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Network Rewiring in Self-Repairing Network: from Node Repair to Link Rewire

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Abstract: Among self-action networks: self-recognition network and self-repairing networks, the self-repairing network allows the state change of nodes as a result of action (repair). The self-repair network is extended to allow network change as a result of action (rewire). Self-rewiring algorithm is also extended from the self-repairing algorithm. The extended algorithm can be applied to several problems such as stable marriage problem and distance adjustment problem. Comparison between node repair and link rewire as well as further extension will be discussed.

Keywords: Network rewiring, self-action network, self-repairing network, probabilistic algorithm.

1 INTRODUCTION

Dynamic network has been attracting attention for large-scale systems such as genetic network, collaboration network. Preferential attachment of link has been studied extensively after pioneering work by Barabási, Albert and Jeong [1]. In contrast to such dynamic and growing networks, rewiring networks, which assumes preferential rewiring (of existing links) [2] rather than attachment also have been studied. The model and algorithm proposed here belongs to the latter class: network rewiring models. The self-rewiring algorithm proposed can also be understood as a generalization of Gale-Shapley algorithm [3, 4].

We have been studying self-action networks where the actions by nodes through arcs mutually affect the state of nodes, and the state of nodes in turn affects the result of the actions. As self-action networks, two networks (i.e., self-recognition network [5, 6, 7] and self-repairing network [8]) has already been proposed. The remarkable feature of self-action networks is that each agent (expressed as a node in the network) not only acts on other agents that are connected (expressed by an arc in the network) but also being acted from other agents connected. This paper proposes yet another self-action network: a self-rewiring network as an extension of self-repairing network. In the self-rewiring network, each agent indirectly acts on other agents through reconfiguration of arcs (or edges).

Self-recognition network assumes recognition of other agents as the self-action. Expressed by a graph, agents correspond to nodes; recognition to arcs; and results of the recognition to sign associated to the arc.

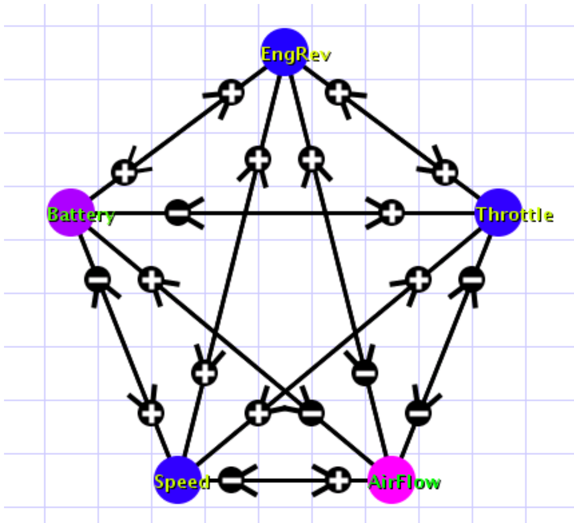

Fig.1 An example of self-recognition netwo rk for automobile engine diagnosis.
EngRev: Engine revolutions; Battery: Batt ery voltage. Gray level in the nodes indicat es credibility. Dark nodes correspond to hig h credibility, while light nodes to low credi bility (i.e. evaluated as faulty) [6].

Fig. 1 shows an example of self-recognition network expressed by a graph. The self-recognition network and technology to build the network have been extensively studied to apply to automobile engine [6], home security [9], motherboard [10], and information security [11]. The self-recognition network can be technique to recon ciliate and unify the observed data and inference, similarly to data reconciliation and can be related to data assimilation [12]. The self-recognition network where the recognition is based on the physical relation is also comparable to on-line simulation [13] where missing data will be inter- or extrapolated based on the observed data.

