An Intelligent Agent Negotiation Strategy in the Electronic Marketplace Environment

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Abstract: E-commerce will strongly penetrate the market if coupled with appropriate technologies and mechanisms. Mobile agents may enhance the intelligence and improve the efficiency of systems in the e-marketplace. We propose a dynamic multilateral negotiation model and construct an efficient negotiation strategy based on a ranking mechanism that does not require a complicated rationale on behalf of the buyer agents. This strategy can be used to extend the functionality of autonomous intelligent agents, so that they quickly reach to an agreement aiming to maximise their owner's utility. The framework proposed considers both contract and decision issues, is based on real market conditions, and has been empirically evaluated. Moreover, it is shown that in a linear framework like the one we employ more elaborate ranking mechanisms do not necessarily improve efficiency.

Keywords: Intelligent Agents, Negotiation Protocol & Model, Strategy, Ranking Mechanism

1. INTRODUCTION

The ongoing liberalisation and deregulation of the telecommunication market will introduce new actors (Zuidweg et al., 1999). In principle, the main role of all players in such a competitive environment will be to constantly monitor the user demand, and in response to create, promote and provide the desired services and service features. The following are some key factors for success. First, the efficiency with which services will be developed. Second, the quality level, in relation with the corresponding cost, of new services. Third, the efficiency with which the services will be operated (controlled, maintained, administered, etc.).

The challenges outlined above have brought to the foreground several new important research areas. Some of them are the definition of new business models, the elaboration on e-business concepts (Ghosh, 1998; Field and Waidner, 2000), the specification of service architectures (SAs) & service creation environments (SCEs) (Tag, 1996) and the exploitation of advanced software technologies, (e.g., distributed object computing[1] and intelligent mobile agents (Glitho, 1998)). The aim of this paper is, in accordance with efficient service operation objectives, to propose enhancements to the sophistication of the negotiation functionality that can be offered by e-commerce systems in open competitive communications environments. This study is based upon the notion of interacting intelligent agents which participate in trading activities on behalf of their owners, while exhibiting properties such as autonomy, reactivation, and pro-activation, in order to achieve particular objectives and accomplish their goals.

Mobile intelligent agents can act as mediators in five of the six e-commerce phases (He et al., 2003): *need identification*, *product brokering*, *buyer coalition formation*, *merchant brokering* and *negotiation*. After a user's need has been identified (*need identification*), the agent acting on behalf of the user is involved in determining what product to buy to satisfy the specific need (*product brokering*) and finding an appropriate merchant to purchase the good from (*merchant brokering*), either alone or forming a group with other similar buyers (*buyer coalition formation*), thus exploiting potential economies of scale. The next step is to negotiate the terms and conditions (e.g., delivery time, gift services, warranty, quality of service, performance) under which the desired product will be delivered (*negotiation phase*). However, it is often the case that the most appropriate merchant is identified after the agent has negotiated with all candidate merchants (Louta et al., 2002). Negotiation may be defined as "*the process by which a joint decision is made by two or more parties. The parties first verbalise contradictory demands and then move towards agreement by a process of concession or search for new alternatives*" (Pruitt, 1981). In human negotiations, the parties bargain to determine the price or other transaction terms. In automated negotiations, software agents engage in broadly similar processes. In more detail, the agents prepare bids for and evaluate offers on behalf of the parties they represent aiming to obtain the maximum benefit for their owners, following specific negotiation strategies.

Automated negotiation is a very broad and encompassing field. For this reason, it is important to understand the dimensions and range of options that are available. When

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building autonomous agents capable of sophisticated and flexible negotiation, three broad areas need to be considered (Faratin et al., 1998): (i) what negotiation protocol and model will be adopted, (ii) what are the issues over which negotiation will take place, and (iii) what negotiation strategies will the agents employ. The negotiation protocol defines the "rules of encounter" between the agents (Rosenschein and Zlotkin, 1994). Then, depending on the goals set for the agents and the negotiation protocol, the negotiation strategies are determined (Roussaki and Louta, 2003). Given the wide variety of possibilities, there is no universally best approach or technique for automated negotiations (Jennings et al., 2001), rather protocols, models and strategies need to be set according to the prevailing situation.

This paper concentrates predominantly on the first issue, proposing a negotiation protocol to be employed in an automatic multi-lateral multi-issue negotiation model and on the third point providing an efficient negotiation strategy for the electronic *Business-to-Consumer* (B2C) marketplace. In this framework, the roles of the negotiation agents may be classified into two main categories that, in principle, are in conflict. Thus, the negotiating agents may be divided into two subsets: $\{Agents\} = \{SellerAgents\} \cup \{BuyerAgents\}$. The *Buyer Agents* (*BAs*) and the *Seller Agents* (*SAs*) are considered to be self-interested, aiming to maximise their owners' profit.

The purpose of this paper is twofold. First, to exploit a multi-round negotiation mechanism, which demonstrates inherent computational and communication advantages over single step mechanisms in such complex frameworks (Conitzer and Sandholm, 2003). In essence, the agents hold private information, which may be revealed incrementally, only on an as-needed basis. This is often the case when the disclosure of information is not acceptable, possible, or desired by the parties involved in the transaction (e.g., the Buyer is not willing to reveal the maximum price to pay for a specific service to a Seller in fear of first-degree price discrimination with the Seller (unfairly) capturing the whole surplus in the market). The negotiation environment considered covers multi-issue contracts and multi-party situations, while being a highly dynamic one, in the sense that its variables, attributes and objectives may change over time. Second, to provide an efficient negotiation strategy, for the case where the negotiators face strict deadlines, which is in most cases private information (Vulkan, 1999), and assist agents to reach to a satisfactory agreement within the specified time-limits.

The rest of the paper is structured as follows. In *Section 2*, the negotiation protocol and model adopted are presented. A simple contract ranking mechanism is employed instead of the usual alternating sequential offers pattern, while the concept of decision issues is

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[1] http://www.orbix.com

introduced. *Section 3* presents the designed negotiation strategy, which demonstrates exceptional efficiency in cases where the Buyer is not able to provide all his/her requirements in a completely quantified way, while being capable of selecting the contract that best satisfies his/her needs. In *Section 4*, a set of results demonstrating the efficiency of the proposed framework is provided, while a comparison with other frameworks is given. Finally, in *Section 5*, conclusions are drawn and directions for future plans are presented.

2. NEGOTIATION PROTOCOL & MODEL

In order to create a successful negotiation framework, the design of an appropriate protocol that will govern the interactions between the negotiation participants is necessary. Depending on the specific negotiation problem that needs to be solved, a protocol is the set of rules that correspondingly constrain the proposals that the negotiation parties are able to make. In this section, after briefly reviewing existing negotiation protocols, we discuss on a protocol based on a ranking mechanism on the Buyer's side, which is adopted in the context of this study.

Subsequently, an efficient dynamic negotiation model is presented, based on the multi-issue value scoring system introduced by Raiffa (Raiffa, 1982), in the context of bilateral negotiations. Our aim is to extend this framework into a multi-party, multi-issue, dynamic model. Based on the designed negotiation protocol, the proposed model is exploited by the Seller to create subsequent contracts, and by the Buyer to evaluate the contracts offered. In *subsection 2.1*, an overview of the related research work is provided, while in *subsection 2.2* the designed negotiation protocol and model are presented.

2.1 Related work

Mechanism design involves the design of protocols for governing multi-agent interactions, such that these protocols have certain desirable properties (Rosenschein and Zlotkin, 1994; Sandholm, 1999): computational efficiency, communication efficiency, individual rationality, distribution of computation, maximization of social welfare. It is difficult to design a negotiation protocol that clearly demonstrates all the qualities aforementioned. Nevertheless, these properties can be used as a reference point of what an ideal protocol should offer to the negotiation parties.

In (Jennings et al., 2001) a generic framework for automated negotiation is presented. The simplest protocol, which minimises the complexity of the rationale behind the decision models of the agents, specifies that the agents can only accept or reject others' proposals. Nevertheless, in complex cases where multiple issues are considered, this convention may lead to a very time-consuming and inefficient process, since the agents have no means to verify why the specific proposal is unacceptable, or towards which direction of the negotiation space they should move. Hence, the proposer is essentially offering contracts on the basis of his beliefs as to what the other party prefers. In order to improve on the efficiency of the negotiation process, the responding agent should be able to transmit to the offer generating party some feedback on the proposal it receives. One possible form this feedback may take is *critique*, which is a list of comments on elements of the proposal the agent likes or dislikes. A specific *critique* may suggest constraints on particular negotiation issues (e.g., I am willing to pay for the specific service requested up to $P_{\max}$), or may indicate the specific issues of the proposal that are violating the party's constraints constituting thus the offer unacceptable (e.g., the quality of the service is fine, but the price is too high). The feedback sent by the recipient of a proposal to the offer generating party may take the form of a *counter proposal*. It is an alternative proposal more favorable to its sender, generated in response to an offer, thus increasing the probability of an agreement. Counter proposals may change parts of the proposal (i.e., the value of some of the issues under negotiation), or extend the initial proposal (i.e., introduce new issues to be considered). Counter proposals differ from critiques in the sense that the feedback the proposer receives is less explicit. The initial proposer has to consider the counter proposal and infer the other party's preferences/constraints from the way it is re-composed. However, the counter proposals scheme often enables the initial proposer to identify the contract space of the counter party.

The aforementioned protocol types may be extended in order for the parties to be able to justify to their opponent a particular position they have employed in the context of a negotiation (e.g., the delivery date of a particular car could not be earlier as the car Seller is out of stock), or even try to persuade them to change their negotiation attitude (e.g., the car Seller provides a radio CD gift in order to make his/her offer more attractive or to convince the Buyer that a specific feature of the car provided is more important than the one which currently constitutes the offer unacceptable for the Buyer). Thus, the ability to provide some form of additional information (justification for a negotiation attitude, arguments for a specific position, etc) may lead to the establishment of agreements in a more time-efficient manner. There is a wide range of argument types the negotiating parties may adopt (Karlins and Abelson, 1970; Kraous et al., 1998). Common categories include: *threats* (failure to accept this proposal would result to negative consequences), *rewards* (if you accept the proposal you will receive a positive payoff), and *appeals* (this option should be preferred over the alternative one for some reason). In general, the role of the argumentation based negotiation is either to modify the recipient's acceptable contract region or its evaluation function.

