

IMPLEMENTATION OF A TOPOLOGY CONTROL ALGORITHM FOR MOBILE AD HOC NETWORKS

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ABSTRACT

Recently mobile ad hoc network (MANET) has attracted great interest with a variety of real applications. Rigorous research work, mainly on efficient routing protocol designs has been done and numerous MANET routing protocols have been developed. While designing the routing protocols it is assumed that the network is fully connected (i.e. there are no partitions). Mobility plays an important role in MANET. Relative node movement can break links and thus change the topology. In this paper we propose a physical implementation of a topology control algorithm for MANETs using freeway mobility model. The proposed algorithm maintains the topology without any control message. There is no need to change routing table as connectivity of the network is maintained all through. Each mobile node is equipped with a transceiver and a GPS receiver. Each node in a network transmits their coordinate location information and velocity periodically to its preceding node. After receiving this information from the following node, if requires, it will modify its own velocity for maintaining the connectivity/topology with the following node. In this approach each node will try to maintain the neighborhood topology with its following node. Results obtained through the experimentation with the prototype developed, demonstrate that the connectivity and hence the topology of the network is always maintained.

Keywords: Mobile Ad-hoc Network, Topology control, Freeway Mobility model, Hardware Implementation

1. INTRODUCTION

Mobile Ad hoc Network is a group of autonomous mobile multi-hop wireless nodes, without any fixed infrastructure, such as base station, underground cable, etc. There is no need of any fixed infrastructure, and hence it is an attractive and demanding networking option for connecting mobile devices quickly and spontaneously. Ad hoc networks have found great applications in disaster recovery, battle field, search-and-rescue operations, military activities, etc [1-3]. Each node in the network acts not only as an end-system, but also as a router to forward packets. In MANET the nodes can move in an arbitrary manner. Connectivity in a MANET is difficult to achieve, due to unpredictable nature of node mobility. The current focus of many researchers is to find an efficient routing protocol, which will ensure node connectivity whenever required without much delay and overhead [1-2]. Rigorous research work on efficient routing

protocol designs has been done and numerous MANET routing protocols have been developed. While designing the routing protocols it is assumed that the network is fully connected (i.e. there are no partitions). Mobility plays an important role in MANET. Relative node movement can break links and thus change the topology and this may result in partitioning of the network. Once the network is partitioned none of routing/broadcast protocol can be successful and very rare chances to form the connected network. For example, suppose node a and node b are neighbors in the network at time t , but somehow move out of the communication range at time $t+\epsilon$. During this period routing is unaware of this broken link and node a still forward packets to b and it will never reaches to node b . To keep the topology unchanged without disconnecting any node within the network needs topology management scheme.

Most of the work on topology control has dealt with achieving connectivity with node selection as a secondary problem. The primary problem usually attempts to find topologies to minimize power consumption and increased network longevity (life span). Little work has been done to maintain a topology of a connected network in a MANET. Wattenhofer *et al.* [4] has developed an algorithm that increases network lifetime with guaranteed global connectivity. Their algorithm describes that a node increases its transmission power until it finds a neighbor node in every direction based on directional information. But the question remains unanswered if, none of the neighbor node does not exist within the maximum transmission range of the node. Insufficient analysis is provided on connectivity and how to sustain it in a mobile environment. Ramnathan *et al.* [5] proposed the topology scheme using the idea of logarithmic change in power depending on the number of neighbors. They described an algorithm to adjust the node transmission power to maintain network connectivity. This algorithm does not guarantee network connectivity in all cases. Betstetter [6] modeled the neighboring node distribution by nearest neighbor methods known from analysis of spatial data. They have used random way point mobility model for analysis. Their work provides little evidence to show how randomly distributed nodes can be modeled using such a distribution. Most of the work deals with randomly distributed static nodes. None of the discussed schemes guarantees the connectivity of the network in mobile environment and all are studied through simulations only.

Studies in [7] presented the effect of mobility on the network capacity. The impact of mobility on the performance of routing protocols is discussed in [8]. Several papers address the time period for the two nodes to remain in close proximity for maintaining connectivity [9]. Camp *et al.* [10] described different mobility models for MANET. These models are based on either the mobility of a single node or a group of nodes. In group mobility models, the mobile nodes (MNs) movement decision depends upon the other mobile nodes in the group and needs topology management. Several mobility models for wireless nodes are discussed in [8], [11-15]. Implementation of a MANET

in real world is a challenging task, especially when the network topology is changing continuously.

