QoS Provisioning in MANET Using Fuzzy-Based Multifactor Multipath Routing Metric

S. Venkatasubramanian, A. Suhasini, and C. Vennila

Abstract Volatile topology is the basic nature of MANET. Haphazardly, the nodes may move which makes and breaks connection between nodes. Because of this nature, providing quality of service (QoS) is a challenging task. For the applications that use real-time data packets delivery, quality of service (QoS) has to be provisioned. This paper discusses a technique to provide QoS in a heterogeneous network with multipath routing is given. The multipath routes are to be discovered primarily using the parameters such as delay, channel occupation, link quality and residual energy. To choose the best routes between the originating node and the target node, a fuzzy logic mechanism is used. This Fuzzy-based multi-parameter and multipath QoS routing (FMMQR) find out the optimal path for data transmission between the two nodes. This technique gives better performance than some of the existing method. The simulation experiments prove our Fuzzy-based multi-parameter and multipath QoS routing (FMMQR) performs better than other methods.

Keywords MANET · Routing · Fuzzy based · Multifactor · Multipath · QoS

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1 Introduction

MANET consists of a network of wireless nodes without any access point. Here, the nodes form a self-managed network to forward data packets. Each node communicates through multihop with them. There will be frequent changes in the topology as nodes move in different direction. Thus, the provision of quality of service (QoS) routing protocol becomes a challenging task compared to the conventional networks [1]. MANETs are used in emergency situations such as natural catastrophes, military conflicts and medical facilities among others. With the demand for supporting multimedia services, it is the need of the hour to make MANETs to support QoS. Providing real-time media traffics such as audio and video become problematic in the presence of changing network architecture due to the demand of high data rate and delay limits [2].

The two major solutions for providing QoS in MANETs can be either [3] based on resource reservation called stateful approach. Eg: INSIGNIA [4] which do not reserve resource and uses service differentiation called stateless approach. Eg: SWAN [5]. These techniques are applicable when the node mobility is low and for homogeneous nodes. But, with a reasonable mobility and with the heterogeneous nodes, an alternative light weight approach should be used. One such a technique is the theme of this paper.

2 Related Works

Manoharan et al. [2] proposed an adaptive gateway management (AGM) method, in which an excellent gateway from the gateway candidate nodes has to be selected. It uses metrics like balance energy, signal strength and movement speed to select these. When an elected gateway loses its energy and due to the dynamic unstable topology, it makes it unavailable to other nodes. Adaptive gateway migration method was used to sustain the connectivity between networks. A predefined threshold value is used in the gateway selection method by selecting optimal gateway.

Load balancing and congestion avoidance are the core in the adaptive multipath routing protocol with congestion controlled proposed by Soundararajan et al. [6].The algorithm for determining multipath routes computes fail-safe multiple paths, which supply the principal path with multiple routes to all intermediate nodes on the path. The fail-proof multipath includes nodes for the minimum load, necessary battery power, and appropriate energy. A threshold value is used to see whether the load on a node along the route exceeds a certain threshold. If this is the case, traffic is divided into multiple multipath routes to alleviate the strain on a crowded network.

A routing strategy considering the stability of the link and energy-aware routing protocol with energy monitoring was suggested by De Rango et al. [7], which has tried to account for stability of the link and for minimum energy consumption rate.

To validate the exactness of their proposed strategy, a bi-objective optimization was formulated.

Chandrakant et al. [8] have projected heterogeneity in packet sizes, protection mechanisms, mobility among nodes in MANETs. The security management and communication management are the focus of their work. Diverse encryption techniques such as packet sizes and protocols are used by every node in such a way that every node did not understand security methods of every other node.

Power-aware QoS multipath routing (PAQMR) protocol was proposed by Santhi et al. [9] to eliminate the loop formation in heterogeneous MANET; therefore to reduce congestion in the channel. An enhancement version of ad hoc on demand multipath distance vector (AOMDV) protocol was suggested.

In power-aware rate adjustment with the cross-layer-based routing MAC protocol [10], fuzzy logic system 1 is used for best path selection and rate adjustment were done by fuzzy logic system 2. By fuzzifyng the inputs such as delay and packet loss ratio, state of transmission rate was estimated. By comparing the output of fuzzy logic system 2 with the initial transmission rate of path, the current transmission rate of the path is tuned.

Santhi et al. [11] proposed a multi-constrained QoS routing with mobility prediction based on fuzzy costs (FCMQR). Their goal was to create a cost metric that took into account available bandwidth, end-to-end delay and hop count. Our paper compares the performance with this work.

