Competitive Contract Net Protocol*

Jiří Vokřínek, Jiří Bíba, Jiří Hodík, Jaromír Vybíhal, and Michal Pěchouček

Department of Cybernetics, Faculty of Electrical Engineering
Czech Technical University in Prague
Technická 2, 166 27 Prague, Czech Republic
{vokrinek|biba|hodik|vybihj1|pechouc}@labe.felk.cvut.cz

Abstract. The proposed Competitive Contract Net Protocol has been designed to facilitate a flexible cooperation in competitive multi-agent environments and to support automated or semi-automated negotiations in competitive domains. The protocol is based on FIPA standards. The protocol covers not only the phase of contracting the commitments, but also allows for a decommitment negotiation and contract termination. Thus, it consists of three phases: (i) a contracting phase, where conditions of agreement are concluded, (ii) an optional decommitment phase, where contract may be breached, and (iii) a contract termination phase, where the compliance with the concluded contract conditions is evaluated. Both the decommitment and non-compliance are bounded with penalties which measurably ensure a compliance with the commitments, but also allow an opportunistic behaviour of the agents at some price.

1 Introduction

Various negotiation mechanisms are used in order to achieve an agreement among the agents concerning a mutually advantageous cooperation. The *1:m* (one to many in parallel) negotiations are often carried out as auctions which are implemented by means of negotiation protocols. They may be iterative (like *English auction* and *Dutch auction*) or one-shot (*First-price-sealed-bid auction* and *Vickrey auction*). An another (and one of the most popular) *1:m* negotiation protocol is Contract Net Protocol [1]. All the above mentioned protocols have been standardized e.g. by the *Foundations of Intelligent Physical Agents* (FIPA) [2]. A cooperation among agents has been formalized by means of social commitments by Wooldridge and Jennings in 1999 [3]. The agents commit themselves to carry out actions which lead onwards to achievement of their joint goal. The time period in which the commitments are met may be substantially longer than the time period in which the commitments are negotiated and concluded. Then the attitudes of the involved agents towards the commitments – especially among rational self-interested agents – are likely to evolve in time on account of events occurring in parallel.

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The above-mentioned negotiation protocols provide for the phase of negotiating the commitments while they do not cover the phase of executing the commitments enough. It is rather disregarded or simplified to a mere report of results. However, the conclusion of the commitments is rather a beginning of the following mutual cooperation. Therefore, a negotiation protocol should allow not only for conclusion of commitments, but also for a possible evolution of the agents' attitudes, eventual decommitments as well as for a non-compliance with the agreed conditions (e.g. quality of service) at the termination of the cooperation. This specially applies to applications of the agent paradigm as a negotiation means in real-world businesses (e.g. supply/value chains cooperation support), because the dependencies among the involved parties are usually non-trivial and the decommitments or non-compliance with commitments may result in unexpected damages for the involved parties[1].

We propose an iterative negotiation protocol that has been designed to provide means for a flexible and robust contracting in competitive environments. Our protocol is inspired by Contract Net Protocol, but it supports both the contract conclusion as well as contract dissolution negotiations.

2 Cooperative and Competitive Environments

A cooperation between agents is defined as a provider-customer relationship with defined conditions – i.e. the provided service (of proper quality), the price, the due-date, penalties, etc. An established cooperation is confirmed by a contract concluded by both the sides. The utility gained by each the participant in the contract is given by the conditions of the cooperation and each participant's current state.

Let us introduce a difference between a collaborative and a competitive multi-agent environment [4]. By a *collaborative multi-agent environment* we understand an agent community, where the agents usually share a common goal which they try to achieve cooperatively. In other cases the agents may have different goals, but their primary motivation is a maximization of their social welfare - the total sum of all the individual utilities (profits) of the collaborative agents. On the contrary, by a *competitive multi-agent environment* we understand an agent community, where the primary motivation of the agents is a maximization of their individual utilities; no matter what the social welfare of the community is (agents are so called self-interested). The agents establish a cooperation on the process of achieving a common goal only if it contributes to maximization of their individual utilities. The willingness of the agents to keep the agreed contracts also differs in both cases [5].

