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Scalable Distributed Organizational Structure and Self-Organization Mechanisms for Unmanned System Cluster

Haibo Liu[1], Yang Lin[1], Jing Shen[1, *], Xing Wang[2, *], Changting Shi[1], Jiayu Zhang[1]

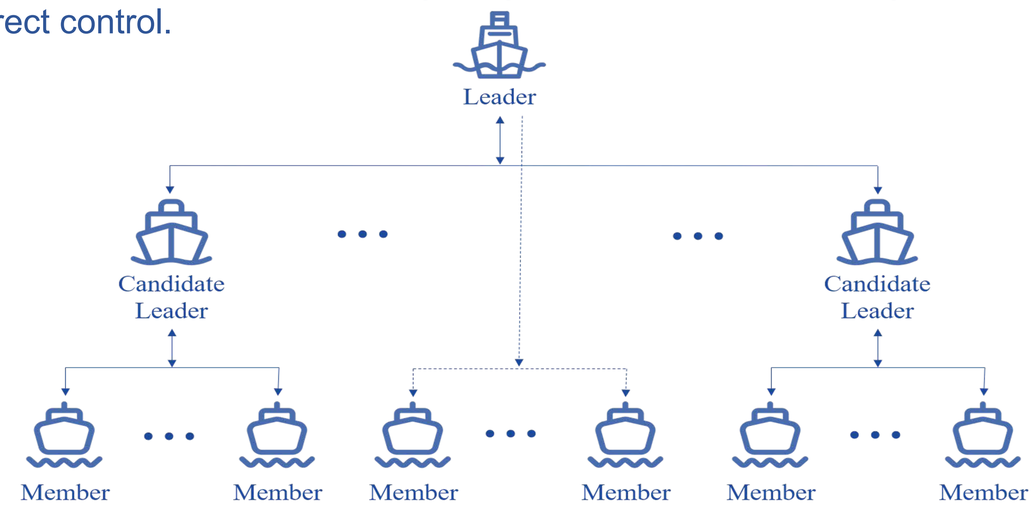
[1]*College of Computer Science and Technology, Harbin Engineering University, Harbin 150001，China*
[2]*Science and Technology on Complex System Control and Intelligent Agent Cooperation Laboratory, Beijing 100074，China*

Abstract

Reasonable control organizational structure can help an unmanned system cluster cooperate more effectively to complete tasks. Previous research of existing organizational structures has problems implementing the task in a natural environment, such as the cluster's lack of scalability. This paper proposes a three-layer scalable distributed organizational structure and dynamic self-organization mechanisms, which overcomes the lack of scalability and ensures that the cluster can still perform stably after the cluster size changes. The simulation results show that the organizational structure realizes information sharing and cross-layer control, which enhance the flexibility and stability of unmanned system clusters. Comparison results show that our achievements can make a good performance, contributing to this area of future research.

Methods

1. The cluster organizational structure is designed as a flexible three-layer scalable distributed organizational structure adapted to the "1 + *C* + *X*" mode. According to the task needs and observation conditions, it can realize the automatic reconstruction of three structures and control modes: three-layer structure, two-layer control, two-layer/three-layer hybrid structure, direct/two-layer hybrid control, and two-layer structure direct control.

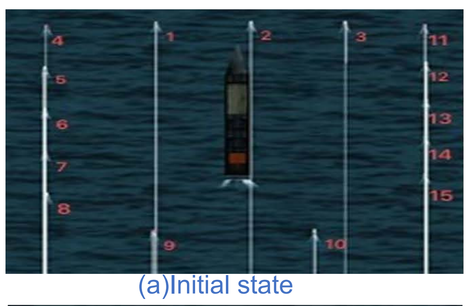


Three-layer scalable distributed organizational structure of the unmanned system cluster

2. The research on the dynamic self-organization mechanisms of the unmanned system cluster mainly considers the construction of mechanism, such as registration, check-in, rollcall, leave and cancellation, delisting, leader generation, candidate leader generated, team generation, dynamic reconstruction, global data maintenance, sharing and security authentication of new unmanned system, and dynamic update of global data.

Results and discussion

In order to verify the performance of the proposed scalable distributed organizational structure, the unmanned ship is used as the unmanned system entity, and the following two experiments are carried out in the unmanned ship cluster experimental simulation platform.

