Reduction of Task Complexity in Coalition Planning

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Abstract

The problem of planning humanitarian relief operations within a high number of hardly collaborating and vaguely linked non-governmental organizations is a challenging problem. We suggest an alternative knowledge based approach to the coalition formation problem for humanitarian and peace-keeping missions. Owing to the very special nature of this specific domain, where the agents may eventually agree to collaborate but are very often reluctant to share their knowledge and resources, we have combined classical negotiation mechanisms with the acquaintance models and social knowledge techniques.

1 Introduction

The application domain of this coalition formation research belongs to the area of war avoidance operations such as peace-keeping, non-combatant evacuation or disaster relief operations. Unlike in classical war operations, where the technology of control is strictly hierarchical, operations other than war (OOTW) are very likely to be based on cooperation of a number of different, quasi-volunteered, vaguely organized groups of people, non-governmental organizations, institutions providing humanitarian aid but also army troops and official governmental initiatives. Each such body can be represented by an agent.

Specific features of the coalition planning for OOTW, like reluctance of certain bodies (agents) to provide information and to keep it private, or the need to keep the openness of the whole system were already summarized in [Pěchouček, 2001c]. In the case of OOTW, the prevalence of privacy of information has a higher priority than the optimality of coalitions. Maximum reduction of complexity of communication and decision-making is the other requirement specific to OOTW as some of the bodies are extremely reluctant to communicate. That's why we have proposed to use a special architecture of the MAS combining a centralized registration of agents with the contract net protocol and acquaintance model techniques [Pěchouček, 2001b]. Besides the coalition as targeted product of the coalition formation process we have introduced the concept of alliances as a community of agents who agreed to form eventually a coalition and are ready to share their private and semi-private knowledge. We also present a new formalisation of the coalition formation approach used in the CPlanT system, we try new experimental results, and mainly to explain how the reduction of the problem complexity has been achieved.

2 CPlanT System Architecture

CPlanT is a multi-agent system for planning humanitarian relief operations. Classical negotiation algorithms such as contract net protocol (CNP) are used in combination with acquaintance models techniques [Pěchouček, 2001a]. The CPlanT architecture consists:

Resource Agents - (r-agents) representing the in-place resources that are inevitable for delivering humanitarian aid, such as roads, airports.

In-need Agents - (in-agents) which are critical bodies in the entire simulation. They will represent the centres of conflict that call for help (e.g. cities, villages).

Humanitarian Agents - (h-agents), computational models of the participating humanitarian agencies. Like the r-agents, h-agents provide humanitarian aid.

In this paper, we will investigate coalition formation processes among the h-agents.

3 Knowledge Architecture

Computational and communication complexity of forming a coalition depends on the amount of pre-prepared information the agents administer one about the other and on the sophistication of the agents' capability to reason about the other agents' resources, plans and intentions. Agents can allow others to reason about them and at the same time they can reason differently about the agents belonging to different categories according to the agent's interest. Therefore, we distinguish among several types of agents' neighbourhoods:

– $\alpha(A_0)$ – **agent's total neighbourhood**, all agents that the agent A_0 is aware of, (e.g. A_0 knows of their existence and can communicate with them),

– $\mu(A_0)$ – **agent's social (monitoring) neighbourhood** which is a set of agents about who the agent

A_0 reasons and keeps knowledge about services they provide (status, load, etc.). The agent's social neighbourhood consists of agents that the agent A_0 reasons about $\mu^+(A_0)$ and the agents that reason about A_0 - $\mu^-(A_0)$. Therefore must be true that

$$\forall \ B \in \mu^-(A): A \in \mu^+(B),$$

– $\varepsilon(A_0)$ – **agent's cooperation neighbourhood** that is a set of agents jointly collaborating (or committed to do so) in achieving one or many shared goals.

