A Distributed Algorithm for Topology Management in Mobile Ad-Hoc Networks

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Abstract— **This paper presents a distributed algorithm for adaptive movement of nodes in a mobile ad-hoc network (MANET) to maintain the overall topology of the network. Each node in the network is free to travel with its own velocity. Individual node can take the decision on their own to change the velocity for maintaining the connectivity with the other nodes. The present approach assumes that each node is enabled with a GPS receiver. All the nodes in a network transmit their position and velocity information periodically. Each node will obtain this information from its neighbors and decide its own velocity to maintain topology. Results obtained through simulation studies show the effectiveness of the proposed algorithm.**

Index Terms: **Mobile Ad-hoc Network, Distributed Algorithm, Topology Maintenance, Routing Overhead**

I. INTRODUCTION

MOBILE Ad hoc Network (MANET) is an autonomous reconfigurable mobile multi-hop wireless networks without the required intervention of any centralized access point. Each node acts not only as an end-system, but also as a router to forward packets. The nodes are free to move about and organize themselves into a network without using any pre-existing infrastructure [1], [2]. 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, unplanned meetings, spontaneous interpersonal communications etc. where fixed infrastructure is absent and sudden data acquisition is necessary [1], [5].

When a mobile node wants to communicate with an other node, the later should be within the communication range of the system. Since all the nodes are mobile, it is a challenging task to keep them connected, so that, a route for communication can be formed. The route may be single-hop or multi-hop. A route can only be formed if all successive pair of nodes are always within the maximum communication range

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Random mobility of node makes routing an essential requirement for MANET. Due to mobile nature of a node it may so happen that when the source node wants to transmit packets, the destination node may be out of the range of the source node. Hence, the current focus of many researchers is to find out an efficient routing protocol which ensures node connectivity whenever required without much delay and unnecessary overhead. There are many existing routing schemes for MANET namely proactive, reactive and hybrid. The frequently employed routing schemes include Destination Sequence Distance Vector (DSDV), Wireless Routing Protocol (WRP), Optimized Link State Routing (OLSR), Cluster Switch Gateway Routing (CSGR) under proactive scheme, Ad hoc On-Demand Distance Vector Routing (AODV), Dynamic Source Routing (DSR), Associativity Based Routing(ABR), Temporally Ordered Routing (TORA) etc. under reactive scheme and landmark Ad hoc Routing Protocol (LANMAR), Zone Routing protocol (ZRP), Preemptive Routing (PR) etc. under hybrid scheme. Besides this flooding and dynamic cluster based routing are also prevalent [2]. None of this routing scheme guarantees the constant connectivity of the network. Protocol designers assume that the network is always intact i.e. the all nodes in the network are neighborer of someone and the network is remain connected during movement also. But in real life nodes may be disconnected due to their random movements.

Studies in [6] presented the effect of mobility on the network capacity. The impact of mobility on the performance of routing protocols was discussed in [7]. Camp et al. [3] describes various mobility models for MANET. In group mobility models, the mobile node's movement decision depends upon the other mobile nodes in the group. The Column mobility model, Nomadic Community mobility model, Pursue mobility and Reference Point group mobility model require topology management. If initially two nodes were neighboring nodes, they will continue to be so during the movement also.

Centralized topology management schemes in [1], [4], [8] discuss a self-adaptive movement control algorithm, which ensures the retention of network connectivity even during the positional variation of the nodes. But a coordinator has to be elected and all other nodes should follow the instructions from the coordinator to maintain the topology. The main disadvantages of the centralized topology management scheme are increased control overhead and non-scalability. Further if a node goes out of communication range the whole network will remain standstill for some time and nodes are not free to select their own velocity [1]. Once the coordinator fails to perform, the whole network becomes non-functional.

