Extending Schelling's Model for Topology Adaptation of an Overlay Network with Heterogeneous Nodes

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Abstract—For building a large-scale overlay network, its topology must be configured with an autonomous and decentralized mechanism. If the overlay network topology is configured without taking account of node heterogeneity, the overall performance of the overlay network might be severely degraded. On the other hand, it is well known in sociology that Schelling's model explains the segregation phenomenon between races. Singh *et al.* proposed a topology adaptation method based on Schelling's model for P2P overlay networks. Their method realizes efficient topology configuration for P2P overlay networks with two types of nodes. In this paper, we propose a topology adaptation method for overlay networks with heterogeneous nodes by extending the method proposed by Singh *et al.*. Namely, we extend Singh's method so that multiple types of nodes can be handled. We also investigate the characteristics of the proposed method by simulation. Our simulation results show that the proposed method is efficient and has good convergence property.

1. Introduction

For constructing an efficient overlay network with many nodes having different characteristics, its topology should be configured by taking account of node heterogeneity. For building a large-scale overlay network, its topology must be configured with an autonomous and decentralized mechanism. If the overlay network topology is configured without taking account of node heterogeneity, the overall performance of the overlay network might be severely degraded.

For instance, if nodes with significantly different characteristics are connected by overlay links, a node with the least capability becomes the bottleneck, so that the end-to-end performance between overlay nodes is limited, resulting in low network transmission capacity. If the overlay network topology is configured so that nodes with similar characteristic are interconnected, it leads to high end-to-end performance between overlay nodes, resulting in high network transmission capacity.

On the other hand, it is well known in sociology that Schelling's model [5] explains the segregation phenomenon between races. Schelling's model is one of cell automaton models. In Schelling's model, two types of agents repeatedly and autonomously move to another cells if the agent is surrounded by dissimilar agents. Schelling's model shows that segregation are not caused by a central authority, or desire of agents to stay away from dissimilar agents; but is a cumulative effect of simple actions of agents.

In [6, 7], Singh *et al.* proposed a topology adaptation method called *Schelling's algorithm* based on Schelling's model for P2P overlay networks. Singh *et al.* focused on autonomous decentralized and self-organizing properties of Schelling's model. Schelling's algorithm realizes efficient topology adaptation for P2P overlay networks with two types of nodes; i.e., Schelling's algorithm interconnects similar nodes using an overlay link replacement mechanism based on Schelling's model.

In this paper, we propose a topology adaptation method called *Extended Schelling's algorithm* for overlay networks with heterogeneous nodes by extending the method proposed by Singh *et al.*. Namely, we extend Schelling's algorithm so that multiple types of nodes can be handled. The proposed method changes the overlay network topology gradually so that the nodes with similar characteristic are interconnected. Thereby, we enable application of Schelling's algorithm to more realistic networks with heterogeneous nodes. We also investigate the characteristics of the proposed method by simulation. Our simulation results show that the proposed method is efficient and it has good convergence property.

The structure of this paper is as follows. First, Section 2 introduces related works. Section 3 describes the topology adaptation method for overlay networks with heterogeneous nodes. Section 4 investigates the characteristics of the proposed method by simulation. Finally, Section 5 summarizes this paper and mentions future works.

2. Related Works

Schelling's model is one of social models and explains the segregation phenomenon between races [5] . Segregation is a phenomenon that a place of residence separates owing to people who have the same property as the whole society gathering in the society constituted by people with different properties (e.g., races and cultures).

Singh's works [6, 7] are the pioneering researches that applied Schelling's model to the engineering purposes. Singh *et al.* proposed a topology adaptation method called *Schelling's algorithm* for P2P overlay networks by applying Schelling's model.

In this paper, we distinguish "Schelling's model", which is the cell automaton model explaining the segregation phenomenon between races, and "Schelling's algorithm", which is the topology adaptation method for P2P overlay networks proposed by Singh *et al.*.

If nodes with significantly different characteristics are connected by overlay links, the node with the least capability becomes the bottleneck, so that the end-to-end performance between overlay nodes is limited, resulting in low network transmission capacity. In Schelling's algorithm, the overlay network topology is gradually changed so that the node with similar characteristic are interconnected by the method based on Schelling's model. Thus, the overlay network topology is configured so that nodes with similar characteristic are interconnected, it leads high end-to-end performance between overlay nodes, resulting in high network transmission capacity.

since Schelling's algorithm proposed by Singh *et al.* uses the Schelling's model in a simple fashion, it assumes two types of nodes with different processing speeds. On the other hand, the characteristics of nodes should differ variously in real networks. For this reason, Schelling's algorithm is not applicable to real networks without modification.