Provided that Θ is the multi-agent community, we will want our agents to collaborate in such a way that

$$\forall A_0: \varepsilon(A_0) \subseteq \mu(A_0) \subseteq \alpha(A_0) \subseteq \Theta.$$

In order to reason one about the other, the agents must share some pieces of their knowledge. We say that the agent A_0 shares its knowledge $\mathsf{K}(A_0)$ with a set of agents $\delta(A_0) \subseteq \Theta$ provided that:

$$\mathsf{K}(A_0) = \{\varphi\} : \forall\varphi \in \mathsf{K}(A_0) : \forall A_i \in \delta(A_0) : (\mathsf{Bel}\ A_i\ \varphi) \wedge \forall B_i \notin \{\delta(A_0) \cup A_0\} : (\mathsf{Bel}\ A_0\ \neg(\mathsf{Bel}\ B_i\ \varphi))$$

According to this classification, we suggest three levels of h-agents' knowledge sharing:

Public knowledge is shared within the entire community. If we assume that all the agents know one about the other (i.e. $\forall A, A \in \Theta : \alpha(A) = \Theta$), the public parts of knowledge $\mathsf{K_P}(A_0)$ of an agent A_0 is defined as

$$\mathsf{K_P}(A_0) = \mathsf{K}(A_0) \text{ where } \delta(A_0)=\alpha(A_0).$$

This class of knowledge is freely accessible within the community. As public knowledge we understand the agent's name, type of the organization the agent represents, general objective of the agent's activity, country where the agent is registered, agent's human-human contact (telephone, email), the human-agent type of contact (usually http address), the agent-agent type of contact (the IP address, incoming port, ACL) and, finally, available services.

Semi-private knowledge (also referred to as alliance accessible knowledge) is shared within agents' social neighborhoods. Semi-private knowledge $\mathsf{K_S}(A_0)$ of an agent A_0 is defined as

$$\mathsf{K_S}(A_0) = \mathsf{K}(A_0) \text{ where } \delta(A_0) = \mu(A_0).$$

As we do not assume the knowledge to be shared within the overlapping alliances, we will require the social neighborhood to have the following property:

$$\forall A \in \Theta : \mu^-(A) = \mu^+(A) = \mu(A).$$

Members of a social neighborhood will primarily share approximate information about free availability and price of their resources.

Private knowledge is owned and administered by the agent itself. Private knowledge $\mathsf{K_{Pr}}(A_0)$ of an agent A_0 is defined as

$$\mathsf{K_{Pr}}(A_0) = \mathsf{K}(A_0) \text{ where } \delta(A_0) = \{\}.$$

An important type of private knowledge relates agent's collaboration preferences, alliance restrictions, coalition leader restrictions and possible next restrictions, but also agent's planning and scheduling algorithms.

As an alliance we understand a collection of agents that share information about their resource allocation and that all agree to form possible coalitions. The alliance is regarded as a long-term cooperation agreement among the agents. Members of an alliance will all belong to one others' social neighborhood. Provided that we assume that each agent belongs also to its own social neighborhood – $\forall A \in \Theta: A \in \mu(A)$ (which is what we can do without any loss of correctness), we define the alliance as follows:

Definition: An **alliance** is a set of agents κ, so that

$$\forall A \in \Theta : \exists\kappa : A \in \kappa \wedge \forall A_i \in \kappa : \kappa = \mu(A_i).$$

A singleton agent is regarded as an alliance with just one agent. From the requirements for the reciprocal knowledge sharing within an alliance follows that

$$\forall A \in \kappa : \kappa = \mu(A).$$

Therefore, an important property of an alliance is that it can not overlap with another alliance:

$$\forall \kappa_1, \kappa_2 \subseteq \Theta: (\exists A: A\in\kappa_1 \wedge A\in\kappa_2) \Rightarrow \kappa_1 \equiv \kappa_2.$$

Let us define a **coalition** as a set of agents (an agreement), which agreed to fulfill a single, well-specified goal. Coalition members commit themselves to collaboration with respect to the in-coalition-shared goal. Under an assumption $\forall A \in \Theta: A \in \varepsilon(A)$ we define coalition as follows:

Definition: A **coalition** is a set of agents χ, so that

$$\forall\chi(\tau) \subseteq \Theta: \forall A \in \chi(\tau) : \chi(\tau) \subseteq \varepsilon(A).$$

Let us introduce a set $\varepsilon(A,\tau)$ that is an agent collaboration neighbourhood with respect to a shared goal τ:

$$\varepsilon(A) = \bigcup_{\tau}\varepsilon(A,\tau), \text{ and}$$

$$\forall\chi(\tau) \subseteq \Theta: \forall A \in \chi(\tau) : \chi(\tau) = \varepsilon(A,\tau).$$

A coalition, unlike an alliance, is usually regarded as a short-term agreement among the collaborative agents. While it is better for a coalition to be a subset of an alliance, it is not an inevitable condition. A coalition can consist of agents, which are members of different alliances.

