Routing for Wireless Mesh Networks with Multiple Constraints Using Fuzzy Logic

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Abstract: *Since wireless mesh networks are ad-hoc in nature, many routing protocols used for ad-hoc networks like AODV are also used for wireless mesh networks by considering only the shortest route to destination. Since data transfer in wireless mesh networks 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 wireless mesh networks, 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.*

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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 [12] 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 [6]. 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 protocolas in Figure 1.

For streaming of audio and video information, a feasible path is to be chosen based on multiple constraints. This is called multi constraint routing. The constraints can be for a link and/or for a path. In the case of a link, the constraints specify the restrictions for a single link whereas for a path, the constraints are for the entire path (end to end) [16]. In addition to this, other issues such as routing for multicast applications, scalability of routing protocols, cross-layer design between routing and MAC protocols are also under study [10].

This could become a cheap and simple alternative to wired telephone and cable networks. But there are many important issues [10] 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.

2. Routing in WMN

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 [3, 14] only build and maintain routes on demand. Studies [2, 15] 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 neighbors. 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 [3] and AODV [14] were used.

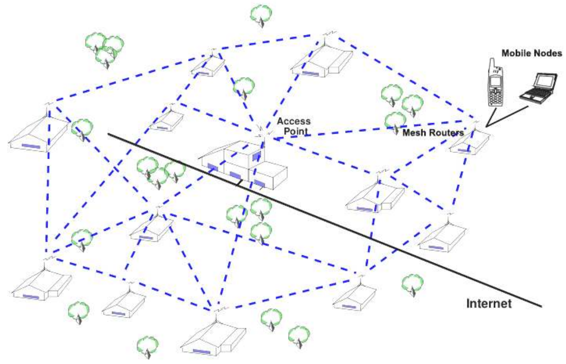

Figure 1. Wireless mesh networks.

But these protocols assume some properties of ad-hoc networks that are no longer true for WMN [1]. 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 [22]. 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 [22] 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. The traffic at any node in the route is the cumulative sum of traffic from the previous nodes in the route [8]. 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.

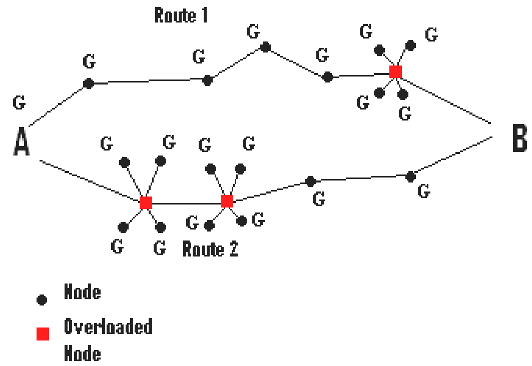

Figure 2. Traffic balancing.

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 [11].

A Fuzzy system is best suited in making optimal routing decisions in a network involving multiple constraints and multiple objectives. There are several studies of fuzzy multi-objective routing where a fuzzy system is implemented over classical methods like DSR to do multi-objective routing. A fuzzy system is considered over classical DSR in [21]. Routes are decided based on the metrics Node Delay, Node loss and node speed. A fuzzy routing algorithm based on several metrics for a mobile ad-hoc network is proposed in [17].

A fuzzy logic system where unnecessary routes are eliminated by removing links not accepted by the system is considered in [19]. An adaptive algorithm based on fuzzy logic to change the security level of the mobile node is proposed in [9].

In this paper, we consider a fuzzy system for making routing decisions in WMN 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.

3.1. Routing with Fuzzy Logic

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.

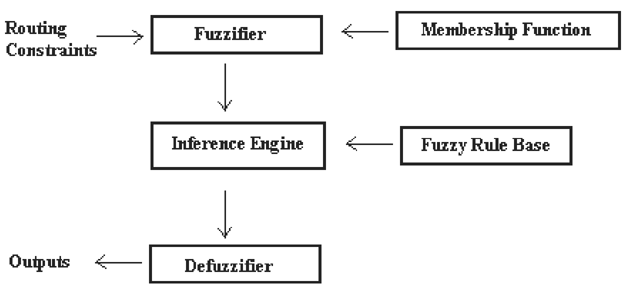

Figure 3. Fuzzy routing.

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

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 [17] and for real-time operations as they provide simple formulae and computational efficiency.

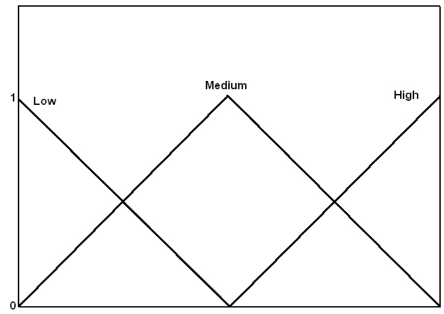

Figure 4. Triangular membership function for buffer occupancy, residual node energy and hop count over a normalized range.

