Energy Optimization Routing Technique for Wireless Mesh Networks

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Abstract -- **Wireless Mesh Networks (WMNs) are an emerging trend in wireless communication: more flexible, reliable and effective than the other competitive wireless technologies. In this paper, we present a generalized fuzzy logic and cluster based architecture based scheme for energy aware routing in wireless mesh networks. Here, we considered a cluster-based architecture for WMN, where a group of nodes is managed by a gateway. To determine the value of cost for a link between two mesh nodes, a fuzzy logic approach has been used. Six input variables are applied to find out the one output variable cost in our proposed fuzzy rule system. In recent years, many approaches and techniques have been explored for the optimization of energy usage in wireless mesh networks. In this paper, we propose a novel routing scheme for 802.11 based wireless mesh networks called Energy-aware Routing Scheme (ERS). The design objective of ERS is to minimize the overall energy consumption in the mesh network. Routing is one of these areas in which attempts for efficient utilization of energy have been made. In this paper, we present a generalized fuzzy logic based approach for energy-aware routing in wireless mesh networks. The proposed approach is thoroughly evaluated and shown to outperform previous approaches substantially in terms of energy consumption.**

Keywords: Wireless Mesh Networks, Fuzzy logic, Routing.

I. INTRODUCTION

WIRELESS Mesh networks (WMNs) are dynamically self organized with the nodes in the network automatically establishing an ad hoc network and maintaining the mesh connectivity. The fundamental features of WMN are large capacity, wide area coverage and high transmission speed. Wireless mesh network configures itself and because of its cost effectiveness, is seen as a solution for the next generation networks. In wireless mesh networks, each mesh node operates both as router and forwarding node for the delivery of packet to desired destination. All nodes maintain profile information of all the others nodes in the network for further processing of routing of packets. These mesh nodes have limited battery energy that is continuously decaying during the process of transmission, forwarding and receiving of packets. Various approaches for optimizing the energy usage in wireless mesh networks have been proposed.

In this paper, we present a fuzzy model for energy aware routing in wireless mesh networks. Existing proposed routing protocols for WMNs use fixed (crisp) metrics for making energy-aware routing decisions. This has the disadvantage of not being easily adaptive to changes in mesh node types because energy metrics vary widely with the type of mesh node implementation platform. Moreover, some of the factors for calculating routing metric are conflicting. For example, short multiple-hops reduces transmission power but results in greater number of hops thereby reducing the energy of a larger number of nodes involved in relaying. Fuzzy logic, on the other hand, has potential for dealing with conflicting situations and imprecision in data using heuristic human reasoning without needing complex mathematical modeling. The potential of fuzzy logic is being fully explored in the fields of signal processing, speech recognition, aerospace, robotics, embedded controllers, networking, business and marketing.

Here, we present a soft computing based approach to energy optimized routing using fuzzy variables and rule base. This results in soft accommodating way of routing in WMNs capable of handling a wide range of energy metrics of different mesh node implementation platform.

We have assumed a cluster-based architecture for WMN, where a group of nodes is managed by a gateway. Various criteria for cluster-formulation have been proposed but in this paper our focus is on routing within a cluster. The gateway is responsible for the management of nodes in its cluster, communicating with other gateways, processing of data received from mesh nodes and transmitting the processed data to the command center. We have assumed that the gateway is much powerful as compared to mesh nodes and has no energy limitation. Moreover, the routing is centralized, i.e., the gateway sets routes for mesh nodes. All mesh nodes have one destination namely the gateway, reachable via various routes through multiple-hops over mesh nodes. The remaining of this paper is structured as follows. Section II summarizes the related work. In section III we describe our system model. We present our fuzzy model in section IV. Simulation results are presented in section V. Section VI concludes our paper.

