A Balanced Approach for Power Aware Routing in MANET using Fuzzy Logic

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ABSTRACT

In Power efficient routing for MANET is very crucial due to its dynamic topology, complexity and limited resources. The battery efficiency and power consumption of the selected routes play a vital role in the network lifetime. An optimum balance between these two constraints has to be made during route selection in order to obtain stable routes that would avoid network partitioning. In this paper, we propose an adaptive routing FBPRA (Fuzzy based Balanced Power Aware Routing Algorithm) that incorporates a path maintenance mechanism and selects the most stable route using fuzzy logic. The path maintenance mechanism reduces the path breakages by establishing a new path via the neighbouring nodes, before the packet transmitted path could break due to the node's mobility.The performance evaluation is done using a simulation program to compare between our fuzzy logic approach and the classical methods. The simulation results show that the algorithm improves the network performance effectively.

Keywords

MANET, Fuzzy, Stable Route, Path Maintenance, Network Lifetime.

1. INTRODUCTION

MANET comprises of mobile nodes that communicate with each other without employing any infrastructure or base stations. These mobile nodes can form a communication network rapidly anytime and anywhere. Due to its rapid and easily establishment, MANET finds application in many environments like battle zones, secluded areas, or any other hard to reach places. Nodes in MANET use batteries for power supply. Due to the limitations of batteries as a source of power, design of a power efficient routing protocol that prolongs network lifetime is very essential. Most of the previous works reported on routing protocols focus either on shortest path or low power consumption path or minimum battery cost path. In Dynamic Source Routing (DSR) [6] the source node broadcasts to its local neighbourhood a route request (RREQ) when it has data for the destination. Any node receiving such a packet adds its own address to the route record and rebroadcasts the packet to its neighbour zone. On receiving the RREQ the destination node replies with a route reply (RREP) through the possible shortest route. Shortest path may not always be the efficient path as it does not involve power awareness in it. Several proposed power aware routing has tried to solve only the stringent requirement of either finding battery efficient routes or low power consuming routes. The power aware routing becomes efficient only when it is capable of solving both these criteria. It must select routes that consume less power and also have good battery power consistency in it, so as to prevent the rapid draining of nodes. In order to have stable routes that would avoid network partition due to the draining of node, it is essential to find an optimum balance between the battery efficiency and power consumption over the selected routes. We propose here a heuristic routing method using fuzzy logic that integrates the battery efficient routing Min-Max Battery Cost Routing (MMBCR) into the low power consumption routing protocol Minimum Transmission Power Consumption Routing (MTPR) in order to avoid the hasty draining of nodes, by falling in all power efficient routes.

One of the common problems in MANET is that the established path for a connection request may break before the end of data transmission. This occurs due to mobility, when pair of nodes forming a hop along the path move out of each other's transmit range. In such case an alternate path must be established to avoid the rebroadcasting of data due to path breakage as it requires additional power consumption. A novel path maintenance mechanism based on fuzzy logic helps to find a battery efficient and low power consuming neighbour to relay data and reduce path breakages. Reduction of path breakages enhances the network lifetime through power conservation..

2. RELATED WORKS

The energy efficient on-demand routing protocols include the battery aware routing and low power consumption routing. The battery aware routing schemes selects the path with nodes having higher residual energy by considering the remaining battery power as a metric in the path cost calculation. Some of the battery aware routing schemes include the MBCR (Minimum Battery Cost Routing) and MMBCR (Min–Max Battery Capacity Routing) [3]. MBCR selects from all available paths the one path with the maximum remaining power as follows,

$$f_i(t) = \frac{1}{C_i(t)} \tag{1}$$

$$B(r_d) = \sum_{i=0}^{d} f_i(t) \tag{2}$$

$$B(r_o) = \min_{r_d \in r_*} \left(B(r_d) \right) \tag{3}$$

Where $C_i(t)$ is the remaining power of node i at time t, $B(r_d)$ is the sum of the inverse of the remaining power of nodes in path d and $B(r_o)$ is the selected path among the r_* available routes. Although MBCR uses the inverse of the remaining power of the nodes in a path to select the desired path, the selected path may have a node with low remaining power. This may cause path breakage during data transmission. To solve this problem in MBCR, MMBCR selects the path in which the minimum remaining power of nodes in this path is greater than the maximum remaining power in other paths as follows,

$$P_{MMBCR} = \min_{R\in S}[\max_{n\in R} \frac{1}{BC_n}] \qquad (4)$$

Where S is the set of all paths, R is a path, and BC_n is the remaining power of node n. Thus, a routing path that contains a node with low remaining power can be avoided in MMBCR.

