Dependence Based Coalitions and Contract Net: A Comparative Analysis

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Abstract. Among several models of dynamic organizations, one can find *Contract Net* [13, 14, 4] and *Dependence Based Coalitions* [10–12] models. In this work, we present a comparative analysis of these models. More precisely, we compare the global communication flow of these two models, by changing some relevant parameters that have influence on the total number of exchanged messages. Our main goal is to be able to detect under which conditions one of the models is better than the other, concerning the global communication flow and the parameters values.

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1 Introduction

In [15,6], the information processing environments of the future are presented as being composed of huge heterogeneous networks of processing resources. These resources, autonomous and distributed, may consist of computers, huge applications and huge databases. Particularly, in [15], the author states that in the future local copies of programs will not be needed: it will be sufficient to ask for a site responsible for the execution of a service to perform it and to send back the results. The author calls these environments "societies of objects". A similar idea is presented in [6], denoted by the expression "electronic organizations".

Let us call *agent* a processing resource like the ones described above[1], *society* the set of agents and *organization* the way this society is put together in order to maximize the efficiency of the original problem solving procedure [11,8].

A system composed of these agents will have the following characteristics: *decentralized design*, *openness*, *autonomy.* By autonomy, we mean that agents have to evaluate in every moment if they wish to cooperate with other agents, if the information received from other agents is reliable, etc. We can give as an irrefutable example of this tendency the current importance of the Internet. The World Wide Web (WWW), for instance, has clearly the three characteristics cited above.

In such a system, as the agents who belong to the system can not be known a priori in design time, the problem solving metaphor is based on dynamic *coalition formation* [16]. We call coalition an organization that is established dynamically by the agents themselves when they need to work cooperatively in order to solve a given problem. Agents must use the information they have about each other in order to detect complementary expertise. In this case, neither a preconceived cooperation style nor a previous organizational structure is established [11].

Among several models of dynamic organizations, one can find **Contract Net** [13,14,4] and **Dependence Based Coalitions** [10–12] models, whose comparative analysis is the focus of this work. More precisely, we intend to compare the global communication flow of these two models, by changing some relevant parameters that have influence on the total number of exchanged messages. Our main goal is to be able to detect under which conditions one of the models is better than the other, concerning the global communication flow and the parameters values.

2 Description of the Models

In the following subsections, we present the main characteristics of each of the models being studied.

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[1] This definition of agent is obviously vague and poor, and it is being used exclusively to stress some essential aspects of this section.

2.1 Dependence Based Coalitions

The Dependence Based Coalitions model (DBC) [10–12] is a dynamic organization model based on Social Power Theory, that uses the core notion of *dependence relation* [2]. Basically, agents interact and form coalitions because they depend on one another in order to achieve their own goals. In this model, an agent choose his partners based on an evaluation of the other agents' susceptibility to help him, i.e., based on the fact that these agents may also depend on him for some of their goals. More details about this topic may be found in [11, 12].

In the DBC model, agents must have some minimal information about the other members of the society before choosing partners in order to form coalitions[2]. This information is acquired during an initial *presentation phase*[3]. Whenever a new agent enters the society, he must present himself to the others, sending them the information they need in order to be able to consider him as a potential new partner for future coalitions. The others send him this information about themselves as well. In a similar way, agents must tell the others when they are leaving the society, for instance to let them be aware that some action or resource has become globally unavailable (for instance, when the leaving agent is the only one able to perform a certain action).

After the presentation phase, the *resolution cycles* start. We call resolution cycle the processing activity that happens when one agent tries to achieve one of his goals. This agent is called an *active agent*[4]. The resolution cycle starts when the active agent chooses a goal to achieve and a plan to perform[5]. The selected plan may be an autonomous plan (i.e., a plan that the agent may perform by himself) or a dependent plan (i.e., a plan where the agent needs the other agents' help to perform at least one action or to release the control of at least one resource). If the agent has chosen an autonomous plan, the active agent may perform it alone and there is no coalition formation. If the agent has chosen a dependent plan, the coalition formation procedure starts.

