Topology Design based on User Relationship for Cascading Failure in D2D-based Social Networking Service

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***Abstract*—In this paper, we propose a topology design based on user relationship for cascading failures in D2D-based social networking service. In the proposed topology design, node resilience is calculated from topologies of a physical network and a social network, and then an optimization problem for the topology design of the social network is formulated so as to maximize the node resilience. In the proposed method, we add some new user relationships to the social network, and a new topology is designed. We evaluate the performance of the proposed topology design with simulation. In numerical examples, we show that the optimal topology for the social network can be derived by using our topology design and the node resilience is improved.**

I. INTRODUCTION

In Device-to-Device based social networking services (D2D-based SNS), the data transmission is performed over two layer networks; a physical network where D2D communications are performed and a social network where users are communicated through SNS with each other [1]. The performance of data transmission in D2D-based SNS depends on the topologies of those two networks. In such two layer networks, when a network failure is occurred in a network, other failures are occurred in the other network, that is called *cascading failure* [2]. This cascading failure degrades significantly the performance of data transmission in D2D-based SNS.

In this paper, in order to decrease the impact of cascading failure for D2D-based SNS, we propose a topology design based on user relationship in a social network. In the proposed method, we add some new relationships to the social network so as to minimize the impact of cascading failure by solving an optimization problem. We evaluate the performance of the proposed method with simulation, and investigate the effectiveness of the proposed method.

The rest of this paper is organized as follows. Section II explains node resilience for cascading failure. Section III describes our proposed topology design with an optimization problem based on user relationship. Section IV shows some numerical examples, and finally we conclude this paper and explain our future work in Section V.

II. NODE RESILIENCE FOR CASCADING FAILURE

In D2D-based SNS, cascading failure affects the performance of data transmission, and this impact can be evaluated as a metric called *node resilience* [3]. This metric denotes the fraction of nodes that are not affected by the cascading failure during its communication time.

Now, let p_f be the fraction of nodes where the initial failure occurs, and those nodes are assumed to be selected at random. We also denote s_∞ as the fraction of nodes that are never affected by the cascading failure. Moreover, let λ be the average communication time of each node, and let T_{max} be the maximum isolation time that is the largest time until a node becomes isolated by the cascading failure. From these parameters, the upper bound and the lower bound of ψ are calculated as follows.

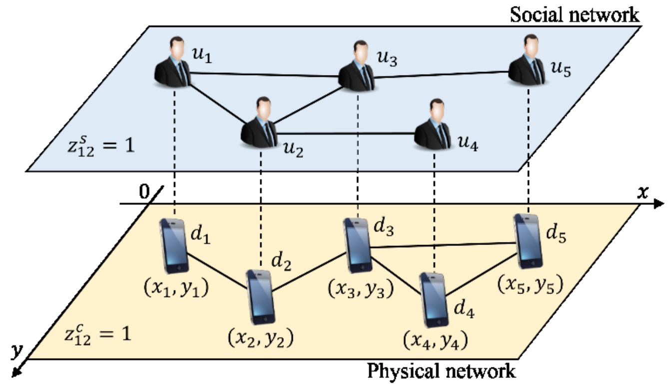

Fig. 1. D2D-based SNS architecture where the number of users is five.

$$\psi \geq s_\infty + (1 - p_f - s_\infty)(1 - e^{-\lambda}) \tag{1}$$

$$\psi \leq 1 - (1 - p_f - s_\infty)e^{-\lambda T_{max}} - p_f \tag{2}$$

When ψ is large (small), a large (small) number of nodes can finish those communication before the nodes are affected by the cascading failure. The second term in (1) means the minimum fraction of nodes whose communication has already finished before those are affected by the cascading failure. Moreover, the second term of (2) denotes the maximum fraction of nodes whose communication fails due to the cascading failure expect for the initial failure.

III. PROPOSED TOPOLOGY DESIGN BASED ON USER RELATIONSHIP

In this section, we propose a topology design based on user relationship for cascading failure in D2D-based SNS.

