A Centralized Algorithm for Topology Management in Mobile Ad-Hoc Networks through Multiple Coordinators

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Abstract. The topology of a MANET is maintained enduring transmission failures by suitably selecting multiple coordinators among the nodes constituting the MANET. The basic philosophy behind the algorithm is to isolate four coordinators based on positional data. Once elected, they are entrusted with the responsibility to emit signals of different frequencies while the other nodes individually decide the logic they need to follow in order to maintain the topology, thereby eliminating the need for routing. The algorithm is going to be formulated in such a way, that the entire network is going to move in one direction while each node can move freely. As far as our knowledge goes, we are the first ones to conceive the concept of multiple coordinators. The simulation results prove the efficacy of the scheme in topology maintenance.

1 Introduction

Ad-hoc networks are an emerging domain in wireless communications for mobile hosts (nodes) where there is no fixed infrastructure such as base stations or mobile switching centers.[1,2] Mobile nodes that are within each other's radio range communicate directly via wireless links, while those that are far apart rely on other nodes to relay messages as routers. Node mobility in an ad hoc network causes frequent changes of the network topology. Thus routing is necessary to find the path between source and destination and to forward the packets appropriately [3].Mobile ad-hoc networks are extensively used to retain connectivity of nodes in inhospitable terrains, disaster relief etc. where preconceived infrastructure is absent and sudden data acquisition is necessary [3-5].

Random node movement makes routing an essential requirement for MANET. Due to frequent node movement it may so happen that when the source node wants to transmit packets, the destination node may be out of range of the source node. Further, transmission losses occurring due to different natural phenomena may be another cause of frequent network disruption. Hence, the current focus of many researchers is to find out an efficient topology management algorithm, which ensures node connectivity without much delay and unnecessary overhead.

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The two widely accepted approaches for topology management are centralized and distributed algorithms [5]. However in the centralized algorithms considered so far, there being only one coordinator, the workload on the coordinator is immense. Moreover as far as our knowledge goes, all of them assume multiple transmission ranges, which is not possible in many practical situations. The distributed approaches on the other hand suffer form the drawback that it is very difficult to maintain complete connectivity among the nodes.

The paper is organized as follows: in the following section we formally state the topology management problem. Section three contains the primary assumptions. The next section is the coordinator election procedure. Section five deals with the movement algorithm. We finally conclude with simulation results and a comparative study with previous algorithms in section seven.

2 Topology Management Problem

Given a physical topology of a mobile ad-hoc network the problem is to control the movements of the individual nodes so as to maintain a stable neighborhood topology. In a system of n nodes (n_0, $n_1 \ldots n_{n-1}$) constituting a MANET, two nodes n_i and n_j are said to be neighboring if and only if they can communicate without the need of routing. Now if we assume that the transmission range of each node be R_{max} and D_{ij} denotes the relative distance between the nodes then the network neighborhood topology will be maintained provided ∃ at least one j such that

$$D_{ij} \leq R_{max} \; \forall \; i,j=0,1,2\ldots n-1$$

3 Primary Assumptions

1. The network moves in only one direction, here the x-direction while the nodes can move in any direction they please.2. Initially all the nodes can communicate with one another.3. Each node knows its initial position through a GPS set.

4 Coordinator Election Algorithm

Among the set of all x-coordinates $\{x_1, x_2\ldots, x_i\ldots, x_n\}$ and the set of all y-coordinates $\{y_1, y_2, \ldots, y_i, \ldots ,y_n\}$ received by a node, the minimum and maximum x-coordinate and the minimum and maximum y-coordinate are selected, denoted by x_{min}, x_{max}, y_{min}, y_{max} respectively. Now let p_{min} and p_{max} respectively denote

$$p_{min} = \min\{x_{min},y_{min}\},\ p_{max} = \max\{x_{max},y_{max}\} \quad (1)$$

Let '4a' denote the distance between (p_{max},p_{max}) and (p_{min},p_{min}).

