Negotiation of Intelligent Agents: Dynamic Model and Contract Ranking Strategy for Electronic Commerce environments

Ioanna Roussaki, Malamati Louta
School of Electrical and Computer Engineering
National Technical University of Athens
9 Heroon Polytechneiou Street, 157 73, Athens
Greece
{nanario,louta}@telecom.ntua.gr

Lambros Pechlivanos
Department of International & European Economic Studies
Athens University of Economics & Business
80 Patision Street, 104 34, Athens
Greece
lpech@aueb.gr

Abstract – **The electronic commerce market segment will further expand, if coupled with the appropriate technologies and mechanisms. The intelligence and efficiency of systems in the e-marketplace can be drastically enhanced by introducing mobile agents in various levels. In this paper, we propose a dynamic multilateral negotiation model and we build an effective seller agent negotiation strategy on the grounds of a weighted ranking mechanism adopted by the buyer agents. The objective of this strategy is to extend the functionality of autonomous agents, so that they reach to an agreement aiming to maximise their owner's utility. This approach considers both contract and decision issues, is based on real market conditions, and has been empirically evaluated.**

I. INTRODUCTION

Recently, e-commerce has evolved to a field dominating present and future transactions. While current e-commerce systems offer advantages to both consumers and merchants, it is often the case that they offer little more than electronic catalogues on which credit card payments can be arranged online. In order to harness its full potential and achieve the degree of automation required, a new technology is necessitated. Agent technology, which is already involved in almost every aspect of computing, seems to play a leading role, enabling a new, more flexible, efficient and intelligent generation of e-commerce systems. In such systems, automated software agents participate in trading activities on behalf of their owner. This paper is based upon the notion of interacting autonomous agents that act in order to achieve particular objectives and accomplish the goals of their owners in a negotiation environment.

Mobile intelligent agents can act as mediators in five of the six e-commerce phases [1]. This paper explores the role and behaviour of agents in the negotiation phase. In human negotiations, the parties bargain to determine the price or other transaction terms. In automated negotiations, software agents adopt broadly similar processes to achieve the same end. When building an autonomous agent that is capable of flexible and sophisticated negotiation, three broad areas need to be considered [2]: (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" [3] between the agents. Then, depending on the goals set for the agents and the negotiation protocol and model, the negotiation strategies are determined [4]. Given the wide variety of possibilities, there is no universally best approach or technique for automated negotiations [5], rather protocols and strategies need to be set according to the prevailing situation.

This paper concentrates predominantly on the 1st and 3rd issue, proposing a negotiation protocol to be employed in an automatic multi-lateral, multi-step negotiation model and providing an efficient negotiation strategy for the electronic Business-to-Consumer marketplace. The roles of the negotiation agents in this framework may be classified into two main categories that, in principle, are in conflict: the Buyer Agents (BAs) and the Seller Agents (SAs), which 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 [6]. In essence, the agents hold private information, which may be revealed incrementally, only on an as-needed basis. The negotiation environment considered covers multi-issue contracts and multiparty 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, and assist agents to reach to a satisfactory agreement within the specified time-limits. In comparison to a more simplified negotiation strategy recently designed by the authors [7], the strategy presented hereafter demonstrates improved performance with respect to time and communication resources required.

The rest of the paper is structured as follows. In *Section II* the negotiation protocol and model adopted are briefly presented, which do not employ the alternating sequential offers pattern but instead use a contract ranking mechanism. *Section III* provides a formal negotiation problem description. *Section IV* elaborates on the negotiation strategy designed, which enables agents to reach to good agreements in reasonable time and is adequate for cases where BAs' rationale is limited. Finally, in *Section V* conclusions are drawn and directions for future plans are given.

II. NEGOTIATION PROTOCOL & MODEL

In relative research literature, the interactions among the parties mostly follow the rules of an alternating sequential protocol, where the agents in turn make offers and counter offers. This model requires an advanced reasoning component on behalf of the BA as well as the SA. In this paper we tackle the case where the BA does not give a counter offer to the SA, but ranks the SA's offers instead. This ranking is then provided to the SA, in order to generate a better proposal. This process continues until a mutually acceptable contract is reached. This is more efficient in cases in which 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.

