

A-LMST: An Adaptive LMST Local Topology Control Algorithm for Mobile Ad Hoc Networks

Luciana B. Abiuzi, Cecilia de A. C. Cesar, Carlos H. C. Ribeiro
 Computer Science Division
 Technological Institute of Aeronautics, Brazil
 Email: {abiuzi, cecilia, carlos}@ita.br

Abstract— The pattern of mobile nodes movement and node removals or additions cause frequent and unpredictable changes in the topology of mobile ad hoc networks. Network performance can thus vary significantly under different mobility models, as well as from the variation in parameters of a given mobility model, such as node movement speed and number of nodes in the network. Hence, the efficiency of a network depends not only on its control protocols, but also on its topology.

In this paper, we first compare the impact that mobility parameter variations produces on typical network metrics - routing packets generated, routing overhead and route discovery average delay - in networks with and without topology control. Results from experiments in a wireless network simulator show that, in networks with topology control using 2 or 3 hops for route discovery depending on the node degree, the number of routing packets decreases, therefore improving the operation and efficiency of the network. Based on these results, a local adaptive self-configuration LMST topology control was then proposed and analysed, producing better results as the network size increases.

Index Terms— Mobile Ad Hoc Networks, Topology Control, LMST, AODV.

I. INTRODUCTION

Wireless ad hoc networks are indicated for situations where it is impossible or inappropriate to install a fixed network, and its application occurs in several areas, such as military, environment, health, home automation and security. In a wireless ad hoc network, devices do not require a pre-existing infrastructure for data transmission, exchanging information with each other directly or through intermediary devices, acting as routers in the network within a transmission range; thus, nodes depend on each other to keep the overall network connected [1]. As a variation, the mobile ad hoc networks (MANETs) have emerged, in which devices (or nodes) may move arbitrarily.

Mobility, in fact, is the main element of a MANET. The movement and the dynamics from adding and removing nodes cause frequent and unpredictable changes in the network topology, hence a constant adaptation and reconfiguration of routes is required such that the network does not become inefficient. In addition, changes in parameter values of a given mobility model also affects the efficiency of a MANET, as incorrectly parameterized simulations can require a traffic communication pattern that can significantly affect the routing protocol and the overall performance. Besides considering aspects related to mobility and routing protocol, some

performance optimization criteria such as bandwidth limit, power consumption and interference should also be taken in consideration. The topology control protocols, responsible for these optimization factors, are also very important to the efficiency of a communication network.

In this work, the routing and topology control protocols work together in mobile ad hoc networks, with the aim of improving the network efficiency with respect to traffic routing protocol packets. For this purpose, we used the reactive AODV protocol [2], since it is suitable for scenarios with high mobility and large number of nodes, in order to avoid waste of bandwidth and minimize processing in network nodes. In this model, traditional routing tables are used to store only the next hop to the destination node. Two mobility models with different movement patterns (random and group) were chosen to be simulated with the AODV routing protocol. By varying the parameters of the mobility models, such as number of nodes and speed; the analyses of network metrics, traffic control packets, routing overhead and discovery route delay were carried out. It was then possible to compare the impact that varying these parameters produces on the performance of networks with topology control and without topology control.

Among the random mobility models, the Random Waypoint Mobility Model (RWP) was chosen because it produces lower traffic control messages when used with the AODV routing protocol [3]. In this mobility model, a node randomly chooses a destination point (x, y) in the simulation area and moves towards it with constant speed v . After reaching the destination point, the node remains paused for a period and then chooses another destination and speed. Studies show that the probability of a node to choose a new destination located in the central region of the simulation area is large, causing a periodically agglomeration of nodes in this region and consequently an oscillatory increase-decrease pattern of local neighborhood sizes. This behavior, which is known as 'density waves', is relative to the speed of the nodes and creates a situation where the nodes converge, disperse, converge again and so forth [4].

To simulate the movement of nodes in groups, we chose the Uniform Group Mobility Model (UG) [5], which adds features of two mobility models, namely: (i) Uniform Mobility Model, which maintains a uniform distribution of nodes in the simulation area, thus solving the problem of neighborhood variation and a concentration of nodes in the center of the simulation area that occurs in the RWP model, and (ii)

Reference Point Group mobility, which allows modeling moving groups of nodes according to a previously defined pattern.