Figure 1 shows D2D-based SNS architecture where the number N of nodes is five. In this figure, the ith ($i = 1 \cdots N$) user is denoted as u_i in a social network and (x_i, y_i) represents the position of u_i in a physical network. Here, in the social network and the physical network, the connectivity between two users is denoted with z_{ij}^c and z_{ij}^s in the following, respectively.

$$z_{ij}^c = \begin{cases} 1, & \text{if } d_i \text{ and } d_j \text{ can be communicated} \\ & \text{directly with D2D communication,} \\ 0, & \text{otherwise.} \end{cases} \tag{3}$$

$$z_{ij}^s = \begin{cases} 1, & \text{there is a relationship between} \\ & u_i \text{ and } u_j \text{ in social network,} \\ 0, & \text{otherwise.} \end{cases} \quad (4)$$

In the proposed method, new user relationship a_{ij}^s is added between u_i and u_j so as to minimize the impact of cascading failure. In the following, a_{ij}^s is given by

$$a_{ij}^s = \begin{cases} 1, & \text{if a new link is added} \\ & \text{between } u_i \text{ and } u_j, \\ 0, & \text{otherwise.} \end{cases} \quad (5)$$

Let A^{max} be the maximum number of user relationships that can be added. In the proposed method, in order to design a new topology where the impact of cascading failure is minimized, the following optimization problem is formulated.

$$\max_{a_{ij}^s} \; 1 - (1 - p_f - s_\infty)e^{-\lambda T_{max}} - p_f \quad (6)$$

subject to:

$$\sum_i \sum_j a_{ij}^s \leq A^{max} \quad (7)$$

In this problem, (6) shows that the upper bound of node resilience ψ can be maximized. Moreover, the number of added relationships is restricted in (7). We assume that new relationships can be added by users with a recommender mechanism.

IV. NUMERICAL EXAMPLES

In this section, we evaluate the performance of the proposed method for the D2D-based SNS where the number N of users is 100. We randomly place each user on a field, and a link is established among any two users within the communication range. On a social network, a link is established between any two nodes at random (see Fig. 2). For this D2D-based SNS, we evaluate the performance of the proposed method. Moreover, we evaluate the conventional method where the topology of the social network does not change.

Figure 3 shows the impact of maximum number of user relationships A_{max} on the node resilience. Here, p_f is equal to 0.3, and λ is equal to 200. In this figure, we consider three cases in terms of the number of links in the physical network; the number of links is 154 (Case 1), the number of link is 200 (Case 2), and the number of link is 228 (Case 3). From Fig. 3, we find that the upper bound of node resilience increases as A^{max} becomes large. This means that D2D-based SNS is not affected significantly by cascading failures when the number of user relationships becomes large by comparing the performance of the proposed method with that of the conventional method, we find that the proposed method can degrade the impact of cascading failure. Moreover, the proposed method is the most effective in Case 1. This is because the number of link in the original social network is the minimum in Case 1 and a new link affects the node resilience.

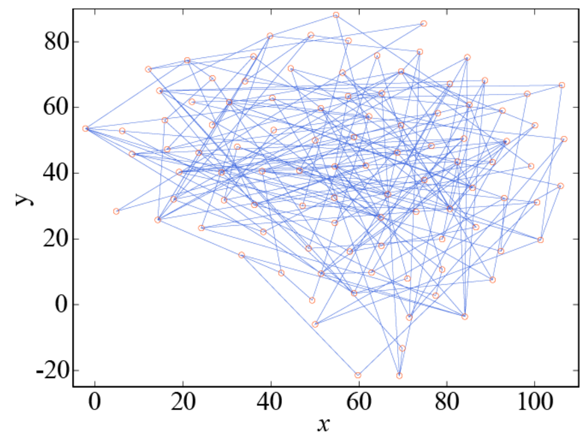

Fig. 2. Topology of social network.

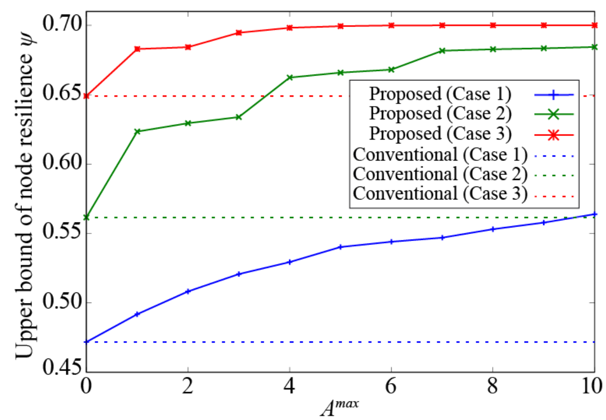

Fig. 3. Impact of A^{max} on the upper bound of node resilience.

V. CONCLUSION AND FUTURE WORK

In this paper, we proposed a topology design based on user relationship for cascading failure in D2D-based SNS. We evaluate the performance of the proposed method with simulation. From numerical examples, we found that the proposed method improves the upper bound of node resilience and the impact of cascading failures can be degraded. In our future work, we will consider a network design of physical network for D2D-based SNS.

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