This paper presents an algorithm for movement of the nodes to ensure connectivity of the network through the topology maintenance. Since the approach is distributed, there is no leader or coordinator to control the movement of the individual nodes. The key concept behind this algorithm is that, every node will always try to maintain connectivity with the node just behind of it.

Rest of this paper is organized as follows: Section II provides some preliminaries and background concept. Section III proposes the topology control algorithm. Section IV explains lemmas and mathematical correlation. Section V presents simulation results in tabular and graphical form. Section VI discusses performance comparison and section VII presents conclusion.

II. BACKGROUND CONCEPT

Each node in a MANET acts as a transceiver. In this paper, we assume that the resultant movement of all the nodes is in the same direction within the range of predefined maximum velocity.

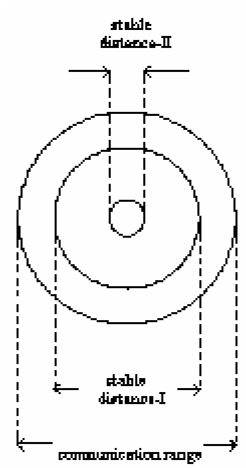

Figure1. Stable distance-I, stable distance-II and maximum communication range.

Initially all the nodes are within a predefined range termed as stable distance-I. There is a predefined maximum communication range and also a minimum stable distance termed as stable distance-II as shown in the fig. 1.

It is very important to determine the beacon interval i.e. the time interval for receiving updated information from the nodes. The beacon interval depends on maximum communication range, stable distance-I, maximum velocity of the nodes. Beacon interval expression is given in Lemma-I in section IV. When the node is out of stable distance-I, it will decrease its velocity to the half the velocity of the behind node (Explained in Lemma-II. in section IV).When the separation between two nodes is less than or equal to the stable distance-II, then the node at front will move with its maximum velocity just to keep their relative positions same.

In this algorithm, each node will try to maintain the connectivity with the node, which is just behind of it. Each node will maintain stable distance-I with its just behind 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. Every pair of nodes will always try to maintain a minimum separation of stable distance-II along the direction of movement so that their relative positions are maintained. Each node requires information from its neighbors to maintain topology. So, before receiving the next updated information each node has to maintain a distance, at least equal to the communication range with it's behind node.

III. PROPOSED ALGORITHM

Proposed algorithm is for maintaining the connectivity of the nodes in a MANET in a distributed manner. There is no leader or coordinator to control the movements of the node rather each node takes its own decision to change its movement to maintain connectivity

A. Algorithm:

1. All the nodes broadcast its position and velocity information.
2. After receiving the information the node will first Check whether there is any node behind of it or not.

   i) If there is no node behind of it, then it will move with its velocity within the range of maximum velocity.

   ii) If there are one or more nodes behind of it then it will check who is nearest to it.

   Now it will check whether its distance from the just behind node is more than stable distance-I or not.

   a) If distance is less than or equal to the stable distance-I then it will check whether separation along the direction of movement is less than or equal to stable distance-II or not. If the distance is less than stable distance-II, then the node will change its velocity to the maximum velocity. But if the separation along the direction of movement is greater than the stable distance–II, then it will take its velocity according to its choice within the range of maximum velocity.
   b) If the distance is greater than the stable distance-I then it will modify its velocity to the half of the velocity of the behind node.
3. Now it will check whether its Y-coordinate has increased or decreased with respect to the initial Y-coordinate.

If Y-coordinate is increased or decreased then it will change its direction by twice the angle of deviation from its previous beacon interval in the opposite direction i.e. if the angle of deviation in the previous beacon interval is positive with normal direction of movement then in the next beacon interval it will try to make same amount by negative angle of deviation with the direction of movement of that node.

IV. LEMMAS

A. Lemma-I. *Selection of Becaon interval time T.*

If maximum communication range is 'P' and stable distance-I range is 'Q', where P > Q, then the Beacon interval time of the network must be equal to (P-Q)/V_m where V_m is the maximum velocity of the node in the network.