Topology control was performed by the Local Minimum Spanning Tree (LMST) protocol [6], which constructs structures that are connected, planar, low-weight, and with a bounded node degree of at most 6 [7]. In LMST, the network topology is achieved by reducing the original graph, thus generating a new graph that keeps some global features of the original network, such as connectivity and coverage. The results of the experiments showed that in networks with topology control the number of traffic control packets decreases, thus improving the operation and efficiency of the network. Having knowledge about the good functioning and efficiency of the network by introducing a topology control protocol, we modified the route discovery mechanism of LMST so that it self-configures according to the degree value of each node. This self-configuration mechanism influences the amount of generated control packets on the network, since it adapts according to the local information of the node neighborhood.

The rest of this paper is organized as follows: in Section II we introduce the local adaptive self-configuration A-LMST topology control, that works with the AODV routing protocol in order to reduce the amount of traffic control packets in the network, and in Section III we evaluate its performance through simulation. Section IV presents our conclusions.

II. A-LMST: ADAPTIVE LMST LOCAL TOPOLOGY CONTROL

In this paper, the routing and topology control protocols work together, in order to reduce the traffic of control packets in the network and improve the availability of channel bandwidth for data information transmission.

First, each node collects its neighborhood information using the AODV protocol, thus building its routing table. Next, the topology control protocol uses the information from these routing tables to optimize the communication routes between nodes. This optimization consists in finding a small graph that maintains network connectivity.

For the construction process of the communication topology between nodes, an adaptation on the route discovery mechanism is proposed: each node u collects information about its one-hop neighbors, denoted by $N_1(u)$, in order to obtain its degree $d(u)$. If $d(u) \geq 4$ then node u collects its 2-hop neighbors information $N_2(u)$, and computes the minimum spanning tree $MST(N_2(u))$ of the induced unit disk graph on its 2-hop neighborhood $N_2(u)$. For degrees $d < 4$, the same process is used for finding the 3-hop neighbors $N_3(u)$ and computing the minimum spanning tree $MST(N_3(u))$. The union of all edges of all minimum spanning trees $MST(N_k(u))$ is the k local minimum spanning tree, denoted by $LMST_k$. We choose the value 4 to compare $d(u)$ because the LMST algorithm have bounded node degree at most 6.

The graph represented in Figure 1 shows a network where the nodes connected by an edge are in the transmission range of each other. For each node in the graph, A-LMST generates a minimum communication tree (the minimum spanning tree)

according to its degree. In this example, we consider nodes A and B.

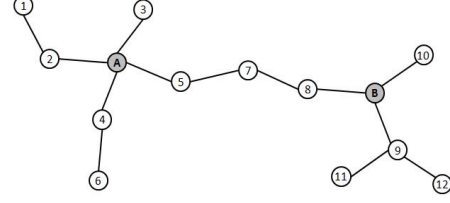


Fig. 1. Minimum communication tree generated by the A-LMST.

In Figure 1 we can see that node A has degree 4, then its communication tree is based on its 2-hop neighborhood ($N_1(A)$ and $N_2(A)$), as shown in Figure 2(a). For node B, which has degree equal to 3, its communication tree is constructed based on its 3-hop neighborhood, i.e., $N_1(B)$, $N_2(B)$ and $N_3(B)$, according to the graph represented in Figure 2(b).

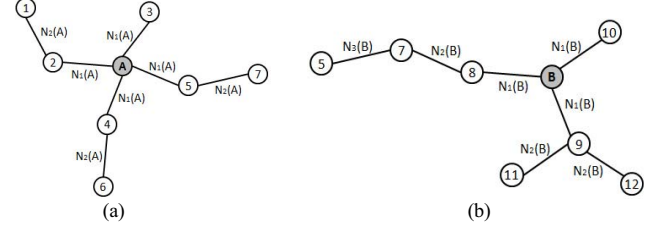


Fig. 2. Communication tree for node A and node B, respectively.

In the adaptation performed in the topology construction process, the nodes decide how many hops to use (either 2 or 3) to construct its communication tree, according to its neighborhood. This local decision is important because it allows for denser regions, whose neighborhood of nodes is generally larger, to have fewer control packets trafficked, since the minimal tree of each node is smaller.

III. SIMULATION METHODOLOGY AND RESULTS

Simulations of RWP and UG mobility models, AODV routing protocol and LMST topology control protocol were carried out in the wireless network simulator JIST/SWANS (Java in Simulation Time / Scalable Ad Hoc Network Simulator), which can process dense networks with higher scalability compared to other simulators [8].

For all experiments, the simulation area was fixed at 500x500 m, the transmission range of each node was equal to 70 m and the duration of each simulation was 360 s. Each node collects its neighborhood information using the AODV routing protocol in the first 10 s of the simulation. After that, every 10 s A-LMST updates the routing tables of the nodes.