Concerning the negotiation models, extensive research has been performed in the economics (mainly in game theory) and in the artificial intelligence (AI) fields. Considering non-cooperative game theory, multi-issue negotiations are not tractable, as relevant problems are mainly addressed by their decomposition into issue-by-issue negotiations (Raiffa, 1982; Bac and Raff, 1996; Fershtman, 2000; Rubinstein, 1985; Ponsati and Sakovics, 1998; Busch and Horstmann, 2002; Chen, 2002; In and Serrano, 2004). The relevant negotiation procedures can be separate, simultaneous or sequential (Inderst, 2000; Gerding et al., 2000). In the context of cooperative game theory (Heiskanen et al., 2001; Heiskanen, 1999; Kalai, 1977; Ponsati and Watson, 1997; Myerson, 1981; Ehtamo et al., 2001; Peters, 1986; Raith, 2000), researchers have laid focus on the design of methods that lead to Pareto-optimal solutions by assuming that agents cooperate and can solve multi-criteria-decision-making problems. Several AI research groups have studied multi-issue negotiations carried out by autonomous agents (Faratin et al., 1998; Kraus and Lehmann, 1995; Fatima et al., 2002; Fatima et al., 2004; Luo et al., 2003; Li and Tesauro, 2003; Sykara, 1989; Sykara, 1990). Usually they aim at designing automated multi-issue negotiation models and tractable negotiation strategies, while they often utilise heuristic or learning methods in this respect. In a nutshell, three main research directions can be distinguished in economics and AI domains that deal with multi-issue negotiations: issue-by-issue negotiations, cooperative multi-issue negotiation, and multi-issue negotiation based on heuristics.

One of the most well-known approaches adequate for multi-issue negotiations was proposed by Raiffa (Raiffa, 1982). In his negotiation framework, win-win situations can be achieved, as one party's gain increase does not necessarily lead to increases on another party's losses. Additionally, Raiffa has addressed various aspects of multi-issue negotiations such as: utility functions, negotiation agendas, tradeoffs, strategic misrepresentations, etc. However, it has been argued in the literature (e.g., (Faratin et al., 1998)) that Raiffa's framework is based on several implicit assumptions that, even though they may lead to good optimisation results, they are inappropriate for the needs of the e-marketplace. Such issues are the following: (i) privacy of information for the negotiators is not supported, (ii) the utility function models must be disclosed, (iii) the value regions for the contract issues for both parties must be identified in advance, (iv) the only parameters that determine the utility of the contracts for the negotiators are the values of the issues under negotiation.

2.2 The proposed negotiation protocol & model

In related research literature, the interactions among the parties follow mostly the rules of an alternating sequential protocol in which the agents take turns to make offers and counter offers (Rubinstein, 1982). This model however necessitates an advanced reasoning component on behalf of the *BA* as well as the *SA*. In this study, we initially tackle a simpler case where *BA* does not give a counter offer (which involves incorporating to the model all *BA's* trade-offs between the various attributes) to the *SA* but instead ranks the *SA's* offers. This ranking is then provided to the *SA*, in order to sequentially generate a hopefully better proposal (move to a different region of the contract space) and find a mutually acceptable contract. This process continues until a mutually acceptable contract is reached. This is more efficient in cases where the *BA* is not able to extract all user requirements and preferences in a completely quantified way, while being capable of selecting, classifying or rating the contract(s) proposed.

Essentially, the ranking of the proposals is a form of a critique, without however providing other information about parts of the contracts offered. In this sense, the ranking concept, even though requiring limited resources on behalf of the *BA*, may lead to an extensive negotiation phase as no other explicit information about specific preferences or constraints will be provided to the *SA*. The ranking concept adopted in this paper is borrowed from *Conjoint Analysis* (Crane, 1991), a quite popular marketing tool for identifying and marketing new product features, relieving the consumer of specifying these features explicitly.

The protocol adopted in the context of this study can be described as follows. Once the agents have determined the set of issues over which they will negotiate, the negotiation process consists of an alternate succession of contract proposals on behalf of the *SA* and subsequent ranking of them by the *BA* according to its preferences and current conditions. Thus, at each round, the *SA* sends to the *BA* N contracts (i.e., N packets consisting on n-plets of values of the n contract issues), which are subsequently evaluated by the *BA* and a rank vector is returned to the *SA*. This process continues until a contract proposed by the *SA* is accepted by the *BA* or one of the agents terminates the negotiation (e.g., if the time deadline is reached without an agreement being in place). Even though negotiation can be initiated by *SAs* or *BAs*, only the *SAs* propose concrete contracts, as there is no counter offer generation mechanism for the *BAs*. In this paper, we consider the case where the negotiation process is initiated by the *BA* who sends to the *SA* an initial *Request for Proposal* (*RFP*) specifying the types and nature of the contract issues and the values of all non negotiable parameters. The main issue is assumed to be the price of the good/service under negotiation, while various other issues may be considered as well.

Concerning the negotiation model, the *Multi Attribute Utility Theory* (*MAUT*) has been considered (Keeney and Raiffa, 1993), which has evolved to one of the most important topics in multiple criteria decision making (Pardalos et al., 1995; Figueira et al., 2005; Brugha, 2004) and has many applications in complex real world problems. *MAUT* aims to represent and model the decision maker's preferences through a utility function $u(\underline{g})$ aggregating all the evaluation attributes, where $\underline{g}$ is the vector of the evaluation attributes $g_1, g_2, \ldots g_n$. When the decision problem is deterministic, the problem of choosing the best alternative is reduced to the problem of assigning a value function $V(g_1, g_2, \ldots g_n)$ over the evaluation criteria. The optimal alternative is then the one that has the largest value as determined by the value function. Considering a set of mutually independent evaluation attributes, the value for the set can be found by summing the value of each evaluation attribute (linear additive model), which is perhaps the simplest approach to value modelling. For many situations a linear value model is adequate. In others it is often a good first approximation to further refine or use for sensitivity analysis. However, for some situations, a multiplicative value function or a Cobb-Douglas function may be more appropriate. In (Karp, 2003) the additive utility function is extended in order to cover multiple simultaneous values for an attribute under negotiation.

The proposed dynamic negotiation model is based on the multi-issue value scoring system introduced by Raiffa (Raiffa, 1982) and used to build a model for bilateral negotiations about a set of quantitative variables. As already mentioned, in Raiffa's approach, the only parameters that determine the utility of the contracts for the negotiators are the values of the issues under negotiation. Nevertheless, there are usually several issues, that even though their values are not under negotiation and they are not included in the contract parameters, they affect the evaluation of the values of the contract issues. Without being exhaustive, such issues may consist of: the number of competitor companies, the number of substitute or complementary products/services, the quantity of product in stock, the number of current potential buyers, the reputation/reliability of each Seller/Buyer, the time until the negotiation deadline expires, the resources availability and restrictions, etc. We will refer to these issues as *decision issues* (*DIs*). The values of the *DIs* may change overtime, depending on the e-marketplace conditions and on the Seller's and Buyer's state. The *DIs* do not only affect the evaluation of the contracts, but they also have an impact on the generation of subsequent offers. At this point it should be noted that *DIs'* values do not necessarily depend on the actions of the negotiating party they affect, while they may affect one or both negotiators. The values of the *DIs* should have a strong and direct influence on the behaviour of the negotiating agents, which should be able to evaluate the utility of the contracts under the current circumstances in the e-marketplace and act accordingly.

From the above analysis, it is clear that optimal solutions cannot be found in the e-commerce domains, as computational and communication resources usually impose non-zero negotiation duration, and time-varying issues may change the negotiation conditions for both parties. Thus, we propose a dynamic model for agent negotiation that can be exploited by strategies in order to construct contracts acceptable to the opponent parties but which, nevertheless, maximise the agent's own utility function.

The agents that represent *Sellers* will be denoted by $S = \{S_1, S_2, ...\}$ and the ones that represent potential *Buyers* will be denoted by $B = \{B_1, B_2, ...\}$. For presentation simplicity reasons, we will in the following analysis confine our description to the relevant bilateral negotiation problem. However, our proposed framework may readily be extended to multi – party situations considering *N* x *M* independent negotiation threads, under the assumption that there are no further strategic interactions between the Buyers or the Sellers. In essence, this means that neither the Seller, nor the Buyer change their strategies in the context of a negotiation, taking into account possible intermediate outcomes from the rest of the negotiation contexts at which they may be involved. The *DIs* values, however, may be affected by the dynamically changing e-market place conditions. For example, an increased number of negotiating Buyers (potential customers) for the same product may result to a high – priced Seller's offer, or on the other hand, assuming increased Seller competition, the Sellers could limit their marginal profit in order to succeed in establishing an agreement with the Buyer, etc.

Our analysis draws heavily from Roussaki and Louta (2003). Let $a(a \in S \cup B)$ represent the negotiating agents of the two parties and $i(i \in \{1,...,n\})$ the issues under negotiation, i.e., the issues, the values of which are included in the proposed contracts. The number of these issues in real world negotiations is always finite. Let $c_i \in [m_i^a, M_i^a]$ be a value for the contract issue i acceptable by agent a. It should be mentioned here that we only consider issues the values of which lie within a delimited range defined by each contract proposing agent. Let $C_k = \{c_{k1},...,c_{kn}\}$[2] denote a contract, or in other words a selection of values for all the contract issues, that is a value in the multi-dimensional space defined by the n issues' value ranges. For the values of the *DIs* we will use the following notation: d_j, $j = 1,...,m$. We may now introduce the utility function of the proposed framework as follows. Let $U_i^a : [m_i^a, M_i^a] \rightarrow [0,1]$ denote the utility that agent a assigns to a value of contract issue i in the range of its acceptable values. Let w_i^a be the importance of issue i for agent a. Moreover $U_i^a(c_i)$ is assumed to be continuous and monotonic. The weights w_i^a are determined based on the preferences, priorities and objectives of the party represented by agent a. That is, in case the negotiator values more contract issue i than contract issue j, then it should stand that: $w_i > w_j$. We assume the weights of all agents are normalised to add up to 1, i.e., $\sum_{i=1}^{n} w_i^a = 1$. Using the above notation, the agent's a utility function for a contract $C_k = \{c_{k1},...,c_{kn}\}$ can be defined as follows: $U^a(C_k) = \sum_{i=1}^{n} w_i^a U_i^a(c_{ki}, d_j^{t=t_k})$, where $d_j^{t=t_k}$, $j = 1,...,m$, is the value of decision issue d_j at the time t_k, when contract C_k is proposed.

