Toward Overlay Network Symbiosis

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Abstract

Simultaneous overlay networks compete for network resources and disrupt each other. If they cooperate with each other, the collective performance can be improved and they can coexist comfortably. Taking inspiration from biology, in this paper we present a model of symbiotic overlay networks. Coexisting overlay networks dynamically evolve, interact with each other, and change their internal structures. Overlay networks in a symbiotic condition eventually establish the strong relationship and finally merge into one. We also evaluate the effect of interconnection of two overlay networks from the viewpoint of the robustness and the rate of message dissemination.

1. Introduction

With emerging needs for application-oriented network services, overlay networks have been widely deployed over physical IP networks. Since overlay networks behave in a selfish and independent fashion to pursue their own benefit and to maximize their own utility, they compete for limited physical resources and disrupt each other. The analysis on coexistence of competitors has been investigated in the field of biology. In the ecosystem, organisms in the same environment live together with direct and/or indirect interactions with each other. In [8], they established the mathematical model of the metabolic pathways of bacterial strains to elucidate mechanisms of coexistence of living organisms of closely related species. They revealed that the coexistence emerged not only from interactions among competitors, but also from changes of their internal states.

In this paper, taking inspirations from biology, we consider the symbiosis among competing overlay networks. We regard an overlay network as an organism. In the model of symbiotic overlay networks, overlay networks in a system evolve, interact with each other, and dynamically change internal structures, as living organisms in the same environment do. Overlay networks meet and communicate with each other in a probabilistic way. Overlay networks that benefit from each other reinforce their relationship, eventually have many inter-overlay links, and become one. Otherwise, they part from each other. All of evolutions, interactions, and internal changes are performed in a self-organizing way. Each node independently decides its behavior based on locally available information. Symbiosis among overlay network emerges as a consequence of independent and autonomous behaviors of nodes and networks.

2. Symbiotic Overlay Networks

An overlay network w starts with a small number of nodes $n_w(0)$. As time passes, new nodes join and some nodes leave. The number of nodes at time t is expressed as $n_w(t)$. In joining a network, a new node establishes one or more connections to nodes already present in the network. There are variety of strategies for new connection attachment, such as the preferential attachment [2], the random growth [4], and Phenix [7].

Next, each node decides whether it establishes an inter-overlay link or not independently of the others or through mediation among nodes. Other overlay networks can be found by using, for example, i3 [6]. The probability p_{wj} that node j newly establishes an inter-overlay link can be uniform among nodes, i.e., random interconnection, or, for example, a monotonically increasing function of the number of neighbors, i.e., degree k_{wj} of node j. In this case, the node with the highest degree is most likely to become a pathway node. By choosing a high-degree node in a scale-free network, we can expect efficient message dissemination [1]. In addition, the average distance between arbitrary two nodes is kept small as in a small world network.

After establishing an inter-overlay link, a pathway node begins to relay messages among overlay networks under a certain policy. As an example scenario, let us consider a P2P file sharing service. When pathway nodes forward query messages to each other, more files can be found. With message aggregation and caching technique, the load on an inter-overlay link can be reduced and further efficient file-sharing can be accomplished. Even if they are operated with the different policy and protocols, inter-overlay links are benefitial since inter-connected overlay networks can provide alternative routes to each other and the robustness against node/link failures can be improved. The probability that pathway node j terminates an inter-overlay link is defined as q_{wj}. If a pathway node considers that an inter-overlay link is beneficial to itself and/or its home network, q_{wj} becomes small. The abovementioned strategy leads to mutualism, where both species benefit from each other. We can consider other forms of symbiosis, i.e., commensalism and parasitism depending on applications.

Inter-overlay communications and resultant changes in network conditions affect overlay networks. Nodes dynamically add, remove, or rewire connections to have more preferable neighbors or network structure. It means that interactions among overlay networks affect internal structures of them as in biological systems. An overlay network normally employs a greedy and selfish strategy to maximize its own performance. In [5] and [3], they proposed a family of rules of link additions and rewiring to improve the robustness of overlay networks, but they require the global and complete information about the network topology. Thus, we need to consider another modification algorithm, where a node does not need any global information and it can add, remove, and rewire connections on its own decisions. For example, through message exchanges with neighboring nodes, a node can know nodes two-hops away [1]. Then, by rewiring a connection from a node with the highest degree to a randomly chosen node, a similar effect to the preferential rewiring [3] can be obtained.

3. Preliminary Experiments

We conducted preliminary experiments on the effect of interconnecting two overlay networks from the viewpoint of the robustness against node removals and the rate of message dissemination. Due to the space limitation, however, figures are not shown in the paper. Each static network has 5,000 nodes whose degree distribution follows power-law distribution $P(k) = 2.6k^{-2.4}$. Overlay networks are connected by s pairs of randomly chosen nodes, i.e., random interconnection, or s pairs of nodes chosen in an descending order of node degree, i.e., maximum interconnection.

The robustness was evaluated by connectivity C, which was given as the ratio of the number S of nodes in the largest connected component to the remaining number of nodes in a system after the removal of fraction f of nodes. From simulation experiments, the maximum interconnection was shown to be more robust against random failures of nodes. The maximum-interconnected network with $s = 10$ showed the similar robustness as a power-law network of 10,000 nodes. However, it was more fragile under intentional attack against the most connected nodes. The rate of messages dissemination was evaluated by reachability R, which was defined as the ratio of nodes visited by messages diffused by flooding. A network interconnected by only a pair of highest-degree nodes could disseminate messages more efficiently than a randomly interconnected network.

4. Conclusion

In this paper, we propose the model of symbiotic overlay networks. Through evolutions, interactions, and inner-transformation of overlay networks, the symbiosis emerges. However, as [8] revealed, the symbiosis does not always appear. There are variety of strategies in growth model, definitions of p_{wj} and q_{wj}, and topology modification. We will give further detailed consideration to those issues and define the space of strategies where the symbiosis emerges. We are now establishing more concrete models of overlay network symbiosis in P2P file sharing systems.

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