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Adequate Evaluation for the Influence of Mobility on Topology Control in Mobile Ad hoc Networks

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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. The term "topology control" is consumed mostly by the wireless ad hoc and sensor networks research community. K-edge connected topology control algorithm have been proposed to construct robost topologies for mobile networks. The original k-edge connected algorithm uniformly using the same value of k for localized topology control algorithms in any local graph is not effective because nodes move at different speeds. Moreover, the existing algorithm need to determine the value of k a priori, but moving speed of the nodes are unpredictable, and therefore it is not practical in Mobile Ad hoc Networks (MANETs). A dynamic method is proposed in this paper to assistant the k-edge connected algorithm. The proposed method automatically determines the value of k for each local graph based on local information while promising the network connectivity. The result provides that dynamic method is more scalable and efficient than the existing k-edge connected topology control algorithms while preserving the network connectivity.

Keywords: *Mobile ad hoc network, topology control, k-edge connectivity, mobility.*

1. Introduction

A mobile ad hoc network (MANET) is a group of mobile wireless nodes working together to form a network. Such networks can exist without a fixed infrastructure and can work in an autonomous manner. Every mobile device has a maximum transmission power which determines the maximum transmission range of the device. As nodes are mobile, the link connection between two devices can break depending on the spatial orientation of the nodes.MANETs have numerous applications such as sensor networks, disaster relief, military operations, business and home applications. Some of the network constraints in MANETs are limited bandwidth, low battery power of nodes, frequent link unreliability due to mobility. The topology of a multi-hop wireless network is a “set of communication links between node pairs used explicitly or implicitly by routing mechanisms” [1]. A topology can depend on uncontrollable factors such as node mobility, weather, interference, noise as well as controllable factors such as transmission power, directional antennas [2] and multi-channel communications [1]. Inappropriate topology can reduce the impact of network capacity by limiting spatial reuse of the communication channel and decrease network robustness. For example, if the topology is too sparse then the network can get partitioned. However, topology control can provide better control over network resources such as battery power and reduce redundancy in network communications.

The primary latency of mobile networks is attributed to unpredictable topology changed due to mobility. The topology control algorithms that can gurantee 1-edge connectivity, such as Relative Neighborhood Graph (RNG) [3], Local Shortest Path Tree (LSPT) [4], no longer applicable in MANETs because the network might be disconnected even single link is broken.Accordingly, more reliable topology control algorithms such as Fault-tolerent Local Spanning Subgraph (FLSS) [5] and Local Tree-based Reliable Topology (LTRT) [6] are considered for MANETs. They can preserve k-edge Connectivity, i.e., removal of any(k-1) edges does not partition the graph. The drawback of these algorithms is that the value of k, referred to as the level of redundancy, is uniformly set for all local graphs regardless of the different moving speeds of nodes. Thus, in order to guarantee network connectivity, they need to use a high value of k to mitigate the case where some nodes move too fast. This might lead to a redundant topology, because some areas in the network may have slow moving nodes and do not need a high value of k.

This paper proposes a dynamic method for k-edge connected algorithm that determines the value of k for each local graph based on local movements while maintaining the required connectivity. Each node periodically broadcasts a “hello” message within its maximum transmission range, which contains information about its position and current moving speed. The “hello” message sending interval is referred to as the topology update interval. Afterward, each node collects information about positions and speeds of its neighboring nodes and builds its own local graph. The node uses a k-edge connected algorithm with k-value decided based on the moving speeds of itself and its neighbors. After applying a topology control algorithm, each node finds its logical neighbors and calculates a new transmission range to cover them. It should be noted that our main focus is in topology control, i.e., how to determine the transmission range of each node in order to maintain network connectivity. In order to find an appropriate value of k corresponding to nodes’ moving speeds, we introduce an analysis about the relationship between network connectivity and the value of k.Li *et al*. [3] calculated the probability that a node moves out of another node’s transmission range. We adopt this result to measure the connectivity of topology constructed by using kedge connected algorithms and calculate the probability that the network is disconnected.

