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RESEARCH ARTICLE

A Novel Fuzzy Stochastic Routing Protocol For Mobile AdHoc Network

M.M.Goswami[1], V. Rughwani[2], Mr. A. Anjikar[3]

[1]Rajiv Gandhi College of Engineering & Research, Dept. of Information Technology, Nagpur, India
[2]Om College of Engineering, Wardha, India
[3]Rajiv Gandhi College of Engineering & Research, Nagpur, India
E-mail: mm_gos@yahoo.com

***Abstract*— Conventional routing algorithms for mobile ad hoc networks such as AODV or DSR consider only one metric, for example, hop count to select best path from source to destination. However due to special characteristics of MANET such as nodal mobility, unstable links and limited resources, conventional routing algorithm found to be unsuitable for routing multimedia traffic or real time applications which require optimization of more than one metric. The paths chosen by conventional routing algorithm deviate far from optimal paths. In the proposed algorithm called Fuzzy Stochastic Routing (FSR) multiple metrics such as hop count, battery power, signal strength are considered using fuzzy logic to give multiple optimal paths. Nodes then forward data stochastically on these multiple paths resulting into automatic load balancing and fault tolerance. Simulation results show the great improvements over the conventional routing algorithm (AODV) in terms of various parameters like packet delivery ratio, no of route discoveries, delay, etc.**

Keywords- Mobile Adhoc Networks; AODV; Fuzzy logic

I. Introduction

Mobile ad hoc network consists of a collection of wireless mobile nodes, which dynamically exchange data among themselves without the reliance on a fixed base station or carried backbone network [1]. Each mobile node acts as a terminal or router and the control of the network activity is distributed to these nodes. This kind of network is very flexible and suitable for applications such as temporary information sharing in conferences, military actions and disaster rescues. However mobile nodes have lower battery power and lower computation ability. Also, the network topology is generally dynamic because the connectivity among the nodes may change with time due to nodal mobility, the effect of radio communication and power limitations. These features of MANET have posed a lot of challenges in designing an effective, reliable and scalable routing protocol [2].

In order to facilitate communication within the network, a routing protocol is used to discover routes between nodes. The primary goal of such an ad hoc network routing protocol is to provide correct and efficient route establishment between pair of nodes so that messages may be delivered in time [3]. MANET routing protocols are mainly clubbed into two techniques, i.e. table-driven and on-demand routing. Table driven routing protocol requirements are periodic advertisement of the changes in the network and its global dissemination of connectivity because of which it is unsuitable for large - sized networks. Protocols based on table-driven technique are Destination Sequence Distance Vector (DSDV) routing [4], Cluster-head Gateway Switch Routing (CGSR) [5], and Wireless Routing Protocol (WRP) [6]. On-demand routing protocols are efficient for routing in large - sized ad hoc networks because they maintain the routes that are currently needed, initiating a path discovery process whenever a route is needed for the message transfer [7]. Popular protocols based on on-demand scheme are ad-hoc on demand Distance Vector (AODV) [8], Dynamic Source Routing (DSR) [9], Temporally Ordered Routing Algorithm (TORA) [10], Signal Stability based Adaptive (SSA) [11] routing and Associativity-Based Routing (ABR) [12].

However in these algorithms route is decided by choosing one or two selection parameters without considering the interplays of different selection parameters. As mentioned above the topology of MANET is determined by many factors such as battery capacity, traffic pattern, link stability and nodal mobility. All of these factors are correlated. Consideration of only one or two factors is not sufficient for choosing an optimal path. For example if the shortest path is decided by the number of intermediate hops and the algorithm is not power aware or mobility aware then the algorithm may select unstable routes or lead to shortening the lifetime of a node which can result in route failures in between active communication sessions due to expiration of batteries of intermediate nodes.

