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HARDWARE IMPLEMENTATION OF A TOPOLOGY CONTROL ALGORITHM FOR MANETS USING NOMADIC COMMUNITY MOBILITY MODEL

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ABSTRACT

Recently mobile ad hoc network 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. 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. Every node in the network is free to travel with its own velocity. Individual node can take the decision on its own to change the position for maintaining the connectivity with the reference node. They can roam around a reference 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 Networks (MANETs), Topology Control, Nomadic Community 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 $t+\Delta t$. 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 with a connected network in the MANET. Wattenhofer et. al. [4] have 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. They also proved that nodes chosen within cones having $2\pi/3$ angle result in a minimum energy network for static network topology. 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 simulation 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 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 using Nomadic Community Mobility model. The algorithm controls the movement of the node with respect to a reference node to ensure the connectivity of the network through the topology maintenance. Nodes are free to move in any direction within the safe zone of the reference node. Each node will take decision on its own, for its movement, to maintain the connectivity within the network. The key concept of the present algorithm is that each node will try to maintain the connectivity with the reference node.

The rest of this paper is organized as follows: we present the nomadic community 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 the nodes in the network. Node architecture is shown in section 5. Experimental results are presented in section 6 and section 7 concludes the paper.

2. NOMADIC COMMUNITY 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 Nomadic Community Mobility model discussed in [8], [15] for our practical implementation. This model emulates the motion behavior of mobile nodes in the group. This mobility pattern may be useful in some military operations and also (with a slower movement) in agriculture robotics [15]. Numerous applications exist for this type of scenario. For example, consider a class of students touring an art museum. The class would move from one location to another together; however, the students within the class would roam around a particular location individually [10].

Fig.1. shows an illustration of eight mobile nodes (MNs) moving with the nomadic community mobility model which is used for our implementation. The reference node (represented by a black dot) moves from one location to another; the MNs (represented by white circle) follows the movement of the reference node.

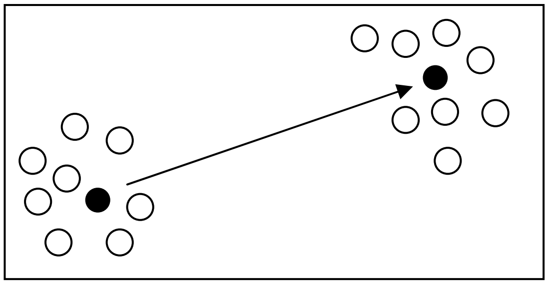

Fig. 1. Movements of MNs in Nomadic Community Model.

The nomadic community is an ancient human behavior, present in some cultures. In this model, the whole community moves, from time to time, from one location to another. After the community having established, each node maintains its own private area, inside of which the node moves more or less randomly. Each MN uses an entity mobility model (i.e. the Random Walk Mobility Model) to roam around a reference node. The nomadic community mobility model represents groups of MNs that collectively move from one location to another location.

Fig. 2 shows the *safe distance*, the *communication range* and the *safe zone* with respect to a *reference node*.

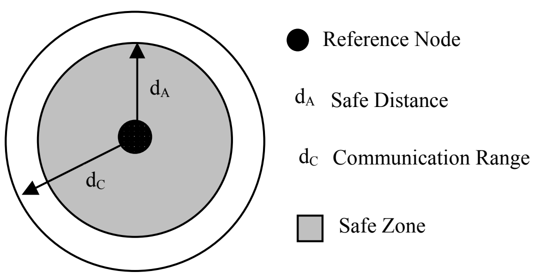

Fig. 2. Showing different distances.

We define a time interval called *beacon interval* after which the reference node sends updated information periodically to all the nodes. The beacon interval depends on communication range, safe distance 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 using hardware setup. In this algorithm, every MN will try to maintain the connectivity with the reference node in the network. Each MN is equipped with a transceiver and a GPS receiver. All MNs except reference node, will freely roam but within the safe zone of the reference node. So, ultimately all the nodes will be within the communication range of the reference node. Each MN will receive velocity and positional (longitude and latitude) information from the reference 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. Resultant movement of all the nodes is in the same direction. A node in the direction of movement of the reference node and behind the reference node is termed as lagging node and the node ahead of the reference node is termed as leading node.