In a collaborative environment, the agents keep the contract as long as the social welfare is maximized. When the social welfare goes down or a better collaboration opportunity arrives, the agents either freely withdraw from the

[1] Therefore, contracted conditions (including possible penalties) have to be set properly in order to avoid constant decommitments as well as non-flexible (unbreachable) commitments.

contracts or are willing to reconfigure the contract. A collaborative behavior of all agents ensures maximal social welfare after decommitment/reconfiguration. No penalty is charged in this case because both provider and customer agree with the decommitment or reconfiguration. On the other hand, in a competitive environment, the contract is secured by penalties to be paid by the agents in case of decommitments or an other breach of the contract. The contract is kept as long as the individual utilities of all parties are maximized. A feasibility of an eventual reconfiguration is then substantially conditioned by the utilities as well.

3 Interaction Protocols for Competitive Environments

The multi-agent systems supporting e-business (by the means of enabling automated or semi-automated cooperation and coordination of independent individuals) operate in rather competitive environments. A utility function of the each agent can differ and the goals do not need to be compatible. A negotiation protocol used should cover all the aspects of competitive domain, such as penalty and decommitment negotiation.

Contract Net Protocol [1] is one of the most popular interaction protocols used. In the agent domain the CNP has been standardized by FIPA [2]. However, this interaction protocol (and most of the related ones that are commonly used, some of them also implemented by FIPA), was developed rather for collaborative environments [6]. A decommitment was possible only from the contractor's party and did not take into account the effort that the contractees they might have already spent for fulfilling the contract. In fact, a payment of any compensations was not relevant, because the decommitment was considered as mutually advantageous (due to the common primary motivation of maximization the social welfare) and the contractees did not mind the loss of their effort or even a loss of their individual utilities. On the other hand, in the interaction protocols developed for competitive environments no party could back from the contract once committed, no matter how future events unravelled [7].

Particularly in competitive environments the negotiation of the commitments is an important, however, not the only phase of a common cooperation. The phase of execution of the commitments is important as well. Sandholm and Lesser introduced a concept of *levelled commitment contracts* [7]. The levelled commitments allow for eventual evolution of attitudes of the participants towards the contract and a possible decommitment. There followed several works aiming at a flexible negotiation and competitive contracting by means of a protocol implementation, e.g. [8,9]. An interesting approach (with respect to the levelled commitments) was presented by Bergenti *et al.* in [10]. The provided general interaction protocol is symmetric and principally does not distinguish whether the negotiation is started by a consumer or a provider of the negotiated services or goods. The party starting the negotiation is denoted *initiator* and the other party is denoted *responder*. The protocol allows the agents to propose and to counter-propose till the agents reach an agreement or any of them decides to

withdraw from the negotiation. If an agreement is reached, any of the parties may decommit and the contract becomes void. If the contract is successfully finished, the responder informs the initiator about it.

Although the protocol by Bergenti *et al.* allows for decommitments, it does not provide means for a negotiation of the decommitment or contract-termination conditions. The penalties for an eventual decommitment from the contract or the penalty for a non-compliance with the commitments at the contract termination may be set during the commitments negotiation phase [10]. However, it is not always feasible and advantageous to agree the conditions in advance. Moreover, an attempt at a decommitment may finish by backing off by the decommitting party as the decommitment may finally appear disadvantageous. It closely relates to the strategies used for setting of the penalties. The penalties are usually set in accordance to chosen punishment philosophy in order to cover appropriate remedies – e.g. expectation damages, reliance damages, opportunity cost or party-designed remedies [11]. A negotiation protocol should generally allow for such opportunistic behaviour as well.

4 Competitive Contract Net Protocol

In this chapter we propose *Competitive Contract Net Protocol* (C-CNP). It is an interaction protocol providing means for both the contract conclusion and contract dissolution negotiations which are rather comparably important in competitive multi-agent environments. The further significant difference to common CNP implementations consists in the approach to *1:m* negotiations which are held in a pairwise manner. We use FIPA-like performatives and define several new performatives where necessary. The semantics of the performatives slightly differs in comparison to FIPA specification as the protocol is designed for competitive agent environments (see section 5).The protocol is composed of three phases: *contracting*, *optional decommitment* and *termination* (see Figure 1).

