

# Optimization of Power Allocation Based on Particle Swarm Optimization in Wireless Location Network



Jinrui Lin, Guangxia Li, Shiwei Tian and Longlong Suo

**Abstract** Wireless location network combines data communication, contextual data collection and navigation. The purpose of this network is to determine the positions of agents based on measurements between nodes and nodes. In order to improve the positioning accuracy of wireless location network, the usual method is to increase the density of nodes, especially the density of anchor nodes, so as to optimize the topology of the network. However, the wireless location network node power is limited, especially the wireless sensor network. It is necessary to increase power consumption to meet the needs of a large number of nodes. However, it is required that a certain level of power consumption should be set in the wireless location network, and even require further reduction in power consumption in daily life. At the same time, we need to maintain a certain positioning accuracy, which requires the optimization of power allocation in the network, to make sure that power and positioning accuracy of the network can meet the needs of the actual living. In this paper, an optimization of power allocation based on particle swarm optimization in wireless location network is proposed to optimize the power allocation. The square position error bound is introduced as the evaluation standard of the network positioning accuracy. Through the power optimization, the positioning accuracy of the network is improved.

**Keywords** Wireless location network · Power optimization allocation  
Square position error bound · Particle swarm optimization algorithm

## 1 Introduction

Wireless location network uses the characteristics of radio waves to determine the specific location of radio equipment in the network. People have proposed various wireless positioning methods, including the arrival time of signals, the arrival angle

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of signals, the intensity of signals and the phase of signals. In [1], the current several indoor positioning technologies are introduced, such as visual positioning, infrared positioning, pole positioning, ultrasonic positioning, WLAN positioning, RFID positioning, inertial navigation, geomagnetic localization, Bluetooth and ZigBee positioning and cellular network positioning.

Currently, Ultra-wideband (UWB) technology is being applied to wireless location networks. [2] points out that ultra-wideband technology can transmit data at the nanosecond level and below by transmitting ultra-narrow pulses, which can achieve GHz-level data bandwidth with low transmission power and no carrier. Because of its high bandwidth, theoretically based on Time of Arrived (TOA) or Time Difference Of Arrived (TDOA) method can achieve centimeter-level positioning. In [3] and [4], the development of ultra-wideband positioning technology, implementation principles and research prospects are reviewed. In [5], the time of arrival (TOA) algorithm is introduced in detail, and the indoor positioning performance of UWB is explored.

In [6], the Cramér–Rao bound in the satellite positioning scenario is introduced as the evaluation criterion of the positioning accuracy. In [7], the square error of position is used in wireless location network. In addition, [8] points out that for wireless wideband location networks, such as wireless sensor networks, resource allocation and optimization play a very important role in positioning accuracy because of the system resources are limited. In the current research of wireless location network, there are few researches about the optimal allocation when resources are limited.

This paper uses the square position error bound in [9] as the criterion for the positioning accuracy of wireless location networks, and focuses on the research of networks based on UWB technology. Base on the analysis of the impact of power allocation in wireless location network on positioning accuracy, the power allocation algorithm using particle swarm optimization theory is proposed.

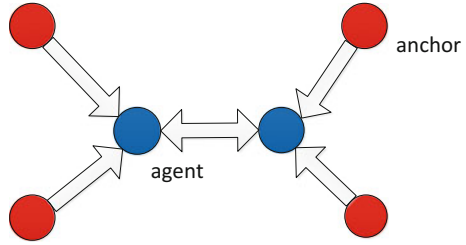
## 2 Wireless Location Network

As shown in Fig. 1, wireless location network contains the anchors and agents. According to [7], agents cannot determine their position, and anchors obtain their positions through the GPS positioning system or other means. The agent can range with the anchor, and can also range with other agents. In fact, an agent needs at least three anchors to achieve positioning.

The distance between agent  $k$  and  $j$  is given by

$$d_{kj} = \|\mathbf{p}_k - \mathbf{p}_j\| \quad (1)$$

**Fig. 1** Wireless location network



The angle from agent  $k$  and  $j$  is given by

$$\varphi_{kj} = \arctan\left(\frac{y_k - y_j}{x_k - x_j}\right) \tag{2}$$

According to [10], the square position error bound of agent  $k$  is given by

$$E\{\|\hat{\mathbf{p}}_k - \mathbf{p}_k\|^2\} \geq p(\mathbf{p}_k) = \text{tr}\{\mathbf{J}_e^{-1}(\mathbf{p}_k)\} \tag{3}$$