The active agent analyses the dependence relations between the potential partners (i.e., those that can perform the needed action/release the needed resource) and himself. The preferred partner is the one whose susceptibility to cooperate is the highest one. This susceptibility is captured by a notion called dependence situation, described in [10, 11], which in some sense models the others' behaviour. The active agents makes then a list of possible partners, ordered by a preference measure. He then asks each agent from the list, from the top to the bottom, if he is willing to take part into the coalition. The procedure stops when some agent accepts to take part into the coalition, and the active agent sends him a coalition formation message.

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[2] Basically, this information consists of the agents' goals, plans, actions and resources, a more comprehensive description may be found in [10, 11].

[3] We consider in this work that all needed agents enter the society at the beginning of the processing activity.

[4] For simplicity, we consider in this work that resolution cycles can not be executed concurrently, i.e., there is one active agent per resolution cycle.

[5] More details about this phases may be found in [11, 12].

2.2 Contract Net

The Contract Net model (CN) [13, 14, 4] is a dynamic organization model based on the notion of economic market. Its main goal is to allocate tasks among agents, using the notion of *negotiation.* Its structure is based on *task announcements, bids,* and *contracts* [1]. This model is very important, because historically it was the first one using a negotiation procedure to form coalitions among agents [9].

We call here RC* a small variant of this model, where agents do not have any information about others[6] [7]. Therefore, unlike the DBC model, there is no presentation phase.

Using the same terminology adopted for the DBC model, we will have several *resolution cycles*, where in each of them an *active agent* will try to achieve one of his goals. The active agent starts the cycle by choosing a goal to be achieved and a plan to follow[7]. If the selected plan is an autonomous plan, the active agent may perform it alone and no coalition is formed. On the other hand, if we have a dependent plan, the active agent sends to all the other agents a *task announcement message*, where he details the action he needs, as well as some relevant parameters for the eligible bids. The possible partners, i.e. the agents able to perform the actions and who are in conformity with the eligibility conditions, reply with a *bid message.* After he has received the bids, the active agent analyses them and chooses the best partner. This choice may occur if a perfect partner has been found or a timeout has been reached. A perfect partner is a partner who obeys totally to all eligibility conditions[8]. If a perfect partner was not found and the timeout has been reached, the active agent chooses the closest partner to the perfect one. The chosen partner receives then a *contract message* when he becomes aware that he has been accepted to take part into the coalition.

3 Mathematical Analysis

In order to formulate a mathematical description, let us suppose a society composed of n agents, where $n \in N$ and $n > 3$. We also suppose that there is m agents, with $m < n$, who are *possible partners*, i.e., who are able to perform some needed action in a resolution cycle[9]. Particularly, we will consider the case where the active agent needs only *one single action* to achieve his goal. This hypothesis is adopted to simplify the analysis procedure. Details of how the DBC model can be extended to multi-partner coalitions can be found in [3]. We will analyze the models' performance after the occurrence of g resolution cycles.

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[6] In fact, some extensions to the original model, like considering autonomy cases, were introduced in order to enable a better comparison to the DBC model. These assumptions may be found in [7].

[7] More details may be found in [7].

[8] More details may be found in [7].

[9] For simplicity, we restrain our analysis to action dependence.

3.1 Dependence Based Coalitions

In the DBC model, agents initially exchange messages to perform the presentation phase. Each agent broadcast a *presentation message* to the other members of the society. If we suppose n agents in the society, each of them sends $(n-1)$ presentation messages. The sum of exchanged messages in the presentation phase is represented by the function $S_{presentation} = n(n-1)$.

In each resolution cycle, there is also a pattern of exchanged messages. The active agent sends *coalition proposal messages* to the possible partners until he finds a partner or the possible partners' list becomes empty[10]. The possible partners, however, always reply to the coalition proposal message, by sending either an *acceptance message*, or a *refusal message*, or a *revision message*[11]. When the active agent receives an acceptance message, he then replies with a *coalition formation message* in order to inform the partner that he has been selected and the coalition is established. Obviously, this last message is not sent when no partner was found.

Let us suppose that the active agent has sent k coalition proposal messages, where $k \leq m$ holds[12]. During a resolution cycle, we can have the following situations:

- A partner is found in some interaction step. The communication flow (S_{cycle}) is represented by the function: $S_{cycle} = 2k + 1$;
- No partner is found. In this case, we have: $S_{cycle} = 2m$;
- Either the active agent is autonomous or there are no possible partners in the society. In this case, we have $S_{cycle} = 0$.