This paper extends the idea of using fuzzy logic in AODV to present a multi-objective multipath routing algorithm for MANETs to find the most preferred route by evaluating the alternatives against the multiple objectives and selecting the routes which best achieves the various objectives. The different routing metrics are taken into consideration using a fuzzy logic system to capture interplay of various metrics which return multiple optimal paths. Routes selection is then performed stochastically and data is forwarded over optimal routes resulting into distribution of traffic which alleviate congestion and fault tolerance. Thus, this probabilistic routing strategy leads to data spreading according to the estimated quality of paths. The rest of the paper begins with section II that describes the basics of AODV routing protocol since proposed routing protocol FSR is inspired from AODV. Design of fuzzy logic system is discussed in section III. Section IV presents proposed routing protocol. Then, in section V, simulation and results are given and section VI concludes the paper.

II. AODV PROTOCOL

Ad hoc on demand Distance Vector routing protocol uses a broadcast route discovery mechanism, and it relies on dynamically established routing table entries at intermediate nodes. The functions performed by AODV protocol include local connectivity management, route discovery, route table management and path maintenance. Local connectivity management happens as follows.

Nodes learn about their neighbors by either receiving or sending broadcast packets from or to their neighbors. Receiving the broadcast or HELLO from a new neighbor or failing to receive HELLO messages from a node that was previously in the neighborhood, indicates that the local connectivity has changed.

The source node initiates path discovery by broadcasting a RREQ route request packet to its neighbors. When a node receives RREQ, in case it has routing information, it sends the reply, RREP, packet back to the destination. Otherwise, it rebroadcasts RREQ packet further to its neighbors. As the

RREQ packet travels from the source to the destination it automatically sets up the reverse path from all nodes back to the source.

As the RREP travels back to the source, each node along the path sets up a forward pointer to the node from which the RREP came and updates its timeout information for route entries to the source and destination.

For each destination of interest a node maintains a single route table entry that contains the address of the destination, the next hop along the path to that destination, the number of hops to the destination, and other route related parameters. If a node is presented with two different routes to the destination it chooses the fresher route. If both routes were discovered simultaneously, the route with fewer hops is preferred.

Path maintenance is performed as follows: When any node lying along established path moves so that some of the nodes become unreachable, the special ERROR message is sent to affected source nodes. Upon receiving notification of a broken link, the source node restarts the path discovery process, if it still requires that route.

III. USE OF FUZZY LOGIC IN ROUTING

Fuzzy control is a control technique based on the principles of fuzzy set theory, and the control systems are designed to mimic human control better than classical control systems by incorporating expert knowledge and experience in the control process. This is achieved by using linguistic variables in the control system to enable the designer to include control rules that naturally follow human thought. A key feature of fuzzy logic is to handle uncertainties and non-linearities, existing in physical systems. Fuzzy systems are used to approximate functions. It is can be used to model any continuous function or system. The advantages of fuzzy logic are :-

- Conceptually easy to understand
- Flexible
- Tolerant of imprecise data
- Can model nonlinear functions of arbitrary complexity
- Can be built on top of the experience of experts
- Can be blended with conventional control techniques
- Based on natural language

The inputs to the fuzzy controller to be designed for routing are: (i) hop count,(ii) remaining battery power and (iii) signal stability. These three selection parameters reflect the network status and the node's ability to reliably deliver network packets. The steps involved in use of fuzzy logic for routing in MANET are elaborated as follows:

A. STEP I. Fuzzification of inputs and outputs

The three input variables to be fuzzified are the energy consumption rate (B), the hop count (H) and the signal strength (SS). On the basis of existing knowledge of MANET, the terms "Low", "Medium" and "High" are used to describe the energy consumption rate and "Less", "Medium" and "High" to describe hop count. "Strong", "Medium" and "Weak" are terms for representing the signal strength. Even though the choice and specification of the membership functions are widely subjective, there are several principles for membership function selection that can produce good adequate results. The trapezoidal functions and triangular functions are chosen for input and output respectively as the membership functions since they have been extensively used in real-time applications due to their simple formulas and computational efficiency. We show these membership functions in Fig. 1,2,3,4. We normalize the linguistic values of inputs and outputs in the range from 0 to 1. The output of FIS is a link cost, which represents cost of node participating in the route. The link cost from lowest to highest are defined as VL (very low), L, M (Medium), H, VH (very high).