II. LITERATURE SURVEY

Sara MAMECHAOUI *et al.* [11] proposed energy efficiency cross layer protocol for wireless mesh network. This protocol is based on Green Networking. This proposed cross layer protocol is implemented in time division multiplex (TDM) access based WMN MAC protocol. Also a comparative analysis of AODV, DSDV, AOMDV in respect of routing categories, route maintained in, discovery of necessary route, necessary periodic update, update from, uses 'Hello' message, route inserted into the header of the packet, uses timer route, multiple route available. Keeping in view the limitations in these protocols, a new cross- layer protocol for WMN has been proposed. For simulation purposes, network simulation-2 has been applied.S.P. Shiva Prakash, T.N. Nagabhushan, Kirill Krinkin has proposed energy aware power save mode in wireless mesh networks [12]. 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. Tarique Haider and Marian Yusuf have argued a fuzzy approach for energy optimized routing in WSN (wireless sensor network). The proposed approach [4] is based on cluster technique and fuzzy logic system. The gateway is responsible for the management of nodes in its cluster. The one gateway can communicate to another gateway. Cluster based architecture has been assumed for wireless sensor network. To calculate the cost for a link between two sensor nodes, fuzzy model approach has been applied. For the proposed fuzzy model, 144 rules have been generated. Here six input variables transmission energy, remaining energy, rate of energy consumption, queue size, distance from gateway and weight are used to find out one output variable 'cost'. MatLab 7.2 has been used for simulation purposes. Adeel Akram and Mariam Shafqat have proposed a modified AODV protocol [7] 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. S.P. Shiva Prakash, T.N. Nagaabhushan, and Kirill Krinkin [12] have proposed an energy aware power save mode scheme WMN (wireless mesh network). In this proposed work, EAPSM (Energy Aware Power Save Mode) has been generated to overcome the deficiency of low PDR. Remaining energy calculator, transmission mode identifier and PSM scheduler are the three modules for EAPSM. The researcher argued that the EAPSM enhance the quality of service (QoS) by the increase of PDR when compared to conventional (Power Supply Mode) PSM. Maria Zogkon *et al*. have proposed a energy aware new metric in IEEE 802.11s Wireless Mesh Networks. The proposed metric takes into account the residual energy of a node by calculating the total energy consumed by a node. K.Sasikala and V.Rajamani [2] have proposed a fuzzy logic based routing approach for wireless mesh network. Here, a fuzzy logic system based algorithm has been proposed to provide the best optimal best case performance. For simulation purposes, network simulator-2 has been applied. A comparison between proposed routing protocol and obvious routing protocol has been done.

III. SYSTEM MODEL

Cluster-based routing has been shown to be quite effective in wireless mesh networks. WMN is usually formed for a specific application; gateways can be chosen to be much powerful as compared to the mesh nodes. This relieves the energy-constrained mesh nodes of communicating directly with the remote sink. In this paper, we have assumed a cluster-based architecture for WMN, where a group of nodes is managed by a gateway. The gateway can communicate directly with all the mesh nodes and can retrieve their status. All mesh nodes have one destination namely the gateway to which they send their received data. Nodes can communicate directly with the gateway but this will be very costly for those nodes which are not close to the gateway. Therefore, the gateway is also reachable via various routes through multiple-hops over mesh nodes in the network. The gateway is responsible for setting up of routes for mesh nodes and for the maintenance of the centralized routing table that indicates the next hop for each mesh node. Gateway periodically invokes the fuzzy routine to determine the cost of link between any two mesh nodes. Once the costs of all possible links to the single destination (gateway) are computed using fuzzy logic, the route can then be determined using any shortest path algorithm. We have used Dijkstra's algorithm for our simulation. Routing table entries are periodically refreshed to reflect the updated state of the network. We have further assumed that the gateway is much powerful as compared to mesh nodes and has no energy limitation. In this paper, we have not considered the issues of cluster formation, routing between gateways and energy optimization of gateways as our main focus is on effective energy optimized routing within the cluster. We have used Heinzelman's energy model for sensor networks.