2. Related Works

Topology control aims to minimize energy consumption in the entire network by appropriately adjusting transmission range at each node, which mitigates the collision problem. 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.

LMST is a Minimum Spanning Tree (MST) based localized topology control algorithm proposed by Li *et al.* [3]. The common idea of MST-based algorithms is to find the minimum spanning tree of a graph that connects all vertices and has the minimum total link weight. In LMST, each node uses information from its 1-hop neighbors to construct a local minimum spanning tree. Thus, LMST can preserve the connectivity with a rather small average node degree. The node degree of a node is the number of edges that connect to it. By using Prim’s algorithm, the time complexity of LMST is computed to be O (n2) when using simple searching and O (m + n log n) when using Fibonacci heap. Here, m is the number of edges and n denotes the number of vertices. LMST also has the lowest complexity among the five algorithms that are evaluated in this work, as shown in Table I.

Toussaint [7] proposed Relative Neighborhood Graph (RNG) that attempts to remove redundant edges while maintaining the connectivity. An edge (u, v) is redundant if there is a node w satisfying d (w, u) < d (u, v) and d (w, v) < d (u, v), where d (u, v) is the distance between u and v. The constructed topology is the remained graph after removing all redundant edges. RNG is also carried out in the local graph of each node to become a localized topology control algorithm. Cartigny et al. [8] prove that with the same graph, the topology generated by LTRT is a sub-graph of RNG’s topology.

Table 1: Computation Time Of The Considered Algorithms

Algorithm	Complexity
LMST	$O(m + n \log n)$
RNG	$O(n \log n)$
LSPT	$O(m + n \log n)$
FLSS	$O(m(m + n))$
LTRT	$O(k(m + n \log n))$

Therefore, the average node degree and total transmission power of RNG are higher than those of LMST. RNG can be implemented with a computational cost of O (n2). By using the simple idea that an edge will be removed if there is a 2-hop path between the two nodes consuming a lower transmission power than the directed way, Rodoplu and Meng [9] proposed another topology control algorithm. Li and Halpern [10] then extended the algorithm by using k-hop paths instead of 2-hop paths. Accordingly, the algorithm can be explained as carrying out Dijkstra’s algorithm [11] for a graph with the weight function E = dα where E and d are the weight and length of the edge, respectively. Localized version of this algorithm is called Local Shortest Path Tree (LSPT) and can run in O (m + n log n) time when using Fibonacci heap. Although LMST, RNG, and LSPT can preserve a connected topology, the network is still 1-edge connected. Consequently, the connection can easily be dropped when one link is broken. In order to come up with a fault-tolerant solution, Li and Hou [5] proposed Fault-tolerant Local Spanning Subgraph (FLSS) algorithm that guarantees k-edge connectivity if the original network is k-edge connected. In terms of maximum transmission power, FLSS is proven to be a min-max optimal algorithm. However, the complexity of FLSS is O(m(m+n)), which is not applicable for dense networks. Recently, Miyao et al. [6] proposed Local Tree-based Reliable Topology (LTRT), a reliable topology control algorithm that can preserve k-edge connectivity. While FLSS is a minmax optimal algorithm, LTRT is a near-optimal one, but much lower complexity, O (k(m + n log n)). The initial proposal of tree-based reliable topology (TRT) was made by Ansari et al. [12] and LTRT can be considered as a localized version of TRT.

