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A Fuzzy Based Distributed Approach to Maintain Connectivity of Nodes in Mobile Ad-Hoc Networks Considering Pursue Mobility Model

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Abstract: *The highly dynamic character of a Mobile Ad-Hoc Network (MANET) poses significant challenges on network communications. Previous work on MANET has resulted in numerous routing protocols aiming to maintain network connectivity among the active nodes. This paper presents a fuzzy based distributed algorithm to maintain connectivity in MANET. Mobile nodes follow the characteristics of the Pursue Mobility model. There is no need to change routing table as connectivity of the network is maintained all through. 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 velocity for maintaining the connectivity with the node being pursued (target node). In this approach each node is enabled with a GPS receiver. Target node transmits its velocity and coordinate information periodically to all pursuer mobile nodes in a network. The pursuer nodes, after receiving this information from the target node will modify its own velocity, to maintain the topology. Results obtained through simulation studies show the correctness of the proposed algorithm.*

Keywords: *Mobile Ad hoc Networks, Connectivity Maintenance, Mobility Model, Distributed Algorithm, Fuzzy Logic*

1. INTRODUCTION

A mobile ad-hoc network (MANET) 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]. Therefore, mobile ad-hoc networks are suitable for temporary communication links. Ad-hoc networks form self-organizing architecture that are rapidly deployable and that are adaptable to the propagation conditions and mobility pattern of the network nodes. In mobile Ad-hoc network there are no fixed routers-instead each node acts as a router as well as a host [1, 3]. In case of wireless networks there is always a base station, which reaches out to destination nodes, but in case of ad-hoc networks a mobile node may be out of range of transmission of the source node emitting packets. Besides a frequent cause of network disruption may be due to the transmission losses, which occur due to several natural phenomena. This makes routing an essential requirement in MANET. The current focus of many researchers is to find an efficient routing protocol, which will ensure node connectivity whenever required without much delay and unnecessary overhead. The primary goal of such an ad-hoc network routing protocol is to establish route efficiently. Route construction should be done with a minimum of overhead and bandwidth consumption. There are different types of routing topologies including DSDV, CGSR, WRP, AODV, and DSR, ABR etc [2, 4, 5, and 9]. Recent research has addressed many aspects of MANET operation and management, including routing, multicasting, media access protocols, distributed service discovery etc. In these areas an overarching concern is mobility. The impact of mobility is severe on several protocols, which work, well in traditional fixed (wired) networks. As a result, scalability is affected in networks with a large number of communicating pairs of nodes. 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 in order to maintain a good topology of the MANET. Wattenhofer *et al.* [4] 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] models the neighboring node distribution by nearest neighbor methods known from analysis of spatial data. They have developed an algorithm that increases network lifetime with guaranteed global connectivity. Several mobility models for wireless nodes are discussed in [8, 11, and 14]. Implementation of a MANET in real world is a challenging task, especially when the network topology is changing continuously. To maintain routing scalability in spite of mobility, a possible approach is to exploit motion affinity. Centralized topology management schemes in [2, 16, and 17] discuss a self-adaptive movement control algorithm; this gives an idea for topology management. In [18, 19] distributed connectivity maintenance schemes are discussed assuming that all the nodes are moving in the same direction. In this paper we are going to present one fuzzy based distributed algorithm for maintaining connectivity of nodes assuming unidirectional movement of the nodes. Here we shall assume pursue mobility model. For routing we can use any existing scheme but routing is possible if all the nodes remain connected during their movement. The fuzzy based distributed algorithm proposed by us ensures that all the nodes of the network will remain connected during movement to overcome the problem of loss of connectivity.

The rest of the paper is organized as follows. Section-2 presents the pursue mobility model. The formal definition of the problem statement along with some parameter definition is provided in section-3. The fuzzy based movement control algorithm is proposed in section 4. Simulation results are presented in Section 5 and section 6 concludes the paper. Lemma for selecting the beacon interval and the proof of the lemma is shown in the appendix.