3. Topology Adaptation Method for Overlay Networks Based on Schelling's Model

3.1. Schelling's Algorithm

First, we explain the Schelling's algorithm proposed by Singh *et al.*.

Schelling's algorithm is the method that realizes efficient topology configuration for P2P overlay networks. In Schelling's algorithm, each node replace overlay links in an autonomous fashion. Schelling's algorithm assumes two types of nodes with different processing speeds.

In Schelling's algorithm, the overlay network topology is gradually changed so that the nodes with similar characteristic are interconnected by the method based on Schelling's model. Each node has a parameter $\theta (0 \leq \theta \leq 1)$ called *tolerance*. Each node calculates the ratio of similar nodes to all the neighbor nodes . If this value is larger than or equal to the tolerance θ, the node performs nothing. Otherwise, the node searches for a similar node by depth first search, and replaces overlay links. Namely, One overlay link is chosen at random among overlay links connected to dissimilar neighbor nodes, and is deleted. Then, an overlay link to the similar node discovered by the search is created.

To avoid the link concentration to a specific node, the number of overlay links connected to a node is limited by L_{max}. Also, the range of node search is limited by S_{max} hops.

3.2. Extended Schelling's Algorithm

In what follows, we propose a topology adaptation method called *Extended Schelling's algorithm* for overlay networks with heterogeneous nodes by extending the method proposed by Singh *et al.*. Namely, we extend Schelling's algorithm so that multiple types of nodes can be handled. The overlay network topology is configured so that nodes with similar characteristic are interconnected by Extended Schelling's algorithm .

Extended Schelling's algorithm is an extension of Schelling's algorithm in a natural fashion.

We denote the number of node types with $N (\geq 2)$. Let $T = \{t_1, t_2, \ldots, t_N\}$ be a set of node types, and $t(i)$ be the type of node i . For enabling handling of multiple node types, we define similarity $d_{n,m}$ between types t_n and t_m. Note that Schelling's algorithm proposed by Singh *et al.* is equivalent to the case of $N = 2$ and

$$d_{n,m} = \begin{cases} 1 & \text{if } t_n = t_m \\ 0 & \text{otherwise.} \end{cases} \quad (1)$$

In Extended Schelling's algorithm, each node has a parameter $\theta (0 \leq \theta \leq 1)$ called *tolerance*.

In Extended Schelling's algorithm, each node replaces overlay links as follows.

(1) Calculate the average distance D_i to neighbor nodes

Node i calculates the average distance D_i to neighbor nodes. By using the similarity $d_{t(i),t(j)}$ between node i and node j, D_i is defined as

$$D_i = \frac{\sum_{j \in A_i} d_{t(i),t(j)}}{|A_i|}, \quad (2)$$

where A_i is a set of node i's neighbor nodes.

(2) Compare the average distance D_i and tolerance θ

If the average distance D_i to neighbor nodes is less than tolerance θ, proceed to step (3) where an overlay link is changed by the same algorithm with that in [6]. Otherwise, return to step (1).

(3) Search for a similar node j, which is a candidate for overlay link connection

Search for a similar node within S_{max} hops whose number of overlay links is less than L_{max} by depth first search. If the node j that satisfies the conditions can be discovered, proceed to step (4). Otherwise, return to step (1).

(4) Delete an overlay link with a dissimilar neighbor node k

Randomly choose one dissimilar node k from dissimilar neighbor nodes of node i. If the degree of node k is larger than or equal to two, an overlay link with

Table 1: Processing speeds for different node types

number of node types N	processing speeds [Mbit/s]
2	1, 10
3	1, 5.5, 10
4	1, 4, 7, 10
5	1, 3.25, 5.5, 7.25, 10

Table 2: Parameters used in simulation

number of nodes	1,000
average degree of initial network topology	3
range of node searh S_{max}	5
limit of the number of overlay links L_{max}	10

node k is deleted and proceed to step (5). Otherwise, return to step (1).

(5) Create an overlay link to the similar node j

Create an overlay link to the similar node j, and return to step (1).

4. Simulation

4.1. Simulation Setup

In what follows, we investigate the efficiency and convergence of Extended Schelling's algorithm.

In this paper, the same simulation model except node heterogeneity with that in [6] are used. In [6], there exist just two types of nodes (i.e., nodes with processing speeds of 1 and 10 [Mbit/s]). In this paper, there exist N types of nodes (i.e., nodes with processing speeds ranging from 1 to 10 [Mbit/s] (see Tab. 1)).

