Research on Distributed Target Assignment Based on Dynamic Allocation Auction Algorithm

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Abstract. Under the premise of many types and large numbers of targets, how to solve the problem of rational allocation of dynamic multi-objectives has always been a hot issue for experts and scholars. In this paper, a distributed target allocation method based on dynamic allocation auction algorithm is used to solve this kind of problem. This paper establishes a mathematical model based on air defense combat, and uses this method to solve the problem. Finally, the effectiveness and real-time performance are proved by simulation.

1. Introduction

In actual air defense operations, the battlefield environment is dynamically changing. We cannot make decisions based on the battlefield situation at a certain moment. This makes us have to make a target allocation mechanism that can change itself according to the changes in the battlefield situation. However, the centralized centralized target allocation is unified by all the information to the superior command and control center for unified decision-making. When the battlefield environment changes, we pass the battlefield information to the superior command and control center, which will command and decide and distribute it. The results are distributed to the lower-level command and control centers and then to the air defense weapons and equipment. Such a process wastes a lot of time and the real-time performance will be poor. Moreover, all decisions are taken care of by the superior

command and control center. If our superior command and control center is hit by the enemy air strike target, so that it can not continue to work normally, then our air defense system will be paralyzed. The subordinate distributed cooperative operations target allocation is supplemented by the upper-level centralized target allocation, and it is necessary to solve the problems existing in the upper-level centralized target allocation.

Many people have put forward their views on the solution of this problem. Jia [1] used a centralized command-distribution autonomous coordination structure to build a model, and used the method based on consistent distributed auction and heuristic based method for decision making. It shows that the algorithm has a good distribution effect. Lei [2] combined the cloud model with the genetic algorithm to improve the convergence speed and verify the feasibility. Sun [3] proposed an improved cuckoo search algorithm, and through simulation experiments, the algorithm can effectively balance the relationship between convergence speed and global exploration ability. Xu [4] used single/double potential well position updating method and particle swarm mutation algorithm to distribute air defense firepower, and verified the effectiveness of the algorithm through simulation. These methods solve this kind of problem quickly, but the real-time performance is poor and cannot be updated in real time. Based on the centralized target allocation in article [5], this paper proposes a distributed target allocation method based on dynamic allocation auction algorithm, which can solve the problem of target allocation well.

2. Description of the problem

In the lower-level distributed cooperative operational target allocation model, each lower-level command and control center can share information, and each lower-level command and control center can receive and send messages to each other. When the target is assigned, the target mobile sensor will be found. The information is sent to the lower-level command and control center, and is coordinated by the lower-level command and control network. The sensor can receive the tracking command sent by the lower-level command and control center, or send the target information to the lower-level command and control center. The air defense weapon can receive the lower-level command and control center. As a result, the target is hit. We use the ellipse to indicate the subordinate accusation center, the circle represents the sensor, and the pentagon represents the air defense weaponry. As shown in Figure 1
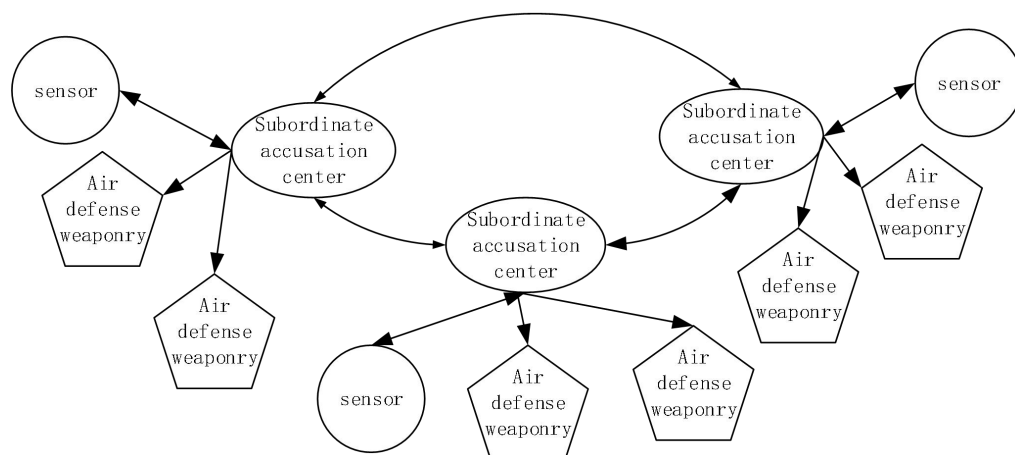

Figure 1. Subordinate distributed collaborative operational decision-making process.

