Cluster-Head Fuzzy Routing for Mobile Ad-hoc Networks

K. Venkata Subbaiah[1], M.M. Naidu[2], Ch.D.V. Subba Rao[3]

Abstract

Mobile ad-hoc networks operate in the absence of any supporting infrastructure. The absence of any fixed infrastructure in mobile ad-hoc networks makes it difficult to utilize the existing Techniques for network services, and poses number of various challenges in the area. The discovery and maintenance of energy aware routing is most flinty challenge.

In recent years, many approaches and techniques have been explored for the optimization of energy usage in Mobile Ad-hoc networks. Routing is one of these areas in which attempts for efficient utilization of energy have been made. These attempts use fixed (crisp) metrics for making energy-aware routing decisions. In this paper, we present a novel generalized fuzzy, logic-based approach for energy aware routing in Mobile Ad hoc networks. This generalized approach is soft and tunable and hence it can accommodate ad hoc networks comprising of different types of Mobile nodes.

Key words : Mobile ad-hoc networks, Routing, Fuzzy logic, Cluster-head routing

1. Introduction

A mobile ad hoc network consists of a set of mobile nodes that are connected by wireless links. The network topology in such a network may keep changing randomly. Routing protocols that find a path to be followed by data packets from a source node to a Destination node used in traditional wired networks cannot be directly applied in ad hoc wireless network due to their highly dynamic topology, absence of established infrastructure for centralized administration bandwidth constrained wireless links, and Resource (energy) constrained nodes. A variety of Routing protocols for ad hoc wireless networks has been proposed in the recent past.

Mobile nodes in MANET'S are battery operated and once deployed are unattended and expected to operate for a long period of time. Thus, energy is a scarce resource in a MANET'S and hence its efficient usage is crucial for extending the life of the whole MANET. A Mobile node's energy is mainly consumed in the three main activities: sensing, computing and communicating. Various approaches for optimizing the energy usage in wireless Mobile networks have been proposed [2][3][4]. These include physical-level design decisions such as modulation scaling, voltage scaling etc. to energy-aware routing and energy-aware MAC protocols [5][6][9].

In this paper, we present a novel fuzzy model for energy-aware routing in MANET'S. Existing proposed routing protocols for MANET'S use fixed (crisp) metrics for making energy-aware routing decisions [7][8]. This has the disadvantage of not being easily adaptive to changes in mobile nodes because energy metrics vary widely with the type of mobile node implementation platform [10]. Moreover, some of the factors for calculating routing

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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 [11].

We have assumed a cluster-based architecture for MANET, where a group of nodes is managed by a gateway. Various criteria for cluster-formation 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 sensor nodes and transmitting the processed data to the command center. We have assumed that the gateway is much powerful as compared to mobile nodes and has no energy limitation. Moreover, the routing is centralized in which the gateway sets routes for mobile nodes. All mobile nodes have one destination namely the gateway, reachable via various routes through multiple-hops over mobile nodes.

The remaining of this paper is structured as follows: Section 2 summarizes the related work. In Section 3 we describe our system model. We present our Fuzzy model in Section 4. Simulation results are presented in Section 5. We conclude our paper in Section 6.

2. Related Work

The cluster-head gateway switch routing protocol (CGSR) (41) uses a hierarchical network topology, unlike other table-driven routing approaches that employ flat topologies. CGSR organizes nodes into clusters, with coordination among the members of each cluster entrusted to special node named cluster-head. This cluster-head is elected dynamically by employing a leas cluster change (LCC) algorithm (41). According to this algorithm, a node ceases to be cluster-head only if it comes under the range of another cluster-head, where the tie is broken either using the lowest ID or highest connectivity algorithm. Clustering provides a mechanism to allocate bandwidth, which is a limited resource, among different clusters, thereby improving reuse. For example, different cluster-heads could operate on different spreading codes on CDMA system. Inside a cluster, the cluster-head can coordinate the channel access base on a token-based polling protocol. All member nodes of a cluster can be reached by the cluster-head within a single hop, thereby enabling the cluster-head to provide improved coordination among nodes that fall under its cluster. A token-based scheduling (assigning access token to the nodes in a cluster) is used within a cluster for sharing the bandwidth among the members of the cluster. CGSR assumes that all communication passes through the cluster-head. Communication between two clusters takes place through the common member nodes that are members of both the clusters. These nodes which are members of more than one cluster are called gateways. A gateway is expected to be able to listen to multiple spreading codes that are currently in operation in the clusters in which the node exists as a member. A gateway conflict is said to occur when a cluster-head issues a token to a gateway over a spreading code while the gateway is tuned to another code. Gateways that are capable of simultaneously communicating over two interfaces can avoid gateway conflicts.