$$4a = \sqrt{2} * (p_{max} - p_{min}) \quad (2)$$

Considering a square with coordinates P (p_{max}, p_{max}), Q (p_{max}, p_{min}), R (p_{min}, p_{min}), S (p_{min}, p_{max}), the diagonals PR and QS are divided into four equal parts as shown in Figure 1 and the points of division are obtained as D,O,B and A,O,C with

A= $((p_{max}+3p_{min})/4, (3p_{max}+p_{min})/4)$, B= $((p_{max}+3p_{min})/4, (p_{max}+3p_{min})/4)$
C= $((3p_{max}+p_{min})/4, (p_{max}+3p_{min})/4)$ D= $((3p_{max}+p_{min})/4, (3p_{max}+p_{min})/4)$

Now, following the initial coordinator movement procedure stated in section 4.1, 4 nodes occupy positions A, B, C, D and declare themselves as coordinators C_1, C_2, C_3 and C_4 respectively and emit messages in this regard. The coordinators now emit signals continuously of frequencies f_1, f_2 ,f_3 and f_4 respectively and of range $R_{max}=a=(p_{max}-p_{min})/(2\sqrt{2})$. Thus all nodes initially lie within the square PQRS as is evident from Figure1.

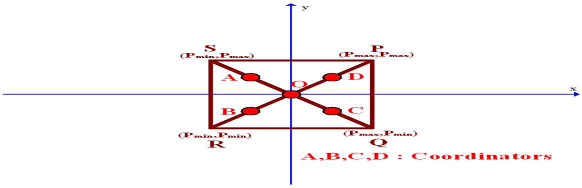

Fig. 1. Election of Coordinator

4.1 Initial Coordinator Movement Procedure

At first each node calculates its distance from A, B, C and D and sends it to all the other (n-1) nodes in the network. A node now checks if its distance from A is less than the other (n-1) nodes. If the answer is positive then it moves to the point A by moving along the x direction for a time T_x and then along the y direction for a time T_y with $T_x = |x_i - x_A| / V_{imaxx}$ and $T_y = |y_i - y_A| / V_{imaxy}$. Thus the total time required for the node to move to A is $T_A = T_x + T_y$. However if the answer obtained is negative a similar procedure is repeated for points B, C and D.

5 Movement Algorithm

The nodes now forward their maximum velocities along the x-direction V_{imaxx} to the coordinators. Let $V_x=\min \{V_{imaxx}\}$. The coordinators now decide to move with a velocity $V_c < V_x$ and inform it to all other nodes.

Since all the nodes are initially in the region PQRS as referred to Figure 1, it receives either of f_1, f_2, f_3 or f_4. During movement only when it does not receive any frequency, it realizes it has moved just out of range. Since the algorithm is instantaneous the instant a node fails to receive f_1, f_2, f_3 or f_4, it is at the edge of the circles with C_1, C_2, C_3 or C_4 as centers.

5.1 Failure of a Node to Receive f_1 or f_2

As soon as a node fails to receive f_1 or f_2, it realizes that it has moved out through arcs 12 or 23 as in Figure 2. It then decides to shoot to regain a stable position in the topology.

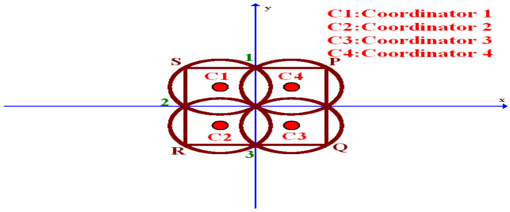

Fig. 2. Movement of nodes on failing to receive f_1 or f_2

Since a node is provided with a GPS set it knows its position (x_i,y_i) at that instant. Let us consider that a node was receiving f_1 or both f_1 and f_2 before it moved out of range. Since y_{c1} of coordinator C_1 is fixed it calculates x_{c1} from the relation

$$|x_{c1} - x_i| = \sqrt{R_{\max}{}^2 - (y_i - y_{c1})^2}\ .$$

The node now decides its movement algorithm depending on its y-coordinate.

