The Sixteenth International Symposium on Artificial Life and Robotics 2011 (AROB 16th '11),
B-Con Plaza, Beppu,Oita, Japan, January 27-29, 2011

A Systemic Payoff in a Self-Repairing Network

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Abstract: Cooperation among agents is a crucial problem in autonomous distributed systems composed of selfish agents pursuing their own profits. An earlier study of a self-repairing network revealed that a systemic payoff enabled to make the selfish agents cooperate with other agents. The systemic payoff is a payoff mechanism that sums up not only the agent's own payoff but also neighborhood's payoff. In the systemic payoff, the distance effect between the agents has not been studied yet. This paper considers the systemic payoff that involves the distance effect among the agents. We study the effectiveness of the proposed mechanism for the network performance by computer simulations.

Keywords: Autonomous distributed systems, self-repairing network, selfish agents, kin selection, game theory.

I. INTRODUCTION

Autonomous distributed systems are composed of selfish agents pursuing their own profits. In the autonomous distributed systems, selfish agents need to cooperate with other agents because collective selfish acts of the selfish agents would lead the systems to absorbed states. Studies on selfish routing reported that if agents route their traffic selfishly then the network would show a poor performance [1, 2].

Cooperation is a crucial issue in the autonomous distributed systems. Cooperation mechanisms for preventing the worst performance are investigated in congestion games. The studies [3, 4] introduced the cooperation factor to the agents in which the factor elicits the altruistic behaviors by a tunable parameter.

In evolutionary game theory, several studies for the evolution of cooperation have been investigated by a payoff mechanism and related to the present paper. An earlier [5] investigates effects of a neighborhood size and connectivity in spatial games because spatial structures affect cooperation among individuals.

In the self-repairing network, cooperation is also an important problem in order to maintain the agents [6, 7]. The self-repairing network is a model in which the agents repair other agents mutually [8]. In the self-repairing network, to bring out cooperation among the agents has been studied using spatial strategies and the payoff mechanism.

Earlier studies [7, 8] revealed that the systemic payoff is capable of making the agents cooperate with other agents in the self-repairing network. Moreover those studies reported that the systemic payoff was similar to kin selection [9]. The systemic payoff sums up not only its own payoff but also the neighborhood's payoff connected. Finally, those studies concluded that the agents with the systemic payoff improved the network performance.

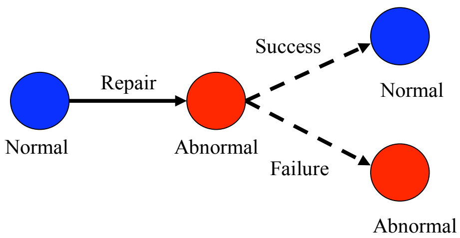
The earlier studies [7, 8] of the self-repairing network have not deeply mentioned a distance effect among the agents in the systemic payoff. In an information network, the agents are connected according to a network structure and distance. This paper considers that a cooperation factor needs to include the distance effect. The earlier studies have not considered the network performance caused by the distance effect of the systemic payoff.

This paper deals with the systemic payoff involving the distance effect between the agents in the self-repairing network. In this assumption, the agents are connected with any distance and connection weight. A connection weight of the systemic payoff represents strength of the relationship among the agents and is different according to the distance among them. We study the performance of the proposed systemic payoff by computer simulations.

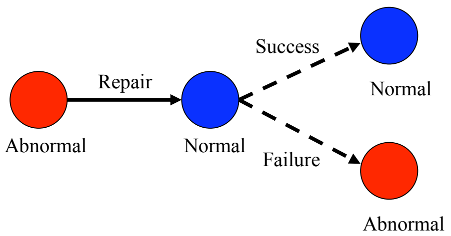
II. MODEL

1. Self-Repairing Network Model

We model the self-repairing network by a Spatial Prisoner's Dilemma [5, 6, 7]. The agents make their decision either repair or not repair. The abnormal agents



(a) Repair by normal agents



(b) Repair by abnormal agents

Fig. 1 Repair scheme of the self-repairing network. The blue and red circles indicate the normal and abnormal agents respectively.

will spread if no agents repair other agents. However, the agents are reluctant to consume their resources. This situation can be modeled by the Spatial Prisoner's Dilemma.

Each agent has binary states: normal or abnormal. We assume that the agents cannot know their own states and the states of other agents. Each agent is placed at each cell in a square lattice network. Basically, interactions of the agents are restricted in eight neighbor agents (Moore neighborhood). The Moore neighborhood of this assumption corresponds to a radius $r = 1$ for the interactions. The agents will repair other agents in the Moore neighborhood. However, the agents are able to communicate for the payoff with the eight neighbors besides the other agents outside of the Moore neighborhood ($r = 1$).