IV. FUZZY MODEL

*Overview of Fuzzy Logic***:** Fuzzy Logic is used in this work as main implementation of perceptive reasoning. Fuzzy logic imitates the logic of human thought, which is much less rigid than the calculations computers generally perform. Fuzzy Logic offers several unique features that make it a particularly good alternative for many control problems. It is inherently robust since it does not require precise, noise-free inputs and can be programmed to fail safely. The output control is a smooth control function despite a wide range of input variations. Since the FL controller processes user defined rules governing the target control system, it can be modified and tweaked easily to improve or drastically alter system performance. Fuzzy Logic deals with the analysis of information by using fuzzy sets, each of which may represent a linguistic term like "Warm", "High" *etc*. Fuzzy sets are described by the range of real values over which the set is mapped, called domain, and the membership function. A membership function assigns a truth value between 0 and 1 to each point in the fuzzy set's domain. Depending upon the shape of the membership function, various types of fuzzy set can be used such as triangular, beta, PI, Gaussian, sigmoid *etc*. A Fuzzy system basically consists of three parts: fuzzifier, inference engine, and defuzzifier. The fuzzifier maps each crisp input value to the corresponding fuzzy sets and thus assigns it a truth value or degree of membership for each fuzzy set. The fuzzified values are processed by the inference engine, which consists of a rule base and various methods for inferring the rules. The rule base is simply a series of IF-THEN rules that relate the input fuzzy variables with the output fuzzy variables using linguistic variables, each of which is described by a fuzzy set, and fuzzy implication operators AND, OR *etc*. The part of a fuzzy rule before THEN is called predicate or antecedent, while the part following THEN is referred to as consequent. The combined truth of the predicate is determined by implication rules such as MIN-MAX (Zadeh) and bounded arithmetic sums. All the rules in the rule-base are processed in a parallel manner by the fuzzy inference engine. Any rule that fires contributes to the final fuzzy solution space. The inference rules govern the manner in which the consequent fuzzy sets are copied to the final fuzzy solution space. Example, techniques are MIN-MAX and fuzzy adaptive method. The defuzzifier performs defuzzification on the fuzzy solution space. That is, it finds a single crisp output value from the solution fuzzy space. Common defuzzification techniques are centroid, composite maximum, composite mass, *etc.*

A. Description

The objective of our fuzzy routine is to determine the value of cost for a link between two mesh nodes such that the life of a mesh network is maximized. The lifetime of wireless mesh networks is generally defined as the time when the energy level of the first mesh node becomes zero. The fuzzy rule base has been tuned so as to not only extend the life time of the mesh network but also to balance the routing load among mesh nodes effectively so that a maximum number of nodes have sufficient energy to continue performing their own receiving tasks.

The input fuzzy variables are:

- Transmission Energy—low, high
- Remaining Energy—low, medium, high
- Rate of Energy Consumption—low, medium, high
- Queue Size—small, large
- Distance from gateway –small, large
- and weight—small, large

- The rule base therefore consists of 2^4 x3^2 =144 rules.
- Output variable Cost—svery low, low, low medium, high medium, high, very high
- There is a single output fuzzy variable, namely cost the defuzzified value of which determines the cost of link between two mesh nodes.

In determining the cost of link from node *x* to node *y*,
"Transmission Energy" represents the energy needed to transmit a data packet from node *x* to *y.* Lower value of transmission energy leads to lower link cost.
"Remaining Energy" indicates the energy level of node *y*. Nodes with less value of remaining energy should be avoided in being selected as next-hop. Consequently, it slower value results in a higher link cost.
"Energy Consumption rate" of node *y* is another important parameter. It is possible to have a node with a high value of initial energy, resulting in a higher value of remaining energy in spite of its high rate of energy consumption. Nodes with high rate of energy consumption are, therefore, assigned higher link costs.

The fuzzy input variable ***"Distance from the gateway"*** enables selection of routes with minimum hops. Nodes nearer to the gateway are thus assigned lower link cost.

Each mesh node is assigned a dynamic ***weight*** depending upon its current status. This parameter helps in selecting nodes which are either inactive or are only in the receiving state. Thus, a high value of weight makes the node favorable for next-hop, resulting in a lower value of link cost. The input fuzzy variable ***"queue size"*** indicates the buffer capacity at node *y*. This parameter helps avoid packet drops due to congestion at the receiver. The output fuzzy variable consists of six membership functions. A cost between 0 and 1 is assigned to each link. The domains of input fuzzy variables have been selected according to our simulation environment, but they can be easily modified to make them general purpose. MIN-MAX inference technique has been used in the fuzzy controller. To find a crisp output value from a solution fuzzy region, the controller uses Centroid Defuzzification method. Centroid defuzzification finds the balance point of the solution fuzzy region by calculating the weighted mean of the fuzzyregion. Our rule base consists of 144 rules. A few rules are explained as below:

Rule 1: If TE is Low and RE is High and EC is Low and QS is Small and DG is Small and Weight is Large Then Cost is VL.