It has been shown in [10] that the network EFIM of  $N_a$  agents in a cooperative localization network can be written as

$$\mathbf{J}_e^G = \begin{bmatrix} \mathbf{J}_{1,1} & \cdots & \mathbf{J}_{1,N_a} \\ \vdots & \mathbf{J}_{i,j} & \vdots \\ \mathbf{J}_{N_a,1} & \cdots & \mathbf{J}_{N_a,N_a} \end{bmatrix} \tag{4}$$

where

$$i = j, \mathbf{J}_{ij} = \mathbf{J}_e^A(\mathbf{p}_i) + \sum_{k \neq i} \mathbf{C}_{ik} \tag{5}$$

$$i \neq j, \mathbf{J}_{ij} = -\mathbf{C}_{ij} \tag{6}$$

$\mathbf{J}_e^A(\mathbf{p}_k)$  and  $\mathbf{C}_{kj}$  are the ranging information of agent  $k$  obtained from all  $N_b$  anchors and agent  $j$ , expressed as

$$\mathbf{J}_e^A(\mathbf{p}_k) = \sum_{j \in N_b} \lambda_{kj} \mathbf{q}_{kj} \mathbf{q}_{kj}^T \tag{7}$$

$$\mathbf{C}_{kj} = \mathbf{C}_{jk} = (\lambda_{kj} + \lambda_{jk}) \mathbf{q}_{kj} \mathbf{q}_{kj}^T \tag{8}$$

where  $\mathbf{q}_{kj} = [\cos \varphi_{kj}, \sin \varphi_{kj}]^T$

Moreover, the range information intensity can be given by

$$\lambda_{kj} = \zeta_{kj} \frac{p_k \beta_k^2}{d_{kj}^\delta} \quad (9)$$

where  $\zeta_{kj}$  is the range channel gain between agent  $k$  and  $j$ .  $p_k$  is the normalized power and  $\beta_k$  is the effective bandwidth allocated to agent  $k$ .

According to [11], the total SPEB of all agents can be obtained as

$$\sum_1^{N_a} p(\mathbf{p}_k) = \text{tr}\{(\mathbf{J}_e^G)^{-1}\} \quad (10)$$

With the square position error bound (SPEB), the positioning accuracy of the network can be evaluated. Research on the power resources in wireless location network mainly refers to the function of the square position error bound and the transmit power. By constraining the power allocation of agents in the network, it is further explored how to optimize the power allocation and increase the network positioning accuracy.

In fact, the optimal power allocation problem in this paper can be modeled as follows

$$\begin{aligned} \min & \sum_{k \in N_a} \sum_{j \in N_a \cup N_b} p(\mathbf{p}_k, \{p_j\}) \\ \text{s.t.} & \quad p_j \leq p_{peak} \quad \forall j = 1, 2, \dots, N_a \cup N_b \\ & \quad \sum_{j \in N_a \cup N_b} p_j \leq p_{total} \end{aligned} \quad (11)$$

where  $p_j$  is the normalized power of each agent in the network.

### 3 Algorithm Design

Particle swarm optimization algorithm is initialized to a group of random particles (random solution), and then find the optimal solution through iteration. In each iteration, the particle updates itself by keeping track of the two extremes; the first one is the optimal solution found by the particle itself, which is called the individual extreme; the other extreme is the optimal one found so far for the entire population, this extreme is the global maximum. Alternatively, instead of using the entire population but only one of them as a particle's neighbor, the extreme value in all neighbors is the local extreme.

Based on the wireless location network, the power allocation algorithm designed in this paper is as follows.

Step 1: Initialize the parameters of Particle swarm optimization.  $c_1 = 1.4962$ ,  $c_2 = 1.4962$ ,  $w = 0.7268$ .

Step 2: According to the above derivation, calculate the square position error bound of each agent in the wireless location network. Each agent is located with all other nodes, including the anchor and the agent. In this process, the normalized transmit power of the node needs to be limited according to the constraints.

Step 3: Calculate the square position error bound of the whole wireless location network, and get the function of the square position error bound of the wireless location network and the normalized transmitting power of the agents as the objective function of particle swarm optimization.

Step 4: Substituting the objective function and constraints into the particle swarm optimization algorithm for optimal solution. All vectors to be optimized form the dimension of power, i.e.

$$\mathbf{p}_j = (p_1, p_2, \dots, p_j) \tag{12}$$

In order to obtain the global optimal solution of power, we set the algorithm precision as  $10^{-6}$ , the maximum number of iterations is 250. All the algorithm parameters are given in Table 1. N represents the number of particles.  $c_1$  and  $c_2$  mean the learning factors of Particle swarm optimization.  $w$  represents inertia weight of Particle swarm optimization.

