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Efficient Contract-Net Protocol for Formal Modeling of Multi-Agent Systems

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Abstract: Contract net protocol is widely used in multi-agent systems because of its high extensibility and flexibility in a dynamic environment. However, many shortages exist while applying the traditional contract net protocol in multi-agent systems, such as rapidly increasing of the negotiation cost along with the system's dimension, no guarantee of the negotiation quality and difficulties in adapting the dynamic environment, etc. A multi-agent negotiation model based on the acquaintance coalition and the extended contract-net protocol is presented to improve the efficiency of the negotiation. The structure of the multi-agent negotiation model is given to support the extended contract-net protocol. The acquaintance coalition policy, the trust degree parameter and the adjustment rules are introduced and used to construct the extended contract-net protocol. Thus, it enhances the time efficiency for the negotiation process between contractor and the bidder. Main contribution of this research is the efficient contract-net protocol which helps agents to achieve efficiency during the task allocation method.

Keywords: Multi-Agent System, Cloud Computing, Exigency Services, Traffic Management

1. Introduction

Multi-Agent Systems (MAS) are typically set in dynamic environments where new plans of action might have to be devised to achieve the systems goals [1]. They offer a scope for the interactions, manage uncertainty and coordinate agents to enhance potency and avoid conflicts. Social goals are organizational objectives that are originated within the MAS organization. These goals don't seem to be essentially shared by the individual agents. Organizations and social goals are particularly relevant to MAS in complicated, dynamic, and distributed domains. In order to deal with the success and efficiency delivering the good social goals, they need to be allotted to the foremost applicable agents; it may be done by using task allocation protocols [1].

Task allocation has seen as a good technique of communication in MAS. It has a tendency to use a Contract Net Protocol (CNP) mechanism to allot goals to the agents. The plan is to seek out the agent, which will finish the social goal most effectively, out of all eligible agents. Once all agents collaborate within the task allocation process then the allocation is based on the bids they proposed and task will be given to at least one of those agents. In Multi-agent system, all agents communicate with one another by message passing using agent communication language (ACL). [2] has defined different sort of messages that agents will exchange. Messages that agents communicate have linguistics that are proposition, rules or action. Well-defined protocols should be able to cater all MAS functionalities. For increasing the modeling proficiencies during dynamic interactions, we consider most widely used protocol in MAS, which is contract-net protocol. Contract-net protocol is a standard cooperation strategy in the distributed computing for the task and resource allocation problems [3].

Unlike centralized scheme there is no central decision maker, only initiators are in charge for considering the execution of tasks and processing the results of their execution. Participants are in charge of the actual execution of the tasks. Agents not previously defined as managers or contractors can take any role dynamically during the time of problem solving. Initiator announces the available tasks in the negotiation process. Participants estimate these tasks and suggest bids on those tasks that are suitable for them. After that initiator evaluates the bids submitted by the participants and grant contract to the agent considering it to be most suitable. All task allocation controls will be distributed because processing and communication will not only be considered at specific nodes [4].

In this study we focus on the traditional way of human's business dealing. Humans while doing business with others

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occasionally prefers those whom they have interacted in the past as they have established an element of trust with them. The longer history they have with someone, the more they will prefer to do business with him. We have used this traditional method of humans to utilize the element of trust in agents. We mathematically devised different parameters to represent the interaction history among agents. We incorporate these parameters to compute a mathematical score. This score is then used to allocate tasks among agents.

2. Related Work

There are several coordination protocols presented in the past. Most popular among them are auction and contract-net. Agent will allocate resources and tasks to agents to perform their required goal using these solutions. In [5] FIPA (Foundation for Intelligent Physical Agents) protocol based formal model of auction and contract-net as a coordination technique in multi-agent's systems has been aspired. They explained various parameters regarding auction and contract-net technique, basic structure designed for each group of agents so they can easily create cases according to their requirement. Commonly used task allocation protocol in multi-agent system is contract-net protocol with various benefits like low communication cost, speed and flexibility. With so many advantages it has some drawbacks according to [4]. If the task requirement is more complex and difficult then CNP (contract-net protocol) is limited and has complexity.

According to [6] ordinary CNP is deficient in coordination for task allocation so they introduced the ECNP model because of the unavailability of CNP. Using the CNP the efficiency will be improved by the control of degree in the awarding phase when the MMAs are in the specified phase. They introduced methods to estimate specific states from the bid values which have not been used effectively. Their demonstrated CNP policy gives much better performance than naïve CNP and other CNP's that have flexible policies even though their policy didn't have global information [7]. CNP is one of the coordination mechanisms which is applicable by multi-agent systems that exalt coordination through interaction protocols. In direction to conquer the limitations of customary CNP, [8] proposed updated-CNP which is a variant of standard CNP. In their new technique a CNP is updated in response to its condition of limitations of modifiability.