Terminology:

T_b	– Beacon interval.
$T_b(i)$	– i^{th} beacon interval.
d_A	– Safe distance between the reference node and the mobile node.
d_C	– Communication range of a node (reference/mobile node).
P	= {$P_1, P_2, \ldots, Pr, \ldots, Pn$}, set of mobile nodes.
N	– Reference Node.
$d(N, P_r)$	– Distance between the reference node N and the mobile node P_r.
$V_N(i)$	–Velocity of the reference node for the i^{th} beacon interval.
$V_r(i)$	– Velocity of the mobile node P_r 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, randomly selected i. e. $V_{min} \leq V_o \leq V_{max}$.

Preliminaries:

- The communication range of the reference node and the mobile node is same.
- Every node updates its location coordinate through GPS in each beacon interval.
- Initially, $d(N, P_r) < d_A$, for P_r, where r = 1, 2, 3,….,n.
- Initially, all nodes are static.

Algorithm

Step1. Let $i = 1$.

Step2. For $T_b(i)$, reference node broadcasts its current location coordinates and velocity to all the MNs.

Step3. For the r[th] MN,

If $| d(N, P_r) | \leq d_A$,

$$V_r(i+1) = V_r(i) \pm V_o$$

Else if (Node is leading) & ($d(N, P_r) > d_A$)

$$V_r(i+1) = V_N(i)/2$$

Else if (Node is lagging) & ($d(N, P_r) > d_A$)

$$V_r(i+1) = V_{rush}$$

Step4. Entire network starts moving for the duration T_b.

Step5. $i = i+1$.

Step6. Go to step 2.

4. LEMMAS

The important lemmas for the topology control are listed below.

A. Lemma-I. Selection of the Beacon interval time T_b.

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

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

$$d_A + T_bV_{max} = d_C$$

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

When the leading MN is out of the safe zone, it cannot take greater velocity than the reference node. So, if we choose beacon interval $T_b = (d_C - d_A)/V_{max}$, there is no chance for any MN to go out of the communication range.

B. Lemma-II. Selection of the velocity of the leading MN if it goes out of the safe zone.

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

Proof:

Let $x = d(N, P_r)$, where $x < d_A$

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

$$y(i) = x + V_r(i)\, T_b - V_N(i)\, T_b$$

Let us assume that,

$$y(i) > d_A$$

$$\text{i.e. } x + V_r(i)\, T_b - V_N(i)\, T_b > d_A$$

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

$$y(i+1) = y(i) + V_r(i+1)\, T_b - V_N(i+1)\, T_b$$

In the $(i+1)^{th}$ beacon interval, if $V_r(i+1)$ is reduced to $V_N(i)/2$

then,

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

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

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

So,

$$(V_N(i)/2 - V_N(i+1))\, T_b < 0$$

Therefore,

$$y(i+1) = y(i) + (V_N(i)/2 - V_N(i+1))\, T_b < y(i) \quad \text{-- (1)}$$

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

C. Lemma-III. Selection of the velocity of the lagging MN if it goes out of safezone.

If the lagging MN goes out of the safe zone, then to keep it in within the safe zone, the velocity of the lagging MN must be increased to the rush velocity.

Proof: Let us consider the case that, when the lagging MN and the reference node are at a distance of d_A. In worst case, we assume that the reference node may move with the velocity V_{max} and lagging MN with the velocity V_{min}. In the next beacon interval, the separation between these two nodes will increase to $(d_A + T_bV_{max} - T_bV_{min})$. According to the algorithm in the next beacon interval the lagging MN have to come within the distance d_A. Now to compensate this distance in the next beacon interval, assume that the lagging 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 distance d_A, in the next beacon interval,

$$d_A = d_A + T_bV_{max} - T_bV_{min} - (V_x - V_{max})T_b$$

$$V_x = 2V_{max} - V_{min}$$

Assume,

$$V_{min} = 0,$$

therefore,

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

5. NODE ARCHITECTURE

Fig. 3 shows the architecture of the mobile node used for experimentation. It consists of a Microcontroller, a GPS receiver, a Bluetooth transceiver, Servomotors for movement and Batteries for power supply.