This paper presents an algorithm and its hardware implementation to maintain topology in MANETs. For implementation we have considered freeway mobility model. Each node will take decision on its own, for its movement, to maintain the connectivity with the following node in the network. We are considering the neighborhood connectivity of the node. The key concept of the present algorithm is that each node will try to maintain the connectivity with its following node.

The rest of this paper is organized as follows: we present the freeway mobility model and terms used in this work in section 2. The topology control algorithm is proposed in section 3. Section 4 presents lemmas and mathematical correlation for the selection of various parameters, required for maintaining connectivity of nodes in the networks. Node architecture is shown in section 5. Experimental results are presented in section 6 and section 7 concludes the paper.

2. FREEWAY MOBILITY MODEL

Mobility models are necessary for studying various parameters of MANET. Since not many MANETs have been deployed, most of the research in this area is simulation based. These simulations have several parameters including the mobility models [7-8], [10], [13] and the communication traffic patterns. MANET protocol performance may vary drastically for different mobility models [7-8], [13]. In a MANET the nodes should move in some coordinated manner depending upon the application. In literature there are various mobility models which are used for simulation. These are Random Waypoint mobility model, Reference Point Group mobility model, Freeway mobility model, Nomadic Community mobility model, Manhattan mobility model and Random Gauss-Markov model [8], [11-15]. Out of these models we have selected the Freeway Mobility model discussed in [8], [15] for our practical implementation. Numerous applications exist for this type of scenario. This model emulates the motion behavior of mobile nodes on a freeway. This mobility pattern may have application in a scanning and searching purposes e.g. anti-personal mines deactivation robots [15] and can be used in exchanging traffic status or tracking a vehicle on a freeway [8]. e.g. forming a “one following the other” motion, also present in some robotics activities and for transportation convoy. The freeway mobility model used in our implementation is shown in Fig. 1.

There are several freeways on the map and each freeway has lanes in both directions. Following are the important characteristics of freeway mobility model.

- (a) Each mobile node is restricted to its lane on the freeway.
- (b) The velocity of mobile node is temporally dependent on its previous velocity.

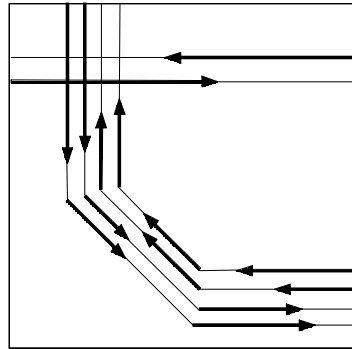


Figure 1: Map used in Freeway Mobility Model

- (c) The following node is not allowed to cross the preceding node.
- (d) If two nodes on the same freeway lane are within the minimum allowable safe distance, the velocity of the following nodes cannot exceed the preceding node.

Due to the above characteristic, the freeway mobility pattern is expected to have high spatial dependence and high temporal dependence. It also imposes strict geographic restrictions on the node movement by not allowing a node to change its lane.

Fig. 2 shows a *safe distance-I*, a *safe distance-II* and a *communication range* with respect to the node N_3 . The region between the safe distance-I and the safe distance-II is termed as a *safe zone*. Solid black arrow indicates the direction of movement of the network.

Fig. 2 shows five nodes N_1 to N_5 . For the consecutive nodes N_2 and N_3 , the node N_2 is the preceding node with respect to N_3 and N_3 is the following node with respect to N_2 . Through GPS we identify the position of the following node as well as that of the preceding node.

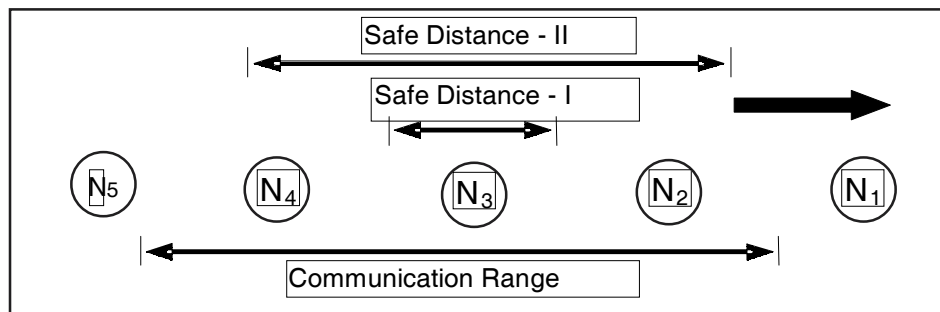


Figure 2: Showing Different Distances

We define a time interval called *beacon interval* after which the each following node sends updated information periodically to its preceding node. The beacon interval depends on communication range, safe distance-II and maximum allowable velocity of the node. The expression for the beacon interval is given in Lemma-I in section 4. When a mobile node goes out of the safe zone, it has to modify its velocity to come within the safe zone as explained in Lemma-II and Lemma-III in section 4.

