Agent Based Risk Management Methods for Speculative Actions

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Abstract. In multiagent systems, a cooperative action requires a mutual agreement among multiple agents and the agreement is generally reached by exchanging messages between them, but the delay of message may cause the delay of agreement, and the delay of agreement may reduce the effect of the cooperative action. A speculative action is an action that is taken before agreement not to reduce the effect of cooperative action. However, it needs to be cancelled by paying a penalty if the agents do not reach an agreement. In this framework, we have two risks; a risk to reduce the effect of cooperative action and a risk to cancel the speculative action. In this paper, we propose two risk management methods called the hybrid method and the leveled method, which are viewed as a single agent approach and a multiagent approach respectively, and discuss their advantages using a meeting room reservation problem.

1 Introduction

Generally speaking, a cooperative action in multiple agents requires an agreement and the agreement is normally achieved by exchanging messages among the agents[5, 6]. However, the agreement may delay because of two reasons; (1) message delay caused by the communication channel connecting the agents, and (2) that caused by the agents themselves.

The first one is caused by congestion or interruptions of communication channel that connects the agents. To a query from an agent, even if another agent replies as soon as it receives, the reply message may take a long time to reach the former agent because of the bad condition of communication channel.

The second one is caused by the character of agent. In multiagent systems, we often assume that each agent behaves autonomously and rationally to maximize its profit. When the profit to the agent depends on the reply, it may take a time to gather information as much as possible to maximize its profit.

In this paper, we mainly discuss the delay of agreement caused by the second reason. Especially, we have interest in cases where the delay of agreement reduces the effect of cooperative action among multiple agents. For example, let us consider a meeting room reservation problem in which an agreement between a host agent and a member agent is required to have a meeting in a room, which should be reserved in advance by the host agent. When they succeed to have a meeting, the host agent receives a reward from the outside and the member agent receives a share from the host agent. We assume that the more time the agents take to reach an agreement, the more difficult it is to reserve a room, and that a cost is charged when an agent cancels a reserved room. In this problem, if the agents take a long time to reach an agreement for a cooperative action (having a meeting in a room), they have a risk that the delay reduces the effect of cooperative action because the more time they take to reach an agreement, the more difficult it is for them to succeed in reserving a meeting room.

Speculative action [4] is a remedy to cope with the delay of agreement. It is an action taken before reaching an agreement supposing the agreement is reached later. If the agreement is surely reached later, the speculative action is effective because it does not reduce the effect of cooperative action. On the other hand, if it fails to be reached, the action should be cancelled or rolled back and it may be charged some amount of cost. For example, in a meeting room reservation problem, let us assume that the host agent reserves a room as a speculative action before an agreement with the member agent. If the member agent replies with an agreement, the two agents can have a meeting without caring about the difficulty of reserving a meeting room. On the other hand, if the member agent disagrees, the host agent has to cancel the reserved room by paying a cancel charge. When an agent takes a speculative action, it has to take a risk when the action needs to be cancelled.

When we use a speculative action to cope with the delay of agreement, we have to consider a risk of failing to take a cooperative action and a risk of cancelling a speculative action, and need a risk management method to take a speculative action effectively according to the situation.

This paper proposes two risk management methods for speculative actions, the hybrid method and the leveled method. In the hybrid method, the host agent estimates the probability of agreement and decides whether it takes a speculative action or not. This method can be viewed as a single agent approach because it is based only on estimation of a single agent. In the leveled method, the host agent makes a pre-agreement with the member agent and either of the agents can cancel the pre-agreement by paying a penalty. This method can be viewed as a multi-agent approach because it is based on a pre-agreement among multiple agents.

In Section 2, we mention the definition of the meeting room reservation problem and two fundamental agreement methods called the basic method and the speculative method and discuss these methods from a view point of expected profit. In Section 3, we discuss two risk management methods called the hybrid method and the leveled method and the individual rationality that agents should satisfy in the leveled method. We mention related works in Section 4 and conclude this paper in Section 5.

2 Meeting Room Reservation Problem

2.1 Definition

To make the discussion of speculative action concrete, we use a problem called meeting room reservation problem. There exist a host agent and a member agent, and they negotiate to have a meeting in a room to be reserved in advance.

