A Situated Contract Net Protocol Realization in Command and Control

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ABSTRACT

Contract net protocol is utilized for task assignment and distribution in command and control system. Basic contract net protocol and most enhanced versions are not as intelligent as needed in multi-agent system. From the point view of embodied cognition, situation awareness is critical for system intelligence. This proposal realized a situated contract net protocol where a situation factor is introduced to represent the impact of situated environment on agent task execution. Contract net protocol bidding policy is redesigned based on situation factor, cost function and task benefit function. Experimental results show that communication cost is reduced and mission success rate is improved.

CCS CONCEPTS

• **Information systems**; • **Expert systems**; • **Networks**; • **Network protocol design**;

KEYWORDS

multi-agent system, contract net protocol, situation factor

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1 INTRODUCTION

In the future of information warfare, the battlefield environment is increasingly complex and rapidly changing, with tactical operations in various forms. However, the common feature is responsive and flexible decision-making. The mosaic warfare style has emerged with the dynamic changes in the battlefield environment and the complex diversity of combat missions.

Mosaic warfare refers to designing many different forms of force by arranging and reorganizing minor functional elements of force structure. Mosaic warfare is an unmanned, autonomous, and intelligent style of warfare, featuring automated mission decomposition and delivery, optimal selection and clustering of combat units or sensors, and adaptive construction and dynamic reorganization of kill networks. Mosaic warfare force generation follows the "tender - bid - win" mechanism. This competitive force generation mechanism, based on cross-domain coordination, allows for faster closure and more efficient optimization of the kill chain from sensor to shooter.

In mosaic operations, whether it is combat system reconfiguration [1], multi-UAV collaboration [2], or mission redistribution [3], the core of all three is to achieve good mission collaboration and distribution in a limited time. Sunita Bansal and Chittaranjan Hota proposed a new distributed scheduling algorithm for independent tasks to be assigned optimally amongst available machines [4]. Mahendra Bhatu Gawali and Subhash K. Shinde proposed a Standard Deviation based Modified Cuckoo Optimization Algorithm for task scheduling to efficiently manage the resources [5]. As an algorithm to study the task allocation among multiple agents, the Contract Net Protocol (CNP) based on the market " tender - bid - win " mechanism has good convergence and the solution's robustness and fault tolerance [1, 3]. The contract net protocol enables the force market to provide more flexible and efficient force formation, but it also achieves the local optimum of force formation.

Randall Davis and Reid G. Smit proposed CNP in 1980 as a protocol for solving task collaboration and assignment in a distributed problem-solving environment. The protocol simulates the human bidding and evaluation mechanism in the commercial market to achieve task collaboration and allocation to find the local optimal solution to complete the task.

With the widespread popularity and continuous application of contract net protocol, the basic contract net protocol has also revealed many shortcomings. After an in-depth analysis and study and summarizing the failures of the basic contract net protocol, Chao Guo et al. broadly categorized the failures of the basic contract net protocol into three categories: first, the large amount of negotiated communication cost; second, the lack of an effective collaboration mechanism; and third, the imperfect evaluation of task qualifications [6]. However, no scholars have yet pointed out that the influence of environmental factors on the execution of tasks is enormous. If manager does not consider environmental influences, the successful bidder may not be able to perform the task due to environmental factors leading to task reassignment or, more likely, direct failure of the task.

In this paper, we apply for the first time a contract net protocol to the command and control system. To solve the problem that the environment impacts task execution, we introduce the concept of environmental impact factor and propose a bidding strategy and evaluation strategy considering the impact of the task environment

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in combination with an improved contract net protocol. By qualitatively analyzing the environmental impact at the bidding stage and quantitatively analyzing the environmental impact at the bid evaluation stage, the improved contract net protocol effectively reduced the communication cost and improved task assignment precision.

In Section I, we briefly introduce the research background, the contract net protocol, and innovation points. Section II describes the related work. We design and improve the contract net protocol with application scenarios in Section III. Experimental verification and analysis comes in Section IV. Conclusions in Section V.

2 RELATED WORK

2.1 Basic Contract Net Protocol

In the contract net protocol, there are three categories of objects.

- Issuer: Also called manager, issuer generally refers to an agent that finds a new mission or has an agent that is unable to complete the task on its own.
- Bidder: A bidder generally refers to an agent other than the issuing bidder.
- Successful bidder: Successful bidder is the one who is awarded the task after the evaluation of the bid.

The agent executing the contract net protocol does not need to be pre-assigned the roles of issuer or bidder. Any agent can become an issuer by issuing a bid, a bidder by bidding, or an agent can be both an issuer of task A and a bidder of task B at a specific moment.

The contract net agreement distinguishes four stages: bidding, tendering, winning, and signing [7].

- Bid issuance/task posting. When an agent finds that it cannot complete a task independently, it analyzes the task and then formulates a tender message. This agent publishes bidding information to all the agents.
- Bidding/competitive bidding. After other agents receive bidding information, they calculate the bidding proceeds. If they decide to bid, they prepare bids and send them to the issuer to participate in the bidding.
- Bid evaluation/winning. After the issuer receives the bid information from the bidders, it evaluates the bids according to the task requirements and its evaluation criteria. It selects the most suitable bidder as the winning bidder.
- Contracting. The issuer and the successful bidder agree on the task contract and then sign the contract, and the successful bidder gets the right to execute the task.

2.2 Improvement of contract net protocol

Many scholars have studied the shortcomings of the basic contract net protocol in more depth. They have proposed various improvements to improve and enhance the usability of the protocol according to their needs and the different problems they face.

To reduce the high negotiated communication costs in the basic contract net protocol. Haijun Zhang et al. proposed the concept of a dynamic contract net based on the threshold model in group intelligence [8]. Xinyu Zhao et al. proposed the agent trustworthiness model in contract net protocols [9]. Dalin Chen introduced a dynamically adjusted trustworthiness index [10]. Jinliang Gong et al. proposed to limit the number of bidding agents to reduce the communication pressure of the system [11]. Qisong Zhang proposed a method based on a contract net and combined with an acquaintance collaboration mechanism to solve the dynamic task allocation mechanism method of global and local in a dynamic environment [12]. Ning Liu et al. introduced the agent's mental state parameters and node rejection strategy. They introduced the auction idea in economics to propose an improved contract net protocol based on the auction mechanism [13]. Ming Chen et al. proposed a multi-agent collaboration model based on the acquaintance model and mental coefficient contract protocol [14].

To address the lack of an effective collaboration mechanism in the basic contract net protocol, Wunan Wan et al. introduced the concept of task acquaintance set. They proposed an improved contract net model and a selection mechanism based on task acquaintance set to select candidate nodes and negotiation strategy methods [15]. Ming Li et al. introduced the agent's capability model and improved the bidding and tendering phases of the contract net protocol based on the agent's capability model [16]. The contract net protocol based on the FIPA standard system added "confirm" and "reject" mechanisms [17].

In response to the imperfect evaluation of mission eligibility in the protocol, Hangping Qiu et al. proposed a dynamic task assignment algorithm based on a multi-attribute assessment of winning bidding strategies [18]. Xinliang Li et al. use the trust degree and trust degree threshold to decide the bidding scope of tasks and consider the influence of the agent's load balance degree and trust degree when determining the winning agent [19]. Xiaohui Hu et al. improved the task assignment strategy, introduced precision to evaluate the bidding value, and proposed a contract net model suitable for wireless sensor networks [20].

In addition to improving these three types of defects, some scholars have also made improvements from a norm-based perspective. Chao Guo et al. propose that norms can be introduced in the initial stage as a complementary measure without historical information [7]. Zhijie Guo et al. present to force the issuance of bids to complete the task when no one is bidding, ensuring that the mission does not fail due to aborted bids [21]. Zhiwei Liang et al. determine the priority according to the role and prioritize the active bidding strategy according to the contractor's preference while introducing the offer publicizing mechanism into the task assignment model [22].

3 SITUATED CNP

3.1 Scenario description

The MAS in this paper consists of a hybrid formation of multiple reconnaissances, combat UAVs, and transport UAVs and a command and control agent to accomplish a materiel escort mission based on an improved contract net protocol. According to operational requirements, a batch of equipment needs to be safely escorted and transported from location A to location B. During the transportation process, a hybrid formation may encounter hostile situations.

3.1.1 *Task flow.*

The commander will give the command and control agent the material escort task. The command and control agent completes the decomposition and distribution of the material escort

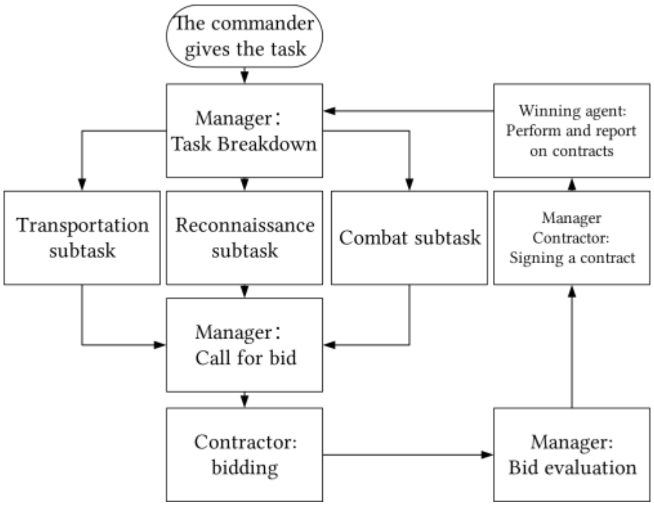

Figure 1: Material escort task flow

task. The mission of the uncrewed vehicle is to complete the material transportation task. The reconnaissance drone is responsible for completing the reconnaissance task of the enemy situation near the travel path. The combat drone is responsible for completing the strike task of the discovered enemy situation.

The entire material escort mission process is as follows, and Figure 1 shows the process.

The commander identifies the material escort mission and notifies the command and control agent. The command and control agent breaks down the materiel escort mission and breaks down this mission into three sub-tasks: the materiel transport mission, the air reconnaissance mission, and the airstrike mission. The command and control agent creates bids for the requirements of the three subtasks and then issues them. Other agents assess their capabilities based on the bids and send bids to the command and control agent. The command and control agent evaluates the bids of the bidding agent and selects the winning agent. The command and control agent signs a contract with the winning agent and gives the order. The winning agent performs the task and reports the completion of the mission to the command and control agent.

3.1.2 Formal description. The following quaternion can characterize the distribution problem of the material escort mission:<T, A, P, D>.

- T denotes the set of atomic tasks to be assigned after the decomposition of the material escort task, $T=\{T_1, T_2, T_3, \ldots, T_n\}$ and each subtask T_i can be completed independently by a single agent. A six-tuple can describe each atomic task, T_i={ *TID, Type, Taskcontent, TaskPos, TCapability, Tvalue*}. *TID* indicates the task number, *Type* means the task type, *Taskcontent* indicates the task content, *TaskPos* indicates the task target point location, *TCapability* indicates the base capability required to complete the task, and *Tvalue* indicates the task value.
- A denotes the set of agents involved in the mission, $A=\{A_1, A_2, A_3, \ldots, A_m\}$. A six-tuple can describe each A_i, A_i={ *AID, Atype, Value, AgentPos, Load(R/Fd), environment*}. *AID* marks the agent code. *Atype* indicates the type of mission participated in. *Value* means the value of the agent. *AgentPos* suggests its position. *Load(R/Fd)* represents the agent's load/reconnaissance radius/firepower Destruction indicator, *environment* indicates the environmental impact factor.
- P indicates the priority of this material escort mission.
- D indicates the date required to complete this material escort mission.

3.2 Contract net protocol design based on material escort scenarios

3.2.1 Comprehensive capability of the agent. The command and control agent evaluates the essential ability, state of mind, environmental influence factor, and loading degree to get the combined capability of an agent.

- Basic ability

The size of the agent's capability is a decisive factor for task distribution and a fundamental indicator of whether the agent can complete the task.

- Basic ability of transport agent

The command and control agent measures the cargo capacity and the average transport speed to obtain the base capability value of the transport agent. Assume that the load capacity of agent A_i is $Load_i$. The demanded load capacity in the task is $Load_{desired}$. Agent A_i has completed the job a total of SC times in history, the distance from the jth completed assignment to the target is len_j, the time to complete the task is t_j, and the rated maximum travel speed is V_{max}.

Define the base capacity of the transport agent as follows, where φ is a weighting factor.

$$Capability = \phi \times \frac{Load_i}{Load_{desired}} + (1-\phi) \times \frac{\sum_{j=1}^{SC} \frac{len_j}{t_j}}{V_{\max}} \tag{1}$$

- Basic ability of reconnaissance agent

The command and control agent measures the reconnaissance radius and average flight speed to define the base capability value of the reconnaissance agent. Suppose the reconnaissance radius of agent A_i is R_i. The reconnaissance radius required in the mission is $R_{desired}$. The distance from the jth task completed to the target is len_j , the time to achieve the mission is t_j, and the rated maximum flight speed is V_{max}.

Define the base capability of the reconnaissance agent as follows, where φ is a weighting factor.

$$Capability = \phi \times \frac{R_i}{R_{desired}} + (1-\phi) \times \frac{\sum_{j=1}^{SC} \frac{len_j}{t_j}}{V_{\max}} \tag{2}$$

- Basic ability of combat agent

The command and control agent measures the reconnaissance radius and average flight speed to define the base capability value of the combat UAV. The command and control agent determines the fire damage indicators of combat drones by the type of weaponry and ammunition they carry.

Assume that the fire damage indicator of agent A_i is Fd_i and the fire damage indicator required in the mission is $\mathrm{Fd}_{\mathrm{desired}}$. Define the base capability of the combat agent as follows, where φ is a weighting factor.

$$Capability = \phi \times \frac{Fd_i}{Fd_{desired}} + (1-\phi) \times \frac{\sum_{j=1}^{SC} \frac{len_j}{t_j}}{V_{\max}} \tag{3}$$

- State of mind

The agent's state of mind contains three parameters: trust, familiarity, and positivity.

- Trust level

Trust level refers to the degree of trust of the issuing agent in other agents. The main factor that affects agent trust lies in the number of tasks completed. The more times an agent completes tasks, the higher its trust value. Assume that in the record of previous task completion, the total number of times the bid agent A_i won the task is *TO*, and the number of times the agent completes the task is *SC*.

Define the trust degree of agent A_i as follows.

$$Trust = \frac{SC}{TO} Trust \in [0,1] \tag{4}$$

- Familiarity

In MAS, an agent chooses to sign contracts with agents who have successfully worked together. Hence, familiarity represents the familiarity between issuing agent and the binding agent, and it is one of the essential reference indicators for issuing and selecting bids and winning bids in contract net protocol.

Assume that the total number of previous bidding tasks issued by the issuing agent is N_{cfb}, and the total number of times the agent wins and completes the task is *SC*.

Define the familiarity of agent A_i as follows.

$$F = \frac{SC}{N_{cfb}} F \in [0,1] \tag{5}$$

- Positivity

Aggressiveness represents an agent's motivation to bid and indicates its willingness to complete the task, independent of whether it wins the bid. The issuing agent is more willing to give the offer to the more active agent in bidding under the same circumstances.

Assume that N_{cfb} denotes the total number of tasks issued, and N_{bid} denotes the total number of bids submitted by bid agent A_i. Define the positivity of agent A_i as follows.

$$P = \frac{N_{\mathrm{bid}}}{N_{cfb}} P = [0,1) \tag{6}$$

- Environmental impact factors

Environmental factors are also critical in the execution of combat missions. Environmental factors include meteorological, geographical, hydrological, electromagnetic, and battlefield environments, such as temperature, wind speed, bridges, rivers, electromagnetic interference, fire coverage, etc. At the same time, different backgrounds have different degrees of influence on the same equipment and equipment. The same environment has different degrees of impact on various equipment types. Still, these environmental factors always affect the success or failure of mission execution.

Environmental impact factor Ef as an evaluation factor of the bidding agent is introduced into the evaluation strategy so that the evaluation strategy is better, the value assessment of the agent is more reasonable, and the possibility of completing the task is higher.

- Load degree

The load degree represents the busy degree of an agent. If the command and control agent does not consider load balancing of MAS, there will be some agents who are very busy and have incomplete tasks to execute. Some agents are very idle and waste resources, which will lead to the degradation of the whole system performance and is not conducive to the sustainable operation of the system.

Assuming that the workload of agent A_i in MAS is L_i, and the number of agents of the same type in the system is *M*. Define the average workload in the system as follows.

$$\overline{L} = \frac{\sum_{i=1}^{M} L_i}{M} \tag{7}$$

Define the task load degree of agent A_i as follows.

$$TL = \frac{L_I}{\overline{L}} TL \in [0,1) \tag{8}$$

3.2.2 Tendering strategy. To reduce the negotiation communication cost during bidding, the issuing agent introduces a qualitative analysis of the factors influencing the task environment and prioritizes bidding to the appropriate agent. We can construct the tender screening evaluation function by the three mental state parameters of the agent's trust, familiarity, and positivity. We define the bid screening evaluation function as follows, where α, β, and γ are constant weighting factors.

$$J = \alpha \times Trust + \beta \times F + \gamma \times P, \quad \alpha + \beta + \gamma = 1 \tag{9}$$

The constant weighting factors characterize the weight of trust, familiarity, and positivity for the final screening.

When bidding, the command and control agent reviews the basic capability and environmental impact of the agent first, and when the basic ability meets the task requirements and the environmental impact is not significant, the command and control agent uses an evaluation function to evaluate and screen the agent. If the basic capability of the agent is insufficient or the environmental impact is significant, the agent does not participate in the bidding screening. If the value of $\mathcal{J}$ of the agent is greater than or equal to the fixed value of θ, the agent will pass the tender screening. If $\mathcal{J}$ is less than θ, the agent will not pass the screening. The command and control agent invites bids from screened agents. The command and control agent will conduct a broadcast bidding if all agents fail the screening or all agents invited to bid reject the bid. Figure 2 shows the tendering algorithm flow.

3.2.3 Bidding strategy. When receiving bidding information or an invitation to bid, an agent evaluates whether its essential capability meets the task requirements. It calculates the task benefit and cost if it meets the requirements. It makes a bid according to the conditions when the net benefit reaches the expected fixed value Ψ. If it does not meet the bidding requirements or the net benefit is less than

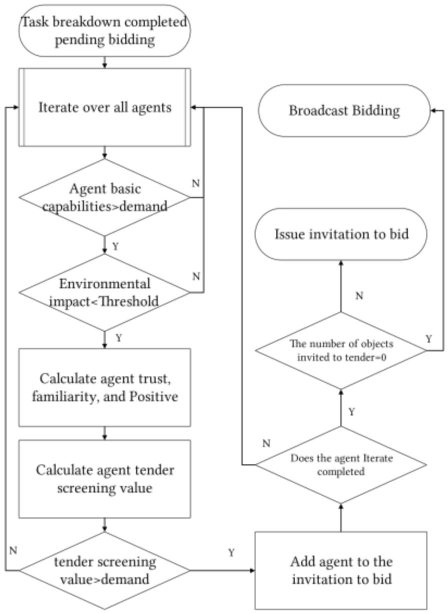

Figure 2: Tendering algorithm flow chart

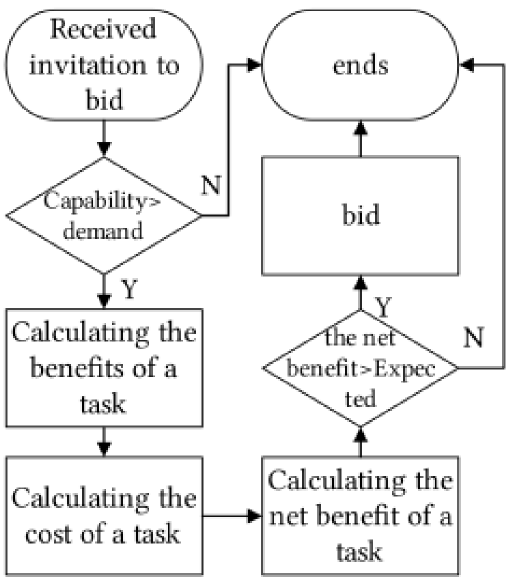

Figure 3: Bidding algorithm flow

Ψ, the agent rejects the bid. Figure 3 shows the bidding algorithm flow.

- Task benefit function

The value of the target mission and the capability of the agent executing the task determine the mission benefit [6]. The value of the target mission is specified when the mission is issued, and the ability of the agent to perform the assignment refers to the agent's own inherent warfare technology performance. We express the agent's capability in terms of its probability of completing the task and survival.

Suppose the task value of the target task T_i is *TValue*, the probability of the agent completing the task T_i is P_c, and the likelihood of the agent surviving during the execution of the job is P_s.

Define the reward of the agent for completing this task as follows.

$$Reward = Tvalue \times P_c \times P_s \tag{10}$$

- Cost function

Any agent performing the mission will incur costs, and the costs, in general, can be divided into two areas: the cost of the road and the cost of destruction [23].

The road cost refers to the price consumed on the road, which mainly contains the execution time, power consumption, and fuel consumption, directly related to the target's distance. Therefore, proximity to the target is an important principle when selecting and assigning tasks.

The cost of destruction refers to the cost incurred by the agent performing the mission against the enemy in a strong confrontation environment. The cost of destruction mainly contains the price of detection and destruction by enemy forces and the cost of ammunition consumption.

Please assume that the distance from the agent to the mission target is *l*, the agent's value is *value*, and the probability of being destroyed by enemy forces is *(1-P_c)*. Define the road cost as follows, where μ is the magnitude factor that unifies the magnitude of the road cost with the ruin cost.

$$C_{road} = \mu \times l \tag{11}$$

Define the destruction cost as follows.

$$C_{destruction} = Value \times (1 - P_s) \tag{12}$$

Define the cost function for the agent to perform the task as follows.

$$\text{Cost} = C_{road} + C_{destruction} = \mu \times len + Value \times (1 - P_c) \tag{13}$$

We define the net benefit as the difference between the task benefit function and the cost function.

$$NE = reward - \text{Cost} \tag{14}$$

3.2.4 Bid evaluation strategy. In the bid evaluation strategy, the issuing agent quantifies the impact of environmental factors on the agent, performs quantitative analysis, and incorporates the environment into the evaluation index for a comprehensive assessment. Therefore, we construct an agent comprehensive value evaluation function to evaluate the essential ability, state of mind, environmental influence factor, and loading degree.

Define the integrated value assessment function formally expressed as follows.

$$ACapability = \rho \times Capability + \omega \times J + \eta \times Ef + \delta + TL, \quad \rho + \omega + \eta + \delta = 1 \tag{15}$$

After a comprehensive capability evaluation of all bid agents, the command and control agent ranks the Acapability. The agent with the highest score will be assigned to this task and become the winning bidder. Figure 4 shows the bid evaluation algorithm flow.

