Efficient Multi-alternative Protocol for Multi-attribute Agent Negotiation

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Abstract: In this paper we present a novel multi-alternative negotiation protocol for multi-attribute agent negotiations. It allows for improvement of negotiation outcomes in terms of time needed to reach an agreement and the Pareto optimality of the outcome. By allowing the agent to offer a proposal comprising a set of alternatives we eliminate the problem of making trade-offs in the negotiation. We experimentally evaluate the proposed approach to show how it performs in comparison to a typical negotiation protocol.

1 INTRODUCTION

In this work we propose a novel negotiation protocol for multi-attribute agent negotiations allowing agents to improve the negotiation outcome both in terms of time needed to perform a successful negotiation and Pareto efficiency of agreements. Typical negotiation protocols used for solving the multi-attribute agent negotiations are based on exchanging single offers. This means that in the consecutive rounds of negotiation an agent can only propose a single agreement alternative. Such a negotiation protocol requires an agent to trade-off between multiple attributes of an object under negotiation in order to improve the negotiation outcome in terms of Pareto efficiency. However, making trade-offs in multi-attribute negotiations is a difficult problem since it is hard to determine the direction of trade-offs that guarantees the optimal outcome.

Works of John Nash (Nash, 1950) formulate the negotiations as cooperative games and propose a solution in the form of an arbitration scheme, which underpins mediation in negotiations. Based on the Nash bargaining solution a negotiation protocol needs to allow the agents to truthfully reveal their preferences to a trusted third party, i.e. a mediator. The preferences are aggregated by the mediator to determine a solution satisfying a series of axioms. The problem in such an approach is the assumption of truthful revelation of preferences. Therefore, instead of revealing the full structure of preferences, a number of negotiation protocols assume the agents can exchange single offers repeatedly until they reach an agreement. The method based on multiple exchange of offers is more practical and realistic since the structure of preferences is not revealed.

In general, most existing approaches are based either on the assumption of knowledge about the opponents preferences or the use of a trusted third party, i.e. mediator that can guide the negotiation agents in making efficient trade-offs and reaching an agreement. In the mediation approach the parties submit some knowledge about their preferences to the mediator that fuses the knowledge of both parties and proposes solutions. Ethamo et. al (Ethamo et al., 1999) present a constraint proposal method to generate a Pareto frontier of a multi-attribute negotiation. The mediator generates a constraint in each consecutive step and asks the parties to find an optimal solution satisfying this constraint. If the feedback from the agents coincide then a solution is found, otherwise the mediator updates the constraint based on the received feedback and the procedure continues. The approach proposed by Klein et al. (Klein et al., 2003) addresses mediation in the case of complex contracts where the values of issues are binary (either 0 or 1). In each stage of mediation the unbiased mediator generates an offer and proposes it to the parties. In the next stage the agents vote whether to accept the offer or not according to their private strategies. If both agents vote to accept the proposed offer it is mutated in the next stage (values of some issues are switched) and the procedure is repeated. In the case one of the agents votes to reject an offer, the last acceptable of-

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fer is mutated and proposed again to the parties. In the work of Li et al. (Li et al., 2011) the authors present an approach for supporting mediation with the use of the Conditional Preference (CP) Networks. Similarly to the approach of Klein et al. (Klein et al., 2003) the approach is applicable for issues with low level of options. The agents build their CP networks that encode their preferences and then submit them to the third party which fuses the preferences by the use of majority rule-based aggregation.

The approaches to trade-off performed by individual agents, rather than the mediator, include a mechanism proposed by Faratin et al. (Faratin et al., 2002) that uses similarity criteria. The trade-off is performed according to a similarity measure between the last offer proposed by the counterpart and the current proposal of the negotiation agent. In making a trade-off the indifference curve is considered. An alternative located on the indifference curve that maximizes the similarity to the last offer proposed by the counterpart is selected for a proposal. Other approaches modify protocols of negotiation allowing the agents to include in the proposal different type of knowledge apart form the negotiation alternative, i.e. the agent can also send to the counterpart arguments aiming at convincing the partner to change his beliefs. A belief that can be influenced by such a kind of persuasion is typically the utility function of the counterpart. Sycara (Sycara, 1991) proposes an approach incorporating argumentation into negotiation and illustrates the merit of argumentation-based reasoning in negotiation dialogues.

