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A Reliable Routing Algorithm in MANET Using Fuzzy Logic

B. Vamsee Mohan* — *PBR VITS*, India
V. V. Sunil Kumar — *PBR VITS*, India
J. Vamsi Nath — *PBR VITS*, India

Abstract— In mobile ad hoc networks, each node acts as both host and router and performs all the routing and state maintenance. Due to the unpredictable movement of mobile nodes, the network topology of a mobile ad hoc network changes frequently. It will directly cause the routes to be broken and greatly degrade the network performance. In this paper, we propose a novel Reliable Routing Algorithm (RRA) in mobile ad hoc networks using fuzzy Petri net and its reasoning mechanism. The algorithm allows structured representation of network topology, which has a fuzzy reasoning mechanism for finding the sprouting tree from source node to destination node. Finally, by comparing the degree of reliability the most reliable route can be computed. This algorithm can be applied to most existing routing protocols, and the simulation shows that the percentage of improvement of routing reliability is more than 80% when applying our algorithm to the AODV routing protocol.

Keywords— Mobile Ad-hoc Networks, Fuzzy Logic, AODV protocol, Route Discovery, Route maintenance.

I. INTRODUCTION

Mobile ad hoc networks (MANET) [1] have been receiving a lot of attention during the past few years due to the rapid expansion of mobile devices and the interest in mobile communication. A mobile ad hoc network is a special case of mobile network without any fixed links to support each node and provide connectivity to communicate with each other. Each node acts as both host and router at a time and performs all the routing and state maintenance operations. The network topology of a mobile ad hoc network changes frequently and unpredictably due to the arbitrary movements of mobile nodes. Furthermore, because the bandwidth of the wireless medium is less than that of the wired media, routing in mobile ad hoc networks is a challenging research problem. In recent years several routing algorithms [2] have been proposed, but most of these works only focus on routing hops or routing cost instead of providing reliable routes when selecting routes.

These algorithms will increase the probability of using potential unreliable routes. The direct consequence of using unreliable route is that routes will be broken frequently. In order to rebuild routes after routes broken, existing routing algorithms usually deposit the outgoing packets in the buffer, and packets will be dropped if buffer overflowed. Hence, frequent routes breaking will badly affect the utilization and throughput of ad hoc networks. For the reason that existing routing algorithms do not provide reliability, we propose a reliable routing algorithm to tackle the routing reliability problem. In this paper we propose a novel Reliable Routing Algorithm (RRA) in mobile ad hoc networks using fuzzy Petri net and its reasoning mechanism. Firstly we define certainty factor (cf) between each neighboring mobile node that is obtained by computing the relative velocity and the relative motion distance, then we utilize the reasoning mechanism of fuzzy Petri net to find a route with the highest reliability. The simulation result shows that our algorithm greatly decreases the number of routes broken and packets delivery delay.

The rest of the paper is organized as follows. Section 2 is the representation of an ad hoc network using fuzzy Petri net. In section 3, we use fuzzy reasoning mechanism of Petri net to find the most reliable route. In section 4, we do some simulations and present a comparative performance of AODV [2] with RRA and AODV without RRA. Section 5 concludes the paper.

II. REPRESENTATION OF AN AD HOC NETWORK USING FUZZY

A. Network topology

In some mobile ad hoc networks, all nodes are equipped with Global Position System [11] (GPS). Today's GPS receivers are extremely accurate, according to their parallel multi-channel design. The mobile nodes with GPS receiver can get the measures (latitude, longitude and altitude) from GPS unit. Since nodes in an ad hoc network have no fixed infrastructure available, each node floods its GPS measures to all nodes in an ad hoc network. Based on the measures each node can update its local network topology. However, not all the ad hoc networks are equipped with GPS. In this case, each node could update its local network topology by exchanging routing table in some routing protocols such as DSDV [3] (Highly Dynamic DSDV Routing). Actually, in our algorithm, we don't need to compute the ad hoc network topology and we only need the information of neighboring nodes for each node. In order to clearly describe the fuzzy

Petri net model and our algorithms, we still draw the network topology below. Fig. 1 shows the network topology computed by node 1 at the time when it needs to communicate with node 11.