Suraki et al. [12] proposed a cross-layer approach at transport, network and MAC layers in which fuzzy logic system is used in intermediate and destination nodes as a dynamic tool for controlling the congestion problem. The fuzzy rule was drafted based on the packet length, buffer size and congestion level.

Chen et al. [13] in their paper proposed how an AODV can adopt to the topological change and devised TA-AODV routing protocol. To provide QoS, this can adapt to high-speed node mobility. A stable path selection technique is used in this protocol to give connection stability probability between nodes by using path selection characteristics such as residual energy, available bandwidth and queue length.

Yas et al. [14] proposed "A trusted MANET routing algorithm based on fuzzy logic", in which the routing algorithm relies on two main principles as trust level and shortest path (hops count).

Mukesh KumarGarg et al. [15] have taken fuzzy of security Level of trust and a value of trust as main parameters to decide the routing.

Ran et al. [16] have taken the states of the nodes and form a blockchain and the nodes that match the QoS restrictions are filtered out via a smart contract on the blockchain. S. Venkatasubramanian et al. [17] have considered the multi-factors in MANET to provide QOS. But the fuzziness of the values are considered in that work.

3 System Design and Protocol

For MANET, a routing metric with support for QoS is designed in a way each node along with a congested link should use optimal available bandwidth and least end-to-end latency. So our algorithm should rely on the individual links weightage which is based on parameters including channel busyness, end-to-end delay, link quality and node energy.

3.1 Link Quality Estimation

The nodes in the network compute its quality of links. During a slot T_{win}, if N_h is the number of HELLO message packets received and P_h is the HELLO message packets percentage received during the previous time duration, then the quality of the link L_{qual} is

$$L_{\text{qual}} = \beta . P_h + (1-\beta) . N_h \tag{1}$$

where β represents the degree of weighting factor between 0 and 1. Then, the route quality is the summation of all link quality along the path.

3.2 End-to-End Delay Estimation

RREQ and RREP report a node with hop count $H_{\text{count.}}$ The number of packets comprised in each up and down stream is $2H_{\text{count}}$. The node uses the latency between RREQ and RREP and finds the average delay D_{avg} of the packets received. The selection of route also depends in the delay and transmits data packets only when the average is within the threshold level.

3.3 Channel Occupancy Estimation

The channel occupancy is the time and a node utilizes the channel for its transmission. For this estimation, the packets such as request-to-send (RTS), clear-to-send (CTS), data and acknowledgement (ACK) of the IEEE 802.11 MAC with the distributed coordination function (DCF) are used. Then, the channel occupation will be

$$C_{\text{occ}} = t_{\text{RTS}} + t_{\text{CTS}} + 3t_{\text{SIFS}} + t_{\text{acc}} \tag{2}$$

where *CTS* and *RTS* times are t_{CTS} and t_{RTS}, respectively, and s the *SIFS* period is t_{SIFS}. The time taken during contention is t_{acc}. If congestion occurs but is not handled, it can diminish a link's capacity and cause it to become congested.

3.4 Residual Energy

Whenever a node communicates, certain amount of battery power will be drained. Owing to the limited energy resources for communication will have an impact on the lifetime of the network and nodes [18].

The energy consumed for transmitting RTS and CTS are given by:

$$\mathrm{Energy}^{\mathrm{RTS}} = r * t_N^L * p_{\mathrm{RTS}} \tag{3}$$

$$\mathrm{Energy}^{\mathrm{CTS}} = r * t_N^L * p \tag{4}$$

where r denotes the receiver's threshold, t_{N} is the maximum transmission range, L denotes the path loss exponent and p_{RTS} and p_{CTS} denote the RTS and CTS transmission times, respectively. The source uses Eq. 5 to compute the overall energy consumption of each path.

$$\text{Total Energy } E = \ \mathrm{Energy}^{\mathrm{RTS}} j + \mathrm{Energy}^{\mathrm{CTS}} j \tag{5}$$

The residual battery power across each route is determined using the battery power consumed at each node along the path.

$$R_i^b = \sum_{\in M_L} R_i \tag{6}$$

where

$$R_{\mathrm{i}} = \text{Initial Energy}_i^E - (\mathrm{Energy}_i^{\mathrm{RTS}} + \mathrm{Energy}_i^{\mathrm{CTS}}) \tag{7}$$