3. THE PROPOSED ALGORITHM

This paper describes an efficient algorithm to maintain the connectivity and topology of the network in a mobile environment and tests the algorithm in actual physical environment by prototype developed (hardware setup). In this algorithm, each node will try to maintain the connectivity with its following node in the network. Each *MN* is equipped with a transceiver and a GPS receiver. Every mobile node will try to remain in the safe zone of its following node. So, ultimately all the nodes will be in the range of multi-hop communication. To keep the routing table unchanged, relative positions of the nodes must be same as they were initially. Each *MN* will receive velocity and positional (longitude and latitude) information from its following node to maintain topology. If any *MN* goes out of the safe zone then, in the next beacon interval, it will take necessary action to come within the safe zone of its following node. So, before receiving the next updated information each mobile node must be in a safe zone of its following node. Resultant movement of all the nodes is in the same direction.

3.1. Terminology

- T_b – Beacon interval.
- $T_b(i)$ – i^{th} beacon interval.
- d_A – Safe Distance-I (Minimum allowable safe distance between the preceding node and the following node).
- d_B – Safe Distance-II (Maximum allowable safe distance between the preceding node and the following node).
- N_p – Preceding Node.
- N_f – Following Node.
- $d(N_p, N_f)$ – Distance between the preceding node and the following node.
- $V_p(i)$ – Velocity of the preceding node for the i^{th} beacon interval.
- $V_f(i)$ – Velocity of the following node for the i^{th} beacon interval.
- V_{min} – Minimum velocity of a node.

- V_{max} – Maximum velocity (Maximum allowable velocity of a node).
 V_{rush} – Rush velocity (Maximum possible velocity of a node).
 $= 2V_{max}$
 V_o – Offset velocity, selected randomly i.e. $V_{min} \leq V_o \leq V_{max}$.

3.2. Preliminaries

- The communication range of all mobile nodes is same.
- Every node updates its location coordinate through GPS in each beacon interval.
- Initially, $d_A < d(N, P_r) < d_B$, for all N_p and N_f .
- Initially, all nodes are static.

3.3. Algorithm

Step 1: Let $i = 1$.

Step 2: For $T_b(i)$, each following node broadcasts its current location coordinates and velocity to preceding node.

Step 3: For the MN ,

$$\begin{aligned} &\text{If } d_A \leq d(N_p, N_f) \leq d_B, \\ &\quad V_p(i+1) = V_p(i) \pm V_o. \\ &\text{Else if } d(N_p, N_f) \leq d_A, \\ &\quad V_p(i+1) = V_{rush}. \\ &\text{Else if } d(N, P_r) > d_B, \\ &\quad V_p(i+1) = V_j(i)/2. \end{aligned}$$

Step 4: Entire network starts moving for the duration T_b .

Step 5: $i = i + 1$.

Step 6: Go to step 2.

4. LEMMAS

The important lemmas for the topology control are listed below.

4.1. Lemma I: Selection of the Beacon interval time T_b .

If the communication range is d_C and safe distance-II is d_B , where $d_C > d_B$, the beacon interval of the network must be equal to $(d_C - d_B) / V_{max}$.

Proof: Let us consider the preceding node is on the border of the safe distance-II. Further we assume that the relative velocity of the preceding node with respect to the following node is V_{max} . In one beacon interval T_b , it will move by distance $T_b V_{max}$. To keep these two nodes always within the communication range, $(d_B + T_b V_{max})$ may be maximum d_C . So, in the worst case,

$$d_B + T_b V_{max} = d_C$$

$$T_b = (d_C - d_B) / V_{max}$$

When two nodes are out of safe distance-II, the preceding node can not take greater velocity than the node at following. So, if we choose beacon interval $T_b = (d_C - d_B) / V_{max}$, there is no chance for any pair of nodes to go out of the maximum communication range.