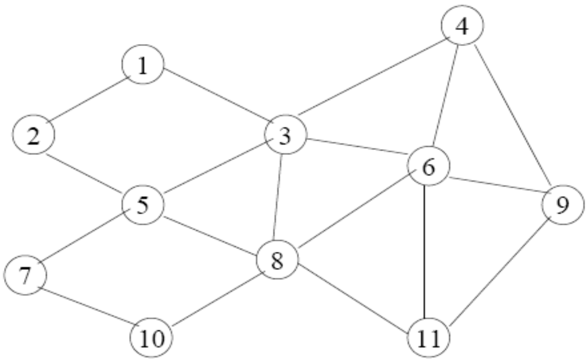

Figure 1. The network topology computed by node 1.

B. Fuzzy Net model

Petri net is a modeling tool used for modeling discrete, dynamic, parallel, asynchronous system. For the simple graphical description function and the strong function interpretation ability, Petri net is widely used for system modeling and performance analysis in recent years. It allows structured representation of knowledge, and has a systematic process to support an antecedent-consequence relationship from a proposition to a proposition.

In our paper, we use fuzzy Petri net that is a branch of Petri net and the reasoning algorithm to model and analyze routing algorithm in ad hoc network. The fuzzy reasoning algorithm is based on the certainty factors approach. It can determine whether there exists a neighboring relationship from mobile node $d\,s$ to mobile node $d\,j$, where $d\,s \neq d\,j$. Furthermore, if the degree of reliability of mobile node ds is given, then the degree of reliability of mobile node $d\,j$ can be evaluated as well.

A fuzzy Petri net is a bipartite directed graph, which contains two types of nodes: places and transitions, where circles represent places and bars represent transitions. Each place may or may not contain a token associated with a truth value between zero and one. Each transition is associated with a certainty factor value between zero and one. Directed arcs represent the relationships from places to transitions and from transitions to places.

In the ad hoc networks environment, we define fuzzy Petri net as a 9-tuple:

$FPN = (P, T, D, A, M_o, C_f, \alpha, \beta, \theta)$,

Where

$P = \{p_1, p_2, ..., p_n\}$ is a finite set of places,

$T = \{t_1, t_2, ..., t_m\}$ is a finite set of transitions,

$D = \{d1, d2, ..., dn\}$ is a finite set of mobile nodes, $P \cap T \cap D = \phi$, $|P| = |D|$,

$A \subseteq (PXT) \cup (TXP)$ is a finite set of directed arcs,

$M_0 : P \rightarrow [0,1]$ is the initial fuzzy marks of places between zero and one,

$C_f : T \rightarrow [0, 1]$ is an association function, a mapping from transitions to real values (certainty factor) between zero and one,

$\alpha : P \rightarrow [0,1]$ is an association function, a mapping from places to real values (degree of reliability) between zero and one,

$\beta : P \rightarrow D$ is an association function, a bijective mapping from places to mobile nodes,

$\theta \rightarrow [0,1]$ is an association function, a mapping from transitions to threshold value between zero and one.

Having the above definition, in order to simplify the fuzzy Petri net for our model, we make the following assumptions. We choose one-way direction from the source node to destination node. Hence, in Fig. 2 we model a marked fuzzy Petri net for the network topology of Fig. 1.

In Fig. 2, let θ_{36} be a threshold value of transition t_{36} between mobile node $d3$ and mobile node d_6. If the degree of reliability of mobile node $d3$ is $\alpha(d3)$, $\alpha(d3) \in [0,1]$, then

Case 1: if $\alpha(d3) \geq \theta 36$, then transition $t36$ can be fired. It indicates that the degree of reliability of the mobile node $d6$ is $\alpha(d3)$X $Cf36$

Case 2: if $\alpha(d3) < \theta 36$, then transition t_{36} cannot be fired.

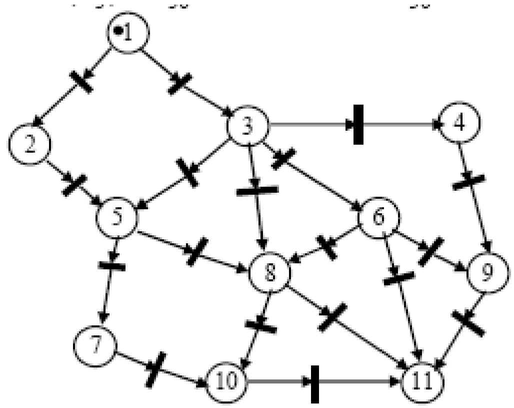

Figure 2. A marked fuzzy net of Fig. 1

C. Certainty factor and threshold value of transitions

In the real-world situations, mobile ad hoc network nodes move quickly in an invariant or variant velocity, which makes the link between nodes unstable. Each node has no idea when the neighboring nodes will move out of the communication range. It will directly cause the routes between each node broken and brings serious consequences. So we defined certainty factor and threshold value for every transition in the fuzzy Petri net model.