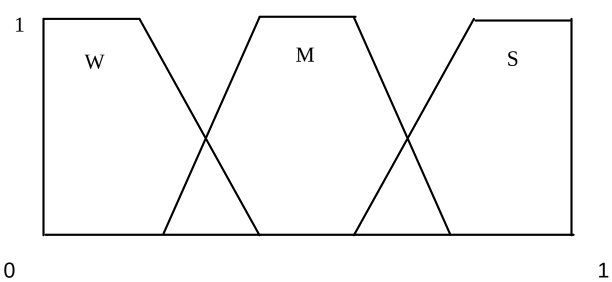

Figure 1. Fuzzy Membership function for signal strength(SS)

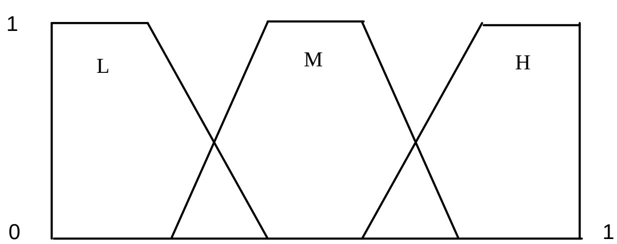

Figure 2. Fuzzy Membership function for battery capacity(B)

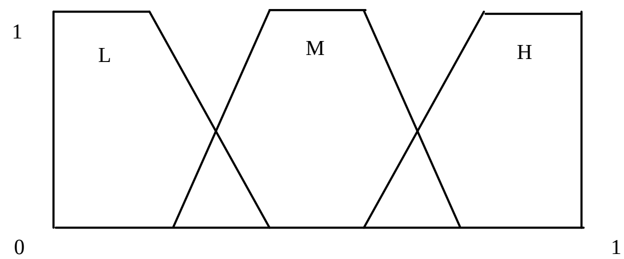

Figure 3. Fuzzy Membership function for hop count(H)

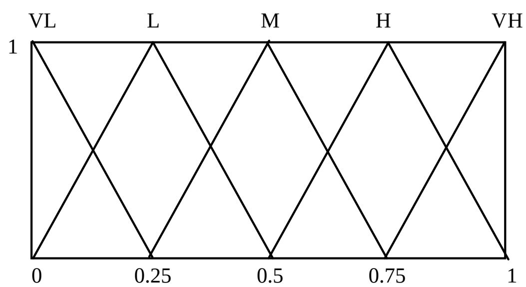

Figure 4. Fuzzy Membership function for link cost(LC)

B. STEP 2. Inference engine and knowledge base

The knowledge base is a set of rules developed using expert knowledge. We design the knowledge based rules connecting the inputs and the output based on a thorough understanding of the system. The parameters and rules of our FLS are initially set, induced from many analytical results of MANET routing. The fuzzy rules have IF-THEN structure. The inputs are then combined using the AND operator. The following is an example of rule, which describes the input output mapping.

TABLE I. FUZZY RULES TABLE FOR WEAK SS

B / H	**Low**	**Medium**	**High**
Less	H	M	VL
Medium	H	M	L
High	VH	H	H

if battery power is medium(M) and no of hops are less(L) and signal strength is weak(W) then the link cost is medium(M).

Table 1 shows the fuzzy rules for the weak signal strength in fuzzy logic system. The fuzzy set parameters and rules of FSR are set by expert knowledge and heuristics. Similarly, fuzzy rule tables for medium and strong signal strength are formulated.

C. STEP3. Defuzzification

Defuzzification refers to the way a crisp value is extracted from a fuzzy set as a representation value. There are many kinds of defuzzifiers. Here we take the centroid of area strategy for defuzzification.

$$LC = \frac{\sum_{AllRules} x_i.\mu(x_i)}{\sum_{AllRules} \mu(x_i)}$$

Where LC is the link cost, x_i is the element and $\mu(x_i)$ is its membership function. This is the most widely adopted defuzzification strategy, which is reminiscent of the calculation of the expected value of probability distributions.