4.2. Lemma II: Selection of the velocity of the preceding *MN* if it goes out of the safe zone.

If the preceding *MN* goes out of the safe zone of the following *MN* then, to keep the preceding *MN* in the safe zone, the preceding *MN* must set its velocity to half the velocity of the following node.

Proof: Let $x = d(N_p, N_f)$, where $x < d_B$

In the next beacon interval let the distance be $y(i)$, where

$$y(i) = x + V_p(i) T_b - V_f(i) T_b$$

Let us assume that

$$y(i) > d_B$$

i.e.

$$x + V_p(i) T_b - V_f(i) T_b > d_B$$

So, in the $(i + 1)$ th beacon interval separation of these two nodes will be

$$y(i + 1) = y(i) + V_p(i + 1) T_b - V_f(i + 1) T_b$$

In the $(i + 1)$ th beacon interval, if $V_p(i + 1)$ is reduced to $V_f(i)/2$

then,

$$y(i+1) = y(i) + V_f(i)T_b/2 - V_f(i + 1)T_b,$$

assuming that, the following node will not reduce its velocity by less than 50% of its previous velocity,

hence,

$$V_f(i + 1) > V_f(i)/2$$

So,

$$(V_f(i)/2 - V_f(i+1)) T_b < 0$$

Therefore,

$$y(i+1) = y(i) + (V_f(i)/2 - V_f(i+1)) T_b < y(i) \quad (1)$$

From the inequality (1) we can prove that, once the distance is greater than d_b , then in the next beacon interval there is no chance to increase the separation between the nodes, rather it will decrease. So, there is no chance for a preceding MN to go out of the communication range of the following node.

4.3. Lemma III: Selection of the velocity of the preceding node to keep the preceding node always ahead of the following node.

If the separation between the two nodes is less than the safe distance-I then, to keep the preceding node always ahead of the following node, the velocity of the preceding node must be increased to the rush velocity.

Proof: Let us consider that, the preceding node and the following node are at a distance of d_A . In worst case, we assume that the following node may move with the V_{max} velocity and preceding node move with V_{min} velocity. In the next beacon interval, the separation between these two nodes will decrease to $(d_A + T_b V_{min} - T_b V_{max})$. According to the algorithm in the next beacon interval the distance between preceding node and following node must be greater than or equal to d_A . Now to compensate this distance in the next beacon interval, assume that the preceding node will move with the velocity V_x and hence the relative velocity will be $(V_x - V_{max})$. Now to bring these two nodes within the safe zone, in the next beacon interval,

$$\begin{aligned} d_A &= d_A + T_b V_{max} - T_b V_{min} - (V_x - V_{max}) T_b \\ V_x &= 2V_{max} - V_{min} \end{aligned}$$

Assume,

$$V_{min} = 0,$$

therefore,

$$V_x = 2V_{max} = V_{rush}$$

Since the preceding node moving with the rush velocity which is greater than the following node velocity, the distance between these two node will increase and hence, the following node will not able to cross the preceding node and preceding node always remain ahead of the following node.

5. NODE ARCHITECTURE

Fig. 3 shows the architecture of the mobile node used for experimentation.

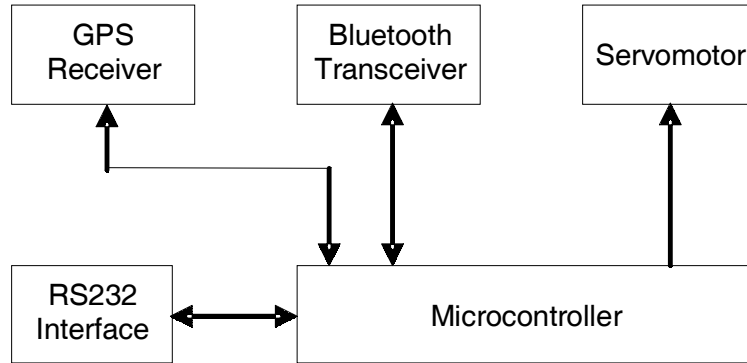


Figure 3: Mobile Node Architecture

It consists of a Microcontroller, a GPS receiver, a Bluetooth transceiver, Servomotors for movement and Batteries for power supply.

Description of the hardware components used in a MN (prototype developed) is as follows-

Microcontroller: The Microcontroller consists of general purpose I/O pins, Internal flash RAM and EEPROM.