The performance of routing is influenced by token scheduling and code scheduling (assigning appropriate spreading codes to two different clusters) that are handled at cluster-heads and gateways, respectively. The routing protocol used in CGSR is an extension of DSDV. Every member node maintains a routing table containing the destination cluster-head for every node in the network. In addition to the cluster member table, each node maintains a routing table which keeps the list of net-hop nodes for reaching every destination cluster. The cluster (Hierarchical) routing protocol is used here. As per this protocol, when a node with packets to be transmitted to a destination gets the token from its cluster-head, it obtains the destination cluster-head and the next-hop node from the cluster member table and the routing table, respectively. CGSR improves the routing performance by routing packets through the cluster-heads and gateways. Cluster-heads gain more opportunities for transmission, the cluster-heads, by means of a dynamic scheduling mechanism, can make CGSR obtain better delay performance for real-time flows. Route reconfigure-tion is necessitated by mainly two factors: firstly, the change in cluster-head and secondly, the stale entries in the cluster member table and routing table. CGSR depends on the table update mechanism to handle the latter problem, while the least cluster algorithm (41) handles the former.

CGSR is a hierarchical routing scheme which enables partial coordination between nodes by electing cluster-heads. Hence, better bandwidth utilization is possible. It is easy to implement priority scheduling schemes with token scheduling and gateway code scheduling. The main disadvantages of CGSR are increase in path length and instability in the system at high mobility when the rate of change or cluster-heads is high. In order to avoid gateway conflicts, more resources (Such as additional interfaces) are required. The power consumption at the cluster-head node is also a matter of concern because the battery-draining rate at the cluster-head is higher than that at a normal node. This could lead to frequent changes in the cluster-head, which may result in multiple path breaks.

Among the various approaches that have been proposed in literature for minimizing the energy usage in MANET, energy-aware routing attempts to extend the life of a MAET at network layer. Energy-efficient routes can be computed using either the minimum energy path, maximum residual energy path, path with minimum number of hops to sink etc. [2]. Chang et al [16] have argued that always selecting the route with minimum energy will quickly deplete the energy of Mobile nodes on the minimum energy path, thereby decreasing the life of MANET. Rahul et al.[12] have presented an energy aware routing protocol that keeps a set of minimal energy paths and randomly selects one of these sub-optimal paths, thereby significantly in increasing network lifetime. In [16], the problem of maximizing network lifetime by energy-aware routing has been formulated as integer-programming problem, whereas in' [17] convex non-linear optimization techniques have been Used. Jain et al [14] have presented an energy-aware multi-path routing approach that attempts to spread the traffic over the

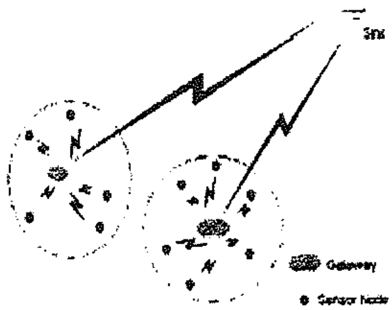

Figure 1. Cluster-Based Wireless Sensor Network

nodes lying on different possible paths connecting the source to the sink, in proportion to their residual energy. In [8], an energy-aware routing algorithm for cluster-based wireless networks have been proposed in which a cost function is defined between two mobile nodes in terms of energy conservation, delay optimization and other performance metrics.

The above approaches make use of fixed (crisp) metrics and mathematical modeling for finding energy-aware routing metrics. In this paper, we present a novel approach for calculating the cost of link between any two mobile nodes, using fuzzy logic.

Fuzzy logic has been successfully applied in various areas including communications and has shown promising results [11],[18]. However, the potentials of fuzzy logic in wireless networks still need to be explored. Optimization of wireless networks involve various tradeoffs, for example, lower transmission power vs. longer transmission duration, multi-hop vs. direct communication, computation vs. communication etc. Fuzzy logic is well suited for applications having conflicting requirements.

Moreover, in MANET, as the energy metrics vary widely with the type of Mobile node implementation platform, using fuzzy logic has the advantage of being easily adaptable to such changes. We, therefore, present our fuzzy based approach for energy-aware routing in MANET'S and compare our solution with conventional crisp approaches.

3. System Model

Cluster-based routing has been shown to be quite effective in wireless networks [21]. The main advantage of using this approach is that as the data gathered by mobile nodes in the close vicinity is usually redundant, the gateway can perform the task of data aggregation before sending it to the remote command node (sink). Moreover, as MANET is usually formed for a specific application, gateways can be chosen to be much powerful as compared to the mobile nodes. This relieves the energy-constrained mobile nodes of communicating directly with the remote sink.

In this paper, we have assumed a cluster-based architecture for MANET, where a group of nodes is managed by a gateway. The gateway can communicate directly with all the mobile nodes and can retrieve their status. All mobile nodes have one destination namely the gateway to which they send their data. Mobile nodes can communicate directly with the gateway but this will be very costly for those mobile nodes, which are not close to the gateway. Therefore, the gateway is also reachable via various routes through multiple-hops over mobile nodes in the network.