Some works also consider protocols dependent on the shape of preferences. Ito et all. (Ito et al., 2007) consider non-linear utility functions, and propose a protocol where the agents employ adjusted sampling to generate proposals and use a bidding-based mechanism to find social welfare maximizing deals. However, in their work they also assume that the bids are submitted to the mediator, which again is an issue since such a protocol assumes revelation of private information. Similarly as in other works (Hattori et al., 2007), (Fujita et al., 2010a) (Fujita et al., 2010b) there is an issue with assuming a central authority to which the information about utilities is revealed. Such solutions require the presence of a third trusted party that is unbiased, independent and capable of carrying out intensive computation.

In the work (Bichler and Segev, 2001) authors present an approach towards establishing a toolset for the design of negotiation protocols on electronic markets focusing rather on mechanism of auction and assuming single-offer bids.

The work of Lai et al. (Lai et al., 2008) presents a decentralized model for self-interested agents aiming at reaching win-win solutions in the multi-attribute negotiation. At each negotiation round an agent proposes a multi-alternative offer, namely it offers several alternatives in one round. When making a counter-offer the partner uses heuristic search in order to propose an offer located on the indifference curve that is closest to the best alternative contained in the set proposed by its counterpart in the previous offer. This alternative is used as a seed and the remaining alternatives that will be send together with the seed are chosen from the neighbourhood of this alternative. However in that approach there is no guarantee of reaching a Pareto optimal solution.

In this paper we propose a protocol that uses multi-alternative offers and allows the agents to reach a Pareto optimal solution. In our approach the agents exchange offers consisting of sets of alternatives determined by α-cuts of the search space in each round of negotiation. Therefore, we do not need to apply any heuristic to search the space of alternatives that can be proposed. The proposed protocol is presented in Section 2. Its experimental evaluation and discussion of the results is presented in Section 3. The concluding remarks are presented in Section 4.

2 THE NOVEL NEGOTIATION PROTOCOL

Typical protocols used in agent negotiation are based on exchanging single alternative proposals. Namely in each consecutive round of negotiation an agent sends to its counterpart an offer consisting of a single alternative. In such an approach the agents are forced to perform trade-offs while looking for agreement that can satisfy the preferences of both negotiation parties. In this paper we consider an approach in which instead of single alternative offers the agents can use multiple alternatives enclosed in one negotiation proposal. In such a situation the sending agent assumes that all alternatives enclosed in the offer are acceptable with the same value of utility. This means that all alternatives proposed in one round of negotiation are indifferent to the proposing agent. The counterpart receiving the offer can check each of the alternatives contained in the offer to what extend its preferences are satisfied. In such a situation the receiver can select the alternative maximizing its utility and decide if such an alternative is suitable to form an agreement. It is intuitive that in the case of multiple alternatives forming one proposal the chance of finding an agreement is higher than in the case of a protocol where a single alternative is proposed. Indeed, as we will show later in this paper an agreement is reached faster and its value is more efficient than in the case of a typical protocol. More specifically the proposed protocol is realized as follows. The preferences of a negotiator are encoded by an utility functions assigning to each feasible alternative a score. The agent concedes during the negotiation process in the space of utility according to its negotiation strategy. At each negotiation round the agent proposes a full set of alternatives (in a discrete space of alternatives) exceeding the current value of utility. The offer comprising all alternatives exceeding particular value of utility that eliminates the need of using trade-offs since the offer contains the whole indifference curve.

2.1 Negotiation Thread

The negotiation thread is a sequence of proposals and counter-proposals of two negotiation parties. As said above the elements of the sequence are subsets of the acceptance sets of two negotiation parties. Let us assume that the agents defined its utility functions u^a and u^b over the sets of feasible two-attribute alternatives D^a and D^b (acceptance sets) of agent a and agent b, respectively.

Definition 1. *A Negotiation thread between agents $a,b \in Agents$ at time $t_n \in Time$ is any finite sequence of length n of the form $(C^{t_1}_{a\to b}, C^{t_2}_{a\to b}, \dots, C^{t_n}_{a\to b})$ with $t_1, t_2, \dots, t_{n-1} \leq t_n$, where:*

1. *$t_{i+1} > t_i$*
2. *Each offer $C^{t_i}_{a\to b}$ proposed by agent a is determined in the following way: $C^{t_i}_{a\to b} = \{(x,y) \in D^a \,|\, u^a(x,y) \geq f^a(t_i)\}$ where $f^a(t_i)$ is the concession in utility space in time point t_i for agent a*
3. *The analogous offer $C^{t_i}_{b\to a}$ proposed by agent b is determined in the following way: $C^{t_i}_{b\to a} = \{(x,y) \in D^b \,|\, u^b(x,y) \geq f^b(t_i)\}$ where $f^b(t_i)$ is the concession in utility space in time point t_i for agent b*

The negotiation thread is active if none of the agents accepted the offer or withdrew from the negotiation.