GPS Receiver Module: Navigation update rate is once per second. Module contains built-in rechargeable battery for memory and real time clock backup. Module provides either standard raw NMEA0183 strings (e.g. GGA, GSA, GSV, RMC, etc.) or specific user requested data via the serial command interface and tracks up to 12 satellites. The module provides current time (UTC), date, latitude, longitude, altitude, speed etc.

Bluetooth Transceiver: Transceiver open field range is 100 metre, and operates in the 2.4 GHz ISM band (license free band). Frequency Hop Spread Spectrum (FHSS) modulation technique is used and transmission is omni-directional, and non-line-of-sight through walls.

RS232 interface: RS232 interface is used for communication to computer. It is useful for programming the microcontroller and collecting the data.

Servomotor: Variable speed servomotors are used for movement of the MNs.

Battery: Battery 6Volt D.C. 4.5 A/h is used to supply the power to all components of MN.

6. EXPERIMENTAL RESULTS

Experiments were carried out using the following data at the Jadavpur University playground.

Number of mobile nodes in the network = 3

Communication Range (d_c) = 30 m

Maximum velocity of Node (V_{max}) = 30 m/min

Safe Distance-II (d_B) = 20 m

Therefore, Beacon interval (T_b) = 20 s

Fig. 4, Fig. 5 and Fig. 6 show the traces of the movement of the Node N_1 , N_2 and N_3 . Node N_1 is the front most node and node N_3 is the behind most node in the network. Practical results obtained after each beacon interval are shown in Table-1.