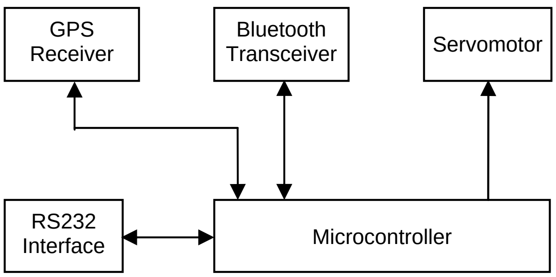

Fig. 3. Mobile Node Architecture.

Description of the hardware components used in a MN 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 (d_A) = 20 m
Therefore, Beacon interval (T_b) = 20 s

Fig. 4 shows the trace of the movement of the node N_0 which is the reference node. Fig. 5 and Fig. 6 show the traces of the movement of node N_1 and node N_2 which are moving within the safe zone of the reference node in the network.

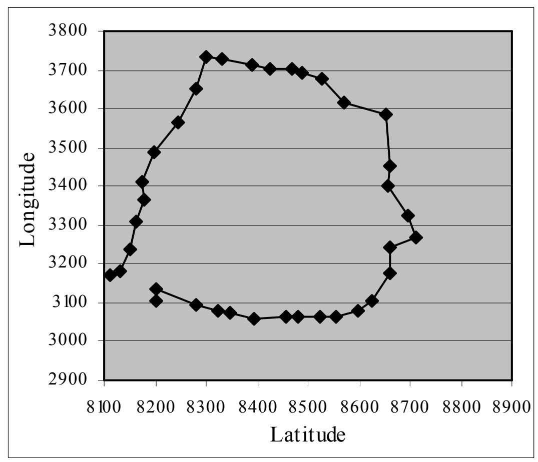

Fig. 4. Path Traced by the Node N_0.

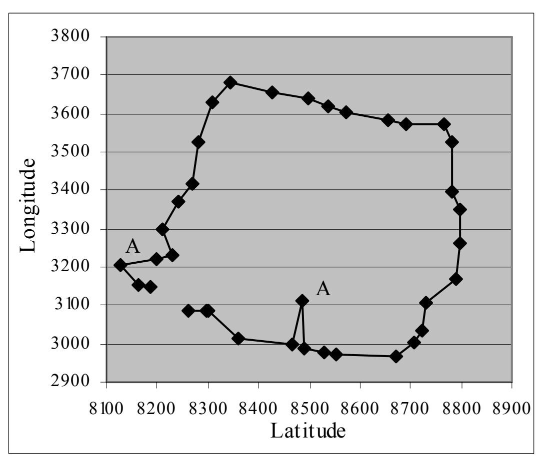

Fig. 5. Path Traced by the Node N_1.

Point A in the Fig. 5 and point B in the Fig. 6 show that node N_1 and node N_2 can roam around the reference node N_0.

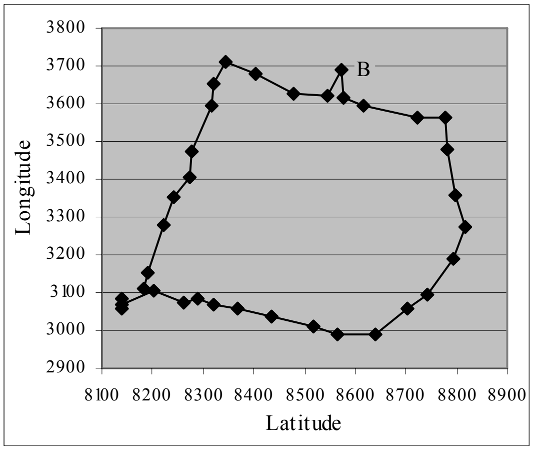

Fig. 6. Path Traced by the Node N_2.

Practical results obtained after each beacon interval are shown in Table-1.

Table 1.