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.

3.2. Constraints

In this paper, a fuzzy system is built over the AODV [5] protocol with the following constraints:

1. *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.

2. *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 [18].
3. *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 1: 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:

  1. 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.
  2. 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.

- *Phase 2: 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 3: 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.

3.3.1. Fuzzy Rule Base

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.

Table 1. Rule base for fuzzy system.

For Low Residual Energy			
HC \ BO	**Low**	**Medium**	**High**
Low	0.70	0.62	0.51
Medium	0.43	0.38	0.22
High	0.12	0.07	0
For Medium Residual Energy			
HC \ BO	**Low**	**Medium**	**High**
Low	0.88	0.75	0.61
Medium	0.54	0.42	0.36
High	0.16	0.10	0.05
For High Residual Energy			
HC \ BO	**Low**	**Medium**	**High**
Low	1.00	0.90	0.85
Medium	0.60	0.50	0.45
High	0.30	0.20	0.15

The rule base used in our fuzzy system gives out a crisp value instead of a fuzzy set. Since our aim is to choose the better routes, we don't need to defuzzify the output to a numerical value. The crisp value represents the fuzzy grade. The crisp values present in the rule base are calculated based on simulation studies and expert knowledge. Instead of the fuzzy rule base, a lookup table can also be used to make routing decisions but it takes time to develop, debug and tune. For example, if we assume that each input requires eight bits, a lookup table would require 3 x 64K entries which make it very time consuming to implement. The fuzzy approach requires significantly less entries than a lookup table depending upon the number of labels for each input variable. Rules are much easier to develop, and simpler to debug and tune compared to a lookup table. An example rule in our fuzzy system can look like the following:

If (Buffer Occupancy = Low and Residual Energy = High and Hop Count = Low)
Fuzzy Grade = 1

4. Simulation and Performance Analysis

The network simulator version 2 (ns-2) [13] 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 [7] with data rate 18Mbps. The propagation model used is TwoRayGround. The transmission range and the carrier sensing range of the Mesh router antennae are taken as 15m. The corresponding threshold is 8.5457e-07. 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 simulations are also done for a UDP based transfer for the same CBR source.

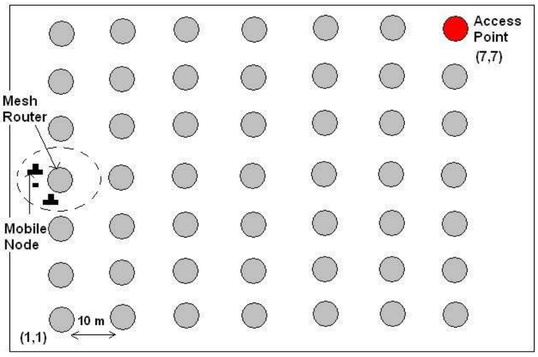

Figure 5. The grid.

The mobile nodes are initially placed under the mesh routers in the grid in Figure 5. Then the mobile nodes start moving under their mesh router at a constant velocity. Then simulation is done for various mobility of the mobile node viz 10m/s, 20m/s and 30m/s. 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. Spatial distribution of this model is studied in [4]. The results are plotted in Figures 6 to 10.

1. *Average Throughput per Flow for Different Mobility*: The average throughput for TCP using different protocols is tabulated in Table 2. The average throughputs show that fuzzy routing outperforms AODV and traffic balancing as it always chooses the optimal path. It has highest values for each velocity since it always chooses the most optimal path. From Figure 6, it can also be inferred that fuzzy routing is quite stable over the different velocities. Though traffic balancing is also quite stable for various speeds, it 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 hence rerouting is required. Figure 7 shows the simulation results for a UDP source attached to the mobile nodes. We see that the results are as expected as UDP is a best effort service.

Table 2. TCP.

Protocol\Speed(m/s)	10	20	30
AODV	139	100	160
Traffic Balancing	160	160	150
Fuzzy Routing	181	161	175

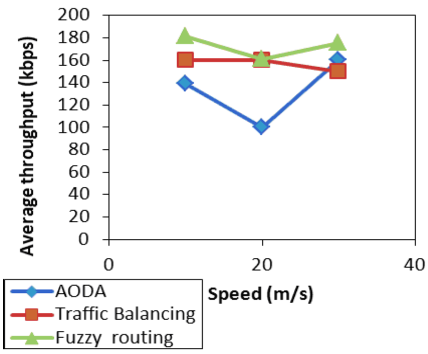

Figure 6. Average throughput per flow TCP.