In the context of this study, the Buyer's/Seller's utility function for a contract considers a linear additive model incorporating the utilities of each contract issue that is involved in the negotiation. In essence, we assume that the various issues are substitutes, e.g. price and quality. Linearity can also be a result of assuming risk neutral agents. (Keeney and Raiffa, 1993).

However, it should be noted that the utility function of each individual contract issue may be of any continuous and monotonic functional form, either concave or convex, (e.g., linear, polynomial, exponential, multiplicative, quasi-linear, etc) of the contract issue value and the decision issue value at the time the contract is proposed, without affecting the basic ideas of our proposed negotiation model and strategies.

In order for the utility function of any contract issue i for any negotiator to lie within the range $[0,1]$, the value of issue i must lie within the range of its acceptable values. To ensure this, we introduce the notion of *value constraints*, that is expressed as follows: $m_i^a \leq c_i \leq M_i^a$. In case the *value constraints* hold for all contract issues, the utility function can be used to measure the satisfaction of a negotiator as far as the proposed contract is concerned. Nevertheless, often, the value constraints are not met for some contract issues, thus constituting the contract completely unacceptable, regardless of the utility level. In this case, there is not much value in using the above specified utility function to measure the satisfaction degree of this negotiator, as the contract is completely unacceptable. In that sense, agents exhibit lexicographic preferences. Thus, we may introduce a *value constraint validity vector*: $VCV^a = \left[VCV_i^a\right]$, $i = 1,...,n$, where $VCV_i^a \in \{0,1\}$, depending on whether the value constraint for negotiating party a is met for contract issue i (i.e., $VCV_i^a = 1$) or not (i.e., $VCV_i^a = 0$). In order to refer to the case where the mere presence or absence of a particular feature is required by a negotiator, we could add boolean constraints to our model. However, as they can be reduced to value constraints, they will not be further analysed.

In principle, *SAs* and *BAs* present conflicting interests in the values of the contract issues. Thus, the utility functions must verify that given a Seller agent S and a Buyer agent B negotiating the value for contract issue i, then: $\left[\partial\left(U_i^S\right)/\partial c_i\right]\cdot\left[\partial\left(U_i^B\right)/\partial c_i\right] < 0$, i.e., under the same conditions, in case higher values of contract issue i result in higher (lower) utility for the *SA* at the same time they result in lower (higher) utility for the *BA*. Nevertheless, it must be mentioned that there are cases where the *SAs* and *BAs* may have a mutual interest for the value of a contract issue (Raiffa, 1982).

As already mentioned, the *BA* ranks the contracts proposed by the *SA*. For the simplest ranking function, the ranks that may be assigned to any contract proposed are boolean variables, i.e., one instance of the set $\{accept, reject\}$. In a more sophisticated approach, the

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2 c_{ki} represents the value of the contract issue i for the k contract.

ranks lie within a range $[m_r, M_r]$, where any contract rated with less than M_r is not acceptable by the *BA*, while, when a contract is rated with M_r, then the proposed by the *SA* contract is accepted by the *BA*. The second formulation of the ranking function range (which is adopted in this version of the study) is more flexible than the simple $\{accept, reject\}$ rating system, as it highly contributes to reducing the duration of the negotiation procedure. In order to signal the case where at least one value constraint is not met for the BA for a certain contract, we introduce another parameter called *contract value constraints validity* that will be denoted by $CVCV_k^a$ for contract C_k and is given by the following equation: $CVCV_k^a = \prod_{i=1}^{n} VCV_{ki}^a$. Based on the previous analysis, in case all *value constraints* are met for contract C_k, it stands that $CVCV_k^a = 1$. On the other hand, in case at least one *value constraint* is not valid for contract C_k, it stands that $CVCV_k^a = 0$, and then the particular contract is definitely rejected.

In order to introduce the time parameter in our negotiation model, we represent by $P^t = \{C_1^t, ..., C_N^t\}$ the vector of the $N \geq 1$ contracts proposed by the Seller agent S to the Buyer agent B at time t, by $C_k^t = \{c_{k1}^t, ..., c_{kn}^t\}$ the vector of the n contract issues values proposed by S to B at time t for the k-contract of this proposal ($k = 1, ..., N$), and by c_{ki}^t ($i = 1, ..., n$) the value for issue i proposed by S to B at time t for the k-contract of this proposal. Let now $R^t = \{r_1^t, ..., r_N^t\}$ be the vector of ranking values that B assigns at time t to the previous contracts proposal made by S, and r_k^t ($k = 1, ..., N$) be the rank that B assigns at time t to the k-contract of this proposal. The range of values acceptable to agent $a \in \{S, B\}$ for issue i will be represented as the interval $[m_i^a, M_i^a]$.

A contract package proposal is accepted by B when at least one contract is rated with M_r, while the negotiation terminates either in case the agent(s) deadline is reached or in case a boolean variable expressing the wish of the agents to quit the negotiation is set to true. The wish of S to quit (continue) the negotiation at time t will be expressed by $Q_S^t = 1$ ($Q_S^t = 0$), while the wish of B to quit (continue) the negotiation at time t will be expressed by $Q_B^t = 1$ ($Q_B^t = 0$). If an agreement is finally reached we call the negotiation successful, while in case one of the negotiating parties quits (i.e., its deadline expired) it is called unsuccessful. In any other case, we say that the negotiation thread is active.

In the analysis above, we have addressed the case of quantitative contract issues. The proposed model can easily be extended for qualitative contract issues. Hereafter, an example of such an extension is provided. Let $c_i \in \{c_i^x\}$ be a value set for the qualitative contract issue i acceptable by agent a, where c_i^x can be an integer, real number, string, boolean, etc. Each agent has a utility function $U_i^a : \{c_i^x\} \rightarrow [0,1]$, which provides the utility that agent a assigns to a value of contract issue i in the range of its acceptable value set. Notice that the agent's utility function for a contract $C_k = \{c_{k1},...,c_{kn}\}$ can be expressed by the same equation as before, i.e. $U^a(C_k) = \sum_{i=1}^{n} w_i^a U_i^a(c_{ki})$.

In (Roussaki et al., 2004a) the proposed model was applied to a simple test case involving two parties and two contract issues, via which we illustrated the fact that the utility of different contracts and the resulting contract preference hierarchy for the two negotiators, may highly depend not only on the values of the contract issues, but also on the values of the decision issues that are not under negotiation, while their values do not depend –at least directly– on the actions of the two parties. The same conclusion is reached for multilateral negotiation situations, based on some more complicated test cases (Roussaki and Louta, 2003).

3. THE PROPOSED NEGOTIATION STRATEGY

Hereafter, our focus is laid on the rationale of the *SA*, since its adopted strategy will define the outcome of the negotiation, while rather simplified assumptions regarding *BA's* logic are subsequently made. We consider that a negotiation is successful, if a mutually acceptable contract is reached within reasonable time. Since an exhaustive exploration of the possible contract space may form a computationally intensive task for the *SA*, it should be able to infer the acceptable contract space for the *BA* until a predefined deadline. To be more specific, *SAs* hereafter will be provided with a mechanism enabling them to find good (near optimal) solutions in reasonable time, by means of computationally efficient algorithms. The rest of this section is structured as follows. In *subsection 3.1* the negotiation problem is formally described and in *subsection 3.2* the focal assumptions, on which the negotiation strategy is built, are provided. In *subsection 3.3* the ranking mechanism of the Buyer is presented, while in *subsection 3.4* the contract generation mechanism of the Seller is thoroughly described.

3.1 Negotiation Problem Description

The objective of our problem is to find a contract $C_{final} = \{c_{1final}, c_{2final},..., c_{nfinal}\}$ that maximises the *SA's* overall utility function $U^S(C_{final})$, i.e., the *SA's* satisfaction stemming from the proposed contract. The constraints of our problem are the following. First, each contract issue i ($i = 1,...,n$) should lie within the acceptable value ranges for both the *BA* and the *SA*, i.e., no value constraint violation should exist for both parties. Second, the constraint regarding the *BA's* (*SA's*) utility reservation value should be preserved. Therefore, the total *BA's* (*SA's*) utility for a proposed contract should not lie below a predefined value $U^{B}_{\min Acc}$ ($U^{S}_{\min Acc}$) representing the minimum satisfaction that may be experienced by the *BA* (*SA*) in order for an agreement to be reached. Thus, the conditions $U^{B}(C_{final}) \geq U^{B}_{\min Acc}$ and $U^{S}(C_{final}) \geq U^{S}_{\min Acc}$ should hold. Finally, the constraint regarding the *SA's* deadline should be preserved. Therefore, an agreement with the *BA* may be reached only if $t_l \leq T$, where T denotes the *SA's* deadline and t_l the time of negotiation round l during which contract C_{final} is proposed.