For the negotiation, the agents exchange messages following a protocol like the Contract Net Protocol [5]. Initially the host agent sends an announcement of meeting to the member agent. The member agent sends a reply of agreement or disagreement to the host agent. Finally the host agent reserves a meeting room if the member agent agrees with having a meeting.

The host agent receives a reward a from the outside when a meeting takes place and the member agent receives a share from the host agent. The amount of share is specified in the announcement message. The member agent receives announcements not only from the host agent but also other agents, and decides whether it accepts to have a meeting with the host agent considering shares offered by the other agents. Announcements sequentially reach the member agent, and the probability of getting a better share monotonically increases as the time goes by. Hence, to an announcement from the host agent, the member agent does not reply promptly but rather wait as long as possible to increase its profit. This makes a delay of forming an agreement between the host agent and the member agent. When the agents follow the Contract Net Protocol, the host agent can set the expiration time of receiving replies in announcement and the member agent sends a reply within the expiration time. For convenience, we set the time interval of expiration to be fixed as T. Hence, after the member agent receives an announcement, it waits a time interval of T for announcements from the other agents. The probability P_m that the member agent agrees with the host agent to have a meeting is specified as

$$P_m = \int_0^{\rho} f(b)db, \tag{1}$$

where b is the best share offered by the other agents until the expiration time, $f(b)$ is the probability distribution function of b, and ρ is the share offered by the host agent.

We assume that the probability of succeeding to reserve a meeting room decreases as the time goes by. For convenience, we set the probability to be 0 at the initial stage when the host agent sends an announcement, and that to be P_r when the host agent receives a reply after the time interval T.

2.2 Agreement formation for meeting room reservation problem

We discuss two naive agreement formation methods; the basic method and the speculative method, for the meeting room reservation problem.

In the basic method as shown in Fig. 1 (a), the host agent first sends an announcement message with an indication of share ρ to the member agent. After it receives an agreement from the member agent, it tries to reserves a meeting room and succeeds to do with the probability of P_r.

In the basic method, even if the member agent agrees with having the meeting, the host agent may fail to reserve a room because of the delay of agreement. When it fails, it has to pay the share ρ that it promises to pay in the announcement message.

In the speculative method as shown in Fig. 1 (b), the host agent announces a meeting and reserves a room at the same time without a reply from the member agent. We assume that the agent never fails to reserve a room. When it receives a reply, if the reply is agreement, then the meeting will be held. Otherwise, the host agent has to cancel the reserved room by paying a cancel charge c.

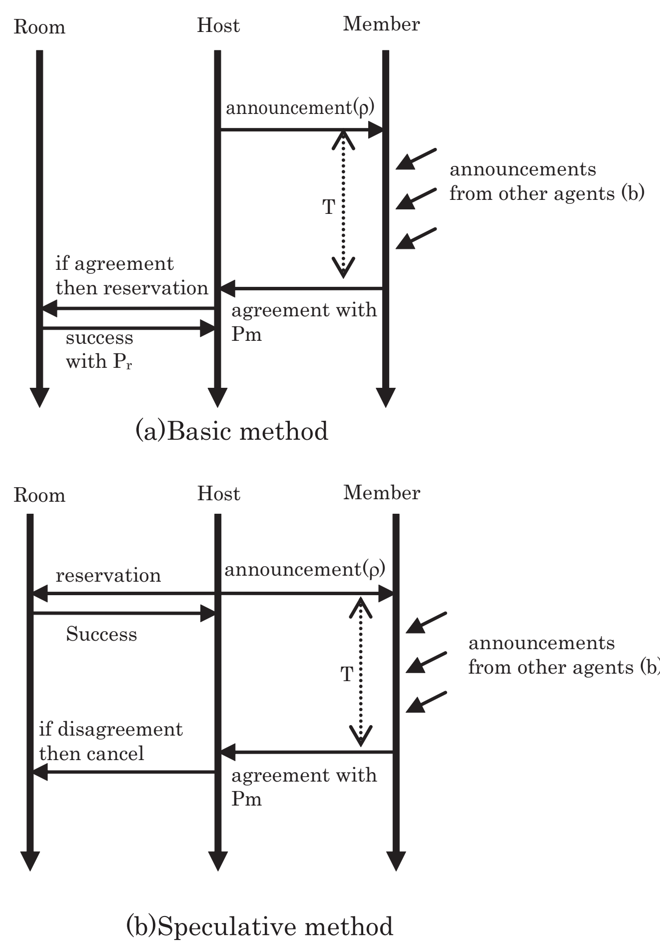

Fig. 1. Basic method and speculative method.

