A Method for Selecting Decision Center of Heterogeneous Operational Networks Based on Operational Capability Analysis

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Abstract. In order to improve the operational capability of heterogeneous combat networks (HCN), a decision center (DC) selecting method is proposed in this paper. According to the characteristics of modern information warfare, the entities in HCN are divided into influencer entities, decider entities, sensor entities and DC entity. The optimal distributed set of information flow links is obtained based on genetic algorithm. In light of the degree of each entity in this set, the entity with highest degree is selected as DC. Since DC has higher decision capability, highest degree means that the operational capability of majority operational chain is enhanced. And thus, the overall HCN operational capability is improved.

1. Introduction

With the development of information technology, the operational entities of different regions can participate in the battle at the same time, which makes the combat system-of-systems more and more complex [1]. Complex networks are important tools for portraying complex systems, which can help us understand the system deeply and then guide the construction and improvement of the system [2]. Different from the general complex network, the entities in the combat network have different functions and task division, so the combat network is a heterogeneous network, and the nodes are heterogeneous [3]. Researchers focus on heterogeneous combat network (HCN) in recent years, different researcher has proposed different entity classification methods, but decider entities always appeared in different methods [4-6]. However, they did not further divide the decider nodes. In modern warfare, there must be a decision center (DC) entity among decider nodes. DC is a must to ensure the unified coordination of the joint forces. Moreover, as the amount of information in the war increases, only the DC can effectively process massive data. Therefore, according to HCN, the decider entities are divided into DC and ordinary decider entities in this work, which helps to further reveal the rules of modern warfare.

One of the research purposes of HCN is to improve the operational capabilities of the network. The measures of combat capabilities include the network connectivity measures, spectrum measures, and operational capability index (OCI) measures. The OCI reflects the heterogeneity of nodes and links and is suitable for HCN [7]. OCI is based on the operational chain which is originated from the OODA theory [8]. In this paper, to improve HCN operational capability, genetic algorithm is used to select DC among the decider entities.
2. HCN combat capability analysis

HCN can be expressed as $G=(V,E)$, where $V$ is a node set, $E$ is a link set. The node set $V=(v_1,\cdots,v_i,\cdots,v_n)$ represents a set of entities in the HCN. Link set $E=(e_1,\cdots,e_i,\cdots,e_m)$ represents an information flow between two entities in HCN. Li [7] divided $V$ for three categories: sensor nodes $S$, decider nodes $D$, and influencer nodes $I$, as shown in Figure 1.

![Diagrammatic sketch of HCN](image)

Figure 1. Diagrammatic sketch of HCN

On the basis of Figure 1, the entities are divided into four categories in this work, namely, the sensor entities $S$, the DC $D_c$, the decider entities $D$ and the influencer entities $I$. Because of the obvious differences in the physical forms of sensor, decider and influencer, the distinction of $S$, $D$ and $I$ is apparent. However, to figure out $D_c$ from $D$ does not depend entirely on the entity itself, but also on the location of the entity, the battlefield environment, and other entities around it. The main work of this paper is to make reasonable calculations on the decider entities based on Figure 1, and further divide the decider nodes into $D_c$ and $D$. The OCI measures can reflect the characteristics of HCN effectively. The method to calculates the operational capabilities of one operational chain, and then sum multiple OCs to obtain the operational capabilities of the entire network. A single operational chain operational capability $C(l_j)$ is defined as [7]:

$$C(l_j) = \frac{1}{|l_j|} \times \max Cs(s_j) \times \max Cd(d_j) \times \max Ci(i_j)$$  \hspace{1cm} (1)

Where $|l_j|$ is the length of OC, $Cs(s_j)$ is the sensor capability, $Cd(d_j)$ is the decider capability, and $Ci(i_j)$ is the influencer capability. Then the operational capability of HCN can be expressed as:

$$H = \sum_{j=1}^{G} C(l_j)$$  \hspace{1cm} (2)

In above definition, the decider capability of the decider entities is an important part of the overall network's combat capability. The greater the decider capability in the operational chain is, the stronger the operational capability of the entire network. Obviously, the DC has stronger decider capability than other common decider entities. Therefore, the DC must be the convergence node of the information link. And then more operational pass through the DC. That means $\max Cd(d_j)$ in (1) is easy to obtain the maximum value, and the whole network has the best operational capability.

