ROUTING FOR WIRELESS MESH NETWORKS WITH MULTIPLE CONSTRAINTS USING FUZZY LOGIC

C.Mala¹, M. Siddhartha Sankaran², Shishir Kumar Prasad³ N.P.Gopalan⁴
Department of Computer Science and Engg.
National Institute of Technology, Tiruchirapalli
¹* mala@nitt.edu, ²CS10458@nitt.edu, ³ CS10456@nitt.edu, ⁴gopalan@nitt.edu
¹* Corresponding author

ABSTRACT
Since Wireless Mesh Networks (WMN) are ad-hoc in nature, many routing protocols used for ad-hoc networks like AODV are also used for WMN by considering only the shortest route to destination. Since data transfer in WMN is to and from the AP, these protocols lead to congested routes and overloaded APs. To reduce congestion, the routing protocols such as Traffic Balancing which choose routes based on medium usage of the route were used. However, routing is a multi constraint problem. To make routing decisions based on more than one constraint viz., buffer occupancy, node energy and hop count and to provide an efficient routing method for WMN, a Fuzzy Multi – Constraint AODV routing is proposed in this paper. Simulation results in ns-2 verify that they perform better than single constraint routing.

Keywords: mesh networks, multi constraints, traffic balancing, congestion, AODV, power aware routing

1. INTRODUCTION
A Wireless Mesh Network (WMN) is based on ad-hoc networks, where each node transfers data to and from an Access Point (AP) which is connected to the Internet by a wired or wireless network. These AP need not be in the reach of all the nodes in the network. Nodes around the AP forward the packets from the faraway nodes to the AP. If there are a significant number of nodes in the network, faraway nodes can transfer data with the AP in a few hops. Besides mobility, WMN have the advantages [1] viz., they can work in a decentralized fashion, are cheap with minimum investment for initial infrastructure, more reliable, scalable and provide increased coverage. They are widely used in Campus networks, metropolitan area networks, transportation system, security surveillance system, etc., Thus, they eliminate the drawbacks predominant in a traditional network which uses a wired connectivity to a base station, wherein every user connects it through a point to multi-point protocol [2]. Instead of using WMN, few Access Points can be setup which can schedule the Medium usage scheduling for the different users in the network. Users may use different routes based on the routing protocol. This can be depicted as in Figure 1. Also WMN can become an excellent last-mile option for Wireless Broadband Access. Mesh mode in 802.16 can become a de facto standard in wireless broadband over WAN's and has been considered for providing QoS in [3]. This could become a cheap and simple alternative to wired telephone and cable networks. But there are many important issues [4] such as integrating multiple performance metrics into a routing protocol to achieve an optimal overall performance, scalability of routing protocols, routing for multicast applications, and cross-layer design between routing and MAC protocols.
Routing protocols can be classified into proactive and reactive. Proactive protocols need to maintain routes between all node pairs all the time, while reactive routing protocols only build and maintain routes on demand. Studies have shown that reactive routing protocols perform better in terms of packet delivery ratio and incur lower routing overhead especially in the presence of high mobility.

In WMN, transfer of data takes place to and from the AP. Each node sends route requests to its neighbours. When the requests reach the different APs, they send back a route reply. The sending node receives all these replies and decides which route and AP to use based on different conditions. Since transfer of data in ad-hoc networks is similar to this, the existing ad-hoc routing protocols like DSR and AODV were used. But these protocols assume some properties of ad-hoc networks that are no longer true for WMN. In the case of ad-hoc networks, most of the transfer might be among the different computers in the network itself and the network usage is spread over different routes. Unlike ad-hoc networks, in WMN most of the data transfer is between the nodes and a few APs. Moreover, most of these ad-hoc protocols choose the shortest route to the destination. Some of the paths in the network are more utilized compared to others. Hence, when these protocols are used in WMN it leads to congested routes. Some of the APs are over used while others have a low traffic. This might lead to busy nodes in some routes, while others are rarely used. Presence of overloaded nodes in a route may lead to high collision rates, packet drops in the queue and long delays in waiting at the queues. Also this leads to wastage of the bandwidth. Hence, there is a great demand for an efficient routing protocol for WMN.

