A Game Theoretic Analysis on Incentive for Cooperation in a Self-Repairing Network

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***Abstract*-This paper discusses when selfish agents begin to *cooperate* instead of *defect*, taking a specific task of maintenance of themselves. The network cleaning problem where a collection of agents capable of repairing other agents by overwriting its content can clean the collection will be discussed. With this problem, *cooperate* corresponds to repairing other agents and *defect* to not repair. Although *both defect* is a Nash equilibrium: no agent is willing to repair others when only the repair cost is involved in the payoff, agents may cooperate with each other when system reliability is also incorporated in the payoff and with certain conditions satisfied. Incentive for cooperation will be stronger when further system wide criterion such as availability is involved in the payoff.**

I. INTRODUCTION

Unexpected growth of the large-scale information systems such as the Internet suggests that an open and evolutionary environment for selfish agents will lead to collective phenomena. Internet is undoubtedly the most complex and large-scale artifact that human has ever invented. Observing how the internet has been built and grown up suggests that systems of this complexity may be built not by a usual design but by its own growth logic that the designer even did not think of before its maturation: a synthetic view that a self-repairing network could be embedded in the field.

After the Internet forms itself as a field that allow many selfish activities, several utilities and protocols converges on what may be called "Nash equilibrium" from where no players want to deviate [1]. In the seminal paper by Papadimitriou [2], a problem for the network protocol is posed, which will lead to economic models that allow TCP as an equilibrium point. These studies shed a new light on computational intelligence. That is, rather than implementing an intelligent program, design a field in the Internet that allows intelligent systems to emerge as Nash equilibrium of the Internet field.

Further, the game theoretic approaches to the Internet reveal that obtaining some Nash equilibrium is computationally difficult. This fact, looked from reverse side, would indicate that a computationally difficult task may be solved by selfish agents. Resource allocation, for example, which is computationally tough, may be solved by a market mechanism where many selfish agents participate in. Mechanism Design, a subfield of economics, has been studied [3] and has been extended to Algorithmic Mechanism Design [4] and to Distributed Algorithmic Mechanism Design recently [5].

This article aims a very first step toward embedding a computational intelligence in the Internet field by selfish agents. That is whether selfish agents can ever cooperate and even converge on some tasks. Selfish routing and task allocation have been studied extensively in computational game community, then can agents ever take care of themselves in the first place? We first pose the problem of self maintenance in an agent population, and then a game theoretic approach will be tested whether or not cooperation would occur or under what condition the cooperation will occur.

While this paper amounts to a microscopic analysis focusing on conditions when two interacting agents have incentive to cooperate (i.e. mutually repair), another paper in this volume [22] amounts to a macroscopic studies on the network with many interacting agents.

Section II discusses motivations and paradigm of the present research. The problem of cleaning a self-repair network will be described. Section III discusses the incentives for selfish agents to cooperate based on system reliability and availability of mutually repairing agents that do not have recognition capability. Section IV discusses when and how the selfish agents will cooperate based on the result of Section III.

II. ECONOMIC THEORY FOR THE SELFISH AGENTS

Game theoretic approach has demonstrated its power in the field of economics and biology. Internet has already reached to the level of complexity comparable to economic system and biological system. Moreover agents approach permits a structural similarity where selfish individual (in economic system of free market) and selfish genes (in biological systems) cooperate or defect in an open network where many things have been left undetermined before the convergence.

Economic approach has been actively studied in Distributed Artificial Intelligence community (e.g. [6, 7]), and application

T. Sobh (ed.), Innovations and Advanced Techniques in Computer and Information Sciences and Engineering, 505–510.

to auction may be one of successful domain (e.g. [8]). Economic approach, a game theoretic approach in particular, has been extensively studied in the algorithm and computation community and giving an impact on the network application. Rigorous arguments with the equilibrium concepts, Nash equilibrium among others, are framing a ground theory for economic aspect on the Internet. The cost of the selfish routing has been estimated with how bad the selfish routing might end up to the equilibrium (Nash equilibrium from where no one wants to deviates) relative to the optimal solution. Protocols such as TCP [10], Aloha, CDMA and CSMA/CA have been studied. Packet forwarding strategies in wireless Ad Hoc Networks can also be recast in the framework. Network intrusion detection has also been investigated [11] in a framework of two players' game: Intruder and Defender.

