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Dynamic Topology Update Mechanism in Local Tree-based Reliable Topology (LTRT) based MANETs

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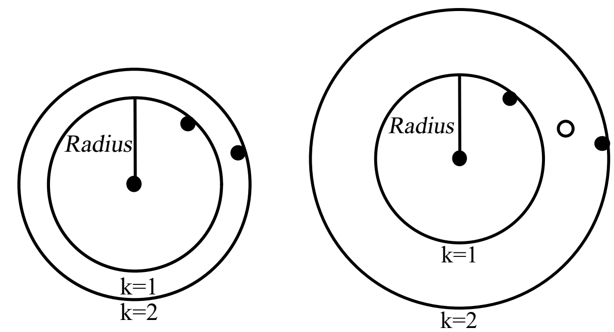
***Abstract*—Topology control is a powerful solution to reduce power consumption and the number of collisions by minimizing the transmission range of each node by maintaining a certain level of network connectivity. Although many topology control algorithms have been developed for static networks, e.g., sensor and ad hoc networks with less topology change, where nodes are fixed and the network topology never changes, the topology control technologies can also be adopted for dynamic networks such as Mobile Ad hoc NETworks (MANETs) with an aim to efficiently construct reliable networks. However, in order to apply topology control technologies into MANETs, it is essential to address the issue of performance degradation due to node mobility. Topology information in each node needs to be frequently and appropriately updated according to its moving speed so as to maintain the connectivity with neighbors. In our proposed mechanism, each node determines an appropriate value of topology control update interval according to the mobility information of its neighbors. The proposed mechanism with an adopted topology control technique, based on a localized algorithm, can maintain local connectivity which results in keeping global network connectivity although the network is dynamic. This is a significant advantage of our approach. Simulation results demonstrate that our scheme can ensure a certain level of network connectivity even in MANETs.**



(a) Small difference in distance

(b) Big difference in distance

Fig. 1. Connectivity and Robustness in different node distributions

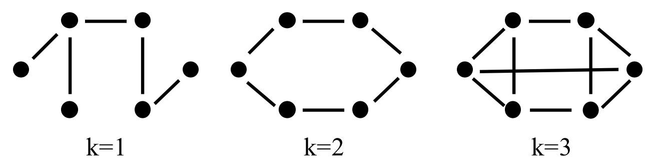


Fig. 2. Network topologies having different k-edge connectivities.

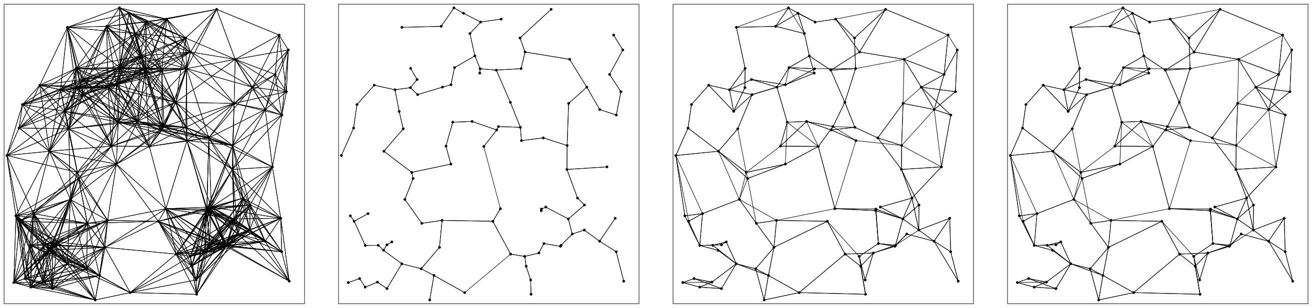
I. Introduction

Mobile Ad hoc Networks (MANETs) have recently attracted much attention due to their mobility and scalability, which are essential aspects for ubiquitous networks where we can communicate anytime and anywhere. The dramatic revolutions in wireless communication networks and wireless devices development technologies in the past decade allow us to easily construct MANETs. Since the MANET is a network which can be constructed by mobile terminals without any infrastructure such as access points or base stations, it becomes a feasible solution to construct networks even in disaster areas.

