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Analysis of Reward Function for Incentive-based Participation Promotion Method

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***Abstract*—A lot of research has been done on delay tolerant networks (DTNs) that are effective in situations where networks are not continuously connected, and many of them are designed for disaster situations. However, we believe that DTNs are valuable not only in times of disaster, but also in non-disaster situations where continuous network connectivity is possible. In this paper, we investigate the incentive-based participation promotion method that provides an incentive to participants for each message forwarded during contact, and we study a reward function to calculate incentive of the method. Since this method seems to be effective in vitalizing areas where community events are held using this system, we consider a function that determines the reward for participants and investigated the effect of the reward function on probability of participation in the system using game theory and simulation. As a result, we proposed new reward function, and then it is considered that users actively participate in system because of high reward. The proposed method is more effect than previous research in order to accelerate users to participate in and also restrain game owner's cost. It is revealed that the proposed reward function is suitable in terms of area activation and reward control for event organizers.**

***Index Terms*—delay tolerant network (DTN), game theory, area activation, incentive-based participation promotion methods**

I. Introduction

Delay tolerant network (DTN) is proposed to be effective way for the situation without any continuous network connections. This network was first studied as a way for interplanetary communication [1]. In order to do interplanetary communication, there are many problems, such as TCP time out, end-to-end ARQ and routing protocol. However, DTN is designed as an alternative way to solve those problems. When some data are deliver to other planet, data are delivered via orbital satellite of objective planet. DTN is defined as simple connection delivery model that has hierarchized functions [1].

There is research that applies this DTN on the earth. Originally, DTN is a way for the situation without any continuous connections like between planets, DTN is seemed to be effective for that situation [2]. Currently, since the internet is spread, we seldom experience the situation with unstable network connections. However, if it is unstable or stopped by a disaster, DTN is seemed to be effective way. If we apply DTN on the earth, we have a problem. It is how do we choose the next node to deliver messages. In the situation to deliver messages to an objective node, there is a lot of research that is how do we choose relay nodes and how do we raise the message deliver rate to the objective node [3].

Therefore, we think that DTN is effective in the situation with stable network connections besides unstable like disasters. The system that adopts DTN is built and people exchange messages to other people who pass them to each other again and again on the system. If the users as deliverers get the incentive like money along with the number of contacts. It makes people accelerate participation of that DTN system. It is called incentive-based participation promotion method [4]. The incentive-based participation promotion method that determine the incentive along with the number of contacts is proposed, and then research that influence on regional vitalization is studied. The calculation method is studied [5].

In this paper, we regard the number of deliveries for each person as just one time, incentive-based participation promotion method is proposed. In the N non-cooperative game with DTN system, we analyze in point of game theory in order to research the influence of participation probability by reward function in incentive-based participation promotion method. In addition, we simulate the situation that is more real than previous research [4], [5] in terms of map and patern of walking, analyze whether walking patern of users is influence on participation probability or not. As a result, new reward function is more effective than previous research in order to accelerate users to participate in and also restrain game owner's cost.

II. Previous Research

In this section, we explain incentive-based participation promotion method proposed by Tachibana [4]. The model is explained in sectoin II-A, and analysis of the model is described in sections II-B and II-C.

A. Incentive-based Participation Promotion Method

Incentive-based participation promotion method is the way to accelerate participation to system by giving incentive to each user, and incentive is calculated from the number of contacts.

In a DTN system shown in Fig. 1, the number of potential users who is available for proposed method is N, and the number of users who participate in DTN system at the time t is

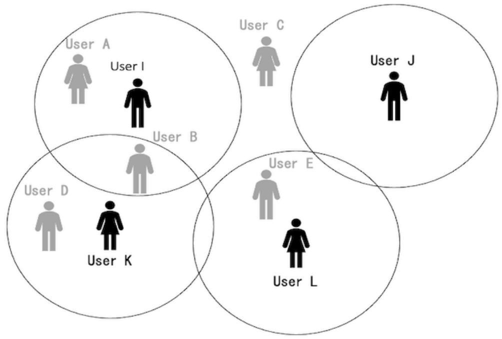

Fig. 1. DTN System

$n(t)(n(t) \leq N)$. In addition, the total usage time of proposed method is h_i for user $i \quad (i = 1, \cdots, n(t))$. At the time t, if there are $m_i(t)$ users in the contact range of user i, the number of contacts M_i of user i is following eq. (1).