The number of nodes in the chosen path and the path with the most leftover energy are denoted by M_L. The W for the link from node i to a specific neighbouring node for an intermediate node i having established transmission with several of its neighbours is given by

$$W = \left(L_{\mathrm{qual}} + C_{\mathrm{occ}} + R_i^b\right) / \ D_{\mathrm{avg}} \tag{8}$$

Each node calculates the weight of its entire links and when an incoming RREQ packet comes with the previous nodes' weight W1, the current node adds its weight to

Table 1 Link weight table maintained at each node

Neighbour node	Destination	C_{occ}	Link weight
1	*D*	24%	0.7
7	*D*	32%	0.72

it. When the RREP packets are sent to the source from the target node, the originating node, which initiates the route discovery process, will receive response from multiple paths. It stores the response in the local table a shown (Table 1)

The same table is maintained in all the nodes. The node will use the link with best link weight. If that link breaks due to mobility of the node, then the node selects the alternative link by selecting the next best metric from table. Channel occupation due to MAC contention (C_{occ}) is an important parameter used in this paper for deciding about the link congestion. A threshold value is chosen for this parameter depends upon the nature of the data packet. If the C_{occ} value is below the threshold, then it is a normal traffic. But if near to the threshold value, then the node changes the Bluetooth interface from "sniff mode" to "connected mode (active)" and starts sending the data packets via Bluetooth interface to any of the neighbouring node from the table. This switching occurs only for the packets marked with real-time data. The numbers indicated in the Fig. 1 are the paths to reach the destination node.

A. ***Route Request***

The route finding process starts with the source node sending the RREQ packet as shown in Fig. 2.

Few new fields are incorporated in the format of AOMDV, which includes link quality, average path delay, channel occupancy and residual energy of a node. When

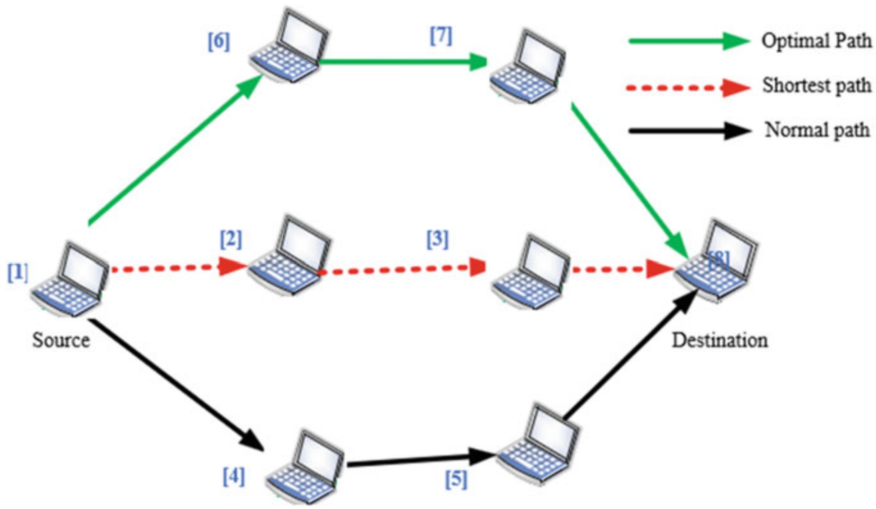

Fig. 1 Optimal path selection

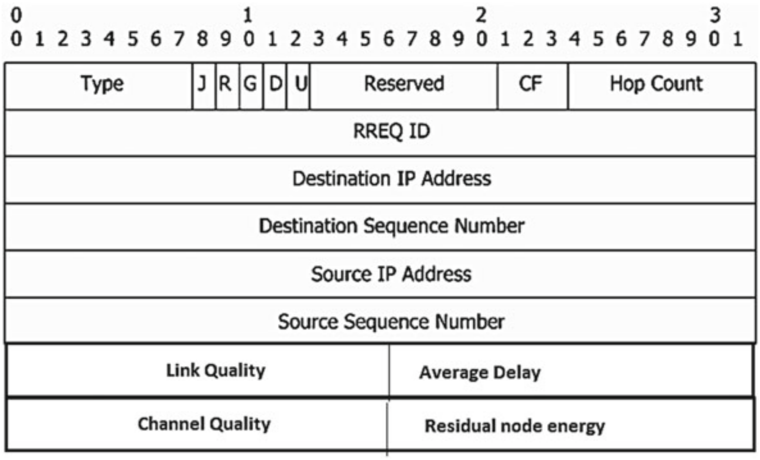

Fig. 2 Format of modified RREQ packet

an intervening node gets a RREQ, FMMQR updates the quality of the link, average path delay, channel occupancy and residual energy values in the RREQ field and then sends a new RREQto its one-hop neighbour.

