Abstract—In this paper we apply a data association in Track-Before Detect (TBD) with a Polar Hough Transform (PHT) in a radar network. The proposed algorithm is applied in Multiple Input Multiple Output (MIMO) radar system. We study the sensitivity of TBD multi-radar system as a function of the errors of target trajectory parameters measurement. The results are obtained in the presence of Randomly Arriving Impulse Interference (RAII) and the target coordinates (range and azimuth) are measurable with and without errors. The study of the signal processing used in detectors is performed through Monte-Carlo simulations in MATLAB computing environment.

Index Terms — MIMO radar system, Track-Before-Detect (TBD) with Polar Hough Transform (PHT), Randomly Arriving Impulse Interference (RAII).

I. INTRODUCTION

The data association problem is of significant importance in the process of building up multiple radar system for detection of target and trajectories. It is known that in radar nets information unification is carried out for signal, detected target or trajectory [1,2]. Conventional approaches for data association of the multi-radar system are: the centralized and the decentralized approach [2-4].

In centralized radar nets, the processing consists of two parts. The first detection is performed on signals for each of the monostatic/bistatic cases, i.e. in a decentralized pre-processing. Next, all the decisions are jointly fused, so the system can provide a final output.

Based on the way the net works, systems are divided in two groups – synchronous and asynchronous. Radar nets have better detection efficiency than the single radars.

Recently the development of the mobile communications makes possible solving of different tasks - Secondary Applications of Wireless Technology (SAWT). This and the contemporary application of the MIMO approach in radar/communication nets require new processing algorithms.

Because of that we research different possible structures of TBD detectors in asynchronous nets in the presence of RII jamming [5].

In [5] we study the performance of centralized and decentralized structures of TDB detectors in asynchronous nets in presence of RAI. We show that when there are no errors in measuring radar coordinates the centralized three channels algorithm is more efficient than the decentralized one.

In [6] we research the influence of measurement errors to the dimensions of the Hough space of three channels decentralized TBD detector in asynchronous net, in presence of white noise.

In our paper, we propose a new multisensor data association approach, which uses the Polar Hough Transform (PHT). The polar Hough transform is considered as a track initiator in a track-before-detect (TBD) system. The algorithm under study includes a CFAR detector, which works successfully in conditions of impulse interference and uses the polar Hough transform. In contrast to the HT, proposed by Carlson, Evans, and Wilson in [7], the polar Hough detection algorithm proposed by Garvanov and Kabakchiev in [8] and considered in the paper, is very effective for track and target detection because the input parameters of the transform are the output parameters of the search radar [8,9].

The presence of randomly arriving impulse interference in radar resolution cells can cause drastic effectiveness degradation of a CFAR processor and Hough detector. False alarms caused by impulse noise make difficult track detection.

In our previous research, different types of CFAR Hough detectors operating in the presence of randomly arriving impulse interference were studied under the assumption that the target trajectory parameters in Hough space (rho and theta) are defined without errors. In this case, the target detection was improved [10-16].

In the present paper we consider the target detection efficiency of decentralized multichannel TBD detector. The proposed algorithm performs successfully in asynchronous nets in conditions of RAI.

Our hypothesis was that the potential characteristics of the
new TBD detector will place it between the centralized and decentralized ones. In this case the radar measurement errors will naturally lead to less detection efficiency.

II. SIGNAL MODEL

It is assumed that the target is fluctuating according to the Swerling II case. It is also assumed that the total background environment includes two situations: (i) Poisson interference plus noise, which may appear at the receiver input with a probability of \( e_0 \), and (ii) noise only with a probability of \( 1-e_0 \). The probability density function (pdf) of the signal power is given in [17] and used in [8-13].

\[
f(x_n) = \frac{(1-e_0)}{\lambda_0(I+S)} \exp\left(-\frac{-x_n}{\lambda_0(I+S)}\right) + \frac{e_0}{\lambda_0(I+S)} \exp\left(-\frac{-x_n}{\lambda_0(I+S)}\right)
\]

where \( \lambda_0 \) is the average power of the receiver noise, \( I \) is the average interference-to-noise ratio (INR) of impulse interference, \( S \) is the average signal-to-noise ratio (SNR).

III. DECENTRALIZED NONSYNCHRONOUS MULTIRADAR POLAR HOUGH DETECTOR

The researched TBD radar system includes a few transmitting and receiving stations. A block diagram of a netted Polar Hough detector is presented on Figure 1. This scheme has parallel topology. The signal processing in each receiving station includes optimum linear filtration, square law detection (SLD), CFAR detection and plot extraction (PE), which maintains a constant false alarm probability in the process of target detection. In such a detector, target detection is declared if the signal sample exceeds a preliminary determined adaptive threshold.

