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An Energy-Efficient Routing using Fuzzy Model Based Clustering for Mobile Ad Hoc Network

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Abstract: Mobile Ad hoc NETwork (MANET) is an infrastructure-less, autonomous network, the nodes are connected through the wireless multi-hop links. The absence of infrastructure and dynamic environment demands to form a new set of routing protocol for MANET. Routing is a main issue in MANET due to its mobility and inadequate resource availability. Especially, energy-efficient routing is essential because every node is operated by exhausted battery power. Power failure of an individual node partitioned the entire network architecture. So, routing in MANET shall use the available battery energy in an effective way to enhance the network lifetime. The Fuzzy Model-based Clustering (FMC) algorithm recognizes the reliable and loop-free route between the nodes by choosing an optimal cluster head. The FMC uses the speed, residual energy and signal strength as factors in order to find the efficient cluster head. The nodes are implementing the fuzzy logic mechanism to estimate the node cost. The node with the highest cost is selected as cluster head. The cluster head achieves the data packet transmission. Hence, the FMC preserves the stable network by reducing the reselection of cluster head and minimizes the re-affiliation of all the nodes in the cluster. The FMC algorithm maintains the packet delivery ratio, average delay, energy consumption by 87.3%, 17.5 %, and 25.83% respectively, over the existing AODV and FCESRB protocols.

Index Terms: autonomous, clustering, fuzzy logic, signal strength.

I. INTRODUCTION

The wireless network is an emerging technology because of the rapid development in the wireless devices. Generally, the wireless network is classified in two ways: infrastructure and infrastructure-less networks. In infrastructure-based connection, nodes is connected and maintained via fixed central controller, example: Wireless Local Area Networks (WLANs). In infrastructure-less network nodes are assembled in an ad hoc manner, where nodes are establishing the communication through multi-hop wireless links [3] [4]. A set of mobile nodes forms the network individually without any pre-defined infrastructure Such a network is recognized as a Mobile Ad hoc NETwork (MANET). The MANET is an autonomous system of the wireless nodes that moves arbitrarily and connects through wireless multi-hop links[9]. In MANET, nodes are performing like a router to forward the data packets in the network [14], [16-17].

In MANET, nodes are moving freely, and the architecture of such a network changes automatically, that makes the routing difficulty in the route discovery process. The features of MANETs are flexible, rapid deployment, robustness, scalability and mobility [8].

Energy-efficient routing is a solution to increase the lifetime of the MANET [5], [7]. The mobility and low resource obtainability in MANET demands to create an energy based routing protocol. The fuzzy logic mechanism is used to improve the effectiveness of routing in MANET [11], [15]. The fuzzy logic can able to evaluate the correctness of the output based on the approximation of the parameters involved.

In MANET clustering mechanism supports the availability and enhances the scalability of the networking function [2], [20]. The clustering method provides an efficient way to reduce the energy consumption by minimizing the number of packets transmitted to the neighboring nodes[12]. The clustering technique makes the network architecture in a smaller and manageable to increase the network performance and minimizes the routing overhead [6]. This research work proposed the fuzzy-based energy-efficient clustering mechanism for MANET.

II. LITERATURE SURVEY

The Cluster Based Routing Protocol (CBRP) that partitioning the network into a number of overlapped two-hop diameter clusters. In every cluster, the cluster head preserves the cluster affiliation information. The cluster membership information used to choose the cluster head. The clustering mechanism decreases the flooding in the route discovery phase and increases the routing mechanism [10]. The Low Energy Adaptive Clustering Hierarchy (LEACH) algorithm randomly chooses the cluster head and exchanges the node role to distribute the node energy consumption [7]. The Hybrid Energy-Efficient Distributed (HEED) clustering mechanism that is used to extend the network lifetime. According to HEED, the cluster head selection is based on the node residual energy to enhance the network lifetime. The aim of HEED is to minimize the energy consumption during cluster head selection phase and extend the network lifetime [19]. The Vice Cluster head on Cluster Based Routing Protocol (VCHCBRP) introduced to increase the performance of the CBRP [10]. Specially, it was designed to support self-healing clusters.

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The performance of VCHCBRP increases the network stability and clustering performance [1]. Improved Cluster Based Routing Protocol (i-CBRP) which is an enhancement of CBRP [10] in order to form a stable cluster [13].