In the RWP model, the nodes were initially arranged randomly in the simulation area. The following parameter values were set: number of nodes = {20, 40, 60, 80, 100}; speed (m/s) in the ranges {0-20, 0-60, 0-100} and 1 s pause time between consecutive movements. The UG model was parameterized with the same variations, regarding number of nodes, node speed and pause time. Other specific parameters to UG model are the number of reference nodes – set to 10% of the total number of network nodes, and the square diagonal $D = 50$ m.

For each parameter configuration, 10 experiments were performed to obtain an average result for the following metrics: total AODV packets sent, total AODV packets received, total AODV generated packets (packets sent + received), average delay in route discovery and routing overhead. For all simulations a confidence interval of 95% has been applied.

Networks that do not have topology control are identified in the graphics as -TC; networks with LMST topology control using 2 hops to route discovery are identified as +TC-2H; using 3 hops to route discovery are identified as +TC-3H; and those using A-LMST for discovering routes are identified as +TC-A.

A. Routing Packets Generated

The AODV protocol uses four types of control packets: Route Request (RREQ) and Route Reply (RREP), used to discover routes; and Route Error (RERR) and (HELLO), used to maintain routes. The number of AODV generated packets is obtained by the sum of control packets sent and received.

In almost all experiments with LMST topology control, the number of generated control packets is smaller than on networks without topology control, even in networks with high mobility (0-60 m/s and 0-100 m/s). For instance, in networks without topology control with 20 nodes moving at 0-20 m/s using the RWP mobility model (Figure 3a), 42,000 control packets were generated on average, whereas in networks with topology control this value was 22.4% lower when using 2-hop for discovery routes; 20% lower when using 3-hop to discovery routes and 20.2% lower when using the adaptive control for discovery routes. As expected, by increasing the number of network nodes, the amount of generated control packets also increases, and A-LMST topology control produces better results.

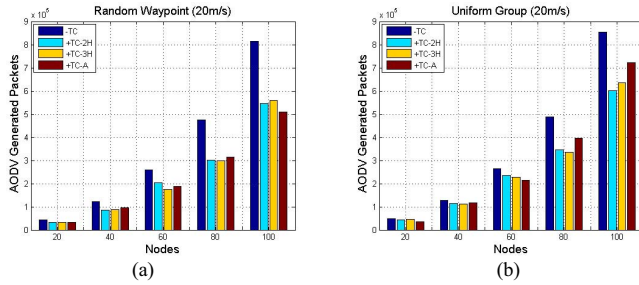


Fig. 3. AODV generated packets in the RWP and UG mobility models.

With respect to the UG model (Figure 3b), for networks with 20 nodes at 0-20 m/s without topology control, 48,000 control packets were generated, while in networks with topology control this value was 10.4% lower when using 2-hop for discovery routes; 1.5% lower when using 3-hop to discovery routes and 25.1% lower when using the adaptive control for discovery routes. Comparing the two mobility models we can observe that in UG the amount of generated packets was larger than for RWP. When a group is moved, all of its members are subject to lose routes, thus increasing the number of RREQ packets.

In networks without topology control, the neighborhood is updated by the routing protocol only when a node needs to send information to another node. Depending on the frequency

of message exchanges between the nodes, the routes may become obsolete, since due to network mobility some nodes may not realize that their neighborhood has changed. When using topology control, the neighborhood is checked and updated every 10 seconds regardless of the need for exchanging information between nodes, i.e., with updated routing tables, the number of control packets used to discover and maintain routes tends to decrease.

B. Routing Overhead

The routing overhead is the ratio between the numbers of all transmitted AODV control packets and the total number of generated AODV control packets. In networks with 20 nodes moving at 20 m/s, the use of topology control does not always improve the overhead, since the nodes are more distant from each other and the loss of communication between them occurs more frequently. As the number of nodes increases, the tendency is topology control presenting better results, due to the increase of the neighborhood and the number of communication routes.

Regardless of the mobility pattern and node speed, in networks with 20, 40 and 60 nodes, adaptive topology control uses most 3 hops for the discovery of routes. The situation is reversed for 80 nodes, where the topology control starts to use more frequent 2 hops to discover routes.

In the RWP model, as the frequency with which a neighborhood increases and decreases (i.e., the frequency of the density waves) is relative to the nodes speed, thus affecting the rate of establishment and obsolescence of routes and generating a large number of updates in the routing table. We note this behavior analyzing the speed change of nodes in networks with 100 nodes without topology control: when the speed is 60 m/s, the overhead is 23% higher compared to the overhead observed in networks with nodes moving at 20 m/s; when the speed is increased to 100 m/s, the overhead increases approximately 31%. However, in networks with adaptive topology control A-LMST, the increased overhead does not exceed 6% when we change the speed of 20 m/s to 60 m/s or 100 m/s. This means that the effect of density waves is reduced when we apply topology control.

