ICIC Express Letters
Volume **10**, Number **12**, December **2016**

ICIC International ©2016 ISSN 1881-803X
pp. **2787–2792**

POWER ALLOCATION AND SENSOR ASSIGNMENT IN LPI RADAR NETWORK FOR MULTIPLE-TARGET TRACKING

Ji She, Fei Wang and Jianjiang Zhou*

Key Laboratory of Radar Imaging and Microwave Photonics, Ministry of Education
Nanjing University of Aeronautics and Astronautics
No. 29, Yudao Street, Qinhuai Dist., Nanjing 210016, P. R. China
*Corresponding author: zjjee@nuaa.edu.cn

Received May 2016; accepted August 2016

Abstract. *In this paper, we consider a joint strategy of power allocation and sensor assignment to improve the low probability of interception (LPI) performance of distributed radar network for multiple-target tracking. The received signal to noise ratio (SNR) of radar network can provide a measurement of target detection performance. Using a given threshold of the minimum acceptable SNR, the suitable radar which operates in an active way of each target with minimum transmitted power can be selected. Simulation results demonstrate that the proposed algorithm can effectively reduce the total transmitted power of radar network to improve LPI performance.*

Keywords: Low probability of interception (LPI), Power allocation, Sensor assignment, Radar network, Multiple-target tracking

1. **Introduction.** The concept of low probability of intercept (LPI) radar network has been paid considerable interest in the past few years. With the development of interceptor, it is quite possible that radar systems which have good LPI performance will be of more use in the future battlefield. The study of LPI optimization by radar network has been widely researched. Yang et al. propose an optimization algorithm of radio frequency (RF) stealth for multiple-input multiple-output (MIMO) radar in tracking mode [1]. Shi et al. propose novel LPI optimization schemes for radar network system in single target scenario based on security information [2]. Narykov and Yarovoy investigate a sensor selection algorithm for target tracking using multiple phase array radars to select the sensor and its parameters adaptively, minimize the resource loading and guarantee a certain level of tracking performance [3]. Andargoli and Malekzadeh propose a target assignment and power allocation algorithm in LPI searching radar [4]. To the best of authors' knowledge, there is no literature investigating the LPI performance of radar network for multiple-target tracking.

This paper investigates a sensor assignment and power allocation algorithm for multiple-target tracking in LPI radar network. This algorithm can be formulated to minimize the total transmitted power of radar network subject to satisfying the given SNR threshold which provides a measurement of target detection performance. A significant reduction of total transmitted power of radar network can be achieved through the proposed strategy. Hence, the LPI performance of radar network for multiple target tracking can be effectively improved.

The remainder of this paper is organized as follows. Section 2 provides the system model of radar network. Section 3 proposes a sensor assignment and power allocation algorithm in LPI radar network based on the predetermined SNR threshold. Numerical simulations are provided in Section 4. Finally, Section 5 concludes this paper.

2. **System Model.** We consider a distributed radar network system with N radars, which share data and information to improve overall performance. A set of Q targets is assumed to be detected. All radars in the radar network are synchronized properly. In this paper, we assume the radar network works cooperatively in such a mode that each target tracking using single selected radar which operates in an active way and the other radars can receive echoes reflected from the target of the signals transmitted from the active radar. One of the radars is set as fusion center, in which information fusion, power allocation and sensor assignment have been given.

Assuming target q, $q = 1, \ldots, Q$, tracking uses one transmitter node and N receiver nodes of radar network. It can be seen that the whole network can be broken down into $1 \times N$ transmitter-receiver pairs for target q, each with a bistatic component contributing to the overall SNR of radar network. Assuming the ith radar operates in an active way for target q, the overall SNR of radar network is the sum of partial SNR of each transmitter-receiver pair [5], as follows:

$$SNR_q = \sum_{j=1}^{N} \frac{P_{ti}^q G_{ti} G_{rj} \sigma_{ij}^q \lambda_i^2}{(4\pi)^3 k T_s B_i L_{ij} N_{Fj} R_{ti}^{q2} R_{rj}^{q2}} \tag{1}$$

where P_{ti}^q is the ith transmitted power, G_{ti} is the ith transmit antenna gain, G_{rj} is the jth receive antenna gain, σ_{ij}^q is the radar cross section (RCS) of target q for the ith transmitter, the jth receiver, λ_i is the ith transmitted wavelength, k is Boltzmann's constant, T_s is the receiving system noise temperature, B_i is the bandwidth of the matched filter for the ith transmitted waveform, L_{ij} is the system loss for the ith transmitter, the jth receiver, N_{Fj} is the noise factor at the jth receiver, R_{ti}^q is the distance from the ith transmitter to target q, and R_{rj}^q is the distance from target q to the jth receiver.