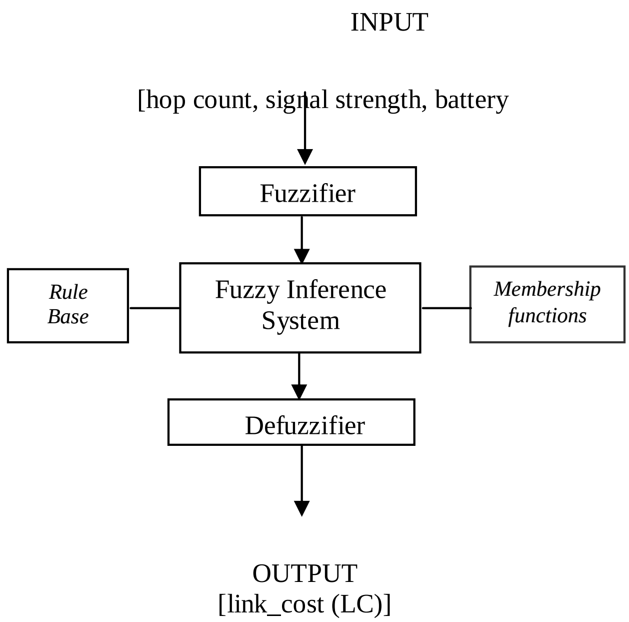

Figure 5. Computation of link cost(LC) when RREQ visits the node.

IV. DESCRIPTION OF PROPOSED PROTOCOL

The working of FSR is similar to AODV except the strategy for route selection process using fuzzy logic described in this section in detail. As mentioned earlier, the FSR utilizes three input variables i.e. hop count, signal strength and battery life of nodes. When a source wants to maintain a path to a destination, it broadcasts a RREQ packet throughout the network in order to find a path. When intermediate node receives RREQ, it calculates its link cost of participating in the route and adds it to the sum of the link costs in the RREQ packet. Also the value of resulting sum is stored in the node. The intermediate nodes as shown in fig. 5 make use of fuzzy logic to calculate the cost, which is dependent on multiple metrics mentioned earlier. In this way as the RREQ packet travels through its route, link cost gets accumulated at each intermediate node.

When the RREQ packet reaches the destination, RREP packet will be generated and the total cost for whole path, TOTAL_COST, is calculated as shown in fig. 7, which is carried in the RREP packet. When RREP is received at intermediate node while traveling back to the source, the sum of link costs stored in the node earlier will be subtracted from the TOTAL_COST and follows the path in reverse. The result is route_cost of a path from intermediate node at which RREP is received to destination given by following Eq.(1)

$$Route\_cost^{i}_{j,d} = \sum_{l=1}^{t} LC_l^{l+1} \qquad (1)$$

where t is the number of traversed routes(or links) in the path starting with current node i (l=1) and finished with node d (l=t) via neighbor node j. LC_l^{l+1} is the link cost between adjacent nodes l and l+1.

Routing cost table corresponding to the RREQ's destination is then updated as follows:

$$Route\_Cost^{i}_{j,d}(t) = (1-\rho)Route\_Cost^{i}_{j,d}(t-1) + \rho Route\_Cost^{i}_{j,d} \quad (2)$$

where ρ is learning rate and set to 0.7 and the probability table is updated by using (3) as follows:

At node i, For Destination d, the probability is:

$$P^{i}_{j,d} = \frac{1/Route\_Cost^{i}_{j,d}(t)}{\sum_{l} 1/Route\_Cost^{i}_{j,d}(t)} \quad (3)$$

Where l ∈ neighbor (i)

When RREP reaches finally back to source node, the routing cost table and probability table of the source node is updated.

V. Simulation and Results

We conducted experiments to evaluate and compare the performance of the routing protocol FSR with AODV. In these experiments, we used network simulator, OMNET++ with mobility framework, which offers high fidelity in wireless ad hoc network simulation by including an accurate implementation of data link and physical layers. Fifty mobile nodes were moved according to the random waypoint mobility model within a 1500 m * 300 m area. Each node had a radio propagation range of 250m and channel capacity was 2Mb/s. All simulations were run for 600 seconds of simulated time. We did our experiments with movement patterns for 7 difference pause times: 0, 100, 200, 300, 400, 500 and 600 seconds. Thirty mobile nodes acted as traffic sources generating 4 packets/second each, and data traffic was generated using constant bit rate