The process of payments either for the successfully implemented contract (contract price) or for decommitment or for agreement non-compliance (penalties) is not considered within the negotiation protocol as it is out of scope of this protocol itself. Moreover, in a real world the payments are carried out by means of interactions with third parties (i.e. banks) that are not bound with the particular contract anyhow (i.e. do not take any role in the contract except facilitating the financial issues) and eventual reluctance to fulfilling the financial obligations or other disputations are resolved per curiam.

4.1 Contracting Phase

The first phase of the protocol - contract conclusion bargaining - is started by sending Cfp messages (Call-for-Proposals). It resembles the FIPA Iterated CNP (see Figure 2), though, as the negotiations are pairwise, the initiator does not need to wait until all the (potential) contractees reply with their proposals or refusals, but may handle the interactions independently (e.g. the initiator

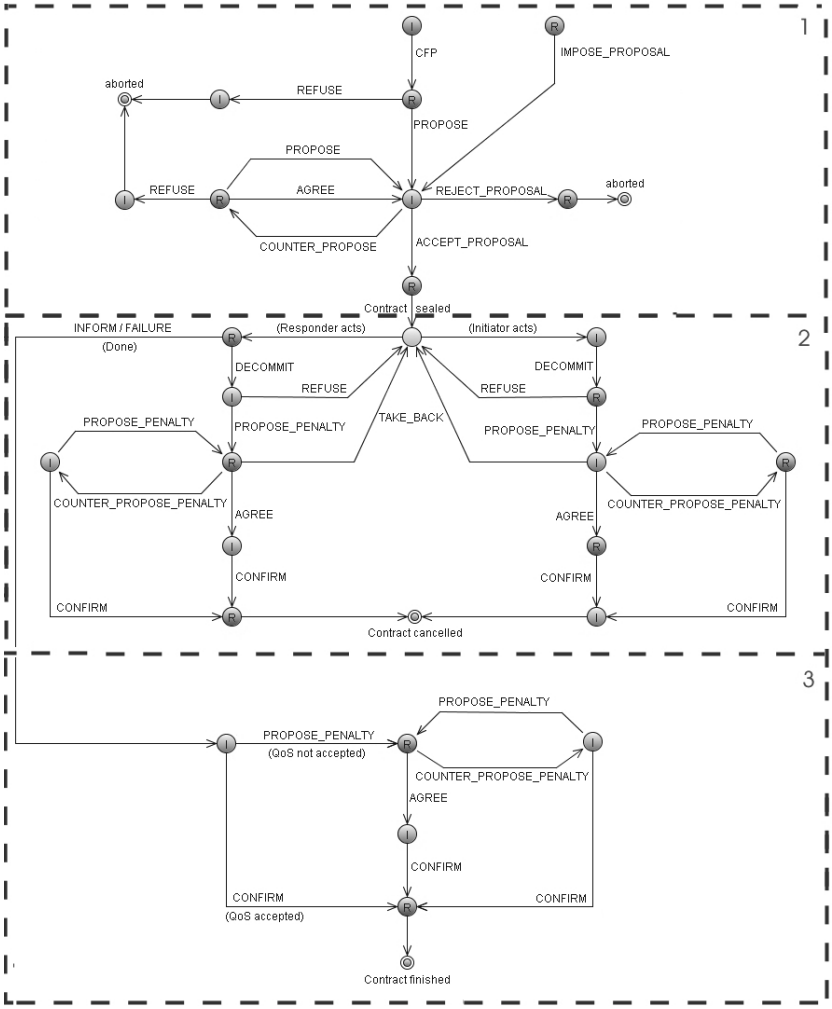

Fig. 1. Hybrid state/sequence diagram of the Competitive Contract Net Protocol. 1 = contracting phase, 2 = decommitment phase and 3 = contract termination phase of the protocol.

may be still waiting for a reply to a Cfp message in a conversation with a particular contractee while in the conversations with another contractees it may already bargain in the Propose/Counter-Propose round). Of course, not only the knowledge resulting from a particular conversation, but all the knowledge gathered from all the contractees may be used for decision making in that conversation. However, the manner of use of the available knowledge is rather a separate issue and does not relate to the protocol itself. All the contractees involved in the negotiation also does not need to be addressed by the initiator at the beginning by means of a Cfp message. The protocol allows a contractee to