3. Effects of Mobility on Topology Control

3.1 Mobility Effects

In general, topology control attempts to decide the appropriate transmission power for each node that adequately assure the connectivity of the node. In static networks, we can protect the network as there was no effect on mobility of nodes. However, in MANETs network topologies varies and fluctuates owing to mobility, and thus we may not be able to preserve the network connectivity. Therefore, one of our contributions is providing a performance evaluation of topology control algorithms in MANETs. Although the influence of mobility on topology control in MANETs is obvious, an adequate evaluation of this influence is essential. A node pair (a, b) is considered connected if and only if there exists a path from a to b, and vice versa. Denote T as the connectivity ratio of a given network topology, G(N,E), where N is the set of nodes and E is the set of links; T can be computed as follows:

$$\frac{T = \sum a, b \in N\, T_{ab}}{|N|(|N| - 1)} \qquad (1)$$

Where

$$T_{ab} = \begin{Bmatrix} 1, if\ a \neq b\ and\ (a,b) is\ connected, \\ 0,\ otherwise \end{Bmatrix}$$

By using this equation, the network connectivity can be evaluated without data transmission.

3.2 Evaluation of Mobility Effects

The two methods are available for the improvement of connectivity of resulting topologies when we use topology connected algorithms. The first strategy that can be applied to maintain the network connectivity is to frequently update the topology. This method obviously improves the network connectivity because every node has the updated information of its neighbours and is able to decide the needed transmission power. However, frequent updating also leads to the huge cost of constructing topology. Another method is using k-edge connected algorithms with an appropriate value of k in order to achieve redundant edges that help the topology to become more fault-tolerant. The primary challenge for this method is to tolerate the trade-off between topology control and the reliability of the network.

4. Enhanced Method For k-Edge Connceted Algorithms

In this section, we propose a method to help the k-edge connected algorithms to be more applicable in mobile networks. First, we provide analyses about network connectivity and relationship with the value of k. By using these analyses we can set up a network model with the desirable connectivity level.

4.1 Rationale

A graph is said to be k-edge connected if the removal of any (k-1) edges does not partition the graph. Another illustration of *k*-edge graphs is depicted in Fig. 1. Here, the graph *G*(*N*,*E*) can be seen as a combination of two sub-graphs including two sets of nodes *{N*1*}* and *{N*2*}*, respectively, where *{N*1*}∪{N*2*}* = *{N}*. The two sub-graphs are connected together by the set of edges *{e*1, *e*2, ..., *ek}*, referred to as a cutting edge of *G*(*N*,*E*). A graph is *k*-edge connected if any cutting edge of the graph has at least *k* edges. A cutting edge of a graph is a set of edges that will partition the graph if all edges in the set are removed.

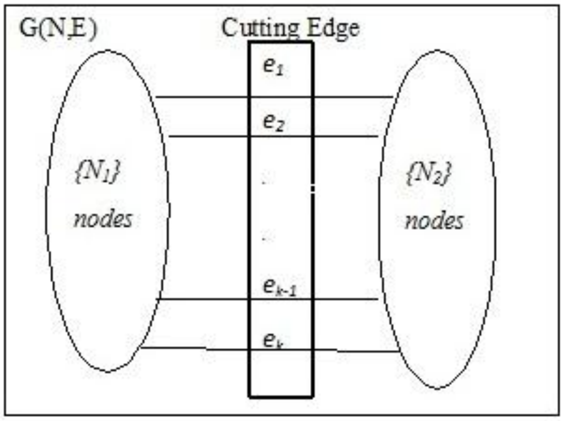

Fig. 1 A Cutting edge of G (N,E).

The original k-edge connected algorithms are done using the same value of k for every local graph in the network. The nodes generally move with different speeds in MANETs. In low moving speed areas, it is not necessary to use the high value of k which leads to redundancy. In case of, high speed moving areas, if it uses small value of k leads to robust network. Therefore, using same value of k is not effective. Generally, we cannot able to predict the moving speeds of all network nodes correctly in MANETs. We use an assumption that the network will be disconnected if and only if there exists a node such that all the links connected to its neighbours are broken. This proposal can be an extension any k-edge connected algorithms.