2. PURSUE MOBILITY MODEL

For studying various parameters of MANET mobility models are necessary. Since not many MANETs have been deployed, most of this research work is simulation based. These simulations have several parameters including the mobility models [7, 8, 10, and 13] and the communication traffic patterns. MANET protocol performance may vary drastically for different mobility models [7, 8, and 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, Free Way mobility model, Nomadic Community mobility model, Pursue mobility model, Manhatten mobility model and Random Guass-Markov model [8, 11, and 14]. Out of these models we have selected the Pursue Mobility model discussed in [8, 15]. This model emulates scenarios where several nodes attempt to capture single mobile node which is ahead. This mobility model could be used in target tracking, law enforcement and convoy of VIP [10, 13, and 15]. Fig. 1. shows an illustration of six mobile nodes (MNs) moving with the Pursue Mobility model which is used for our algorithm. The solid black node represents the node being pursued i.e. target node and the white node represents the pursuer i.e. seeker nodes. The node being pursued moves freely according to the Random Walk Mobility Model i.e. entity mobility model. The pursuer nodes try to intercept the target node by moving toward the target node. The new position of each pursuer node is calculated by using a random velocity vector and acceleration.

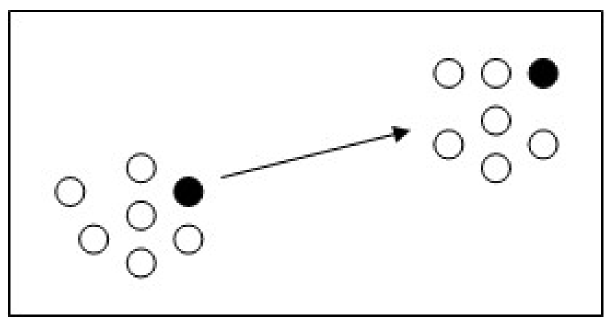

Figure 1: Showing Pursue Mobility Model with Target and Pursuer Nodes

3. PROBLEM FORMULATION & PARAMETER DEFINITIONS

3.1. Parameter Definitions

In MANET all the nodes are mobile, so the problem is to control the movements of the individual nodes so as to maintain a connected network at every instant of time to allow the nodes to communicate amongst them.

Initially all the nodes will have to maintain minimum distance from the front most node i.e. the target node. This distance is called safe distance (‘R_{SAFE}’) though maximum communication range is greater than safe distance and this maximum communication range is denoted as ‘R_{MAX}’ as shown in Fig. 2. Each and every node will broadcast their velocity and position

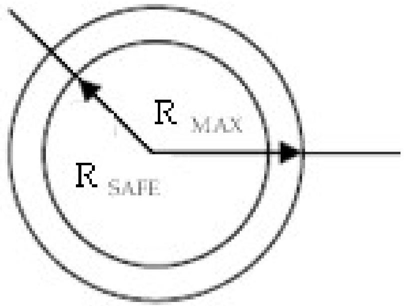

Figure 2: Illustrating Maximum Communication Range, 'R_{MAX}' and Safe Distance, 'R_{SAFE}'

information after a period of time interval. This interval is termed as beacon interval, which is denoted as 'T'. Beacon interval is chosen $(R_{MAX} - R_{SAFE}) / 2 V_{MAX}$ where V_{MAX} is the predefined maximum velocity of the nodes. The proof for choosing beacon interval is shown in lemma in the appendix. The front most node in the pursue mobility model is termed as 'target node' and all other nodes behind the front most nodes are called pursuer nodes as shown in the Fig. 1.