If $|y_i - y_{c1}| \le R_{\max}/\sqrt{2}$ then it is on the arc 1′ 2 as shown in Figure 3. It then shoots along the direction of movement with a velocity V_{imaxx} for a time $t_{shoot} = |x_{c1} - x_i|/(V_{imaxx} - V_c)$.

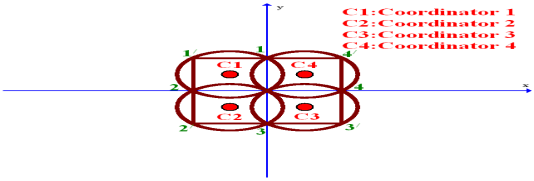

Fig. 3. Movement of nodes on failing to receive f_1 or f_2 depending on y –coordinates

However, if for a node $|y_i - y_{c1}| > R_{\max}/\sqrt{2}$ it lies on the arc 1′ 1 as depicted in figure 3. It then moves forward with a velocity $V = V_c\hat{i} - V_{imaxy}\hat{j}$ for a time $t_1 = (R_{\max} - (R_{\max}/\sqrt{2}))/V_{imaxy}$ .After moving for t_1, it shoots forward for a time t_{shoot1} with V_{imaxx} as stated earlier. The movement algorithm is similar if a node fails to receive f_2.

Lemma 1. The maximum value for t_{shoot} for a particular node is $R_{\max}/(V_{imaxx} - V_c)$.

5.2 Failure of a Node to Receive f_3 Or f_4

As soon as a node fails to receive f_3 or f_4, it realizes that it has moved out through arcs 14 or 43 as in Figure 3. It then decides to stop to regain a stable position in the topology. Let us consider that a node was receiving f_3 or both f_3 and f_4 before it moved out of range. Since y_{c3} of coordinator C_3 is fixed it calculates x_{c3} from the relation

$$|x_{c3} - x_i| = \sqrt{R_{\max}{}^2 - (y_i - y_{c3})^2}\ .$$

If $| y_i - y_{c3} | \le R_{\max} / \sqrt{2}$ it stops for a time $t_{stop}=|x_{c3}-x_i|/V_c$. If however $| y_i - y_{c3} | > R_{\max} / \sqrt{2}$ it initially moves with a velocity $V=V_c\hat{i}-V_{imaxy}\hat{j}$ for a time t_1 as calculated in section 5.1 and then it stops for a time t_{stop}. The movement procedure is identical if a node fails to receive f_4.

Lemma 2. The maximum value of t_{stop} for all nodes is R_{max}/V_c.

5.3 Transmission Losses

The movement algorithm ensures that even if there is a loss of a single frequency for an extended time period none of the nodes diverge out.

Suppose that a node, which was previously receiving f_1 or f_2 suddenly fails to receive any frequency. Following the movement algorithm stated in section 5.1 it checks for its y-coordinate. If $| y_i - y_{cj} | \le R_{\max} / \sqrt{2}$ where j=1 or 2 depending on f_1 or f_2, this node is in the shaded region 1 as shown in the Figure 4. The node now shoots in the positive x-direction for a time t_{shoot}. The maximum shooting period is $R_{max}/(V_{imaxx}-V_c)$ vide Lemma 1. Thus the maximum distance that the node covers relative to the coordinators during this period is R_{max}. Hence even if the node initially was in the unstable positions X or Y as shown in Figure 4 or at any other position at the rim of the circles with centers C_1 or C_2, at the end of shooting it is either going to receive f_3 or f_4. Thus even after t_{shoot} if a node does not receive any frequency it realizes transmission loss and moves with a velocity V_c in the positive x-direction until it receives a frequency again. Again if $| y_i - y_{cj} | > R_{\max} / \sqrt{2}$ where j=1 or 2 then the node is in the shaded region 1′ as shown in figure. If it suddenly fails to receive any frequency then it moves with a velocity $V = V_c\hat{i}-V_{imaxy}\hat{j}$ or $V=V_c\hat{i} + V_{imaxy}\hat{j}$ for a time t_1 according as whether it received f_1 or f_2 previously vide section 5.1. This brings it back within the square PQRS. Now it shoots forward in the positive x-direction for a time t_{shoot} whence by previous arguments we conclude that after a time t_1+t_{shoot} the node must receive a frequency. If it does not, it realizes transmission loss and moves with velocity V_c until it receives a frequency again.