2.3 Expected profit of agents in meeting room reservation problem

The profit tree in Fig. 2 shows the expected profits of the host and member agents in the meeting room reservation problem depending on the situation. If the host agent and the member agent agree with having a meeting by using the speculative method, the host agent receives a reward a and pays a share ρ to the member agent, so the profit of the host agent is $a - \rho$ and that of the member agent is ρ. If the member agent does not agree, the host agent has to pay c to cancel a meeting room, so the profit of the host agent is $-c$ and that of the member agent is 0. Hence, the expected profit of the host agent and the member agent using the speculative method is calculated as

$$profit^h_{SM} = P_m \cdot (a - \rho) + (1 - P_m) \cdot (-c) \tag{2}$$

and

$$profit^m_{SM} = P_m \cdot \rho \tag{3}$$

respectively.

When both agents use the basic method, even if the member agent agrees and the host agent succeed to reserve a meeting room, the host agent receives a reward a and pays a share ρ to the member. In this situation, the profit of the host agent is $a - \rho$ and that of the member agent is ρ. However, if the host agent fails to reserve a meeting room, it has to pay ρ receiving no reward. In this situation, the profit of the host agent is $-\rho$ and that of the member agent is ρ. Consequently, the expected profit of the host and member agents using the basic method is calculated as

$$profit^h_{BM} = P_m \cdot P_r \cdot (a - \rho) + P_m \cdot (1 - P_r) \cdot (-\rho) \tag{4}$$

and

$$profit^m_{BM} = P_m \cdot \rho \tag{5}$$

respectively.

Fig. 3 shows the expected profit of the host agent using the basic and speculative methods with $a = 50$, $\rho = 35$, and $c = 10$. When we use the basic method, the expected profit of the host agent changes depending on P_r. When P_r is large (ex. $P_r = 0.8$), the profit of the host agent increases as the probability of the member's agreement (P_m) increases because the host agent rarely fails to reserve a meeting room. On the other hand, when P_r is not large (ex. $P_r = 0.5$), even the member agent agrees with having a meeting, the host agent rarely succeeds to reserve a room. The profit of the host agent decreases as P_m increases because it has to pay ρ to the member agent even though it receives no reward from the outside. The speculative method never fails to reserve a meeting room, and the profit of the host monotonically increases as the probability of the member's agreement increases. However, if the probability is low, the host agent has to pay a cost to cancel a meeting room. As a conclusion, the speculative method has no risk of failing to reserve a room, but has a risk of canceling the action. Especially when the probability of agreement is low, the basic method returns

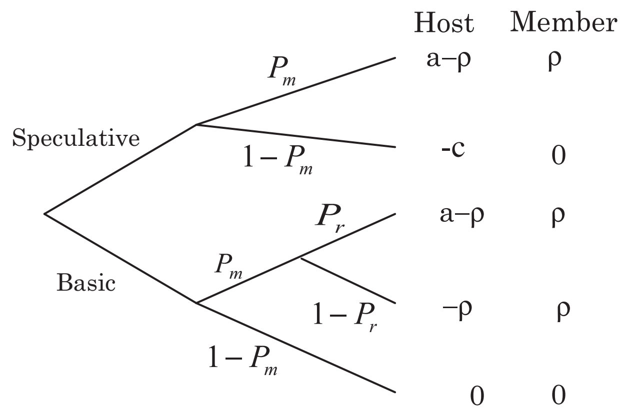

Fig. 2. Profit tree of the host and member agents.

a better profit than the speculative method. Hence, we need a risk management method for speculative actions to increase the profit and propose two methods in the next section.

3 Risk Management Methods for Speculative Actions

The speculative method does not take a risk of failing cooperative actions because of delayed messages, but it has to take another risk of canceling the speculative action failure. We here propose two risk management methods called the hybrid method and the leveled method to balance two risks according to the situation.