Self-repairing network, on the other hand, assumes repairing on other agents as the self-action. It can be expressed by a graph similarly to the self-recognition network. However, to derive significant results such as critical phenomena for a network cleaning problem [6], regular graph (as is often the case in cellular automata) is often assumed. While the self-recognition network assumes sensor networks as a potential application area, the self-repairing network assumes actuator network for applications. Both self-recognition and self-repairing network can be applied to a computer network where recognition as well as (software) repair are possible.

Section 2 briefly reviews the self-repairing network. Section 3 proposes a self-rewiring network and self-rewiring algorithm based on the self-repairing network. Section 4 presents possible applications to stable marriage problem and distance adjustment problem that intrinsically require network rewiring.

2 SELF-REPAIRING NETWORKS

A self-repairing network consists of agents capable of repairing other agents connected. In this study, each agent is placed at each node of one-dimensional lattice (Fig. 1) with a periodic boundary condition (leftmost

Fig.2 Cellular automaton with one-dimensional lattice and two states: normal (0) and abnormal (1) [6]

agent and rightmost agent are connected). Each agent has two states: normal (0) and abnormal (1).

Each agent tries to repair its neighbor agents. However, since the repairing is done possibly by abnormal agents, the repair could damage the neighbor agents rather than repair. Frequency of the repair trial is controlled by a parameter: repair rate ***Pr***. As shown in Fig. 3, the repair will be successful with a rate ***Prn*** (the repair success rate by normal agents) when the repair is done by a normal agent, and with a rate ***Pra*** (the repair success rate by abnormal agents) when it is done by an abnormal agent.

Self-repairing network consists of three elements (***U, T, R***) where ***U*** is a set of nodes, ***T*** is a topology connecting the nodes, and ***R*** is a set of rules of the interaction among nodes. A set of nodes is a finite set with ***N*** nodes, and the topology could be n-dimensional

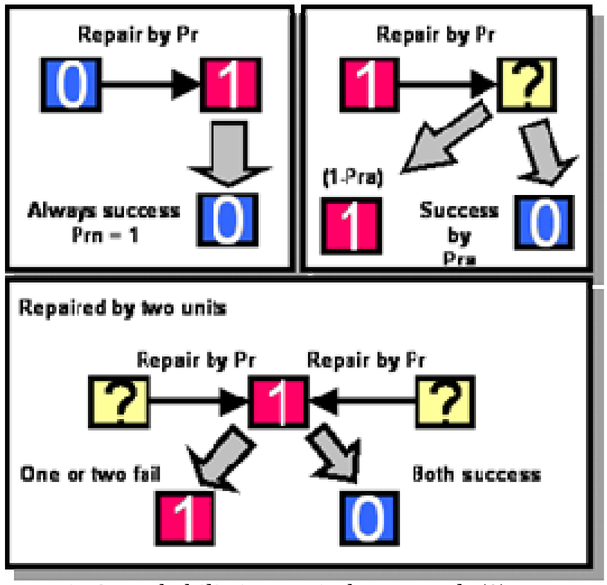

Fig.3 Probabilistic repair by normal (0) agents (*above left*) and by abnormal (1) agents (*above right*). Repair by two agents (*below*) [6].

array, complete graph, random graph, or even scale-free network where each node could have *S* neighbors for each nodes with a boundary condition, i.e. the structure of the array is a ring with node 1 adjacent to the node *N*. Also, we restrict the case where each node has a binary state: normal (0) and abnormal (1). Each node tries to repair the adjacent nodes in a synchronous fashion with a probability P_r. The repairing will be successful with the probability P_{rn} when it is done by a normal node, but with the probability P_{ra} when by an abnormal node ($P_{ra} < P_{rn}$). The repaired nodes will be normal when all the repairing is successful. Thus, when repairing is done by the two adjacent nodes, all these two repairing must be successful in order for the repaired node to be normal.