The last term, that we have to introduce is a **team action plan**. In planning humanitarian relief operations, equally as in the case of any other collaborative action planning, the agents must agree on how they will achieve the goal τ. The team action plan is thus a decomposition of a goal τ into a set of tasks $\{\tau_i\}$. The tasks will be delegated within the coalition members. Apart from the responsible agent each task shall be denoted by its due time, start time and price.

Definiton: The team action plan $\pi(\tau)$ is defined as a set

$$\pi(\tau) = \{\langle\tau_i, A_j, \mathsf{start}(\tau_i), \mathsf{due}(\tau_i), \mathsf{price}(\tau_i)\rangle\},$$

where agent A_j is responsible for doing the task τ_i in time $\mathsf{due}(\tau_i)$, starting at $\mathsf{start}(\tau_i)$, for the price $\mathsf{price}(\tau_i)$.

We say that the team action plan $\pi(\tau)$ is **correct** if $\forall\langle\tau_i, A_j, \text{start}(\tau_i), \text{due}(\tau_i), \text{price}(\tau_i)\rangle \in \pi(\tau)$ the agent A_j is able to do the task τ_i in the given time and for given price. We say that the team action plan $\pi(\tau)$ is **accepted** by the agent A_j if it committed itself to implementing the task τ_i in the given time and for the given price. Similarly, we say about the goal τ to be **achievable**, if there exists such $\pi(\tau)$ that is correct and the goal τ to be **planned**, if there exists such $\pi(\tau)$ that is committed. Obviously, there is an important relation between a team action plan and a coalition. We say that a coalition $\chi(\tau)$ achieves a goal τ by implementing a team action plan $\pi(\tau)=\{\langle\tau_i, A_j, \_, \_, \_\rangle\}$ if $\chi(\tau)= \{A_j\}$.

4 Inter-agent Communication

Before explaining the lifecycle of the system let us comment the main techniques that have been used in the CPlanT system: central registration services, contract net protocol, and acquaintance models. We have tried to minimize the use of a **central communication services**, as they are an important communication bottleneck of the system operation and a center where the agents' private knowledge may be easily disclosed.

4.1 Contract Net Protocol

The CPlanT implementation relied heavily on the **contract net protocol** (CNP) negotiation techniques. Any agent can initiate the coalition forming process (hereafter we refer to this agent as a service **coordinator**) by requesting all the agents in the community (potential service **collaborators**) for services the requestor may need. Upon receiving proposals for collaboration, the coordinator carries out a computational process by which it selects the best possible collaborator(s). Coalition planning process can also be multi-staged. In this case the coordinator does not like any of received proposal and re-specifies its original request. This approach on its own is resource consuming and will fail in complex communities, where for each single-staged CNP within a community of n agents, we would need to send $2{*}n$ messages.

4.2 Acquaintance Models

The alternative communication strategy is based on exploitation of the agents' social knowledge. First, let us briefly describe the acquaintance model contraction cycle. A coalition coordinator subscribes (by sending a subscribe-type of a message) the potential collaborators for specific services they may want to exploit in the future. Upon a change in the collaborators' capabilities they provide the coordinator with an update in the form of an inform-type of message. When the coordinator triggers the coalition formation phase, it parses the prepared service offers and selects the best collaborator(s) without further negotiation. The coordinator sends a request, the collaborator updates its resources and confirms the contract. The change in collaborator resources is advertised to all the coordinators which subscribed the collaborator.

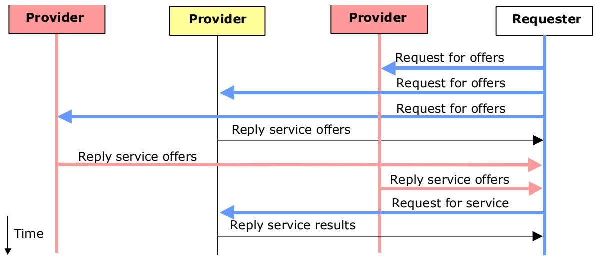

Figure 1 – Contraction based on Contract Net Protocol

If there is a single event in the community Θ that affects all agents (n = $|\Theta|$) and all agents are mutually subscribed, then in the worst case there is ($n(n–1)$) messages required for the social knowledge maintenance on this event. However, this is rarely the case. Agents never subscribe all each other (we could easily use a central communication component instead). Such an event that triggers the social knowledge recomputation is usually a change in agent services that results from committing to another agent.