According to the propagation regulations of wireless signal, the mobile receiver's power is in inverse proportion with the distance between sender and receiver, so we use distance between each node to approximately evaluate the communication signal strength. Let Γ □ denotes the communication range of each node in an ad hoc network.

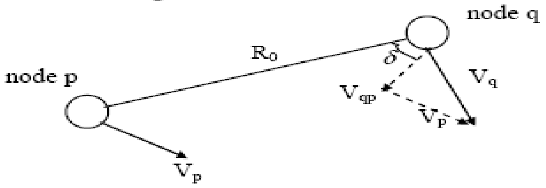

Figure 3. Relative motion between node p and q

Fig. 3 shows a case that two mobile nodes are moving respectively in different speed and different direction. Let $\overline{V_p}$ and $\overline{V_q}$ denote the velocity of node p and node q respectively, $\overline{V_{qp}} = \overline{V_q} - \overline{V_p}$ is the relative speed between p and q, and let R0 denote the initial distance between node p and q. In order to simplify the analysis, we assume $\overline{V_p}$ and $\overline{V_q}$ are invariant in a small time slot Δ_t.

Assume after a slot Δ_t, the distance between p and q changes to Rt. According to the Fig. 3, Rt can be concluded.

$$R_t^2 = R_0^2 + (V_{qp}.\Delta t)^2 - 2R_0.V_{qp}.\Delta t.\cos\delta \quad (1)$$

R_0, can be derived from the route discovery packets between each neighboring node, and $\overline{V_{qp}}$ can be computed by $\overline{V_p}$ and $\overline{V_q}$.

We define the certainty factor of transition *t* as:

$$cf_t = 1 - \frac{R_0}{\Gamma} - \frac{\Delta R}{\Gamma}.\Delta R = R_t - R_0 \qquad (2)$$

So the general formulation of cf_t is

$$cf_t = 1 - \frac{R_0 + \Delta R}{\Gamma} = 1 - \frac{R_t}{\Gamma} \qquad (3)$$

and we define the threshold value of transition t as:

if $\Delta R \geq 0, \theta t = \frac{\Delta R}{\Gamma}$

if $\Delta R < 0, \theta t = 0.$

If $\Delta R < 0$, it means that the two neighboring nodes are moving closely within Δt, so we consider the link between the two nodes is a stable link within Δt and set up $\theta_t = 0$.

Certainty factor and threshold value indicate the stability and reliability of each neighboring node. The higher the certainty factor is, the more reliable the link between two nodes is. If the true of reliability $\alpha(p_i)$ of place p_i exceeds the corresponding threshold value θ_t, the transition will be fired. It means mobile node *pi* could pass the transition and reach mobile node p_j, $\alpha(p_j) = \alpha(p_i) \text{X } cf_t$. If $\alpha(p_i) < \theta_t$, p_i cannot pass this transition for the reason that this route is not stable or reliable for a short time, so the source node has to give up this route and try to find another stable route. In the following section, we will introduce the reasoning routing algorithm in ad hoc network using fuzzy net.

III. RELIABLE FUZZY ROUTING ALGORITHM

The fuzzy reasoning algorithm can be expressed by a sprouting tree [13]. Each node in the tree is denoted by a triple (p_k, $\alpha(p_k)$, $IRS(p_k)$) , where $p_k \in P$ and $IRS(p_k)$ is the immediate reachability set of p_k.

For example, Fig. 4 shows a simple mobile ad hoc network, each place represents a mobile node. This network topology is computed by p_1 at the time it needs to communicate with p_6. The initial mark of p1 is 1.00.

Assume each transition's *cf* has been computed using (1), (2) and (3) in Fig. 4. In order to simplify the model, we assume all the thresholds of transitions equal 0.1.

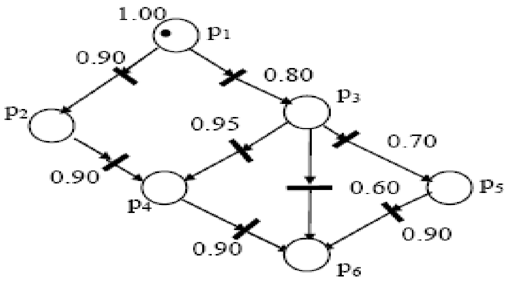

Figure 4. A marked fuzzy net

The immediate reachability set (IRS) and the reachability set (RS) for each place *pi* in Fig. 4 are shown in Table I.