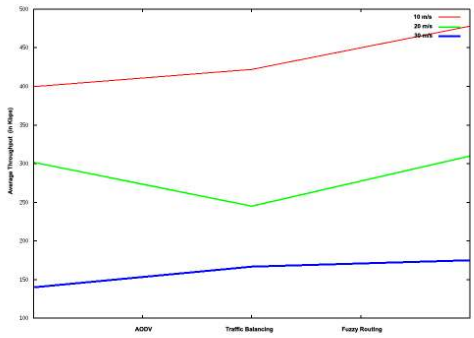

Figure 7. Average throughput per flow UDP.

2. *Average Round Trip Time per Flow*: RTT for different protocols are tabulated in Table 3. 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.

Table 3. RTT.

Protocol\Speed(m/s)	10	20	30
AODV	100	18	72
Traffic Balancing	73	70	75
Fuzzy Routing	73	68	76

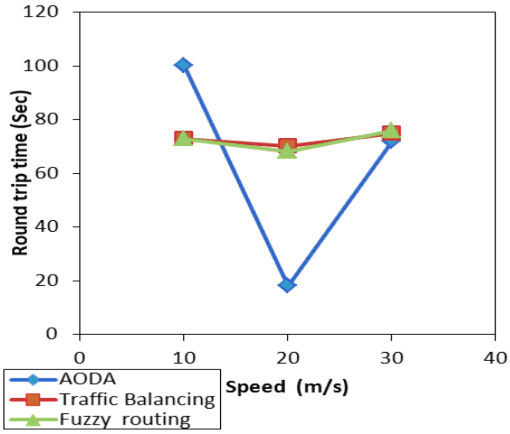

Figure 8. Average RTT per flow.

3. *Routing Overhead*: Table 4 summarizes the routing overhead for different protocols. 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. The best way to study ad-hoc networks is by using random deployment. We have used random waypoint model to study the behavior in random deployment. There are numerous other studies like [20] and [6] which have used random waypoint model for the mobility modeling. In this case, the motion is not uniform and is distributed over the topography of the network. The graphs clearly show that fuzzy multi-constraint routing protocol gives better.

Table 4. Routing overhead.

Protocol\Speed(m/s)	10	20	30
AODV	0.039	0.081	0.027
Traffic Balancing	0.057	0.042	0.037
Fuzzy Routing	0.041	0.039	0.027

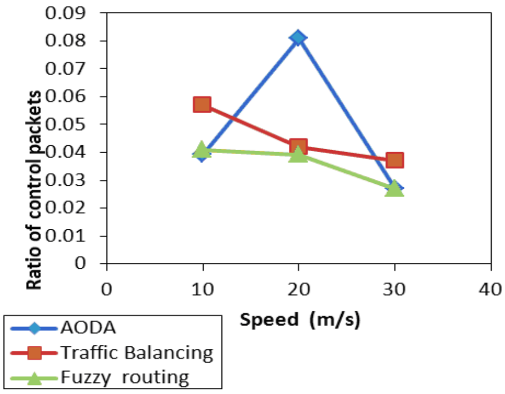

Figure 9. Average routing overhead per flow.

4. *Random Waypoint Model Average Throughput per Flow*: 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.

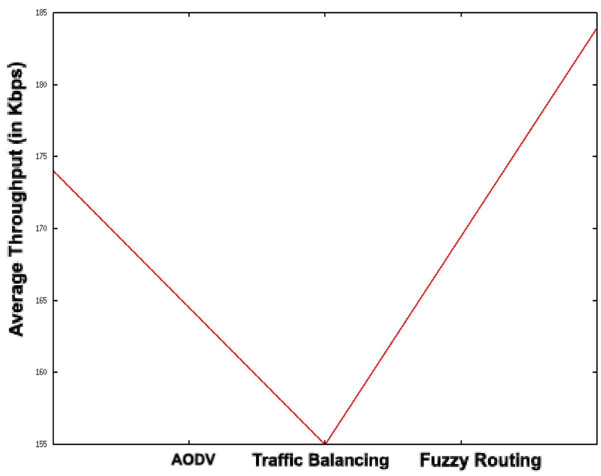

Figure 10. Random movement.

5. Conclusions

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. It always chooses the optimal path for routing with minimum routing overhead, and maximizes the throughput. This is attributed to the fact that fuzzy routing produces routes that are optimal and stable. As such, this reduces the possibilities of congestion in the network.

This work can be extended for group communication in wireless mesh networks.

References

[1] Ann L. and Paul W., "A Study of Routing Algorithms in Wireless Mesh Networks," *in Proceedings of Australian Telecommunication Networks and Applications Conference*, USA, pp. 302-309, 2004.