3 SELF-REWIRING NETWORKS

Self-repairing network and its probabilistic repairing algorithm have been extended to include not only node repair but also link rewiring. The extended model and algorithm can deal with a wide variety of problems that require link rewiring to be solved. Such problems range from a naïve matching problem of Stable Marriage Problem (that requires link rewiring in bipartite graph) to a practical adjustment problem of inter satellites distance in the system of autonomous networked satellites.

In the extension, each node will evaluate the current link and rewire it from the current target node to other target node by conditions specific to the problem. Since

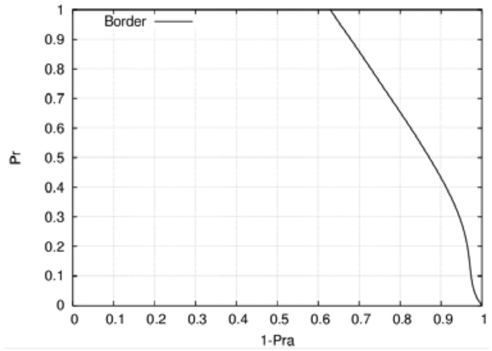

Fig.4 Frozen Phase (*left region* where all the agents are normal) and Active Phase (*right region* where some units remain to be abnormal) [6].

the evaluation will be done by a node with limited information, the evaluation could be wrong, hence the "double edged sward" would take place similarly to the original self-repairing network.

Self-repairing network with the probabilistic repairing algorithm is known to have a specific threshold in model parameters to eradicate all the abnormal nodes. This paper investigates if such specific threshold exists for the extended Self-repairing network in the network rewiring. If the threshold exists, engineering should be carried out in the close vicinity of the threshold, for the phase may be critically changed across the threshold, while the parameter regions far from the threshold need not be carefully managed.

Although the self-repairing networks assume a fixed network, the self-rewiring networks allow the network to change the connection. The state of nodes: normal or abnormal depends on the connection of the node. Normal state should be understood as the state that the agent cannot be better by changing the links incident to the node, while abnormal state as the state that agent can improve by changing the links. The self-rewiring algorithm can be similarly defined to the self-repairing algorithm.

[Step 1] Each agent will be activated with a probability *Pr*.

[Step 2] For the activated agent, try to activate the link with a probability proportional to the preference.

[Step 3] The other agent connected by the activated agent will accept the connection, if the connection improves the agent.

With this algorithm, all the agents become normal state, and this all normal state is a probabilistically stable. That is, once all nodes become normal state with a certain configuration, then transition probability to other configuration is smaller than the transition probability to the attained configuration.

4 APPLICATIONS OF THE SELF-REWIRI NG NETWORK

4.1 Stable Marriage Problem

The Stable Marriage Problem (SMP) assumes *n* women and *n* men each of them has an ordered preference list (or a rank) without tie to the opposite sex. As in the example shown in Fig. 5, the men m_2 has an ordered preference list (w_2, w_3, w_1) or a rank (2, 3, 1), which means m_2 likes w_2 best, and he prefers w_3 to w_1.

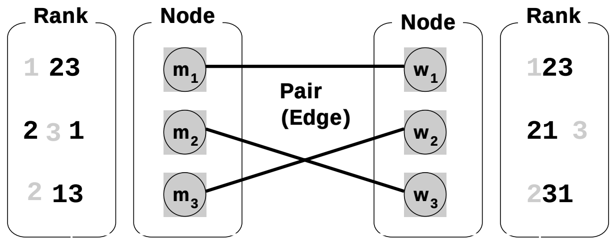

Fig. 5. An illustration of Stable Marriage Problem with size three.

Under the above assumptions, SMP seeks for the complete matching between *n* women and *n* men, which satisfies stability. The stability requires the concept of blocking pair. Two pairs (m_i, w_p) and (m_j, w_q) are blocked by the pair (m_i, w_q) if m_i, prefers w_q to w_p and w_q prefers m_i to m_j. For example, a pair (m_2, w_3) and (m_3, w_2) will be blocked by the pair (m_2,w_2). A complete matching without being blocked is called *stable* matching.