In MANETs, selecting a path that has a high transmission bandwidth or a high delivery rate of packets can reduce power consumption and shorten transmission delay during data transmission. MTPCR (Minimum Transmission Power Consumption Routing) [5] protocol analyses the signal strength of the received packets and contentions in the contention-based MAC layer to discover the desired routing path that has reduced power consumption during data transmission as follows,

$$PC_j = \frac{[(NCC_j - 1)\times PC_{listen} + PC_{tx}]}{r_j} \qquad (5)$$

$$PC_i = \sum_{j=1}^{n} PC_j \quad \text{where} \quad n = \frac{datasize}{packetsize} \qquad (6)$$

$$TPC = \sum_{i=1}^{H} PC_i \qquad \text{where} \quad i \in H \qquad (7)$$

$$MTPC = \min_{r\in R}(TPC_r) \qquad (8)$$

Where, PC_j is the power consumed in transmitting a packet j, r_j is the success ratio of transmitting packet j, NCC_j is the number of nodes contending for the channel in the MAC layer, PC_{listen} and PC_{tx} are the power consumed in receiving and transmitting a packet.

Aggregating both the battery aware routing scheme and the low power consumption routing scheme using fuzzy logic helps to obtain both the benefit of reduced route failure and enhanced network lifetime.

3. FUZZY LOGIC

It was first introduced by L. Zadeh in the 1960s as a means to model the uncertainty of natural language, and has been widely used for supporting intelligent systems. Fuzzy logic can handle uncertainties and reasoning, which makes it very attractive for decision making systems. Fuzzy systems are used to approximate functions. The fuzzy can be used to model any continuous function or system. The quality of fuzzy approximation depends on the quality of the rules. The basic unit of fuzzy function approximation is "*If-then*" rules. A fuzzy system is a set of if then rules that maps input to output. A membership function is a mathematical formation of representing a fuzzy set.

A fuzzy logic system comprises basically three elements: A fuzzifier, an inference method (rules and reasoning) and a defuzzifier. Fuzzification is a procedure where crisp input values are represented in terms of the membership function, of the fuzzy sets. The fuzzy logic controller triangular membership functions are defined over the range of the fuzzy input values and linguistically describe the variable's universe of discourse. Following the fuzzification process the inference engine determines the fuzzy output using fuzzy rules that are in the form of if then rules. De-fuzzification is then used to translate the fuzzy output to a crisp value.

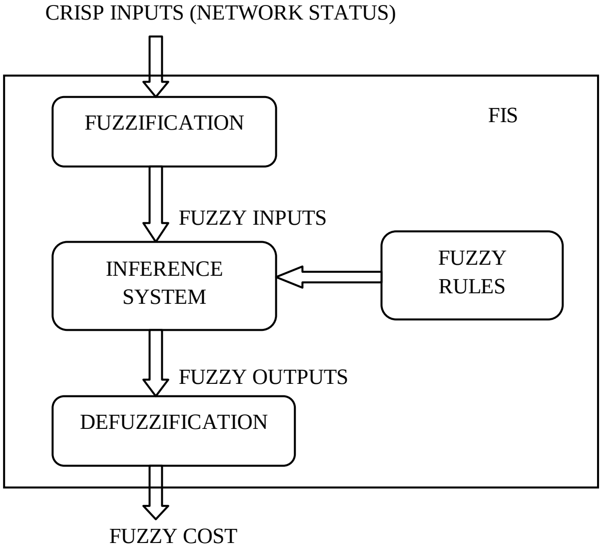

Fig 1: Fuzzy System

4. FUZZY BASED BALANCED POWER AWARE ROUTING ALGORITHM

4.1 Fuzzy Inference System

The Fuzzy Inference System (FIS) for FBPRA is a mamdani type system with two inputs and one output. The two main parameters that make the routing algorithm more consistent are battery cost value and power consumption of each node.

4.1.1 Battery Cost Evaluation

The battery cost of every route is calculated with the remaining battery power of all the nodes in the route based on MMBCR. Lower the battery cost value higher would be the network consistency.

4.1.2 Power Consumption Evaluation

The power consumed at every node depends upon the received signal strength, data size to be transmitted and the number of nodes contending for channel in the MAC layer. The power consumed over every route is calculated based on the MTPCR. Low power consumption over a route implies increased network consistency.

The system inputs are battery cost and power consumption. The both inputs are characterized by the fuzzy membership functions as shown in Figure 2 and Figure 3. The membership functions for the fuzzy sets of inputs are chosen to be triangular for its easiness in computation, clarity, and noise tolerance. Both of inputs are normalized between (0, 1) before applying to FIS. The input have five membership functions titled as VL, L, M, H, and VH which mean Very Low, Low, Medium, High, and Very High respectively.