[9] proposed a formal plan that extends the formal contract-net using real-time constraints, explained as interaction interval and communication deadlines, and fault tolerance to handle the agents demise exception. [10] encountered a problem using a FIPA specification i-e every participating agent is either initiator or participant during his life cycle. They projected a way out that allows agents to change their vital behavior dynamically depending on their necessities. A multi-agent system based energy coordination contract net protocol is designed in [11] to competently join production units of energy renewable based wind-photovoltaic energy storage system (PUER-WPESs) to Grid. The negotiation protocol is a two-level bidding method based on the CNP.

Aiming at the shortcomings of focused and distributed task placing methods, and confederated with the characteristics of manned/unmanned aerial vehicle structure, task assignment way supported on Contract Net Protocol (CNP) is presented in [12]. A new method has been proposed in [13] to solve the problem related to the communication protocols time-out set-up. Utilizing CNP in system to dispense social objectives for agents. Formalization of the bidding and awarding decision process that was left undefined in the original contract net task allocation protocol has been discussed in [14].

[15] has presented DynCNET, a convention for dynamic undertaking task that broadens standard contract net (CNET). DynCNET permits the operators associated with the convention to switch the task of errands progressively. [16] proposes a trans active energy scheme (TES) in light of multifaceted assessment and CNP to decide vitality-exchanging methodologies among presume to acknowledge financial and stable task of dissemination arrange. MAS-ASC depends on the CNP in which the specialists trade their recommendations in the type of call for proposition. [17] actualized on Java Agent Development structure stage and tried to conserve the utilization of vitality in a smart lighting framework case. Dynamic pickup and delivery problems (PDPs) require online calculations for dealing with an armada of vehicles. For the most part, vehicles can be overseen either halfway or on the other hand de centrally [18]. A typical method to arrange specialists de centrally is to use the contract-net protocol (CNET) that utilize sales to assign errand among agents.

[19] centers around multi-Agent system (MAS) based calculations for assignment allotment, especially in assembling applications. Proposed component is a spearheading approach for execution assessment of offering based MAS approaches for assembly booking. In [20] an Improvised CNP is actualized by the distribution specialists to either revamp abundance obtainable amounts among acquirement specialists or tag to processing operators. Booking operators tackle a vehicle routing problem with multiple cross-docks to decide close ideal steering utilizing a particle swarm optimization approach. [21] used the CNP that has been considered as a type of multi-cast communication and can be a source of overhead. In [22] CNP is used for managing the tasks, and it is responsible for bidding of the tasks.

3. The Proposed Efficient Contract Net Protocol

Important features of the proposed efficient contract-net protocol such as all required parameters that represent an agent's history is based on the fact that history is difficult to define formally. Task allocation process has been shown in the Fig. 1. It is based on five initiator and participants.

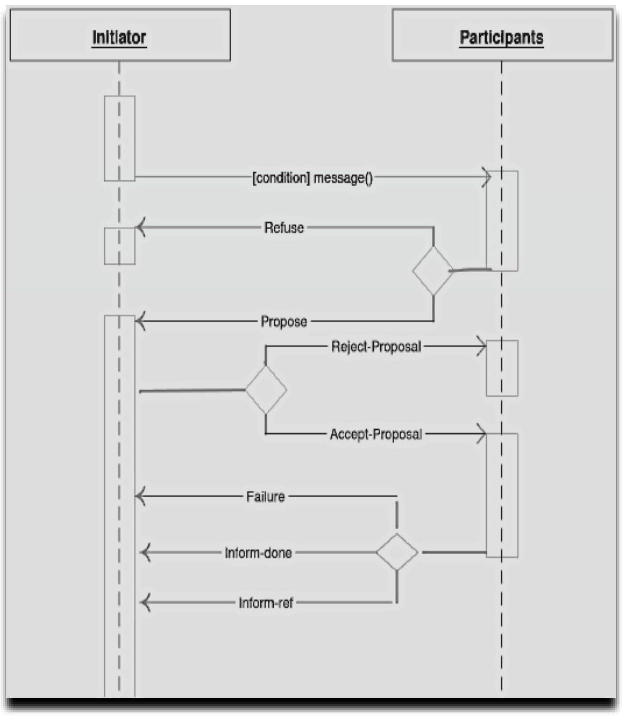

Figure. 1. Task Allocation

We formally defined a task in Fig. 2 for a precise unambiguous notation.

TaskType ::= REFLEX | DELIBERATIVE
AgentType ::= INAGENT | ARTISAGENT

Task

resource : Resource
length : T
margin : $\mathbb{N}$

INIT
$length > 0$

ReflexExecute
$\Delta length$
$\delta = length$
$length' = 0$

DeliberativeExecute
$\Delta length$
$\delta = length + margin$
$length' = 0$

Figure. 2. Formal definition of task

We address the problem of historical interaction by ensuring that each agent knows about the history parameters before replying to the task allocation process. Each agent has an estimated policy that is used for the calculation of prioritization agent score. We also assumed the importance factor of parameters given by the initiator when announcing the task. Agents will define their parameter values with the help of a policy that shows which parameter is less or more important for them. The defined importance factor can range from 0-9. Table I given below shows the parameters and their importance factor.