The lower-level distributed cooperative combat target allocation is the last step of the allocation of air defense cooperative combat targets. It has the function of adjusting the centralized target assignment result of the superior, and can deal with the battlefield information in time. Its characteristics are as follows:

(1) High real-time

The air defense battlefield situation information changes rapidly, and the battlefield state will be different at each moment. When the lower-level distributed cooperative combat target changes, we need to adjust it in the lower-level command and control network in time, using the prescribed algorithm. The problem is solved quickly, and finally the target is distributed and hit in time, so that the distribution result has high real-time performance, so as to ensure effective attack.

(2) High synergy

I In the lower level command and control network, information interaction can be achieved, and each lower level command and control center can collect information and send information.

II Multiple air defense weapons can be used to strike a single target if conditions require it.

III When a node is defeated by an attack, other nodes can cooperate to meet the operational requirements.

(3) Rationality of results

By using the lower-level distributed collaborative operational target allocation, the results of the upper-level centralized target allocation can be detected and corrected, and the final allocation result can be rationalized.

(4) High resistance

In the mechanism of lower-level distributed cooperative combat target allocation, each element is deployed in a decentralized manner, making air defense weapons less vulnerable to attack, and no single node is our "critical". When a node is attacked by a target and does not work properly, it can help each other to complete the task that the node should have completed[6].

3. Model establishment

3.1. Target transfer judgment model

When the goal of the upper-level centralized target allocation exceeds the effective strike range of the air defense weapon （The route shortcut is out of range, the target speed is too fast, the incoming target height is higher than the maximum value, the incoming target height is less than the minimum value, or the radar scattering cross-sectional area is less than the minimum value）.Can't continue to strike it.

$$
\begin{aligned}
&l_i > l_{\max} \quad or\\
&h_i > h_{\max} \quad or\\
&h_i < h_{\min} \quad or\\
&v_i > v_{\max} \quad or\\
&RCS_i < RCS_{\min}
\end{aligned}
\tag{1}
$$

3.2. Combat information transfer model

In the lower-level distributed cooperative combat target allocation, we will speed up the

decision-making speed according to the actual situation, in order to save communication time and communication cost, and the firepower unit will notify the lower-level command and control center within a certain communication range when the target unit is transferred. As shown in picture 2.
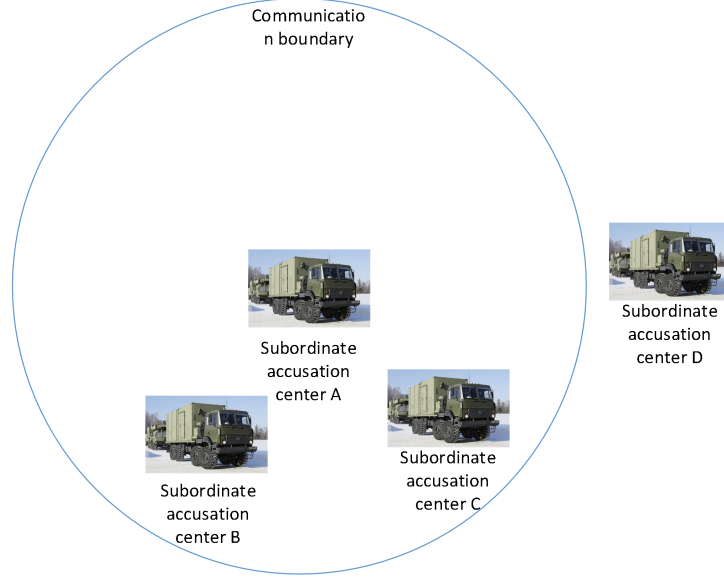

Figure 2. Communication relationship between subordinate units.

$$E = f_E(W, P_s) = \sum_{i=1}^{n} W_i \times \left\{ 1 - \prod_{j=1}^{m} \left[d_{ij} \times (1 - P_{sij}) \right] \right\}$$

(2)

The range in which the lower-level command and control center A can communicate is indicated by a blue circle, indicating that the lower-level command and control center A can inform its lower-level command and control center B and the lower-level command and control center C in the lower-level distributed cooperative operations. The set of lower-level command and control centers that satisfy the communication range constraints can be expressed by the formula (2).

$$T = \{x \mid \|P_x - P_A\| \leq D_{\text{Communication}}, \ x \in Z\}$$

（2）

P_x is the location of the lower-level command and control center x, $\|P_x - P_A\|$ is the Euclidean distance from the lower charge center x to A . $D_{\text{Communication}}$ is the communication range, Z is the set of all lower-level command and control centers, and C is the set of all lower-level command and control centers that meet the communication scope constraints.