3. HCN decision center selection algorithm

In order to improve the operational capability of the HCN, it is necessary to ensure that the location of the DC is the convergence node of the information flow. This section describes the method to obtain the location.
3.1. Information flow aggregation analysis

The information flow in HCN is not arbitrary. The link with suitable condition is suitable for more information to flow. In addition, in HCN, according to the OODA theory, the information flow in decider entities, sensor entities, and influencer entities are not homogeneous. For example, for the wisdom of the group, the information flow between decider entities will be frequent; The influencer entities are usually the end node of the information flow and is only connected to the decider entities; the sensor entities are usually not directly connected to the influencer entities, and they can communicate the information to other sensor entities or multiple decider entities. Therefore, for $S$, $D$, $I$, $D$ usually have more information links, and the number of connected information links for $S$ is medium and the number of links for $I$ is the least. Moreover, in certain warfare, different pair of entities have different attraction coefficients, and information links are more likely to be generated between the two nodes with high attraction coefficients. The reasonable distribution of information links in HCN could be obtained according to above factor. By calculating the degree of different decider entities in this distribution, the entity with highest degree indicate that it has the most information flow, and is more suitable to act as a DC.

3.2. Objective function construction

Considering three factors discussed in 3.1 which are used as the optimization targets of the HCN, the objective function can be expressed as:

$$F = \sum_{j} e_j \cdot r_j \cdot w_j \cdot \sqrt{k_{start}^{start} \cdot k_{end}^{end}}$$

where $e_j$ is the information link in HCN and its value is 0 or 1. 1 indicates that the link exists in the network, 0 indicates that the link does not exist. $r_j$ is the stability factor of the link. $w_j$ is the attraction coefficient between the two entities of the link. $k_{start}^{start}$ and $k_{end}^{end}$ are information convergence factor for two endpoints of the link $e_j$ respectively. When the endpoint is the decider entity, the $k_j$ value is the largest. And when the node is influencer entity, the value $k_j$ is the smallest. Therefore, if the number of information flow links is constant, when the value of (3) is the largest, the information flow is most reasonable in the HCN. The entity with the largest degree is more suitable to serve as the DC. Since the operational capability of OC generally increased, the operational capability of HCN has also been improved.

3.3. Algorithm implementation

As discussed in 3.2, the key step in this paper is to use (3) as the objective function to find the distribution of information flow links for each entity. This work is similar to the network topology optimization problem. And genetic algorithm (GA) is suitable for solving those problems. GA is a non-deterministic intelligent search algorithm that simulates the natural selection of biological evolution. Different organisms have different genes, so their ability to adapt to the outside world is also different. Individuals with strong adaptability are usually able to survive and reproduce through natural selection. The gene may be mutated during its transmission to the offspring and can enhance or reduce the genetic adaptability. According to the above theory, the GA encodes the solution of the problem space. Each solution represents a chromosome. Through the selection and crossover of chromosome genes, fitness function values are used as targets for natural selection.

In HCN, the chromosome of the GA is a possible distribution of information flow links, which is encoded by common binary coding. The selection operator uses the tournament operator, which is more sensitive to the difference of the fitness values of the children. In a group of individuals, the optimal individual can always be selected, which is suitable for the optimization problem under multi-constraint conditions. The crossover operator uses the single-point interchange cross method. The method steps are: selecting two parent chromosomes, randomly selecting the position with a value of 1 of one parent, and judging whether the same position gene in the other parent is 0, and if so, exchange
two genes. Otherwise, re-select the position. The mutation operator uses the single point variation method, that is, selecting one 1 and one 0 in a certain chromosome, and changing the position of these two genes.