TABLE I. Parameters and Their Importance Factor

Parameters	Importance factor
Load	[0-9]
Cost	[0-9]
Reactivity	[0-9]
Duration/Time	[0-9]
Reliability	[0-9]
Efficiency	[0-9]

1) Policy Factor

Policy factor is a value that defines numerically defines the importance of parameters for the agents (participants). Policy factor will be given to the agents applying for the task allocation and willing to get the task done. Table II given below shows the defined policy and its corresponding values.

TABLE II. POLICY AND ITS VALUES

Policy	Value
ST	Strong
MD	Moderate
WK	Weak
No	None

2) Agent's Load

Load is also considered in this stage. In our case it is defined as the number of tasks multiplied with complexity of the task. Complexity can vary from task to task.

l = Number of tasks * Complexity of the task (3.1)

3) Agent's Load

After defining the policy and all other values final prioritization score will be calculated by the proposed mathematical formula which is as follow:

$$S_j = \left[\sum_{j=1}^{k} t_{ji} * W_{ji} \right] + [l] \qquad (3.2)$$

t = policy factor values for the parameters (i) for agent (j)
w = importance factor of parameters for agent given by initiator.
k = No of parameters
l = Load

Using the equation priority rank will be calculated and decided that task will be allocated to which agent. If we allocated the task to agent 1 and for instance it is not available, then the task will be automatically allocated to the next agent with highest priority score. To calculate the priority score, the calculation is shown in Table III.

TABLE III. PROPOSED METHOD FOR EFFICIENT CONTRACT NET PROTOCOL

Parameters	Importance	Agent 1	Agent 2	Agent 3	Agent 4	Agent 5
Load		ab	cd	ef	gh	ij
Cost	[0-9]	MD	WK		MD	WK
Reactivity	[0-9]	ST		MD	MD	WK
Duration/Time	[0-9]		ST	ST		WK
Reliability	[0-9]		WK	WK	WK	MD
Efficiency	[0-9]	WK			WK	MD
	Score					
	Prioritization Rank					

Previously, in CNP initiator has to call the proposal and wait for the agent to submit the bid during the waiting time but in our proposed efficient contract-net protocol task will be allocated on the basis of the previous interactions between the agents or on the basis of the history.

4. DEMONSTRATION OF THE PROPOSED EFFICIENT CONTRACT NET PROTOCOL

*A. **Post-Earthquake task allocation***

In this section, we present the working of our proposed efficient contract-net protocol with the help of different case studies. CNP for task allocation through search and rescue in post-earthquake is presented. It presents example that consist of an agent based system for post-earthquake operations, establish the way how the proposed method is useful for task allocation in post-earthquake system and how to find the agent that will be appropriate for the post-earthquake search rescue tasks in certain areas. The case study deals with the seismic risk in the 2005 Muzafarabad earthquake magnitude 7.6. The earthquake occurred at the western extremity of the Himalaya, where the arc joins the Karakorum, Pamir, and Hindukush ranges. This earthquake occurred on pre-existing active faults, the newly deformed area occupies a 90-100 km long northeast trending strip extending from Balakot, Pakistan, southeast through Azad Kashmir. It cuts across the Hazara syntaxes, reactivating the Tanda and Muzafarabad faults. North of Muza_arabad the surface rupture coincides approximately with the MBT, on the south-western bank of the syntaxes. The fault offset was 4m on average and peaks to 7m northwest of Muzafarabad. The rupture lasted for 25sec and propagated up dip and bi-laterally with a rupture velocity of about 2 km/s The heavily damaged area north of Muzafarabad, Kashmir shows the maximum deformation. There are known active faults stretching to the northwest and southeast near the epicentre, which reveal some 46 uplift on the northern side and dextral, right-lateral strike-slip activities. The known active faults are divided in two fault groups, the Muzafarabad fault, northwest of Muzafarabad and the Tanda fault, southeast of Muzafarabad [23].