Considering the occurrence of g resolution cycles, the total number of messages exchanged between agents after all the g resolution cycles (S_{DBC}) is:

$$S_{DBC} = S_{presentation} + \sum_{i=1}^{g} S_{cycle_i} = n(n-1) + \sum_{i=1}^{g} S_{cycle_i}, \tag{1}$$

$$\text{where } S_{cycle_i} = \begin{cases} 2m_i & \textit{no partner found} \\ 2k_i + 1 & \textit{partner found} \\ & \text{where } 0 < k_i \leq m_i \\ 0 & \textit{agent autonomous} \end{cases}$$

Whenever an agent leaves the society, he must broadcast an *exit message* to the other members. Therefore, we should include in the final formulation $n-1$ messages for each agent that leaves the society[13]. For simplicity, we do not consider this aspect in this work.

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[10] In our model, as agents are not considered benevolent, there may be the case that neither of the possible partners has accepted to take part in the coalition.

[11] More details about these messages may be found in [11, 12].

[12] This means that $k-1$ agents have replied either a refusal or a revision message.

[13] Moreover, we need to update the current value of n, by decrementing its value.

3.2 Contract Net

There is no presentation phase in the CN* model, and therefore there is no initial communication flow among the agents. All the messages are exchanged during the resolution cycles. In each cycle, the active agent broadcasts a *task announcement message*, except when he is autonomous for the selected goal. The number of messages sent is $S_{announcement} = n - 1$.

Let us suppose that among the m agents who are possible partners only b agents reply with a *bid message*. This limitation may be due to the expiration of bid's timeout. We can have the following situations:

- A partner was found. In this case, we have $S_{bid} = b + 1$, where $0 < b \leq m$;
- There are no bids. In this case, we have $S_{bid} = 0$.

Therefore, the total number of messages exchanged after each resolution cycle is $S_{cycle} = S_{announcement} + S_{bid} = n - 1 + S_{bid}$, where either $S_{bid} = b + 1$ *if* $0 < b \leq m$ or $S_{bid} = 0$ *if* $b = 0$.

In the CN* model, all the messages are exchanged during the resolution cycles. Therefore, the total number of messages exchanged between the agents after all the g resolution cycles (S_{CN*}) is:

$$S_{CN*} = \sum_{i=1}^{g} S_{cycle_i} \ , \tag{2}$$

$$\text{where } S_{cycle_i} = \begin{cases} n - 1 & \textit{no partner found} \\ n + b_i & \textit{partner found} \\ & \text{where } 0 < b_i \leq m_i \\ 0 & \textit{agent autonomous} \end{cases}$$

4 A Particular Scenario

If we analyze the mathematical models, we can conclude that the parameters that take part into the global communication flow in both models are the following: the total number of agents in the society (n) and the total number of resolution cycles, i.e., the total number of goals to be achieved (g). Considering the DBC model, other relevant parameters are the number of possible partners (m) and the number of agents to whom coalition proposals are sent (k). As for the CN* model, a relevant parameter is the total number of agents that send proposals (b).

Let us then consider for analysis purposes a particular scenario of a society composed of n agents, with g different goals that need one single partner to execute some action. Let us also suppose that in each resolution cycle, except for the active agent, all other $n - 1$ agents are able to perform this action (this means that we are considering the upper bound case where $m = n - 1$). In this society, we also consider that agents are never autonomous (i.e., none of the third definitions of equations (1) and (2) hold) and they always find possible partners (i.e., none of the first definitions of these equations hold either). We will also consider that the parameters b, k, m are *constant in all resolution cycles.* Considering this hypothesis, the global communication flow is a simplification of equations (1) and (2):