The subordinate that can attack the target is calculated, as shown in formula (3).

$$N = \{x \in Z \mid l_x \leq l_{\max} \ and \ h_{\min} \leq h_x \leq h_{\max} \ and \ v_x \leq v_{\max} \ and \ RCS_x \geq RCS_{\min}\}$$ （3）

Among them, N indicates all subordinates that meet the attack limit.

The lower-level command and control center will send the information of the target to the command and control center of the firepower unit that can receive the information and attack the target. The formula is as follows.

$$F=\{x \in Z | x \in (T \cap N)\}$$
（4）

F is the collection of subordinate command and control centers that should be sent to.

3.3. Target priority model

Target priority refers to the priority order of the current target to confirm the allocation. It can be composed of the following factors: the type of enemy target, the criticality of the incoming target, and the urgency of time. The key types of enemy target types and incoming targets can be judged by the model given above. The urgency of time and the target criticality model are established below.

(1) Urgency of time

The urgency of time refers to the length of time between the current moment and the moment we have to strike. The shorter the time difference, the more urgent we will be on the target. It is expressed by the formula (5).

$$A_{ti}=e^{-\frac{t_i}{t_{\text{definition}}}}$$
（5）

A_{ti} is the time urgency function value of the incoming target i, t_i is the time difference between

the time of the target i and the current time, and $t_{\text{definition}}$ is the value we set.

(2) Target priority model We use the above mentioned elements to solve the priority model, as shown

in equation (6).

$$G_i=A_{ti} \times (\gamma_1 A_{1i} + \gamma_6 A_{6i})$$
（6）

G_i is the priority value of goal i, γ_1 and γ_6 are the weights of the enemy target type factor and the key factors of the incoming target.

(3) Based on dynamic allocation auction algorithm

The auction algorithm is a market mechanism that realizes the rational allocation of resources. The auctioned items are auctioned in an open auction, and finally the one with the highest price is sold. The auction algorithm was first proposed by Bertsekas to solve the single task assignment problem [7]. Xu [8] established a distributed auction algorithm model by considering constraints such as drone capability, and solved the problem by dual decomposition of the problem, and verified the performance and efficiency of the algorithm. There are also many scholars who have analyzed and practiced auction algorithms [9-11].

The auction algorithm has the advantages of simple operation and low complexity. Although these auction algorithms can solve some target allocation problems well, the algorithm is not very suitable for specific situations, and it is easy to conflict. We distribute according to the lower level. The

characteristics of the coordinated operation target allocation, and a set of auction algorithms that meet the characteristics of the operation are developed.

This paper proposes an auction algorithm based on dynamic allocation, which can guarantee the high quality of the results and resolve the conflicts. The algorithm is faster. The algorithm steps are as follows:

Step 1: Initialize, sort the priority of the upper-level centralized assignment target by the target priority model.

Step 2: Put the highest priority in the sealed auction algorithm for calculation.

Step 3: According to the target transfer judgment model, it is judged whether the target is not within the attack range of the upper-level centralized allocation of the air defense weapon, or the missile has been allocated by the target with the highest target priority. If yes, go to step 4, if not, keep the original plan and go to step 6.

Step 4: Seal the auction for the target, and send the target information according to the combat information transfer model. Each superior command and control center that receives the information calculates the profit value and killing probability that can be brought by the superior, and transmits it to the auctioneer. The auctioneer assigns a lower-level command and control center with a higher probability of killing in the original target allocation plan (if the accusation center is destroyed, the nearest lower-level command and control center is selected).

Step 5: Select the scheme with the largest absolute return value as the pre-selection scheme.