For investigating properties of Extended Schelling's algorithm, the underlying network is assumed not to be the performance bottleneck [6]. In other words, in our simulation, the processing speed of an overlay node becomes the bottleneck of the overlay network.

The number of overlay nodes is 1,000, and the initial topology of the overlay network is given by a random network with the average degree of 3. L_{max} and S_{max} are set to 10 and 5, respectively. Equation 1 is used for similarity $d_{n,m}$.

Unless explicitly stated, parameters shown in Tab. 2 are used in all simulations.

We performed ten simulations, and calculated the average of all measurements.

4.2. Efficiency

Figure 1 shows the *average bottleneck bandwidth* of the overlay network when changing the tolerance θ from 0 to 1. The average bottleneck bandwidth is one of indices that measure the transmission capacity of an overlay network. It is defined as the average of bottleneck link bandwidths among all node pairs. The average bottleneck bandwidth was measured after performing sufficiently long simulation.

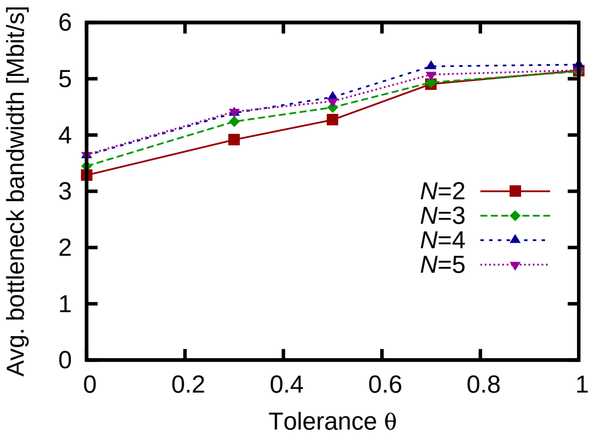

Figure 1: The average bottleneck bandwidth of an overlay network when changing the tolerance θ from 0 to 1.

Simulation results with $N = 2$ is equivalent to those with Singh's Schelling's algorithm. Also, simulation results with $\theta = 0$ corresponds to not performing Extended Schelling's algorithm (i.e., topology adaptation is not performed).

This figure indicates that Extended Schelling's algorithm is effective; i.e., the average bottleneck bandwidth increases as the tolerance θ increases. This figure also indicates that Extended Schelling's algorithm works quite well for any number of node types N, which suggests that Extended Schelling's algorithm is effective for topology adaptation of an overlay network with heterogeneous nodes.

4.3. Convergence Property

Figure 2 shows a dynamical behavior of Extended Schelling's algorithm during simulation. Namely, this figure shows the mean of average distances D_i's of all nodes for $\theta = 0.3$ sampled at every 1,000 time slots.

This figure indicates that Extended Schelling's algorithm converges at 3000 time slots in terms of the mean of average distances. This implies fast convergence of Extended Schelling's algorithm. In our simulation, there are 1,000 overlay nodes and only a single node is activated at each time slot. Thus, on the average, each node is needed to be activated just three times before reaching the convergence.

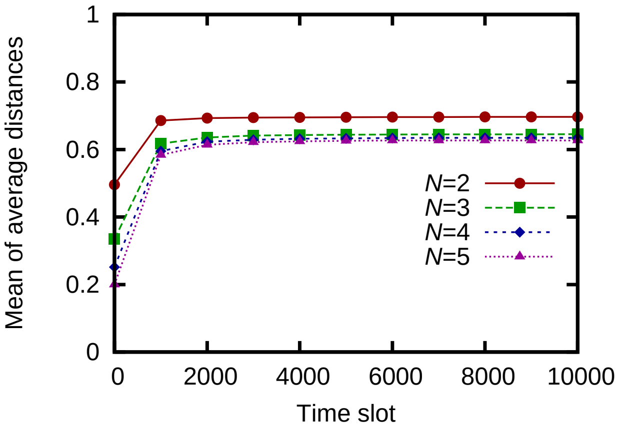

Figure 2: The mean of average distances D_i's of all nodes for $\theta = 0.3$ sampled at every 1,000 time slots.

5. Conclusion

In this paper, we have proposed a topology adaptation method called *Extended Schelling's algorithm* for overlay networks with heterogeneous nodes by extending the method proposed by Singh *et al.*. We have also investigated the characteristics of the proposed method by simulation. Our simulation results have shown that the proposed method was efficient and it had good convergence property.

As future work, we are planning to investigate the performance of Extended Schelling's algorithm in a network with highly dynamic nodes (i.e., nodes frequently join to/leave from the overlay network).

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