3.3 Estimation of Network Connectivity

It provides an analysis about the network connectivity to evaluate the lower bound of the network connectivity when the network is disconnected. We then derive an expression of the relationship between network connectivity and probability that the network is partitioned. The smallest value is considered as the lower bound of network connectivity ratio. By using probability, we can calculate average lower bound of the network connectivity. Given τ_{local} *as* the probability that a network is disconnected due to mobility, the average lower bound of the network connectivity is calculated as follows,

$$T_{Lower\ Bound} = (1-\tau_{global})\times 1.0 + \tau_{global} \times T_{Avg\ Sep\ Lower} \qquad (2)$$

By using this result, we can determine the network connectivity for the whole network.

3.4 Correlation between Network Connectivity and Node Speed

We start the relationship between disconnection of a link and node moving speed. After that we can calculate probability of a link broken between the neighbours and then evaluate the probability of disconnection of a local graph and the whole network.

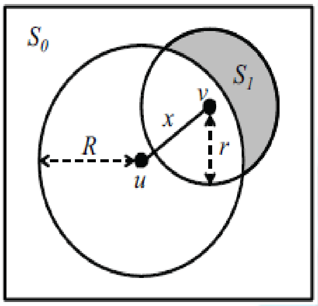

Fig. 2 Calculation of the Probability that node moves of disk D(u,R) .

3.4.1 Moving speed versus link disconnection

We use the probability that a node moves out of the transmission range of another node, τ, as an indication of link disconnection. The value of τ has been studied in [3] by Li et. al. as the probability that node v moves out of the disk D(u,R) (as shown in Fig. 2). Here, the disk D(v, r) is the area that node v can move during the topology update interval, Δt. If vmax is the maximum speed of nodes, then r = 2vmax × Δt. The nodes are supposed to move randomly in an area S0. Herein, we consider only the nodes that moves out of one transmission range of another node.

3.4.2 Detachment of local and global graphs

Inorder to establish the relation between the τ_{local} and τ_{global}, we have to obtain the global view of the network. But, this is not possible in MANETs network, since each node only know its local information. We can derive using an assumption that the netwok will be disconnected if and only if there exists a nodewhich loses all of its links connection to its neighbours. Its relationship is calculated as,

$$\tau_{global} = 1-(1-\tau_{local})^{n} \qquad (3)$$

After calculating τ_{global} by using Eq. (2), we can use the result shown in Eq. (3) to compute τ_{local}. Then, we can estimate the value of k for each local graph by finding the smallest value of k satisfying:

$$\tau^{k} \le \tau_{local} \qquad (4)$$

3.4.3 Proposed Method of k-Edge Connected Algorithms

The k-edge connected method consists of two main phases: maiden phase and dynamic topology control, which produces the appropriate value of k for each local graph. In the maiden phase, which attempts to find the value of τ_{local}, and dynamic topology control, which assigns the appropriate value of k for each local graph. The maiden phase can be initiated only one time with the value of $\tau_{global,}\tau_{local}$ and network connectivity.

Each node keeps its own moving history, and periodically broadcasts a "hello" message within its maximum transmission range containing its node ID, position, and moving speed. Also, each node stores such information whenever it receives "hello" messages sent from its neighbors. This information is used for building the local graph in each node. The maximum moving speed among the speeds of its neighbors is utilized for the computation of the value of τ in the local graph. After calculating τ, the smallest number satisfying the condition represented by Eq. (4) is determined as the optimal value of k. Finally, the node's transmission range is adjusted by running a k-edge connected algorithm with the optimal value of k, and is maintained until the next topology update.

4. Conclusion

In this paper, we consider the influence mobility over the MANETs. Our proposed method, focus on providing appropriate transmission power for each node with respect to the moving speed of the node. Therefore, it is scalable and effective compare to the existing localized topology algorithms. As future work , this dynamic method can be applied to any k-edge connected algorithms such as and FLSS for the global connectivity, and the performance evaluation can be calculated between their original and this dynamic method algorithm using Network Simulator (NS-2).

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