$$M_i = \int_{t=0}^{h_i} m_i(t)dt \tag{1}$$

In DTN system, there are 5 people who do not participate in and 4 people who participate in, called potential users. Fig. 1 shows that DTN system.

Fig. 1 shows an example of DTN system. Black users are potential users and they also get reward if they do not participate in. Currently, the number of potential users (I, J, K, L) is 4, it means $N = 4$. On the other hand, gray users (A, B, C, D, E) show that they already participate in DTN system. They are not included in the number of potential users N, but they are counted as the number of contacts. At the time t, if 4 users (user I,J,K,L) participate in, it is $n(t) = 4$. And then, it is $m_I(t) = 2$ because user I is passing with 2 users(user A,B). Similarly, it is $m_J(t) = 0$ because user J is not passing any each others. It is $m_K(t) = 2$ because user K is passing with 2 users (user B,D). It is also $m_L(t) = 1$ because user L is passing with user (user E).

Users who participate in this DTN system get each reward based on the number of contacts. If the number of contacts of user i is M_i, the his/her reward R_i is calculated by the following equation.

$$R_i = f(M_i) + \theta_i \tag{2}$$

In eq. (2), reward function f is non-decreasing function in order to increase reward with increasing users' number of contacts. Users decide by their own reward whether they participate in system or not. In addition, some users seems to come from other area, and they need to pay transportation expenses to come. θ shows it. Therefore, we need to define carefully function $f(\cdot)$ and θ_i because there is a possibility that excessive rewards ruin the system.

B. Analysis with Game Theory

In this section, incentive-based participation promotion method is analyzed with game theory. DTN system used this method is simulated with N Non-cooperative game.

The number of potential users is N, and each user have two executable strategies. The one is participation in system, the other one is no participation. The strategy of user i is denoted by a_i. Participation strategy is $a_i = 0$ and no participation strategy is $a_i = 1$. User i takes participation strategy $a_i = 0$ with probabitily p_i^0 and no participation strategy $a_i = 1$ with probability p_i^1. Regarding to probabilities $p_i^0,\ p_i^1$, it is $p_i^0 + p_i^1 = 1$.

If user i participate in DTN system ($a_i = 0$), user i gets reward R_i which is calculated by eq. (2). On the other hand, there is also probability that user i takes no participation strategy. However, if user i do not participate in DTN system ($a_i = 1$), user i get another reward $\hat{R}_i$. $\hat{R}_i$ depends on the number of participants and is also given by eq. (3).

$$\hat{R}_i = g_i(n) \tag{3}$$

In eq. (3), $g_i(n)$ simply increase with n in order to prevent failure of DTN system in the case of few participants. And if $n \leq n'$, it is $g_i(n) \leq g_i(n')$. Therefore, user i's utility function U_i is following eq. (4).

$$U_i = \begin{cases} R_i & (a_i = 0) \\ \hat{R}_i - \eta_i & (a_i = 1) \end{cases} \tag{4}$$

In eq. (4), η_i means user i's motivation (awareness of the issues) for area activation. It means that utility function U_i decrease in the situation that user takes strategy of no participation in DTN system ($a_i = 1$) if user i's motivation for area activation is high rather than if in the situation that users' motivation are low. Because it accelerate users to take participation strategy in order to maximize their own rewards in situation that taking no participation strategy decrease reward function. As a result, it is considered that user i takes strategy $a_i = 0$ and positively walk around the city.

In the above model, each users' aim is maximization of their own rewards and they always take optimal strategy. However, there is a case that some users prevent others from maximize their rewards, and then we analysis it with game theory used N Non-cooperative game.