2.1 Traffic Balancing

In this routing, nodes are designated as overloaded based on the medium usage around them. If this medium usage exceeds a specific threshold value, then the node can be declared as overloaded. One method of choosing a route is to consider the number of overloaded nodes in a route. The routing protocol can decide the route based on the number of overloaded nodes in each of the available routes. The route with least number of overloaded nodes is chosen as the best route. If two routes have the same number of overloaded nodes, then the one with the lesser number of hops is chosen. But this method is not a sufficient condition to check the load in a route. This is because overloaded nodes might differ in their extent of overloading. Consider the WMN shown in Figure 2.
Assume that node B is the destination AP and node A is source node. If the protocol suggested in [10] is used, then the Route 1 will be chosen as it has lesser number of overloaded nodes. Suppose each node in the network generates a traffic G on its own. Also, assume that all the overloaded nodes have the same medium usage around them. [11] states that the traffic at any node in the route is the cumulative sum of traffic from the previous nodes in the route. Hence by using that rule, traffic serviced by the overloaded node in Route 1 is 5G. In Route 2, the traffic at the two overloaded nodes is G and 2G respectively. Sending such high traffic to an already overloaded node, the average delay spent in this overloaded node may increase and packets may be dropped at a high rate. Also, it may lead to failure of this node. It is better to use Route 2 in this case rather than further loading the overloaded node in Route 1 by sending 5G through it. It is clear here that the cumulative traffic serviced by the node is also an important factor to be considered and it is not enough if only the number of overloaded nodes in the route is considered. Suppose a node on the route is having a lot of collisions around it and if a high traffic is sent towards this node, then a lot of packets will be dropped due to buffer overflow during the back off period. Moreover packets may become invalid due to their long wait time in the queues.

The problem in Traffic Balancing and shortest path routing like AODV is that it is not possible for efficient routing if only one constraint is considered as the various constraints are interrelated in the case of WMN. Moreover lot of bookkeeping is done to keep track of the medium usage around a given node over a period of time. This leads to inefficient routing as route discovery phase takes a long time. To overcome the problems faced in Traffic Balancing, a Fuzzy Multi-Constraint routing is proposed in this paper.

2.2 Fuzzy Routing

In a network like the WMN, the various constraints like collisions, traffic level, buffer occupancy, battery power, etc. need to be considered. It is not enough if only one constraint is considered. This is because of the complex relationship existing between the different constraints. Multi-constrained routing is a NP-complete problem and does not have a polynomial solution. It is required to use various heuristics and soft computing techniques to solve them [12]. A Fuzzy system is best suited in making optimal routing decisions in a network involving multiple constraints and multiple objectives. [13-15] are examples of fuzzy multi-objective routing where a Fuzzy system is implemented over classical methods like DSR to do multi-objective routing. [13] considers a fuzzy system over classical DSR[5]. Routes are decided based on the metrics Node Delay, Node Loss and Node Speed. [14] proposes a fuzzy routing algorithm based on several metrics for a mobile ad-hoc network. [15] considers a fuzzy logic system where unnecessary routes are eliminated by removing links not accepted by the fuzzy logic system. In this paper, we consider a Fuzzy System for making routing decisions in Wireless Mesh Networks where the destination AP is common for several users. Here it is necessary that the traffic gets spread across the system for
maximum bandwidth usage. Various constraints that are considered are Buffer Occupancy, Residual Energy of nodes and the distance of source (hops) from the AP.

3. PROPOSED MULTI CONSTRAINT ROUTING USING FUZZY LOGIC

The block diagram of the proposed Multi constraint routing using fuzzy logic is shown in Figure 3. In this routing, the constraints first undergo fuzzification and are mapped into sets using membership functions. Then the inference engine with the help of the rule base computes the fuzzy output. This fuzzy output is sent back after defuzzification.

3.1.1. Fuzzifier and Membership Function

The membership function of a fuzzy set represents the degree of truth. Fuzzy truth represents membership in vaguely defined sets, not likelihood of some event or condition. Membership functions on any fuzzy input X represent fuzzy subsets of X. In the membership function under consideration, the fuzzy inputs Buffer Occupancy and Hop Count have been divided into three fuzzy subsets – Low, Medium and High. Fuzzifier is the mechanism that is used to map the real-world fuzzy inputs to the range [0,1]. Triangular membership functions as shown in Figure 4 have been extensively used for fuzzification of inputs [14] and for real-time operations as they provide simple formulae and computational efficiency.

3.1.2. Inference Engine and Fuzzy Rule Base

The fuzzy inference engine takes the value of fuzzy inputs at each node and scans through the Fuzzy Rule Base to find the appropriate entry corresponding to the fuzzy inputs to calculate the Fuzzy output cost for each node.