3.1 Hybrid method: a single agent approach

As shown in Fig. 3, the speculative method works well in cases where the probability of the member's agreement is large, and the basic method works well in cases where it is low because the probability of canceling reserved room is low. The hybrid method switches between the speculative method and the basic method by estimating the probability of the member's agreement. If the probability is estimated to be high, it uses the speculative method for forming an agreement, and if it is estimated to be low, it uses the basic method. Because it is based on the estimation of the host agent, it is viewed as a single agent approach.

In this method, it is important to decide the timing to switch from one to another. The condition in which the speculative method is superior to the basic method is given as

$$P_m \cdot (a - \rho) + (1 - P_m) \cdot (-c) \geq P_m \cdot P_r \cdot (a - \rho) + P_m \cdot (1 - P_r) \cdot (-\rho), \quad (6)$$

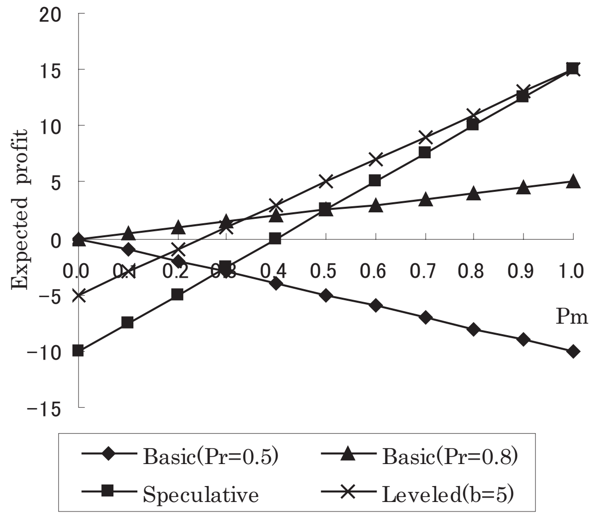

Fig. 3. Expected profit of the host agent depending on P_m.

considering the expected profits of both methods.

When we pay attention to the probability P_m of the member's agreement, the inequality can be rewritten as

$$P_m \geq \frac{c}{(1 - P_r) \cdot a + c}. \tag{7}$$

Fig. 4 shows the expected profit of the host agent using the hybrid method when $a = 50$, $\rho = 35$, $c = 10$, and $P_m = 0.5$. If the host agent can accurately estimate P_m, the hybrid method returns a better profit in every P_r than the basic method or the speculative method. However, if the host estimates P_m incorrectly, the profit decreases. For example as shown in Fig. 4, if the host agent underestimates P_m as $P_m* = 0.3$, it uses the speculative method in the interval of $0.53 < P_r < 0.8$ inappropriately and the profit reduces comparing with the case where the estimation is correct. Likewise, if P_m is overestimates to be 0.7, the host agent uses the basic method in the interval of $0.8 < P_r < 0.91$ inappropriately and the profit reduces.

We need to discuss how the host agent estimates the probability of the member's agreement. As mentioned in Section 2, the probability can be estimated from ρ, the share given by the host, and $f(b)$, the probability distribution function of the maximum shares offered by other agents. The host agent does not know $f(b)$, but it may be able to estimate $f(b)$ by using the history information of agreements in the past. As a simplest way, if the member agent has agreed 5 times out of 10 invitations, the host agent can estimate that $P_m = 0.5$. Actually, the agreement made by the host agent depends on ρ. If the agent records the history according to ρ, its estimation will be improved. Generally speaking, if the host agent fails to estimate P_m correctly, its profit reduces. This means a limitation of the hybrid method in which the host agent switches between two methods based on the estimation of agreement.