C. N Non-cooperative Game

In this section, incentive-based participation promotion method is analyzed by N Non-cooperative game. Users who participate in this game take implementable strategy used mixed strategy by probability.

The game G is defined $G = \langle \mathcal{N}, \mathcal{A}, \mathcal{U} \rangle$ because of finite N-person game in normal form. $\mathcal{N} = \{1, 2, \ldots, N\}$ means set of potential users, cartesian product of user i's action set $A_i = \{0, 1\}$ is $\mathcal{A} = \{A_1 \times A_2 \times \cdots \times A_N\}$, and set of user i's utility function (eq.4) is $\mathcal{U} = \{U_1, U_2, \ldots, U_N\}$. Utility function matrix is following table I.

TABLE I
UTILLITY FUNCTION MATRIX OF PREVIOUS RESEARCH

User 2 / User 1	PT	Non-PT
PT	$R_1,\ R_2$	$R_1,\ \hat{R_2}-\eta_2$
Non-PT	$\hat{R_1}-\eta_1,\ R_2$	$\hat{R_1}-\eta_1,\ \hat{R_2}-\eta_2$

III. PROPOSED METHOD

In this section, we explain the proposed method. We assume that User 1 and User 2 participate in the DTN system by using proposed method. We can solve problem that we make users promote participation by lots of money such as raising incentive, because the aim of this method is promoting participation for area activation. However, high incentive cause increase the owners' costs and might ruin the system. The ideal model is that users can get certain incentive even by a few number of contact and decreasing excessive incentive and the owners' costs as possible.

Therefore, we analyze reward function $f(\cdot)$ which defines reward. In previous research, $f(M_i) = 2M_i(t)$. In section IV, we compare previous one and proposed one, and then research the influence of function to participation probability.

A. Preparation for Comparison

Before comparing functions, we need to define the basis of reward and the number of contacts. We normalize reward and the number of contacts, and make graphs. X-asis is $0 \le M_i \le 1$ because of ease of comparison. We need to define carefully because Y-asis is reward and also owners' costs. Therefore, in previous research, the range of X-asis is $0 \le M_i \le 1$ because reward function is $f(M_i) = 2M_i$, and in this paper, we define the range of Y-asis as $0 \le y \le 2$.

B. Variation of Reward Functions

The start point is $(0, 0)$ and the end point is $(1, 2)$ because of the definition $0 \le M_i \le 1,\ 0 \le y \le 2$. We research which function is better. Fig. 2 shows the comparison. Here, we regard function $f(M_i)$. We use following five functions (5)–(9) for this comparison.

$$f(M_i) = 2M_i \tag{5}$$
$$f(M_i) = \frac{2}{e-1} \times (e^{M_i} - 1) \tag{6}$$
$$f(M_i) = \frac{2}{\log 2} \times \log(M_i + 1) \tag{7}$$
$$f(M_i) = 2\sqrt{M_i} \tag{8}$$
$$f(M_i) = 2M_i^{\frac{1}{3}} \tag{9}$$

Fig. 2 shows that logarithmic function shown in eq. (7) and upwardly-convex monotonically-increasing functions such as eqs. (8) and (9) are better than previous one shown in eq. (5), because each of them gives certain reward by a few number of contacts and restrains owners' costs of larger number of contacts ($M_i > 1$). On the other hand, downwardly-convex