Thus, based on the selected protocol and the proposed model, designing a negotiation strategy can be reduced to a decision problem that can formally be stated as follows:

Given:

(i) two negotiating parties: an *SA* that may provide a specific good (i.e., service or product) and a *BA* that is interested in this good's acquisition,

(ii) n contract issues (index: $i = 1,...,n$) defined by the negotiators and the acceptable for the *SA* ranges $\left[m_i^S, M_i^S\right]$ within which their values must lie,

(iii) m decision issues and their current values d_j , $j = 1,...,m$,

(iv) a deadline T up to which the *SA* must have completed the negotiation with the *BA*,

(v) the vector $P^{t_l} = \left\{C_1^{t_l},...,C_N^{t_l}\right\}$ of the N contracts $C_k^{t_l} = \left\{c_{k1}^{t_l},...,c_{kn}^{t_l}\right\}$ ($k = 1,...,N$) proposed by the *SA* to the *BA* during the previous round l ,

(vi) the vector $R^{t_l} = \left\{r_1^{t_l},...,r_N^{t_l}\right\}$ of the ranking values $r_k^{t_l}$ ($k = 1,...,N$) that the *BA* assigns to the previously made by the *SA* contract proposal at the negotiation round l , and

(vii) the value constraint validity vector $VCV_k^B = \left\{VCV_{ki}^B\right\}$ ($i = 1,...,n$) for at least one of the contracts proposed,

find the vector $P^{t_{l+1}} = \left\{C_1^{t_{l+1}},...,C_N^{t_{l+1}}\right\}$ of the N contracts $C_k^{t_{l+1}} = \left\{c_{k1}^{t_{l+1}},...,c_{kn}^{t_{l+1}}\right\}$ ($k = 1,...,N$) that should be proposed by the *SA* to the *BA* in the next round $l+1$, in order to eventually reach to an acceptable (near optimal) agreement between the two parties, while the *SA* aims to maximise its individual utility of the agreed contract under the *SA's* constraints, i.e., $VCV_k^S = \left\{VCV_{ki}^S\right\} = \underline{1}$ ($i = 1,...,n$), $U^S(C_k^{t_{l+1}}) \geq U^{S}_{\min Acc}$ and $t_l \leq T$, and subject to the existent resource and computational limitations.

In general, there may be a significant amount of computations associated with the optimal solution of the negotiation problem presented above. Exhaustive search (i.e., algorithms scanning the entire contract space) should be conducted only in case the solution space is not prohibitively large. The cost of the respective solutions is evaluated and finally, the best solution is maintained. The complexity of the negotiation problem is increased with regards to the number of the contract issues involved and the range of their acceptable values. In this respect, the design of computationally efficient algorithms (e.g., simulated annealing (Aarts and Korts, 1989), tabu search, genetic or greedy algorithms, hybrid or heuristic techniques, etc. (Papadimitriou and Steiglitz, 1982)) that may provide good (near-optimal) solutions in reasonable time is required. Thus, the *SA* should be capable of selecting distinct contract points from the acceptable contract space in order to reach to an agreement with the *BA* within the predefined time limits.

3.2 General Negotiation Strategy Elements on the Seller Side

The proposed negotiation strategy is designed based on the following focal assumptions. First, the *SA* and the *BA* will reach to an agreement, only if a contract is found, where the contract issues values lie within the acceptable ranges of both negotiating parties, while their individual utilities are above a minimum acceptable threshold. Second, it is assumed that the values of all decision issues are invariable and equal to $\underline{d}^{t_0} = \{d_j^{t_0}\}$ for the maximum possible duration T of the negotiation procedure between the *SA* and the specific *BA*, where t_0 is the initiation time of the specific negotiation thread. Third, the computational and communication capabilities of the two negotiating agents, as well as their locations in the communication network, are assumed to lead to an almost constant duration of each negotiation round. Thus, it is assumed that quantity $t_{l+1} - t_l$ is constant $\forall l$ and that the *SA* is aware of its value. Thus, the maximum number of rounds within which the *SA* is authorised to complete the negotiation with the *BA* is: $L = INT\left(\frac{\mathrm{T}}{t_{l+1} - t_l}\right)$.

As already presented in the negotiation protocol analysis, we consider the case where the negotiation process is initiated by the *BA* who sends to the *SA* an *RFP* specifying the types of the contract issues and the values of all non negotiable parameters. Alternatively, the *RFP* may comprise a complete specification of the service requested (i.e., values assigned for n contract issues). *SA* could exploit this additional information by deploying learning from experience techniques in order to infer the bounds of the mutually non violating contract space (*contract intersection region*) in a quicker manner. This alternate approach is considered to be a standalone issue, which has been addressed in (Louta et al., 2005). Based on this *RFP*, the *SA* proposes an initial contract $C^{t_0} = \{c_1^{t_0}, ..., c_n^{t_0}\}$ to the *BA* at $t = t_0$, setting all contract issues at the values that maximise the *SA's* utility (i.e., if $\frac{\partial \left[U^{S}\left(C_{k}, \underline{d}^{t_0}\right)\right]}{\partial c_i} > 0$, then the *SA* sets $c_i^{t_0} = M_i^{S}$, while in case $\frac{\partial \left[U^{S}\left(C_{k}, \underline{d}^{t_0}\right)\right]}{\partial c_i} < 0$, then the *SA* sets $c_i^{t_0} = m_i^{S}$). The utility of the initial contract C^{t_0} for the *SA* will be denoted by: $U^{S}\left(C^{t_0}, \underline{d}^{t_0}\right) = U_{\max}^{S,t_0}$, as $U_{\max}^{S,t_0}$ is the maximum utility that can be achieved for the *SA*, given the values of the decision issues $\underline{d}^{t_0} = \left\{d_j^{t_0}\right\}$ at time $t = t_0$.

The general idea of the proposed approaches is that all contracts $C_k^{t_l}$ ($k = 1,...,n$) of a negotiation round l are generated by the same "source" contract that will be hereafter denoted as $C_0^{t_l}$. All contracts of the same round are generated so that they present equal utilities for the *SA*, given the values of the decision issues $\underline{d}^{t_0}$ at the beginning of the negotiation, i.e., $U^{S}\left(C_k^{t_l}, \underline{d}^{t_0}\right) = U^{S}\left(C_{k'}^{t_l}, \underline{d}^{t_0}\right)$, $\forall k, k' \in \{1,...,n\}$, $\forall l = 1,...,L$. If an agreement is not reached until round $l-1$, then at the next round l, the *SA* will make a compromise (concession), reducing its utility by a certain quantity $\Theta^{t_l} = U^{S}\left(C_k^{t_{l-1}}, \underline{d}^{t_0}\right) - U^{S}\left(C_k^{t_l}, \underline{d}^{t_0}\right)$. This quantity Θ^{t_l} can be time dependent, it can be resource dependent (Faratin et al., 1998), depending on the current values of the decision issues following a Boulware (Raiffa, 1982), Conceder (Pruitt, 1981) or Linear scheme, it may be based on imitative behaviour of the *SA* (Axelrod, 1984; Axelrod, 1997), depending on the utility compromise of the *BA*, etc. As only the results and not the formulation of the designed negotiation strategy depend on the exact value of Θ^{t_l}, without loss of generality, we may assume that Θ^{t_l} is constant, i.e., $\Theta^{t_l} = \Theta^{t_0}$, $\forall l = 1,...,L$. However, this assumption may be drawn and the parameter Θ^{t_l} can be determined by the *SA* taking into account the specific constraints and conditions of the e-market that influence its decision issues values in each negotiation round. This issue will be considered in a future version of this study. Hereafter, according to the previous analysis, we have the following: $U^{S}\left(C^{t_0}, \underline{d}^{t_0}\right) = U_{\max}^{S,t_0}$ and $U^{S}\left(C_k^{t_L}, \underline{d}^{t_0}\right) = U_{\min Acc}^{S}$. Using these two equations we may define quantity Θ^{t_0} as follows: $\Theta^{t_0} = \frac{U_{\max}^{S,t_0} - U_{\min Acc}^{S}}{L}$. This means that at each negotiation round, all contracts proposed by the *SA* will present *SA* utility reduced by $\frac{U_{\max}^{S,t_0} - U_{\min Acc}^{S}}{L}$, with regards to the contracts of the previous negotiation round.

As already mentioned, contract C^{t_0} for which it stands $U^S\left(C^{t_0}, \underline{d}^{t_0}\right) = U^{S,t_0}_{\max}$ is the "source" contract of the first complete negotiation round ($l = 0$), i.e., $C_0^{t_1} = C^{t_0}$. The core concept of the proposed *SA's* strategy is to propose N contracts at each negotiation round l, which yield the same utility concession Θ^{t_o} with respect to the source contract $C_0^{t_l}$. Thus, the utility of the contracts proposed is equal to $U^S\left(C_k^{t_l}, \underline{d}^{t_0}\right) = U^S\left(C_0^{t_l}, \underline{d}^{t_0}\right) - \Theta^{t_0}$, while $U^S\left(C_k^{t_{l-1}}, \underline{d}^{t_0}\right) = U^S\left(C_0^{t_l}, \underline{d}^{t_0}\right)$, $\forall k = 1,...,n$. According to the previous analysis, we have the following: $U^S\left(C^{t_0}, \underline{d}^{t_0}\right) = U^{S,t_0}_{\max}$ and $U^S\left(C_k^{t_L}, \underline{d}^{t_0}\right) = U^S_{\min Acc}$. It is noted that in case an agreement between *BA* and *SA* is feasible (that is there exist at least one contract $C_k^{t_l}$ for which it stands: $U^S\left(C_k^{t_l}\right) \geq U^S_{\min Acc}$ and $U^B\left(C_k^{t_l}\right) \geq U^B_{\min Acc}$), our approach will succeed in reaching within the negotiation thread upon an agreement due to the assumption that as its deadline approaches, the Seller concedes up to its reservation value $U^S_{\min Acc}$.

As already described in *subsection 2.2*, the *SA* provides the *BA* with a contract proposal $P^{t_l} = \left\{C_1^{t_l},...,C_n^{t_l}\right\}$ at each negotiation round l. The *BA* in return, sends to the *SA* the ranking vector $R^{t_l} = \left\{r_1^{t_l},...,r_n^{t_1}\right\}$ for the respective contract package proposal, along with the *value constraint validity vector* $VCV^{B,t_l} = \left\{VCV_i^{B,t_l}\right\}$, $i = 1,...,n$, for at least one contract of the round, where $VCV_i^{B,t_l} \in \{0,1\}$, depending on whether the value constraint of the *BA* is met for contract issue i (i.e., $VCV_i^{B,t_l} = 1$) or not (i.e., $VCV_i^{B,t_l} = 0$) for this contract.