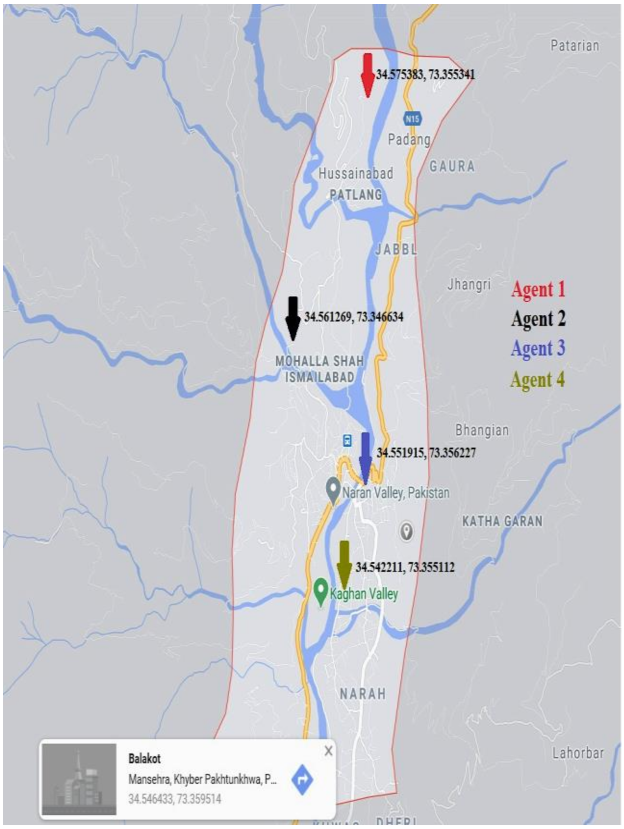

Figure. 3. Location of earthquake on 8 October 2005

Three main parts will be catered first in consideration of the data, locating the agent and implementing the proposed method for task allocation. Firstly, it is required for the detection of vulnerabilities in buildings and position of wounded in case of an earthquake. For finding all these JICA model is used as proposed in [24]. The input for the model is building year of construction, building height, building material and distance from fault. For calculation of injured building population has been used. For the implement of the model it is imperative to have a record of people living on the construction site at the time of earthquake. Result obtained from considering the structural damage number of casualties will be calculated from the equation used in [24]. There is no information available in actual search and rescue situation though. In this study central agent will categorize the task depending on the information gathered from the environment and assign the task to the nearest agent. That agent will then send auction notice to the sub-group agents. If the sub-group finds any casualty in the environment, then they will try to select the most suitable group from the rescue agents that has been considered by the tender notice assigning them the task of rescue operation. Rescue agent will be sent to the environment to find the injured needing help and find the best medical team from the list of medical teams available. Different uncertainties have been considered in task allocation stages. Fig. 4 shows post-earthquake search and rescue implementation steps.

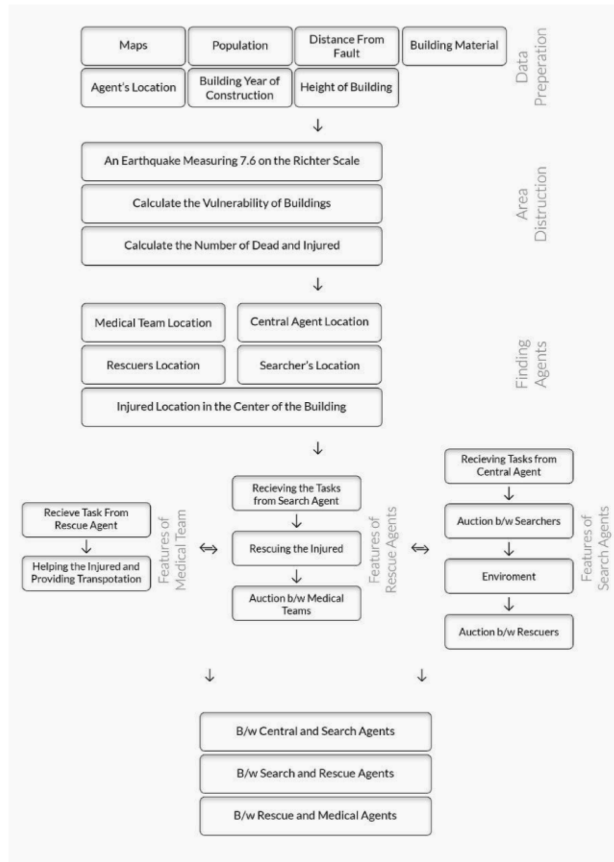

Figure. 4. Post- earthquake search and rescue implementation steps

The case study consists of five groups including middle agents, search agents, rescue agents, health agents and needy agents. These agents are autonomous entities which can move and get the environment and observe the status of their neighboring agents. Each of these agents can be considered as a physical entity of search and rescue operation which may include planning and decision making functions. Except for the injured agent all other agents are independent agents and can interact with each other. They have full right in speaking out their parameters for participating in tender in the interval form. In the present study rescuing includes the cooperation between the four types of agents. Search and rescue operation can be completed with the collaboration between different agents. Each agent in the system has a precise task.

Middle agent: According to the priority order tasks can be sorted, finding the nearest search agent, estimating the different subgroups of search agents, declaring the assigned task to the nearest rescue agents.

Search agent: This agent will be responsible for finding the upset agents in the environment seizing a searcher allocation auction, sending the group abilities and order for the agents to the searcher auctioneer responsible for the rescue.

Rescue Agent: This agent will be accountable for rescuing injuries from the fragments, recognizing the feature intervals and announcing them to the coordinator agents, finding medical auction.

Health Agent: This agent will be responsible for providing medical facilities and sending injured to the hospital, determining the feature intervals and declaring to the coordinator agent.

