Routing in Wireless Mesh Networks Based on Fuzzy Logic

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***Abstract*— Modern wireless communications provides an insight into the different wireless applications in use today. This paper presents a real application of fuzzy logic applied to decision making in Wireless Mesh Networks (WMNs).We propose the use of fuzzy logic in the decision-making processes of the DSR routing protocol, in order to select the best nodes to be part of the routes. In this research work, fuzzy logic improves the selection of routing metrics. It details parameter selection and definition, and fuzzy-rule set design. Finally, we show a complete series of simulation results using MATLab 7.0**

Keywords*— Wireless Mesh Networks, DSR-F, Fuzzy Logic, Fuzzy Rules, AODV

I. INTRODUCTION

Wireless networking is allowing businesses to develop WANs, MANs, and LANs without a cable plant. The IEEE has developed 802.11 as a standard for wireless LANs. The impact of wireless communications has been and will continue to be profound. Very few inventions have been able to "shrink" the world in such a manner. A wireless mesh network (WMN) is a communications network made up of radio nodes organized in a mesh topology. Wireless networks often consist of mesh clients and mesh routers. Mesh routers contain additional routing functionality due to the presence of wireless interface card in them. Wireless mesh networks are most popular wireless networks due to its support for ad-hoc networking, and capability of self-forming, self healing and self organization. Routing in such a wireless network environment is a big challenge due to its design and configuration issues. The design and implementation of routing schemes that are able to effectively and efficiently support information exchange and processing in WMNs is a complex task. Developers must consider a number of theoretical issues and practical limitations such as energy and computation restrictions. A number of research works has been taken out on routing in wireless mesh networks. Mostly the protocols used in wireless ad-hoc networks such as DSR and AODV) are also used in WMN. But no one is compatible to full fill up the desired requirements for WMNs. A number of limitations have been found out by using AODV and DSR for WMN. Such as a limited number of parameters are considered for routing decisions in these protocols. Hence, here a new routing protocol DSR-F (Dynamic Source Routing using Fuzzy) is been proposed.

We propose the use of fuzzy logic in the decision-making processes of the DSR routing protocol, in order to select the best nodes to be part of the routes. In this paper, fuzzy logic improves the selection of routing metrics. It details parameter selection and definition, and fuzzy-rule set design. Finally, we show a complete series of simulation results with the help of fuzzy logic toolkit of MATLab 7.0.

This work is structured as follow, in section I a brief introduction about the technology has been explained. Section II discusses the detailed survey about this research while section III tells us about proposed DSR-F. Section IV explains about the simulation results and discussions about all over the process. At the end of the paper, we conclude this research work.

II. LITERATURE SURVEY

In [2] Pankaj Sharma et al. proposed a DSR Routing Decision technique for MANET. This technique is based on fuzzy logic system. For this, a number of routing metrics have been applied such as node density, pause time, node mobility, number of packets transferred etc. For simulation purposes NS-2 and MAT Lab 7.0 has been used. Here, based on routing metrics, the performance of DSR has been analyzed.

In [3] Taqwa Odey et al. proposed a enhanced AODV routing protocol for mobile ad hoc networks using fuzzy rule based system. Two input variables i.e. hop count and delay is used for the output. Triangular membership functions were used for input and output variables. For performance evaluation purposes, packet delivery ratio, average end-to-end delay, normalized routing load metrics were used. $OMNET^{++}$ 4.0 simulator was used for simulation work.

S.P. Shiva Prakash, T.N. Nagabhushan, Kirill Krinkin has proposed energy aware power save mode in wireless mesh networks [5]. The proposed EAPSM (energy aware power save mode) comprise of energy consumption calculator, transmission mode identifier, PSM (power save mode) Scheduler. Also an algorithm used to schedule PSM of a node has been presented. T.N. Naabhshan et al have proposed a new routing scheme named "minimum battery draining rate aware OLSR (Optimized Link State Routing) scheme for WMNs (Wireless Mesh Networks). In this proposed research work [8], each node declares its willingness value by calculating its own energy status. Based on two metrics named as 'Residual Energy' and 'Draining Rate', MPR Selector works i.e. select the MPRs (Multipoint Relays). In MPR selection process, some of the modules are: create network, install OLSR routing to each node, install RV battery model to each node, calculate available energy, calculate energy draining rate, MPR/Route selection etc. for simulation purposes, network simulator-2 has been used. Also a comparison work of OLSR algorithm and proposed MDRA-OLSR algorithm has been taken out.