3.1.3. Defuzzifier

Defuzzifier produces a quantifiable result in fuzzy logic. Thus, defuzzifier produces a real-world output from the fuzzy outputs which are in the range [0,1] by using defuzzification techniques. Since the objective of our system is to choose the paths with the best fuzzy cost, it doesn't require the fuzzy outputs to be defuzzified and results can be derived by comparing the fuzzy costs itself. As an example, consider two paths P1 and P2. The better path can be derived as follows without further defuzzifying the fuzzy outputs:

If Fuzzy(P1) < Fuzzy(P2) Better path = P1 else Better path = P2.

Figure 3

The functions performed by various units in the fuzzy controller are explained as follows:

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3.2 Constraints

In this paper, a Fuzzy System is built over the AODV [6] protocol with the following constraints:

(i) **Buffer Occupancy**: The length of buffer is an important indicator of the load serviced by the route. Since nodes in ad-hoc networks are expected to serve traffic for others also, it is expected that they have bigger buffers. For optimal usage of network resources, the buffers should be uniformly used and several nodes alone shouldn’t be overused.

(ii) **Node Residual Energy**: Energy is spent by each node for transmitting and receiving packets. Energy might not be a big issue for fixed hardware like APs as they might have plugged power supply. But it is very crucial in the case of laptops and handheld devices where the battery capacity will be a few thousand joules. Hence, the routing protocol should ensure that the energy of nodes are uniformly used up and not that of specific users. Power-Aware routing is discussed in [16].

(iii) **Hop Count**: As the length of the route increases, the throughput achieved also reduces. So, it is required to ensure that the number of hops is not too high and the route chosen is also not much congested. These two constraints are very important in WMN since here traffic is mainly directed towards the APs.

3.3 Implementation of Fuzzy multi constraint routing

There are 3 phases involved in the implementation of proposed multi constraint routing using Fuzzy logic.

**Phase I: Sending Route Requests**

Whenever a node wants to discover a new route, it sends Route REQuest (RREQ) packets to its neighbors. It starts a time window as soon as it sends this RREQ. This is the time till which it will receive the route replies sent back from the destination node. At each node on the path, the routing constraints are measured. Then the Fuzzy system works as follows:

I. The constraints are divided into sets of Low, Medium and High based on the Membership function for that constraint which is decided by repeated trials and expert analysis.

II. The fuzzy inputs are then fed into the inference engine which decides the Fuzzy Grade of that node with the help of the Rule Base is given in Table 1.
**Table 1**  
For Low Residual Energy

<table>
<thead>
<tr>
<th>HC</th>
<th>BO</th>
<th>LOW</th>
<th>MEDIUM</th>
<th>HIGH</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOW</td>
<td></td>
<td>0.70</td>
<td>0.62</td>
<td>0.51</td>
</tr>
<tr>
<td>MEDIUM</td>
<td></td>
<td>0.43</td>
<td>0.38</td>
<td>0.22</td>
</tr>
<tr>
<td>HIGH</td>
<td></td>
<td>0.12</td>
<td>0.07</td>
<td>0.0</td>
</tr>
</tbody>
</table>

For Medium Residual Energy

<table>
<thead>
<tr>
<th>HC</th>
<th>BO</th>
<th>LOW</th>
<th>MEDIUM</th>
<th>HIGH</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOW</td>
<td></td>
<td>0.88</td>
<td>0.75</td>
<td>0.61</td>
</tr>
<tr>
<td>MEDIUM</td>
<td></td>
<td>0.54</td>
<td>0.42</td>
<td>0.36</td>
</tr>
<tr>
<td>HIGH</td>
<td></td>
<td>0.16</td>
<td>0.10</td>
<td>0.05</td>
</tr>
</tbody>
</table>

For High Residual Energy

<table>
<thead>
<tr>
<th>HC</th>
<th>BO</th>
<th>LOW</th>
<th>MEDIUM</th>
<th>HIGH</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOW</td>
<td></td>
<td>1.00</td>
<td>0.90</td>
<td>0.85</td>
</tr>
<tr>
<td>MEDIUM</td>
<td></td>
<td>0.60</td>
<td>0.50</td>
<td>0.45</td>
</tr>
<tr>
<td>HIGH</td>
<td></td>
<td>0.30</td>
<td>0.20</td>
<td>0.15</td>
</tr>
</tbody>
</table>

The rule base gives the Fuzzy Grade of a given node for various combinations of the fuzzy inputs. The Fuzzy Grade tells about the level of preference given to a node in a route. They are implemented by means of if-then-else clauses, in which the inputs are connected by AND operator. An example can look like the following:

*If (Buffer Occupancy = Low and Residual Energy = High and Hop Count = Low)*

*Fuzzy Grade = High*

**Phase II: Route Reply Phase**

When the RREQ packets arrive at the destination node, it sends back a Route REPly packet (RREP) to the source node, through that given route with the Fuzzy Grade value in its packet header.