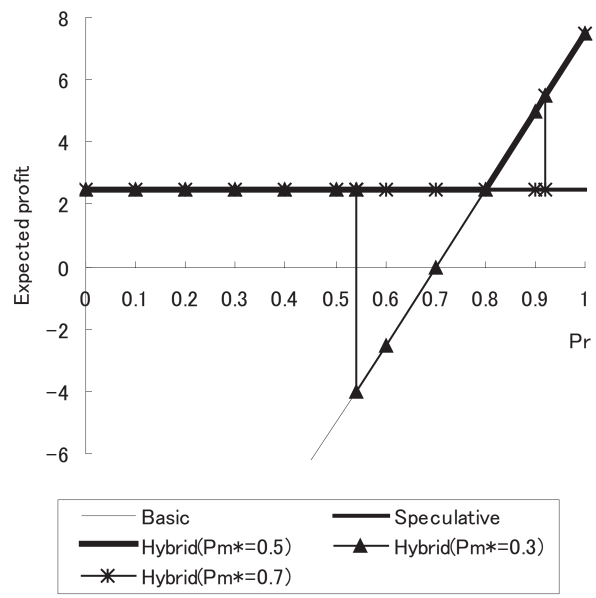

Fig. 4. Expected profit in the hybrid method. P_m* means the estimated value of P_m.

3.2 Leveled method: a multi-agent approach

In the leveled method, the host agent and the member agent make a pre-agreement, and each of them can cancel it by paying a penalty. By making a pre-agreement, the host agent can reduce the risk of canceling a speculative action when the member agent disagrees. The leveled method is a risk management method based on a pre-agreement made by both of the host and member agents and can be viewed as a multi-agent approach.

The protocol of the leveled method is shown in Fig. 5. The host agent takes a speculative action after it makes a pre-agreement. When the expiration time of the final agreement comes, the member agent replies whether it agrees or not to the host agent. If the member agent disagrees, the member agent pays a penalty d and the host agent cancels a room by paying a cancel charge c. The profit tree of the leveled method is shown in Fig. 6.

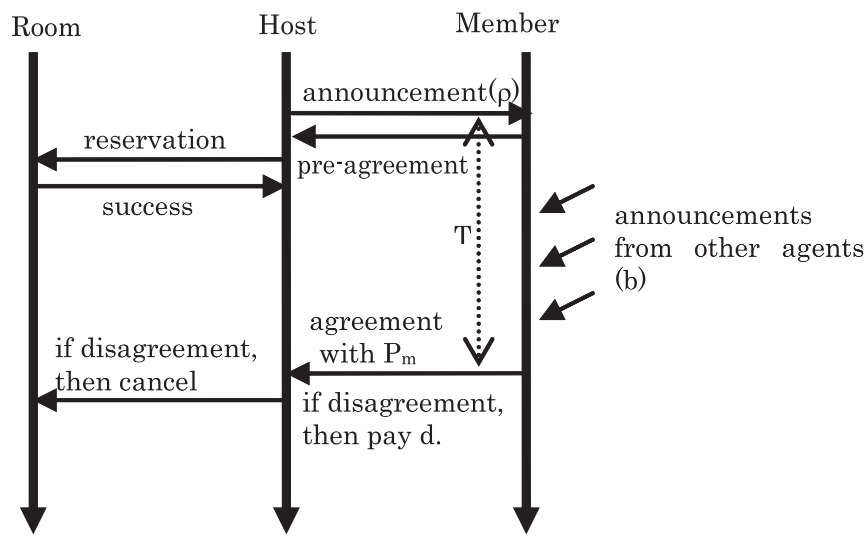

Fig. 5. The leveled method.

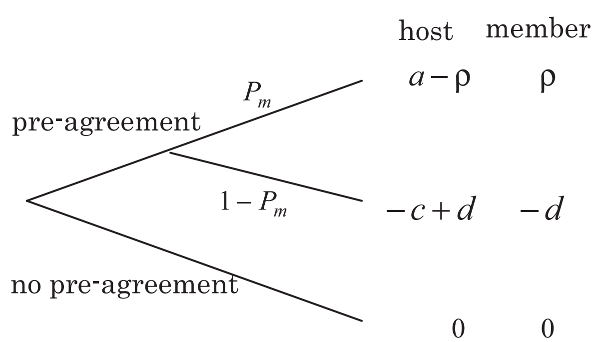

Fig. 6. The profit tree of the leveled method.

The expected profit of the host agent in the leveled method is given as

$$profit_{LM}^{h} = P_m \cdot (a - \rho) + (1 - P_m) \cdot (d - c) \quad (8)$$

and it is more than that in the speculative method for $(1 - P_m) \cdot d$. This is because the member agent compensates a part of the charge to cancel a room by paying the penalty of breaking the pre-agreement. Fig. 3 shows that the expected profit of the leveled method is better than that of the speculative method at any P_m. When P_m is low, the basic method is superior to the leveled method. If we can estimate P_m properly, we can switch between the basic method and the leveled method as well as in the hybrid method.