III. PROPOSED FMC ALGORITHM

The aim of Fuzzy Model-based Clustering (FMC) algorithm is to enhance the lifetime of the MANET by choosing an energy-efficient cluster head using fuzzy logic mechanism. The FMC algorithm is designed to build an energy-efficient path to avoid the full drain of the energy from the node. The suitable cluster head selection maintains the node energy during the route discovery process. The proposed cluster model is based on the fuzzy logic technique that helps to reduce the network traffic and routing overhead. Once the nodes are positioned in the network, they are partitioned into clusters. The node within the cluster computes the speed, residual energy and signal strength of its intermediate nodes. The nodes are applying the fuzzy logic technique to evaluate the node cost. The node with the maximum cost is selected as cluster head. The cluster head executes the data packet transmission. The node cost is computed for every fixed time T, and if the computed cost is less than the previous node cost, then the node with maximum cost is selected as cluster head.

A. Estimation of Metrics

The following section explains the routing parameters employed in the FMC algorithm. The FMC algorithm uses the residual energy, speed and signal strength to build a reliable cluster head.

Residual Energy

The node's residual energy denotes the node remaining energy capacity. The node can droplet the energy due to various reasons such as size of packet, type of packet and distance among the nodes. The available energy denotes the amount of energy spent during the network operation. Hence, the available energy is used to increases the network lifetime, and it is defined by Equation (1):

$$RE = Ei-((tn * Etx) + (rn * Erx)) \quad - - -(1)$$

Here, Ei-initial energy,tn – no.of.data packets transmitted, Etx- transmission power, rn –no.of.data packets received, Erx - total energy consumption.

Speed

The speed is denoted by the distance travelled by time. The speed (SD) of the node is depending on the drive of node from one place to another place.

$$SD = \sum_{t=1}^{T} \frac{\sqrt{(a_t - a_{t-1}) + (b_t - b_{t-1})}}{T} \quad - - - (2)$$

(at, bt) and (at−1,bt−1) – node coordinates at time t (t − 1)- average of the speed for each node till current time T.

Signal Strength

The Signal Strength (SS) reveals the transmission of power at transmitting node (Ptx) and the receiving power at the receiving node (Prx). Based on Friis' equation, the detected signal strength is depends on the sender distance. The receiving power is denoted by Equation (3):

$$SS = p_{tx}.\,\alpha.\,\beta.\left(\frac{\lambda}{4\pi d}\right) - - - (3)$$

p_{tx} - sender transmission power, SS – receiving power of the receiver, α -transmitter gain, β-receiver gain, λ - wavelength, and d -distance.

IV. CLUSTER FORMATION

The steps comprised in the FMC algorithm are described as follows:

Step 1: The set of nodes (n_i, i=1, 2, …, n) are positioned in the network. Every n_i partitions the set of nodes into neighboring sets called clusters.

Step 2: For each neighboring node, n_i computes the Residual Energy, Speed and Signal Strength.

Step 3: Each n_i, applies the fuzzy logic technique for the computed inputs Speed, Residual Energy, Signal Strength and gets the output as Cost.

Step 4: By computing cost, each n_i chooses one of its neighboring nodes with the maximum cost is choosen as Cluster Head (CH).

Step 5: Each n_i directs with Join_Request message to the choosen CH. After receiving the Join_Request message, the CH reports back with a CH_ACK message to every nodes in the cluster.

V. FUZZY-BASED CLUSTER HEAD SELECTION

The following section explains the selection of optimal path based on the fuzzy inference system. In fuzzification module, the three input parameters such as speed, residual energy, and signal strength are fuzzified. The triangular membership function has been applied for the proposed research work. The triangular membership function is the easiest membership function that is shaped using straight lines.

Figures 1, 2 and 3 represents the fuzzy input sets such as Residual Energy, Speed and Signal Strength. Figure 4 defines the fuzzy output set such as Node Cost.

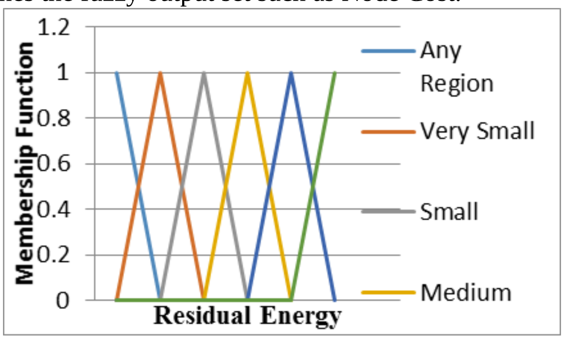

Figure:1 Membership Function for Residual Energy

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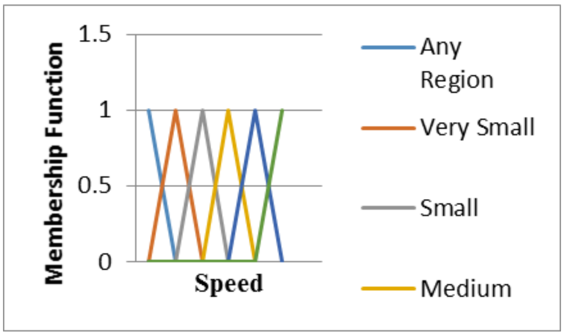