Once the agents have determined the set of issues over which they will negotiate, the negotiation process consists of an alternate succession of N contract proposals on behalf of the SA, and subsequent rankings of them by the BA, according to its preferences and current conditions. At each round, the SA sends to the BA N contracts (i.e., N packets consisting of 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. Hereafter, 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 non-negotiable parameters' values.

In [8] we presented an efficient dynamic multi-party, multi-issue negotiation model appropriate for the needs of the e-marketplace. Based on the designed negotiation protocol, the proposed model is exploited by the SA to create subsequent contracts, while used by the BA to evaluate and rate the contracts offered. Hereafter, only the aspects of the model that are necessary for the comprehension of the proposed strategy will be presented.

We introduce the notion of *decision issues* (*DIs*), whose values are not under negotiation and they are not included in the contract parameters, but they affect the evaluation of the values of the contract issues. Such issues may include the competitor companies number, the substitute or complementary products/services number, the quantity of product in stock, the number of current/potential buyers, the time upon which the negotiation deadline is reached, the resources availability and restrictions, etc. 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 not only affect the evaluation of the contracts, but they also have an impact on the generation of subsequent offers, as negotiators must be able to evaluate the utility of the contracts under the current conditions in the e-marketplace and act accordingly.

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 the values of the DIs we will use the following notation: d_j, $j=1,...,m$. Let $U_i^a:[m_i^a,M_i^a]\to[0,1]$ express the utility that agent $a\in S\cup B$ assigns to a value of contract issue i in the range $[m_i^a,M_i^a]$ of its acceptable values. Let w_i^a be the importance of issue i for agent a. 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: $U^a(C_k)=\sum_{i=1}^{n} w_i^a U_i^a\left(c_{ki},d_j^{t=t_k}\right)$, 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 order for the utility function of any contract issue i for any negotiator to lie within the range $[0,1]$, the value c_i of issue i must lie within the range of its acceptable values. To ensure this, we introduce the *value constraints* notion as follows: $m_i^a\le c_i\le M_i^a$. Based on this, we define the *value constraint validity vector*: $VCV^a=[VCV_i^a]$, $i=1,...,n$, 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., $VCV_i^a=0$).

As already mentioned, the BA ranks the contracts proposed by the SA. For the ranking function proposed, the 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 negotiation terminates as the proposed by the SA contract is accepted by the BA. 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: $CVCV_k^a=\prod_{i=1}^{n} VCV_{ki}^a$. In case all *value constraints* are met for contract C_k, it stands $CVCV_k^a=1$, otherwise $CVCV_k^a=0$ and 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 $N\ge1$ 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 of 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.

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 if they decide to quit the process. If an agreement is finally reached, then the negotiation is successful, while in case one of the negotiating parties quits it is unsuccessful. In any other case, we say that the negotiation thread is active.

III. NEGOTIATION PROBLEM DESCRIPTION

The objective of our problem is to find a contract $C_{final}=\{c_{1final},c_{2final},...,c_{nfinal}\}$ that maximises the Seller's overall utility function $U^S(C_{final})$, i.e., the Seller's satisfaction stemming from the proposed contract, while the constraints on the acceptable value ranges, the utility reservation values and the negotiation deadlines for both the BA and the SA are satisfied. 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 $[m_i^S,M_i^S]$ 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 $P^{t_l}=\{C_1^{t_l},...,C_N^{t_l}\}$ of the N contracts