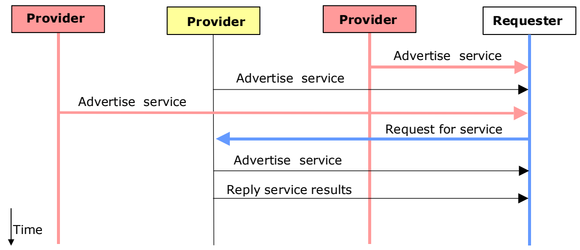

Figure 2 – Contraction based on Acquaintance Model

The agents' **social knowledge** [Mařík, 2001] (that expresses the other agent's behavioral patterns, their capabilities, loads, experiences, resources, commitments, knowledge describing conversations or negotiation scenarios) is usually stored separately from the agents' computational core – in the agent's **acquaintance model**. Based on the tri-base acquaintance model [Pěchouček, 2001a], the social knowledge in CPlanT is organized in four separate knowledge structures:

- **community-base** (Com-BB) – is a collection of the public knowledge of the community members:

  $\text{Com-BB}(A_0)=\{\text{K}_\text{P}(A_i)\}$ for $\forall A_i \in \alpha(A_0)$,

- **self-belief-base** (Self-BB) – where the agent's reflective knowledge about itself is located

  $\text{Self-BB}(A_0)= \{\{\text{K}_\text{P}(A_0)\}, \{\text{K}_\text{S}(A_0)\}, \{\text{K}_\text{Pr}(A_0)\}\}$,

- **social-belief-base private** (Soc-BB) – with the semi-private knowledge of other alliance members,

  $\text{Soc-BB}(A_0)=\{\text{K}_\text{S}(A_i)\}$ for $\forall A_i \in \mu(A_0)$.

- **coalition-base** (Coal-BB) – a dynamic collection of past and possible future coalitions as much as permanent coalition-formation rules.

5 CPlanT Operation Lifecycle

The CPlanT multi-agent system operates in four separate phases: **registration** for agents' login/logout to/from the community, **alliance formation** for forming of alliances, **coalition formation** for finding a group of agents which can fulfil a well specified task and the **team action planning** for resource allocation within the specific coalition. In the following we will comment each of the phases.

As pointed above, we did not adopt one technique. We were trying to find a middle ground among central registration, contract net protocol, and acquaintance model based approach in order to optimise:

- **communication traffic** (and computational resources) requirements in both (i) the coalition formation and team-action planning phases and (ii) periodic communication traffic in the agents' idle times (mainly maintenance of the social models),
- **quality of the formed alliance**, **coalition** and primarily a **team action plan**, and
- the amount of the **private information** that the agents have to disclose when forming a coalition.

5.1 Registration

Throughout the registration phase, a new-coming agent registers within the multi-agent community informing the facilitator (a central registering agent). Subsequently, the facilitator informs all the already existing agents about the new agent, and vice versa. After the registration phase, all the agents will be aware of the other existing agents

Similarly the agents can deregister with facilitator. Any registered agents store the public knowledge about all members of its total neighbourhood $\alpha(A)$ that has been stored in the Com-BB(A) bases.

5.2 Alliance Formation

In this phase, which follows the registration process, the agents analyse the information they have about the members of the multi-agent system and attempt to form alliances. In principle, each agent is expected to compare its own private knowledge with the public knowledge about the possible alliance members. Had the agent detected a possible future collaborator, the agent would propose possible collaboration. Throughout the negotiation process the agent either chooses the best alliance considering mutual collaboration preferences or it may start a new alliance by itself. The alliance formation phase is carried out in parallel with the registration phase.

The **quality of an alliance** is understood in terms of maximizing the number of partners where the semi-private information will be shared and minimizing the amount of information disclosed to hostile agents. This is just opposite from the requirements for the **quality of a coalition** where we seek minimal cost (≈ a number of partners) for implementing a shared goal. It is important to note that this process does not give us any guarantee of optimal alliance allocation.