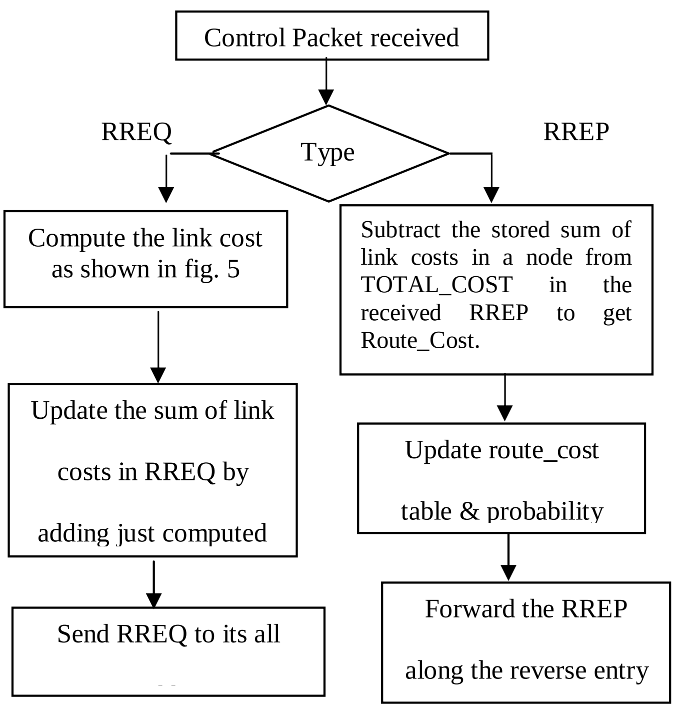

Figure 6. Response/Action of intermediate node when control packet (RREQ/RREP) is received

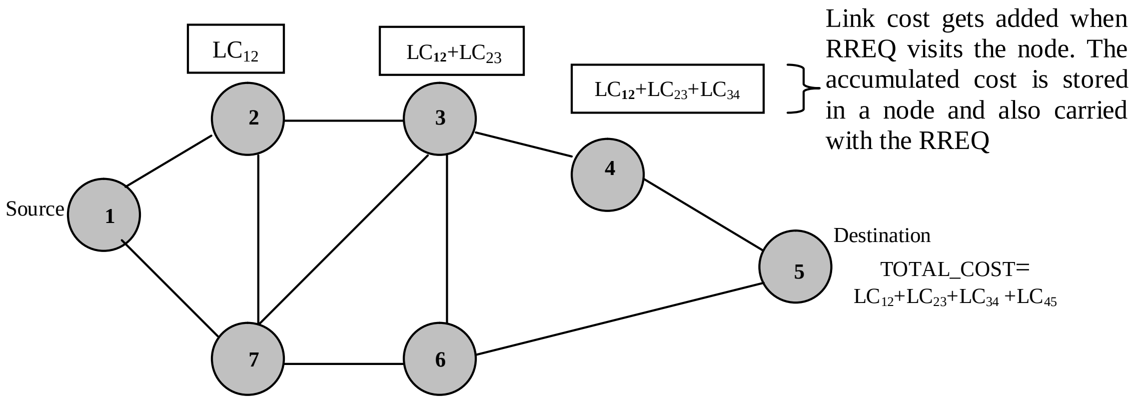

Figure 7. Updation of Link_Cost(LC) when RREQ visits the node

CBR) UDP traffic sources. The medium access control protocol was the IEEE 802.11 DCF. The size of data packet was 512 bytes. The minimum and the maximum speeds were set constant to zero and 20m/s respectively. Packet delivery ratio is important as it describes the loss rate that will be seen by the transport protocols, which in turn affects the maximum throughput that the network can support. Fig. 8 presents that packet delivery ratio is higher for FSR, which is due to its ability to select a set of stable and least congested routes thus having the lowest amount of congestion loss and very few route failures.