$C_k^{t_l} = \{c_{k1}^{t_l},...,c_{kn}^{t_l}\}$ ($k = 1,...,N$) proposed by the SA to the BA during the previous round l, (vi) the vector $R^{t_l} = \{r_1^{t_l},...,r_N^{t_l}\}$ 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 $VCV_k^B = \{VCV_{ki}^B\}$ ($i = 1,...,n$) for at least one of the contracts proposed, *find* the vector $P^{t_{l+1}} = \{C_1^{t_{l+1}},...,C_N^{t_{l+1}}\}$ of the N contracts $C_k^{t_{l+1}} = \{c_{k1}^{t_{l+1}},...,c_{kn}^{t_{l+1}}\}$ ($k = 1,...,N$) that should be proposed by the SA to the BA at 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., $VCV_k^S = \{VCV_{ki}^S\} = \underline{1}$ ($i = 1,...,n$), $U^S(C_k^{t_{l+1}}) \geq U_{\min Acc}^S$ 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 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, SAs are in the following section provided with a mechanism enabling them to find near-optimal solutions in reasonable time, by means of computationally efficient algorithms.

IV. THE PROPOSED NEGOTIATION STRATEGY

In this section an efficient negotiation strategy that fully exploits the potential of the designed negotiation model is described. This 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, whose contract issues values lie within the acceptable ranges for 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 duration $t_{l+1} - t_l$ of each negotiation round l is considered to be almost constant. Thus, the maximum number of rounds within which the SA is authorised to complete the negotiation with the BA is: $L = INT(T/(t_{l+1} - t_l))$. The rest of the section is structured as follows. *Subsection IV.A* provides the ranking mechanism of the BA, *subsection IV.B* presents in detail the SA's negotiation strategy, while in *subsection IV.C* the proposed negotiation strategy is applied to a use case.

A. The Ranking Mechanism of the Buyer

In this negotiation strategy, the Buyer provides ranks that are estimated on the basis of the Buyer's utility function, which in essence measures the degree of the Buyer's satisfaction stemming from each contract proposed by the Seller. In case a value constraint for one or more contract issues in the context of contract $C_k^{t_l}$ are violated (i.e., if for $c_{ki}^{t_l}$ it stands that $VCV_i^{B,t_l} = 0$) the rank of $C_k^{t_l}$ returned to the Seller is equal to zero (i.e., $r_k^{t_l} = 0$). Hereafter, for notation simplicity, we consider that the ranks are normalized, i.e., they lie within the range $[0,1]$. Two different approaches may be adopted for the calculation of the Buyer ranks. The first and more general approach uses the following expression: $r_k^{t_l} = \frac{U^B(C_k^{t_l})}{\max U^B(C_k^{t_l})}$, $k = 1,...,N$, where $r_k^{t_l}$ is the rank assigned to contract $C_k^{t_l}$, $U^B(C_k^{t_l})$ denotes the Buyer's utility stemming from the C_k^t contract proposed by the Seller at time t_l and $\max U^B(C_k^{t_l})$ is the maximum utility the Buyer may acquire with regard to the contract and decision issues' values depending on environmental conditions, and limitations at the time the Seller's proposal P^{t_l} was generated. Thus, $r_k^{t_l}$ indicates the relative success of each contract with respect to the best – for the Buyer–possible contract at each negotiation round (i.e., to the one representing the maximum utility the Buyer may acquire at time t_l).

Since decision issues values are considered to be invariable and equal to $\underline{d}^{t_0} = \{d_j^{t_0}\}$ during the whole negotiation procedure, quantity $\max U^B(C_k^{t_l})$ is constant, and can be denoted by $U_{\max}^{B,t_0}$. It is noted that it stands $U_{\max}^{B,t_0} \leq 1$, where $U_{\max}^{B,t_0} = 1$ in case the environmental conditions are the most favorable to the Buyer. Therefore, in this negotiation strategy, the ranks are estimated based on the following formula: $r_k^t = \frac{U^B(C_k^t)}{U_{\max}^{B,t_0}}$, $k = 1,...,N$. Ranks could also be given by the function: $r_k^t = U^B(C_k^t)$, without affecting the designed algorithm results. Thus, hereafter, we consider that the Buyer gives ranks strictly proportional to the utility of the contracts under assessment.