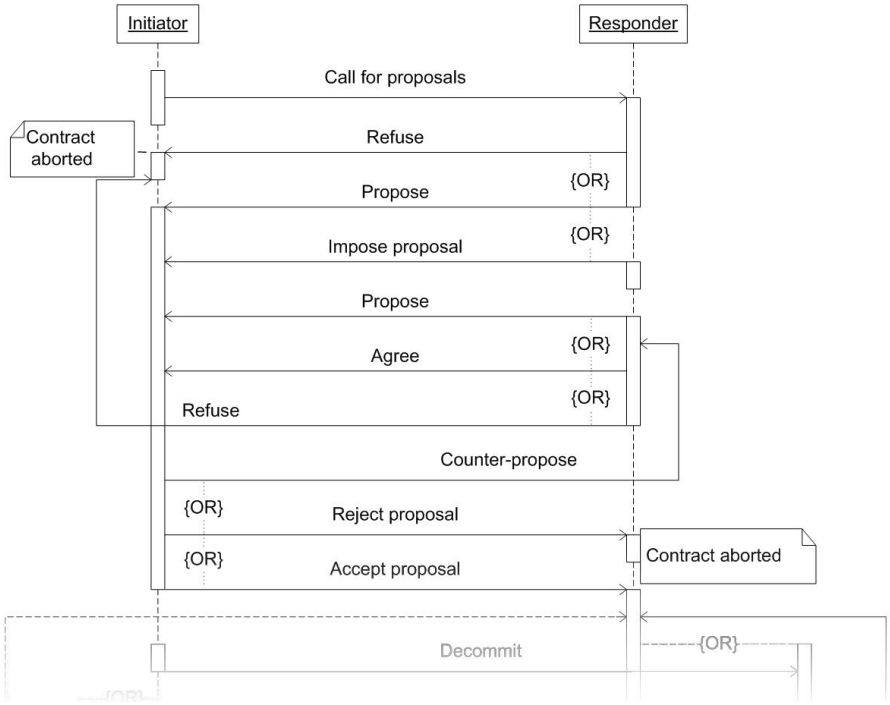

Fig. 2. Sequence diagram of the contacting phase of the C-CNP (next phases continue on Figure 3)

send an Impose-Proposal message. The message contains a proposal based on information about the particular negotiation that the contractee obtained from a third party. Both the sides may back out of the negotiation by means of sending Refuse (contractee) or Reject-Proposal (contractor) messages. As soon as all the contractees which remained in the negotiation are sent Reject/Accept-Proposal messages by the initiator, the contract is concluded.

4.2 Optional Decommitment Phase

The second phase of the protocol - contract dissolution - allows for an optional sequential decommitment (see Leveled Commitment Contracts [7]) by any of the parties of the pair-wise contract (the contractor or contractee) besides a regular contract dissolution (see Figure 3). Both the decommitments and regular dissolution reflect competitive-contract setting, i.e. not only the price and services/goods together with a required quality of service are the subject of negotiation, but also the penalties for breaching the contract or non-compliance with the agreed quality of service. Thus both this dissolutions ways allow for bargaining about penalties based on the reached progress of the contract. Once the contract is concluded, both the parties may send a Decommit message. The