In MANETs, nodes are battery-powered devices such as cellular and smart phones, and laptop computers. Saving power consumption while transmitting data can significantly extend the operating time of a single charge. As the data transmission power is proportional to the square of transmission range, power consumption can be minimized by dynamically adjusting transmission range according to the distance with neighboring nodes. Geographic information on each node's location can be obtained by using a Global Positioning System (GPS), whose receive is implemented in various kinds of mobile terminals nowadays.

The techniques used to control transmission range/power according to the network topology is referred to as topology control. In literature, a lot of topology control schemes have been proposed for sensor networks where nodes are fixed. It has been shown that the topology control has a significant effect on decreasing power consumption and mitigating the collision problem, which are also desirable in MANETs where mobile nodes exist. However, further enhancement is necessary while applying topology control techniques in MANETs because network connectivity can be significantly degraded by node mobility.

In [1], the performance of topology control algorithms in MANETs have been analyzed in detail. Network connectivity degradation due to node mobility can be improved by (i) increasing the number of neighbors, and/or (ii) increasing the frequency of topology updates. In topology control, a parameter, k, represents the number of the links with the neighboring nodes. A larger value of k contributes to having more neighbors and a higher connectivity. Based upon this, the first approach towards improving network robustness against node movements is to use a high value of k in each node. However, in some situations, if the nodes are not uniformly



(a) No topology control (b) LMST (c) FLSS (k=2) (d) LTRT (k=2)

Fig. 3. Comparison among topology control algorithms.

distributed in the field, it is not ensured that increasing the value of k results in high robustness against topology changes. For example, as shown in Fig. 1(a), if the neighboring nodes are very close to the considered node, increasing the value of k at the node (e.g., getting more neighbors) does not increase its transmission range. On the other hand, if the neighboring nodes have a big difference in distance to the considered nodes as shown in Fig. 1(b), increasing the value of k at the node highly contributes to an increase in its transmission range which results in higher power consumption. In other words, higher connectivities do not always represent higher robustness.

The second approach to improve network robustness against node mobility is to update topology information with higher frequency. In the topology control algorithms designed only for fixed ad hoc networks, the calculation of topology is invoked only one time which is during the initial phase. In contrast, the topology configuration operation needs to be carried out periodically in MANETs in order to accommodate changes in topology. Here, the update interval in topology configuration should be appropriately controlled according to the node's moving speed. In this paper, we focus on a localized topology control algorithm, named as Local Tree-based Reliable Topology (LTRT) [2], and propose a method to dynamically adjust a topology update interval in MANETs.

The remainder of this paper is organized as follows. Several existing topology control algorithms are briefly introduced in Section II. Our proposed scheme is presented in Section III followed by its performance evaluation through computer simulations in Section IV. Section V concludes the paper.

II. Topology control algorithms

Topology control aims to minimize energy consumption in the entire network by appropriately adjusting transmission range at each node, which mitigates the collision problem. Although it is necessary to know the node distribution over the network in order to optimize the topology control, which is almost impractical in large scale ad hoc networks due to the corresponding large amount of overhead for message exchanges between the nodes. To cope with this issue, some localized algorithms have been proposed. In the localized topology control algorithms, nodes which can directly communicate with each other exchange useful information about local networks, e.g. node identification and location. Then, each node calculates and determines the local topology, representing the connectivity of the corresponding node. Finally, the transmission range of the node is determined by following the distance to its farthest connecting node.

Topology control algorithms can be characterized by using the k-edge connectivity criteria. A network can be considered to have k-edge connectivity if the network is never divided into two subsets when any $(k-1)$ edges are removed. Fig. 2 depicts the network topologies having different connectivities from 1 to 3. Smaller values of k contribute to configuring more efficient network topologies with a small number of links. In contrast, higher values of k allow topologies to have some redundant links to increase network connectivity.

In the remainder of this section, we first introduce notable examples of topology control algorithms designed for static networks, i.e., Local Minimum Spanning Tree (LMST) [3], Cone-Based distributed Topology Control (CBTC(α)) [4], [5], Fault-tolerant Local Spanning Subgraph ($FLSS_k$) [6], Tree-based Reliable Topology (TRT) [7], and Local Tree-based Reliable Topology (LTRT) [2]. LMST is designed for 1-edge connected topology, and others can construct topology having higher connectivity. Fig. 3 demonstrates a comparison among the topology control algorithms in sensor networks.