B. The Contract Generation Mechanism of the Seller

Based on the *RFP* sent by the BA, 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 Seller's utility (i.e., if $\partial[U^S(C_k, \underline{d}^{t_0})]/\partial c_i > 0$, then the SA sets $c_i^{t_0} = M_i^S$, while in case $\partial[U^S(C_k, \underline{d}^{t_0})]/\partial c_i < 0$, 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: $U^S(C^{t_0}, \underline{d}^{t_0}) = U_{\max}^{S,t_0}$, as $U_{\max}^{S,t_0}$ is the maximum utility that can be achieved for the Seller, given the values of the decision issues $\underline{d}^{t_0} = \{d_j^{t_0}\}$ at time $t = t_0$. Subsequently, the initial contract C^{t_0} is ranked by the Buyer with r^{t_0}.

The proposed negotiation strategy is designed so that the number N of the contracts proposed by the SA to the BA at each negotiation round is equal to the number n of the contract issues, i.e., the following equation holds: $N = n$. The general idea of the proposed approach 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 Seller, given the values of the decision issues $\underline{d}^{t_0}$ at the beginning of the negotiation, i.e., $U^S(C_k^{t_l}, \underline{d}^{t_0}) = U^S(C_{k'}^{t_l}, \underline{d}^{t_0})$, $\forall k, k' \in \{1,...,n\}$, $\forall l = 1,...,L$. Contract C^{t_0} is the "source" contract of the first complete negotiation round ($l = 0$), i.e., $C_0^{t_1} = C^{t_0}$.

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

$\Theta^{t_l} = U^S(C_k^{t_{l-1}}, \underline{d}^{t_b}) - U^S(C_k^{t_l}, \underline{d}^{t_b})$. 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., $\Theta^{t_l} = \Theta^{t_b}$, $\forall l = 1,...,L$. Hereafter, we consider that upon the Seller's deadline, the SA concedes up to its reservation value. Thus, the following stand: $U^S(C^{t_b}, \underline{d}^{t_b}) = U_{\max}^{S,t_b}$ and $U^S(C_k^{t_L}, \underline{d}^{t_b}) = U_{\min Acc}^S$. Using these two equations we may define quantity Θ^{t_b} as follows: $\Theta^{t_b} = \frac{U_{\max}^{S,t_b} - U_{\min Acc}^S}{L}$, i.e., at each negotiation round, all contracts proposed by the SA correspond to Seller utility reduced by Θ^{t_b}, with regards to the contracts of the previous round.

As already mentioned, contract C^{t_b} for which it stands $U^S(C^{t_b}, \underline{d}^{t_b}) = U_{\max}^{S,t_b}$ is the "source" contract of the first complete negotiation round ($l = 0$), i.e., $C_0^{t_l} = C^{t_b}$. 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_b} with respect to the source contract $C_0^{t_l}$. Thus, the utility of the contracts proposed is $U^S(C_k^{t_l}, \underline{d}^{t_b}) = U^S(C_0^{t_l}, \underline{d}^{t_b}) - \Theta^{t_b}$, while $\forall k = 1,...,n$ $U^S(C_k^{t_{l-1}}, \underline{d}^{t_b}) = U^S(C_0^{t_l}, \underline{d}^{t_b})$. Any contract $C_k^{t_l}$ 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., $C_k^{t_l} = \{c_{01}^{t_l},...,c_{0(k-1)}^{t_l}, c_{kk}^{t_l}, c_{0(k+1)}^{t_l},...,c_{0n}^{t_l}\}$, whose value $c_{kk}^{t_l}$ is selected so that the utility of contract $C_k^{t_l}$ for the Seller is respects the aforementioned aspect. According to the previous analysis, we have the following: $U^S(C^{t_b}, \underline{d}^{t_b}) = U_{\max}^{S,t_b}$ and $U^S(C_k^{t_L}, \underline{d}^{t_b}) = U_{\min Acc}^S$. It is noted that in case an agreement between BA and SA is feasible, our approach will succeed in reaching within the negotiation thread upon an agreement due to the assumption that as its deadline approaches, the SA concedes up to its reservation value $U_{\min Acc}^S$.