Step 6: Determine if the killing probability does not exceed our given minimum value or if the selected air defense missile is available, but not enough. If yes, go to step 7, if not, keep the original plan and go to step 8.

Step 7: We reserve a missile with a high probability of killing (if the pre-selection scheme only has one missile to strike, then retain the missile), and the second missile is sealed and auctioned according to step 4.

Step 8: Determine if the minimum kill probability is met. If yes, go to step 9. If not, go to step 10.

Step 9: Find the scheme with the largest absolute return value as a pre-selection scheme if the probability of killing is met. Go to step 11.

Step 10: Select the plan with the highest probability of killing among all the bids as the pre-selection plan.

Step 11: Determine if the target is the target with the lowest priority. If yes, go to step 12. If not, replace the target with the target that the priority is after, and go to step 3.

Step 12: Output and save the assignment result.

Step 13: Determine whether the upper-level centralized allocation is updated. If yes, go to step 1. If not, go to step 2.

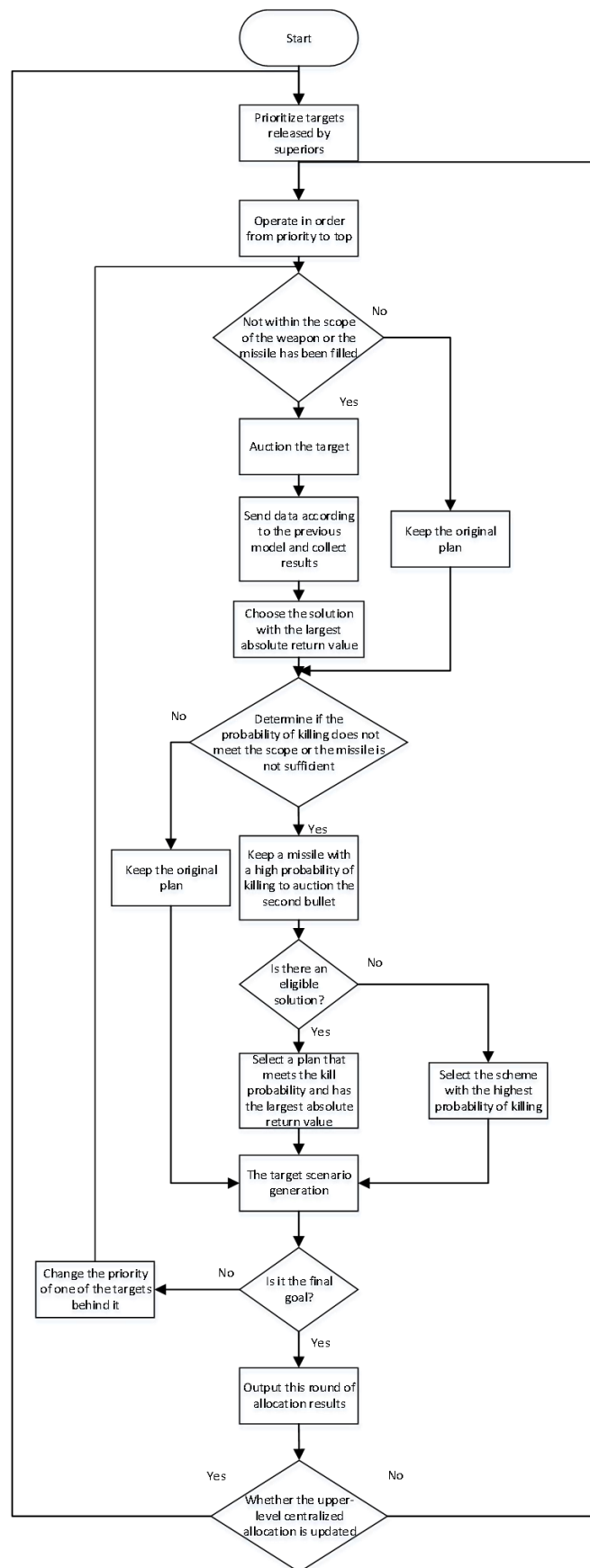The algorithm flow is shown in Figure 3.

Figure 3. Dynamic allocation auction algorithm flow.

4. Simulation analysis

We use the hypothesis and results of the article [5] to solve the algorithm. We use the result of a centralized assignment of the superior as the initial state of the simulation. The solution of the upper-level centralized target allocation is shown in Table 1.