2.2 Evaluation Decisions

The evaluation decision says when the negotiation agent can propose its next offer, accept the counterpart's offer or withdraw from the negotiation. When the offer that an agent a is going to propose in the next round overlaps with the last offer of counterpart b the agent a is ready to accept the partners last proposal. The existence of non-empty overlap is equivalent to the condition that the utility function u^a of the agent a exceeds the current level of its concession over the last proposal of the counterpart b. When the overlap is empty the agent a proposes the next offer. In the case of exceeding the time given for negotiation the agent a withdraws.

Definition 2. *For the agent a and its associated utility function u^a, a's interpretation (I) at time t' of the counterpart offer $C^t_{b\to a}$ proposed at time $t < t'$, is defined as:*

$$I_a(t', C^t_{b\to a}) = \begin{cases} withdraw(a,b) & \text{if} \quad t' > t_{max} \\ accept(a,b,p(C^t_{b\to a} \cap C^{t'}_{a\to b})) & \text{if} \quad f(t',\beta^a) \in u^a(C^t_{b\to a}) \\ offer(a,b,C^{t'}_{a\to b}) & \text{otherwise} \end{cases} \tag{1}$$

where f is a decision function and β^a is the parameter determining the shape of concession curve generated with function f and p is a function choosing any point from the set. The equivalent definition of interpretation is of the following form:

$$I_a(t', C^t_{b\to a}) = \begin{cases} withdraw(a,b) & \text{if} \quad t' > t_{max} \\ accept(a,b,p(C^t_{b\to a} \cap C^{t'}_{a\to b})) & \text{if} \quad C^t_{b\to a} \cap C^{t'}_{a\to b} \neq \emptyset \\ offer(a,b,C^{t'}_{a\to b}) & \text{otherwise} \end{cases} \tag{2}$$

According to the above interpretation the negotiation outcome is one point taken from the set $C^t_{b\to a}$. The agent a will accept such a point if its current acceptance threshold $f(t',\beta^a)$ lies in the image of last opponents offer $C^t_{b\to a}$ under the utility function u^a of agent a. Equivalently, the agent a will accept the point $p(C^t_{b\to a})$ if the intersection of sets $C^t_{b\to a}$ and $C^{t'}_{a\to b}$ is not empty.

2.3 Concession Generation Decisions - Tactics

In order to compute the counter-offer $C^{t'}_{a\to b}$ in the form of a set an agent uses functions called tactics. The tactics allow for computing concessions in the utility space $[0,1]$ that then are used in computation of the proposal.

2.3.1 Time-dependent Tactics

When an agent uses the time-dependent tactic it generates its offers according to time that elapses from the beginning of negotiation. In other words the predominant factor influencing the value of concession is the current point in time. The decision function generating offers in the case of time-dependent tactic is dependent on deadline. The agent is conceding in the utility space down to the lowest value 0 when it is approaching the deadline.

The set proposed at time t, with $0 < t < t^a_{max}$, is determined by a function $\alpha^a(t)$ specifying the current level of utility concession.

$$C^t_{a\to b} = \{(x,y) \in D^a \,|\, u^a(x,y) \geq (1 - \alpha^a(t))\}$$

Table 1: The results of experiment - comparison of the classical approach and the efficient approach for different negotiation strategies. The Table contains utility values obtained by the first agent for two approaches.

β^a / β^b	0.1		0.2		0.5		1		2		5		10	
	u_c	u_a	u_c	u_a	u_c	u_a	u_c	u_a	u_c	u_a	u_c	u_a	u_c	u_a
0.1	0.23	0.28	0.41	0.49	0.74	0.74	0.8	0.8	0.84	0.88	0.92	0.92	0.92	0.95
0.2	0.23	0.28	0.41	0.49	0.63	0.63	0.73	0.73	0.81	0.81	0.86	0.89	0.89	0.92
0.5	0.20	0.23	0.33	0.33	0.48	0.48	0.6	0.6	0.71	0.71	0.73	0.78	0.83	0.83
1	0.14	0.14	0.23	0.23	0.36	0.36	0.46	0.46	0.59	0.59	0.67	0.73	0.76	0.76
2	0.087	0.10	0.15	0.15	0.26	0.26	0.33	0.36	0.46	0.46	0.59	0.59	0.65	0.65
5	0.05	0.05	0.08	0.08	0.26	0.14	0.2	0.23	0.30	0.30	0.40	0.40	0.49	0.49
10	0.02	0.03	0.04	0.05	0.08	0.08	0.13	0.13	0.19	0.19	0.29	0.29	0.49	0.49

Table 2: The results of experiment - comparison of the classical approach and the efficient approach for different negotiation strategies. The Table contains utility values obtained by the second agent for two approaches.