$$S_{DBC} = n(n-1) + g(2k+1) \text{ , where } 0 < k \leq m \tag{3}$$

$$S_{CN*} = g(n+b) \text{ , where } 0 < b \leq m \tag{4}$$

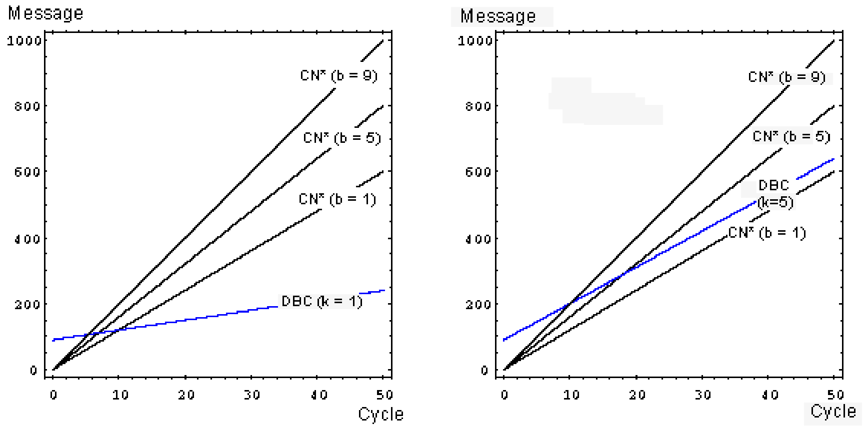

Fig. 1. Number of messages for k = 1 (left) and for k = 5 (right) (DBC model) compared to b = 1, 5 and 9 (RC* model)

We will fix in all resolution cycles the number of agents to whom coalition proposals are sent in the DBC model (k) and the number of agents who send proposals in the CN* model (b) to the following values:

i. Values for k:
   - $k = 1$, i.e., the first agent contacted accepts to take part in the coalition (lower bound of k, best case of DBC model);
   - $k = \left\lceil \frac{n}{2} \right\rceil$, i.e., the active agent sends proposal messages to half the number of members of the society before finding a partner (intermediate value for k);
   - $k = n - 1$, i.e., the last agent contacted accepts to take part into the coalition (upper bound of k, worst case of DBC model).

ii. Values for b:
   - $b = 1$, i.e., the contractor receives only one bid message (lower bound of b, best case of CN* model);

- $b = \left\lceil \frac{n}{2} \right\rceil$, i.e,, the contractor receives bid messages from half the number of the members of the society (intermediate value for b);
- $b = n - 1$, i.e., the contractor receives bids from all the members of the society (upper bound for b, worst case of CN* model).

If we substitute the above mentioned values in equations (3) and (4), we obtain some generic equations for our scenario. In order to visualize graphically this scenario, let us consider that our society has 10 agents ($n = 10$) and substitute this value in these equations. We obtain the results shown in figures 1 and 2 left. We then show in figure 2 right the upper and lower bounds for both models.

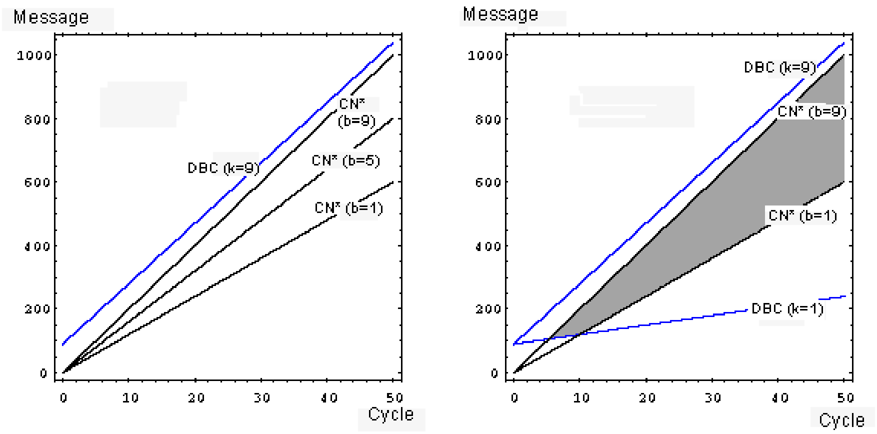

Fig. 2. Number of messages for k = 9 (left) (DBC) compared to b = 1, 5 and 9 (RC*) and upper and lower bounds of DBC and RC* models for a society of 10 agents(right)

One may notice that a particular point deserves a more detailed analysis. This point correspond to the intersection of the lines obtained from equations (3) and (4) in the figures shown above. From this point on, it is more advantageous to use the DBC model since we have $S_{DBC} < S_{CN*}$. This situation starts in a special resolution cycle which we will call *critical cycle* ($g_{critical}$).