Injured agents: Residing in the environment

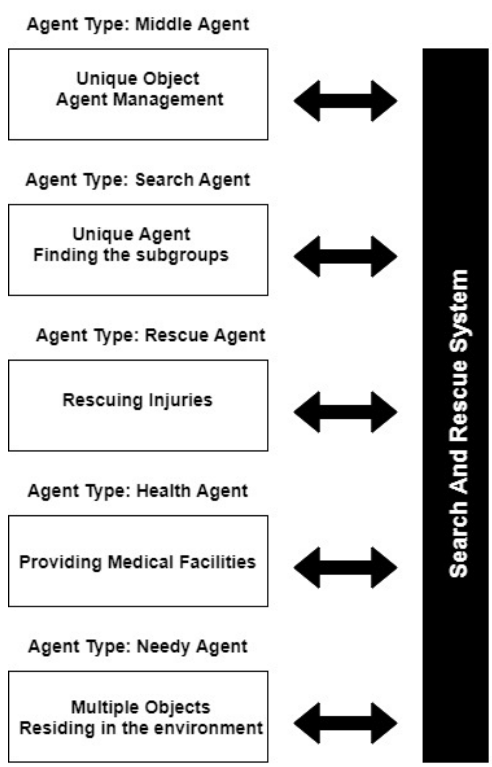

Figure. 5. Types of agents

In our case study, a technique is given with respect to the ecological vulnerabilities when allocating tasks and building up coordinated effort between agents. The proposed strategy can be utilized for undertaking designation and coordinated effort between agents, in spite of the nearness of vulnerability in the data. The proposed technique is general and relies upon the connection between two agents, A and B. For this situation, Agent A is expected to have a lot of tasks, and in addition needing to choose a lot of Agents B for these assignments. Proposed method will be used for the task allocation and collaboration between the agents. Fig. 6 demonstrate the steps of assigning the tasks to the set of agents. The method is general and depends on the interaction between two say agent A and B.

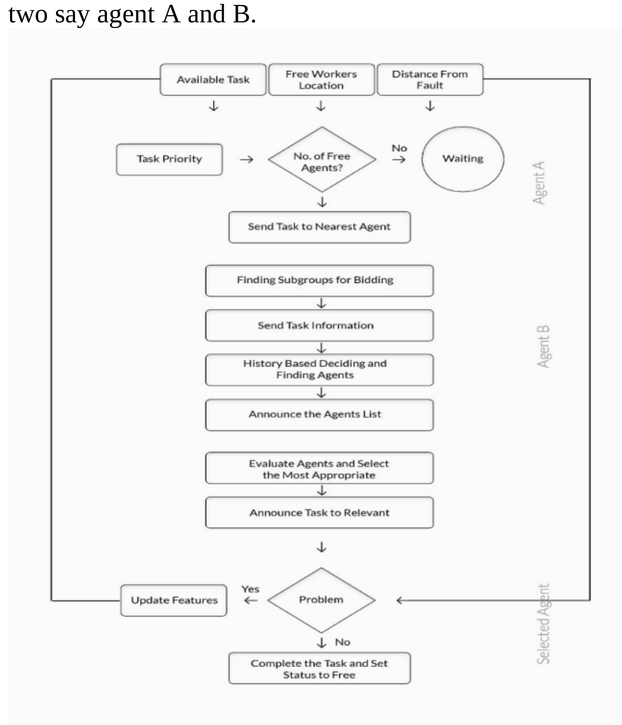

Figure. 6. Assigning set of tasks

Agent A can be considered as a central agent with set of tasks. These tasks can be performed according to their priority. Different factors can be considered when saving an agent in natural hazards. Several parameters are considered when assigning the task for agents in different intervals. Intervals are defined by the uncertainty in the environment. After central agent ordered the tasks the closest search agent is selected as the auctioneer (initiator). A message related to work features will be sent to the auctioneer by the Central agent. Search agent will conduct a tender for each of the task. While choosing the subgroups for the tender two important points will be reviewed i.e. spatial distance and the unavailability of free agents. Every task will be assigned in the proportional distance. If an agent fails to consider the distance extra effort will be wasted and large operation time will be used to complete the task. That is why spatial distance has to be defined for agents of subgroups i.e. 1 km from the tender area. The duties are always greater than the number of agents so it has to be considered that there will be no free agent in the environment for taking up the task. There is no condition defined for an agent that it is free that is why tasks will not be assigned to the free agents when there is unavailability of free agents. If an agent is free and available in 1 km from the area of tender, then task will be given to it otherwise it will be given to the busy agent. In the auction phase CNP is used where uncertainty is considered as one of the most important coordination technique for conveying tasks and sources for making collaboration among agents. The four steps of a CNP are task recognition, task announcement, receiving offers and task allocation [24]. In the wake of getting work highlights, Agent B holds the tender and declares the undertaking to the subgroup agents, which are B types. Every agent in the subgroup gauges the dimension of hazard for example, its area, and sends the comparing interim to the organizing agent. After that searcher agent will perform sorting on the candidate agents to check the suitability corresponding to the requested task using the proposed solution in this paper. The weights of all the parameters are considered as the policy in this case. The parameters used to prioritize the agent will be cost, reactivity, time, reliability and efficiency. Policy for prioritizing the agents will be 9, 3, 1, 0 which will be strong, moderate, weak and no respectively. When the search agent will finish prioritizing the agents, it will then assign the task to the agents according to their priority rank in the proposed model. After considering all the coordinator agents list, the central agent will assign the task to the agents that have given the best-estimated priority for the job. Then agent will drop that task and agent from the list and continue the task allocation technique with the rest of existing free agents.