We introduce a binary variable u_i^q as sensor assignment index. $u_i^q = 1$ means the ith radar selected to operate in an active way for target q; otherwise $u_i^q = 0$. SNR_q can be rewritten as:

$$SNR_q = \sum_{i=1}^{N} \sum_{j=1}^{N} \frac{u_i^q P_{ti}^q G_{ti} G_{rj} \sigma_{ij}^q \lambda_i^2}{(4\pi)^3 k T_s B_i L_{ij} N_{Fj} R_{ti}^{q2} R_{rj}^{q2}} \tag{2}$$

3. **Power Allocation and Sensor Assignment.** According to the discussions above, the overall SNR of radar network for target q is a function of sensor assignment index (through the u_i^q in (2)) and transmitted power (through the P_{ti}^q in (2)). As is well known from standard detection theory, the received SNR of radar can provide a measurement of target detection performance using either Neyman-Pearson or Bayesian decision rule. Then the overall SNR of radar network can be used as performance metrics for target detection, the intercept probability of radar network can be minimized by assigning the suitable radar operates in an active way for each target and managing its transmitted power optimally under a predetermined SNR constraint. The objective function of optimization can be defined as the minimum total transmitted power of the radar network at each sampling instant. Hence, the problem of power allocation and sensor assignment based on LPI can be summarized as follows:

$$\begin{aligned} &\min \sum_{i=1}^{N} P_{ti}^q \\ &\text{s.t.} \begin{cases} SNR_q \geq SNR_{\min} \\ P_{ti}^q = 0 \quad u_i^q = 0 \\ 0 < P_{ti}^q \leq P_{\max} \quad u_i^q = 1 \\ \sum\limits_{i=1}^{N} u_i^q = 1 \quad \sum\limits_{q=1}^{Q} u_i^q \leq 1 \end{cases} \end{aligned} \tag{3}$$

$SNR_{\min}$ is the predefined SNR threshold. If the ith radar has not been assigned to target q in an active way, then $P_{ti}^q = 0$. $P_{\max}$ is the upper limit of transmitted power. $\sum\limits_{i=1}^{N} u_i^q = 1$ means only single radar assigned to each target in an active way, and $\sum\limits_{q=1}^{Q} u_i^q \leq 1$ means each active radar can track only single target at each time instant.

The solution to solve the optimization problem described in (3) is to partition the two optimization variables (u_i^q, P_{ti}^q). For a given sensor assignment scheme, assuming the mth radar is selected to operate in an active way for tracking target q, the optimization problem can be reformulated as:

$$\begin{aligned} &\min P_{tm}^q \\ &\text{s.t.} \begin{cases} SNR_q \geq SNR_{\min} \\ 0 < P_{ti}^q \leq P_{\max} \quad i = m \\ P_{ti}^q = 0 \quad i \neq m \end{cases} \end{aligned} \tag{4}$$

It is a simple linear optimization problem with one variable. Due to the fact that the radar network SNR for target q is an increasing function of P_{tm}^q, then the minimum transmitted power of the mth radar for tracking target q can be obtained by:

$$P_{tm,opt}^q = \sum_{j=1}^{N} \frac{(4\pi)^3 k T_s B_m L_{mj} N_{Fj} R_{tm}^{q2} R_{rj}^{q2} SNR_{\min}}{G_{tm} G_{rj} \sigma_{mj}^q \lambda_m^2} \tag{5}$$

For each target, the minimum requires power of each assignment scheme can be calculated. By solving a set of NQ linear optimization problems, the optimal results $P_{ti,opt}^q$, $i = 1, \ldots, N$; $q = 1, \ldots, Q$ at each time instant can be obtained. In this case, the optimal sensor assignment result with the minimum transmitted power can be calculated as:

$$\begin{aligned} &\min \sum_{i=1}^{N} \sum_{q=1}^{Q} u_i^q P_{ti,opt}^q \\ &\text{s.t.} \begin{cases} \sum\limits_{i=1}^{N} u_i^q = 1 \\ \sum\limits_{q=1}^{Q} u_i^q \leq 1 \end{cases} \end{aligned} \tag{6}$$

(6) is an unbalanced assignment problem which can be efficiently solved by the fixed Hungarian algorithm. The detailed process of fixed Hungarian algorithm for sensor assignment is shown in Table 1.