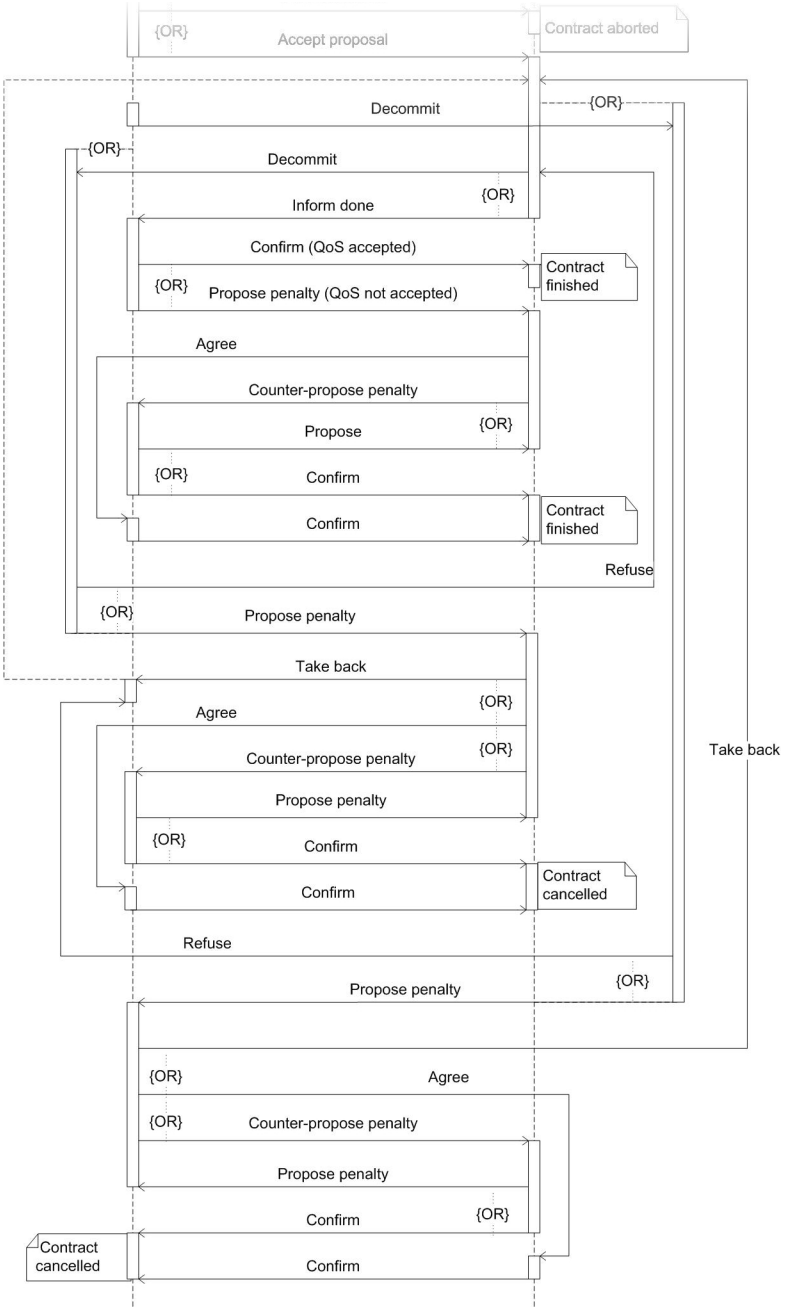

Fig. 3. Sequence diagram of the decommitment a termination phase of the C-CNP (continued from Figure 2)

other party has an option to refuse it immediately by means of a REFUSE message or to encounter penalty bargaining process by means of sending PROPOSE-PENALTY/COUNTER-PROPOSE-PENALTY messages. The party considering a decommitment may back out of its attempt by means of sending a TAKE-BACK message. In both cases of sending TAKE-BACK or REFUSE messages in this stage of the negotiation the decommitment is aborted and the contract is considered to continue normally. As soon as the decommitting party is satisfied with the proposed penalty it sends AGREE message and then obtains a CONFIRM message confirming the contract dissolution. If the decommitting party submits a COUNTER-PROPOSE-PENALTY message and the bid is acceptable for the other party, the contract is dissolved by means of sending a CONFIRM message to the decommitting party.

4.3 Contract Termination Phase

If the decommitment does no occur, the contract may be dissolved in a regular way by the contractee by sending INFORM or FAILURE message (see Figure 3). While the FAILURE performative should be used in case of a total failure in implementation of the contract, the INFORM message is intended to be sent in case of implementation of the contract in some way. Based on the result reported in the INFORM message the contractor evaluates whether the implementation complies with the agreement and either confirms the dissolution of the contract immediately by means of sending CONFIRM message or starts bargaining about penalty for non-compliance with the agreement. The rest of the negotiation about the penalty proceeds in the same way as in the case of decommitment except the option of sending the TAKE-BACK/REFUSE messages as it does not make sense in this stage of negotiation.

5 Semantics of Performatives Used in C-CNP

The semantics of communicative acts used in C-CNP slightly differs from the FIPA semantics specification as the C-CNP has been designed for contracting in competitive environments (the FIPA CNP assumes rather collaborative environments [6]). Besides introducing new performatives we also re-define the communicative acts known from the FIPA specification. The semantics is described below:

Cfp – an action of calling for proposals used for starting a negotiation on account of joint implementing a given contract. A typical message content is introduced by an n-tuple describing contract conditions - e.g. the tasks to be carried out together with required abilities/competencies, task precedences/dependences, contract deadline, penalties, eventually further contract-related information.

