Market-Driven Agents with Uncertain and Dynamic Outside Options

Fenghui Ren
School of IT and Computer Science
University of Wollongong
NSW 2522, Australia
fr510@uow.edu.au

Kwang Mong Sim
Department of Computer Science
Hong Kong Baptist University
Hong Kong, China
bsim@Comp.HKBU.Edu.HK

Minjie Zhang
School of IT and Computer Science
University of Wollongong
NSW 2522, Australia
minjie@uow.edu.au

ABSTRACT

One of the most crucial criterion in automated negotiation is how to reach a consensus agreement for all negotiators under any negotiation environment. Currently, most negotiation strategies can work under the static environment only. This paper presents a model for designing negotiation agents that makes adjustable rates of concession by reacting to changing market situations with uncertain and dynamic outside options. This work is based on the model of market-driven agents (MDAs). To determine the amount of the concession for each trading cycle, these market-driven agents are guided by four mathematical functions of *trading opportunity*, *trading competition*, *trading time and strategy* and *trading eagerness*. The contribution of this paper is designing and developing an extended MDA model with the flexibility to respond to uncertain and dynamic outside options, so as to increase problem solving ability for agent negotiation in broad application domains.

1. INTRODUCTION

Automated negotiation [5] [1] is being an active research area in recent years. One of the most crucial criterion is how to reach a consensus agreement for all negotiators under different negotiation environments. According to the complexity of a negotiation environment, Sycara et. al. [2] fractionize general negotiation into three levels, which are *single-threaded* negotiation, *synchronized multi-threaded* negotiation and *dynamic multi-threaded* negotiation. In the early stage, most negotiation strategies [4] [3] are only suitable to work for the *single-threaded* negotiation, in which the negotiation is only progressed between two negotiators without outside options. In 2002, Sim [7] [6] proposed Market-Driven Agents(MDAs) model which has the ability to work for the *synchronized multi-threaded* negotiation. In this stage, negotiation is allowed to perform with outside options but it also assumes that there are no outside options coming in the future. Therefore, each negotiator's decision is made based on the concurrent existing outside options and there is no uncertainty about outside incoming options. However, in practice, negotiators usually are free to enter and leave a negotiation in midway. Since the original MDAs model cannot estimate the sequentially available outside options, so an extended MDAs model is proposed in this paper to extend its application domain to the *dynamic multi-threaded* negotiation. In the *dynamic multi-threaded* negotiation, negotiation is processed with both concurrently and sequentially available outside options. The outside options may come dynamically in the future. Hence negotiation strategy would be involved in a random variable and changes with time. The negotiators should act probatively to the possible arrivals based on the prediction information.

The rest of the paper is organized as follows. In Section 2, the MDAs model are introduced briefly. In Section , the highlights of this research, which are forecasting all changing on the negotiation environment and the outside options, and generating decisions for negotiators by combining all possibilities, are introduced in detail. Section 4 concludes this paper.

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. To copy otherwise, to republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee.
AAMAS'07 May 14–18 2007, Honolulu, Hawai'i, USA.
Copyright 2007 IFAAMAS .

2. MARKED-DRIVEN AGENTS MODEL

In this section, both the basic principle and limitation of the MDAs model [7] is briefly introduced. In the original MDAs model, negotiators' decisions in each negotiation cycle are determined by assessing current negotiation environment according to the following four concession factors:

1. Trading opportunity ($O(n, <\omega_i>, \upsilon)$) determines the amount of concession according to an agent's own expectation, number of trading partners and their bides.

$$O(n, <\omega_i>, \upsilon) = \frac{1}{p'}(1 - p_i) \tag{1}$$

where p_i is the probability that the agent will obtain its desired utility with at least one of its trading partners.

2. Trading Competition ($C(m, n)$) determines the probability that an agent is ranked as the most preferred trader by at least one of its trading partners.

$$C(m, n) = 1 - (\frac{m-1}{m})^n \tag{2}$$

where m and n is the total number of competitor and partner, respectively.

3. Trading Time and Strategy ($T(t, t', \tau, \lambda)$) determines an agent's rate of concession by considering the re-

978-81-904262-7-5 (RPS) ©2007 IFAAMAS

maining trading time and concession strategies.

$$T(t, t', \tau, \lambda) = \frac{1 - (\frac{t'}{\tau})^\lambda}{1 - (\frac{t}{\tau})^\lambda} \quad (3)$$

where t and t' represents the current and next negotiation cycle, τ represents agents' deadline ($t \le \tau$) and λ ($\lambda \ge 0$) represents agents' concession strategies.

4. Trading eagerness ($E(\varepsilon)$) represents an agent's desire to make concession and to finish the negotiation.

$$E(\varepsilon) = 1 - \varepsilon \quad (4)$$

where ε ($0 \le \varepsilon \le 1$) is a constant value assigned by the agent designer.