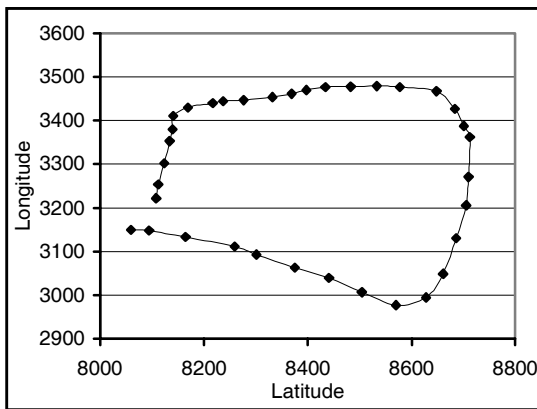


Figure 4: Path Traced by Node N_1

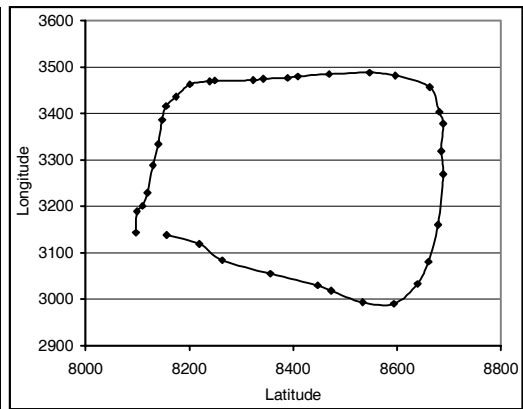


Figure 5: Path Traced by Node N_2

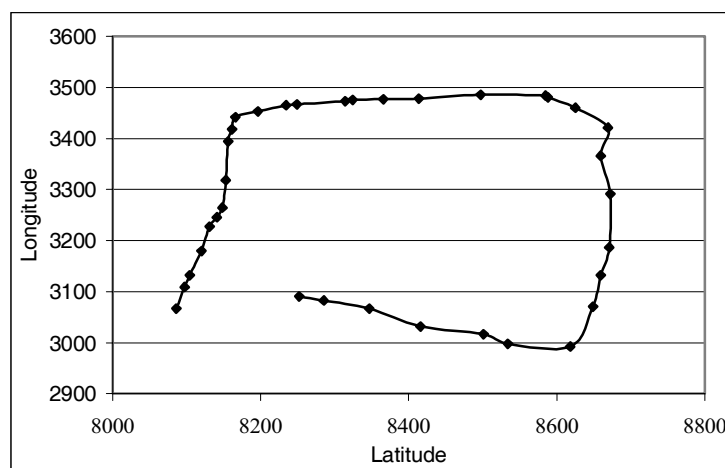


Figure 6: Path Traced by Node N_3

Table 1
Distance Between Pair of Nodes in Each Beacon Interval

<i>Beacon Interval(s)</i>	<i>Distance Between the Node</i>		<i>Remarks/Action Taken by the Node (Velocity)</i>	
	<i>N₁ and N₂</i>	<i>N₂ and N₃</i>	<i>Increases</i>	<i>Decreases</i>
0	14	13		
20	12	14		
40	18	12		
60	22	9	N ₂	N ₁
80	16	11		
100	14	15		
120	9	21	N ₁	N ₂
140	12	17		
160	11	8	N ₂	
180	14	11		
200	16	14		
220	21	9	N ₂	N ₁
240	13	15		
260	16	16		
280	17	13		
300	22	15		N ₁
320	19	18		
340	18	23		N ₂
360	17	17		
380	13	14		
400	9	21	N ₁	N ₂
420	18	18		
440	19	17		
460	23	18		N ₁
480	18	22		N ₂
500	15	18		
520	14	17		
540	16	17		
560	17	14		
580	18	12		
600	26	9	N ₂	N ₁
620	19	11		
640	18	14		
660	22	13		N ₁
680	16	18		

Resulting distances of nodes for each beacon interval are depicted graphically in Fig. 7. Fig. 7 also shows that no pair of nodes exceeds the communication range, i.e. 30m and also maintains the safe distance-I, i.e. 10m.

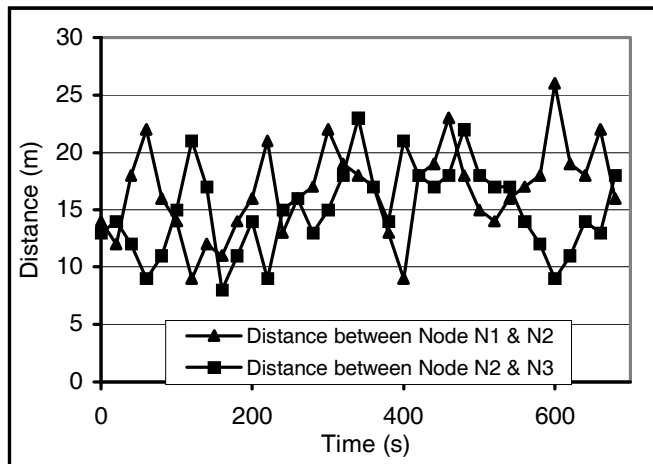


Figure 7: Distance between the MNs

Fig. 8. (a), (b) and (c) show the snapshots of the relative position and the distance of the mobile nodes with respect to each other during different beacon intervals. Black block arrow indicates the direction of the movement of the network.

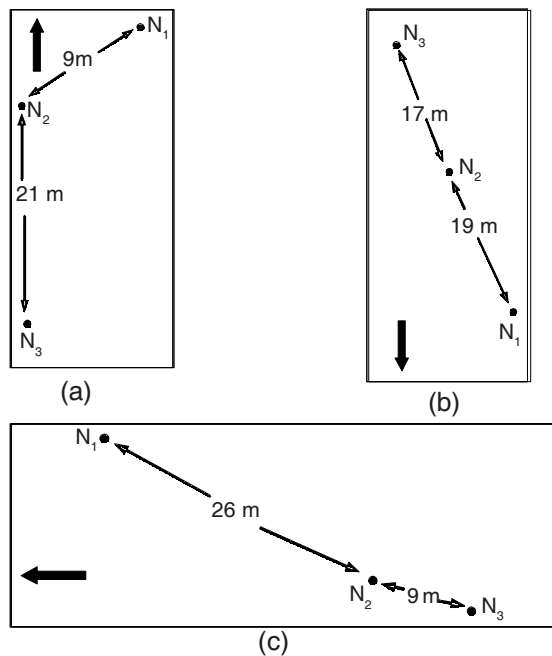


Figure 8: Snapshot of Nodes During the Beacon Interval (a) 7th, (b) 23rd, and (c) 31st

7. CONCLUSION

In the proposed topology control algorithm for MANETs, the system never becomes static as a whole and hence greater efficiency is achieved in terms of time. No node ever diverges out of communication range. Even if any mobile node goes out of the safe zone, communication with the node would not be hampered, since the communication range is higher than the safe zone range. The proposed algorithm maintains the topology without any control message. There is no need to change the routing table as the connectivity of the network is maintained all through. We have successfully implemented the topology control algorithm in real environment using freeway mobility model. Experimental results demonstrate that the algorithm is able to maintain connectivity of the MANET through the topology maintenance. The proposed algorithm is able to keep the network intact (i.e. not partitioned). At present we are planning to test the proposed algorithm with more number of mobile nodes.

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