β^a / β^b	0.1		0.2		0.5		1		2		5		10	
	u_c	u_a	u_c	u_a	u_c	u_a	u_c	u_a	u_c	u_a	u_c	u_a	u_c	u_a
0.1	0.23	0.28	0.23	0.28	0.23	0.23	0.14	0.14	0.08	0.10	0.05	0.05	0.02	0.03
0.2	0.41	0.49	0.41	0.49	0.33	0.33	0.23	0.23	0.15	0.15	0.07	0.08	0.04	0.05
0.5	0.68	0.74	0.63	0.63	0.48	0.48	0.36	0.36	0.26	0.26	0.12	0.14	0.08	0.08
1	0.8	0.8	0.73	0.73	0.6	0.6	0.46	0.46	0.36	0.36	0.2	0.23	0.13	0.13
2	0.84	0.88	0.81	0.81	0.71	0.71	0.55	0.59	0.46	0.46	0.3	0.3	0.19	0.19
5	0.92	0.92	0.89	0.89	0.78	0.78	0.67	0.7	0.59	0.59	0.40	0.40	0.29	0.29
10	0.89	0.95	0.89	0.92	0.83	0.83	0.76	0.76	0.65	0.65	0.49	0.49	0.49	0.49

Table 3: The results of experiment - comparison of the classical approach and the efficient approach for different negotiation strategies. The Table contains numbers of rounds used to reach agreement in case of two approaches.

β^a / β^b	0.1		0.2		0.5		1		2		5		10	
	u_c	u_a	u_c	u_a	u_c	u_a	u_c	u_a	u_c	u_a	u_c	u_a	u_c	u_a
0.1	2	1	2	1	5	2	12	6	20	10	36	18	46	22
0.2	2	1	2	1	8	4	16	8	28	13	40	19	46	23
0.5	5	2	8	4	14	8	22	12	30	16	42	22	50	25
1	10	6	16	8	22	12	30	16	38	19	46	23	50	26
2	18	10	26	13	32	16	38	19	42	22	50	25	54	27
5	34	18	37	19	44	22	46	23	50	25	54	27	54	28
10	44	22	45	23	49	25	50	26	54	27	54	28	54	28

The offer defined above includes all alternatives from the acceptance set D^a of the agent a that exceed in terms of utility the current level of concession $1-\alpha^a(t)$. The function $\alpha^a(t)$ can be defined in variety of ways under the condition that $0 \leq \alpha^a(t) \leq 1$. This range is universal since it can be rescaled to fit the space in which the agent is conceding. Faratin (Faratin et al., 2002) proposed two families of functions, namely the polynomial decision functions and exponential decision functions. Both families are parametrized by a value of $\beta \in R^+$ specifying the shape of the concession curve.

- **polynomial** $\alpha^a(t) = k^a + (1-k^a_j)(\frac{min(t,t^a_{max})}{t^a_{max}})^{\frac{1}{\beta}}$
- **exponential** $\alpha^a(t) = e^{(1-\frac{min(t,t^a_{max})}{t^a_{max}})^{\beta} ln k^a}$

where the parameter k^a specifies the first concession, β^a is responsible for the shape of a curve, t^a_{max} is the deadline of the agent a and t is the current point in time. In the next sections we extend the negotiation tactics proposed by Faratin (Faratin et al., 2002) to fit the proposed protocol.