3.3 *The Ranking Mechanism of the Buyer*

The strategy proposed in this paper considers the case where the *BA* returns to the *SA* an identification sign of the "*best contract*" comprised in the contract package proposal $P^{t_l} = \left\{C_1^{t_l},...,C_N^{t_l}\right\}$ in the context of each negotiation round l. In essence, the *BA* in such a case may only identify the contract that better satisfies his/her needs, requirements and constraints and not provide a specific rank as a measure of his/her satisfaction stemming from the proposed contracts. Therefore, the *BA's* rationale may be quite simple, but the *SA's* task is still quite difficult due to the limited information provided. The best contract $C_k^{t_l}$ at each negotiation round l is identified by a rank signal BC (i.e., $R^{t_l} = \left\{0_1^{t_l},...,BC_k^{t_l},...,0_N^{t_l}\right\}$), whereas in case a contract $C_k^{t_l}$ is accepted to form the final agreement between the negotiating parties the specific rank provided at the respective contract position of the ranking vector R^{t_l} is set equal to 1 (i.e., $R^{t_l} = \left\{0_1^{t_l},...,1_k^{t_l},...,0_N^{t_l}\right\}$). At this point it should be noted that in case all contracts proposed present a value constraint violation (i.e., if for $c_{ki}^{t_l}$, $i = 1,...,n$,

$\forall k = 1,..., N$, it stands that $VCV_k^{B,t_l} = 0$), the ranks comprised in the ranking vector R^{t_l} returned to the *SA* are set equal to 0 (i.e., $r_k^{t_l} = 0$, $\forall k = 1,..., N$).

3.4 The Contract Generation Mechanism of the Seller

The basis for the proposed negotiation strategy for the Seller is thoroughly described in *subsection 3.2*. As already mentioned, contract C^{t_0} for which it stands $U^S\left(C^{t_0}, \underline{d}^{t_0}\right) = U_{\max}^{S,t_0}$ is the "source" contract of the first complete negotiation round ($l = 0$), i.e. $C_0^{t_1} = C^{t_0}$. With respect to this initial contract C^{t_0} two distinct cases may be identified. First, no *value constraint violation* exists and the contract C^{t_0} is ranked by the *BA* with a rank signal BC (i.e., $r^{t_0} = BC$). Second, *value constraint violation* occurs, in which case $r^{t_0} = 0$, and the *BA* provides also its *value constraint validity vector* VCV^{B,t_0}. In case the initial contract C^{t_0} presents a *value constraint violation*, the *SA*, as a first step, tries to acquire a contract that respects *BA's* value constraints. We will refer to this step as *negotiation phase I*, during which until a non value constraint violating contract C^{t_l} is acquired (thus, $r^{t_l} \neq 0$), at each negotiation round $l > 1$ only one new contract is generated on the basis of the contract $C^{t_{l-1}}$ proposed at negotiation round $l - 1$ (which in essence forms the source contract $C_0^{t_l}$, i.e., $C_0^{t_l} = C^{t_{l-1}}$), reducing *SA's* utility by quantity Θ^{t_0}.

In the context of *negotiation phase I*, a new contract is generated based on the contract $C^{t_{l-1}}$ proposed at negotiation round $l-1$, which in principle has all contract issues values equal to the ones of contract $C^{t_{l-1}}$, except from the value(s) $c_i^{t_{l-1}}$ of contract issue(s) i, for which a constraint violation has occurred, ($VCV_i^{B,t_{l-1}} = 0$). For example, in case contract issue k of contract $C^{t_{l-1}}$ violates the value constraints, the new contract proposal would be $C^{t_l} = \left\{c_{01}^{t_l},..., c_{0(k-1)}^{t_l}, c'^{t_l}_{0k}, c_{0(k+1)}^{t_l},..., c_{0n}^{t_l}\right\}$. The value(s) of contract issue(s) k, $c'^{t_l}_{0k}$, are selected so that the utility of contract C^{t_l} for the *SA* is equal to: $U^S\left(C^{t_l}, \underline{d}^{t_0}\right) = U^S(C^{t_{l-1}}, \underline{d}^{t_0}) - \Theta^{t_0}$. In order to reach to a non violating contract within a reasonable number of negotiation rounds, it is assumed that the concession quantity Θ^{t_0} is shared equally amongst the contract issues whose value is not acceptable to the *BA*. The exact values of contract issues are determined in accordance with the following: $c'^{t_l}_{0i}$:

$$U^S\left(c_{0i}^{t_l}, \underline{d}^{t_0}\right) - U^S\left(c'^{t_l}_{0i}, \underline{d}^{t_0}\right) = \left[\sum_{k=1}^{n} \overline{VCV_k^{B,t_l}}\right]^{-1} \cdot \frac{\Theta^{t_0}}{w_i^S}.$$

This process continues until a non value constraint violating contract C^{t_l} is acquired (i.e., $r^{t_l} \neq 0$), while at this point the *SA's* strategy is modified in order to acquire a mutually acceptable contract within reasonable time. Specifically, this contract becomes the "source" contract for the next negotiation round, during which the *SA* provides the *BA* with a contract package proposal comprising $N = n$ contracts. The negotiation round upon which the first negotiation phase ends (hence, the strategy of the Seller is modified) will be hereafter denoted as nr_{fs}. It is noted that in any negotiation round $l > nr_{fs}$, due to the specific approach adopted (i.e., sequential utility concession by quantity Θ^{t_0}), no contract proposed may present any value constraint violation.

Moving now to *negotiation phase II*, concerning the generation process of the "source" contract $C_0^{t_l}$ of a negotiation round $l > nr_{fs}$, the current version of this study considers the simplest possible assumption, that is the "*best contract*" proposed to the BA at the negotiation round $l-1$, as determined by the ranking vector R^{t_l} returned to the SA, forms the "source" contract for negotiation round l. Alternatively, for the specification of the source contract $C_0^{t_l}$, the SA could employ exploration techniques. To this end, several approaches could be found in the literature, e.g., the Boltzmann exploration strategy (Kaelbling et al., 1996; Kapetanakis and Kudenko, 2002).

Up to this point, we have not yet presented the way the $N = n$ contracts of any negotiation round $l > nr_{fs}$ are generated by the round's "source" contract $C_0^{t_l}$. As a first step, the contract generation mechanism may consider the reallocation of the utility concession of each round to each one of the contract issues considered in the negotiation process. As a second step, we modified the contract generation mechanism based on the idea that in any $C_k^{t_{l+1}}$ the *SA* at each negotiation round $l+1$ may in principle concede mostly with respect to the contract issue which have been on the previous negotiation round l preferred by the *BA*, while through the modification of one additional contract issue up to a certain amount the *SA* infers the direction towards which should move in order to reach to an agreement with the *BA*.

Considering the first negotiation round l of *negotiation phase II* (i.e., $l = nr_{fs} + 1$), the *SA* proposes n contracts, which will in principle have all contract issues values equal to the ones of the "source" contract $C_0^{t_l}$, except from the value $c_{kk}^{t_l}$ of contract issue $i = k$, i.e., $C_k^{t_l} = \left\{c_{01}^{t_l},...,c_{0(k-1)}^{t_l}, c_{kk}^{t_l}, c_{0(k+1)}^{t_l},...,c_{0n}^{t_l}\right\}$. The value $c_{kk}^{t_l}$ is selected so that the utility of contract $C_k^{t_l}$ for the *SA* is equal to: $U^S\left(C_k^{t_l}, \underline{d}^{t_0}\right) = U^S\left(C_0^{t_l}, \underline{d}^{t_0}\right) - \Theta^{t_0}$. Subsequently, the *SA* explores what is the impact of the value concession of each one of the contract issues. The *SA* may observe that for the "*best contract*" $C_k^{t_l}$ indicated by the *BA*, the same *SA* utility reduction Θ^{t_0} due to adjustments on the value $c_{kk}^{t_l}$ of contract issue $i = k$, is valued higher by the *BA*. On the other hand, in case any contract $C_k^{t_l}$ is not indicated as the "*best contract*" on negotiation round l (where all Seller utility reduction Θ^{t_0} is due to adjustments on the value c_{kk}^{t} of contract issue $i = k$), this indicates that contract issue $i = k$ is not very important for the *BA*. Thus, in the context of the next negotiation round, the *SA* exploits the "*best contract*", as indicated by the *BA* in the R^{t_l} vector, which forms the "source" contract for the next round. Thus, in case this contract is $C_k^{t_l}$ (i.e., $C_k^{t_l} = C_0^{t_{l+1}}$), it does "worth" it for the *SA* to propose during the next negotiation round $l+1$ a contract package proposal, whose main characteristic is that a high percentage of the total Seller utility reduction Θ^{t_0} is due to adjustments on the value $c_{kk}^{t_l} = c_{0k}^{t_{l+1}}$ of contract issue $i = k$.