B. Post-Earthquake task allocation scenarios

After applying the proposed method there will be different scenarios in which an agent will handle the task allocation method for tackling all these problems. Central agent has been considered as the Agent A who will be responsible for sending the tasks information to the search agent to announce the task and select the sub-group for completing the task. When selecting the task spatial distance and absence of free agents has to be considered.

*1) **Scenario 1: Perform search and rescue***

When finding the sub-groups for the task allocation geographical distance has to be considered. That agent who will be willing to complete the task has to be in the range of 1 km. Central agent has set of task for the sub-groups of search, rescue and medical agents. After finding the area, the locations of the agents will be determined. Injured location will be considered in the center of the building. Central agent will find the sub-group of searcher agents considering the previous interaction between the central and searcher agents who has previously participated in the tasks.

a) Auction between central and search agents

After the historical data final calculation for the auction phase will be based on the proposed efficient contract-net protocol with the importance factor and parameter values. The values for the importance factor will range from 0-9 in this scenario. The first auction is between the central and search agents. Table IV given below shows the parameters and their corresponding importance factor.

TABLE IV. IMPORTANCE FACTOR VALUES FOR SEARCH AGENTS

Parameters	**Importance factor**
Cost	5
Reactivity	4
Duration/Time	8
Reliability	2
Efficiency	9

After determining the importance factor for the initiator, policy will be defined through which the parameter factor will be recognized. Table V shows the defined values for policy A.

TABLE V. IMPORTANCE FACTOR VALUES FOR SEARCH AGENTS

Policy A	**Values**
ST	9
MD	3
WK	1
No	0

After getting the policy factor values and parameter importance factor, load will be considered. As load is already defined in the previous section we just consider the load values here. Generic values for agent's load are defined in Table VI.

TABLE VI. GENERIC VALUES FOR AGENT'S LOAD

Agents	**No. Of Tasks**	**Complexity**	**Load**
Agent 1	2	0.2	0.4
Agent 2	1	0.11	0.11
Agent 3	4	0.21	0.84
Agent 4	3	0.7	2.1
Agent 5	6	0.45	2.7

After collection of all the required parameters we will calculate the final values for the task allocation process through the proposed efficient contract-net protocol as shown in Table VII.

TABLE VII. CALCULATION FOR THE AUCTION BETWEEN CENTRAL AND SEARCH AGENTS

Parameters	**Importance**	**Agent 1**	**Agent 2**	**Agent 3**	**Agent 4**	**Agent 5**
Load		0.4	0.11	0.84	2.1	2.7
Cost	5	3	1		3	1
Reactivity	4	9		3	3	
Duration/Time	8		9	9		1
Reliability	2		1	1	1	3
Efficiency	9	1			1	3
	Score	60.4	79.11	86.84	40.1	48.7
	Prioritization Rank	3	2	1	5	4

b) Auction between search and rescue agents

After selecting the search team through the auction phase with the help of efficient contract-net protocol now auction takes place between search and rescue agents. Table VIII shows the parameters and their corresponding importance factor.

TABLE VIII. IMPORTANCE FACTOR VALUES FOR RESCUE AGENTS

Parameters	**Importance factor**
Cost	2
Reactivity	5
Duration/Time	7
Reliability	1
Efficiency	5

After determining the importance factor for the initiator, policy will be defined here and it will be the same for all the auction process. Table IX shows the defined values for policy A.

TABLE IX. IMPORTANCE FACTOR VALUES FOR RESCUE AGENTS

Policy A	**Values**
ST	9
MD	3
WK	1
No	0

After getting the values for policy factor, parameter, and importance factor we will compute the load. As load is defined already in the previous section we just consider the load values here. Table X below shows the number of tasks per agent, complexity of tasks and their corresponding load.

TABLE X. LOAD VALUES FOR RESCUE AGENTS

Agents	**No. Of Tasks**	**Complexity**	**Load**
Agent 1	1	0.21	0.21
Agent 2	3	0.10	0.3
Agent 3	5	0.1	0.5
Agent 4	2	0.2	0.4
Agent 5	8	0.5	4

After collection of all the required parameters we will calculate the final values for the task allocation process through the proposed efficient contract-net protocol as shown in Table XI.

TABLE XI. CALCULATION FOR THE AUCTION BETWEEN SEARCH AND RESCUE AGENTS

Parameters	**Importance**	**Agent 1**	**Agent 2**	**Agent 3**	**Agent 4**	**Agent 5**
Load		0.21	0.3	0.5	0.4	4
Cost	2	3	1		3	1
Reactivity	5	9		3	3	
Duration/Time	7		9	9		1
Reliability	1		1	1	1	3
Efficiency	5	1			1	3
	Score	56.21	66.3	79.5	27.4	31
	Prioritization Rank	3	2	1	5	4

c) Auction between rescue and medical agent

After selecting the rescue team through the auction phase with the help of efficient contract-net protocol now auction takes place between the rescue and medical agents. For the process importance factor, policy and load values has to be considered. Table XII shows the parameters and their corresponding importance factor.