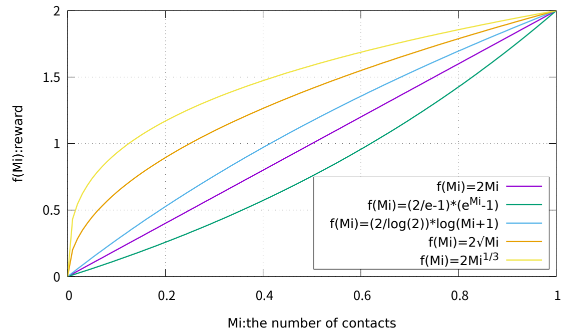

Fig. 2. comparison of reward functions

TABLE II
UTILITY FUNCTION MATRIX OF PROPOSED METHOD

User 2 / User 1	PT(p_2^0)	Non-PT($1-p_2^0$)
PT(p_1^0)	$2\sqrt{\beta},\ 2\sqrt{\beta}-0.2$	$2\sqrt{\beta-0.1},\ 5.5-\eta_2$
Non-PT($1-p_1^0$)	$6-\eta_1, 2\sqrt{\beta-0.1}-0.2$	$4-\eta_1,\ 3.5-\eta_2$

function such as shown in (6) is not valuable because it is hard for participants to increase their reward by the number of contacts.

Therefore, upwardly-convex irrational function seems to be better than linear function in terms of DTN system with proposed method in order to promote participation. In following section, we define reward function as upwardly-convex irrational function such as eq. (8), and then research the influence or changes of participation probability in the same situation as previous research. In addition, we research it by more reality simulation.

IV. RESULTS OF ANALYSIS

We research changes of users' participation probability when reward function is irrational function such as $f(M_i) = 2\sqrt{M_i}$. First, users' reward R_i in shown in eq. (10) comes from eq. (2)

$$R_i = 2\sqrt{M}_i + \theta_i \tag{10}$$

We regard reward as $\hat{R_i}$ as with previous research in case that user i do not participate in system. The number of contacts is $M_i = \beta$. On the other hand, the number of contacts is $M_i = \beta - 0.1$, if only one of participants participates in system because it causes a little reduction of the number of contacts by just one side participating. And also, $\theta_1 = 0.0, \theta_2 = -0.2$. It assumes that user 2 come from far away than user 1 because user 2 must pay more then user 1 such as transportation expenses in oder to participate. In eq. (3), as same as previous research, $g_1(0) = 4.0, g_1(1) = 6.0, g_2(0) = 3.5, g_2(1) = 5.5$. Therefore, Table II shows uility function matrix.

Table II shows changes of users' participation probability in case of changes of the number of contacts β related to the number of contacts. And then, shows changes of users' paritipation probability in case of changes of motivation η related to the number of contacts, too.

A. Influence to Participation Probability by the Number of Contacts β

First, we research changes of users' participation probability in case of changes of the number of contacts β when motivation η is fixed. User 1's and User 2's motivation η related to thier motivation are fixed such as $\eta_1 = \eta_2 = 4.0$. We research user 1's and user 2's expected utility $E[U_1], E[U_2]$ and optimal reaction p_1^0, p_2^0 by Table II.

$$E[U_1] = \Big[(2\sqrt{\beta} - 2\sqrt{\beta - 0.1} - 2)p_2^0 \quad (11)$$

$$+2\sqrt{\beta - 0.1}\Big]\, p_1^0 + 2p_2^0$$

$$p_2^0 = \frac{\sqrt{\beta - 0.1}}{1 - \sqrt{\beta} + \sqrt{\beta - 0.1}}, since\ 0 \leq p_1^0 \leq 1 \quad (12)$$

$$E[U_2] = \Big[(2\sqrt{\beta} - 2\sqrt{\beta - 0.1} - 2)p_1^0 \quad (13)$$

$$+2\sqrt{\beta - 0.1} + 0.3\Big]\, p_2^0 + 2p_1^0 - 0.5$$

$$p_1^0 = \frac{2\sqrt{\beta - 0.1} + 0.3}{2 - 2\sqrt{\beta} + 2\sqrt{\beta - 0.1}}, since\ 0 \leq p_2^0 \leq 1 \quad (14)$$

By eqs. (12) and (14), we compare between value of p_1^0, p_2^0 which are mixed strategy nash equilibrium and previous value.

In Fig. 3, X-axis shows probability p_1^0 which user 1 select to participate in system($a_1 = 0$), Y-axis shows probability p_2^0 which user 2 select to participate in system($a_2 = 0$). Fig. 3 (a) shows each users' participation probability in case of using previous function such as $f(M_i) = 2M_i$, Fig. 3 (b) shows each users' participation probability in case of using proposed function such as $f(M_i) = 2\sqrt{M_i}$.