Proof: Let us consider the front node is on the verge of stable distance-I. Assume that the relative velocity of the front node is V_m, in one beacon interval (T) it will move by distance TV_m, to keep these two nodes always within the communication range, ($Q + TV_m$) may be maximum P. So, in worst case,

$$Q + TV_m = P$$
$$T = (P - Q) / V_m$$

When two nodes are out of stable distance-I the front node can not take greater velocity than the node at behind. So, if we choose beacon interval T = (P– Q) / Vr, there is no chance for any pair of nodes to go out of the maximum communication range.

B. Lemma-II. *Selection of velocity of front node if it goes out of stable region-I.*

If the node goes out of stable region-I, then to keep the node in stable region-I the velocity of the front node must be reduced to half the velocity of the behind node.

Proof: Let us consider the front node and the behind node moving with velocity V_1 and V_2 respectively. If the separation between these two nodes is increases than the stable distance-I then in next beacon interval front node will reduce its velocity to half the velocity of its behind node i.e. $V_1 = V_2/2$. So, the separation between these two nodes decreases and nodes will come to stable region-I.

C. Lemma -III. *Selection of the velocity of the front node to keep the front node always ahead of the behind node.*

To keep the front node always ahead of the behind node, if the separation between two nodes is less than the stable distance-II then the velocity of the front node must be maximum velocity V_m.

Proof: let us consider the case the separation between two node is less than the stable distance-II and the behind node traveling with more velocity than the front node. Then behind node may cross the front node after few beacon intervals. To avoid this if front node increases its velocity to maximum velocity V_m then in next beacon interval separation will increase. The node at just behind will not be able to cross the node just in front of it.

D. Lemma –IV. *After one beacon interval if angle of deviation is 'θ', then if the node makes '2θ' amount of angle in the opposite direction i.e. if it makes '– θ'angle with the direction of the movement of the node then, two node maintaining their stable distance will be able to acquire their stable distance in the communication region even if they go out of the stable region.*

Proof: Let 'Y' is the initial Y-coordinate of a particular node. Now after one beacon interval the node may move with a certain angle of deviation. Let the angle is 'θ'. The node may deviate in positive or negative direction with the direction of propagation as shown in the figure bellow. Then after one beacon interval new Y-coordinate of the node will be

$Y + T.V.\sin(\theta)$ when angle of deviation is positive

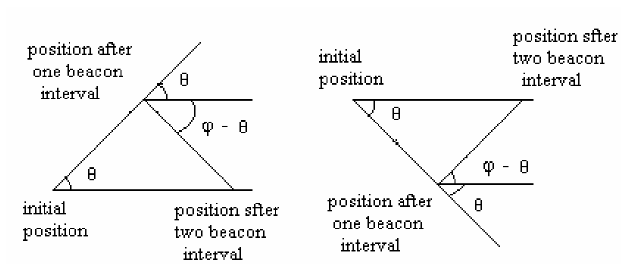

Figure 2. Demonstrating angle of deviation

$Y - T.V\sin(\theta)$ when angle of deviation is negative
Where 'T' is the beacon interval
'V' is the current velocity of the node.
Now in the next beacon interval the node has to make an angle 'φ' with the previous direction of propagation of that node to come back to it's original direction of propagation as shown in figure-2.

i) If we consider the velocity is unchanged then after next beacon interval Y-coordinate will be

$Y + T.V.\sin(\theta) - T.V.\sin(\varphi - \theta)$ for the first case

$Y - T.V.\sin(\theta) + T.V.\sin(\varphi - \theta)$ for the second case

Now, the new 'Y' coordinate will be equal to the initial 'Y' coordinate for maintaining no deviation along 'Y'-axis i.e.