Rule 2: If TE is Low and RE is High and EC is Medium and QS is Small and DG is Small and Weight is Large Then Cost is VL.

Rule 3: If TE is Low and RE is High and EC is Medium and QS is Small and DG is Large and Weight is Large Then Cost is L.

Rule 4: If TE is Low and RE is High and EC is Low and QS is Small and DG is Large and Weight is Large Then Cost is L.

Rule 5: If TE is Low and RE is High and EC is Low and QS is Large and DG is Large and Weight is Large Then Cost is LM.

Rule 6: If TE is Low and RE is Medium and EC is High and QS is Small and DG is Small and Weight is Large Then Cost is LM.

Rule 7: If TE is Low and RE is Medium and EC is Medium and QS is Large and DG is Small and Weight is Small Then Cost is HM.

Rule 8: If TE is High and RE is Medium and EC is Low and QS is Small and DG is Small and Weight is Small Then Cost is HM.

Rule 9: If TE is High and RE is Medium and EC is Medium and QS is Large and DG is Small and Weight is Small Then Cost is H.

Rule 10: If TE is High and RE is Medium and EC is Medium and QS is Large and DG is Large and Weight is Large Then Cost is H.

Rule 11: If TE is High and RE is Low and EC is Low and QS is Small and DG is Small and Weight is Large Then Cost is VH.

Rule 12: If TE is High and RE is Low and EC is Medium and QS is Small and DG is Large and Weight is Small Then Cost is VH.

Rule 13: If TE is High and RE is Low and EC is High and QS is Large and DG is Small and Weight is Large Then Cost is H.

Rule 14: If TE is High and RE is Low and EC is Low and QS is Small and DG is Large and Weight is Large Then Cost is HM.

The rules have been formulated according to the criteria described above. The input fuzzy variables have been denoted by TE, RE, EC, QS, DG and WEIGHT. These represent the input fuzzy variables viz., transmission energy, remaining energy, rate of energy consumption, queue size, distance from gateway and weight respectively. The output fuzzy variable is denoted by COST.

V. SIMULATION RESULTS

The Proposed fuzzy system and clustered routing approach in wireless mesh network is implemented in Matlab 7.0. We used dynamically created network topology based on arbitrary number nodes. All links are bi-directional with different parameters (explaining the links status and network topology) for different directions. Network topology, connectivity and number of nodes are changeable and user can define them through appropriate Graphic User Interface. Each link is described with six parameters: transmission energy, remaining energy, rate of energy consumption, queue size, distance from gateway, weight. All values for all parameters are randomly generated and scaled to the interval [0-1].

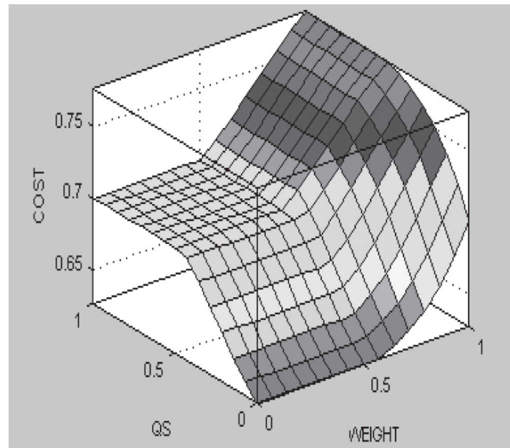

Figure 1. 'COST' O/P w.r.t. 'QS' and 'WEIGHT'.