Refuse – a general action of refusing a proposal, a request or an action proposed by the other party. A typical message content consists in a subject of refusal

(eventually together with a reason for the refusal) which may be an n-tuple describing the proposal/request/action or an attribute of the n-tuple causing the refusal.

Propose – an action of proposing a participation on a given contract. A typical message is introduced by an n-tuple with fully evaluated attributes describing the contract conditions (see CFP).

Counter-Propose – an action of counter-proposing the other-party participation on a given contract. A typical message is introduced by an n-tuple with fully evaluated attributes describing the contract conditions (see PROPOSE).

Agree – a general action of agreeing with a proposal, a request or an action proposed by the other party. A typical message content may be introduced by an n-tuple with fully evaluated attributes describing the contract conditions (see PROPOSE). Performative AGREE states clearly and emphasizes that the other-party proposal/request/action is fully agreed without any modifications.

Impose-Proposal – an action of imposing a participation proposal on a given contract based on information obtained from a third party. A typical message content consists in an n-tuple with fully evaluated attributes describing the contract conditions (see PROPOSE).

Reject-Proposal – an action of rejecting a participation proposal. A typical message content may be empty or it may consists in the subject of rejection (eventually together with a reason for the rejection). It finishes the negotiation about the given contract with the particular agent.

Accept-Proposal – an action of accepting a participation proposal. A typical message content is introduced by an n-tuple with fully evaluated attributes describing the contract conditions (see PROPOSE). It grants the cooperation between two parties which is defined by contract conditions negotiated formerly and practically establishes the cooperation (both the parties are expected to start fulfilling of their obligations according to contract conditions).

Decommit – an attempt at a decommitment from a running cooperation (i.e. after a conclusion of contract conditions and establishing the cooperation - see ACCEPT-PROPOSAL). A typical message content consists in the subject of decommitment (eventually together with a reason for the decommitment) which may be an n-tuple describing the contract conditions or an attribute of the n-tuple causing the decommitment. It starts an optional decommitment phase which may finish either by granting the decommitment or by resuming the usual continuation of the contract according to formerly agreed conditions. The optional decommitment phase may be encountered several times in one running cooperation (provided the eventual former decommitment phases have been aborted by REFUSE or TAKE-BACK).

Propose-Penalty –an action of proposing a penalty either in case of a decommitment or eventually at a regular contract termination. A typical message content is introduced by an n-tuple of pairs bounding particular attributes of the contract conditions with penalties (eventually together with an aggregated

penalty). It proposes conditions of breaking a mutual cooperation in any case of the other-party violating its commitments.

Take-Back – an action of backing out from an attempt at a decommitment. A typical message content may be empty or may contain a reason for backing out from the decommitment attempt. It resumes an usual continuation of the contract.

Counter-Propose-Penalty – an action of counter-proposing a penalty either in case of a decommitment or eventually at a regular contract termination. A typical message content is introduced by an n-tuple of pairs bounding particular attributes of the contract conditions with penalties (eventually together with an aggregated penalty).

Confirm – a general action of confirming a decision, proposal or an action submitted by the other party. A typical message consists in a subject of confirmation which may be an n-tuple describing the decision/proposal/action submitted by the other party. Performative CONFIRM states clearly and emphasizes that the other-party decision/proposal/action is acknowledged without any modifications.

Inform – a general action of informing about results or announcing another kind of information. A typical message content is introduced by the subject of information (e.g. an n-tuple of pairs bounding particular attributes of the contract conditions with results of their implementation).

Failure – a general action of informing about a failure in fulfilling of formerly-agreed obligations (e.g. due to violating a deadline). A typical message consists in the subject of failure (e.g. an n-tuple of particular attributes of contract conditions which were failed to be brought to a good end).

6 Implementation

The protocol has been implemented[2] in the JADE[3] agent platform [12] that is one of the fully FIPA-compliant agent platforms. The implementation employs JADE class implementing final state automaton (FSMBehaviour) and redefines ACLMessage in order to add needed performatives that are not defined in the FIPA standard. The newly defined performatives are: IMPOSE-PROPOSAL, COUNTER-PROPOSE, DECOMMIT, TAKE-BACK, PROPOSE-PENALTY, and COUNTER-PROPOSE-PENALTY. An example of an ACL message initiating a decommitment is on Figure 4.