Adeel Akram and Mariam Shafqat have proposed a modified AODV protocol [6] for wireless mesh network. To optimize the battery and frequency, AODV protocol has been modified. To remove the conflicts between channel re-use, an algorithm has been implemented in this work. At the last of this research work, a comparison between AODV and proposed modified AODV has been taken.

III. FUZZY INFERENCE SYSTEM

Fuzzy logic is a powerful approach that has demonstrated to be effective when combining with other disciplines such as routing approaches for WMNs. The potential of fuzzy logic goes beyond traditional control systems and can be used on many research fields, allowing multidisciplinary approaches and performance improvements.
The fuzzy logic model is implemented in MATLab utilizing fuzzy logic toolbox. The basic steps of the model are identified of relevant input/output variables, development of fuzzy profile of these input/output variables defining relationships between inputs and outputs variables. Develop fuzzy profile (of identified variables) is the first step in incorporating human knowledge into engineering systems in a systematic and efficient manner.

Input/output variables gathered are fuzzy in nature and is characterized by membership function. We have considered either triangular or trapezoidal membership function, for each variable. Fuzzy membership functions are generated utilizing the linguistic categories such as Low (L), Medium (M) etc identified by a human expert to express his/her assessment. Figure shows membership function and fuzzy profile of all the selected input/output variables for visualization purpose.

Develop fuzzy rule base

The most important part of the FIS is the rules, and how they interact with each other in order to generate results. The rules come from the experts. To develop fuzzy rule base, we can acquire knowledge from different sources such a domain experts, historical data analysis of similar or earlier system, and engineering knowledge from existing literatures.

Information processing phase

In this phase, fuzzy system maps all inputs on to an output. This process of mapping inputs on to output is known as fuzzy inference process or fuzzy reasoning. Basis for this mapping is the number of fuzzy IF-THEN rules, each of which describes the local behavior of the mapping. The Mamdani fuzzy inference system is considered here for all the information processing.

Fuzzification

Fuzzification is the process of making a crisp quantity fuzzy. We do this by simply recognizing that many of the quantities that are consider to be crisp and deterministic are actually not deterministic at all; they carry considerable uncertainty. If the form of uncertainty happens to arise because of imprecision ambiguity, or vagueness, then the variable is probably fuzzy and can be represented by a membership function.

Defuzzification

- Defuzzification of a fuzzy set is the process of "routing it off" from its location in the unit hypercube to the nearest (in a geometric sense) vertex. If one thinks of a fuzzy set as a collection of membership values, or a vector of values on the unit interval, defuzzification reduces this vector to a single scalar quantity.
- Defuzzification is the process of deriving a crisp from a fuzzy set using any defuzzification methods such as centroid, Bisector, Middle of maximum, Largest of maximum, and Smallest of maximum. The most commonly used method is the Centre of area under the curve, is used in here for defuzzification.

Fuzzy set theory: Fuzzy set theory is a generalization of normal set theory and was introduced by Zadeh in 1965. In normal set theory, an object is either a member of a set or net, and the set is often referred to as a crisp set. Fuzzy sets, on the other hand, have degree of membership to that set. Fuzzy set is a set containing elements that have varying degree of membership in the set. Elements of a fuzzy set are mapped to a universe of membership values using a function theoretical form. A normal fuzzy set is one where membership function has at least one element x in the universe where membership value is unity.

IV. DYNAMIC SOURCE ROUTING WITH FUZZY (DSR-F)

The use of fuzzy logic in the decision-making processes is detailed herein in order to select the best nodes to be part of the routes, and the incorporation of a timer when a new RREQ is received, to be able, if necessary, to evaluate several RREQs received (with the same ID and sequence number) and just forward the best of all those, instead of sometimes forwarding a worse RREQ and later a better one, as the traditional DSR does. With this timer we aim to reduce the number of messages used to discover routes, and so the network congestion caused by this high number of messages. The lack of an efficient metric to evaluate node conditions in AODV has been solved by the definition of a new metric based on the combination of different node and network parameters by using a fuzzy-logic system. The idea is to specify the input parameters in natural language and, with the help of a fuzzy-rule set, to define the relationship among different inputs with the output, which represents the suitability or quality of a node to be selected as a part of the incoming route.