The QoS-aware route discovery starts with the node S broadcasting RREQ. When a neighbour node receives an RREQ packet, it calculates the required metrics using the estimations stated in the preceding section.

The weight W_{RI} of the node $H1$ is computed using (8).

$$RREQ_{HI} \xrightarrow{W_{R1}} H2$$

In a similar manner, $H2$ computes its weight and adds it to the $H1$ weight. The packet is subsequently forwarded with the additional weight.

$$RREQ_{H2} \xrightarrow{W_{R1}+W_{R2}} H3$$

Finally, the aggregate of node weights along the path reaches the target node.

$$RREQ_{H3} \xrightarrow{W_{R1}+W_{R2}+W_{R3}} D$$

B . ***Route Reply***

The target node D unicast the route reply packet to the upstream neighbour node$H3$, together with the overall node weight.

$$RREP \xrightarrow{W_{R1}+W_{R2}+W_{R3}} H3$$

Now, $H3$ calculates the cost depending on the data provided by $RREP$ as

$$C_{R3} = (W_{R1} + W_{R2} + W_{R3}) - (W_{R1} + W_{R2}) \quad (9)$$

The intervening hosts calculate its cost by the same method. On reception of $RREP$, the source chooses the route with the best cost value out of all the options.

Based on simulation outcomes in the next section, it is seen that these calculations will never raises the overhead and thereby will not be reducing the network performance.

4 Fuzzy-Based QoS Provisioning

This paper proposes a protocol which is designed to select a route with an objective of (i) selecting a route to reduce the end-to-end delay (ii) increase delivery of packets and (iii) maximize the path lifetime. To achieve these objectives, various metrics have been used to come up with a single cost metric (C) is end point latency (D), count of hops (N), channel occupancy (Cocc) and node residual energy (REi). This is the novel work proposed in this paper.

The cost function C_f and the other metrics have the following relationship:

The three key methods such as fuzzification, fuzzy inference and defuzzification as depicted in Fig. 3 are used in the fuzzy logic system. The data that our fuzzy logic system accepts are end-to-end delay, channel occupancy, link quality and node's energy.

The IF–THEN structure forms the fuzzy rules. The AND operator is used to combined the inputs.

The rule mapping example is as follows:

If (quality of link is "High") AND (delay is "High").

AND (channel occupancy is "Low") AND (residual energy is "High") Then weight is "Medium".

There are four input variable and the number of feasible fuzzy inference rules for each of the three linguistic states is 4* 3 * 3 = 36. Table 2 lists a few of the fuzzy rules utilized in the fuzzy controller.

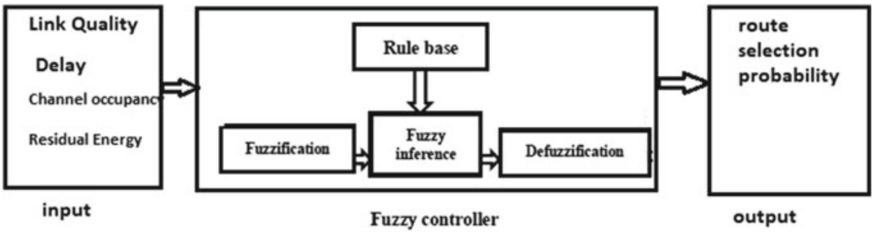

Fig. 3 Fuzzy logic system key processes

Table 2 Fuzzy set rules

Rule#1	Link quality	Delay	Channel occupancy	Residual energy	Output
1	Low	Low	Low	Low	Bad
2	Low	Medium	Low	Medium	Bad
3	Medium	Medium	Medium	Medium	Medium
4	High	Low	Low	Medium	High
5	High	High	Low	High	Bad
6	Medium	Medium	Low	High	High
7	High	Medium	High	Medium	Medium
8	Low	Low	Low	Medium	Medium

Defuzzification is a method for obtaining a plump value as a representation value from a fuzzy collection. The type of defuzzification technique taken in this paper is the centroid of area.

$$x^* = \frac{\int x\mu_A(x)\mathrm{d}x}{\int \mu_A(x)\mathrm{d}x}$$

where $\mu_A(x) =$ the membership function's aggregated output.