**Phase III: Route Decision Phase**

The source node accepts all RREP packets which arrive within the time frame. It then compares the value of Fuzzy Grade to the route already available in its routing table. If the current route has a better value, then this route replaces the one present in the routing table else this RREP is simply dropped.
4. SIMULATION AND PERFORMANCE ANALYSIS

The Network Simulator Version 2 (ns-2) [17] was used for simulating this protocol. The Fuzzy System was implemented on the AODV protocol present in ns 2.29. The network considered is a grid of dimensions 7x7 and each node is separated from the other by a distance of 10 m. The node (7,7) is the Access Point. The network diagram is shown in Figure 5. The MAC used is that of 802.11g [18] with data rate 18Mbps. The transmission range of the antennae is taken as 250m and the Carrier sensing range is 550m. The initial energy of mobile nodes is taken as 1000J. The energy spent for transmitting and receiving are 0.4J and 0.3J respectively. The queues used are Priority Drop tail Queue to give more priority for control packets. Each of the mobile nodes has a TCP connection with the Access Point. The traffic is generated by a constant bit rate (CBR) application with rate 1Mbps. The packet size is 1000 KB.

The nodes are initially placed in the grid above. Then the grid starts moving at different mobility. Then simulation is done for various mobility of the mobile node. In each case, the average throughput achieved per flow, Average RTTs of flows and Routing Overhead is recorded over the period of the simulation which is 100 seconds. The results are compared with that of AODV and Traffic Balancing. The throughput is calculated as the average amount of packets received by the AP from the respective node over time. A Random Waypoint Mobility Model is also considered. According to [19] this model has good spatial distribution. The results are plotted in Figures 6 to 10.

(i) Average Throughput per Flow for different mobility

The average throughputs show that Fuzzy routing has highest values for each velocity since
it always chooses the most optimal path. It is quite stable over the different velocities. Traffic balancing also is quite stable for various speeds but has a lower throughput as the routes are still not optimal. AODV on the other hand is not stable. The throughputs vary in a wide range. This is because the routes chosen are the shortest and mostly unstable. This leads to frequent link failure and rerouting.

(ii) Average Round Trip Time per Flow

![Figure 7](image_url)

Again we see a similar phenomenon as in throughputs. While AODV and Traffic Balancing choose somewhat stable routes, AODV is unstable and has higher delays associated. Average Delays for AODV and Traffic Balancing are almost same as both protocols use diverse routes instead of a few short routes.

(iii) Routing Overhead

![Figure 8](image_url)
Contrary to belief that Fuzzy routing might have more routing overhead because of measuring lots of constraints at each node on the path, it has the least overhead due to routing. It is true that a lot of time is spent initially for setting up of the route. But since Fuzzy routing always leads to stable routes, the routes are used for a longer period. Hence the need for routing is reduced leading to a low routing overhead. AODV on the other hand produces unstable routes leading to frequent routing and lot of overhead.

(iv) Random Waypoint Model – Average Throughput per flow

![Average Throughput per Flow under Random Movement](image)

The best way to study ad-hoc networks is by using random deployment. In this case, the motion is not uniform and is more distributed over the topography of the network. The graphs clearly show that Fuzzy Multi-constraint routing protocol gives better performance compared to Traffic Balancing and Ad-hoc protocol AODV. The performance of Traffic Balancing on the other hand is not satisfactory due to a lot of overhead caused by bookkeeping operations like recording medium usage around a node and is found to perform poorer than AODV in the case of Random Deployment. Moreover, Traffic Balancing might be using very long routes as the load in that route is less which might lead to lower throughputs.

Performance in WMN can be maximized only if multiple interrelated constraints are considered. This is done in Fuzzy Multi-constraint routing and hence it fares better than the Traffic Balancing and AODV. Thus maximum throughput is achieved with Fuzzy Multi-constraint routing.

5. CONCLUSION

Wireless Mesh Networks are becoming a promising option for last mile internet access as their initial infrastructure cost is low. One of the most important factors influencing performance of WMN is the routing protocol used. Existing protocols such as Traffic Balancing select the routes based on its usage and AODV chooses routes based on their length. To maximize the performance of WMN, a multi constraint routing with constraints viz., buffer occupancy, Residual Energy and hop count, using Fuzzy logic is proposed in this paper. Our simulation results show that this Fuzzy based Multi constraint routing outperforms the existing routing algorithms. This is attributed to the fact that Fuzzy routing produces routes that are optimal and stable.
REFERENCES


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