5.3 Coalition Formation

In this phase, the agents group together not according to a similar mission objective, but they form coalitions with respect to a single, well-specified task that needs to be accomplished. Both the CNP and the acquaintance model techniques are used in the coalition formation process. First let us talk about the coalition formation process within an alliance. Whichever an agent A, member of an alliance, which faces the role of coordinating the goal τ achievement process, parses its social neighbourhood $\mu(A)$ and detects the set of the most suitable collaborators (cooperation neighbourhood) – $\varepsilon(A, \tau)$. Upon the approval from each of the suggested agents, the respective coalition $\chi(\tau) = \varepsilon(A, \tau)$ is formed.

The agent's cooperation neighbourhood for the current, past and potential tasks have been stored in the Coal-BB knowledge structure. Maintaining the agent's social neighbourhood will save an important part of the agents' interaction. Agents will not need to broadcast a call for collaboration each time they will be required to accomplish a task. Instead, they will consult this pre-prepared knowledge and will contract agent of which they knew it is the best to work with.

As said in the previous we disregard forming coalitions across alliances ($\forall$ τ: $\varepsilon(A, \tau) \subseteq \mu(A)$). However sometimes an alliance fails to achieve a goal. Instead of forming a coalition across the alliances we suggest creating clusters of collaborating coalitions, each within one distinct alliance. A coalition leader who failed the coalition forming process may then use the classical CNP and broadcast a proposal for collaboration to agents from its total neighbourhood $\alpha(A_0)$.

5.4 Team Action Planning

Once the coalition is formed, the agents share a joint, high-level commitment to achieve the goal [Tambe, 1997]. Within a coalition, a **team action plan** must be developed. The team action plan (denoted as $\pi(\tau)$), that is a result of the coalition planning activity, is a joint commitment structure that defines how exactly each team member will contribute to achieving the shared goal (amount of resources, time). Let us assume that the coalition leader will also initiate team action planning.

The team action plan is constructed collaboratively. The coalition members advertise their services in the most informative while efficient form. Based on this knowledge that is kept in the acquaintance model of the coalition leader, the leader suggests the most optimal request decomposition and resource allocation. This is sent to the coalition members which reply with a specific collaboration proposal. The coalition leader may find out that the suggested decomposition was not optimal and thus its social knowledge was not accurate enough. As result of such an occurrence, the social knowledge gets updated and the coalition leader sends another proposal. After few negotiation steps the agents are expected to form jointly a team action plan.

6 Experiments

Testing correctness of the CPlanT requires a well-defined, formal, but realistic enough scenario that can represent, model and initiate all aspects of agents' nontrivial behaviour. The above specified principles and ideas has been tested and implemented on a subset of the OOTW types of operations – humanitarian relief operations. For this purpose we have designed and implemented a hypothetical humanitarian scenario in an imaginary country – Sufferterra (inspired by [Rathmell, 1999], [Walker, 1999]). The scenario knowledge has been encoded in XML and the computational model of the scenario has been implemented in Allegro Common Lisp.

The CPlanT system has been successfully tested on the Sufferterra scenario. The system's architecture has been implemented in Allegro Common Lisp and is complemented by a Java based visualizing meta-agent.

Communication traffic has been observed in different architecture arrangements of the community (e.g. different number of alliances have been considered) and for different complexity of the tasks sent to the community (e.g. different number of contracts). Having 20 agents we have experimented with the sample of all the agents being in one alliance, with agents clustered in 2 alliances, 4 , 7 and 20 alliances. From the definition of the lifecycle of the community follows that the latter case ($\forall A$: $\mu(A)=\emptyset$) does not exploit any advantage of the acquaintance model contraction and the community behaves such as no social knowledge is administered and used. As the social knowledge requires lots of maintenance, we have also measured how does the maintenance messages affect the overall efficiency of the system. 19 measurements for each community arrangement have been carried out. The values in the graphs are averages from these measurements.