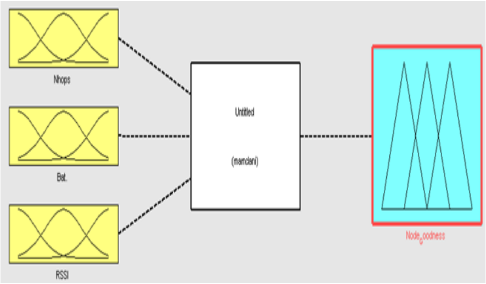

Fig.1: Fuzzy Mechanism for DSR-F

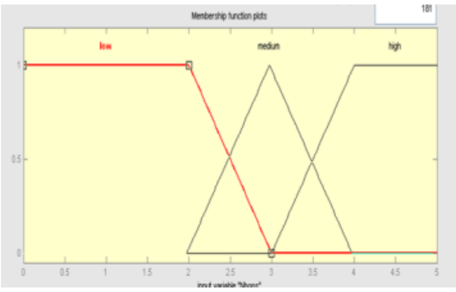

Fig.2: Membership function for Input parameter 'Number of Hops'

The input parameters to be considered are:

• ***Number of hops:*** This is the length of the path. In general, a lower number of hops will represent a better route, but this is not true at all, since it is possible that some nodes in the route have low battery or bad Received Signal Strength Indicator (RSSI), so it is very important to consider more variables to decide the route. This input fuzzy set is shown in Figure. The maximum number of hops observed in our experiments has been 5.

These fuzzy sets can be customized depending on each particular network size.

• ***Local Battery level***: this parameter must be considered in order to avoid nodes with low battery taking part in data paths since they can cause failures in communication. Route construction considering nodes with high energy levels will help to save the energy of low-battery nodes and will cooperate to balance network lifetime. Moreover, the consideration of the battery level will ensure data transmission, preventing nodes in the route from running out of battery.

• ***RSSI (Received Signal Strength Indicator):*** the strength of the received signal is an indicator of the quality of communications between two nodes. In order to ensure quality communications and prevent data loss, data paths will consist of nodes that are able to communicate with a certain level of signal quality. Figure shows the fuzzy sets declared for this variable.

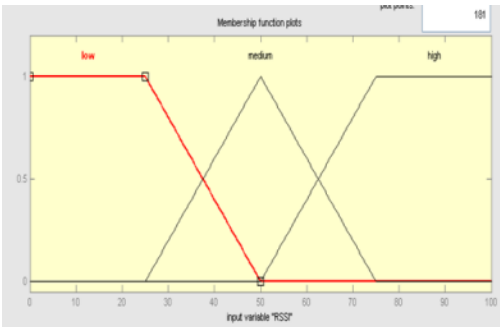

Fig.3: Membership function for Input parameter 'RSSI'

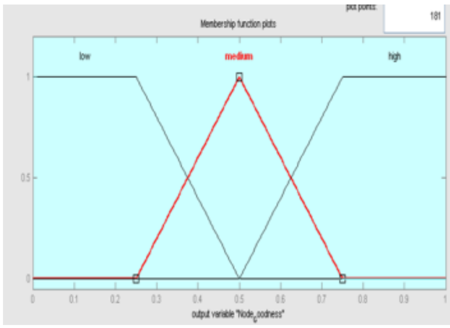

Fig.4: Membership function for Output parameter 'Node Goodness'

The output of the fuzzy system (see Fig. 4) represents the suitability of a node to be considered for inclusion in the route. Input and output sets are combined through a set of rules in order to obtain the corresponding output. Table 1 depicts the fuzzy-rule base used in the experiments. The objective of the fuzzy rules is to serve as a basis to determine, during the route discovery process, the best node to forward its request/reply packet, with the objective of reducing packet overhead and energy consumption.
Fuzzy Rules are explained as below:

Rule 1: IF Nhops is Low and Bat is Low and RSSI is Low is Low THEN Output is Low.

Rule 2: IF Nhops is Low and Bat is Low and RSSI is Medium is Low THEN Output is Low.

Rule 3: IF Nhops is Low and Bat is Low and RSSI is High is Low THEN Output is Medium.

Rule 4: IF Nhops is Low and Bat is Medium and RSSI is Low is Low THEN Output is Low.

Rule 5: IF Nhops is Low and Bat is Medium and RSSI is Medium is Low THEN Output is Medium.

Rule 6: IF Nhops is Low and Bat is Medium and RSSI is High is Low THEN Output is High.

Rule 7: IF Nhops is Low and Bat is High and RSSI is Low is Low THEN Output is Medium.

Rule 8: IF Nhops is Low and Bat is High and RSSI is Medium THEN Output is High.

Rule 9*:* IF Nhops is Low and Bat is High and RSSI is High THEN Output is High.

Rule 10*:* IF Nhops is Medium and Bat is Low and RSSI is Low THEN Output is Low.

Rule 11: IF Nhops is Medium and Bat is Low and RSSI is Medium THEN Output is Low.

Rule 12: IF Nhops is Medium and Bat is Low and RSSI is High THEN Output is Medium.