Even though MDAs has shown its good performance in different situations under static environments [7], it still cannot handle issues in *dynamic multi-thread* negotiation successfully. The reason is that the original MDAs model does not contain any mechanism to estimate the incoming outside options. For example, the concession factor *trading opportunity* does not estimate the situation that some agents may enter or leave the negotiation in next cycle. Therefore, the original MDAs model cannot generate an effective decision to guide agents' action. The motivation of this research is to overcome the limitation. In the following section, an extended MDAs model is introduced. The four concession factors in the original MDAs are all modified in order to make them suitable to work for the negotiation with uncertain and dynamic outside options.

3. THE EXTENDED MDAS MODEL

In this section, an extended MDAs model based on Sim's work is proposed. All the concession factors are modified by considering both the concurrent and consequent outside options and introduced in each subsection, respectively.

3.1 Trading Opportunity

1. Partners Enter Negotiation Only: When there are no more than m partners will enter the negotiation in next cycle, if the probability of each partner enters the negotiation is p_{in}, the extended *trading opportunity* function is:

$$O(n, <\omega_i>, v)_{in} = \frac{1}{p'} \sum_{i=0}^{m} [C(i, m, p_{in}) \times (1 - \prod_{j=1}^{n} p_j \times \prod_{k=1}^{i} \frac{\sum_{j=1}^{n+i-1} p_j}{n+i-1})] \quad (5)$$

$$C(i, m, p_{in}) = C_m^i \times (p_{in})^i \times (1 - p_{in})^{m-i} \quad (6)$$

where $C(i, m, p_{in})$ is the probability that i partners will enter and $m - i$ partners will not enter the negotiation in next cycle. $\sum_{j=1}^{n+i-1} p_j/(n + i - 1)$ is the probability that agent will obtain its desired utility from the new coming partner i. Equation 5 includes all possible cases when no more than m partners are allowed to enter the negotiation freely.

2. Partners Leave Negotiation Only: When there are no more than n partners will leave the negotiation in next cycle, if the probability of each partner leaves the negotiation is p_{out}, the extended *trading opportunity* function is:

$$O(n, <\omega_i>, v)_{out} = \frac{1}{p'} \sum_{i=0}^{n} [C(i, n, p_{out}) \times (1 - \sum_{j=1}^{C_n^i} \frac{\prod_{k \in \overline{\varphi}_i^j} p_k}{C_n^i})] \quad (7)$$

where $C(i, n, p_{out})$ is the probability that i partners will leave and $n - i$ partners will not leave the negotiation in next cycle. $\prod_{k \in \overline{\varphi}_i^j} p_k / C_n^i$ is the probability that agent will obtain its desired utility from its remaining partners. Therefore, Equation 7 includes all possible cases when no more than n partners are allowed to leave the negotiation in next cycle freely.

3. Partners Enter and Leave Negotiation Freely: When there are no more than m and n partners enter and leave the negotiation freely, the extended *trading opportunity* function is:

$$O(n, <\omega_i>, v)_{all} = [O(n, <\omega_i>, v)_{in} + O(n, <\omega_i>, v)_{out}]/2 \quad (8)$$

3.2 Trading Competition

3.2.1 Considering Change of Competitors Only

In this part, the concession factor *trading competition* is extended by considering the change of trading competitors only.

1. Competitors Enter Negotiation Only: When there are no more than p competitors enter the negotiation, then the probability that the agent will be considered as the most preferred partner by at least one of its partners is:

$$C(m, n)_{cin} = \sum_{i=0}^{p} (C(i, p, p_{in}) \times [1 - (\frac{m+i-1}{m+i})^n]) \quad (9)$$

where $1 - (\frac{m+i-1}{m+i})^n$ is the value of factor *trading competition* when i competitors enter the negotiation.

2. Competitors Leave Negotiation Only:

When there are no more than t competitors leave the negotiation, then the probability that the agent will be considered as the most preferred partner by at least one of its partners is:

$$C(m, n)_{cout} = \sum_{i=0}^{t} (C(i, t, p_{out} \times [1 - (\frac{m-i-1}{m-i})^n]) \quad (10)$$

where $1 - (\frac{m-i-1}{m-i})^n$ is the value of factor *trading competition* when i competitors leave the negotiation.

3. Competitors Enter and Leave Negotiation Freely:

Based on the combination of above two situations, when competitors are allowed to enter and leave the negotiation freely, the concession factor *trading competitor* is:

$$C(m, n)_c = [C(m, n)_{cin} + C(m, n)_{cout}]/2 \quad (11)$$

3.2.2 Considering Change of Partners Only

In this part, the concession factor *trading competition* is extended by considering the change of trading partners only.

1. Partners Enter Negotiation Only: When there are no more than p partners enter the negotiation, then the probability that the agent will be considered as the most preferred partner by at least one of its partners is:

$$C(m,n)_{cin} = \sum_{i=0}^{p}(C(i,p,p_{in}) \times [1-(\frac{m-1}{m})^{n+i}]) \quad (12)$$

where $1-(\frac{m-1}{m})^{n+i}$ is the value of factor *trading competition* when i partners enter the negotiation.