Fig. 3 shows that user 1's and user 2's participation probability are high by raising value of the number of contacts β. It means that we expect that the higher the number of contacts is, the more users' participation are. In addition, in case of the number of contacts $\beta = 0.2$, participation probability to system is also high in proposed way when the same number of contacts. Because this is why users think that participating is the best way for increasing their utility considering reward that users get by a little umber of contacts, and it shows we expect that users participate in system rather than previous way.

B. Influence to Participation Probability by Motivation η

Second, we research changes of users' participation probability in case of changes of motivation η related to users' motivation when the number of contacts β related to the number of contacts is fixed. And then, User 1's and User 2's the number of contacts β related to contacts are fixed such as $\beta = 0.6$, $\eta = \eta_1 = \eta_2$.

The same as section IV-A, we research user 1's and user 2's expected utility $E[U_1], E[U_2]$ and optimal reaction p_1^0, p_2^0 by Table II.

$$E[U_1] = \Big[(2\sqrt{0.6} - 2\sqrt{0.5} - 2)p_2^0 + 2\sqrt{0.5}\Big]\, p_1^0$$

$$+ 2p_2^0 + 4 - \eta \quad (15)$$

$$p_2^0 = \frac{2\sqrt{0.5} - 4 + \eta}{2 - 2\sqrt{0.6} + 2\sqrt{0.5}}, since\ 0 \leq p_1^0 \leq 1 \quad (16)$$

$$E[U_2] = \Big[(2\sqrt{0.6} - 2\sqrt{0.5} - 2)p_1^0$$

$$+2\sqrt{0.5} - 3.7 + \eta\Big]\, p_2^0 + 2p_1^0 + 3.5 - \eta \quad (17)$$

$$p_1^0 = \frac{2\sqrt{0.5} - 3.7 + \eta}{2 - 2\sqrt{0.6} + 2\sqrt{0.5}}, since\ 0 \leq p_2^0 \leq 1 \quad (18)$$

By eqs. (16) and (18), we plot value of p_1^0, p_2^0 which is mixed strategy nash equilibrium, and then compare between them and value by previous way.

In Fig. 4(a), 4(b), X-axis and Y-axis are the same as section IV-A. Fig. 4(a), 4(b) shows that the higher value of motivation η related to users' motivation is, the higher user 1's and user 2's participation probability are. It means that hight of motivation accelerate users participate to system. In addition, in case of motivation $\eta = 3.4$, participation probability to system is higher than previous one even if the same value of motivation. It means that we expect that participation to system rather than previous way even if in case of low motivation.

C. Simulation

1) Simulation Setting: In this section, we research the changes of participation probability by reward function in the same simulation situation, and then we simulate in more real situation than previous situation.

In previous research, they set up the situation that is in the field of 100×100 and there are two potential users($N = 2$), 30 participants walk around the city with two type of walking patern and each node move length 1 per an hour. These nodes walk randomly. In our research, the walk pattern is ShortestPathMapBasedMovement from The ONE simulator. The number of potential nodes is two($N = 2$) and 98 participants, the sum of participants is 100, walk around the city. In addition, we set the simulation time to six hours because we assume it holding real game event. Under these conditions, we evaluate by output data that records contact history of nodes.

User 1's and user 2's participation probability(p_1^0, p_2^0) to system are 0.05 in default and we set up parameters based on Table II. Regarding to value of η, we set up $\eta = 4.0$, and then we repeat following steps five times the same as previous research.

1) Based on probability p_1^0, p_2^0, we calculate user 1's and user 2's the number of contacts M_i by simulation. We reset the seed value of each simulation 100 times, and

then the number of those simulations' contacts is new M_i.

2) Based on calculated M_i, we change user 1's and user 2's the average number of contacts to new M_i, and then we calculate new probability p_1^0 and p_2^0 which are mixed strategy nash equilibrium by $\beta = M_i/100$.