The rules of the FIS are designed such that a fair route having an optimal balance between the battery cost and the power consumption is selected. Table I shows rule base for the FIS. In this table the Values for the amount of goodness from lowest to highest are defined as LL (Very Low) , LM, LH, ML, MM (Medium), MH, HL, HM, and HH (Very High). The output of FIS is the route fairness, a fuzzy based cost function which is applied to the software simulation for evaluations.

$\mu_A(x_1)$

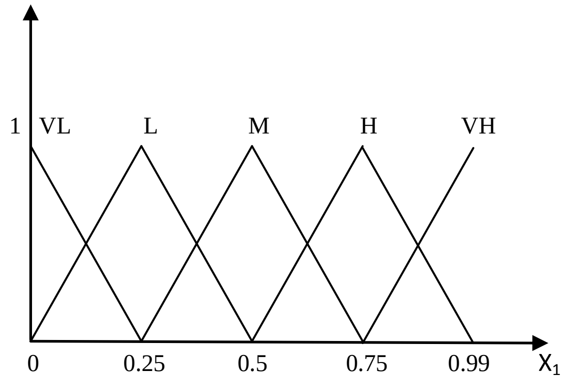

Fig 2: Membership Functions for Battery Cost

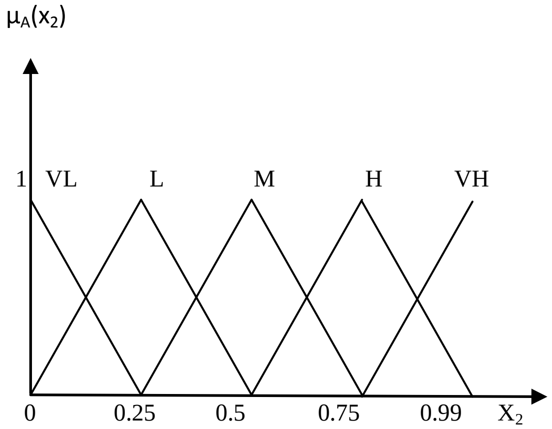

Fig 3: Membership Functions for Normalized Power Consumption

The rules of the FIS are designed such that a fair route having an optimal balance between the battery cost and the power consumption is selected. Table 1 shows rule base for the FIS. In this table the Values for the amount of goodness from lowest to highest are defined as LL (Very Low) , LM, LH, ML, MM (Medium), MH, HL, HM, and HH (Very High). The output of FIS is the route fairness, a fuzzy based cost function which is applied to the software simulation for evaluations.

Table 1. Rule Base for FIS

ROUTE_FAIRNESS		POWER CONSUMPTION				
		VL	L	M	H	VH
BATTERY COST	VL	HH	HM	HL	MH	MM
	L	HM	HL	MH	MM	ML
	M	HL	MH	MM	ML	LH
	H	MH	MM	ML	LH	LM
	VH	MM	ML	LH	LM	LL

There are 25 rules defined for this fuzzy system. For example, two of the rules are as follows:

R1: If Battery Cost is VL and Power Consumption is VL then Link Goodness is HH.

…

R25: If Battery Cost is VH and Power Consumption is VH then Link Goodness is LL.

Design of Fuzzy Inference System is the process of formulating the mapping from a given input to an output using fuzzy logic. Mamdani-type inference expects the output membership functions to be fuzzy sets. After the aggregation process, there is a fuzzy set for output variable as shown in Figure 4.

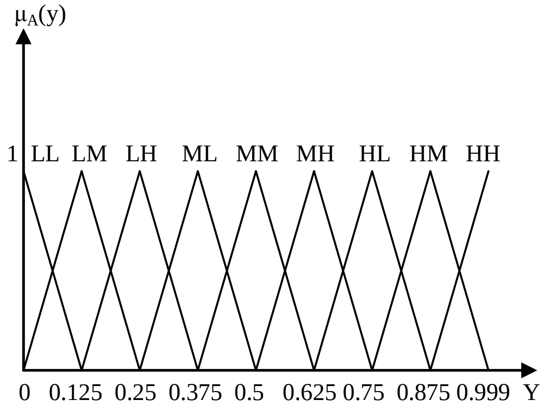

Fig 4: Membership Functions for Output Variable Y (Route_fairness)