The algorithm for route request and reply is as follows:

1. Each node calculates its energy, delay to neighbour, link quality
2. And initial channel occupancy.
3. If a node's buffer got a route to destination then goto step 7
4. Else, broadcast RREQ (with packet format as shown Fig. 2)
5. If not destination node, stores the required parameters in the RREQ packet, computes the fuzzy value and send the broadcast RREQ.
6. If destination node, send RREP packet and computes the fuzzy value.
7. From the fuzzy values received, the node selects one path and keeps the next choice in reservation.
8. Emit the data packet
9. If link breaks, choose the next path stored.

5 Simulation Experiment and Results

5.1 Setup and Settings for Simulation

NS2 tool was used in the simulation of the proposed scheme. The channel capacity of node is set to 2 mbps. IEEE 802.11's MAC layer protocol distributed coordination function (DCF) is used. The simulation's settings are summarized in Table 3.

Table 3 Simulation experiment parameters

Nodes	From 25 to 100
Area dimension	1200 × 1100 m
Layer 2	802.11
Coverage range	250 m
Simulation run time	100 s
Data type	CBR
Packet size	512
Mobility model	Random way point
Velocity	5–20 m/s
Pause time	5 s

5.2 Metrics of Performance

The FMMQR protocol is evaluated with the AOMDV [6] and FCMQR [11] protocol**.** The following performance metrics are considered for the evaluation of our FMMQR protocol.

5.2.1 Average End-To-End Delay

The average latency in sending data packets from source node and receiving acknowledgement at the same node.

5.2.2 Average Packet Delivery Ratio

It is the proportion of successfully received valid data packets to total packets delivered (Fig. 4).

From Fig. 5, in our FMMQR, we have noticed a reduction in latency because FMMQR uses multipath routing. Even if one path breaks, it takes alternate path to send the data. Also our FMMQR provides a minimum latency, as it preciously finds the optimal path using fuzzification.

From Fig. 5, it is proved that our FMMQR nodes forward the data via Bluetooth interface, even the link congestion occurs due to burst data traffic. The packet loss in our proposed method is less as the optimal path with good conditions for the packet travel is chosen.

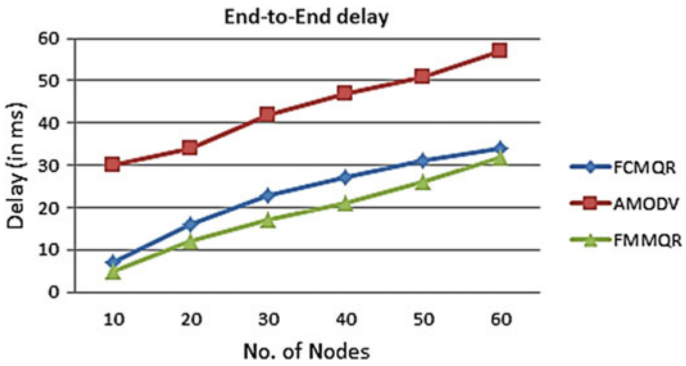

Fig. 4 Nodes versus delay

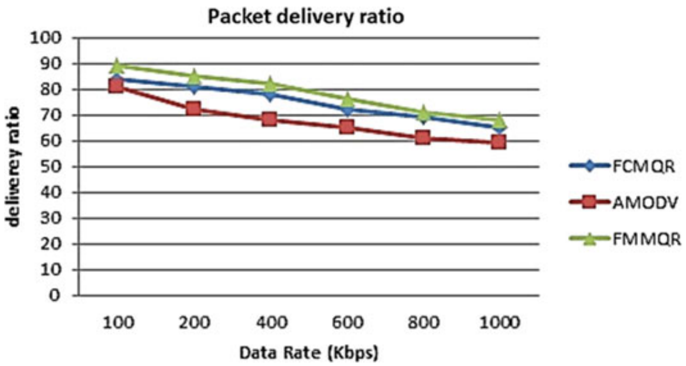

Fig. 5 Data rate versus packet delivery ratio

6 Conclusion

This work proposed a Fuzzy-based multi-parameter and multipath QoS routing (FMMQR) to facilitate quality of service in mobile ad hoc networks by allotting individual links weightage that depends on the metrics such as end-to-end delay, link quality, channel occupation and residual energy. The fuzzy weight cost value helps the routing protocol to select a best path and sending data packets via the congested area is avoided. Thus, provides a balanced traffic and an improved network capacity. The performance of the proposed scheme achieves increased delivery of packet with less latency is also demonstrated by simulation results. This paper can be further extended by formation of clustering and security in transmission of data.

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