***Rule 13**:* IF Nhops is Medium and Bat is Medium and RSSI is Low THEN Output is Low.

Rule 14: IF Nhops is Medium and Bat is Medium and RSSI is Medium THEN Output is Medium.

Rule 15: IF Nhops is Medium and Bat is Medium and RSSI is High THEN Output is Medium.

We aim to:

• Reduce the number of packets sent, so reducing the global energy consumption.

• Improve route formation by selecting, at each hop, the best available node, ensuring route stability and avoiding data loss.

• Maintain routing table size, not making the use of extra memory space.

V. SIMULATION RESULTS AND DISCUSSION

To implement the proposed technique, fuzzy logic toolkit of MATLab 7.0 is used here. A number of simulation cases are performed successfully. In this section, 3D decision surfaces and rule viewer (which shows the status of input and output variable values) has been explained in detail.

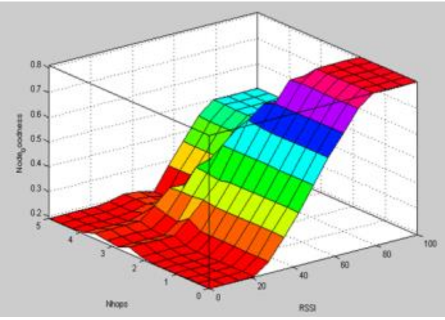

Fig.5 : 'Node Goodness' O/P w.r.t. 'No. of Hops' and 'RSSI'

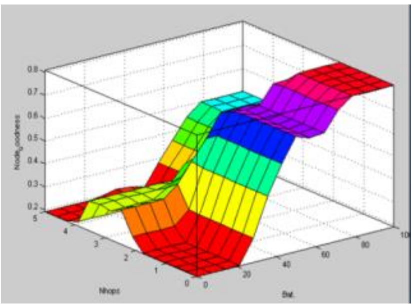

Fig. 6: 'Node Goodness' O/P w.r.t. 'No. of Hops' and 'Battery Level'

In **figure6** the inputs of the protocol (Number of Hops and Battery Level) are on the horizontal axes and the output (Node Goodness) is on the vertical axis.

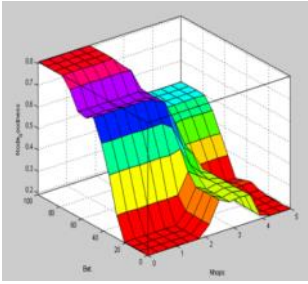

Fig. 7: 'Node Goodness' O/P w.r.t. 'Battery Level' and 'No. of Hops'

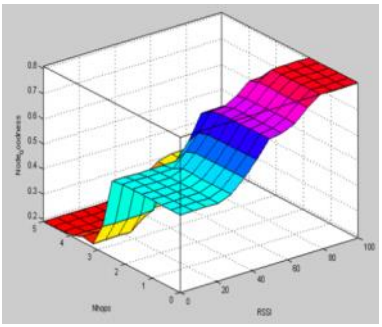

Fig.8 : 'Node Goodness' O/P w.r.t. 'No. of Hops' and 'RSSI'

In **figure 7**the inputs of the protocol (Battery Level and Number of Hops) are on the horizontal axes and the output (Node Goodness) is on the vertical axis. In **figure 8** the inputs of the protocol (Number of Hops and Received Signal Strength Indicator) are on the horizontal axes and the output (Node Goodness) is on the vertical axis.

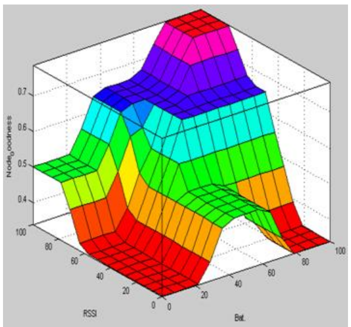

Fig.9 : 'Node Goodness' O/P w.r.t. 'RSSI' and 'Battery Level'

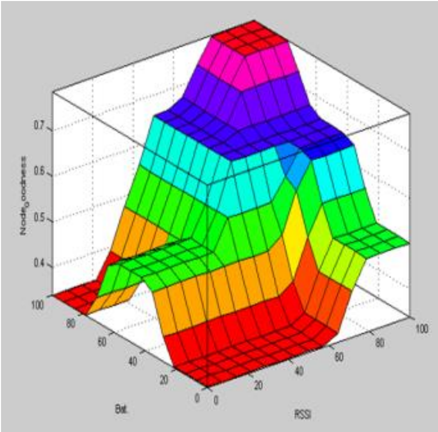

Fig.10 : ‘Node Goodness’ O/P w.r.t. ‘Battery Level’ and ‘RSSI’

In **figure 9** the inputs of the protocol (Received Signal Strength Indicator and Battery Level) are on the horizontal axes and the output (Node Goodness) is on the vertical axis. In **figure10** the inputs of the protocol (Battery Level and Received Signal Strength Indicator) are on the horizontal axes and the output (Node Goodness) is on the vertical axis.