4. **Simulation Result.** In this section, the LPI performance of radar network system based on power allocation and sensor assignment is evaluated. In the simulations, we consider the radar network with 4 two-dimentional radars located at $(x_1, y_1 = -10, 10)$km, $(x_2, y_2 = 10, 10)$km, $(x_3, y_3 = -10, -10)$km, and $(x_4, y_4 = 10, -10)$km. The number of targets is set to be $Q = 2$, the initial position of target 1 at $(-15, -3)$km and that of target 2 at $(13, 3)$km. The targets are moving with constant velocity in straight lines, the velocity of target 1 is $(1, 0)$km/s and that of target 2 is $(-1, 0)$km/s. It is assumed that each radar in the network has the same parameters. The maximum transmitted power is 4KW, radar carrier frequency is 3GHz, radar bandwidth is 1MHz, radar system loss is 5dB, transmit antenna gain and receive antenna gain are both equal to 30dB. The sampling interval of target tracking is set to be 1s. The number of samples in the duration is set to be 20s. The configuration of radar locations and target trajectories are shown in Figure 1.

Table 1. The fixed Hungarian algorithm

Step 1. Add $N-Q$ virtual column vectors with zero elements to matrix $\boldsymbol{P}_{\boldsymbol{t,opt}}$. The result matrix is $N \times N$ matrix $\boldsymbol{P}_{\boldsymbol{t,opt}(0)}$.

Step 2.

Step 2.1. Substract the smallest element of each row from all the elements of its row. Suppose matrix $\boldsymbol{P}_{\boldsymbol{t,opt}(1)}$ is the result of that.

Step 2.2. Substract the smallest element of column from all the elements of its column of matrix $\boldsymbol{P}_{\boldsymbol{t,opt}(1)}$. Suppose matrix $\boldsymbol{P}_{\boldsymbol{t,opt}(2)}$ is the result of that.

Step 3. Draw lines through appropriate rows and columns of matrix $\boldsymbol{P}_{\boldsymbol{t,opt}(2)}$ so that all the zero elements of this matrix are covered and the minimum number of such lines is used.

Step 4. If the minimum number of covering lines is less than N, go to Step 5; else go to Step 6.

Step 5. Determine the smallest element not covered by any line. Substract this element from each uncovered row, and then add it to each covered column to simplify $\boldsymbol{P}_{\boldsymbol{t,opt}(1)}$. Return to Step 3.

Step 6. Find an individual set which contains N zeros in $\boldsymbol{P}_{\boldsymbol{t,opt}(1)}$. If the element of $\boldsymbol{P}_{\boldsymbol{t,opt}(1)}$ at i, q belongs to the individual set, set $u_i^q = 1$; otherwise, $u_i^q = 0$. Then output $\boldsymbol{U}$ and stop.

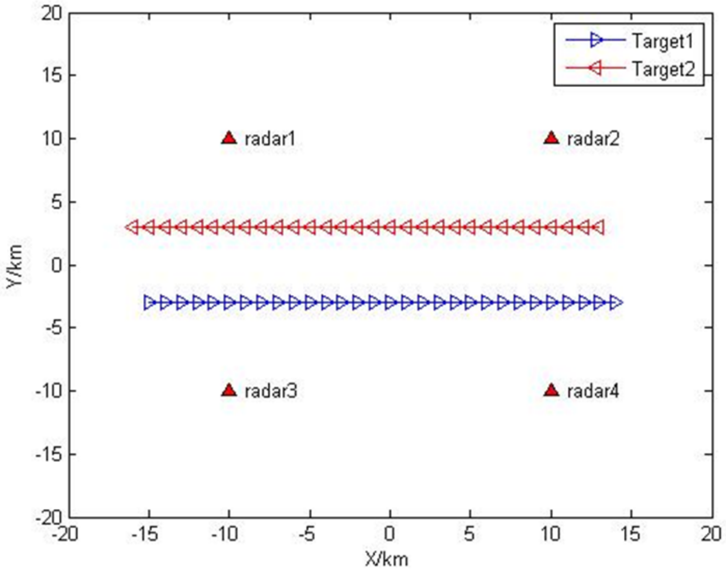

Figure 1. The configuration of radar network and target trajectories

Table 2. Minimum power at the second interval

Minimum Power/KW		Target	
		T_1	T_2
Radar	R_1	0.619	1.508
	R_2	2.493	0.150
	R_3	0.217	1.848
	R_4	2.091	0.489

For simplicity, we assume the RCS of all targets is equal to 1m^2 the SNR threshold is 15dB. The minimum transmitted power of each assignment scheme can be calculated. For example, Table 2 shows the minimum power matrix at the second tracking interval.