3.4. Calculation process
The process of determining the DC of the HCN is shown in Figure 2. First, according to the characteristic of HCN, especially heterogeneous entities, determine the stability factor $r_j$ of each information link, the attraction coefficient $w_j$ between entities and the information convergence factor $k_j$ of entities. Second, based on genetic algorithm, using (3) as the objective function, the optimal distribution set of the information flow links is calculated. Third, calculating the degree of each decider entity according to the optimal distribution set of the information flow link, and the decider entities are ranked by according to the degree. Fourth, the decider entity with highest degree indicates that more information flows through it, and it is more suitable to act as a DC.

![Diagram](image)

**Figure 2.** DC selection process

4. Numerical examples and simulation
Taking the HCN in Figure 1 as an example, one decision center node is determined from four decider entities. The position of the node in Figure 1 reflects the distance relationship of different nodes. According to the general rule of communication technology, the closer the communication link of the node is, the more stable the information flow link stability factor $r_j$ is. In addition, the information aggregation factors $k_j$ of three types of nodes $S$, $D$, $I$ are 5, 10, and 1, respectively. The majority of the attraction coefficients between the nodes in Figure 1 are 1. However, the attraction coefficient between D4 and S3, D1 and I1 is 5.

The convergence of the GA used in our method are proved in Figure 3. The GA runs in the situation of 10, 15, 20, and 25 information flow links respectively, and the fitness change of the objective function of (3) is obtained. It can be seen from Figure 3 that the GA used in this work has good convergence under different link numbers, indicating that the obtained information flow link distribution set is the optimal one.
Figure 3. Fitness curve under different information flow links

Figure 4 shows the optimal distributed set of information flow links of Figure 1 under different number of information flow links. Since the $k_j$ of the influencer entity is small, no matter how many the information flow link increases, only a few links pass through the two entities. The $k_j$ of decider entity is the largest, so the information flow link is more likely to connect to the decider entity. In addition, because the decider entity is located at the geographic center, there are more links connected to it. The links of D1 and I1, D4 and S3 appear in all four figures due to their large attraction coefficient.

Figure 4. The optimal distributed set of information flow links

Table 1 records the degree of each entity in Figure 4. It can be seen that the degree of the four decider entities is significantly larger than others, and the degree of the D1 is the largest, indicating that the D1 has more information flowing, which is most suitable to be the DC. Figure 5 is a diagrammatic sketch of HCN after the D1 is selected as a DC entity.
Table 1. Degree of each node in a heterogeneous operational network.

| Number of links | S1 | S2 | S3 | D1 | D2 | D3 | D4 | I1 | I2 |
|-----------------|----|----|----|----|----|----|----|----|----|
| 10              | 1  | 1  | 1  | 4  | 3  | 4  | 4  | 1  | 1  |
| 12              | 1  | 1  | 1  | 6  | 4  | 4  | 4  | 1  | 1  |
| 15              | 2  | 3  | 2  | 7  | 4  | 4  | 6  | 1  | 1  |
| 20              | 4  | 4  | 4  | 8  | 6  | 6  | 6  | 1  | 1  |

Figure 5. Diagrammatic sketch of improved HCN

According to the topology of Figure 5, the people and devices with strong decision-making capability are concentrated in the DC entity, so that the decision-making capability of the DC is higher than that of other decider entities. Since more OCs pass through DC, according to (1), the operational capability of overall HCN is improved finally.

5. Conclusions

In order to improve the operational capability, this paper presents a new method for partitioning HCN. Based on the influencer entities, decider entities and sensor entities, the DC is added. By using the genetic algorithm, the information flow of each entity is obtained by calculating the distribution of the optimal information flow links. The decider entity with the largest information flow is selected as DC. The selection method of the DC ensures that more operational chain pass through the DC, thereby improving the operational capability of overall HCN.

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