## 4 Simulation Analysis

The typical ranging signals are UWB signal (CM1 in the IEEE 802.15.4a channel model). And the pulse width of 2 ns Gaussian pulse signal (occupied bandwidth of 3.1–3.6 GHz) as the transmit waveform. Other parameters are given in Table 2.

Set up such a wireless location network, there are some agents in the network (label) randomly distributed in a square area, the square area is  $U [0,10] * [0,10]$ . Also set 4 anchors (base station). The total power is normalized to unity and the power peak for a single agent is 0.4. According to Table 2, the range channel gain is  $10^{15}$ . The path attenuation factor is 2.

**Table 1** Algorithm parameters

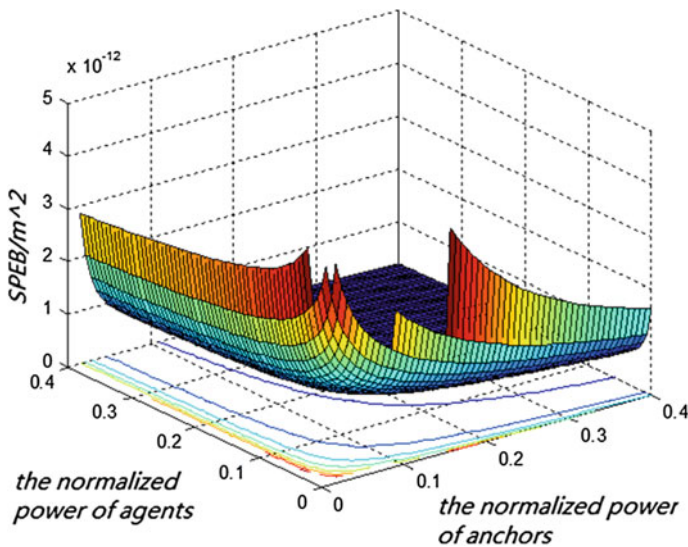
Parameters	Value
N	30
$C_1$	1.4962
$C_2$	1.4962
$w$	0.7268
Algorithm precision	$10^{-6}$
Maximum number of iterations	250

**Table 2** UWB signal parameters

Parameters	Value
Bandwidth (W)	500 MHz
Wavelength ( $\nu$ )	0.1 m
Ratio of DP ( $\bar{\gamma}_{DP}$ )	0.2
Path overlap factor ( $\bar{\lambda}_{kj}$ )	0.32
Power spectral density (PSD)	41.3 dBm/MHz
Noise power spectral density ( $N_0$ )	-174 dBm/Hz

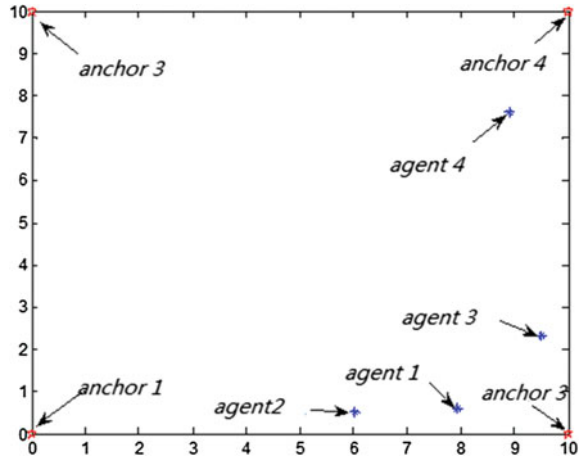
In order to compare the impact of the transmit power of the anchors and the agents on the positioning accuracy of the network, different transmit power is used for the anchor and the agent. In this case, when the agent and the anchor use different transmit power, the square position error bound of the network with respect to the transmit power can be obtained, as shown in Fig. 2.

It can be seen from Fig. 2 that the influence of power of anchors and agents on the square position error bound of network is different. Obviously, when the transmit power of the anchor and the agent reach the maximum, the square position error bound of the location network can reach the minimum, and the network's positioning accuracy reaches the highest. However, it is not clearly from Fig. 2 that the anchor and the agent have different influences on the square position error bound of the positioning network. In order to know more clearly the different influences of these two on the network positioning accuracy, a location network with 4 agents and 4 anchors will be used in simulation. The location of anchors and agents is shown in Fig. 3. Red dots represent anchors, while blue dots represent agents.