If we increase the amount of penalty d, the expected profit of the host agent increases but that of the member agent decreases. To reach a pre-agreement, each of the host and member agents must satisfy its individual rationality. The individual rationality means the expected profit under making a pre-agreement must be more than that under making no pre-agreement.

In the next section, we discuss the condition in which both individual rationalities of the host and the member agents satisfy to reach a pre-agreement.

3.3 Individual rationality in the leveled method

In the leveled method, the condition in which the host agent makes a pre-agreement is given as

$$profit_{LM}^{h} \geq 0, \quad (9)$$

and the condition in which the member agent makes a pre-agreement is given as

$$profit_{LM}^{m} \geq E[b], \quad (10)$$

and only when both conditions are satisfied, the host and member agents make a pre-agreement.

For example, when $a = 45$, $c = 10$, and

$$f(b) = \begin{cases} 0.01 & (0 \leq b \leq 100) \\ 0 & (\text{otherwise}) \end{cases} \quad (11)$$

the host's expected profit is calculated as

$$\begin{aligned} profit_{LM}^{h} &= (45 - \rho) \int_{0}^{\rho} f(b)db + (d - 10) \int_{\rho}^{100} f(b)db \\ &= (45 - \rho) \cdot \frac{\rho}{100} + (d - 10) \cdot \frac{100 - \rho}{100} \quad (12) \end{aligned}$$

The member's expected profit is calculated as

$$\begin{aligned} profit_{LM}^{m} &= \rho \int_{0}^{\rho} f(b)db + \int_{\rho}^{100} (b - d) \cdot f(b)db \\ &= \frac{\rho^2}{100} + \frac{1}{100}[(5000 - 100d) - (\frac{\rho^2}{2} - d\rho)] \\ &= \frac{1}{200}(\rho^2 + 2d\rho + 10000 - 200d) \quad (13) \end{aligned}$$

In Fig. 7 and Fig.8, we depict the condition in which both of the host and member agent's individual rationalities are satisfied following equations (12) and (13). Fig. 7 shows an expected profit graph when we fix $d = 10$ and change the share ρ, and Fig. 8 shows another one when we fix $\rho = 40$ and change the penalty d. These figures show that the agents can make a pre-agreement only in a limited range of ρ or d.

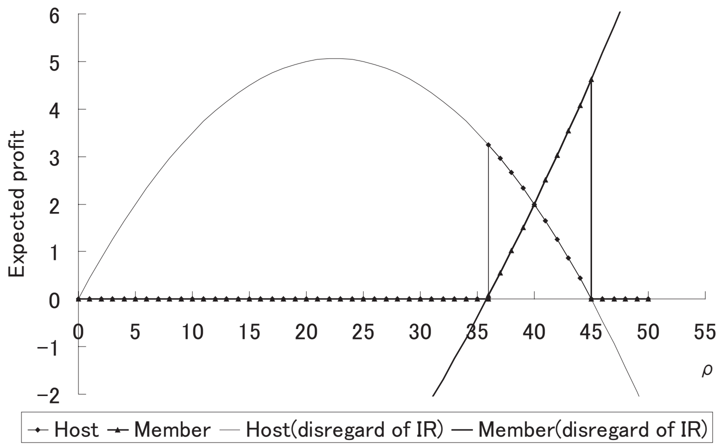

Fig. 7. The share ρ that satisfies individual rationalities when $d = 10$.

Fig. 7 shows that the host agent gets the maximum profit if it makes a pre-agreement with $\rho = 45/2$. On the other hand, the expected profit of the member agent is less than 0 when $\rho = 45/2$. This condition does not satisfy the member's individual rationality, so the member agent does not make a pre-agreement. It reaches a pre-agreement only when $34.20 < \rho < 45$. If the setting does not satisfy either individual rationality of the host or member agent, the expected profits of the host and member agents are 0.