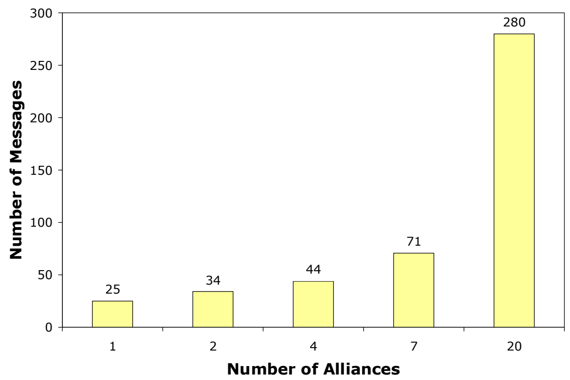

Figure 3 – Communication traffic in the critical time

As already explained, an important part of the communication traffic is carried out in the critical time – i.e. in the moment when the system is requested to provide a plan. By exploiting the social knowledge, we aimed at minimizing the communication traffic.

Figure 3 depicts dependency between the structure of the community (number of alliances) and communication traffic in the critical time. The cost we have paid for this was the increased communication traffic in the idle times of the community when the agents work on maintaining their social knowledge. This is depicted in Figure 4. In Figure 5, there is the total communication traffic in the community presented.

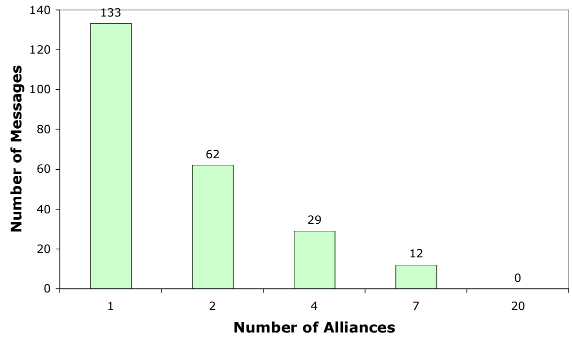

Figure 4 – Acquaintance model maintenance

The experiments confirmed that with increasing numbers of alliances $|\{\kappa_i\}|$ the amount of the saved communication traffic reduces. A community with a single alliance ($|\{\kappa_i\}| = 1$) results in all agents having a social model one about the other ($\forall A_i$: $\mu(A_i) \cup A_i = \kappa_0$). This brings maximal communication savings as all the coalition formation process is carried out within one alliance κ_0 where no CNP is required. On the other hand if each agent constitutes an alliance of its own ($|\{\kappa_i\}| = |\Theta|$) and agents do not store any social knowledge ($\forall A_i$: $\mu(A_i) = \{\}$), no communication traffic is saved as the agents communicate exclusively through the CNP protocol.

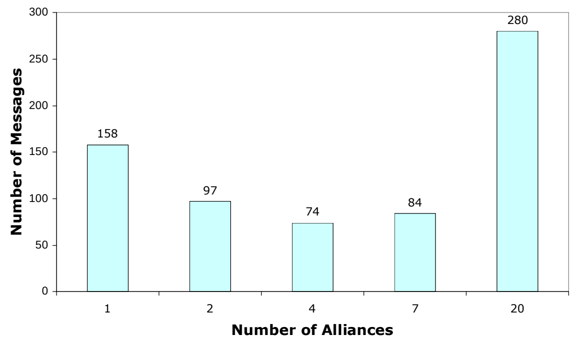

Figure 5 – Entire communication traffic

An interesting fact is that neither of the two extreme cases (a single alliance, no alliance) is the best one for concealing the agents' private and semi-private knowledge. With one alliance, the semi-private knowledge becomes public while with no alliance the information about the contractor intentions will be revealed. It is rather difficult to find a good compromise. What matters, is the probability that a request will not be fulfilled within one alliance and the coalition leader will have to subcontract other agents. Amount and structures of alliances in our domain emerges naturally according to agents' private knowledge and other collaboration restriction. Therefore it makes no sense to suggest an optimal number of alliances for a given community. As mentioned earlier, the agents did not group into alliances in the most optimal way. With a different order of registration, various alliances may be closed. Apart from the range of services an alliance can provide, the amount of the disclosed private and semi-private knowledge is used for assessing appropriateness of the alliance allocation.

7 Conclusion

The research described in this article contributes by an suggesting alternative, a knowledge based approach to the coalition formation problem. Our research has been driven by the very specific domain OOTW.