In LMST [3], each node constructs a local topology based on Minimum Spanning Tree (MST). At first, nodes broadcast a hello message with their maximum transmission range. Since the hello message includes information on node identification and location, each node can easily calculate the MST within its transmission range. It has been presented in [8] that LMST running the above-mentioned procedures can construct a topology similar to MST in the entire network. While the computational complexity of LMST is relatively small compared with other algorithms, the network connectivity is relatively low. This is because LMST constructs a tree-based topology, as shown in Fig. 3(b), which slightly includes redundant links.

CBTC [4], [5] takes the local distribution of nodes into consideration in the calculation of the minimum transmission range. Node's transmission range, which is a circle, is divided into several sectors, and the minimum transmission range is determined so that there exists a node in each sector. The size of a sector can be controlled by using a parameter called α. The transmission range tends to become smaller with a larger value of α, and vice versa. It is known that the network connectivity is guaranteed when α is smaller than $2\pi/3$. In addition, CBTC can ensure k-edge connectivity by setting α less than $2\pi/3k$ [9] if the original network is k-edge connected. In CBTC, topology computation can be performed only by using the location information of nodes which are reachable with just one hop from the considered node. The performance of CBTC is largely affected by node distributions. In other words, the transmission range dramatically increases when nodes have a large variance in their geographic distributions.

FLSS [6] is another topology control algorithm which guarantees k-edge connectivity. Fig. 3(c) shows the topology generated by using FLSS. It is evident that the topology created by FLSS is well connected, compared with the case of LMST. Although FLSS outperforms CBTC in terms of network connectivity, the computation load is much higher, which can be represented as $O(m(n+m))$ where n and m denote the number of nodes and links, respectively. Actually, in dense networks where m is equal to n^2, the computational complexity becomes $O(n^4)$. This is a significant drawback in the consideration of employing FLSS in MANETs where topology control procedures need to be frequently carried out to follow the topology changes.

LTRT [2] is a topology control algorithm combining two different algorithms, TRT and LMST. TRT is basically an algorithm to efficiently construct 2-edge connected topologies.However, it can be extended for constructing k-edge connected networks by just recursively repeating the same procedures. By comparing topologies presented in Figs. 3(c) and 3(d), we can observe that the topologies are quite similar between LTRT and FLSS. Herein, it should be noted that LTRT is a light algorithm in terms of computation of load in contrast with FLSS, which makes it a good choice to be adapted in MANETs.

After reviewing the existing topology control algorithms, we focus on the LTRT which is considered to be suitable for application in MANETs due to its small computational load and high reliability (connectivity). As mentioned earlier, the LTRT has no functionality to adapt the topology changes caused by node movements. Therefore, in the next section, we propose a dynamic topology update mechanism in LTRT based MANETs.

III. An adaptive topology update mechanism

In this section, we propose a mechanism to dynamically update topology information according to node movements. In our mechanism, LTRT is employed as a topology control algorithm because it is suitable for adoption in MANETs as mentioned in the previous section.

A. Considered network model

Before describing our mechanism, we describe the considered network model. All the nodes are considered to have the same maximum transmission range, and can adjust their transmission range by themselves according to their individual situations. Each node employs a GPS devices, which allows to identify the location, moving speed and direction. We assume that every node can freely move within the given field.

B. Design concept

To apply a topology control algorithm, which is designed for static networks, in dynamic networks such as MANETs, we need an intelligent topology update mechanism in order to maintain network connectivity regardless of node mobility. Although it is possible to keep almost perfect network connectivity by highly frequently updating the topology, at the cost of high computational load, increased message exchanging overhead between nodes, and heavy network congestion. Thus, the topology update interval must be appropriately adjusted according to the environment. If prior knowledge about node mobility exists, it might be possible to determine a unique optimal value of topology update interval, however, such information is not available in general. Therefore, in our approach, each node individually decides its topology update interval according to only the mobility information of its neighboring nodes. The proposed topology update algorithm is compatible with the employed topology control mechanism, LTRT, which is also a localized algorithm.