$Y = Y + T.V.\sin(\theta) - T.V.\sin(\varphi - \theta)$ for the first case

or, $\sin(\varphi - \theta) = \sin(\theta)$

or, $\varphi = 2\,\theta$

$Y = Y - T.V.\sin(\theta) + T.V.\sin(\varphi - \theta)$ for the second case

or, $\sin(\varphi - \theta) = \sin(\theta)$

or, $\varphi = 2\,\theta$

ii) If velocity is increased in the next beacon interval then it is clear that Y-coordinate will decrease for the first case by slightly lower value compared to the previous increment with reference to the initial Y-coordinate and reverse will occur in the second case as shown in figure-2. But, again for the next beacon interval there will be a deviation in opposite or same direction according to the algorithm. In the worst case the displacement along Y-axis may be at most maximum deviation that is allowed by this algorithm.

iii) If velocity is decreased then it is clear that after next beacon interval Y-coordinate will be again greater than that value for the first case and reverse will occur for the second case. But in the next beacon interval it will again decrease the deviation. And for the next beacon interval if there is deviation whether positive or negative it will again try to minimize that. So movement of the node along Y-axis will be such that difference of distance along Y-axis with respect initial Y-coordinate will not be such that the two node will maintain at least stable distance along Y-axis

So in each case there is no possibility to go out the communication range for each pair of nodes. If after few beacon interval, they go out of the stable region they will come back after one beacon interval in the stable region-I, if velocity is not changed. But if the velocity is changed, in the worst case, they will comeback after a number of beacon intervals.

V. Simulation Results

The algorithm is simulated with the maximum communication range of 30 km and stable distance-I of 20 km and maximum node velocity is 60 km / hr. So, beacon interval is (30-20) / 60 hr. i.e. 10 minutes. Stable distance-II is assumed as 5 km and the maximum angle of deviation from the direction of movement is taken as 30^0. So, maximum allowable spacing along Y-axis is 10 km if direction of movement is along X-axis.

Simulation is carried out on more number of nodes. Only some sample network results, snapshot after each beacon interval are shown for four hours (240 min.) in a Table-I and Table-II. Simulation results are shown graphically for thirty hours (1800 min.) in Fig. 3 and twenty hours (1200 min.) in Fig. 4.

A. *Sample-I*

The network consists of five nodes. Their initial coordinates are $Node_1$ (0 km, 7 km); $Node_2$ (18 km, 9 km); $Node_3$ (30 km, 14 km); $Node_4$ (40 km, 21 km); $Node_5$ (57 km, 6 km) and their initial velocities are 23km / hr, 34km / hr, 56km / hr, 18km / hr, 10km / hr respectively. After every beacon interval nodes will change their velocity randomly.

TABLE I.
DISTANCE BETWEEN EACH PAIR OF NODES AFTER EACH BEACON INTERVAL FOR SAMPLE –I

Time (min) Interval= one Beacon interval	Distance between 5^{th} and 4^{th} node (km)	Distance between 4^{th} and 3^{rd} node (km)	Distance between 3^{rd} and 2^{nd} node (km)	Distance between 2^{nd} and 1^{st} node (km)
0	18.11	13.00	12.20	22.67
10	25.66	11.52	09.75	21.48
20	21.40	18.52	07.04	20.89
30	18.74	21.70	08.74	17.77
40	16.81	19.50	09.44	19.31
50	20.23	12.94	11.42	22.75
60	16.84	13.32	14.44	20.50
70	11.87	17.11	14.26	18.76
80	06.96	22.10	14.14	17.53
90	10.08	19.63	17.13	17.51
100	06.57	24.36	16.74	19.07
120	07.17	21.28	21.26	16.30
130	08.14	18.21	19.77	17.49
140	07.72	14.36	21.07	16.51
150	05.42	15.51	19.09	17.42
160	06.66	17.14	17.88	18.95
170	03.38	15.82	19.13	18.97
180	09.83	09.81	18.19	18.64
190	09.65	12.58	14.00	20.78
200	10.34	12.70	12.49	19.18
210	17.86	10.16	12.80	17.71
220	17.28	11.23	10.88	18.15
230	19.23	10.74	10.66	17.85
240	23.24	07.84	9.53	20.22