We hereafter introduce with respect to each contract issue i a variable called *utility concession degree*, denoted as $ucd(i)$, representing the percentage of the total Seller utility reduction Θ^{t_0} due to the adjustment of the contract issue i value. It holds $ucd(i) \in [0,1]$. The n contracts constituting the contract package proposal considered in negotiation round $l+1$ may be generated as follows. The first contract is created by modifying only the value $c_{0k}^{t_{l+1}}$ of k contract issue, whose adjustment on the previous negotiation round l was preferred by the *BA*. Thus, the Seller's utility reduction Θ^{t_0} is introduced only by adjusting $c_{0k}^{t_{l+1}}$ in the source contract. The value $c_{kk}^{t_{l+1}}$ may be calculated by means of the following equation $c_{kk}^{t_{l+1}}$: $U^S\left(c_{kk}^{t_l}, \underline{d}^{t_0}\right) - U^S\left(c_{kk}^{t_{l+1}}, \underline{d}^{t_0}\right) = ucd(k) \cdot \frac{\Theta^{t_0}}{w_k^s}$, where $ucd(k) = 1$. The rest $n-1$ contracts are generated by modifying at each contract the value $c_{0j}^{t_{l+1}}$ of one more issue j ($j \neq k$) in the source contract, up to a certain degree $ucd(j)$, while the utility concession degree $ucd(k)$ of the k contract issue is properly adjusted, so that $ucd(j) + ucd(k) = 1$. This way, the impact of the combined Seller's utility reduction with respect to both modified contract issues is explored. The contracts which are specified in accordance with this concept will be hereafter called "exploration" contracts. The values $c_{kk}^{t_{l+1}}$ and $c_{jj}^{t_{l+1}}$ of contract issues k and j respectively may be acquired by the aforementioned equation. It stands that $\sum_{i=j,k} w_i^S \cdot [U^S(c_{ii}^{t_l}, \underline{d}^{t_0}) - U^S(c_{ii}^{t_{l+1}}, \underline{d}^{t_0})] = \Theta^{t_0}$, which indicates that the Seller's utility of the n contracts of negotiation round $l+1$ is less than the Seller's utility of the negotiation round l by the quantity Θ^{t_0}, which is fully consistent with the presented approach. For the generation of the $n-1$ "exploration" contracts, $ucd(k)$ is set equal to 0.7, while $ucd(j)$ equals 0.3, as it is estimated that 30% is adequate for exploration purposes. Alternatively, a more gradual modification of the utility concession degrees could be considered, which is effective in case the first partial derivatives of the Buyer's utility functions are not steeply altered by the changes introduced by the Seller to the values of the respective contract issues (i.e., $\frac{\partial^2 U^B(C_k)}{\partial^2 c_i}$ is quite small). In such a case, the Seller takes into account the outcome of negotiation round $l-1$, in conjunction to the results obtained on negotiation round l so as to determine the contracts $C_k^{t_{l+1}}$ for the negotiation round $l+1$.

In case the *BA* ranks higher the introduction of the modification of contract issue j with respect to the value adjustment of contract issue k, as a next step, the respective utility concession degrees $ucd(j)$ and $ucd(k)$ are modified so that the relative preference of the *BA* for contract issue j is introduced in the generation process of the next negotiation round $l+2$. Specifically, considering the next negotiation round contract generation, the utility concession degree of contract issue j is increased, while the utility concession degree of contract issue k is decreased as we consider that the *SA* should concede mostly with respect to contract issue j. Thus, $ucd(j)$ is set equal to 0.7, while the rest 0.3 portion of the utility concession quantity Θ^{t_0} is at each contract assigned to each one of the contract issues m in a manner similar to the "*exploration*" policy introduced above.

According to the proposed approach, in case the resulting value $c_{kk}^{t_{l+1}}$ of a contract issue k in contract $C_k^{t_{l+1}}$ ends up to lie outside the acceptable range of the *SA*, then if $c_{kk}^{t_l} < m_k^S$ (or $c_{kk}^{t_l} > M_k^S$), the value selected is $c_{kk}^{t_l} = m_k^S$ (or $c_{kk}^{t_l} = M_k^S$), while the remaining utility is equally "distributed" among the rest of the contract issues that have not yet reached their limit values.

In order to make the proposed contract generation mechanism more comprehensive to the reader, in *Table 1* we present the logic underlying by means of a simple example, considering the case of three contract issues. In this table, the contract generation process is studied in the context of *negotiation phase II* (that is a non value constraint violating contract C^{t_l} (i.e., $r^{t_l} \neq 0$) has been acquired during *negotiation phase I*). Considering the first negotiation round l of *negotiation phase II* (i.e., $l = nr_{fs} + 1$), the *SA* proposes $n = 3$ contracts, which will in principle have all contract issues values equal to the ones of the "source" contract $C_0^{t_l} = (c_1^l, c_2^l, c_3^l)$, except from the value of one contract issue (at each contract), so that each time the Seller may explore what is the impact of the value concession of each one of the contract issues. As illustrated in *Table 1*, the Buyer indicates (c_1^l, c'^l_2, c_3^l) as "best contract" (that means that the Buyer values more the utility concession of the second contract issue), which forms the source contract of the $l+1$ negotiation round. Thereafter, the Seller proposes again $n = 3$ contracts. The first one considers the modification of only the second contract issue ($ucd(2) = 1$), whose modification has been preferred by the Buyer during the previous negotiation round. The other two contracts consider the modification of the second contract issue (where $ucd(2) = 0.7$) and one additional contract issue ($ucd(1) = 0.3$ or $ucd(3) = 0.3$), so as to explore the impact of the combined Seller's utility reduction. As it may be seen the "best contract" indicated by the Buyer at the $l+1$ negotiation round is $(c_1^{l+1}, c'^{l+1}_2, c'^{l+1}_3)$, $ucd(2) = 0.7$, $ucd(3) = 0.3$. Thus, the Buyer prefers the utility concession of the third contract issue with respect to the utility concession of the second contract issue. To this respect, the contract generation mechanism in the $l+2$ negotiation round favors the utility concession of the third contract issue, while for exploration purposes, two of the three contracts consider a combined utility modification, as indicated in *Table 1*.

4. RESULTS

The results of this section aim to evaluate the proposed negotiation model and strategy (including both *SA's* contract generation mechanism and the *BA's* ranking scheme) that could be adopted in the overall e-marketplace framework for reaching an agreement in the context of a specific service request.

As a first step, the negotiation model and strategy will be applied to an illustrative test case in order to become comprehensive to the reader. As a next step, the proposed strategy will be compared to two alternate negotiation strategies designed in the context of (Roussaki and Louta, 2003). Concerning the implementation issues of our experiments, the whole negotiation session has been implemented in Java (Gosling, 1996). The OrbixWeb CORBA compliant platform[3] was used for the inter-component communication. Moreover, the *BA* and the *SA* have been implemented as intelligent, mobile agents based on the use of the Voyager platform[4].

The framework of the selected test case is briefly described subsequently. We consider a Seller agent S and a Buyer agent B that negotiate over the purchase of a specific product (e.g., a certain quantity of bottles of fresh juice). Two negotiation issues exist for the two

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[3] http://www.orbix.com

[4] http://www.objectspace.com

negotiators: price and delivery date, i.e., the price per item required by the Seller to provide the bottles requested and the time required from the moment when an agreement is reached until the bottles of juice are delivered to the Buyer. According to the negotiation model proposed, we may use the following notation: $c_1 = price\_value$ and $c_2 = delivery\_date\_value$, where $i = 1,2 \Rightarrow n = 2$. As decision issue we consider the time until the expiration date of the juice to be purchased (d_1) which has an impact on the utility function of the Buyer as well as of the Seller. The acceptable value ranges for the two contract issues for the two negotiating parties are: $\left[m_1^S, M_1^S\right] = [10,20]$, $\left[m_1^B, M_1^B\right] = [8,18]$, $\left[m_2^S, M_2^S\right] = [2,12]$ and $\left[m_2^B, M_2^B\right] = [1,10]$, while the possible value range for the decision issue is: $\left[m_{d_1}, M_{d_1}\right] = [0,40]$ (i.e., the time from the production date until the expiration date of the product is equal to $M_{d_2} = 40$ days) . The weights for the contract issues utility functions $U_{\{1,2\}}^{\{S,B\}}$ in the overall utility function $U^{\{S,B\}}$ for the two negotiating parties are: $\left[w_1^S, w_1^B, w_2^S, w_2^B\right] = [0.8, 0.6, 0.2, 0.4]$, where the weights are normalised, i.e., $\sum_{i=1}^{2} w_i^S = \sum_{i=1}^{2} w_i^B = 1$. The Seller and the Buyer will reach to an agreement, only if a contract is found, where the contract issues values lie within the acceptable ranges of both negotiating parties, while their individual utilities are above a minimum acceptable threshold. For the presented test case we consider the following values for the minimum acceptable utility values for the Seller and the Buyer, respectively: $U_{\min Acc}^S = 0.38$ and $U_{\min Acc}^B = 0.40$ (i.e., for the final agreement contract $C_{final} = \{c_{f1}, \ldots, c_{fn}\}$, the following must hold: $U^S\left(C_{final}\right) \geq 0.38$ and $U^B\left(C_{final}\right) \geq 0.40$).

It is reasonable to assume that the Seller would value more a purchase of a relatively old product than the one of freshly produced bottled juice. That is because the product value declines as the expiration date (*ED*) approaches and the Seller seeks to reduce the product quantity in stock, in fear of being forced to sell it at very low prices or even not selling it at all. It is also assumed that the *ED* of the bottled juice to be purchased also affect the utility for potential Buyers, as they might not be able to use/resell them shortly. Thus, if d_1 is low (i.e., the *ED* of the product approaches) the value of the quantity purchased is low for the Buyer and high for the Seller, while the Seller would more appreciate an early delivery date. Taking the above analysis into consideration, we may model the utility of a contract C_k for the issue i as follows:

(i) $U_1^S = \left(0.8 + 0.2 \cdot \frac{M_{d_1} - d_1}{M_{d_1}}\right) \cdot \frac{c_1 - m_1^S}{M_1^S - m_1^S}$, $c_1 \in \left[m_1^S, M_1^S\right]$

(ii) $U_1^B = \left(0.8 + 0.2 \cdot \frac{d_1}{M_{d_1}}\right) \cdot \frac{M_1^B - c_1}{M_1^B - m_1^B}$, $c_1 \in \left[m_1^B, M_1^B\right]$

(iii) $U_2^S = \frac{c_2 - m_2^S}{M_2^S - m_2^S}$, $c_2 \in \left[m_2^S, M_2^S\right]$

(iv) $U_2^B = \left(0.6 + 0.4 \frac{d_1}{M_{d_1}}\right) \cdot \frac{M_2^B - c_2}{M_2^B - m_2^B}$, $c_2 \in \left[m_2^B, M_2^B\right]$