Figure.2 Membership Function for Speed

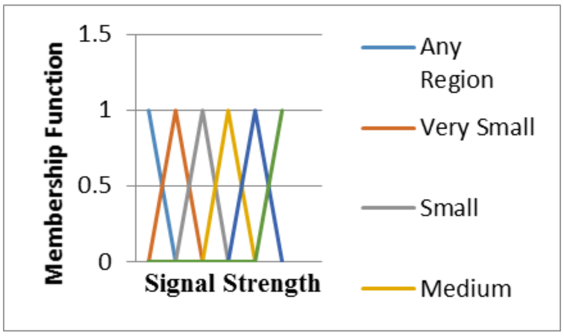

Figure:3 Membership Function for Signal Strength

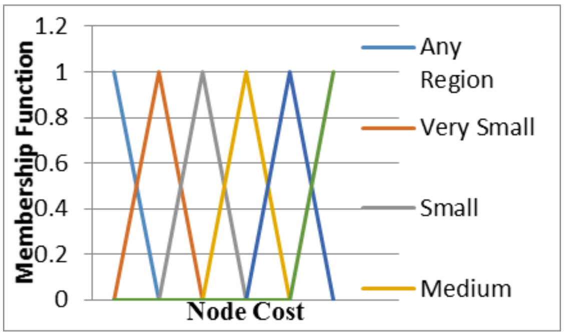

Figure:4 Membership Function for Node Cost

The node with the maximum residual energy plays in routing and saves the node energy of low battery nodes in the network lifetime. The signal strength is used to identify the link quality among the pair of nodes. The speed is considered as an important metrics because the speed of the node inversely disturbs the signal quality. The fuzzy inference system is depending on the fuzzy rule that joins the input membership functions with output membership function. Table 1 specifies the condition for cluster head selection. For simplification, some rules are proposed.

Table 1 Fuzzy Rule for Cluster Head Selection

If			Then
RE	**SD**	**SS**	**Cost**
Any region	Very high	Any region	Any region
Very high	Any region	Any region	Any region
Any region	Any region	Very high	Any region
Any region	Any region	Any region	Very high
Any region	High	Any region	Any region
High	Any region	Any region	Any region
Any region	Any region	High	Any region

Defuzzification is final stage of fuzzy inference system. The defuzzification technique extracts the crisp value from the output fuzzy set. The centroid technique is taken for e defuzzification because of its accuracy (Sameena Naaz et al. 2011). Equation 3.4 denotes the centroid method for defuzzification process.

$$F_{sl} = \frac{[\sum_{all\,rules} x_i * \mu(x_i)]}{\sum_{all\,rules} \mu(x_i)} \qquad (3.4)$$

where, Fsl denotes the stable link, xi - fuzzy variable, μ (xi) -membership function.

VI. SIMULATION ENVIRONMENT

The FMC is simulated in NS-2.34 [18] in order to show the presentation of the algorithm. Table 2 explains the simulation metrics. The FMC algorithm is compared with the AODV and FCESRP routing protocols with similar settings and variables specified in Table 3

Table 2 Comparison of AODV, FCESRP with FMC

Feature	**AODV**	**FCESRP**	**FMC**
Route Computation	Reactive	Reactive	Reactive
Route Structure	Flat	Hierarchical	Hierarchical
Local Repair	Yes	Yes	Yes
Update Period	Event Driven	Event Driven	Event Driven
Cluster Head Selection	-	Bandwidth, Traffic Load, Number of Intermediate Nodes, Computer Efficiency, Power Consumption	Residual Energy, speed, Signal Strength
Additional Cluster Head	-	No	No
Route Selection Metric	Freshness and Shortest Path	Energy-Aware	Energy-Aware
Overhead	High	High	Low
Loop Free	Yes	Yes	Yes
Route Acquisition Time	Low	Moderate	High
Power Conservation	Low	Moderate	High
Multiple Route	Yes	Yes	Yes
Scalability	No	Yes	Yes

