extending the enumeration approach to the multisensor case obtaining a realistic evaluation of the positioning accuracy, that fully includes the effect of SNR. In the remainder of the paper, the derived CRLB is exploited to refine the multistatic passive radar optimization scheme. In particular, after describing the constraints for the relative position of transmitters and receivers, due to the antennas radiation pattern and signal processing (Section III), we introduce our case study (Section IV) and presents some results (Section V) and conclusions (Section VI).

II. EXTENSIVE ENUMERATION CRAMER RAO LOWER BOUND

To extend the approach in [1-3] to the case of N sensors, with detection probability $P_{d\,i}$<1, i=1,..,N and performing an independent detection test, we proceed as follows.

We assume each sensor performs K bistatic range measurements: $R_{Bi,k}=R_{i,k}(x,y)+\varepsilon_{Ri,k}$, with $k=1,..,K,$ that are assumed independent and with Gaussian probability density function with expected value $E\{R_{Bi,k}\}=R_{i,k}(x,y)$ and variance $E\{(R_{Bi,k}-E\{R_{Bi,k}\})^2\}=\sigma^2_{\varepsilon i,k}$. Next, we introduce an observable boolean variable $d_{i,k}$ that corresponds to the event that the target was detected or missed at time k: