A Contract Net Protocol Based on Information Intermediary Service in Multi-agent System

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***Abstract*—Being the first work for decentralized task allocation with a negotiation process involving a mutual selection, Contract Net Protocol (CNP) has been widely applied to kinds of Multi-Agent System (MAS). To solve the problem of flexible and dynamic system integration, agent techniques is introduced. On the basis of researches on CNP, an implementation of Contract Net Protocol based on Information Intermediary Service (CNPIIS) is proposed to support dynamic task allocations between modules wrapped into agents. Combining with the concept of Degree of Credibility (DOC) and Degree of Availability (DOA), CNPIIS made further extensions to CNP by the idea of providing services which enabled the initiator find a contractor more accurately and effectively. The aim of CNPIIS is to relieve the communication load and improve the efficiency of negotiation. CNPIIS was applied to the agent-based system integration tool and has been demonstrated to be effective and of high efficiency with assured quality in the experiment of Border and Coast Defense Simulation System.**

Keywords-contract net protocol; agent; system integration; information intermediary service

I. INTRODUCTION

The Contract Net Protocol (CNP) was proposed in [1]. As a classical negotiation strategy of task distribution and resources allocation, CNP has a wide application in the field of Multi-Agent system (MAS) for coordination among agents in resolving objective, knowledge and resource confliction.

The methodology of agent-based system integration and development has been studied to make system integration more inflexible and dynamic. Systems to be integrated are wrapped into agent modules. Through the negotiations and collaborations of agent modules, integration system will work and complete assigned tasks. CNP plays an important role in the dynamic characteristics of the agent-based system integration framework, providing a mechanism for agents to interact dynamically.

There were much effort to refine and extend CNP with more flexibility, adaptability and better performance. T.Sandholm proposed a formal model [2], whose pricing mechanism generalized CNP to work for both cooperative and competitive agents. By focusing on the issue of self-interest agents in automated negotiation system, Sandholm et al extended CNP to Leveled Commitment Contract [3], which allowed agents to end an ongoing contract if an outside offer was more profitable than current contract. By adding rejection and confirmation communication action, FIPA made the original CNP an important standard for a whole range of prominent agent platform implementations [4]. Besides, there were still some endeavors on formalization of CNP.

In classical CNP, agents, which initiated negotiations to find contractors though CNP, would send call for proposals (cfp) to participants in the beginning. The initiators initially had no idea that which agent was capable to be a potential contractor and usually sent cfps in a broadcast way. With the system scaling up, the number of agents and initiators would increase greatly. Communication load of the system would probably undergo a drastic change and cause communication congestion. The initiator lacking of sufficient information of the system leaded to these unnecessary communication. In the dynamic environment, the capabilities of each agent would dynamically change with time. The classical CNP would not work well in such a situation.

In the filed of agent-based system integration, all agents are considered to be competitive and with initiative. To improve the negotiation efficiency of task allocation and effectively decrease communication costs, an improved Contract Net Protocol based on Information Intermediary Service (CNPIIS) is proposed. In CNPIIS, an information intermediary service facility named Common Message Blackboard (CMB) is introduced to provide public information services for the negotiations and collaborations among agents. The combination of agent initiative and CMB information intermediary service makes CNPIIS more adaptive to dynamic environment. CMB also playes a role in sharing experience among agents of the same task or problem to be solved.

In this paper, section 2 presents and analyzes the classical CNP. In section 3, the CNPIIS is presented with definition, flows and algorithm. In section 4, experiment comparisons on CNP and CNPIIS are made. Section 5 concludes.

II. CLASSICAL CONTRACT NET PROTOCOL

The classical contract net protocol can be defined as follows:

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CNP = < Ag, IA, PA, C, Msg, Time>. Where:

- Ag is set of agents in the system. Ag = <a1, a2, a…, an> (n ≥ 1).
- IA is set of initiator. An initiator is an agent which initiates a negotiation. IA ⊂ Ag.
- PA is set of participant agents, which negotiates with initiators. PA ⊂ Ag.
- C is the valid values of command in the negotiation process. C = {(c_i)| c_i ∈ {refuse, propose, accept, reject}}, where, refuse means the participant refuses to propose, propose means the participator want to bid and will send a propose, accept means the initiator accepts the propose from a participant, reject means the initiator rejects propose from a participant.
- Msg is the message for negotiation.
- Time is negotiation-related system time.

In the classical CNP, task allocation and distributed problem solving is completed through the negotiation and collaboration among the Initiator Agents (IA) and Participant Agents (PA).

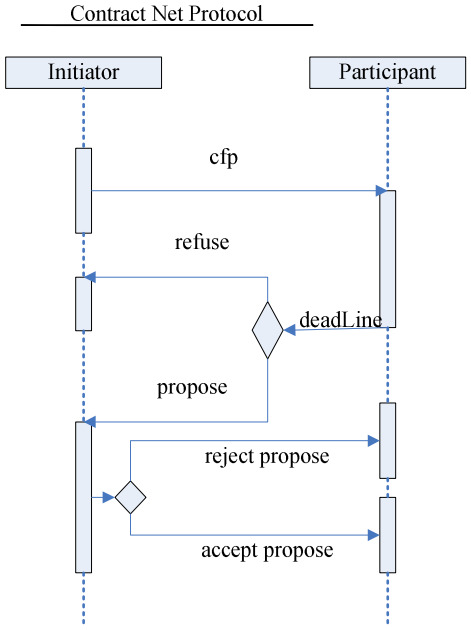

Figure 1. Interaction process in classical CNP

The interaction process between the initiator and participants of CNP is shown in Figure 1.Though the classical CNP could complete task allocation. It will easily lead to network overload and low efficiency of consultation with the system scaling up. Many scholars had refined and improved contract net protocol, but with most concerns focusing on the bidding or evaluating strategy. What's more, the knowledge and information resources of a single agent are limited and exclusive. Without information sharing, it will take a long period and large amount communication for each agent to accumulate and establish a mature and stable model.

III. CNPIIS

In CNPIIS, CMB is introduced as the information intermediary service agency. What' more, it combines the concept of DoC (Degree of Credibility) and DoA (Degree of Availability). DoC is the ratio for an agent to complete task of type t_i successfully and computed by the negotiation record in CMB. DoA is derived from the principle of Maximum Expected-Utility (MEU) and had been discussed in [8]. With these two concepts, the manager evaluates proposals not only by the ability and required costs, it also takes the DoC and DoA of a participant as an important factor in choosing its best, so the negotiation is more rational and efficient.

A. Definition of CNPIIS

The CNPIIS can be defined as follows:
CNPIIS = < Ag, IA, PA, CMB, C, Msg, Time>
Where:

- Ag = <a1, a2, a…, an> (n ≥ 1) is set of agents in the system, the same as CNP.
- IA is set of initiator. An initiator is an agent which initiates a negotiation. IA ⊂ Ag. Compared to CNP, Initiator's responsibility is different.
- PA is set of participant agents. PA ⊂ Ag. Participant agents are considered to be with initiative in CNPIIS.
- CMB (Common Message Blackboard) supports information intermediary service and can be defined as a 3-tuple. CMB = < AgI, Service, History, DoC>, where AgI is the information of agents and sorted by classification, such as the ability information. Service is services provided by CMB and can be defined as Service = {(s_i)| s_i ∈ {enroll, update, query, tenderDeal}}. DoC is the degree of credibility for an agent to complete a specific type of task and is computed by CMB based on the negotiation history record.
- C is the valid values of commands among initiator, CMB and Participate Agents. C = {(c_i)| c_i∈ {announcing, accept, reject, refuse, propose}}}, where announcing represents that initiators send tender to CMB, the others is almost the same as that in CNP.
- Msg is the message for negotiation.
- Time is negotiation-related system time.

In CNPIIS, the structure of tender announced by the Initiator can be described as definition 1. DoC and DoA are described respectively in definition 2 and definition 3.

Definition 1: Tender = <TenderID, Owner, Category, Speci, Expir , Prohi >. Where:

- TenderID is the ID of tender and unique, including the identification of the Initiator.
- Owner is the identification information of the Initiator, including its name and address.

- Category is the specific type of task the Initiator announcing and belongs to the task classification in the system.
- Speci is the description of the task, including common description, input interface and output interface that the Participant should support.
- Prohi is the collection of agents the Initiator forbids to propose.
- Expir is the deadline for participants to propose.

Definition 2: DoC is the credibility of an agent to complete tasks of a particular type.

$$DoC_a = \frac{\sum_i^n t_i \bullet v_i}{\sum_i^n v_i} . \quad (1)$$

Where: t_i denotes the satisfaction to the actual performance of the task evaluated by the Initiator, $t_i \in [0,1]$, vi denotes the weight of task t_i. Each task has a different weight according to its difficulty with default value 1.

Definition 3: DoA is the degree of availability of an agent. The more call for proposal an agent receives, the lower the DoA is.

$$DoA_a = \frac{1}{NCFP} . \quad (2)$$

Where: NCFP denotes the number of call for proposals the participant has received.

B. The process and algorithm of CNPIIS

The interaction process between the Initiator, CMB and participants of CNPIIS is shown in Figure 2.

Once an agent is deployed onto the platform, it will register its ability and other necessary information to CMB. When an agent's ability and status changes, it will also update its corresponding information in CMB initiatively. When an agent wants to find contractors through negotiation, it will announce the task to be allocated by sending a tender to CMB. The tender specifies the task, as well any conditions the Initiator places upon the execution of the task.

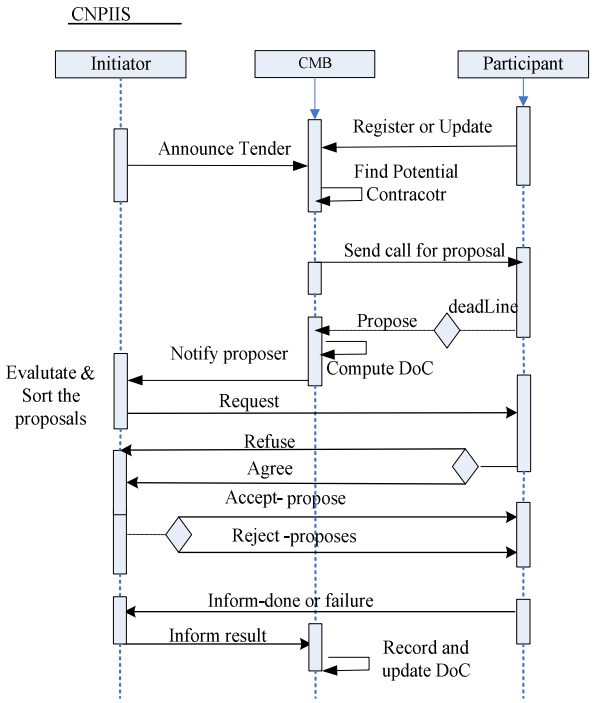

Figure 2. Interaction process in CNPIIS

The pseudo-code description of the announcing can be described as follows.

```
agent_a need to perform the task T.
Planning(T) => T = {t1 ∪ t2 ∪ t3 ∪ ti…}.
//Task t is planned to subtasks in sequences
foreach( subtask ti in T)
{ if (agenta is able to complete subtask ti))
      execute the subtask ti .
  else {
      make announcement and find the contractor for
subtask ti through CNPIIS.
      send tenderi to CMB.}}
```

Receiving an announcing from an Initiator, CMB can get the potential contractor according the announcing. For example, the task in the announcing is type t_i, according to the classification of task. If $agent_j$ has the ability of type t_i, $agent_j$ can be a potential contractor of the Initiator. CMB will send call for proposals to the participants instead of the initiator in CNP. The main difference from CNP is that CMB sends call for proposals to participant according the agent ability information it maintains, not to each agent in a broadcast way in CNP.

Meanwhile, CMB monitors the new register and update information. Once an agent is capable to be a participant, no matter what the reason is, to be a new agent just deployed onto the platform or ability updated, CMB will send the call for propose to the agent if the announcing is still before the declared deadline.

The pseudo-code description of sending call for proposes can be described as follows.

```
Participant(tender_i) =Φ.
∀ agent_j ∈ CMB && agent_j is capable to compelte task t_i
Participatant = Participator ∪ agent_i .
Send call for proposal to each participant.
Put the tender_i in the tender queue.
foreach tender in tender queue
{  while(time < message-deadline of tender_i)
   { if agent_m is new or update its ability and  supports tender_i
     Send call for proposal to agent_m .}}
```

The participant will read the call for propose sent from CMB and make the decision whether to bid. The participant may send proposal to bid or refuse to propose by its own willingness, mainly including its ability, status and self-interest. The participant's propose includes the preconditions that the participant sets out for the task, including the cost and the number of call for proposals it has received etc. The information of call for proposals it has received is helpful to evaluate the degree of availability of the participant and will be an important factor in awarding decision.

When CMB receives a propose form a participant, it computes the credibility of the participant (Degree of Credibility, DoC) to complete the task according negotiation history record in CMB. CMB will inform the Initiator with the information of the participant's proposal and its DoC.

Once the deadline has passed, the Initiator evaluates and sorts the received proposals.

The higher of DoC and lower of DoA, the earlier the participant may receive the offer. The initiator will send a request to the participant in descending order of the computed value. The process of awarding can be described as follows.

```
Read all propose from participant and call this set A.
For each propose p ∈ A.
  Compute the utility of by its cost, DoC and DoA.
Sort the Participant in descending order in List qList.
do {
        Send request to the qList[i].
        if qList[i] Agrees
        { Send accept-propose to qList[i] .
          Send reject-propose to the rest participant in qList.   }
          else i++;
    } while ( i < length of qList)
```

If a participant receives the offer and agrees, the Initiator will send an accept-proposal message to the participant. The participant will be the contractor and begin to execute the specific task. When the task is done or failed, the contractor will inform the Initiator the result of task execution.

The Initiator evaluates the result of task execution and informs CMB. CMB will record the negotiation and adjust the DoC of the participant.

IV. Experiment and Analysis

The purpose of the experiments is to validate the performance of CNPIIS in reducing the communication load and improving efficiency compared to the implementation of classical CNP. The Integration and development of Border and Costal Defense Simulation System (BCDSS) was developed as a test case to analyze the performance difference between CNPIIS and CNP. BCDSS was composed of 7 subsystems. Each subsystem was compose of 2-3 agents .The factors that affect the results of experiment are the number of agents in the system and the number of initiators. The experiment was designed as follows.

The Integration task was to complete one hundred tasks of various kinds. Increase the number of Initiator from 1 to 10, and keep a 10% rate of task repetition. In the experiment, with the number of initiator increasing, the comparison was made between the CNPIIS and CNP in communication load and efficiency.

The communication load here referred to the number of messages related with the negotiation through contract net protocol, respectively base on the implementation of the classical CNP and CNPIIS. The communication load comparison of the experiment is shown in figure 3, where CNP referred to classical contract net protocol.

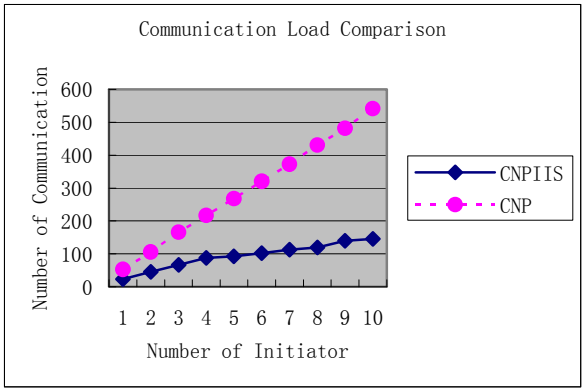

Figure 3. The communication load comparison between CNP and CNPIIS

The comparison of efficiency is made through the time comparison between the CNP and CNPIIS to complete the same number of task with the initiator increasing from 1 to 10. The longer the time it takes, the lower the efficiency of the contract net protocol is.

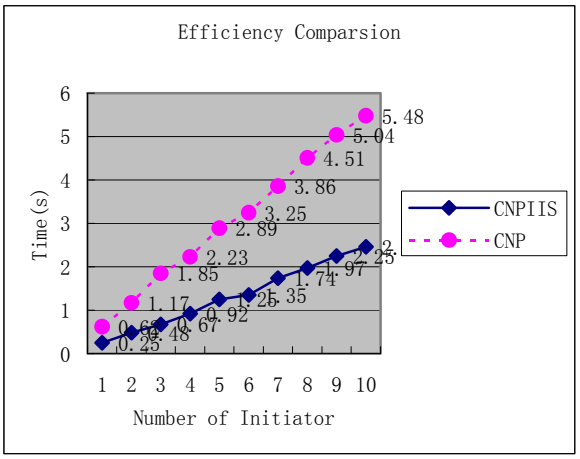

Figure 4. The efficiency comparison between CNP and CNPIIS

As can be seen from figures 3 and 4, when the number of the Initiator is small, the difference between CNP and CNPIIS in efficiency and communication load is not large. With the increasing of number, CNPIIS is showing an obvious advantage and can complete tasks in a shorter time with less communication load.

The mechanism of sending call for proposals just to potential contractors with the required ability saves much unnecessary communication cost and is helpful to improve the efficiency of negotiation. With the concept of DoC and DoA, the information intermediary service and management in CNPIIS shares the negotiation experience among agents and makes a full exploit of the negotiation resources, making the negotiation process more rational and orderly.

V. CONCLUSION

The classical CNP was communication intensive due to the broadcast of task announcements. This limited its usability in a large-scale multi-agent system. A third role called information intermediary service agency is introduced CNPIIS. CNPIIS improves the efficiency of negotiation process and decreases the cost of communication by provision of information services and sharing negotiation resources. What's more, CNPIIS is more adaptive to the dynamic environment with mechanism of dynamic monitoring information of agents. Experiments demonstrated that CNPIIS is superior the classical CNP.

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