3.2. Formal Definition of the Problem

Notations used:

N	:	Number of Nodes
n_i	:	Node having index i (i-th node)
n_f	:	Front most node / target node
R_{MAX}	:	Maximum range of transmission for the nodes
D(i,f)	:	Relative distance between the two nodes n_i and front most node n_f

Let us consider a MANET consisting of N number of mobile nodes $n_0, n_1, n_2 \ldots n_{N-1}$. Let us also assume that each node of the network has a maximum transmission range of R_{MAX}. Now, any two nodes n_i and n_j can communicate amongst themselves without the help of any routing if all the nodes remain connected with the front most node during their movement. So, the two nodes will be connected if and only if

$$D(i, f) \le R_{MAX} \text{ for } \forall\, i, j = 0, 1, 2, 3\ldots\ldots\ldots N-1. \quad (1)$$

4. PROPOSED ALGORITHM

4.1. System Modeling

The MANET network is modeled as shown in the Fig. 1 with some assumption as follows:

(1) All nodes are enabled with GPS receivers. These receivers can furnish the current position and velocity information of an individual node.

(2) All the nodes have a predefined maximum velocity, V_{MAX}.

(3) Initially all pursuer nodes are placed behind the target node but within the safe distance (R_{SAFE}) from the target node.

(4) Each node has a unique identification number.

4.2. Fuzzification

The input variables are distance and velocity. Crisp input values are changed to fuzzy variable small, medium and large. The membership functions are considered to be triangular shaped as shown in the Fig. 3 and Fig. 4.These functions are used to fuzzify the input variables.

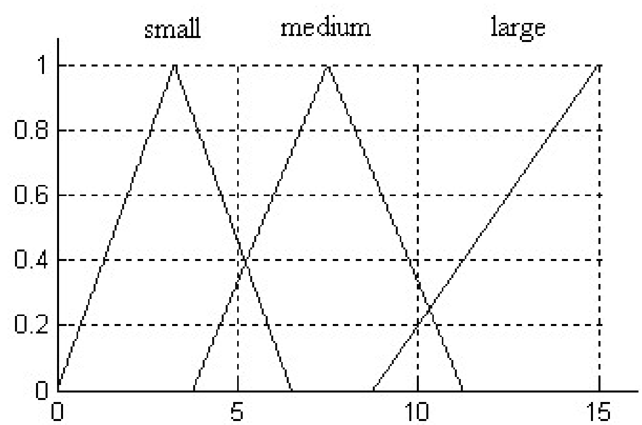

Figure 3: Membership Function for Fuzzyfication of 'Distance'

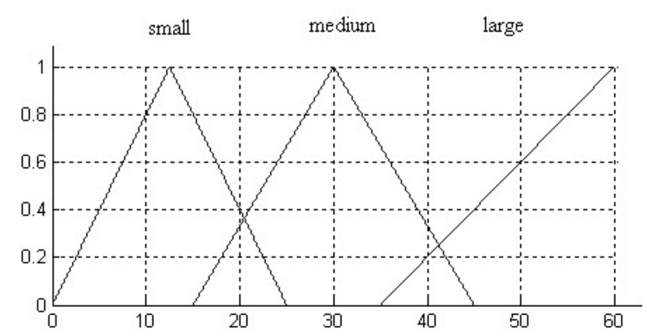

Figure 4: Membership Function for Fuzzyfication of 'Velocity'

4.3. Fuzzy Rule Base

The following fuzzy rule base is used for our algorithm:

Rule 1: If 'distance' is 'small' and the velocity is 'small' then velocity in the next beacon interval is 'small'.

Rule 2: If 'distance' is 'small' and the velocity is 'medium' then velocity in the next beacon interval is 'small'.

Rule 3: If 'distance' is 'small' and the velocity is 'large' then velocity in the next beacon interval is 'medium'.

Rule 4: If 'distance' is 'medium' and the velocity is 'small' then velocity in the next beacon interval is 'medium'.

Rule 5: If 'distance' is 'medium' and the velocity is 'medium' then velocity in the next beacon interval is 'medium'.

Rule 6: If 'distance' is 'medium' and the velocity is 'large' then velocity in the next beacon interval is 'large'.