The fuzzy operator used for the AND method in "if-then rules" such as "If A is a AND B is b then C is c" is "multiplication". The defuzzification is the process of conversion of fuzzy output set into a single number. The method used for the defuzzification is, "mean of centers" as shown in equation (9). Then, the output of fuzzy system after denormalization is applied to the FBPRA algorithm as the Route_fairness which can be used as a criterion for stability of a route.

$$\text{Route\_fairness} \quad \mu_{ij}(t) = \frac{\sum_{l=1}^{M} \bar{y} \prod_{i=1}^{n_f} \mu_{A_i^l}(x_i)}{\sum_{l=1}^{M} \prod_{i=1}^{n_f} \mu_{A_i^l}(x_i)} \tag{9}$$

Where the i is the sending node, j is the receiving node, M is the number of fuzzy rule bases used (M=25), n_f is the number of membership functions for input variables (n_f=2) and $\mu_A{}^l(x_i)$ is the fuzzy value of membership functions.

4.2 FBPRA Algorithm

This section presents a novel adaptive routing algorithm that generates stable routes between the source and destination.

4.2.1 Route Discovery Phase

In MANET path that has higher transmission bandwidth or high delivery ratio is the path that consumes less power. When the source needs to transmit data to the destination it broadcasts the RREQ to its neighbours. The power consumed in a node for a particular data transmission is calculated with the received signal strength and contentions in the MAC layer and is stored in the RREQ. Also the battery cost function of the routes are calculated and stored in the RREQ. The destination node receiving many RREQ via various paths makes fuzzy based decision to select a stable path that has low power consumption and good battery efficiency eliminating the low battery nodes. All the paths discovered through the

RREQ obtain a stability value through the fuzzy logic. The most stable route is the route having highest stability value.

Algorithm:

```
GetRREQInfo(Ri);// obtains information like received signal strength dB value, number of nodes contending for the channel, data size and the remaining battery level of the previous nodes in the path
RiR = Ri.Received_dBvalue;
r = SR(RiR); //calculates Successful Rate with the received dB value
NCC = Ri.Current NCC; // NCC equals to Current NCC from Ri
n = Ri.DataSize/PacketSize; // value of n is rounded up to an integer value
PC = GetPowerConsumed(r, NCC, n); //obtain power consumed
Ri.PathPC + = PC;
Premaining+ = Premaining_i;
if B.id = = Ri.DestID then // checks if the current node is the destination
    Cache (Pi);
else
    Ri.PreID = Ri.CurrentID
    Ri.CurrentID = B.ID
    Broadcast(Ri); //broadcasts RREQ to its neighbours
end if
```

4.2.2 Route Maintenance Phase

The nodes of MANET are mobile in nature. The mobility of the nodes decreases the transmission bandwidth of the selected paths. Low transmission bandwidth of an active path that is under transmission leads to path breakage which requires rebroadcasting. An alternate high transmission bandwidth path is found through the path maintenance mechanism to reduce the power consumption required for rebroadcasting. The decrease in the transmission bandwidth is predicted through the distance between the transmitting and sending node. In order to reduce the frequent search of alternate routes a threshold of 20 metres is set on the distance between the two nodes. When two transmitting nodes start moving more than a 20 metres apart the probability of rebroadcasting increases and an alternate path is found through the neighbouring nodes. The distance between two nodes and the density of the neighbouring nodes is determined by listening to the signals, including RTS, CTS, data, and ACK, issued by its neighboring nodes. An alternate path is set by choosing a potential relay-node for relaying data via the RNREQ (relay-node) request broadcast. The neighboring nodes that receive the RNREQ replies the sender with RNREP (relay-node reply) that contains the calculated power consumption required for relaying data through them and their remaining battery power. The sender makes fuzzy based decision to select a potential relay-node by giving a favorable weightage between the power consumption and remaining battery power obtained in the RNREP of the neighboring nodes. The sending node then sends a path modification packet to the selected neighbouring node and the destination node.

5. SIMULATION AND RESULTS

We conducted experiments to evaluate and compare the performance of the following protocols: FBPRA, MMBR, MTPCR and DSR. For the analysis, we used the discrete time network simulator, ns2, 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 (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. The following metrics are used in computing the network performance:

1) Packet delivery ratio: Packet delivery ratio is the ratio between the number of packets originated by the “application layer” CBR sources and the number of packets received by the CBR sink at the final destination. Figure 5 shows the results of packet delivery ratio for the increasing pause time. The FBPRA scheme has significantly better delivery ratio than the classical methods due to the larger amount of received packets at the destination with reduced packet drops.