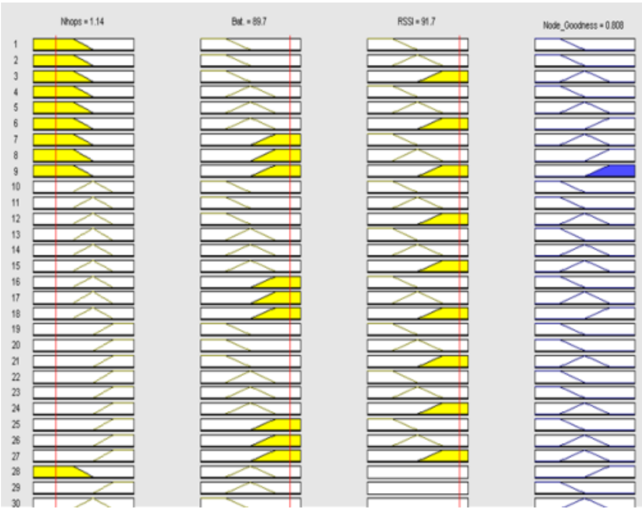

Fig.11:Fuzzy Rule Viewer

In figure 11, Fuzzy rule viewer has been shown. Here Input variables (Nhops=1.14, Bat. =89.7, RSSI=91.72) and output variable (Node Goodness=0.808) are shown.

A number of test cases have been conducted for performance evaluation with the help of Fuzzy Logic tool kit of MATLab 7.0. In table 1, the values of input variables (‘Number of Hops’, ‘Battery Level’, and ‘Received Signal Strength’) with respective output variable ‘Node’s Goodness’ are mentioned.

Table 1: Test Cases

Test Case No.	Nhops	Bat.	RSSI	Output
1.	2.5	50	50	0.655
2.	.801	67	36.8	0.54
3.	.801	67	90	0.752
4.	3.23	67	93	0.623
5.	.679	56.7	93	0.797
6.	3.86	56.7	20.2	0.2.3
7.	3.86	84.3	13.6	0.198
8.	4.69	68.3	13.6	0.205
9.	4.69	68.34	91.72	0.41
10.	1.142	6.33	41.39	0.209
11.	1.14	6.33	8.94	0.192
12.	1.14	6.33	91.7	0.5
13.	1.14	89.7	91.72	0.808
14.	3.66	89.7	91.72	0.808

1. At average no. of hops, average battery level, and medium RSSI, the node’s goodness is medium.
2. But when number of hops are low, but battery level is increasing,, but RSSI is decreasing, the node’s goodness go to its down position.
3. Also at constant number of hops, at constant battery level and high RSSI, the node’s goodness is high.
4. At constant battery level and constant RSSI, when increasing the number of hops, then as a result node’s goodness is decreasing.
5. At constant number of hops, and increasing the battery level and decreasing the value of RSSI, the node’s goodness also decreasing.
6. At constant number of hops, at constant battery level, when RSSI is increasing, the output node’s goodness is also increasing.
7. At constant battery level and constant RSSI when numbers of hops are increasing, the value of node’s goodness remains constant.
8. At last DSR-F works well at medium value of number of hops and also at medium value of battery level. But value of RSSI (Received Signal Strength Indicator) direct effects on node’s goodness.

VI. CONCLUSIONS AND FUTURE RESEARCH

This paper details the use of fuzzy logic to improve the routing protocol used in mesh networks, DSR. The use of fuzzy logic as a metric in network routing improves the performance of real networks. DSR-F uses this metric, achieving an energy reduction of 70% in network route creation, due to a considerable reduction in the number of

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RREQs generated, reducing collisions and the end-to-end delay. In contrast with other proposals that require additional memory or processing costs, the use of fuzzy logic does not imply an extra load on the system, and it improves the performance of the intelligent dense monitoring of physical environments.

Simulation experimental work endorses the suitability of DSR-F for implementation in real wireless mesh networks. Future research can be oriented to the addition of new parameters to the fuzzy logic system, studying the performance achieved by these new variables, such as the number of child nodes, or node density. The use of fuzzy logic in other layers, such as the MAC layer, will help to provide priority in the contention period to those nodes with better conditions.

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