As already described in the negotiation model analysis, at each negotiation round l, the SA provides the BA with a contract proposal $P^{t_l} = \{C_1^{t_l},...,C_n^{t_l}\}$. The BA in return, sends to the SA the ranking vector $R^{t_l} = \{r_1^{t_l},...,r_n^{t_l}\}$ for the respective contract package proposal along with the *value constraint validity vector* $VCV^{B,t_l} = \{VCV_i^{B,t_l}\}$, $i = 1,...,n$, for the "source" contract $C_0^{t_l}$ of the round, where $VCV_i^{B,t_l} \in \{0,1\}$, depending on whether the value constraint of the BA is met for issue i (i.e., $VCV_i^{B,t_l} = 1$) or not (i.e., $VCV_i^{B,t_l} = 0$) for this contract.

One critical issue of this negotiation strategy is the mechanism that leads to the formulation of the "source" contract $C_0^{t_l}$ of a negotiation round $l > 1$. This depends strictly on: (i) the ranking vector $R^{t_{l-1}} = \{r_1^{t_{l-1}},...,r_n^{t_{l-1}}\}$ assigned by the Buyer to the contract proposal $P^{t_{l-1}} = \{C_1^{t_{l-1}},...,C_n^{t_{l-1}}\}$ of the Seller at the $l-1$ negotiation round, (ii) on the "source" contract $C_0^{t_{l-1}}$ of that negotiation round, and (iii) on the *value constraint validity vector* $VCV^{B,t_{l-1}} = \{VCV_i^{B,t_{l-1}}\}$ that the Buyer provided for the "source" contract $C_0^{t_{l-1}}$. Following the presented approach, one may observe that the higher the Buyer ranks contract $C_k^{t_{l-1}}$, then the higher the same Seller utility reduction Θ^{t_b} due to adjustments on the value $c_{kk}^{t_{l-1}}$ of contract issue $i = k$, is valued by the Buyer. On the other hand, in case the rank of any contract $C_k^{t_{l-1}}$ is low (where all Seller utility reduction Θ^{t_b} is due to adjustments on the value $c_{kk}^{t_{l-1}}$ of contract issue $i = k$), this indicates that contract issue $i = k$ is not very important for the Buyer. Thus, in this case, it does not "worth" it for the Seller to start the next negotiation round with a "source" contract $C_0^{t_l}$, where a high percentage of the total Seller utility reduction Θ^{t_b} is due to adjustments on the value $c_{kk}^{t_{l-1}}$ of contract issue $i = k$. This stands in any case, apart from the one where the rank of a contract $C_k^{t_{l-1}}$ is equal to zero ($r_k^{t_{l-1}} = 0$), which indicates that the value $C_k^{t_{l-1}}$ of at least one contract issue is $c_{ki}^{t_{l-1}} \notin [m_i^B, M_i^B]$.

Two priority objectives are set in the formulation of the "source" contract $C_0^{t_l}$: (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). The general idea is that pursuing these two objectives, it is best for the Seller to start the next negotiation round based on a "source" contract $C_0^{t_l} = \{c_{01}^{t_l},...,c_{0n}^{t_l}\}$ that has spread the Seller utility reduction Θ^{t_b} of the round to all contract issues as follows: (i) the maximum possible "compromise" will be assigned to those contract issues that correspond to $VCV_i^{B,t_{l-1}} = 0$ (i.e., their values in the previous "source" contract $C_0^{t_{l-1}}$ do not lie within the Buyer's acceptable range), (ii) for the rest of the contract issues, the "compromise", as far their values are concerned, will be stronger for the ones that present higher ranks and weaker for the ones that present lower ranks. Based on the above analysis, we designed the formula that generates the "source" contract $C_0^{t_l}$ of negotiation round $l > 1$ as follows:

Let $r^{t_{l-1}} = \sum_{k=1}^{n} \left[VCV_{i=k}^{B,t_{l-1}} \cdot r_k^{t_{l-1}} + \overline{VCV_{i=k}^{B,t_{l-1}}} \right]$ be the sum of the ranks of all contracts proposed in $l-1$ negotiation round increased by the number of contract issues that do not lie within the Buyer's acceptable range in the previous "source" contract $C_0^{t_{l-1}}$. Then the new "source" contract $C_0^{t_l} = \{c_{01}^{t_l},...,c_{0n}^{t_l}\}$ can be expressed as follows:

$$c_{0i}^{t_l} : U^S(c_{0i}^{t_{l-1}}, \underline{d}^{t_b}) - U^S(c_{0i}^{t_l}, \underline{d}^{t_b}) = \frac{VCV_i^{B,t_{l-1}} \cdot r_{k=i}^{t_{l-1}} + \overline{VCV_i^{B,t_{l-1}}}}{r^{t_{l-1}}} \cdot \frac{\Theta^{t_b}}{w_i^S}.$$

In this equation the only unknown variable is $c_{0i}^{t_l}$, that can now be defined.

In 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. The same logic is followed, in case the resulting value $c_{0i}^{t_l}$ of a contract issue i in the "source" contract $C_0^{t_l}$ of the negotiation round l ends up to lie outside the acceptable range of the SA.

C. Applying the proposed Strategy in a Use Case

In order for the proposed negotiation strategy to be clear for the reader, an illustrative example is presented in this subsection. The framework of the selected use 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 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: $[m_1^S, M_1^S] = [10,20]$, $[m_1^B, M_1^B] = [8,18]$, $[m_2^S, M_2^S] = [2,12]$ and $[m_2^B, M_2^B] = [1,10]$, while the possible value range for the decision issue is: $[m_{d_1}, M_{d_1}] = [0,40]$ (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: $[w_1^S, w_1^B, w_2^S, w_2^B] = [0.8, 0.6, 0.2, 0.4]$, 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 use case we have $U_{\min Acc}^S = 0.38$ 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: $U^S(C_{final}) \geq 0.38$ and $U^B(C_{final}) \geq 0.40$).

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:

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

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

$$U_2^S = \frac{c_2 - m_2^S}{M_2^S - m_2^S}, \text{ for } c_2 \in [m_2^S, M_2^S],$$

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

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). The maximum possible duration of a negotiation thread is equal to $T = 10\text{sec}$, 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 $t_{l+1} - t_l \approx 1\text{sec} \ \ \forall l$. Thus, the maximum number of rounds within which the Seller is authorised to complete the negotiation with the Buyer is: $L = INT\left(\frac{\text{T}}{t_{l+1} - t_l}\right) = INT\left(\frac{10\text{sec}}{1\text{sec}}\right) \Rightarrow L = 10$. This value indicates that the maximum –acceptable by the Seller– number of rounds is equal to $L = 10 \Rightarrow l \leq 10$. Thus, the utilities of the contract issues for the two negotiators can be expressed as follows: $U_1^S = 0.085 \cdot c_1 - 0.85$, for $c_1 \in [10,20]$, $U_1^B = 1.71 - 0.095 \cdot c_1$, for $c_1 \in [8,18]$, $U_2^S = 0.1 \cdot c_2 - 0.2$, for $c_2 \in [2,12]$, and $U_2^B = 1 - 0.1 \cdot c_2$, for $c_2 \in [1,10]$.

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 *Fig. 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 (in *Fig. 1* marked in blue colour). Based on our negotiation model and strategy, in the case aforementioned, the Seller does not propose the contract generated (that is if $c_1 < 10$ and/or if $c_2 < 2$) but seeks to propose another contract within his/her acceptable contract domain. On the other hand, if such 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.

For our example the number N of the contracts proposed by the SA to the BA at each negotiation round will be equal to $n = 2$ (i.e., the number of the contract