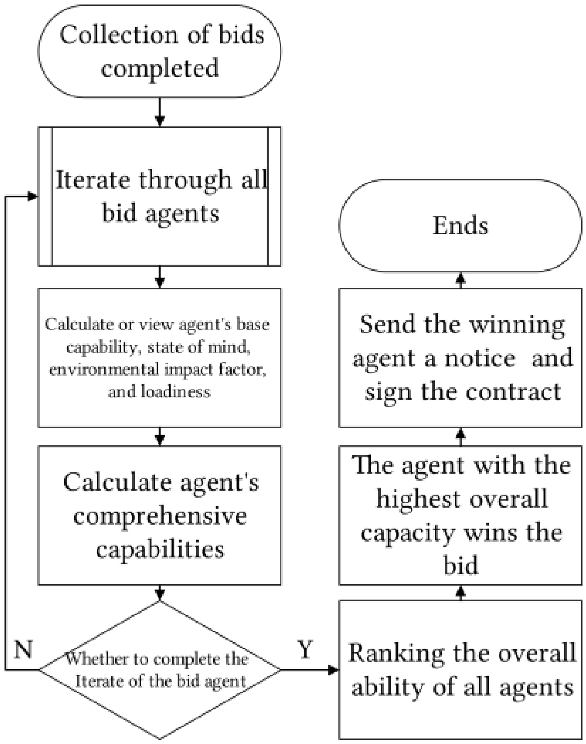

Figure 4: Bid evaluation algorithm flow

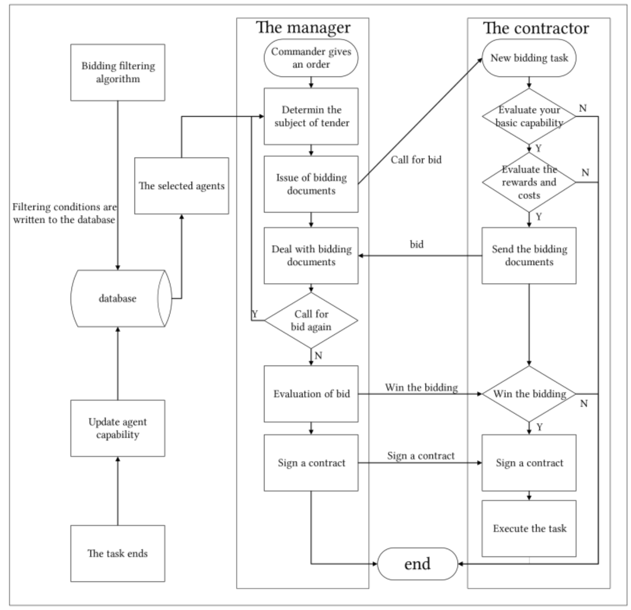

Figure 5: Bidding interaction process

4 EXPERIMENTS AND ANALYSIS

4.1 Simulation experiments

We conduct the corresponding simulation experiments to verify the efficiency of the CNP improvements in this study. The experiments are based on the ubuntu 18.04 and are programmed and implemented using C++.

This experiment performs performance analysis and functional analysis in order to verify the negotiation efficiency and task distribution accuracy.

- Performance analysis. This experiment compares the improved CNP algorithm of this study with the basic CNP algorithm in order to verify that the improved CNP algorithm of this study is more efficient in task distribution. More efficient task distribution refers to a reduction in task distribution time and a reduction in the amount of negotiated communication cost.
- Functional analysis. This experiment compares the CNP execution process without considering the environmental impact with the environmental impact in order to verify that the execution process of CNP with considering environmental impact has a more accurate task assignment.

4.1.1 Improved CNP protocol bidding interaction process. The bidding interaction process for this experiment is divided into eight steps, as shown in the following Figure 5.

- The commander gives the task to manager, and manager begins to execute the CNP.
- Manager breaks down the task and prepares the issuance of bids according to different types of tasks.
- Manager determines the targets for invitations to tender based on the tender selection algorithm and the information in the database.
- Manager issues invitations to bidders.
- After receiving the invitation to bid, the contractor checks whether its essential capacity and environmental impact meet the task requirements. If the agent's capacity or environmental impact does not meet the demand, it will not bid. The agent will calculate its benefits and costs if its capabilities and environmental impact meet the need. The agent will bid to manager when the net benefits meet expectations. Otherwise, it rejects manager.
- Manager processes the bids of the contracted parties and, if no contracted parties bid, decides whether to re-bid. If contracted parties bid, manager evaluates bids according to the winning algorithm, selects the winning bidder, and notifies the winning bidder.
- Manager and the successful bidder sign a contract, and the CNP implementation ends.
- The successful bidder performs the task and updates the contractor-related capability data in manager database after the bidder completes the task.

4.1.2 Comparison of CNP implementation process with and without considering the environmental impact. Figure 6 shows the comparison of CNP execution process with and without considering environmental impact.

- In the execution process of CNP without considering the influence of the environment, manager and the contractor typically conduct bid issuance, bid, bid evaluation, and bid

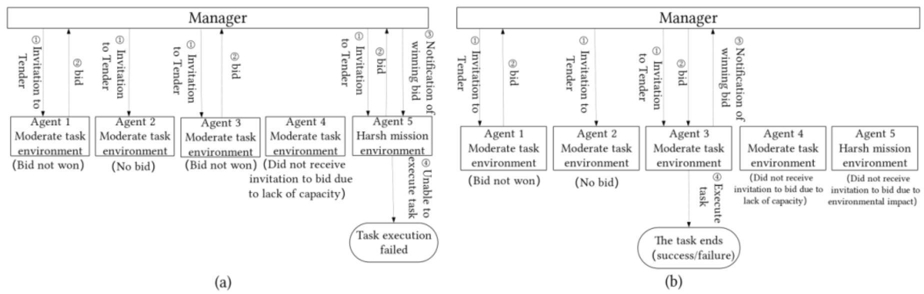

Figure 6: CNP execution process (a) CNP execution process considering environmental impact (b) CNP execution process without considering environmental impact

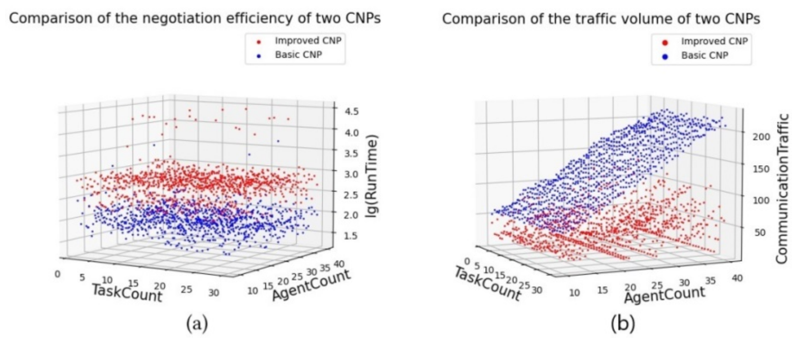

Figure 7: Comparison of basic and improved CNP (a) Comparison of negotiation efficiency of two CNPs (b) Comparison of communication cost of two CNPs

winning. When the winning agent is faced with a mission environment that is very bad relative to it and not suitable for its task, the winning agent eventually cannot execute the task and will give feedback to manager that the execution of the task has failed. Figure 6(a) shows the execution process of CNP without considering the influence of the environment.