Place Pi	IRS(Pi)	RS(Pi)
p1	{ p2,p3}	{ p2,p3,p4,p6}
p2	{p4}	{p4,p6}
p3	{p4, p5, p6}	{p4, p5, p6}
p4	{p6}	{p6}
p5	{p6}	{p6}
p6	φ	φ

TABLE I. IRS AND RS FOR EACH PLACE

By performing the algorithm [13] using IRS (pi), the tree sprouts as shown in Fig. 5.

At the time that mobile node p1 needs to communicate with p6, it will query its immediate reachability set IRS (p1)= {p2, p3}, and soon find p2, p3 are its neighboring nodes, then p1 will record the two routes in its buffer and create two nodes ($p2$, $\alpha(p2)$, $IRS(p2)$), ($p3$, $\alpha(p3)$, $IRS(p3)$) in the sprouting tree and two arcs are directed from the node ($p1$, $\alpha(p1)$, $IRS(p1)$) , then p2 and p3 will compute the value of reliability of the two routes, $\alpha(p2) = \alpha(p1) \text{X} cf_{12}$, $\alpha(p3) = \alpha(p1) \text{X} cf_{13}$, where $\alpha(p1) = 1.00$, $cf_{12} = 0.90$, $cf_{13} = 0.80$. Apparently, $cf_{12} > \theta$.$cf13 > \theta$ when $\theta = 0.1$, so these two transitions fired. Then p2 and p3 continue to find routes using IRS (pi), and finally four available routes can be obtained from mobile nodes p1 to p6. Because of max (0.73, 0.68, 0.48, 0.50) = 0.73, and larger certainty factor means higher reliability of the routes, p1 should choose the route {p1 →p2→p4→p6} to communicate with p6, it will ensure the high reliability and low packet delivery delay when communicating.

For the simplicity of our reliable routing algorithm, RRA can be applied to most existing routing protocols with great improvement of routing reliability and little increase of overhead. The simulation in the following section gives a good validation.

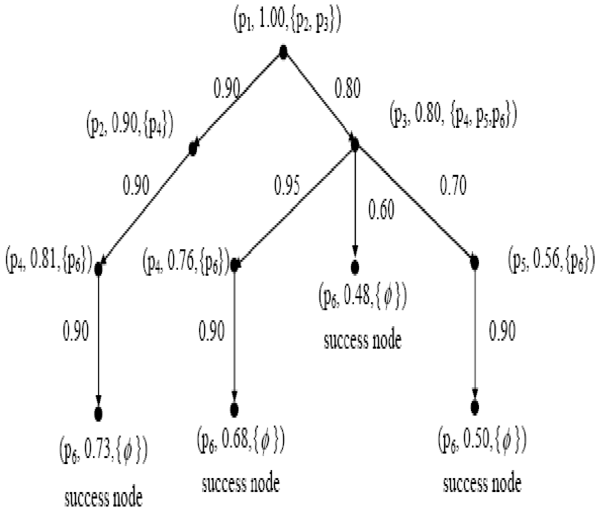

Figure 5. Sprouting tree of Fig. 4

IV. SIMULATION AND COMPARISON

We applied our RRA algorithm to the AODV protocol [2], and assume that wireless mobile nodes are scattered randomly in a 1500*m*□ 800*m* area. Each node moves with a randomly assigned velocity and direction, and the maximum velocity is 20m/s. According to the propagation regulations of wireless signal, the communication range of each node is set to 200m, and we assume Δt □ □ 0.8 . The simulation time is assumed as 900s.

V. CONCLUSIONS AND FUTURE WORK

In this paper, we proposed a reliable routing algorithm in mobile ad hoc networks using fuzzy Petri net. This algorithm can be applied to most existing routing protocols, and it can greatly improve the route reliability and stability. It makes the communication in ad hoc networks more efficient. Currently the proposed algorithm considers only one criterion, i.e., the reliability when selecting routes. In the future work, we plan to use more criterions to select routes, such as hops, routing time, cost, etc. According to these criteria, we will build an object function and several constrained conditions on demand of the requesting mobile node, then set up a linear programming model to reach an optimal solution so that our RRA algorithm can be easily applied to most routing algorithms in mobile ad hoc networks.

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