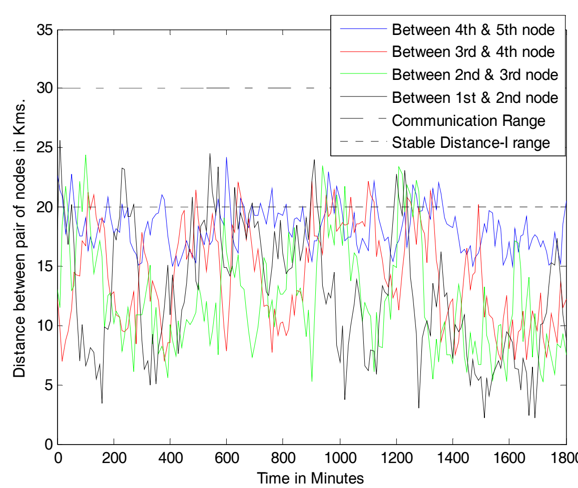

Figure 3. Showing the distance between each pair of nodes for thirty hours for sample-I.

B. *Sample-II*

The network consists of five nodes. Their initial coordinates are $Node_1$ (0 km, 5 km); $Node_2$ (18 km, 11 km); $Node_3$ (30 km, 19km); $Node_4$ (46 km, 25 km); $Node_5$ (60 km, 27km); and their initial velocities are 45km / hr, 58km / hr, 34km / hr, 23km / hr, 10km / hr respectively. After every beacon interval nodes will change their velocity randomly.

TABLE II.
DISTANCE BETWEEN EACH PAIR OF NODES AFTER EACH BEACON INTERVAL FOR SAMPLE –II

Time (min) Interval= one Beacon interval	Distance between 5^{th} and 4^{th} node (km)	Distance between 4^{th} and 3^{rd} node (km)	Distance between 3^{rd} and 2^{nd} node (km)	Distance between 2^{nd} and 1^{st} node (km)
0	8.97	14.42	17.08	14.14
10	19.02	11.88	20.27	9.51
20	18.84	11.22	18.78	15.09
30	17.41	13.88	15.42	14.02
40	15.18	10.57	21.46	9.05
50	16.60	09.57	19.89	10.48
60	19.28	0 8.08	25.76	10.13
70	19.11	0 9.63	20.93	8.97
80	18.86	0 9.32	18.91	11.04
90	17.65	14.07	14.61	11.18
100	15.06	18.76	12.40	8.43
120	15.24	15.07	15.74	10.76
130	14.41	21.47	14.60	6.49
140	15.02	18.89	15.28	8.33
150	12.30	18.28	19.33	6.46
160	12.46	21.84	14.08	10.15
170	13.05	19.83	17.13	7.05
180	10.38	19.07	20.93	8.91
190	10.28	18.77	18.79	13.05
200	11.01	16.27	19.31	14.06
210	10.68	18.37	15.30	13.96
220	8.19	23.86	16.01	8.44
230	6.63	22.62	21.30	5.61
240	10.65	18.03	18.91	6.77

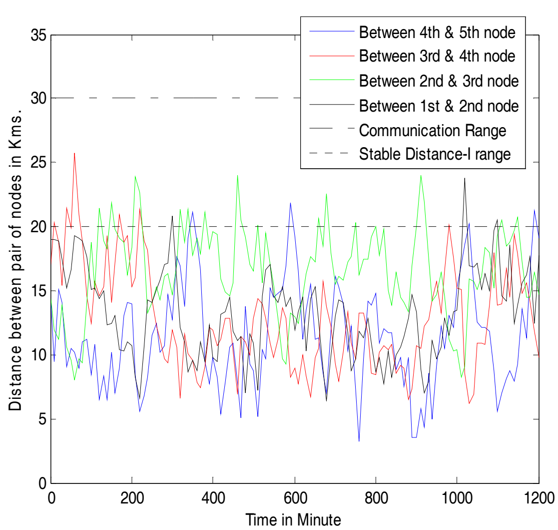

Figure 4. Showing the distance between each pair of nodes for twenty hours for sample-II.