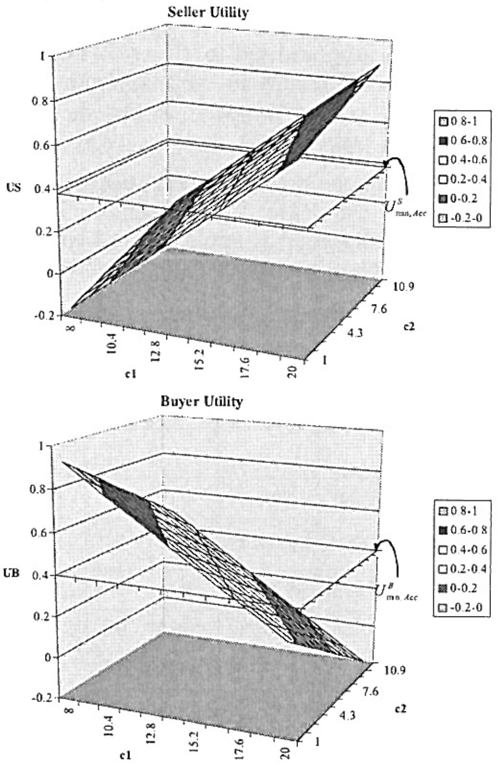

Fig. 1. Utility functions of the two negotiating parties with regards to the two contract issues.

issues). 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: $\Theta^{t_0,l} = \Theta^{t_0} = \frac{U_{\max}^{S,t_0} - U_{\min Acc}^{S}}{L} = 0.05 \Rightarrow$
$U^S\left(C_k^{t_l}, \underline{d}^{t_0}\right) = U^S\left(C_k^{t_{l-1}}, \underline{d}^{t_0}\right) - 0.05 = U^S\left(C_0^{t_l}, \underline{d}^{t_0}\right) - 0.05$, $\forall l = 1,\ldots,10$.

The negotiation process is initiated by the Buyer who sends to the Seller an initial RFP specifying the types of the contract issues and the values of all non negotiable parameters. 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 $U^S\left(C^{t_0}, \underline{d}^{t_0}\right) = 0.88 = U_{\max}^{S,t_0}$. Assuming that the Buyer assigns ranks to the contracts proposed equal to its utility (i.e., $r_k^{t_l} = U^S\left(C_k^{t_l}, \underline{d}^{t_0}\right)$), 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., $C_0^{t_1} = C^{t_0} = [20,12]$.

Subsequently, the SA computes the two contracts to be proposed to the BA. According to the designed negotiation strategy, we will have: $C_1^{t_1} = \left[c_{11}^{t_1}, 12\right]$ and $C_2^{t_1} = \left[20, c_{22}^{t_1}\right]$, so that $U^S\left(C_k^{t_1}, \underline{d}^{t_0}\right) = U^S\left(C_0^{t_1}, \underline{d}^{t_0}\right) - \Theta^{t_0} = 0.83$. In *Table 1* the results for the "source" contract, its value constraint validity vector, the two contracts proposed and the BA's ranks for both contracts are provided, for all the negotiation rounds until an agreement is reached.

As you can see from *Table 1*, the agreement contract (highlighted in blue) is $C_2^{t_9} = [16.32,2.0]$ and is proposed from the SA to the BA at the ninth negotiation round. This contract results in Seller utility equal to $U^S\left(C_2^{t_9}, \underline{d}^{t_0}\right) = 0.4300$ and in Buyer utility equal to $U^B\left(C_2^{t_9}, \underline{d}^{t_0}\right) = 0.4156$. Thus, the negotiation strategy proposed 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.

Via the above use case we presented how the negotiation strategy designed is applied in a two contract issues framework. This illustrative example produced near optimal results, presenting only 2% lower social welfare than the optimal solution.