We have a similar discussion concerning d. When d is too large, the individual rationality of the member agent is not satisfied, and when too small, that of the host agent is not satisfied. Fig. 7 shows that they can reach an agreement when $6.67 < d < 13.33$.

4 Related Work

The idea of speculative action is based on the work on speculative computation [2, 1]. The speculative computation has been proposed as an accelerating method of processing for pipe-lined parallel computers. A pipe-lined parallel computer can pre-fetch commands as many as the number of processors and

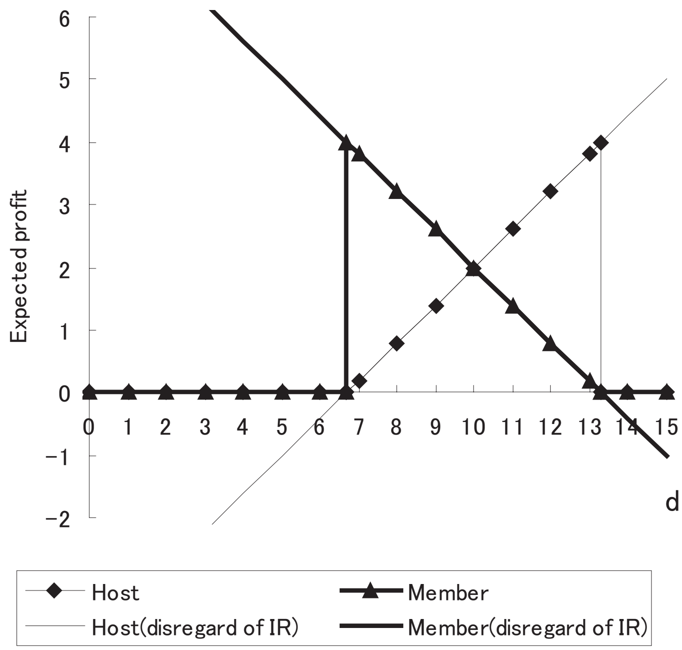

Fig. 8. The penalty d that satisfies individual rationalities when $\rho = 40$.

execute them in parallel. However, if a branch command is included in the pre-fetched commands, the further sequence of commands to be executed changes depending on the result of the branch command. The speculative computation is a method to choose a most plausible command and to execute it speculatively. Since this computation is called speculative, it has a risk to choose a wrong command which contradicts with the result of branch command. When it appears to be a wrong command, it needs to be canceled or rolled back.

Satoh et al [4] introduced the idea of speculative computation into the field of multi-agent systems. They discuss an issue of communication delay in multi-agent systems and deal with it by using a default reasoning technique, which is viewed as a speculative computation.

In previous works, a failure of speculative computation is just recovered by canceling the computation and any side effects are not supposed to be occurred. In this paper, we assume that a speculative action makes a change in the environment and a cost is required to cancel the action. To reduce the risk, we propose two risk management methods; the hybrid method that switches the speculative method and the basic method by estimating the probability of the member's agreement, and the leveled method which makes a pre-agreement between the host and member agents. The latter is based on the leveled commitment method done by Tuomas Sandholm et al [3].

5 Conclusions and Future Work

The speculative action is effective when an agreement for a cooperative action takes a long time by taking the action in a speculative manner. On the other hand, it raises a problem when the action later appears to be contradictory to the agreement and needs to be cancelled by paying a cost. In this paper, as methods to reduce a risk of failing a speculative action, we proposed two methods; the hybrid method that switches between the speculative method and the basic method based on the estimated probability of agreement, and the leveled method which makes the host and the member agents reach a pre-agreement and forces them to pay a penalty when they break the pre-agreement. We showed advantages and disadvantages of these methods by using a meeting room reservation problem. The hybrid method returns the better performance between the basic method and the speculative method if the probability of agreement is correctly estimated. Otherwise, the performance is degraded, so how the host agent estimates it becomes a critical issue in this method. The leveled method is based on a pre-agreement between two agents, so how these agents reach a pre-agreement is a critical issue. We discussed the settings in which two agents can reach a pre-agreement in a view of individual rationality.

In this paper, we used a meeting room reservation problem as a case study to discuss speculative actions, but we need to further discuss how we can apply proposed methods in general contexts. We also need to deal with cases where more than two agents interact.

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