We compare these results obtained by the above steps.

2) Simulation Result: Fig. 5 shows analysis result by simulations. We compare between the situation adopted reward determination function of previous way and the situation adopted reward determination function of proposed way. In these figures, p_1^0 are a little different from p_2^0 because user 2 pay transportation expenses such as cost in order to come from far away. Fig. 5-(a) shows result of previous way,user 1's participation probability converge to 0.6 and user 2's participation probability converge to 0.5. On the other hand, Fig. 5-(b) shows that p_1^0 is more than 0.8 and p_2^0 is around 0.7 because of increasing participation probability to system by situation that is easy for participants to gain the rewards. Including user 2's cost, it is clear that proposed method such as new reward determination function also accelerate participation to system rather than previous method.

V. Conclusions

In our research, we research incentive-based participation promotion method in order to activate area by DTN system. It is not just giving reward based on users' the number of contacts, we analysis the change of participation probability by users' motivation and the effect of proposed method by modeling of N non-cooperative game and game theoretical analysis. As a result, we proposed new utility function. It is considered that users actively participate in system because of high reward. The proposed method is more effect than previous research in order to accelerate users to participate in and also restrain game owner's cost. We researched about influence of pattern of users' walking, however it doesn't effect on participation probability. It means that reward determination function is the more effective than the pattern of walking in order to accelerate users to participate in system.

A. Future Perspective

We determine user's reward based on only the number of contacts in DTN system in our research. First research aim is building system which determinate reward based on the number of users' message forward. However we can not determinate reward based on the definition of current reward function. Therefore, as a future work, we build the system which determinate each reward based on the number of message forward.

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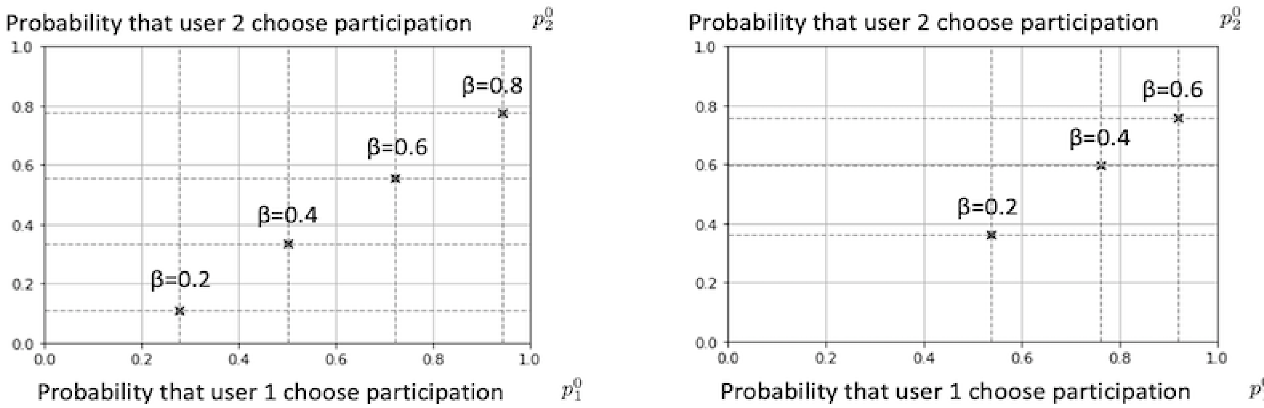
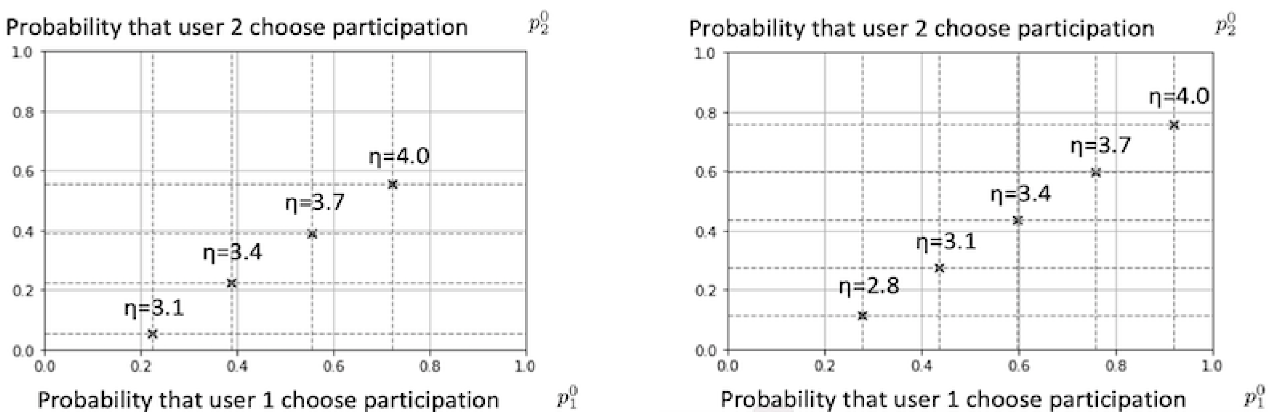