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A. Performance Metrics

Packet Delivery Ratio (PDR): The PDR signifies the number of packets, transported successfully to the destination node.

$$PDR = \frac{\sum(\text{Number of Packet Received})}{\sum(\text{Number of Send})}$$

Average Delay: The average delay denotes to the time occupied for the packet to reach the destination.

$$Average\ Delay = \frac{\sum(Arrival\ Time - Delivered\ Time)}{\sum(Total\ Data\ Packets\ Received)}$$

Energy Consumption: The energy consumption represents the amount of energy consumed by the nodes in the network.

$$Energy\ Consumption = \frac{\sum(Total\ Consumed\ Energy)}{\sum(Total\ Number\ of\ Nodes)}$$

Table 3 Simulation Parameters

Parameters	Value
Number of Nodes	50,100,150,200
Network Size	1000 * 1000 m^2
Speed	5-30m/s
μ	0.5,0.6,0.7,0.8,0.9
Transmission range	250m
Traffic Source	CBR
Simulation Time	200 Seconds
MAC protocol	802.11
Propagation model	Two Ray Ground

B. Performance Comparison by Varying Number of Nodes

This section explains the performance of proposed FMC with the existing AODV and FCESRP routing protocols. Figure 5 shows the packet delivery ratio Vs number of nodes. The average packet delivery ratio for FMC is 87.3% because it elects an effective cluster head, that stabilizes the network structure and minimizes the frequent link failures

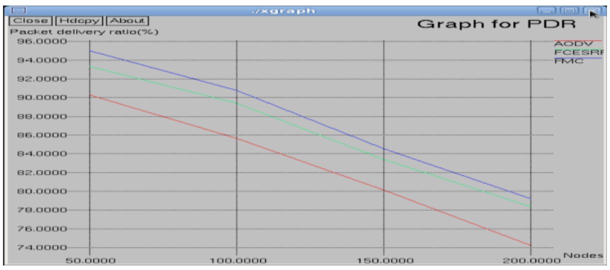

Figure.5 Packet Delivery Ratio Vs Number of Nodes

Figure 6 shows the delay in terms of m/s with the number of nodes. The FMC reveals the lowest end-to-end delay by 17.5% because signal strength is measured as a major metrics for selecting an effective cluster head which reduces the packet drops.

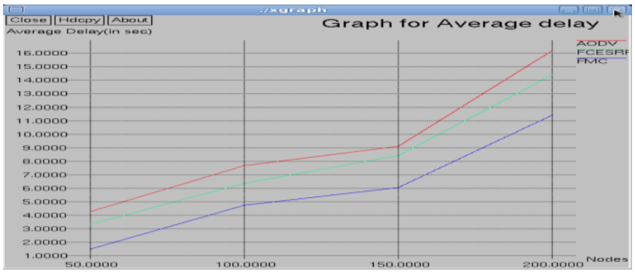

Figure 6 Average Delay Vs Number of Nodes

Figure 7 shows the energy consumption in terms of joules with the number of nodes. The FMC reduces the energy dissipation by 25.83% because the optimal cluster head selection reduces the packet loss and minimizes the retransmission of data packets.

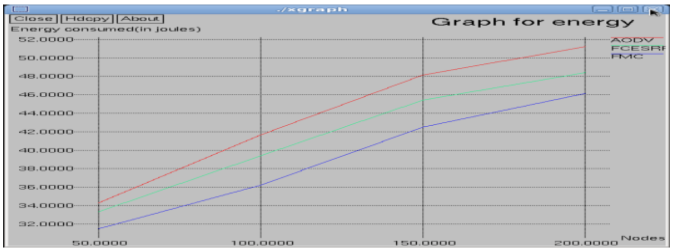

Figure 7 Energy Consumption Vs Number of Nodes

Figure 4.10 shows the graph between different number of nodes and the average throughput in Kbps for FMC, AODV and FCESRP protocols. The FMC maintains the consistent cluster head, which keeps the throughput around 30.78% when the network density increases.

VII. CONCLUSION

The paper proposed Fuzzy Model-based Clustering (FMC) algorithm, the nodes in the cluster execute the residual energy, speed and signal strength of the intermediate nodes. The intermediate nodes are employing the fuzzy logic technique to find the node cost. The node with the highest cost is chosen as the cluster head. During the transmission, the cluster head collects the data from all the nodes and performs the data transmission. In the cluster maintenance stage, the node cost is calculated for every interval time. If the cost of the surviving cluster head drops, the node with the next maximum node cost is chosen as a new cluster head.

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