- In execution process of CNP with consideration of environmental impact, manager will no longer issue bids to the contractors who consider the current mission environment hostile. Manager invites only agents with a low impact on task environment to bid. Finally, the successful bidder will successfully execute the task and give feedback to manager on success or failure of task execution. Figure 6(b) shows CNP execution process considering environmental impact.

4.2 Experimental analysis

This experiment randomly generates manager, transportation, reconnaissance, and combat agent. The commander randomly issues tasks, manager is responsible for distributing tasks, and contract agent is accountable for bidding.

4.2.1 Performance Analysis. The performance analysis experiment set up 1 to 30 tasks, each type of 10 to 40 agents. The experiment distinguishes between number of different works, number of different agents for experimental sampling. The sampling result is CNP negotiation time and communication cost of last task. Figure 7(a) shows the results of comparing negotiation efficiency of basic and improved CNP. Figure 7(b) shows the results of comparing traffic volume of basic and improved CNP.

- Negotiation efficiency. From experimental results, both basic CNP algorithm and improved CNP algorithm of this study change smoothly in CNP negotiation efficiency as the number of tasks increases or the number of agents increases. However, negotiation efficiency of improved CNP algorithm in this study is lower than that of basic CNP algorithm. We attribute low negotiation efficiency to algorithm's complexity in this study. The basic CNP algorithm in which time complexity is linear order O(n), and time complexity of improved algorithm in this study is square order O(n2), so execution efficiency of algorithm is reduced.
- Communication cost. From experimental results, with increase in number of tasks, the change of basic CNP algorithm and improved CNP algorithm communication cost is relatively smooth. Still, basic CNP algorithm communication cost is significantly higher than improved CNP algorithm communication cost. With increase in the number of agents, basic CNP algorithm and improved CNP algorithm communication cost are increasing, and basic CNP algorithm communication cost is rising faster. The basic CNP algorithm communication cost is significantly higher than improved CNP algorithm communication cost.

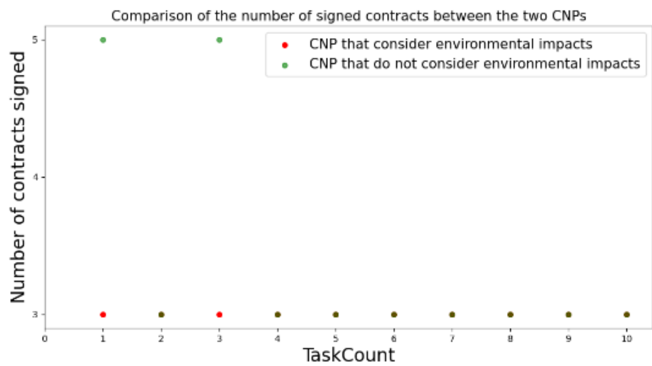

Figure 8: Comparison of number of contracts signed by CNP with and without environmental impact

4.2.2 Functional Analysis. The number of tasks set for functional analysis experiment is ten, with one hundred agents of each type. Figure 8 shows results of comparison of the number of contracts signed by CNP with and without environmental impact in each task distribution process.

If each task is smoothly distributed, manager and successful bidder sign a contract only once for each subtask and three times for entire mission. In Figure 8, except for first and third tasks, manager and successful bidder signed three contracts for all jobs.

During distribution of first task and third tasks, manager and successful bidder signed contract five times in CNP without considering environmental impact. There are sub-tasks with multiple contracts. After manager and successful bidder signed first contract, successful bidder gave feedback to manager that he was unable to perform task because task environment was terrible, which led to a contract re-signing. Manager and successful bidder signed contract three times in CNP that considers environmental impact. Managers have distributed tasks smoothly and with greater accuracy.

Therefore, task distribution without considering environmental impact factor is prone to first task distribution failure, and task redistribution will decrease negotiation efficiency and increase communication cost. Task distribution by assessing environmental impact factor will make task distribution more accurate.

5 CONCLUSION

This proposal introduces situation factor into contract net protocol, which addresses the issue that contractor signs subtask without any information of situated environment. Proposed protocol improves bidding policies and bidding evaluation policies in consideration of situated environment. Authors analyzed environmental impact factors in the bidding process and in the bidding evaluation process, which should reduce communication cost and improve task assignments accuracy. Finally, simulation experiments are carried out to test the performance of the improved contract net protocol considering environmental effects. However, this proposed protocol did not improve the communication efficiency between managers and contractors. In the next step, the authors will refine the contract net model, consider more complex application scenarios, and advance the landing of contract net protocol to operational applications based on improving communication efficiency.