Self-rewiring algorithm applied to SMP may be summarized as follows:

[Step 1] For each agent, activate the agent with a probability *Pr*.

[Step 2] For the activated agent, try to find a higher rank with a probability proportional to the preference.

[Step 3] For the new partner agent being proposed in the previous step, accept the proposal if the new partner agent does not have the current partner, or the new partner agent has a higher rank on the proposing agent than the current partner.

In selecting agent in the step 1, the agents can be selected from male (female, or don't care) agent if the algorithm assumes male (female-optimal, or gender does not matter) as the proposing side (Fig. 6).

4.2 Simulation Result

We consider an instance of SMP with size 3 where every man has a fixed ordered preference list (w_0, w_1,

w_2) and every woman also has a fixed ordered preference list (m_0, m_1, m_2). In the simulation below, male is set to be the proposing side. In the Gale-Shapley algorithm, male-optimal solution will be obtained when the proposing side is fixed to the male side. In the self-rewiring algorithm, however, female side can attain optimal solution with a certain probability (Fig. 6).

In each plots of Fig. 6, horizontal axis is time step and vertical axis the rank attained for each individual shown line type. Figures left are the attained rank for male; and those right are the rank for female. Upper figures are when *Pr* =0.3 and those lower are when *Pr* =0.9. As *Pr* increases, female side attains happier matching (closer to female-optimal). This is because higher *Pr* would lead to more simultaneous proposals to a woman, which will give the woman a chance to select her preferred proposal.

Additional difference from the Gale-Shapley algorithm is on the concept of stability. Although Gale-Shapley algorithm obtain a stable matching, the network rewiring algorithm would obtain the distribution of matchings including all the stable matchings as well as the unstable ones with blocking pairs with a smaller probability than the ones for stable matchings (Fig. 6).

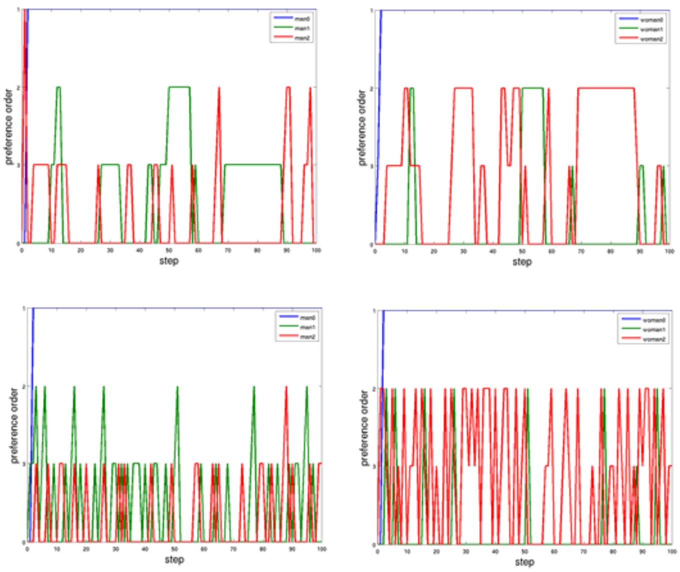

Fig. 6 Probabilistic rewiring applied to the Stable Marriage Problem with size three.

5 DISCUSSIONS

Since the self-rewiring network and algorithm are extension of the self-repairing network and algorithm, they share some commonalities. If we regard the normal state of agents as favorable state of agents (as in the Stable Marriage Problem above) defined similarly to the Nash equilibrium that any rewiring would not improve the satisfaction of agents, then self-rewiring algorithm also allows the normal state to spread.

Although simple and naïve problem of Stable Marriage Problem is used for illustrative purpose, the self-rewiring algorithm could be used for many other problems such as a distance adjustment problem (agents placed in a space will adjust their relative positions to meet a given constraint); and dynamic reconfiguration for embedded systems.

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