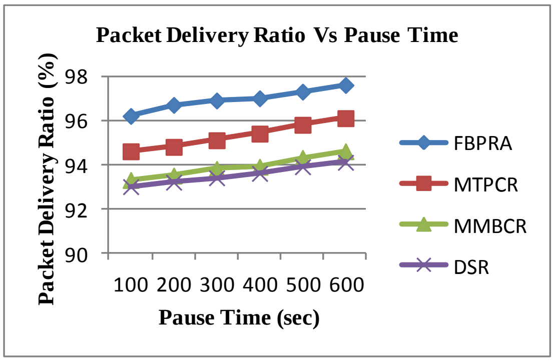

Fig 5: Packet Delivery Ratio Vs Pause Time

2) Throughput: It is the amount of digital data transmitted per unit time from the source to the destination. It is usually measured in bits per sec. Figure 6 illustrates the comparative analysis of throughput for varying pause time. With increased packet delivery ratio the FBPRA has efficient throughput than DSR, MMBCR and MTPR.

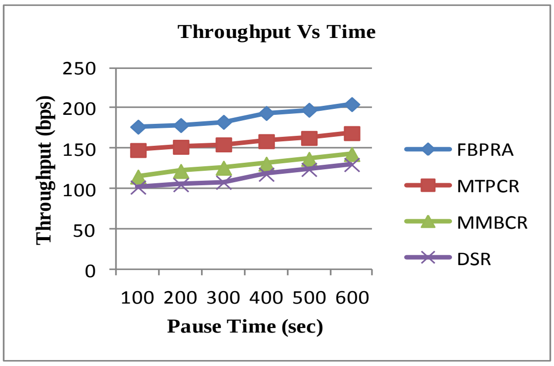

Fig 6: Throughput Vs Pause Time

3) End-to-end Delay: End to end delay refers to the calculation of the typical time taken by the packets to cover its journey from the source end to the destination end. The classical unit of this metric is millisecond (ms). From the Figure 7 that shows the comparison of delay at varying pause time for various protocols, the FBPRA scheme proves to have reduced delay.The more hype in the value of packet delivery ratio with reduced delay represents an added achievable performance of the FBPRA protocol.

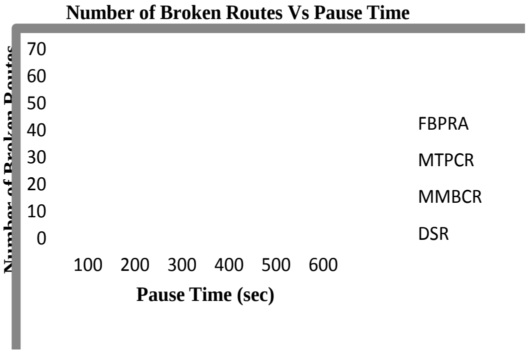

Fig 7: End-to-End Delay Vs Pause Time

4) *Route Stability*: Route stability is a very important performance parameter for a routing protocol. Route stability can be measured in terms of number of broken routes. Figure 8 shows the results of number of broken for the increasing pause time.

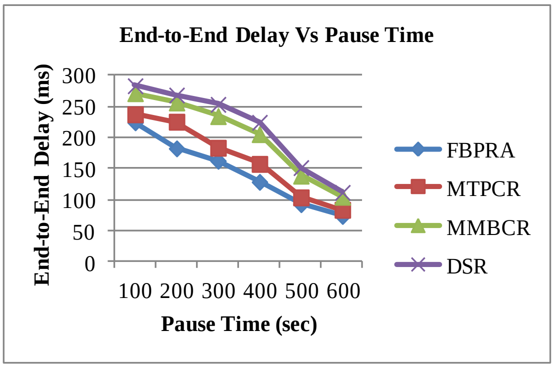

Fig 8: Number of Broken Routes Vs Pause Time

The FBPRA scheme has very reduced route failure due to the optimized path selection and route maintenance phase. Also, the FBPRA scheme mitigates the low battery power nodes from participating in the path thereby avoiding the network partitioning due to the draining of nodes. This enhances the network lifetime.

6. CONCLUSION

Mobile ad hoc networks are full of uncertainties due to its dynamic nature. For such a network, power aware routing protocol satisfying either the battery efficiency or low power consumption of the selected routes cannot prove to be efficient. In this paper we propose an intelligent power aware routing, that uses fuzzy concepts to select stable routes that have a balance between its battery efficiency and low power consumption. From the simulation results the proposed FBPRA routing shows an enhanced packet delivery ratio and throughput with reduced end-to-end delay when compared with the previous algorithm. The reduced path failure due to [13] the fuzzy based path maintenance proves to improve the network lifetime effectively.

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