C. Modification of topology control algorithm

In general topology control algorithms, including LTRT, information only about node identification and location is broadcasted through a hello message. On the other hand, in our mechanism, additional information on velocity (i.e., moving speed and direction) are also included in each hello message. This information is used only for determining topology update interval. Nodes broadcasts a hello message independently and periodically about its latest information regarding mobility and location. The time interval of broadcasting is similar to that of topology update, which is calculated based on the latest information obtained by monitoring hello messages received from neighboring nodes. It should be noted that our mechanism only requires to modify the field definition of hello messages, and never changes the computation process for topology control. Actually, nodes calculate a local topology within their transmission range by using the employed topology control algorithm, i.e., LTRT in our mechanism. If the employed topology control algorithm ensures k-edge connectivity, k nodes located within the maximum transmission range of the considered node are selected as its adjacent nodes, and its transmission range is determined accordingly.

D. Proposed topology update mechanism

In the proposed topology update mechanism, the update interval in each node is determined based on the transmission range and mobility information of its adjacent nodes so that the network connectivity is guaranteed. Fig. 4 shows an example where node n_0 has two adjacent nodes, i.e., n_1 and n_2. The velocities of nodes n_0, n_1, and n_2 are denoted by as v_0, v_1, and v_2, respectively. The moving speed and direction can be

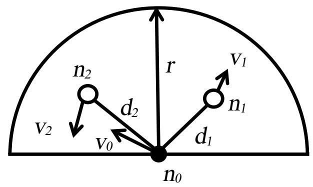


Fig. 4. A local network observed from node n_0.

estimated from the difference between the previous location and the latest location, and time elapsed, i.e., the variation in location divided by the elapsed time. The distances between n_0 and n_1, and between n_0 and n_2 are denoted by d_1 and d_2, respectively. The transmission range of n_0 is indicated by r. Herein, assuming that the velocities of nodes are unchanged, the remaining time before node n_i moves outside of the transmission range of node n_0 can be estimated by using the following equation.

$$T_i = \frac{r - d_i}{|v_0 - v_i|}. \quad (1)$$

However, in fact the moving speed and direction may dynamically vary. Especially, moving direction may vary from time to time while moving speeds generally vary within the certain range largely depending on node types, e.g., by walking, driving, and so on. From this conservative point of view, instead of Eq.(1), our proposed mechanism uses the following equation for estimating the remaining time:

$$T_i = \frac{r - d_i}{|v_0| + |v_i|}. \quad (2)$$

This estimation corresponds to the worst case where nodes move to the opposite direction with each other.

After calculating the remaining time for each adjacent node, the proposed scheme sets the topology update interval, Δ, to the minimum value of them as follows:

$$\Delta = \min_{i \in N} T_i, \quad (3)$$

where N is a set of adjacent nodes. By using the minimum value, network can maintain k-edge connectivity if all nodes do not increase their moving speeds. Furthermore, even if nodes increase their moving speed, the probability of losing network connectivity can be reduced by using higher values of k, which is an advantage of our proposed mechanism. The proposed mechanism for topology update can be summarized as in Mechanism 1. Nodes periodically broadcast their location information and update their local topology. Along with this, they dynamically adjust their topology update intervals according to the current situation.

TABLE I
SIMULATION SETTING.

Field size	1000m $\times$ 1000m
Maximum transmission range	250m
Number of nodes	100
Average speed	0 – 20m/s
Simulation time	10,000s

Mechanism 1 Dynamic topology update in each node

while do
  Broadcast a hello message.
  Update a local topology by using LTRT.
  for $i \in N$ **do**
    Calculate the remaining time T_i of the adjacent node i.
  end for
  Set the update interval Δ to the minimum value of T_i.
  Wait for the time Δ to pass.
end while

IV. Performance Evaluation

We performed computer simulations by using Network Simulator version 2 (NS2) [10] to evaluate the performance of our mechanism. LTRT is used as a topology control algorithm with k equal to 3. One hundred mobile nodes move within a square field of 1000m per side. The maximum transmission range of nodes is set to a quarter of the field side. A Random Waypoint model [11], [12], [13] is used as a node mobility model, and the average speed is varied from 0 to 20m/s. Simulation time is set to 10,000 seconds. All results depicted in the following graphs present the averaged values of one hundred trials. Simulation parameters are listed on Table I.