Distance between pair of Nodes in each beacon interval.

Beacon Interval (s)	Distance Between Node		Remarks/Action Taken by the Node (Velocity)	
	N_0 and N_1	N_0 and N_2	Increases (If lagging)	Decreases (If leading)
0	11	14		
20	6	10		
40	6	13		
60	15	14		
80	22	15	N_1	
100	18	19		
120	18	24		N_2
140	23	17	N_1	
160	19	12		
180	16	18		
200	7	14		
220	11	19		
240	14	22		N_2
260	16	16		
280	18	18		
300	24	18		N_1
320	19	24		N_2
340	17	19		
360	21	19	N_1	
380	19	22		N_2
400	16	19		
420	13	18		
440	22	25		N_1, N_2
460	16	19		
480	19	18		
500	19	14		
520	23	9	N_1	
540	15	13		
560	15	17		
580	13	21		N_2
600	16	15		
620	21	13	N_1	
640	12	18		
660	4	22		N_2
680	16	15		
700	9	9		

From Table-1, it is observed that, at one instant the node which was lagging earlier, becomes a leading node after a few beacon intervals. Resulting distances of node N_1 and node N_2 from node N_0 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. 30 m.

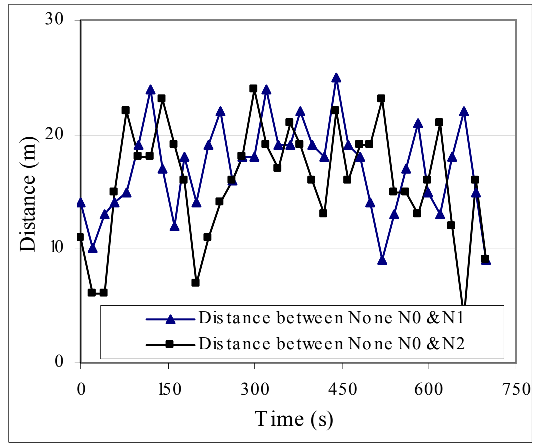

Fig. 7. Distance between the Reference Node and the MNs.

Fig. 8, Fig. 9 and Fig. 10 show the snapshot of the relative position and the distance of the mobile nodes with respect to the reference node during different beacon intervals. Black block arrow indicates the direction of the movement of the network.

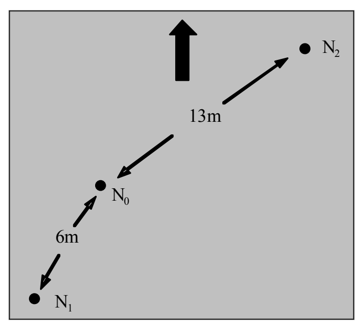

Fig. 8. Snapshot of nodes during 3rd beacon interval.

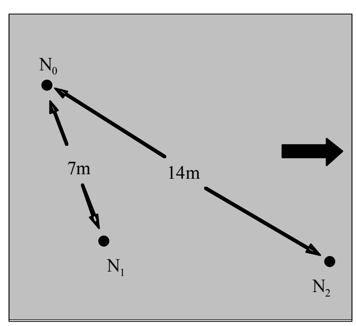

Fig. 9. Snapshot of nodes during 11th beacon interval.

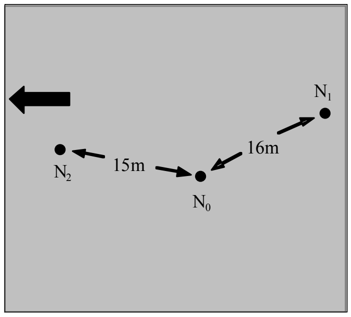

Fig. 10. Snapshot of nodes during 31st beacon interval.

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 node goes out of the safe zone, communication with the reference node would not be hampered, since the communication range is higher than the safe distance. The proposed algorithm maintains the topology without any control message. There is no need to change routing table as the connectivity of the network is maintained all through. We have successfully implemented the topology control algorithm in real environment using nomadic community 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 all mobile nodes within the safe distance of the reference node. Next, we will test the proposed algorithm with more number of mobile nodes.

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