[2] Broch J., Maltz D., Johnson D., Hu Y., and Jetcheva. J., "A Performance Comparison of Multi-Hop Wireless Ad Hoc Network Routing Protocols," *in Proceedings of the 4th ACM/IEEE International Conference on Mobile Computing and Networking*, USA, pp. 85- 97, 1998.

[3] David B., David A., and YihChun H., "RFC 4728: The Dynamic Source Routing Protocol for Mobile ad hoc Networks," available at: http://www.ietf.org/ internet-drafts/draft-ietf-manet-dsr-10.txt, last visited 2004.

[4] Esa H., Pasi L., and Jorma V., "Spatial Node Distribution of the Random Waypoint Mobility Model with Applications," *IEEE Transactions on Mobile Computing*, vol. 5, no. 6, pp. 680-694, 2006.

[5] Hannan S., Lo W., and Chua A., "A Flexible Quality of Service Model for Mobile Ad-Hoc Networks," *in Proceedings of IEEE 51st Vehicular Technology Conference*, Japan, pp. 445-449, 2000.

[6] Ian F., Xudong W., and Weilin W., "Wireless Mesh Networks: A Survey," *Computer Journal of Networks and ISDN System*, vol. 47, no. 4, pp. 445-487, 2005.

[7] IEEE 802.11g Standard, available at: http://standards.ieee.org/announcements/80211gfinal.html, last visited 2006.

[8] Jangeun J. and Mihail L., "The Nominal Capacity of Wireless Mesh Networks," *IEEE Wireless Communications*, vol. 10, no. 5, pp. 8-14, 2003.

[9] Jing N., Jiangchua W., Ji L., Xin H., and Zheng Z., "An Adaptive Fuzzy Logic Based Secure Routing Protocol in Mobile Ad-Hoc Networks," *Computer of Journal Fuzzy Sets and Systems,* vol. 157, no. 12, pp. 1704-1712, 2006.

[10] Karol K. and Mark D., "Why are there so Many Routing Protocols for Wireless Mesh Networks?," *in Proceedings of Irish Signal and Systems Conference*, Dublin, pp. 1-5, 2006.

[11] Korkmaz T. and Krunz M., "Bandwidth-Delay Constrained Path Selection Under Inaccurate State Information," *IEEE ACM Transactions on Networking*, vol. 2, no. 3, pp. 384-398, 2003.

[12] Mihail L., "Wireless Mesh Networks: Opportunities and Challenges," *in Proceedings of the Wireless World Congress*, CA, pp. 1-6, 2005.

[13] Network Simulator, available at: http://www.isi.edu/nsnam/ns/index.html, last visited 2008.

[14] Perkins C., Belding-Royer E., and Das S., "RFC 3561: Ad-Hoc On-Demand Distance Vector Routing," available at: http://www.ietf.org/rfc/rfc3561.txt, last visited 2003.

[15] Royer E. and Toh C., "A Review of Current Routing Protocols for Ad-Hoc Mobile Wireless Networks," *IEEE Personal Communication*, vol. 6, no. 2, pp. 46-55, 1999.

[16] Shetiya H. and Sharma V., "Algorithms for Routing and Centralized Scheduling to Provide QoS in IEEE 802.16 Mesh Networks," *in Proceedings of IEEE Wireless Communications and Networking Conference*, Las Vegas, NV USA, pp. 140-149, 2006.

[17] Shivanajay M., Dipti S., and Chen T., "Evolutionary Fuzzy Multi-Objective Routing for Wireless Mobile Ad-Hoc Networks," *in Proceedings of Congress on Evolutionary Computation*, Singapore, pp. 1964-1971, 2004.

[18] Suresh S. and Mike W., "Power-Aware Routing in Mobile Ad-Hoc Networks," *ACM/IEEE International Conference on Mobile Computing and Networking*, USA, pp. 181-190, 1998.

[19] Susan R. and Dirk P., "Multi-Metric Routing Decisions for Ad Hoc Networks Using Fuzzy Logic," *in Proceedings of 1st International Symposium on Wireless Communication Systems*, USA, pp. 403- 407, 2004.

[20] Wei P. and XiCheng L., "On the Reduction of Broadcast Redundancy in Mobile Ad-Hoc Networks," *in Proceedings of the 1st ACM International Symposium on Mobile Ad-Hoc Networking and Computing*, USA, pp. 129-130, 2000.

[21] Wong Y. and Wong W., "A Fuzzy-Decision-Based Routing Protocol for Mobile Ad-Hoc Networks," *in Proceedings of 10th IEEE International Conference on Networks*, Singapore, pp. 317-322, 2002.

[22] Xiaojing T., Thomas K., and David F., "Traffic Balancing in Wireless Mesh Networks," *in*

Proceedings of the International Conference on Wireless Networks, *Communications, and Mobile Computing*, USA, pp. 169-174, 2005.

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