2.3.2 Behaviour-dependent Tactics

The behaviour-dependent tactic computes the next offer imitating the behaviour of the negotiation partner. The concession in the utility space may be determined based on the previous concessions of the negotiation partner. The agent may imitate the concession in different ways. It may imitate the behaviour proportionally, in absolute terms or it may compute the concession as an average of proportions in a number of previous offers. Hence, given the negotiation thread:

$$\ldots, C^{t_n-2\delta}_{b\to a}, C^{t_n-2\delta+1}_{a\to b}, C^{t_n-2\delta+2}_{b\to a}, \ldots, C^{t_n-2}_{b\to a}, C^{t_n-1}_{a\to b}, C^{t_n}_{b\to a},$$

1. **Relative Tit-for-Tat.** The agent imitates the opponent relative value of concession proposed $\delta > 1$ steps ago. The imitative offer is determined by multiplying previous offer of the decision-maker by the relative concession of the counterpart. The relative concession is the quotient of the two consecutive offers of the opponent proposed δ steps ago. The condition of applicability is $n > 2\delta$.

$$C^{t_{n+1}}_{a\to b} = \{(x,y) \in D^a \,|\, u^a(x,y) \leq min(max(\frac{max\, u^a(C^{t_n-2\delta}_{b\to a})}{max\, u^a(C^{t_n-2\delta+2}_{b\to a})} (1-\alpha^a(t_{n-1})),0),1)\}.$$

The value $max\, u^a(C^{t_n-2\delta}_{b\to a})$ is the utility of the best alternative from the set $C^{t_n-2\delta}_{b\to a}$ from the viewpoint of agent a. Therefore, the coefficient $\frac{max\, u^a(C^{t_n-2\delta}_{b\to a})}{max\, u^a(C^{t_n-2\delta+2}_{b\to a})}$ is the proportion of utility by which the negotiation partner conceded between the round $n-2\delta$ and the round $n-2\delta+2$ from the viewpoint of agent a. The proportion is multiplied by the last level of utility concession $1-\alpha^a(t_{n-1})$ what results in the utility level to which the agent a is conceding in the next round of negotiation. The next offer is computed as all alternative exceeding this level of utility in terms of utility function of the agent a.

2. **Random Absolute Tit-for-Tat.** The agent imitates the concession of the opponent in absolute terms. This means that for example if the concession of the opponent was 0.2 of utility then the agent also concedes by 0.2. Additionally, the concession is modified by a random value in order to enable an agent to avoid a loop of non-improving contract offers or a local minima in the social welfare function (Faratin et al., 1998). The condition of applicability is again $n > 2\delta$.

$$\begin{aligned} C_{a\to b}^{t_{n+1}} &= \{(x,y) \in D^a \mid u^a(x,y) \leq \\ &\leq min(max(max\, u^a(C_{a\to b}^{t_{n-1}}) - max\, u^a(C_{b\to a}^{t_{n-2\delta}}) + (1-\alpha^a(t_{n-1})) + \\ &+ (-1)^s R(M),0),1)\} \end{aligned}$$

where

$$s = \begin{cases} 0 & \text{If } u^a \text{ is decreasing} \\ 1 & \text{If } u^a \text{ is increasing} \end{cases}$$

and $R(M)$ is a random value from the interval $[0,M]$. M is the maximal value by which an agent can change its imitative behaviour.

As in the case of previous tactic the value $max\, u^a(C_{a\to b}^{t_{n-1}})$ is the utility of the best alternative from the set $C_{a\to b}^{t_{n-1}}$ from the viewpoint of agent a. The difference $max\, u^a(C_{a\to b}^{t_{n-1}}) - max\, u^a(C_{b\to a}^{t_{n-2\delta}})$ is the absolute value of concession of the negotiation partner in utility space from the viewpoint of agent a. This difference is summed with the last value of utility concession $1-\alpha^a(t_{n-1})$ of agent a what results in the current utility level to which the agent a is going to concede. All alternatives exceeding this value are included in the next negotiation offer.

3. **Average Tit-for-Tat.** The agent imitates the overall concession of the opponent proposed in $\gamma > 1$. steps. When $\gamma = 1$ then the offer is the same as in the case of Relative Tit-for-Tat with $\delta = 1$. The condition of applicability is $n > 2\gamma$.

$$C_{a\to b}^{t_{n+1}} = \{(x,y) \in D^a \mid u^a(x,y) \leq min(max(\frac{max\, u^a(C_{b\to a}^{t_{n-2\gamma}})}{max\, u^a(C_{b\to a}^{t_n})}(1-\alpha^a(t_{n-1})),0),1)\}.$$

The above tactics can be combined together to form negotiation strategies ((Faratin et al., 2002)).

3 EXPERIMENTAL EVALUATION AND DISCUSSION OF RESULTS

In this section we present results of an experiment illustrating the efficiency of the proposed multi-alternative protocol of reaching negotiation agreement in comparison with a typical single-alternative negotiation approach with similarity-based trade-off (Faratin et al., 2002). We simulate a number of negotiations in a two-attribute scenario.