Table 3. Sensor assignment results

Interval Index	Radar Selected		Interval Index	Radar Selected		Interval Index	Radar Selected	
	T_1	T_2		T_1	T_2		T_1	T_2
1	3	2	11	3	2	21	4	1
2	3	2	12	3	2	22	4	1
3	3	2	13	3	2	23	4	1
4	3	2	14	3	1	24	4	1
5	3	2	15	3	1	25	4	1
6	3	2	16	4	1	26	4	1
7	3	2	17	4	1	27	4	1
8	3	2	18	4	1	28	4	1
9	3	2	19	4	1	29	4	1
10	3	2	20	4	1	30	4	1

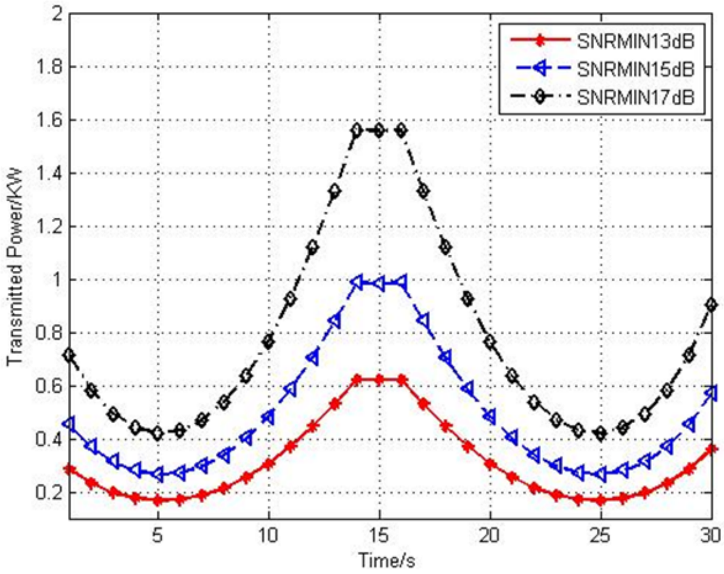

Figure 2. Total transmitted power of radar network

The fixed Hungarian algorithm can be used to deal with the results shown in Table 2. We can get that radar 3 is selected to track target 1 and radar 2 is selected to track target 2 in an active way. The results of sensor assignment at each time index are shown in Table 3.

It can be seen that the radar which is the closest to the target is selected to operate in an active way for tracking this target.

Figure 2 shows the optimal total transmitted power of radar network with different SNR thresholds. We can notice that a significant reduction of total transmitted power of radar network can be achieved through the proposed strategy. And the total transmitted power goes up with the increase of SNR threshold which can be determined by the required detection performance due to the Neyman-Pearson lemma and Bayesian decision rule.

5. **Conclusions.** In order to improve the LPI performance of radar network for multiple-target tracking, a sensor assignment and power allocation strategy has been investigated in this paper. It is shown that this strategy can minimize the total transmitted power under a predetermined SNR threshold. The optimization problem can be divided into a set of NQ linear optimization problems and an unbalanced assignment problem at each time index. Simulation results demonstrate that a significant reduction of total transmitted power

can be achieved through the proposed sensor assignment and power allocation strategy. And the optimal transmitted power goes up with the increase of SNR threshold. Future works will concentrate on other optimization criteria to improve the LPI performance for radar network, as well as complexity increase introduced by combination of radars and complexity increase of resource allocation.

Acknowledgment. This work is supported by the National Natural Science Foundation of China (Grant No. 61371170), the Fundamental Research Funds for the Central Universities (Grant No. NP2015404, No. NS2016038), the Aeronautical Science Foundation of China (Grant No. 20152052028) and the Funding of Jiangsu Innovation Program for Graduate Education (CXLX12_0155).

REFERENCES

[1] S. Yang, T. Cheng and Z. He, A radio frequency stealth approach in MIMO radar tracking mode, *ICIC Express Letters*, vol.9, no.7, pp.1951-1958, 2015.

[2] C. Shi, J. Zhou, F. Wang and J. Chen, Optimal power allocation for low probability of identification in radar network based on security information with cooperative jamming, *ICIC Express Letters*, vol.8, no.12, pp.3401-3406, 2014.

[3] A. S. Narykov and A. Yarovoy, Sensor selection algorithm for optimal management of the tracking capability in multisensor radar system, *European Microwave Conference (EuMC)*, pp.1811-1814, 2013.

[4] S. M. H. Andargoli and J. Malekzadeh, Target assignment and power allocation for LPI radar networks, *International Symposium on Artificial Intelligence and Signal Processing*, pp.234-239, 2015.

[5] Y. Teng, H. D. Griffiths, C. J. Baker and K. Woodbridge, Netted radar sensitivity and ambiguity, *IET Radar Sonar & Navigation*, vol.1, no.6, pp.479-486, 2007.