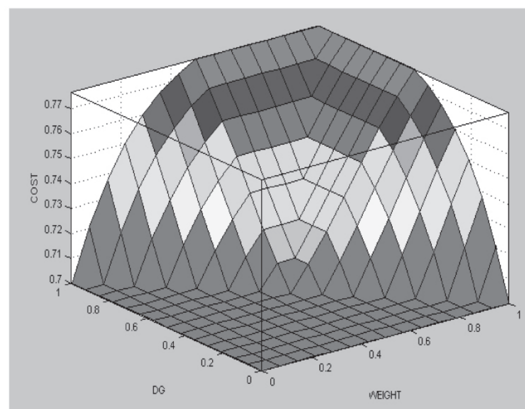

Figure 2. 'COST' O/P w.r.t. 'DG' and 'WEIGHT'.

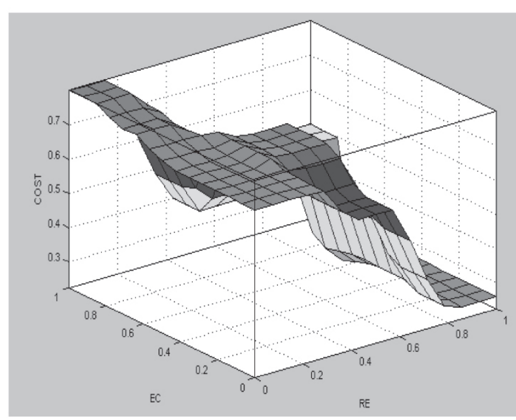

Figure 3. 'COST' O/P w.r.t. 'EC' and 'RE'.

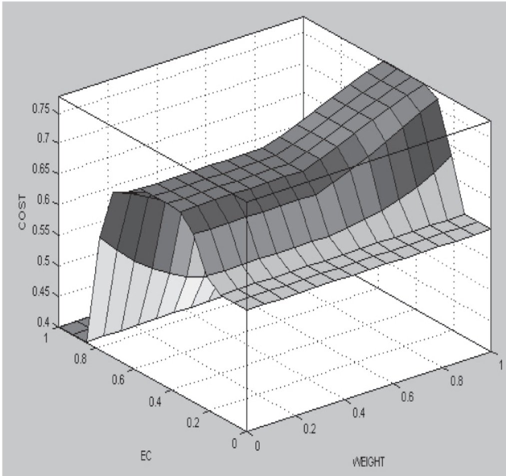

Figure 4. 'COST' O/P w.r.t. 'EC' and 'WEIGHT'.

In **figure 1** the inputs of the protocol (queue size and weight) are on the horizontal axes and the output (cost) is on the vertical axis. In **figure 2** the inputs of the protocol (distance from gateway and weight) are on the horizontal axes and the output (cost) is on the vertical axis. In **figure 3** the inputs of the protocol (rate of energy consumption and remaining energy) are on the horizontal axes and the output (cost) is on the vertical axis. In **figure 4** the inputs of the protocol (rate of energy consumption and weight) are on the horizontal axes and the output (cost) is on the vertical axis.

A number of test cases have conducted. Some of them have been explained with their respective parameters:

TABLE 1: TEST CASES

Test Case No.	TE	RE	EC	QS	DG	WEIGHT	COST
1.	0.891	0.121	0.914	0.11	0.856	0.362	0.80
2.	0.0862	0.925	0.511	0.715	0.983	0.0617	0.281
3.	0.054	0.814	0.471	0.678	0.83	0.051	0.195

- The simulation results shows that when value of transmission energy is high, remaining energy is low, rate of energy consumption is high, queue size is small, distance from gateway is high, weight is small then as a result cost of link between mesh nodes is high.
- Also simulation indicates that when transmission energy is low, remaining energy is high, rate of energy consumption is medium, queue size is large, distance from gateway is high, weight is small, and then as a result cost of link between mesh nodes is low.
- Also it has been analyzed that cost of link between mesh nodes is very low when remaining energy is high, but when remaining energy is low, the link cost between mesh nodes is high and very high and so on.

VI. CONCLUSION

WMN is a novel emerging technology that will change the world more efficiently. It is regarded as a highly promising wireless technology. In this paper we introduced a novel approach for energy aware routing based on fuzzy system for WMN. We have presented a novel fuzzy model for energy optimized routing in wireless mesh networks. Our simulation work has been implemented in MATLab 7.0. The simulation results represent the reliability and efficiency of this approach.

VII. REFERENCES

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