Table 1. Solution of upper-level centralized target allocation.

Combat unit	Combat unit A	Combat unit B	Combat unit C	Combat unit D
Attack target	10	1、6、9	3、7、8	2、4、5

After the target is distributed, many targets are strongly maneuvered. In this paper, the maneuvering situation is expressed as follows according to the maneuvered time node:

Table 2. shows the situation of the target maneuver.

Target	Time frame	Maneuver
1	0.5	The airplane's flight direction is rotated counterclockwise by 37 degrees
2	0.9	The flight speed is slowed to 250m/s, the flight direction is unchanged, and the flight altitude is increased by 0.3km.
7	1.5	Rotate 5 degrees clockwise for other tasks
8	1.5	Rotate 5 degrees clockwise for other tasks

Set the parameters:

$D_{\text{Communication}} = 50\text{km}$, $t_{\text{definition}} = 10$, $\gamma_1 = \gamma_6 = 0.5$, The minimum damage probability is 70%.

The problem is solved by the dynamic allocation auction algorithm designed in this paper. The solution results are shown in Table 3.

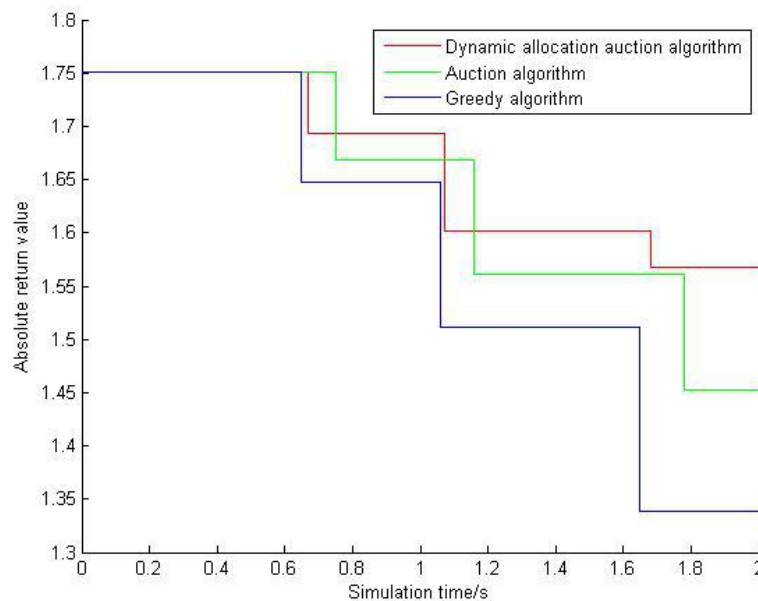**Table 3.** Solution result allocation table.

	Target 1	Target 2	Target 3	Target 4	Target 5	Target 6	Target 7	Target 8	Target 9	Target 10
Combat unit A	0	0	1	0	0	0	0	0	0	2
Combat unit B	0	0	0	1	1	2	0	0	1	0
Combat unit C	0	0	1	1	1	0	1	1	1	0
Combat unit D	2	2	0	0	0	0	1	1	0	0

We compare it with the auction algorithm and the greedy algorithm. The results are shown in Table 4.

Table 4. Comparison of auction algorithm and greedy algorithm.

	Dynamic allocation auction algorithm	Auction algorithm	Greedy algorithm
Time spent in a single algorithm (ms)	186	231	135
Absolute return value	1.568	1.452	1.339
The number of targets that did not reach the minimum probability of killing	0	1	2

The absolute return value of each algorithm at each moment is shown in Figure 4.

Figure 4. Comparison of the absolute returns of the three algorithms.

It can be seen from the above comparison that the dynamic allocation auction algorithm has the largest absolute return value compared with the auction algorithm and the greedy algorithm, and can also well make the probability of the target target damage to the standard. Although the algorithm is not as good as the greedy algorithm, it is also very fast, which can meet our needs and greatly improve the performance.

5. Summary
Based on the understanding of the auction algorithm, this paper proposes a dynamic allocation auction algorithm, which can solve the problem of insufficient ability to solve dynamic targets in the centralized allocation of superiors. It can achieve the absolute maximum return value, and can reach the target damage probability limit to the maximum extent. Although it takes a long time, it is still not particularly time-saving and can be further improved.

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