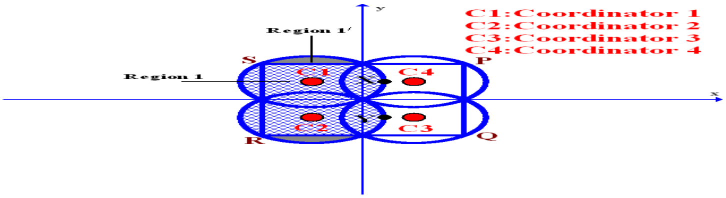

Fig. 4. Transmission Loss of f_1 or f_2: Region Division

A similar argument can be put forth for nodes which previously received f_3 or f_4. In this case the nodes converge after a period a period t_1+t_{stop}.

6 Simulation Results

Extensive simulations in several synthetically designed situations establish that none of the nodes ever diverge out from the topology. A sample illustration is provided in Figure 5.

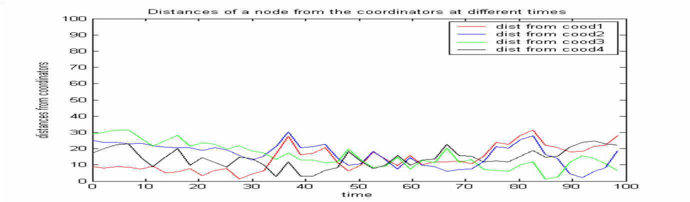

Fig. 5. Distance of a node from the coordinators at various times. Initial position of node (-7,17). V_{imaxx}=11 units. V_{imaxy}=10 units. Coordinator positions (-8,8), (-8,-8), (8,-8) and (8,8). R_{max} = 11.5 units. V_c = 5 units.

7 Conclusion

As proposed earlier, we have been able to develop a novel algorithm in which the nodes of the network always maintain the topology. In addition as compared to single coordinator systems proposed in [3-5] multidirectional node movement becomes feasible. Moreover, the system never becomes static as a whole and hence no time is wasted in maintaining the network topology thereby ensuring greater efficiency. Apart from this no node ever diverges out of communication range. Elongated transmission time loss periods can also be endured. Number of messages transmitted and received being reduced the workload on the coordinator is decreased. Apart from these advantages the requirement of three communication ranges is also eliminated.

References

1. National Institute of Standards and Technology, Mobile Ad Hoc Networks (MANETs), http://w3.antd.nist.gov/wahn_mahn.shtml
2. IEEE 802.11. “Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specification”, Standard, IEEE, New York (November 1997)
3. Gupta, S.S., Ray, S.S., Samanta, S., Naskar, M.K.: An Efficient Topology Management Algorithm for Mobile Ad-Hoc Networks. In: EPMDS 2006. International Conference on Electronic and Photonic Materials, Devices and Systems - 2006 (2006)
4. Gupta, S.S., Ray, S.S., Samanta, S., Naskar, M.K.: A Stochastic Algorithm for Managing Network Configuration of a Mobile Ad-Hoc Network. In: AMOC 2007. 5th Asian International Conference on Mobile Computing - 2007 (2007)
5. Basu, S.S, Choudhury, A.: Self adaptive topology management for mobile ad-hoc networks. IE(I) Journal-ET 84 (July 2003)