Connectivity ratio C, defined as the following equation, is used as a performance metric.

$$C = \frac{\sum c_{x,y}}{n(n-1)}, \quad (4)$$

where n denotes the number of nodes. If there exists a path between nodes x and y, $c_{x,y}$ is equal to one. Otherwise, $c_{x,y}$ is equal to zero. C can be any value in the range from 0 to 1, with values close to 1 indicating high network connectivity. Another measure is the number of hello messages. It is evident that a smaller number of messages reflect efficient communication with lower computational power.

First, the performance degrades due to node mobility when applying the original topology control algorithm, LTRT, with

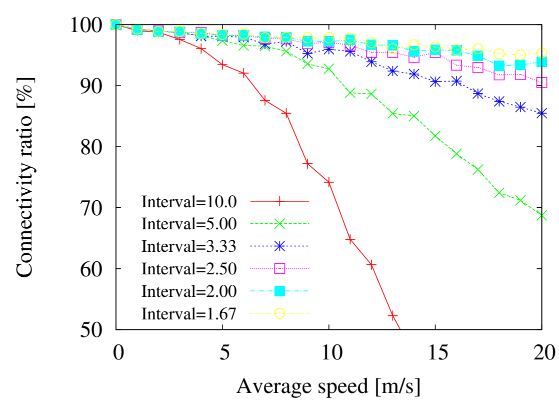
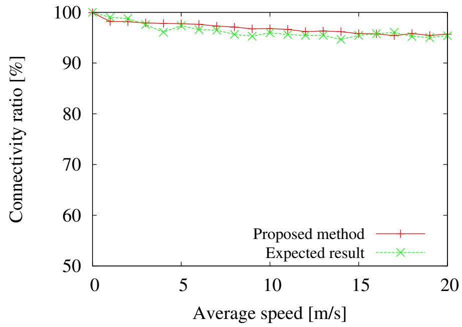
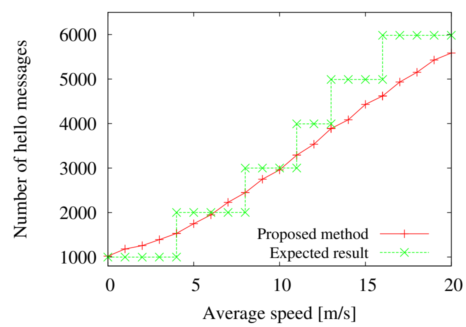


Fig. 5. Effect of node mobility on the network connectivity.



(a) Connectivity ratio for different average speeds.



(b) Communication efficiency for different average speeds.

Fig. 6. Performance of the proposed topology update algorithm for different node moving speeds.

fixed topology update interval, in MANETs. The topology update interval is manually set to fixed values (i.e., 10s, 5s, 3.33s, 2.5s, 2s, or 1.67s). These values correspond to the case that the number of topology update executions within the simulation time is equivalent to 1, 2, 3, 4, 5, or 6 thousands, respectively. Fig. 5 shows the connectivity ratio for different average moving speeds varied from 0 to 20m/s. As shown in the figure, the update interval needs to be smaller for higher average speeds in order to maintain the similar connectivity degree.

Next, we evaluate the performance of the proposed dynamic topology update mechanism. In Figs. 6(a) and 6(b), the red solid line shows the result of the proposed mechanism, and the green dot line shows the expected result by assuming that the update interval is properly controlled manually according to preliminary knowledge. The expected result is obtained from Fig. 5 in order to maintain high connectivity ratio exceeding 95%. For example, the hello interval is set to the same value equal to 5s when the average speed is within the range from 4m/s to 8m/s, which results in the same number of hello messages as shown in Fig. 6(b). It can be observed that the proposed mechanism achieves a high connectivity ratio over 95% by appropriately adjusting the topology update interval according to varying node speeds. Actually, we can confirm that the frequency of the topology updates is gradually increased as the average speed becomes higher.

V. Conclusion

In this paper, we addressed the application of topology control algorithms for MANETs. Since topology control techniques are originally designed only for static networks such as sensor networks, an intelligent topology update mechanism is essential to effectively apply topology control technology in MANETs where nodes can freely move. In this paper, we developed a mechanism to adjust topology update adaptively and automatically in response varying node locations and velocities. The advanced performance of the proposed mechanism was shown through computer simulations. It was also confirmed that the proposed mechanism is able to maintain high connectivity ratio regardless of node speed by dynamically adjusting the update interval according to varying situations.

Acknowledgment

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