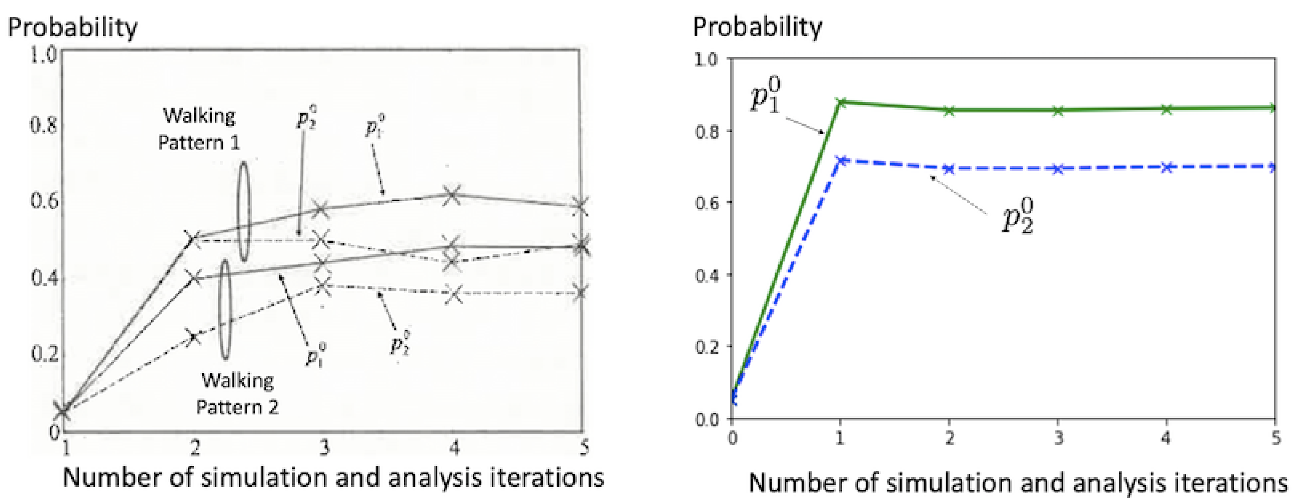
(a) Reward Function $f(M_i) = 2M_i$ (b) Reward Function $f(M_i) = 2\sqrt{m_i}$

Fig. 3. The influence to optimal reaction and mixed strategy nash equilibrium by the number of contacts β



(a) Reward Function $f(M_i) = 2M_i$ (b) Reward Function $f(M_i) = 2\sqrt{m_i}$

Fig. 4. The influence to optimal reaction and mixed strategy nash equilibrium by motivation η



(a) The influence to participation probability by previous method [4]

(b) The influence to participation probability by reward function of proposed method

Fig. 5. Comparison of users' participation probability by reward of proposed method