Following the negotiation strategy proposed, we assume that at $t = t_0$ the value of the decision issue is: $d_1^{t_0} = 30$ (i.e., there are 30 days until the expiration date of the product). Thus, the utilities of the contract issues for the two negotiators can be expressed as follows:

(i) $U_1^S = 0.085 \cdot c_1 - 0.85$, $c_1 \in [10,20]$, (ii) $U_1^B = 1.71 - 0.095 \cdot c_1$, $c_1 \in [8,18]$

(iii) $U_2^S = 0.1 \cdot c_2 - 0.2$, $c_2 \in [2,12]$, (iv) $U_2^B = 1 - 0.1 \cdot c_2$, $c_2 \in [1,10]$

From the equations above we may compute the maximum possible utilities for the two negotiators: $U_{1\max}^{S,t_0} = 0.85$, $U_{1\max}^{B,t_0} = 0.95$, $U_{2\max}^{S,t_0} = 1$, $U_{2\max}^{B,t_0} = 0.9$. Thus, we have: $U_{\max}^{S,t_0} = 0.88$ & $U_{\max}^{B,t_0} = 0.93$, while $U^S = 0.068 \cdot c_1 + 0.02 \cdot c_2 - 0.72$ & $U^B = -0.057 \cdot c_1 - 0.04 \cdot c_2 + 1.426$. In *Figure 1*, the utilities of the two negotiators are depicted with regards to the values of the two contract issues. The minimum acceptable utility level has been highlighted in both diagrams. Notice that in case the value of at least one contract issue does not lie within the intersection of the acceptable value ranges of the Seller and the Buyer (i.e., when $c_1 \notin [10,18]$ and/or $c_2 \notin [2,10]$), the utility of at least one of the two negotiators is negative.

Based on our negotiation model and strategy, considering the case aforementioned, if $c_1 < 10$ and/or if $c_2 < 2$, the Seller does not propose the contract generated, but seeks to propose another contract within his/her acceptable contract domain. On the other hand, if a negative utility contract is proposed by the Seller (that is if $c_1 > 18$ and/or if $c_2 > 10$) then the Buyer assigns zero rank to the specific contract, while setting to zero the respective element of the value constraint validity vector of the "source" contract of the round to be provided to the Seller.

The negotiation process is initiated by the Buyer who sends to the Seller an initial RFP specifying the types of the contract issues (*price* and *delivery date*). Based on this RFP, the Seller proposes an initial contract $C^{t_0} = [20{,}12]$ to the Buyer at $t = t_0$, setting all contract issues at the values that maximise the Seller's utility (i.e., maximum price and latest delivery date). Obviously, $U^S\left(C^{t_0}, \underline{d}^{t_0}\right) = 0.88 = U_{\max}^{S,t_0}$. For the Negotiation Strategy presented in this version of the study, the initial contract C^{t_0} is ranked with $r^{t_0} = 0$, as both contract issues values do not lie within the Buyer's acceptable range ($c_1 = 20 \notin [5{,}15]$ and $c_2 = 12 \notin [1{,}10]$). Thus, the value constraint validity vector of the Buyer provided to the Seller is now: $VCV^{B,t_0} = [0{,}0]$. Contract C^{t_0} will be the "source" contract of the first complete negotiation round ($l = 1$), i.e., $C_0^{t_1} = C^{t_0} = [20{,}12]$.

The maximum possible duration of a negotiation thread is equal to $T = 10\sec$, where T is an upper time bound defined by the Seller. The computational and communication capabilities of the two negotiating agents, as well as their locations in the communication network, are assumed to lead to an almost constant duration of each negotiation round, that is $t_{l+1} - t_l \approx 1\sec \quad \forall l$. Thus, the maximum number of rounds within which the Seller is authorised to complete the negotiation with the Buyer is: $L = INT\left(\dfrac{\mathrm{T}}{t_{l+1} - t_l}\right) = INT\left(\dfrac{10\sec}{1\sec}\right) \Rightarrow L = 10$. This value indicates that the maximum – acceptable by the Seller– number of rounds is equal to $L = 10 \Rightarrow l \le 10$. For each negotiation round l the Seller's utility reduction ($\Theta^{t_0,l} = U^S\left(C_k^{t_{l-1}}, \underline{d}^{t_0}\right) - U^S\left(C_k^{t_l}, \underline{d}^{t_0}\right)$) will be considered to be constant. Thus, the following stands:

$$\Theta^{t_0,l} = \Theta^{t_0} = \frac{U_{\max}^{S,t_0} - U_{\min Acc}^{S}}{L} = 0.05 \Rightarrow U^S\left(C_k^{t_l}, \underline{d}^{t_0}\right) = U^S\left(C_k^{t_{l-1}}, \underline{d}^{t_0}\right) - 0.05 =$$

$$= U^S\left(C_0^{t_l}, \underline{d}^{t_0}\right) - 0.05,\ \forall l = 1,\ldots,10.$$

Table 2 provides the outcome of the application of the proposed *Negotiation Strategy*. Since the initial contract does not belong to the *BA's* acceptable region, the *SA's* contract generation mechanism follows the proposed approach for the *negotiation phase I*, until a non violating contract is reached. As depicted in *Table 2*, *negotiation phase II* starts at round $l = 5$, since at the end of round $l = 4$, the [17.79, 9.5] contract has been proposed, which belongs to the *SA's* and *BA's* contract intersection region. In accordance with the proposed approach for *negotiation phase II*, the contract generation mechanism adopted by the *SA* at each negotiation round $l > 5$ exploits the results of the previous negotiation round $l - 1$. That is, assuming that the contract issue k was preferred by the *BA* on negotiation round l, the *SA* for the generation of the n contracts of negotiation round $l+1$ sets $ucd(k)=0.7$, while $ucd(j)=0.3$ (for all contract issues j). The negotiation ends successfully at negotiation round $l=9$, during which the agreement contract (highlighted in blue) is $C^{t_9}=[16.32,2.0]$. This contract results in Seller utility equal to $U^S\left(C_2^{t_9},\underline{d}^{t_0}\right)=0.43$ and in Buyer utility equal to $U^B\left(C_2^{t_9},\underline{d}^{t_0}\right)=0.41$.

Thus, the proposed Negotiation Strategy in the context of this case led to $U^S+U^B=0.8456$. The optimal solution, which results in the maximum possible social welfare (i.e., $U^S+U^B=\max$), would be contract $C_{optimal}=[18.0,2.0]$ that leads to $\left(U^S+U^B\right)_{optimal}=0.8640$, which is just 2% higher than our strategy's total utility.

As previously mentioned, an objective of our experiments is to provide indicative evidence of the efficiency of the proposed Negotiation Strategy, hereafter denoted by *NS I*, that assists both Sellers and Buyers in reaching to an agreement, considering potential e-marketplace constraints and limitations. In the rest of this section we will provide comparison results with respect to two alternate Negotiation Strategies. The overall presentation is restricted to a qualitative discussion on the experimental results obtained up to this point, since a quantitative presentation is highly dependant on the specific model parameters (e.g., $U^a_{\min Acc}$, $a\in\{S,B\}$, the acceptable value regions for all contract issues for both the Buyer and the Seller, their negotiation deadlines) as well as the dynamics of the market conditions that determine the values of the decision issues. The author's current work is towards quantifying the performance of the negotiation strategies with respect to the model parameters aforementioned and the market conditions dynamics. Subsequently, a brief description of the two alternate strategies is provided.

The first alternate Negotiation Strategy (which is presented thoroughly in (Louta et al., 2004) and will be hereafter denoted by *NS II*) is built upon the simplest possible ranking function, i.e., the ranks assigned to any contract proposed are Boolean variables (one instance of the $\{accept, reject\}$ set). This strategy considers that the Seller sends to the Buyer only one contract at each negotiation round, which is constructed on the basis of the Buyer's response to the previous contract proposal. It has been assumed that the Buyer adopts a simplified rationale and acts as a hill climber (Klein et al., 2002) by accepting at each negotiation round the contract proposed only if all his/her respective value constraints are respected and the utility acquired exceeds the utility stemming from the *last accepted contract*. Regarding the Seller's contract generation mechanism, *negotiation phase I* works in a similar manner to *negotiation phase I* of the *NS I*, while the general idea in the context of *negotiation phase II* is prior to conceding an additional utility quantity to explore the impact of the reallocation of the utility concession to each one of the contract issues involved in the negotiation process. This approach would work well in case the Seller/Buyer does not face strict time deadlines, as the Seller searches the contract space in order to find an alternate contract that better satisfies the Buyer's needs, without however sacrificing any portion of his/her utility. In case this is not feasible, the Seller concedes by offering a contract corresponding to a certain utility reduction. However, in case either party faces time deadlines, the negotiation in many cases proves to be unsuccessful as the procedure of converging to an agreement is very slow, often forcing the parties to withdraw the negotiation when their deadline expires, prior to an agreement being in place.

The second alternate Negotiation Strategy (which is presented in detail in (Roussaki et al., 2004b) and will be hereafter denoted by *NS III*) uses a more sophisticated scheme with regards to both the Seller contract generation mechanism and the Buyer response. The Buyer adopts a more complex rationale, providing ranks that are estimated on the basis of the Buyer's utility function, i.e., ranks provided by strictly increasing functions of the utility of the contracts under assessment. This strategy considers that at each negotiation round the number of contracts sent to the Buyer by the Seller is equal to the number of the issues under negotiation. Initially, the negotiation procedure follows a similar approach to *NS I*, as the Seller generates the same "source" contracts. But in *NS III*, after the first contract that does not violate the Buyer restrictions is proposed, the "source" contract of the subsequent rounds, is not selected among the previously proposed contracts as in *NS I*, but it is estimated based on the Buyer ranks. Once the "source" contract is determined, the contracts of the next negotiation round are calculated using exactly the same algorithm as in the first round of *negotiation phase II* in *NS I*. As far as the formulation of the "source" contract $C_0^{t_l}$ is concerned, two priority objectives are distinguished: (i) to move all contract issues values to acceptable ranges for the Buyer and (ii) to greatly adjust the values of those contract issues that result in higher improvement of the contract ranking (i.e., the ones that affect more strongly the contract utility of the Buyer). Thus, the Seller generates a "source" contract distributing the Seller utility reduction of the round to all contract issues so that the updated values of the ones that present higher ranks "absorb" higher percentage of the round utility "compromise", with regards to the previous round, while the ones with lower ranks "absorb" lower percentage of the round utility "compromise". The relative "source" contract generation algorithm is provided in (Roussaki and Louta, 2003).