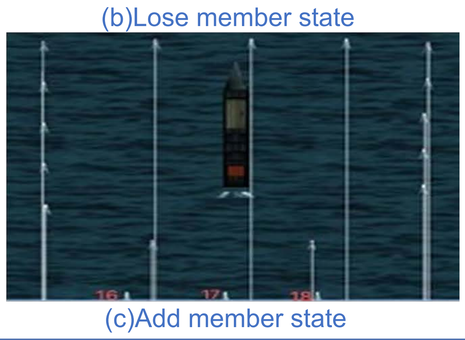


(a)Initial state

The initial cluster system consists of 15 unmanned ships, including 1 leader unmanned ship, 3 candidate leader unmanned ships, and 11 ordinary unmanned ships.

(b)Lose member state

Experiment simulates the loss of three unmanned ships No. 1, No. 9, and No. 7. The operation effect of the cluster formation before and after the loss change is shown in (a) and (b).



(c)Add member state

In the experiment, the situation after adding three unmanned ships No. 16, No. 17, and No. 18 is simulated. The operation effect of the cluster formation before and after the change is shown in (a) and (c).

Formation member data information

	ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
a	role	1	3	3	2	3	3	3	3	2	3	2	3	3	3	3	-	-	-
	state	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-	-	-
	sign	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-	-	-
	cV	25	20	15	24	15	16	16	17	23	21	22	17	18	18	18	-	-	-
	capN	1	1	1	4	4	4	4	4	9	9	11	11	11	11	11	-	-	-
b	role	1	2	3	1	3	3	3	3	2	2	2	3	3	3	3	-	-	-
	state	0	1	1	1	1	1	0	1	0	1	1	1	1	1	1	-	-	-
	sign	0	1	1	1	1	1	0	1	0	1	1	1	1	1	1	-	-	-
	cV	25	20	15	24	15	16	16	17	23	21	22	17	18	18	18	-	-	-
	capN	1	2	2	4	4	4	4	4	9	10	11	11	11	11	11	-	-	-
c	role	1	3	3	2	3	3	3	3	2	3	2	3	3	3	3	2	3	3
	state	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	sign	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	cV	25	20	15	24	15	16	16	17	23	21	22	17	18	18	18	22	15	17
	capN	1	1	1	4	4	4	4	4	9	9	11	11	11	11	11	16	16	16

If the leader loses or the number of candidate leaders is insufficient, the leader or candidate leader is regenerated to ensure the stability of the cluster. And the leader can communicate directly with the No. 16 unmanned ship to appoint it as a new candidate leader and back up the global information to minimize the impact of observation conditions on behavior decision-making.

Based on the above two experimental results, the cluster can retain the global information through the dynamic self-organization mechanisms and the flexible three-layer scalable distributed organizational structure of the "1 + *C* + *X*" mode. Whether losing unmanned ships or adding unmanned ships, the cluster can run stably and support the execution of various tasks.

Performance comparison and analysis of different organizational structures

	Environmental adaptability	Autonomous decision-making ability	Stability	Flexibility	Scalability	Dynamic self-organization	Multitasking	Central node
Chen et. al.	Strong	Strong	Weak	×	√	×	×	×
Liu et.al.	Weak	Strong	Weak	×	×	×	√	×
Crane	Strong	Weak	Strong	×	√	×	×	×
Borrelli et.al.	Strong	Weak	Strong	×	×	×	√	×
Yu et.al.	Weak	Weak	Strong	×	×	×	×	×
Our Work	Strong	Strong	Strong	√	√	√	√	×

From this table, we have compared the performance with Liu et al, Chen et al, Crane, Borrelli et al, and Yu et al. with our scheme. The scalable distributed organizational structure enables the cluster to have flexibility, scalability, strong autonomous decision-making ability, strong environmental adaptability, and good overall performance. Therefore, it has more practical significance than the previous organizational structure design methods.

Conclusions and acknowledgment

The existing organizational structure of unmanned system clusters still has some problems, such as lack of scalability and poor practical application ability. The problem has given complexity to the unmanned system cluster that is applied to the actual scene and meets actual needs .

We consider imposing technical measures to enhance cluster scalability. In this paper, we have designed methods for using the three-layer scalable distributed organizational structure and dynamic self-organization mechanisms so that the cluster can have scalability and meet the actual needs. As simulation experiment results show, the method proposed above can ensure that the system still runs stably and meets the task requirements after the cluster scale changes. Those can be verified by simulation results . Finally, compared with other organizational structures, the results show that our organizational structure can make the cluster have scalability, stronger environmental adaptability.

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