From the above simulation results it is observed that no pair of nodes exceeds the maximum communication range of 30 kilometers.

VI. PERFORMANCE COMPARISON

The algorithm in [8] is also used for maintaining connectivity of nodes in MANETs. A heuristic algorithm is used to modify the node velocity with respect to its neighbor to maintain connectivity in [8] but there is no caution to maintain initial topology in each and every beacon interval. Performance of the proposed algorithm is better in comparison with the algorithm in [8]. Some points are given bellow.

A. Routing overhead: The proposed algorithm guarantees that the nodes will always maintain connectivity as well as initial topology. So, there is no need to update routing table during movements. Hence, routing overhead is nil in the proposed algorithm whereas the algorithm in [8] shows that routing overhead was 60%.

B Choice of Frequency ranges: The algorithm in [8] uses two different frequency ranges; one for voice communication and another for network information. Our proposed algorithm uses only one communication ranges for all purpose.

C. Time taken to calculate predicted velocity: In [8], a node may take lot of iterations to get the predicted velocity. If time required to get predicted velocity is more, there may be problem. In our algorithm a node will always take fixed amount of time to get the velocity for the next beacon interval.

VII. CONCLUSION

This paper describes an algorithm for maintaining topology in a distributed manner in Mobile Ad-hoc Networks (MANETs). This algorithm maintains the topology without any control message, which is essential in the case of centralized approach. There is no need to change routing table as connectivity of the network is maintained all through. Simulation results demonstrate that the algorithm is able to maintain connectivity in Mobile Ad-hoc Networks (MANETs).

VIII. REFERENCES

Periodicals:

[1] S.S.Basu and A.Chaudhari, "Self-adaptive Topology Management for Mobile Ad- Hoc Network", IE (I) Journal-ET, Vol.84, July 2003

[2] Elizabeth M. Royer, and Chai -Keong Toh, "A Review of Current Routing Protocols for Ad-hoc Mobile Wireless Networks" , IEEE Personal Communications, Vol. 6, No. 2, pp. 46-55, April 1999.

[3] T. Camp, J. Boleng, and V. Davies, "A Survey of mobility Models for Ad Hoc Network Research", Wireless Comm. & Mobile Computing (WCMC), special issues on mobile ad hoc networking :research trends and applications, vol. 2, no. 5, pp. 483-502, 2002.

[4] Soumya Sankar Basu, Atal Chaudhari, "Self-Adaptive MANET: A Centralized Approach", Foundations of Computing and Decision Sciences, Vol.29, 2004.

Books:

[5] David B. Johnson and David A. Maltz "Dynamic Source Routing in Ad Hoc Wireless networks" , Computer Science Department, Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, PA 15213 – 3891

Papers from Conference Proceedings (Published):

[6] M. Grossglauser and D. Tse, "Mobility Increases the Capacity of Ad-Hoc Wireless Networks", Proc. IEEE Infocom, Apr. 2001.

[7] F. Bai, N. Sadagopan, and A. Helmy, "IMPORTANT: A Framework to Systematically Analyse the Impact of Mobility on Performance of Routing Protocols for Ad-Hoc Networks", *Proc. IEEE Infocom*, Mar./Apr. 2003.

[8] Samir Biswas, Avik Ray, Kanad Basu and M.K.Naskar "A Distributed Approach to Maintain Network Connectivity in Mobile Ad-Hoc Networks", Proc. 5th Asian International Mobile Computing Conference (AMOC 2007),Kolkata, pp. 83-89, January 2007.

IX. BIOGRAPHIES

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