What has been computed by a market mechanism or more generally by collection of selfish agents turned out to be difficult when tried to obtain by computation (as a typical example: Prices of commodities as an index for resource allocations). This fact indicated that the market economy, or more generally free and hence selfish agents properly networked has a potential for computing something that could be difficult when approached otherwise. Also, the fact that the eradication of planned economy by the market economy and that the market economy remains in spite of perturbations indicated that the market economy may be "evolutionarily stable" [12] within these economic systems.

This fact further indicate that a problem solving framework by properly networked selfish agents may have some advantage over other usual problem solving frameworks such as the one organized with a central authority. Also, solutions can be obtained almost free or as a byproduct of the problem solving mechanism, or solutions are almost inseparably embedded in the solving mechanism. The above two observations encourage to recast the problems which have been known to be computationally difficult or the problems difficult to even properly define and approach, such as attaining self-repair systems.

Studies with agents usually assume that agents can be autonomous, hence allowing different rule of interactions: heterogeneous agents. We further assume that agents are selfish in the sense that it will try to maximize the payoff for an agent itself. Thus, agents can be broader than the program or software and they involve users that committed to the agents. Agents may include not only programs but humans (end-point users and providers running Autonomous Systems for the Internet) behind the programs. Mutually supporting collectives may emerge as interplay among agents. Spam mails, computer viruses and worms may be called as (malicious) agents, but they are not mutually supporting collectives. They are rather *parasitic* lone wolves. DDOS attacks and some distributed viruses and worms, however, can be a beginning of the collectives.

The idea developed here can apply not only to the Internet but also to other information network such as sensor networks, as long as they are put in the model.

The models presented in this paper have the following component:

M1. States: Agents have two states (0 for normal; 1 for abnormal). The state will be determined by the action and state of interacting agents.

M2. Actions: Agents have two actions (C for cooperation; D for defection).

M3. Network: Agents are connected by a network and agents can act only on the connected agents (neighbor agents).

Actions may be controlled uniformly or may be determined by the acting agent itself in a selfish agent framework so that payoff assigned to each agent will be maximized. Network may be defined explicitly with a graph or implicitly by specifying the neighbor agents (e.g. lattice structure as in cellular automata and dynamical network as in scale-free networks).

The network cleaning problem considered here assumes the self-repair network composed of nodes capable of repairing other nodes by copying. Since agents do not have recognition capability, source nodes (repairing agents) can be abnormal and target node (agents being repaired) can be normal. Hence mutual repairing without recognition could cause spreading of abnormal states rather than eradication of abnormal states.

Since we focus on the self-maintenance task by mutual repair, cooperation and defection corresponds to repairing and not repairing, respectively.

In the agent based approach, we place the following restrictions similar to immunity-based systems [13]:

– Local information: For each immune cell mounting receptor or a receptor itself (antibody), only matching or not (some quantitative information on degree of matching is allowed) can be provided as information.

– No a priori labeling: For an immune cell or antibody, an antigen is labeled neither as "antigen" nor as "nonself."

Because of these two restrictions, we face the "double edged sword" in this paper, since effectors part (repairing by copying) could harm rather than cure based on local information. This problem of "double edged sword" [14, 15] may be more significant than that of immunity-based systems because we do not assume recognition capability (that could avoid adverse effect) here as in the immunity-based systems. Actions of agents are motivated by selfishness (payoff) rather than the state of the target.

In the following sections, we use a Markov model used for reliability theory as a microscopic model that incorporates M1,