The protocol implementation allows parallel run of multiple C-CNP in one time and supports determinable multilevel execution (agent acting as participant in one C-CNP can naturally starts new C-CNP to cover requested service when it is not able to provide it as whole).

The implementation also provides for using a timer for timeouts control. It uses standard JADE protocol timing mechanism (machine time based timing), but also supports plugging external timers. The implementation uses the machine

[2] See protocol home page: `http://agents.felk.cvut.cz/c-cnp`.

[3] JADE version 3.3 – `http://jade.tilab.it`

```
(decommit
   :sender partner5@mas13:1099/JADE
   :receiver partner2@mas13:1099/JADE
   :language XML
   :ontology decommit-task-ontology
   :protocol c-cnp
   :content
      (<?xml version="1.0" encoding="UTF-8"?>
         <decommit-task>
           <task-id>Z_211-0242</task-id>
           <date>20060808T120000000</date>
           <progress>0</progress>
         </decommit-task>
      )
)
```

Fig. 4. Example of an ACL message with the DECOMMIT communicative act

time in default, however, there has been implemented also an alternative timer using external time synchronization which is ensured by means of a simulation clock independent of the machine time. Though, any other timing method may be used (an implementation of another timer have to implement a defined timer interface).

We also assume a full accessibility (i.e. messages are never lost - in practical implementations are resolved by means of timeouts) and compliance with the protocol during the negotiation, because the issues of a communication by means of an unreliable link cannot be practically fixed (The Byzantine Generals' problem / Two Generals' Problem) [13,14].

7 C-CNP Deployment and Future Work

The negotiation protocol – *Competitive Contract Net Protocol* – presented in this paper has been designed to facilitate a flexible cooperation in competitive domains with respect to expectations on multi-agent systems operating in such real-life environments.

An early prototype of the protocol has been adopted by ExtraPlanT [15] multi-agent system for production planning. This system operates on two levels: (i) intra-enterprise level represented by a set of *planning* and *resource agents* and (ii) extra-enterprise level represented by *enterprise-to-enterprise* (E2E) *agents* which allow free capacity sharing among independent enterprises. The standard FIPA CNP has been used for intra-enterprise planning where all the agents maximize overall optimality criterion. On this level the contracts are not breached, but may be modified by means of a reconfiguration – no penalty is charged and no negotiation about decommitment is needed. On the contrary, on the extra-enterprise level both the optional decommitment and contract termination negotiations are to be taken into account. Each E2E agent represents one

independent enterprise with it's own goals and other business opportunities. Here C-CNP improves collaboration and cooperation possibilities of the system.

Extra-enterprise part of the ExtraPlanT is being adapted to support a cooperation in ERP value chains (part of FP6 specific targeted research on innovation project PANDA)[4]. A distributed intelligent agent system employs E2E agents for (i) a potential collaborators search, (ii) a contract negotiation among several partners, (iii) a cooperation monitoring, and (iv) replanning and reconfiguration. The E2E agents represent individual ERP vendors or dealers and support a full human control of all the information provided by agents to the system. Contract details and potential penalties are described by *service level agreement* (SLA) [16]. The C-CNP supports a semi-automated negotiation of the SLA and its monitoring.

An another real-use system, that the C-CNP is intended to be deployed into, is a distributed decision making support system [17] for formations and adaptations of virtual organizations within clusters of mutually independent enterprises and institutions.(part of FP6 integrated project ECOLEAD)[5].Although cooperating in a cluster, its members are self-interested. Thus, they may have an intention of leaving an already concluded virtual organization due to more profitable businesses. An another reason for a revision of an already concluded contract is an incapability of a virtual organization to respond to new circumstances that had not been known during the contract conclusion. In order to respect such features of a cooperation in virtual organizations a possibility of both the contract adaptation and dissolution must be taken into account.

In our future research we would like to focus on the process of setting the contract conditions. Both the contract prices and penalties affect substantially the flexibility of the cooperation in competitive environments and their proper setting is a crucial issue in competitive contracting [5]. The C-CNP protocol will be used in an implementation of contracting in an experimental competitive scenario and will facilitate our further research in decommitments and reconfigurations in competitive domains.

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[4] See project home page: `http://www.panda-project.com.`
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