Rule 7: If 'distance' is 'large' and the velocity is 'small' then velocity in the next beacon interval is 'large'.

Rule 8: If 'large' is 'medium' and the velocity is 'medium' then velocity in the next beacon interval is 'large'.

Rule 9: If 'distance' is 'large' and the velocity is 'large' then velocity in the next beacon interval is 'large'.

In the fuzzy rule base minimum membership function is considered. If more than one rule fire then maximum membership of minimum membership function is considered i.e the max min operation is performed.

4.4. Defuzzification

For defuzzification we don't use any conventional defuzzification method. We have defined the defuzzification as follows: if output fuzzy variable is large then actual final velocity will be calculated using speed= (V_{MAX} + membership function x 50) otherwise it will take random velocity within the range of maximum velocity maximum velocity V_{MAX}.

4.5. Algorithm

Our proposed algorithm is formally given as follows:

Begin:

Step1: Initialize the network with finite number of nodes (N)

Step2: Information obtained through GPS is transmitted by target node

For i=1 to N-1

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Step 3: Information from the target node is received by node-i

Step 4: Crisp value of distance and velocity are calculated and function for fuzzification is called to obtain fuzzy variable

Step 5: Fuzzy rule base is called with fuzzy distance and velocity

Step 6: Defuzification method is called to obtain crisp velocity of the node.

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Step 7: Allow all nodes to move for one beacon interval

Step 8: Go to step 2

End

5. SIMULATION RESULTS

We simulated the algorithm assuming a hypothetical network using MATLAB in Windows environment and obtained encouraging results. For our simulation we considered the system parameters as, maximum communication range 'R_{MAX}' = 15km, maximum allowable preferred velocity 'V_{MAX}' = 60km / hr, safe distance 'R_{SAFE}'=10km. So, the beacon interval is (15-10) / 2 x 60 hr. i.e. 2.5 minutes. Simulation is carried out for three different sample network scenarios. For each sample network we simulated our algorithm with different number of nodes. Simulation is carried out for different simulation time ranging for 1 hour to 20 hour. But for the simplicity and clarity of graphical representation, simulation result with five nodes for five hour is shown graphically.

5.1. Simulation for Sample-I

The network is of five nodes and their initial coordinates are (1,-1), (3,0), (5,4), (-4,2) and (6,-2) respectively in kilometers.

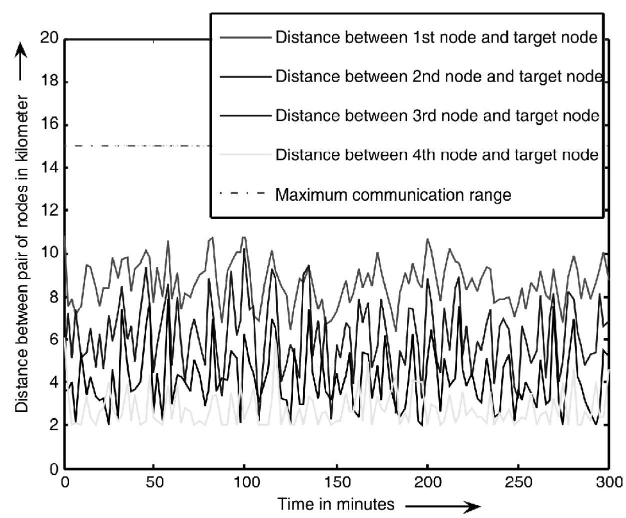

Figure 5: Distances from the Target Node for Sample-I

5.2. Simulation for Sample-II

The network is of five nodes and their initial coordinates are (0,1), (2,1), (2,2), (0,0) and (3,3) respectively in kilometers.

5.3. Simulation for Sample-III

The network is of five nodes and their initial coordinates are (0,0), (5,-2), (7,-1), (-1,3) and (9,0) respectively in kilometers.