Each agent determines the next action: repair or not repair. The agents determine their action based on the strategies. The agents choose either All-C or All-D strategies. The All-C strategy always repairs other agents, while the All-D does not repair.

Fig. 1 shows a repair scheme of the self-repairing network. The repair success rate is different by the states of the agents. We denote the repair success rate of the normal and abnormal agents by α and β respectively. We assume to simplify the model that the repair by the normal agents is always successful ($\alpha = 1$). The repaired agent becomes normal if the repairing by abnormal agents is successful ($\beta = 0.1$) otherwise the repaired agents become abnormal. We

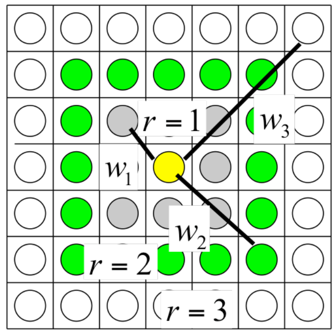


Fig. 2. Simple illustration of the systemic payoff with the distance effect. The agents with the same color are located at the same radius from the central (yellow color) agent.

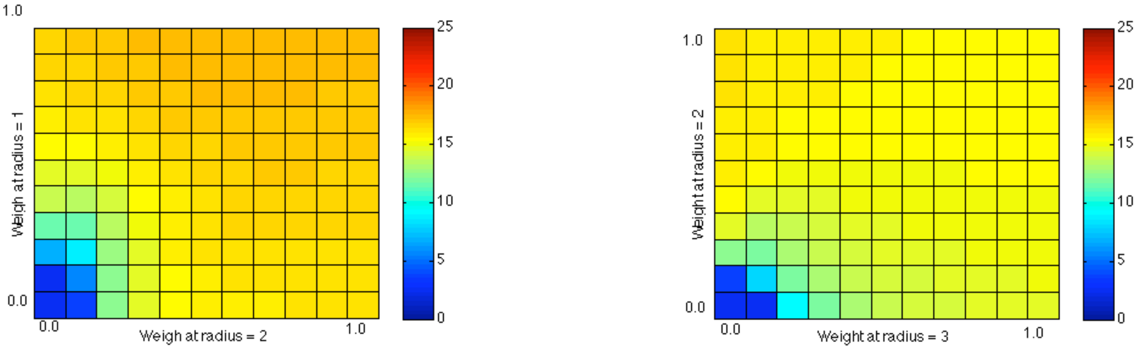
assume that the normal agents become abnormal by a spontaneous failure. We denote the failure rate by λ .

Each agent has the maximum available resources $R_{\max}$. The agents consume their resources R_c for every repairing. The agents assign their remained resources as the available resources to their own task. The remained resources of the abnormal agents are always evaluated as empty resources because they do not work well due to their state.

The agents update their strategies to the strategies that earn the highest payoff in the eight neighbors. The strategy update of the agents is done with strategy update cycle S . The agents sum up their payoff by the systemic payoff mechanism in the agent simulations. The strategy update error occurs when the agents update their strategies. The strategy update errors make the agents switch to other strategies. This mechanism contributes to prevent the local minima of the network performance. We denote the rate of the strategy update error by μ .

2. Systemic Payoff

This paper considers the systemic payoff that involves the distance effect of the relationship between the agents. Environmental effects of the neighbor agents reflect to the agents by their payoff. The agents collect information from the weighted payoff of the other agents. The weight of the connection strength between the agents is different according to the distance between them. The payoffs of the agents are weighted with strength of the connection between the agents. The agents will obtain not only local information (neighbor agents) but also global information (outer of the nearest neighbor agents) from the payoff. The systemic payoff allows gathering local and global information from the neighbor agents through their payoff.



(a) $\boldsymbol{r}$ = 1,2 (b) $\boldsymbol{r}$ = 2,3

Fig. 3. Averaged resources distribution where the connection weights of each radius are varied. The color bars indicate the averaged resources of each cell for the connection weight pairs.

In the systemic payoff, how much the agents involve the payoff of neighbor agents is a crucial issue because of the neighborhood's payoff affects the decision making of the agents. This paper defines the systemic payoff in the square lattice network (Fig. 2). Let a_{ij} and $R(a_{ij})$ denote the agent and its payoff located at (i, j) in the square lattice network. We denote the connection weight of the systemic payoff from the agent with distance r by w_r. In this paper, we assume that the radius of the systemic payoff for involving the neighborhood's payoff is less equal than five. Let denote the summed payoff of the agent a_{ij} by $R_t(a_{ij})$. Let denote the set of the agents on the radius r from the agent a_{ij} by $A_r(a_{ij})$. Therefore, the total payoff of the agents a_{ij} is expressed as follows:

$$R_t(a_{ij}) = R(a_{ij}) + \sum_r \sum_{a_{xy} \in A_r(a_{ij})} w_r R(a_{ij}) \qquad (1)$$

The total payoff of the agents will change by the combination of the connection weights of the systemic payoff. We investigate the relationship between the connection weight of the systemic payoff and the network performance.