REFERENCES

[1] Yao YANING, Yang STORM, Ji LINA, Lv HONGLANG, Bai YQ. Task assignment algorithm based on iterative merit-seeking strategy contract net protocol[J]. Command Control and Simulation,2020,42(04):51-56.

[2] Zhang MengYing, Wang MengYi, Wang XiaoDong, Song Xun. Research on collaborative real-time mission assignment problem of UAV swarm based on improved contract net[J]. Air Weapon,2019,26(04):38-46.

[3] Zhang A, Bi WH, Qiu P, Yuan Y. Multi-UAV strike ground TST mission redistribution based on improved contract net[J]. Tactical Missile Technology,2019(02):39-46.DOI:10.16358/j.issn.1009-1300.2019.7.213.

[4] Sunita Bansal and Chittaranjan Hota. Efficient Refinery Scheduling Heuristic in Heterogeneous Computing Systems[J]. Journal of Advances in Information Technology, Vol. 2, No. 3, pp. 159-164, August, 2011.doi:10.4304/jait.2.3.159-164.

[5] Mahendra Bhatu Gawali and Subhash K. Shinde. Standard Deviation Based Modified Cuckoo Optimization Algorithm for Task Scheduling to Efficient Resource Allocation in Cloud Computing[J]. Vol. 8, No. 4, pp. 210-218, November, 2017. doi: 10.12720/jait.8.4.210-218.

[6] Guo Chao, Xiong Wei, Liu Chengxiang. Status and prospect of contract net protocol improvement research[J]. Journal of Equipment Institute,2016,27(06):82-89.

[7] Jiang Yueqiu, Zong Rui, Guan Qixue, Guan Shijie, Zhang Xin. Improved contract net algorithm based on multi-constraint bidding strategy[J]. Journal of Arms and Equipment Engineering,2022,43(01):206-211.

[8] Zhang HJ, Shi ZZ. Shik. Dynamic contract net protocols[J]. Computer Engineering,2004(21):44-46+57.

[9] Zhao XY, Lin Zuquan. Agent trustworthiness model in contract net protocols[J]. Computer Science,2006(06):150-153+167.

[10] Chen DaLin. Research on process route planning and job scheduling based on contract net protocol[J]. Mechanical Design and Manufacturing Engineering,2020,49(09):78-81.

[11] Gong JL, Wang W, Zhang YF, Lan YB. Task allocation strategy of heterogeneous agricultural agent group based on dynamic stimulus-response model[J]. Journal of Agricultural Machinery,2021,52(05):142-150.

[12] Zhang Qisong. Research on multi-robot collaboration mechanisms based on task assignment mechanisms [J]. Science and Technology Innovation Herald,2013(03):45-46. DOI:10.16660/j.cnki.1674-098x.2013.03.171.

[13] Liu N, Shao JN, Gao F. Improved contract net protocols in multi-agent collaboration[J]. Journal of Guangxi Normal University (Natural Science Edition),2008(03):125-128.

[14] Chen M, Jian YM. Research on multi-agent contract net collaboration model based on mind coefficient[J]. Computer Application and Software,2013,30(06):46-51+56.

[15] Wan Wunan, Zhang Lei. Improvement of a contract net model based on task acquaintance set[J]. Computer Applications,2003(03):3-5.

[16] Li M, Liu W, Zhang Yanduo. Dynamic multi-agent task assignment based on improved contract net protocol[J]. Journal of Shandong University (Engineering Edition),2016,46(02):51-56+63.

[17] Zhou Kun. Research on resource service aggregation model based on the multi-agent system [D]. Xi'an University of Electronic Science and Technology,2014.

[18] Qiu Hangping, Qin Yao, Hu Bend, Guan Liu. Research on task assignment based on improved contract net model in multi-agent systems[J]. Computer Science,2012,39(S1):279-282.

[19] Li XL, Zhai JT, Dai YW. A multi-agent task assignment algorithm based on improved contract nets in dynamic environments[J]. Science Technology and Engineering,2013,13(27):8014-8019.

[20] Hu Xiaohui, Li Lanfeng, Fang Zheng, Liu Xueliang. Research on the application of improved task assignment strategy in WSN [J]. Computer Engineering and Applications,2017,53(02):124-128.

[21] Guo ZJ, Mi YL, Wang JG. Research on collaborative operational decision-making of air defense weapons based on MAS[J]. Military Automation,2016,35(07):80-85.

[22] Liang ZW, Wu HJ. Task assignment algorithm based on improved contract net protocol in RoboCup standard platform group[J]. Computer Engineering and Science,2022,44(01):176-183.

[23] Liao Chengcheng, Tao Wei, Liu Tao. Collaborative ground mission assignment of heterogeneous UAVs based on improved contract nets[J]. Modern Computer,2021(15):100-107.