After radar scan, each of the radars forms the local polar data space \((r, \alpha)\) where \(r_n \in [0, r_{max}]\) and \(\alpha \in [0,360°]\) are the target range and azimuth, respectively of the N-th radar. All co-ordinate systems are oriented to the “North”, and the earth curvature is neglected. The first stage is data association of the N-th radar co-ordinate systems to the Global Co-ordinate System (GCS). The second stage is a Polar Hough Transform (PHT), (fig.3).

The PHT maps points (targets) from every one associated local observation space (associated data map) into curves in the Hough parameter space, termed as the \((\rho, \theta)\) plane, by:

\[
\rho = r_n \cos(\alpha_n - \theta), \quad 0 < (\alpha_n - \theta) \leq \pi
\]

where the parameter \( \rho \) represents the smallest distance between the line trajectory and the origin of the global polar co-ordinate system, while \( \theta \) is the angle of the vector from the origin to this closest point. If a line trajectory exists in the global \((r,\alpha)\) space, by means of polar Hough transform it is represented as a point of intersection of sinusoids defined by PHT.

![Figure 1: TBD Polar Hough Data Association detector](image)

The parameters \( \rho \) and \( \theta \) present the linear trajectory in the Hough parameter space and can be transformed back to the global data space showing the current distance to the target. If the number of binary integrations (BI) of data in the Hough parameter space (of intersections in any of the cells in the parameter space) exceeds the detection threshold, both target and linear trajectory detections are indicated, (fig.4).
The advantage of the proposed by us approach is the data unification in a net of asynchronously working radars with different accuracy characteristics and each of the radars can have different observation sampling period.

The obtained information, which can have different accuracy characteristics of range, time and azimuth, is unified by the proposed decentralized TBD detector. The detector makes use of Polar Hough transform with binary integration with fixed threshold and reverse Hough transform.

Unlike the conventional radar data unifying algorithms, we use the Polar Hough Transform for detection of targets located on one straight-line trajectory at the same time.

When the difference between the accuracy characteristics is significant it is necessary to adjust the dimensions of the Hough parameter space – to increase or decrease the size of accumulator cell. This leads to resolution decreasing when detection closely located of crossing trajectories.

The Polar Hough Transform is only efficient if a high number of radar measurements fall in the right range-azimuth area which correspondence of one accumulator cell in Hough space, so that the binary integration can be easily detected amid the background noise. This means that the accumulator cell must not be too small, or else some radar measure will fall in the neighboring Hough cells, thus reducing the visibility of the main cell.

Also, much of the efficiency of the Polar Hough Transform is dependent on the quality of the input data: the edges must be detected well for the PHT to be efficient. Use of the PHT on noisy background (presence of false alarm) is a very delicate matter and generally, it is necessary more radar measurement, since it has the nice effect of attenuating the noise through summation.

IV. SIMULATION EXAMPLE AND EXPERIMENT DESCRIPTION

Using a TBD Polar Hough Data Association detector, we illustrate, in this paper, the advantages of the netted radar operated in the presence of randomly arriving impulse interference.

Trajectory of a target in a net of asynchronous radars making use of PHT for data unifying is simulated. The experimental results are obtained for the same conditions as described in [5]. The study is carried out using Monte-Carlo simulations in MATLAB computing environment. Like in [6], in the present paper we consider the probability characteristics of a decentralized net in RAI conditions with or without radar measurement errors.

The simulational results for the detection probability are obtained for no RAI and no measurement errors and for fixed constant false alarm rate. As seen on fig.5, the detection probability decreases when the binary rules in the Hough parameter space $(M/Ns)$ increase. The maximum detection probability is obtained when binary rule is $7/20$. The obtained detection probability is small because the input average SNR$\cong15$dB and it is commensurate with INR=10 dB. These results are equal to results obtained with one channel Hough detector (one radar) in condition of white Gaussian noise as in [2,11]. The results have shown that the detection probability of the TBD Polar Hough Data Association detector is between the curves of detector with binary rules in distributed Hough detector $1/3 - 3/3$. 
In the present paper we study the probability characteristics of a decentralized multichannel TBD Polar Hough Data Association detector in asynchronous radar nets with and without measurements errors in conditions of randomly arriving impulse interference. The study is carried out using Monte-Carlo simulations in MATLAB computing environment. The results have shown that the detection probability of the TBD Polar Hough Data Association detector is between the curves of detector with binary rules in distributed Hough detector 1/3 - 3/3.

The results achieved in this paper can be practically used for design of modern Multiple Input Multiple Output (MIMO) radar and communication systems.

REFERENCES