TABLE XII. IMPORTANCE FACTOR VALUES FOR MEDICAL AGENTS

Parameters	**Importance factor**
Cost	7
Reactivity	4
Duration/Time	3
Reliability	5
Efficiency	8

After determining the importance factor for the initiator, policy will be defined here and it will be the same for all the auction process. Table XIII shows the defined values for policy A.

TABLE XIII. IMPORTANCE FACTOR VALUES FOR MEDICAL AGENTS

Policy A	Values
ST	9
MD	3
WK	1
No	0

After getting the values for policy factor, parameter, and importance factor we will compute the load. As load is defined already in the previous section we just consider the load values here. Table XIV below shows the number of tasks per agent, complexity of tasks and their corresponding load.

TABLE XIV. LOAD VALUES FOR MEDICAL AGENTS

Agents	No. Of Tasks	Complexity	Load
Agent 1	5	0.2	1
Agent 2	2	0.34	0.68
Agent 3	1	0.14	0.14
Agent 4	0	0.22	0
Agent 5	3	0.12	0.36

After collection of all the required parameters we will calculate the final values for the task allocation process through the proposed efficient contract-net protocol as shown in Table XV.

TABLE XV. CALCULATION FOR THE AUCTION BETWEEN RESCUE AND MEDICAL AGENTS

Parameters	Importance	Agent 1	Agent 2	Agent 3	Agent 4	Agent 5
Load		1	0.68	0.14	0	0.36
Cost	7	3	1		3	1
Reactivity	4	9		3	3	
Duration/Time	3		9	9		1
Reliability	5		1	1	1	3
Efficiency	8	1			1	3
	Score	74	51.68	59.14	55	43.36
	Prioritization Rank	1	4	2	3	5

2) Scenario 2: No historical data found for any agent

In case if an agent's historical data is not found or agent is interacting for the first time with the initiator then the current load will be considered for the task allocation process. In this scenario only available agents are Agent 1 and agent 2 and all the other agents are busy. We suppose that we had not interacted with the agent 1 and agent 2 before. For calculating the current load formula in proposed section will be used to find the current load.

a) Auction between central and search agents

In this case no importance factor and policy will be used because of no historical data available for the interaction. The calculations for the CNP task allocation will be based on the load values. Table XVI below shows the number of tasks per agent, complexity of tasks and their corresponding load.

TABLE XVI. LOAD VALUES FOR SEARCH AGENTS IN SCENARIO 2

Agents	No. Of Tasks	Complexity	Load
Agent 1	4	0.28	1.12
Agent 2	5	0.34	1.7

Using these values calculation is shown in Table XVII.

TABLE XVII. CALCULATION FOR THE AUCTION BETWEEN CENTRAL AND SEARCH AGENTS IN SCENARIO 2

Parameters	Importance	Agent 1	Agent 2
Load	-	1.12	1.7
Cost			
Reactivity			
Duration/Time			
Reliability			
Efficiency			
	Score	1.12	1.7
	Prioritization Rank	2	1

After calculating the bidding process through the proposed formula here agent 2 is opted for task allocation.

b) Auction between central and search agents

In this case no importance factor and policy will be used because of no historical data available for the interaction. The calculations will be based on only load values as shown in Table XVIII. for the auction between search and rescue agents.

TABLE XVIII. LOAD VALUES FOR RESCUE AGENTS IN SCENARIO 2

Agents	No. Of Tasks	Complexity	Load
Agent 1	2	0.2	0.4
Agent 2	1	0.14	0.14

Using these values calculation is shown in Table XIX.

TABLE XIX. CALCULATION FOR THE AUCTION BETWEEN SEARCH AND RESCUE AGENTS IN SCENARIO 2

Parameters	Importance	Agent 1	Agent 2
Load	-	0.4	0.14
Cost			
Reactivity			
Duration/Time			
Reliability			
Efficiency			
	Score	0.4	0.14
	Prioritization Rank	1	2

After the final calculations Agent 1 will be selected for the rescue task allocations.

c) Auction between rescue and medical agents

In this case no importance factor and policy will be used because of no historical data available for the interaction. The calculations will be based on only load values as shown in Table XX.

TABLE XX. LOAD VALUES FOR MEDICAL AGENTS IN SCENARIO 2

Agents	No. Of Tasks	Complexity	Load
Agent 1	6	0.18	1.08
Agent 2	3	0.54	1.62

Using these values calculation is shown in Table XXI.

TABLE XXI. CALCULATION FOR THE AUCTION BETWEEN RESCUE AND MEDICAL AGENTS IN SCENARIO 2

Parameters	Importance	Agent 1	Agent 2
Load	-	1.08	1.62
Cost			
Reactivity			
Duration/Time			
Reliability			
Efficiency			
	Score	1.08	1.62
	Prioritization Rank	2	1

After calculating the bidding process through the proposed formula here agent 2 is opted for task allocation.