2. Partners Leave Negotiation Only: When there are no more than t partners leave the negotiation, then the probability that the agent will be considered as the most preferred partner by at least one of its partners is:

$$C(m,n)_{cout} = \sum_{i=0}^{t}(C(i,t,p_{out}) \times [1-(\frac{m-1}{m})^{n-i}]) \quad (13)$$

where $1-(\frac{m-1}{m})^{n-i}$ is the value of factor *trading competition* when i partners leave the negotiation.

3. Partners Enter and Leave Negotiation freely: Based on Based on the combination of above two situations, when partners are allowed to enter and leave the negotiation freely, the concession factor *trading competitor* is:

$$C(m,n)_p = [C(m,n)_{pin} + C(m,n)_{pout}]/2 \quad (14)$$

3.2.3 Considering Change of both Competitors and Partners

By considering both change of competitors and partners, when both competitors and partners are allowed to enter and leave the negotiation freely, the probability that the agent will be considered as the most preferred trading partner by at least one of its partners is:

$$C(m,n)^k = [C(m,n)_c^k + C(m,n)_p^k]/2 \quad (15)$$

3.3 Trading Time and Strategy

In this subsection, the concession factor *trading time and strategy* is extended by considering trading strategy λ. According to the physical meaning of λ [7], the bigger the value of λ, the smaller concession is made in the early cycle but larger concession in later cycle, and vice versa. Furthermore, if the value of concession factor *Trading opportunity* or *trading competition* increases, a smaller concession would be made, and vice versa. Therefore, the λ should be a direct radio to both *trading opportunity* and *trading competition*. Therefore, the extended concession factor *trading time* by considering the dynamic outside options is:

$$T(t,t',\tau,\lambda^t) = \frac{1-(\frac{t'}{\tau})^{\lambda^{t'}}}{1-(\frac{t}{\tau})^{\lambda^t}} \quad (16)$$

$$\lambda^t = \lambda^0 \times competition^t \times opportunity^t \quad (17)$$

Where the λ^0 is the initial value of concession strategy, the $competition^t$ and $opportunity^t$ is the value of *trading competition* and *trading opportunity* in negotiation cycle t, respectively.

3.4 Trading Eagerness

In this subsection, the extended concession factor *trading eagerness* is proposed. According to economists, people's eagerness to complete a trading should be a direct ratio to the profit. So it is proposed to modify the *trading eagerness* by employing agents' profit ratio in MDAs. In each negotiation cycle, when agents' potential profits are changed by others' bids, agents' eagerness should also be changed with that. Let pr^t is agents' profit ratio at cycle t, c_i^t and v_i^t is the minimum and maximum profits agent can obtain at cycle t, then the extended *trading eagerness* is:

$$E(\varepsilon_t) = \begin{cases} 1-\varepsilon_0 & t=0 \\ 1-\varepsilon_{t-1} \times pr^t & t>0 \end{cases} \quad (18)$$

where ε_0 is the initial value *trading eagerness*, and $pr^t = v_i^t/c_i^t$.

From Equation 18, it can be seen that if agents' maximum profits are bigger than the baseline, then agents prefer to complete the trading eagerly, and vice versa.

4. CONCLUSION

In this paper, four concession factors in MDAs are modified in order to extend their application domain from the static environment to the uncertain and dynamic environment. We extend the original MDAs model by considering the change of negotiators in future. The proposed approaches can estimate all of possible changes on the negotiation environment, generate suitable decisions in each negotiation cycle, and guide agents' negotiation behavior dynamically. Our further work includes to test the proposed method in real world applications and to extend the current MDAs model to multi-issue negotiation.

5. REFERENCES

[1] N. R. Jennings, P. Faratin, A. R. Lomuscio, S. Parsons, C. Sierra, and M. Wooldridge. Automated Negotiation: Prospects, Methods, and Challenges. *Int. J. Group Decision Negotiation*, 10(2):199–215, 2001.

[2] C. Li, J. A. Giampapa, and K. P. Sycara. Bilateral Negotiation Decisions with Uncertain Dynamic Outside Options. *IEEE Transactions on Systems, Man, and Cybernetics, Part C*, 36(1):31–44, 2006.

[3] A. R. Lomuscio, M. Wooldridge, and N. R. Jennings. A Classification Scheme for Negotiation in Electronic Commerce. *Int. J. Group Decision Negotiation*, 12(1):31–56, 2003.

[4] J. A. Rodríguez-Aguilar, F. J. Martín, P. Noriega, P. Garcia, and C. Sierra. Toward A Testbed for Trading Agents in Electronic Auction Markets. *AI Commun.: Eur. J. Artif. Intell.*, 11(1):5–19, 1998.

[5] J. Rosenschein and G. Zlotkin. *rules of Encounter: Designing Conventions for Automated Negotiation Among Computers*. Cambridge, MA:MIT Press, 1994.

[6] K. M. Sim. A Market-Driven Model for Designing Negotiation Agents. *Computational Intelligence, Special issue in Agent Technology for E-commerce*, 18(4), 2002.

[7] K. M. Sim. and C. Choi. Agents That React to Changing Market Situations. In *IEEE Transaction on Systems, Man and Cybernetics, Part B: Cybernetics*, volume 33, pages 188–201, April 2003.