We consider the following negotiation setup involving two agents, a client agent and a provider agent. For the client agent the acceptance range is a Cartesian product of the ranges corresponding to two attributes:

$$D^a = [0,1] \times [0,1]$$

Therefore, the range for the first and second attribute is $[0,1]$. The acceptance range for the second agent in the role of provider is defined in the same way. Over the sets D^a and D^b the utility functions for both the agents are defined in the additive form. The weights corresponding to the importance levels of the attributes are set to 0.5. Therefore the function for the client is defined as follows:

$$u^a(x_1,x_2) = 0.5u_1^a(x_1) + 0.5u_2^a(x_2)$$

where the functions u_1^a and u_2^a are defined as follows:

$$u_k(x_k) = \begin{cases} 1 & \text{if } x_k < 0.25 \\ \frac{0.75-x_k}{0.75-0.25} & \text{if } 0.25 \leq x_k \leq 0.75 \\ 0 & \text{if } x_k > 0.75 \end{cases} \quad (3)$$

For the provider agent the additive utility function is defined in similar way as for the client agent:

$$u^b(x_1,x_2) = 0.5u_1^b(x_1) + 0.5u_2^b(x_2)$$

However, the single-attribute utility functions are defined with reversed monotonicity compared to the functions of the client agent.

$$u_k(x_k) = \begin{cases} 1 & \text{if } x_k > 0.75 \\ \frac{x_k-0.25}{0.75-0.25} & \text{if } 0.25 \leq x_k \leq 0.75 \\ 0 & \text{if } x_k < 0.25 \end{cases} \quad (4)$$

As described above, the preferences of both agents do not change during the negotiation experiment. What varies in the experiment are the negotiation strategies. We use the time-dependent tactics encoded by the parameter beta indicating how sharp the concession curve is. We apply a wide range of time-dependent tactics varying from the value of 0.1 to 10. We consider seven types of tactics with following values of β parameter:

$$\beta \in \{0.1, 0.2, 0.5, 1, 2, 5, 10\}$$

For the values of β lower then 1 the strategy belongs to Conceder strategy type. For the value of β equal to 1 the shape of concession curve is linear. For the values of β higher then 1 the negotiation strategy resulting from the usage of such β values belongs to Boulware strategy type. The variety of negotiation strategies used in our experiment aims at investigating how the two approaches for negotiation perform. In the Tables 1,2 we present the results of the experiments. For various negotiation strategies we simulate 49 negotiation settings. In the Table 1 we present the utility values (pay-offs) obtained by the first agent using the traditional (column u_c) and proposed (column u_a) approaches. As we can see, the utilities obtained in the scenario where the second approach was used are not worse or better than utilities obtained in the scenario where the first approach was used. The situation is similar for the second agent - the utilities obtained in the scenario where the second approach was used are at least as good as the utilities obtained in scenario where the first approach was used. In the case of scenario where the second approach was used the obtained results are best, and can not be further improved (in terms of Pareto efficiency) under the assumption of particular preferences and negotiation strategies. The reason for this observation is the application of a specific negotiation protocol which allows the agents to propose the full α-cuts. Such a protocol leads to Pareto efficient outcomes since in a particular round of negotiation the agents propose all feasible alternatives exceeding the particular level of utility allowed at this stage of negotiation. Therefore, the second approach results in Pareto efficient outcomes and therefore outperforms slightly the first approach which does not guarantee the Pareto efficiency. In the third Table 3 we present the comparison of numbers of rounds used to reach agreement in scenarios where the first and second approach was used (columns u_c and u_a, respectively). As we can see the number of rounds resulting in agreement in the case of classical approach is approximately twice larger as the number of rounds used to reach agreement in the case of proposed approach and therefore it outperforms the typical, single-alternative approach.

4 CONCLUDING REMARKS AND FURTHER WORK

The paper presents a novel negotiation protocol for multi-attribute agent negotiations based on using α-cuts to determine multi-alternative offers. As shown in the experiments it allows for improvement of negotiation outcomes in the terms of time needed to reach an agreement and the Pareto optimality of the outcome. In addition by allowing the agent to offer a proposal comprising a set of alternatives we eliminate the problem of making trade-off in the negotiation.

In the future work the proposed approach will be tested in scenarios involving different overlaps of acceptance ranges and different deadlines of the negotiating parties. We will also consider a number of issues, higher than two in further experiments.

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