TABLE 1. Example of negotiation strategy application

l	U^S	$C_0^{t_l} = \left[c_{01}^{t_l}, c_{02}^{t_l}\right]$	$C_1^{t_l} = \left[c_{11}^{t_l}, c_{12}^{t_l}\right]$	$C_2^{t_l} = \left[c_{21}^{t_l}, c_{22}^{t_l}\right]$	$r_1^{t_l}$	$r_2^{t_l}$	$VCV^{B,t_l} = \left[VCV_1^{B,t_l}, VCV_2^{B,t_l}\right]$
$l=0$	0.88	[20,12]	-	-	0		[0,0]
$l=1$	0.83	[20,12]	[19.26,12]	[20,9.5]	0	0	[0,0]
$l=2$	0.78	[19.63,10.75]	[18.90,10.75]	[19.63,8.25]	0	0	[0,0]
$l=3$	0.73	[19.26,9.50]	[18.53,9.50]	[19.26,7.0]	0	0	[0,1]
$l=4$	0.68	[18.53,9.50]	[17.79,9.50]	[18.53,7.0]	0.0317	0	[0,1]
$l=5$	0.63	[17.79,9.50]	[17.06,9.50]	[17.79,7.0]	0.0736	0.1317	[1,1]
$l=6$	0.58	[17.53,7.90]	[16.80,7.90]	[17.53,5.40]	0.1528	0.2109	[1,1]
$l=7$	0.53	[17.22,6.44]	[17.49,6.44]	[17.22,3.95]	0.2284	0.2865	[1,1]
$l=8$	0.48	[16.90,5.06]	[16.16,5.06]	[16.90,2.56]	0.3026	0.3607	[1,1]
$l=9$	0.43	[16.56,3.70]	[15.82,3.70]	[16.32,2.0]	0.3761	1	[1,1]

V. CONCLUSIONS

A multiparty, multi-issue, dynamic negotiation model and an effective strategy were presented in this paper, both to be exploited by mobile intelligent agents in an e-commerce environment, in case the disclosure of information is not acceptable, possible, or desired. On the Buyer side, the efficiency of the proposed framework is due to the fact that the Buyer agent adopts a flexible and light reasoning component that employs a weighted ranking mechanism. This approach does not necessitate the explicit statement of all preferences and requirements on behalf of the Buyer in a completely quantified way, thus protecting the Buyers' privacy, while being more time and resource efficient. This 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 negotiators' state. Besides its inherent computational and communication advantages, its efficiency is due to the fact that an agreement between Buyer and Seller is reached in any situation it is feasible, before the predefined by the negotiators 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 presented approach produces near optimal results, in case the number of the negotiation and decision issues is quite high. Future plans involve extensive empirical evaluation of both the model and strategy designed. This evaluation will be carried out against the performance of existent models and strategies and against the optimal solution of the negotiation problem, i.e., the one maximizing the social welfare. Additionally, issues of malicious transactions between the buyers and the sellers should be addressed.

VI. REFERENCES

[1] M. He, N. R. Jennings, and H. Leung, "On agent-mediated electronic commerce", *IEEE Trans. on Knowledge and Data Engineering*, vol. 15, no. 4, pp. 985-1003, 2003.

[2] P. Faratin, C. Sierra, and N. R. Jennings, "Negotiation Decision Functions for Autonomous Agents", *Int. Journal of Robotics and Autonomous Systems*, vol. 24, no. 3-4, pp. 159-182, 1998.

[3] J. S. Rosenschein and G. Zlotkin, *Rules of Encounter: Designing Conventions for Automated Negotiation among Computers*, Massachusetts: The MIT Press, Cambridge, MA, USA, 1994.

[4] M. Louta and I. Roussaki, "Efficient Negotiation Framework and Strategies for the Next Generation Electronic Marketplace", MBA Thesis, 2003.

[5] N. R. Jennings, P. Faratin, A. R. Lomuscio, S. Parsons, C. Sierra, and M. Wooldridge, "Automated Negotiation: Prospects, Methods, and Challenges", *Int. Journal of Group Decision and Negotiation*, vol. 10, no. 2, pp. 199-215, 2001.

[6] V. Conitzer and T. Sandholm, "Computational criticisms of the revelation principle", in *Proceedings of the 5th Workshop on Agent Mediated Electronic Commerce*, Australia, 2003.

[7] M. Louta, I. Roussaki, and L. Pechlivanos, "An effective Negotiation Strategy for simple buyer response in E-commerce environment", in *Proceedings of the 2004 IEEE International Conference on Intelligent Systems* (in press).

[8] I. Roussaki, M. Louta, and L. Pechlivanos, "An Efficient Negotiation Model for the Next Generation Electronic Marketplace", in *Proceedings of the 2004 IEEE Mediterranean Electrotechnical Conference* (in press).