The gateway is responsible for setting up of routes for sensor nodes and for the maintenance of the centralized routing table that indicates the next hop for each mobile node. Gateway periodically invokes the fuzzy routine to determine the cost of link between any two mobile 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 mobile 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 efficient routing within the cluster. We have used Heinzelman's energy model for sensor networks[3].

Energy required for transmitting a k-bit message to a distance d is given by:

$$E_{Tx}(k,d) = E_{elec} \times k + E_{amp} \times k \times d^2 \qquad (1)$$

Energy consumed in receiving a *k*-bit message is given by:

$$E_{Rx}(k) = E_{elec} \times k \qquad (2)$$

Where $E_{elec} = 50nJ/bit$ and $E_{amp} = 100pJ/bit/m^2$

Energy consumed in sensing one bit has been taken to be approximately equal to the energy dissipated in receiving one bit. Computation energy has been taken as the random summation of energies spent in various computational algorithms as mentioned in [3].

4. Fuzzy Model

4.1 Overview of Fuzzy Logic

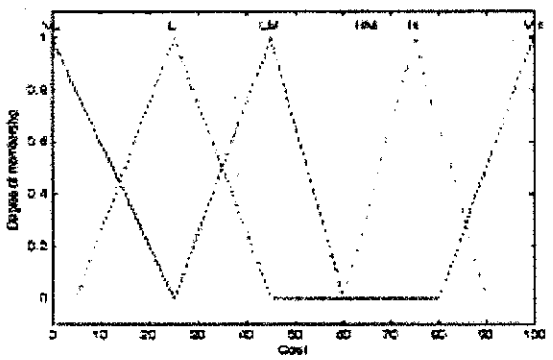

Figure 4. Output Fuzzy Variable

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 sets 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. Details of the theoretical and practical aspects of fuzzy logic can be found in [19][20].

4.2 Description

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

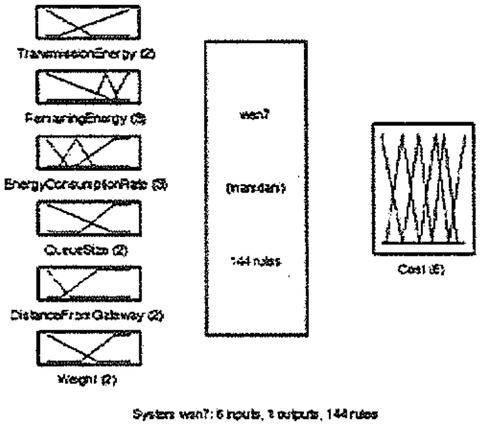

Figure 2. Fuzzy System Model

Figure 2 displays our fuzzy model. The input fuzzy variables are: transmission energy, remaining energy, rate of energy consumption, queue size, distance from gateway and weight. The rule base therefore consists of 2^4 x 3^2=144 rules. There is a single output fuzzy variable, namely cost, the defuzzified value of which determines the cost of link between two sensor nodes.

TABLE I

S#	A	B	C	D	E	F	O
1	low	high	low	small	small	large	VL
2	low	high	medium	small	small	large	VL
3	low	high	medium	small	large	large	L
4	low	high	low	small	large	large	L
5	low	high	low	large	large	large	LM
6	low	medium	high	small	small	large	LM
7	low	medium	medium	large	small	small	HM
8	high	medium	low	small	small	small	HM
9	high	medium	medium	large	small	small	H
10	high	medium	medium	large	large	large	H
11	high	low	low	small	small	large	VH
12	high	low	medium	small	large	small	VH

Figure 3 gives details of the input fuzzy variables. In determining the cost of link from node i to node j, transmission energy represents the energy needed to transmit a data packet from node i to j. Lower value of transmission energy leads to lower link cost. Remaining energy indicates the energy level of node j. Nodes with less value of remaining energy should be avoided in being selected as next-hop. Consequently, its lower value results in a higher link cost.

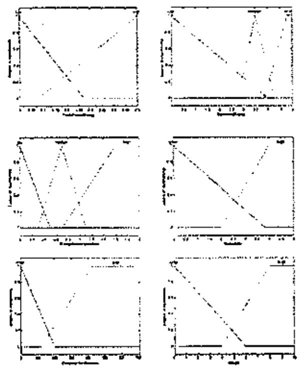

Figure 3. Input Fuzzy variables

Energy consumption rate of node j 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 assigned higher link costs so as to distribute the routing load evenly. Distance from the gateway enables selection of routes with minimum hops. Nodes nearer to the gateway are assigned lower link cost.