Apart from the classical contract net protocol techniques we have used communication strategy based on combination of three techniques: the centralized registration, the acquaintance models and the contract net protocol negotiations.

The agents in the community are organized into smaller, disjunctive groups called alliances. Each agent in the alliance is able to start the negotiation process to form a coalition and a team action plan for a specific task either within the alliance or in collaboration with other alliances. Inside-alliance negotiations explore mainly the social knowledge stored in the acquaintance models but the CNP technique is used as well. The inter-alliance negotiations are based just on the CNP principles (to reduce the leakage of the private information as much as possible).

The general complexity of negotiations when forming a coalition in a MAS is of an exponentially explosive nature [Ketchpel 1993, Sandholm, 1995, Shehory, 1998]. It has been shown that finding and optimal coalition is an NP complete problem when no specific constraints are put on the process. In our case, the negotiation complexity of the coalition formation problem has been reduced because:

a) agents are organized into several disjunctive sets (alliances)
b) the most of coalitions are created just inside an alliance (reduced space of negotiations)
c) the coalition leaders within the alliance is set randomly (each coalition member has got the same coordination capacity and can manage the negotiation process), they don't compete for the role.
d) within an alliance, the negotiation process strongly explores the acquaintance models (social knowledge) in combination with CNP technique
e) the pure CNP negotiations are used just in the case of the inter-alliance negotiations.

While the contract net protocol runs rather inefficiently, it keeps the agents from different alliances independent (they do not have to disclose their semi-private knowledge across alliances). This is why, the acquaintance-model based planning has been used exclusively within the alliances.

In our approach we left the requirement of the total coalition optimality. This is not the main issue in the OOTW systems. The main issue is to develop an acceptable plan without forcing the units (agents) to publish their private knowledge (namely intents and resources). This quite specific OOTW requirement enabled to reduce the complexity of the negotiation problem significantly. It has been measured that optimality of the coalition value slightly increases with the number of alliances (the role of the acquaintance model is getting smaller), while the problem complexity with a smaller number of socially knowledgeable alliances is significantly reduced.

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8 References

[Ketchpel 1993] Ketchpel, S.: Coalition Formation Among Autonomous Agents, Proc. 5th Europ. Workshop on Modeling Autonomous Agents in a Multi-Agent World, Switzerland, 1993

[Mařík, 2001] Vladimír Mařík, Michal Pěchouček, and Olga Štěpánková. Social Knowledge in Multi-Agent Systems. In Multi-Agent Systems and Applications, *LNAI 2086*, Springer, 2001.

[Pěchouček, 2001a] Michal Pěchouček, Vladimír Mařík, and Olga Štěpánková. Towards Reducing Communication Traffic In Multi-Agent Systems. *Journal of Applied System Studies*, Cambridge Int. Science Publishing, UK, Spring, 2001.

[Pěchouček, 2001b] Michal Pěchouček, Vladimír Mařík, Jaroslav Bárta. CPlanT: An Acquaintance Model Based Coalition Formation Multi-Agent-System. In: *Proceedings of CEEMAS'2001*. Krakow : 2001, p. 209-216.

[Pěchouček, 2001c] Michal Pěchouček, Vladimír Mařík, Jaroslav Bárta. Acquaintance Models in Coalition Planning for Humanitarian Relief Operation. In: *Intelligent Agent Technology. Singapore: World Scientific*, 2001, vol. 1, p. 434-443.

[Rathmell, 1999] R. A. Rathmell. A Coalition Force Scenario 'Binni – Gateway to the Golden Bowl of Africa', Def. Eval. Res. Agency, 1999.

[Sandholm, 1995] Sandholm T.W. and Lesser V.R.: Coalition Formation among Bounded Rational Agents, IJCAI-95, pp. 662-669, Montreal, 1995

[Shehory, 1998] Shehory O. and Kraus S., Methods for Task Allocation via Agent Coalition Formation, AI, vol. 101 (1-2), pp. 165-200, 1998

[Tambe, 1997] Tambe M.: Towards flexible teamwork. J. of AI Research, 7:83 – 124, 1997.

[Walker, 1999] Walker, E. C. T., Panel Report: Coalition Planning for Operations Other Than War, Workshop at AIAI, Edinburgh, 1999.