The critical cycle $g_{critical}$ is obtained by making equal equations (3) and (4):

$$\begin{aligned} n(n-1) + g_{critical}(2k+1) &= g_{critical}(n+b) \\ g_{critical} &= \left\lceil \frac{n(n-1)}{n+b-2k-1} \right\rceil , \end{aligned} \tag{5}$$

where $n + b - 2k - 1 > 0$

	$k = 1$	$k = \left\lceil \frac{n}{2} \right\rceil$	$k = n - 1$
$b = 1$	$g_{critical} = \left\lceil n \left(\frac{n-1}{n-2} \right) \right\rceil$	**Impossible**	**Impossible**
$b = \left\lceil \frac{n}{2} \right\rceil$	$g_{critical} = \left\lceil \frac{2n}{3} \left(\frac{n-1}{n-2} \right) \right\rceil$	$g_{critical} = \left\lceil 2n \left(\frac{n-1}{n-2} \right) \right\rceil$	**Impossible**
$b = n - 1$	$g_{critical} = \left\lceil \frac{n}{2} \left(\frac{n-1}{n-2} \right) \right\rceil$	$g_{critical} = \left\lceil n \left(\frac{n-1}{n-2} \right) \right\rceil$	**Impossible**

Table 1. Values for $g_{critical}$

The $g_{critical}$ values with respect to the values of b and k in situations i e ii, and obtained from equation (5), are represented in table 1.

5 Conclusions

From figure 1, we can observe that for certain values of k and b, there will *always* be a critical cycle $g_{critical}$ after which the global communication flow in the DBC model will always be smaller than the one obtained in the RC* model. On the other hand, this will never be the case when we analyze the situation presented in the left of figure 2. We can also observe that as the number of possible partners contacted in the DBC model (k) increases, this critical cycle becomes higher, until we reach a particular situation (with k between 5 and 9 for our example of a society of 10 agents) where this critical cycle $g_{critical}$ does not happen. When it happens, however, we can notice from the figures that it is independent of the number of bids b sent in the RC* model.

This situation can be better explained if we consider both the model equations (1) and (2). As both functions $S_{cycle_{DBC}}$ and $S_{cycle_{CN*}}$ are linear with respect to g, if the linear coefficient of the CN* model ($n + b$) is greater than the linear coefficient of the DBC model ($2k + 1$), then we will always have $S_{cycle_{DBC}} < S_{cycle_{CN*}}$. Moreover, we will have $S_{DBC} < S_{CN*}$ after some critical cycle where the initial communication flow $S_{presentation}$ in the DBC model is counterbalanced.

Generally speaking, we can conclude that given a number of agents n, there will always be a range for the values of k and b (dark area in figure 2 right) where from some critical cycle on, the DBC model will have a smaller communication flow than the RC* model.

From table 1, we can notice that an active agent with a very good social reasoning mechanism, i.e. who obtains acceptance messages to his first proposal ($k = 1$) will *always* be able to obtain a global communication flow inferior to the CN* model, after the critical cycle, independently of the number of agents in the society. On the other hand, if the social reasoning mechanism is very poor ($k = n - 1$), this situation never arises.

If we drop out the simplifying assumptions we have adopted, one can verify that the above conclusions still hold. For instance, the case of having more than an active agent per cycle can be modelled by several resolution cycles, each corresponding to a single active agent. On the other hand, the case of several needed actions can be modelled in the sane way, each cycle corresponding to a certain needed action. Indeed, this last case can be optimized if proposals of sets of actions can be sended, as described in [3].

We can therefore conclude that whenever an agent has got a good social reasoning mechanism, in the long term it is more advantageous for him to form coalitions based on the DBC model rather than based on the RC* model, if one considers the global communication flow of the society. This is particularly important when one considers processing environments like the ones described in the introduction, where autonomous agents may dynamically enter or leave the society without a pre-established centralized control.

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