III. SIMULATIONS

We obtain the simulation results from computer simulations, and then average the data by the number of the trial counts. The computer simulations use the parameters show in Table. 1. We assume that the agents change their connection weight corresponding to the radius of that agent in the calculation of the systemic payoff.

1. Performance for Connection Weight Pair

For the first simulations, we consider that the agents gather their own payoff from the agents located on the combination of the radiuses. In simulations, we give the agents two pairs of the connection weights corresponding to each radius. Those pairs of the connection weights are $r = 1,2$ and $r = 2,3$. We change the connection weight of each radius as simulation parameters from 0.0 to 1.0.

Table 1. Parameters for computer simulations.

Parameter	Description	Value
T_a	Step	10000
N_t	Number of trial	15
$L \times L$	Number of total agents	10000
$N(0)$	Number of normal agents at initial step	2000
$All - C(0)$	Number of repair agents at initial step	2000
R_{max}	Maximum resources	25
R_c	Repair resources	1
λ	Failure rate	0.01
S	Strategy update cycle	100
μ	Strategy update error rate	0.01
w_r	Connection weight at radius	0.0-1.0

Fig. 3 shows the averaged resources distribution for the fixed radius pairs. The averaged resources are sufficiently kept in both cases where either connection weight is larger than 0.4. Fig.3 (b) shows that the averaged resources drop a little than the case that the payoff interaction is restricted to $r = 1,2$ (Fig. 3 (a)). The connection weight between the agents should be adjusted strongly, because the weak relationship between them would cause the bad performance.

2. Performance for Single Radius

We evaluate the network performance for the systemic payoff gathering the payoff from the agents on single radius. We change the connection weight w_r for the

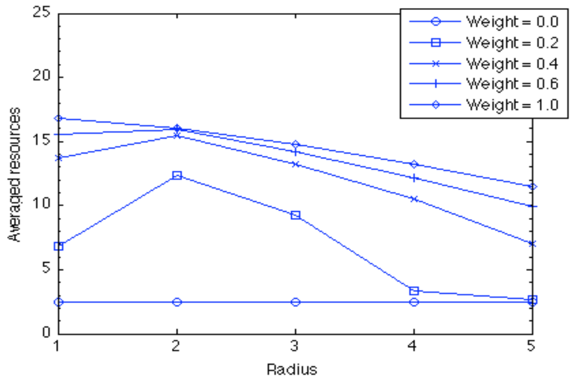


Fig. 4 Averaged resources for the connection weight where the agents obtain from the other agents on single radius.

radius r of the agents. The connection weights excluding the radius r are set to zero.

In Fig. 4, the network performance is worse for all radiuses where the connection weight is less than 0.4. However, the network performance improves as the connection weight grows to the large value. The impact of the connection weight appears when it is set to high, and then the agents choose to the repair action. From these results, the network performance decreases as the distance between the agents becomes longer.

IV. DISCUSSIONS

Agent simulations revealed that the connection weight representing the degree of the relationship between the agents is the dominant parameter for the network performance. From the results, the sufficient large connection weight between the agents can keep the high averaged resources. We think that the strong relationship between the agents in the systemic payoff could support the other agents by repairing because of the sufficient large connection weight could elicit cooperation among the agents.

In computer network, agents interconnect with each other with a distance and structures. It is possible that messages from neighbors to an agent will lose by link failures. In that case, the agents need to determine their decisions based on the neighborhood's payoff. The agent simulations demonstrate that the agents are able to keep the high averaged resources where either connection weight of the pairs is small. These results imply that the systemic payoff involving the distance effect would impact to the decisions of the agents appropriately and have the robustness for the environmental changes.

VI. CONCLUSIONS

We investigated the systemic payoff involving the distance effect that changes the connection weigh according to the distance between the agents. Our simulations showed that the sufficient large connection weight could lead the agents to cooperation, and then network performance improves. Furthermore, the agents can perform well where the agents allow only obtaining local information of the neighbor agents. We consider that the systemic payoff involving the distance effect would support for designing and constructing the autonomous distributed systems.

ACKNOWLEGEMENT

This work was supported by Global COE Program "Frontiers of Intelligent Sensing," from the ministry of Education, Culture, Sports, Science and Technology.

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