**Fig. 2** Effect of signal transmit power on positioning accuracy

**Fig. 3** Location of anchors and agents



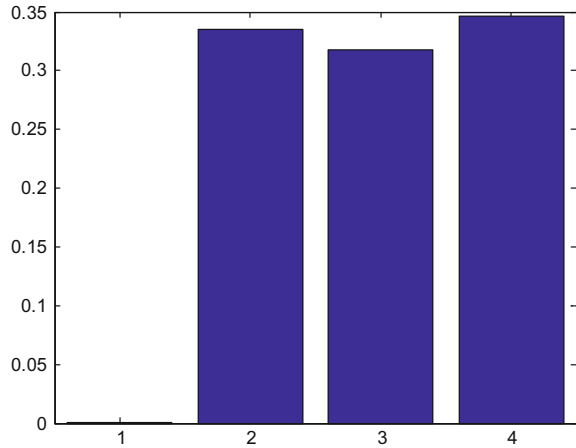
**Table 3** Optimization results

Optimized object	SPEB (m <sup>2</sup> )
Anchor	2.968038260317849e-13
Agent	2.682957452642523e-13

First, the agents of the network use the same transmission power, and the anchors use the algorithm in this paper to optimize the power allocation. Then the corresponding power allocation value of the anchors can be obtained and the square position error bound of the network can be obtained. Then, the anchors of the network use the same transmission power, and the agents use the algorithm in this paper to optimize the power allocation, then the corresponding power allocation value of the agents can be obtained and the square position error bound of the network can be obtained. In this way, the influence of different power distributions on the network positioning accuracy can be compared by comparing the square position error bound of the two. It can be seen that the square position error bound of the network obtained by optimizing the power of the agents is smaller than the gain of the optimized anchors. According to Table 3, It can be seen that the power of the optimized agents is more conducive to improving the network positioning accuracy.

Figure 4 shows the power allocation of anchors. It can be seen that the power allocated by anchor 1 is the lowest and the power allocated by anchor 4 is the highest. As can be seen from Fig. 3, the anchor 1 and the agent 1 and 2 approximate the geometric relationship in a straight line. In this way, the anchor 1 contributes little to improving the positioning accuracy of the two agents, so the power allocated to the anchor node 1 is also reasonable. Anchor 2 and 4 have a similar power allocation because all the agents are more concentrated in the location between these two anchors so the power allocated to anchor 2 and 4 is similar.

**Fig. 4** Power allocation of anchors



**Fig. 5** Power allocation of agents

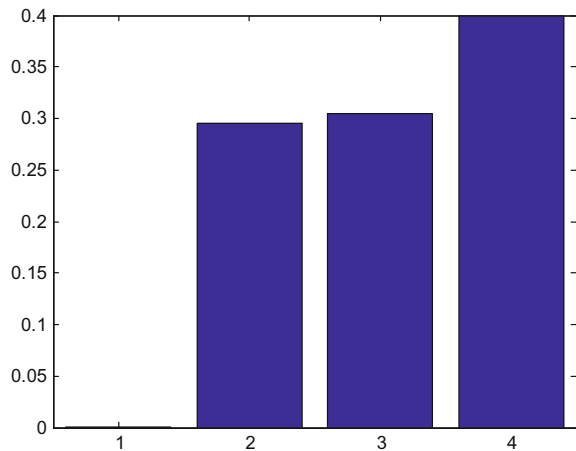


Figure 5 shows the power allocation of the agents. It can be seen that the power allocated by the agent 1 is the lowest and the power allocated by the agent 4 is the highest. In fact, since the distance between agent 1 and 2, agent 1 and 3 is relatively close, the agent 1 is at an intermediate position between the agent 2 and 3, the transmission power required for ranging between agent 1 and them can be lowered, and the agent 4 is far away from other agents, the transmission power required for ranging between the agent 4 and other agents is obviously higher.

In this paper, UWB ranging technology is used to locate the agents of wireless location network. The square position error bound is introduced as the standard of positioning accuracy of wireless location network. The function of the transmit power of ranging signal and the square position error bound of network is established as the objective function of optimization and the necessary constraints are added. Particle swarm optimization is used to iteratively solve the optimization



objective function to get the optimized power configuration solution of the network. The optimization results show that by optimizing the transmission power of network nodes, the positioning accuracy can be significantly improved. At the same time, the transmit power of the anchor and the agent has different impact on the positioning accuracy, which needs to be optimized according to the actual situation. Furthermore, when the anchor and the agent of the location network perform power optimization at the same time, the positioning accuracy of the network will be greatly improved.

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