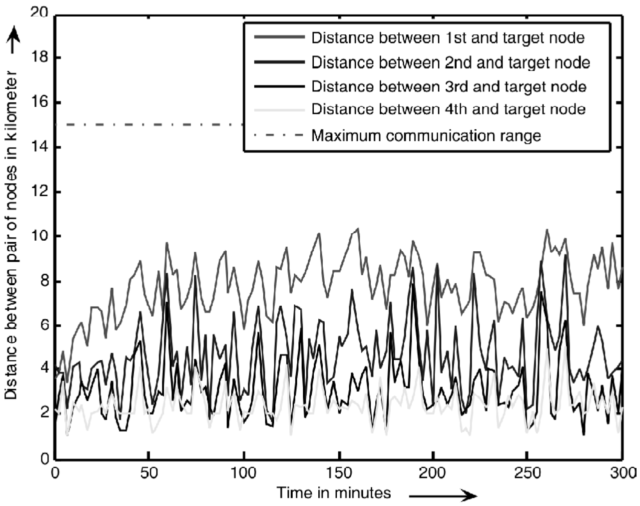

Figure 6: Distances from the Target Node for Sample-II

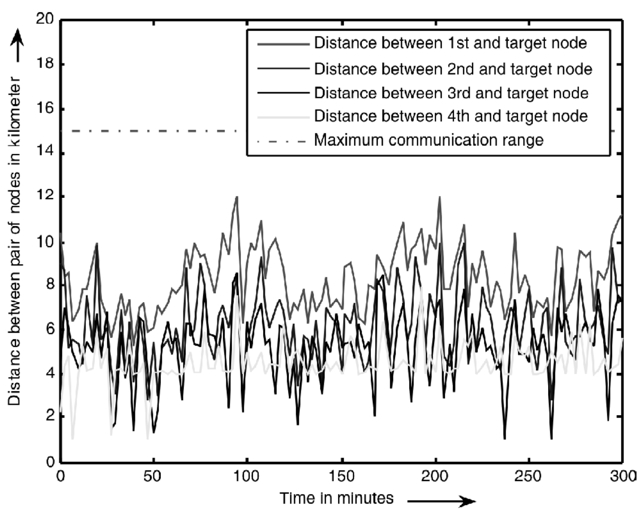

Figure 7: Distances from the Target Node for Sample-III

6. CONCLUSION AND FUTURE WORK

In this paper, we have introduced a fuzzy based distributive algorithm for mobile nodes in MANETs for maintaining connectivity considering pursue mobility model. Due to the distributed scheme the topology is not vulnerable if one of the nodes becomes non-functional, as there is no concept of coordinator. MANET nodes are becoming more intelligent as we have introduced fuzzy based movement control scheme. This algorithm maintains connectivity without any control message, which is essential in the case of centralized approach. Results from simulation study are encouraging. In future we shall try to develop fuzzy based connectivity algorithm adaptable for other mobility model also. Now we are going for hardware implementation of our proposed algorithm to verify performance of our algorithm in real environment.

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APPENDIX

Lemma: If maximum communication range is 'R_{MAX}' and safe distance is 'R_{SAFE}', where $R_{MAX} > R_{SAFE}$, maximum preferred velocity 'V_{MAX}', now if we choose beacon interval $T \leq (R_{MAX} - R_{SAFE}) / 2 V_{MAX}$, then there is no chance for the nodes to go out of the communication range.

Proof: Maximum preferred velocity of a node is V_{MAX}. So the maximum possible relative velocity between two nodes is 2 V_{MAX}, when they are in opposite direction. So the maximum relative distance traveled in a beacon interval is $2T V_{MAX}$. Since initially maximum separation between two nodes may be 'R_{SAFE}', so a neighbor node cannot become non-connected node if $2T V_{MAX} \leq (R_{MAX} - R_{SAFE})$ Or, $T \leq (R_{MAX} - R_{SAFE}) / 2 V_{MAX}$ ....(2)