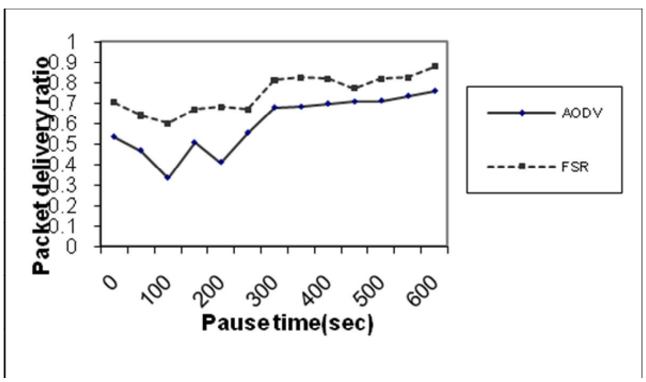

Figure 8. Packet delivery ratio

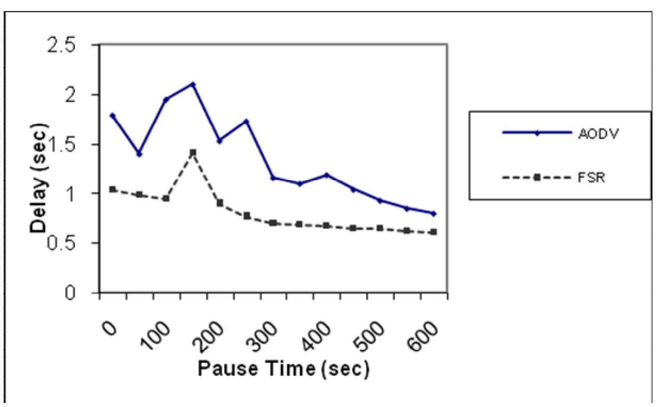

Figure 9. End-to-end delay

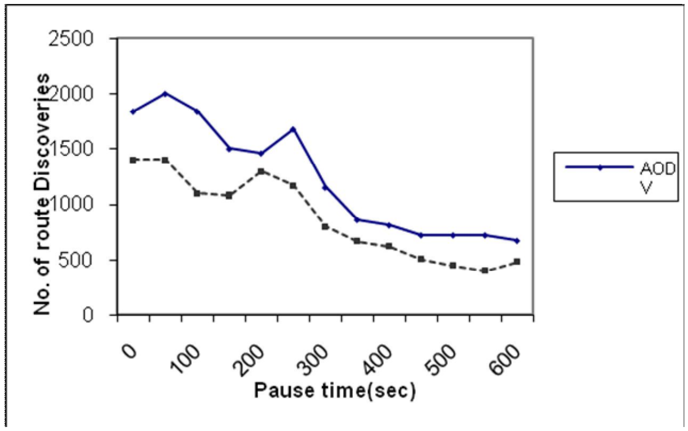

Figure 10. No. of route discoveries

The average end-to-end delay is the average elapsed time to deliver a packet from the source node to the destination node, and it includes all possible delays before data packets arrive at their destinations. The average end-to-end delay for FSR is lower compared with AODV (Fig. 9). It is obvious that AODV have the higher delay because of high congestion. As the mobility decreases (increasing pause time) the delay also decreases due to less route failures at low mobility. Route failures have an impact on the delay, because route failures require re-rerouting and storing of packets in the send buffer.

Route rediscovery is needed to locate an alternate route for the given destination. It is an expensive task. So the less frequency of routing discovery process means the less route discovery latency and lower routing overhead. Fig. 10 shows that the frequency of route rediscovery of FSR is lower among those of the compared routing protocols. Because FSR deals with the uncertainty of MANET and considers the effects of different correlated parameters on network performance, FSR decreases the route failures significantly.

VI. CONCLUSION AND FUTURE WORK

In this paper correlation of different route selection parameters that affect the network performance is captured by fuzzy logic. Also, stochastic routing over multiple optimal paths result into automatic load balancing and fault tolerance improving overall performance over conventional routing protocol, AODV. This is achieved by equipping each node with fuzzy logic system. The results show that fuzzy logic based multipath routing protocol is very promising to take care of various uncertainties of MANET effectively. The result of this research motivates the use of fuzzy logic routing protocol to select the best path stochastically. It can be used to explore other areas of routing in MANET, for example, position of node based routing.

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