In the UG model, the neighborhood variation is reduced and the concentration of the nodes in the center of the simulation area does not occur, so the routing overhead for this model is lower than in the RWP model, independently of the nodes speed.

C. Route Discovery Delay

The route discovery average delay is the difference between the time of stacking a broadcast route request packet (RREQ) from a source node and the time of receipt of the first response to this request route by the source node. The analysis of this metric shows if the graph reduction process, which causes a decrease in the amount of communication routes, performed by the topology control influences the average time of the route discovery. We note that, regardless of the mobility model, both in networks with topology control and without topology control, the average delay for route discovery is similar. Actually, in some situations networks with topology control,

regardless if using 2-hops, 3-hops or adaptive topology control, present better results than networks without topology control.

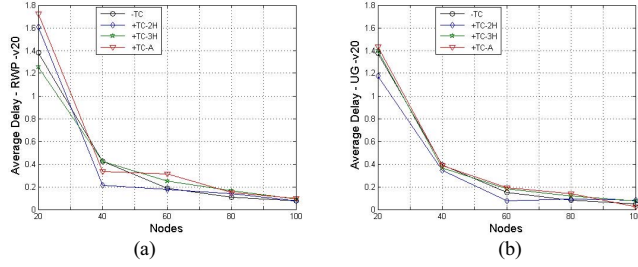


Fig. 4. Average route discovery delay in the RWP and UG mobility models.

For the RWP model (Figure 4a), when the number of nodes is increased and the maximum speed that a node can move is kept, the average delay decreases due to the better nodes distribution in the simulation area, i.e., in denser networks, the neighborhood is larger and the number of routes between nodes increases. For this same situation, the UG model (Figure 4b) produced lower values for average delay, since the number of group elements facilitates the maintenance of routes.

With respect to the speed variation and independently of the mobility model, in networks with topology control the increase in the average delay was smaller than in networks without topology control. In RWP networks without topology control, with 100 nodes moving at 60 m/s, there is a 25% increase in the route discovery delay when compared to networks where the nodes are moving at 20 m/s; by increasing the speed of the nodes to 100 m/s, the increase delay is 34%. By applying adaptive topology control for the same network settings and changing the speed from 20 m/s to 60 m/s, the delay increases 23%; when the speed is changed from 20 m/s to 100 m/s the delay is increased by 26%.

Analyzing the speed variation of the nodes in the UG model, we note that the use of adaptive topology control presented similar results to the analysis for the RWP model. In both cases, the use of the adaptive topology control showed better results when comparing with mobile networks without topology control.

IV. CONCLUSIONS

In this paper, we first verified the impact that parameter variations such as number of nodes and speed of nodes produce on network metrics in MANETs with and without topology control. The Random Waypoint and Uniform Group mobility models were chosen to be simulated with the AODV routing protocol and LMST topology control protocol. Results of the experiments showed that, in networks with topology control using 2 or 3 hops for route discovering, the number of generated routing packets decreases. Then, based on these results, a topology local adaptive self-configuration mechanism was proposed for each node: for nodes with degree greater than or equal to 4, the topology protocol operates with 2 hops, otherwise with 3 hops. We verified that, as the number of network nodes increases, the proposed topology control algorithm (A-LMST) presented better results.

In fact, in small networks the use of topology control did not decrease the routing overhead, since the nodes were more distant from each other. But as the number of nodes was increased, A-LMST presented better results. For the RWP model, by analyzing the node speed change we noted that in networks using topology control the graph reduction is not too affected by the density waves. Independently of the nodes speed, in the UG model A-LMST produced lower overhead than in the RWP model. Finally, for both mobility models, the routing overhead was increased when there was speed increase, as expected.

Concerning the average delay in the route discovery and regardless of the mobility model, both in networks with topology control and without topology control the results were similar; and in some situations the networks with topology control presented better results. Regardless if we use 2-hops, 3-hops or adaptive topology control, the process of graph reduction had no significant impact on this metric. Since in the UG mobility model the number of group elements facilitates the maintenance of routes, it produced lower values for average delay than the RWP model when the number of nodes were increased. With respect to the speed variation, independently of the mobility model, in networks with topology control the increase in the average delay was smaller than in networks without topology control.

Based on the results obtained, the next step of this ongoing work is to add a method for power control that acts in partnership with the adaptive topology control protocol, thus increasing the overall efficiency of A-LMST.

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