A reliable routing algorithm based on fuzzy Petri net in mobile ad hoc networks

HU Zhi-gang (~), MA Hao (~), WANG Guo-jun (~), LIAO Lin (~)
(School of Information Science and Engineering, Central South University, Changsha 410083, China)

Abstract: A novel reliable routing algorithm in mobile ad hoc networks using fuzzy Petri net with its reasoning mechanism was proposed to increase the reliability during the routing selection. The algorithm allows the structured representation of network topology, which has a fuzzy reasoning mechanism for finding the routing sprouting tree from the source node to the destination node in the mobile ad hoc environment. Finally, by comparing the degree of reliability in the routing sprouting tree, the most reliable route can be computed. The algorithm not only offers the local reliability between each neighboring node, but also provides global reliability for the whole selected route. The algorithm can be applied to most existing on-demand routing protocols, and the simulation results show that the routing reliability is increased by more than 80% when applying the proposed algorithm to the ad hoc on demand distance vector routing protocol.

Key words: mobile ad hoc network; fuzzy Petri net; certainty factor; ad hoc on demand distance vector; routing algorithm

CLC number: TP393.04

1 INTRODUCTION

Mobile ad hoc networks (MANET) have been received a lot of attention during the past few years due to the rapid expansion of mobile devices and the gained popularity in mobile communication. A mobile ad hoc network is a special case of mobile networks, without any fixed links to support each node and to provide connectivity to communicate with each other. Each node acts as both host and router at a time and performs all the routings 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 and active researching area. In recent years, several routing algorithms have been proposed in MANET, but most of them only focus on routing hops instead of concentrating on providing reliable routes when selecting routes. In addition, the route with the minimal hops does not always mean the optimal routing path when considering other criterions. These algorithms will increase the probability of using potentially unreliable routes. The direct consequence of using unreliable route is that routes will be broken frequently, and it will require additional time to reconfigure the route from source to destination, which results in increased amounts of flooding control packets. In order to rebuild routes after routes are broken, from the existing routing algorithms, the common approach is to deposit the outgoing packets in the buffers, which will be dropped if buffers are overflowed. Hence, frequent routes breaking will badly affect the utilization and throughput of ad hoc networks. Recently, Kim et al. focused on this general issue, but they only considered the local reliability between each node when deciding routes.

In this paper, a novel reliable routing algorithm (RRA) was proposed in mobile ad hoc networks by using fuzzy Petri net and its reasoning mechanism. Firstly, certainty factor \((c_f)\) between each neighboring mobile node was defined, which was obtained by computing the relative velocity and the relative motion distance, then the reasoning mechanism of fuzzy Petri net was utilized to find a route with the highest reliability. The simulation results show that the algorithm can greatly decrease the number of routes broken and packets delivery delay.

2 REPRESENTATION OF AN AD HOC NETWORKS USING FUZZY PETRI NET

2.1 Network topology

In some mobile ad hoc networks, all mobile nodes are equipped with global position system...
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 adjoining 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 highly dynamic destination sequenced distance vector routing (DS-DV)\cite{3}. Actually, in the algorithm, GPS is used to derive the information velocity and coordinate, of neighboring nodes for each node. In order to clearly describe the fuzzy Petri net model and the algorithms, the network topology is drawn.

Fig. 1 shows the network topology computed by node 1 at the time when it needs to communicate with node 11.

![Network topology computed by node 1](image)

**Fig. 1** Network topology computed by node 1

### 2.2 Fuzzy Petri net model

Petri net is a modeling tool used for modeling discrete, dynamic, parallel and asynchronous system. For the simple graphical description function and the strong function interpretation ability, Petri net has been widely used for system modeling and performance analysis in recent years. It allows the structured representation of knowledge, and has a systematic process to support an antecedent-consequence relationship from one proposition to another proposition\cite{4}. Currently Petri net is widely used in computer networks. In Ref. [13], Petri net was used to model and analyze ad hoc network, and in Ref. [15], the colored Petri net was used to analyze unicast and multicast routing.

Fuzzy Petri net\cite{16}, which is a branch of Petri net, was used to model and analyze routing algorithm in ad hoc network with its reasoning algorithm in this paper. The fuzzy reasoning algorithm is based on the certainty factors approach. It can determine whether there exists a neighboring relationship from mobile node \(d_i\) to mobile node \(d_j\), where \(d_i \neq d_j\). Furthermore, if the degree of reliability of mobile node \(d_i\) is given, then the degree of reliability of mobile node \(d_j\) can be derived with fuzzy reasoning mechanism.

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, respectively. Each place may or may not contain a Token associated with a truth-value in \([0, 1]\); each transition is associated with a certainty factor value in \([0, 1]\). Directed arcs represent the relationships from places to transitions and from transitions to places.

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

\[
FPN=(P, T, D, A, M_0, \alpha, \beta, \theta)
\]

where \(P=\{p_1, p_2, \ldots, p_s\}\) denotes a finite set of places; \(T=\{t_1, t_2, \ldots, t_n\}\) denotes a finite set of transitions; \(D=\{d_1, d_2, \ldots, d_k\}\) denotes a finite set of mobile nodes; \(P\cap T\cap D=\emptyset, \mid P\mid=\mid D\mid; A=\bigcup(T\times P)\) denotes a finite set of directed arcs, \(M_0 : P \rightarrow [0, 1]\) denotes the initial fuzzy marks of places \(m \in [0, 1]\), \(\alpha : P \rightarrow [0, 1]\) denotes an association function, a mapping from transitions to real values (certainty factor) in \([0, 1]\); \(\beta : P \rightarrow [0, 1]\) denotes an association function, a mapping from places to real values (degree of reliability) in \([0, 1]\); \(\theta : T \rightarrow [0, 1]\) denotes an association function, a bijective mapping from places to mobile nodes; \(\theta \in [0, 1]\) denotes an association function, a mapping from transitions to threshold value in \([0, 1]\).

Based on the above definition, in order to simplify the fuzzy Petri net for the model, the following assumptions were proposed. One-way direction from the source node to destination node was chosen. Fig. 2 shows the model of a marked fuzzy Petri net for the network topology of Fig. 1.

In Fig. 2, let \(\theta_{d_6}\) be a threshold value of transition \(\alpha_{d_5}\) between mobile node \(d_5\) and mobile node \(d_6\).

![Marked fuzzy Petri net of Fig. 1](image)