This approach introduces an increase on the communication cost spent on each negotiation, as Buyers do not just send the index of the contract selected to the Seller, but they provide ranks for all the contracts proposed. Nevertheless, this cost increase is negligible with regards to the communication cost needed to send the proposed contracts. In case linear models of the utility functions of the Buyer are used, and/or when the number of contract issues is relatively low, *NS III* results in agreements that present equal or lower Seller utility and equal or higher Buyer utility, with regards to the results of *NS I*, while the duration of the negotiation procedure is often shorter for *NS I*. Nevertheless, the deviation of the social welfare of the two approaches is not considerable. These results seem to be rather paradox, since more information is utilised in the context of *NS III* and the Seller was expected to find an acceptable solution faster in comparison to *NS I*. The efficiency of *NS I* with respect to *NS III* is due to the linear formulation of the utility models of the Seller. Thus, since in the context of *NS I*, one of the contracts proposed at each negotiation round is generated by attributing each round's Seller utility reduction 100% to the contract issue whose value modification was most preferred by the Buyer in the previous negotiation round (and this preference will not change), *NS I* acquires a solution faster than *NS III*, resulting in higher Seller utility in case the *NS I* is adopted. In case the Buyer utility function is not linear, and its slope may considerably deviate along the acceptable value range of the contract issues, *NS III* demonstrates higher performance as far as the Seller is concerned. Initial results (Roussaki and Louta, 2003), indicate that *NS I* is often slower that *NS III*, when the Buyer utility function changes radically between the contract spaces of subsequent negotiation rounds. The number of the contract issues also plays an important role to the performance of both strategies. Initial results, suggest that *NS I* is preferable for the Seller when the number of contract issues is relatively low, while *NS III* is better when the number of contract issues is considerable and the difference between the derivative of the overall Buyer utility function with regards to the contract issues may greatly deviate from one round to the next. What remains to be studied, is which utility functions actually apply to the e-commerce environments. If this is identified, then the more efficient negotiation strategy for the Seller will be clearly distinguished.

5. CONCLUSIONS AND FUTURE WORK

This paper presented a *multi-party, multi-issue, dynamic negotiation model* and an effective strategy, to be exploited by mobile intelligent agents in an e-commerce environment. The proposed framework is adequate in cases where the disclosure of information is not acceptable, possible, or desired by the parties. On the Buyer's side its efficiency is due to the fact that a flexible and light reasoning component is adopted on behalf of the Buyer agent based on a *ranking mechanism*, which does not necessitate the explicit statement of all preferences and requirements of the Buyer in a completely quantified way, while being more time and resource efficient. *Ranking mechanism* replaces the counter-offer complicated scheme, while potential decision issues are considered. Thus, it supports an evaluation of the contracts proposed, based not only on the values of the issues under negotiation, but also on the e-marketplace conditions and the negotiator's state.

The contract generation algorithm of the Seller is coupled with a Buyer ranking mechanism that entails identification of the most suitable contract among the contracts proposed. This framework demonstrates exceptional efficiency in cases where Buyers are not able to provide all their requirements and preferences in a completely quantified way, while being capable of selecting the contract that best satisfies their needs. Besides the inherent computational and communication advantages of the proposed negotiation strategy, its efficiency is due to the fact that an agreement between the Buyer Agent and Seller Agent is reached in any situation it is feasible, before the predefined deadline expires.

The negotiation framework designed has been adopted by self-interested autonomous agents and has performed well on the generation of subsequent offers and the ranking of the contracts proposed, always converging to a mutually acceptable contract, if any. Initial results indicate that the designed framework produces near optimal results, in case the number of the negotiation issues is high, while demonstrating exquisite performance for the Seller, when the Buyer utility function is linear. Future plans involve its extensive empirical evaluation against existent models and strategies and against the optimal solution of the negotiation problem. Additionally, issues of malicious transactions between the buyers and the sellers should be addressed.

The presented work addresses mainly the cases of bilateral negotiations or multi-lateral strategically independent negotiations. However, in case there are Buyers with conflicting interests or/and competitive Sellers, our framework can be extended as follows. At the end of each negotiation thread, the Sellers are additionally provided with information on the agreements they fail to establish. This information can be exploited for determining whether there should be some modification in their policies (e.g., price reduction, alteration of set of attributes or quality levels offered, negotiation strategy modification, etc.). Our on-going research work aims to this direction.

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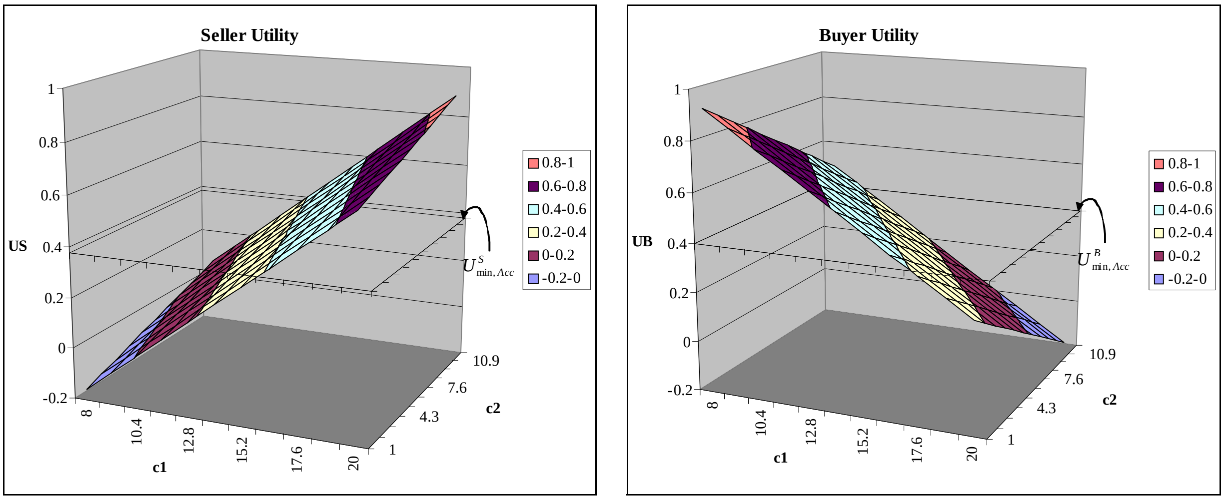

(a) (b)

Figure 1. Utility functions of the two negotiating parties with regards to the two contract issues

Neg. Round	$l = nr_{fs} + 1$	$l+1$	$l+2$
Contracts Proposed	$(c'^{l}_1, c^{l}_2, c^{l}_3)$, $ucd(1)=1$	$(c'^{l+1}_1, c'^{l+1}_2, c^{l+1}_3)$, $ucd(2)=0.7$, $ucd(1)=0.3$	$(c'^{l+2}_1, c^{l+2}_2, c'^{l+2}_3)$, $ucd(3)=0.7$, $ucd(1)=0.3$
	$(c^{l}_1, c'^{l}_2, c^{l}_3)$, $ucd(2)=1$	$(c^{l+1}_1, c'^{l+1}_2, c^{l+1}_3)$, $ucd(2)=1$	$(c^{l+2}_1, c'^{l+2}_2, c'^{l+2}_3)$, $ucd(3)=0.7$, $ucd(2)=0.3$
	$(c^{l}_1, c^{l}_2, c'^{l}_3)$, $ucd(3)=1$	$(c^{l+1}_1, c'^{l+1}_2, c'^{l+1}_3)$, $ucd(2)=0.7$, $ucd(3)=0.3$	$(c^{l+2}_1, c^{l+2}_2, c'^{l+2}_3)$, $ucd(3)=1$
Source Contract	$(c^{l}_1, c^{l}_2, c^{l}_3)$	$(c^{l}_1, c'^{l}_2, c^{l}_3)$, $ucd(2)=1$	$(c^{l+1}_1, c'^{l+1}_2, c'^{l+1}_3)$, $ucd(2)=0.7$, $ucd(3)=0.3$

Table 1. An example of the proposed negotiation strategy

l (round index)	U^S (Seller's utility)	$C_1^{t_l} = \lfloor c_{11}^{t_l}, c_{12}^{t_l} \rfloor$ (first contract)	$C_2^{t_l} = \lfloor c_{21}^{t_l}, c_{22}^{t_l} \rfloor$ (second contract)	$r_1^{t_l}$ (first rank)	$r_2^{t_l}$ (second rank)	U^B (Buyer's utility)		$VCV^{B,t_l} = \lfloor VCV_1^{B,t_l}, VCV_2^{B,t_l} \rfloor$ (value constr. valid. vector)
$l=0$	0.88	[20, 12]		0		-		$[0,0]$
$l=1$	0.83	[19.63, 10.75]		0		-		$[0,0]$
$l=2$	0.78	[19.62, 9.5]		0		-		$[0,1]$
$l=3$	0.73	[18.26, 9.5]		0		-		$[0,1]$
$l=4$	0.68	[17.79, 9.5]		BC		0.032		$[1,1]$
$l=5$	0.63	[17.79, 7]	[17.05, 9.5]	BC	0	0.132	0.0742	-
$l=6$	0.58	[17.79, 4.5]	[17.57, 5.25]	BC	0	0.232	0.2143	-
$l=7$	0.53	[17.79, 2]	[17.57, 2.75]	BC	0	0.332	0.3143	-
$l=8$	0.48	[17.05, 2]		BC		0.374		-
$l=9$	0.43	[16.32, 2]		1		0.41		-

Table 2: Results of application of the proposed Negotiation Strategy