Each sensor node is assigned a dynamic weight depending upon its current status. An in-active node that is neither sensing nor relaying is assigned a highest value whereas a node that is performing both these tasks is assigned a least weight. This parameter helps in selecting nodes which are either inactive or are only in the sensing state. Thus, a high value of weight makes the node favorable for next-hop. Resulting in a lower value of link cost. Queue size indicates the buffer capacity at node j. This parameter helps avoid packet drops due to congestion at the receiver.

The output fuzzy variable, as shown in figure 4, consists of six membership functions. A cost between 0 and 100 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. We have used centroid defuzzification and MINMAX implication.

Our rule base consists of 144 rules. A few rules are given in Table 1. The rules have been formulated according to the criteria described above. In table 1, A, B, C, D, E and F denote the input fuzzy variables viz., transmission energy, remaining energy, rate of energy consumption, queue size, distance from gateway and weight respectively. The last column contains the output fuzzy variable i.e. the cost denoted by 0.

4. Simulation Results

We have simulated our fuzzy model using Matlab 6.5 by randomly deploying sensors in an area of 1000m x 1000m. The gateway was positioned at the center. Initial energy and buffer capacity of each sensor node have been taken as 5 joules and 5 packets respectively. Eighty percent of the sensor nodes have been taken to be initially in the sensing state. A node has been assumed to stop sensing when its energy level drops to zero. Simulation was run for 960 sensed packets, the size of each packet being 10k bits.

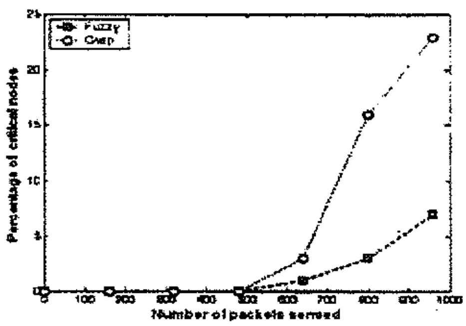

Figure 5. Network Lifetime

For comparison with the crisp approach, the same scenario was simulated using non-fuzzy/crisp variables. The link cost is again determined on the basis of percentage of remaining energy of each node. Consequently, the routes are selected so as to avoid nodes with low remaining energy, thereby extending the lifetime of the sensor network

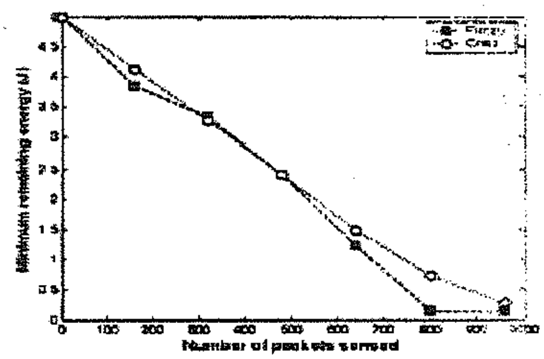

Figure 6. Sensor Node Lifetime

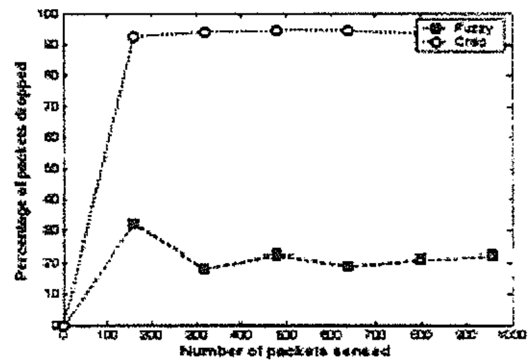

Figure 7. Percentage Of Packets Dropped

Figures 5-7 show simulation results. We have considered a node to be in critical state if its remaining energy becomes less than 40% of its initial energy. In figure 5, it can be seen that fuzzy performs better than the crisp approach as the percentage of critical nodes is significantly lower as compared to the crisp approach. Another metric that we have taken is the least energy that remains with a sensor node.

Figure 6 compares the performance of fuzzy vs crisp approach in terms of the minimum remaining energy at any sensor node against the total packets sensed by the network. Referring figure 6, the lifetime of an individual node is slightly lesser in the fuzzy approach as compared to the crisp one. This decrease in an individual node's lifetime has been traded off with a much longer network lifetime as shown in figure 5.

Packet drop percentage is shown in figure 7. Packets are dropped either due to insufficient buffer capacity at the receiver or because of the lack of energy needed to transmit the packet. Percentage of packets dropped is significantly lower for our fuzzy approach resulting in greater reliability.

5. Conclusions

We have presented a novel fuzzy model for energy aware routing in wireless sensor networks. Our simulation results have demonstrated the reliability and efficiency of this approach. Moreover, as fuzzy approach is soft it can be easily tuned for different network and node conditions simply by changing shapes of the fuzzy sets.

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