3) Scenario 3: Load management

When interacting with the agents, load is considered to be the most important parameter among all. If an agent is already interacting with the maximum number of agents and willing to complete their task, then the task will be given first to the free agent. If there is no free agent, then the agent with the minimum load is considered and if no such possibility exists then the load will be divided among agents with the maximum load. Load management can also handle the network load if there are maximum numbers of agents communicating with each other. There is also possibility that network will not handle the load and task allocation process will be delayed.

5. DISCUSSION

In this section comparison between the proposed efficient contract-net protocol and previously used contract-net protocol is defined through various policies for comparison. Considering the different scenarios as discussed before we can now implement policies on those scenarios for our application of proposed work.

A. Policies for scenario 1.

1) Policy 1: Spatial Distance

a) For auction between central and search agents.

In scenario 1 that is discussed earlier, the auction between the central and search agents, Agent 3 is selected for the search operations. If we consider the typical contract-net protocol, we will select the search agent which is nearest to the fault area and it will be the Agent 4 which is far near to the fault area.

b) For auction between search and rescue agents.

In scenario 1 the auction between the search and rescue agent, Agent 3 is selected through the efficient contract-net protocol. If we consider the typical contract-net protocol Agent 4 will be selected because it is far near to the fault area.

c) For auction between rescue and medical agents

In scenario 1 the auction between rescue agent and medical, Agent 1 is selected through the efficient contract-net protocol. If we consider the typical contract-net protocol Agent 4 will be selected because it is far near to the fault area.

2) Policy 2: First come first serve

a) For auction between central and search agents

In scenario 1 that is discussed earlier the auction between the central and search agents, Agent 3 is selected for the search operations. If we consider the typical contract-net protocol, we will select the Agent 2 who submitted the bid first.

b) For auction between search and rescue agents

In scenario 1, the auction between the search and rescue agent, Agent 3 is selected through the efficient contract-net protocol. If we consider the typical contract-net protocol, Agent 1 will be selected because it submitted the bit first during the auction between search and rescue.

c) For auction between rescue and medical agents

In scenario 1, the auction between the rescue and medical agent, Agent 1 is selected through the efficient contract-net protocol. If we consider the contract-net protocol Agent 5 will be selected because it is the one who bid the task very first.

3) Policy 3: Based on load

a) For auction between central and search agents

In scenario 1 that is discussed earlier the auction between central and search agents, Agent 3 is selected for the search operations. If we consider the typical contract-net protocol on the basis of least task load then Agent 2 will be selected.

b) For auction between search and rescue agents

In scenario 1, the auction between the search and rescue agent, Agent 3 is selected through the efficient contract-net protocol. On the contrary if we use the typical contract-net protocol, Agent 2 will be selected on the basis of lowest task load at the time of task announcement.

c) For auction between rescue and medical agents

In scenario 1, the auction between the search and rescue agent, Agent 1 is selected through the efficient contract-net protocol. If we consider the typical contract-net protocol, Agent 2 will be selected on the basis of lowest task load at the time of task announcement.

B. Policies for scenario 2: No historical data

1) Policy 1: Spatial Distance

a) For auction between central and search agents.

With no historical data Agent 2 is selected with efficient contract-net protocol and with the traditional contract-net protocol, Agent 3 will be selected on the basis of spatial distance.

b) For auction between search and rescue agents

For this auction Agent 2 is selected for the efficient contract-net protocol and Agent 3 will be for the typical contract-net protocol.

c) For auction between rescue and medical agents

For this auction Agent 2 is selected for the efficient contract-net protocol and Agent 3 will be for typical contract net protocol.

2) Policy 2: First come first serve

a) For auction between central and search agents

Agent 2 is selected with the efficient contract-net protocol and Agent 1 will be selected for the typical contract-net task allocation because it bid first for the task.

b) For auction between search and rescue agents

Agent 2 is selected with the efficient contract-net protocol and Agent 1 will be selected for the typical contract-net task allocation because it bid first for the task.

c) For auction between rescue and medical agents

Agent 2 is selected with the efficient contract-net protocol and Agent 1 will be selected with the typical contract-net task allocation because it bid first for the task.

3) Policy 1: Based on load

This policy goes same as for the efficient contract-net protocol and typical contract-net protocol for all three types of auctions.

6. CONCLUSION

In this research, we contributed our work on defining new method for contract-net protocol task allocation process. Proposed formula used to implement the method that enables the efficient task allocation among agents in multi-agent systems. Communication of agents is the most significant characteristic of multi-agent system. It can be used for complex message passing to simple task allocation processes. The most important contribution is defining the history by using parameters of agents previous bidding interactions with the initiator. Our proposed method showed the results using the agent's previous interaction that can be measured by the defined parameters. By using the proposed formula total score is calculated and then task is allocated to the agent with the highest score. Search and rescue case study is used in order to demonstrate the effectiveness of the proposed method. The research provides directions for efficient task allocation process during the communication between agents. The proposed method ensures that the agent whose previous interaction is not available then allocation process is based on an agent's load at the time of task announcement.

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