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Unsupervised Machine Learning based Energy Efficient Routing for Mobile Ad-Hoc Networks

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Abstract— Mobile Ad-hoc Networks (MANETs) are temporary networks formed by a group of mobile hosts without the need for centralized administration or specific support services. Energy consumption is a critical issue in MANETs due to their reliance on limited battery resources. Reducing energy consumption is crucial for increasing network lifespan and throughput. Existing energy-saving techniques often fall short in their effectiveness. This research proposes a novel approach that combines a proactive MANET routing protocol with an energy-efficient strategy to address these limitations. The proposed solution considers both node mobility and energy levels in the routing process. Traditional AODV routing relies on flooding, which broadcasts RREQ packets to all nodes within the sender's range. This often leads to unnecessary retransmissions of RREQ and RREP packets, resulting in collisions and network congestion. To overcome this issue, we propose an optimized route discovery mechanism for AODV. The key idea is to leverage the K-means clustering algorithm to select the optimal cluster of nodes to forward RREQ packets instead of relying on broadcasting. This approach aims to alleviate network congestion and reduce end-to-end delay by minimizing unnecessary control packet transmissions.

Keywords- Mobile ad-hoc Network, K-Means Clustering, Machine Learning, Clustering, Ad-hoc on Demand Distance Vector.

I. Introduction

Wireless communication has seen a groundbreaking addition in the form of Mobile Ad-Hoc Networks (MANETs), representing a departure from traditional wireless networks by eliminating the need for established infrastructure. In this paradigm, the absence of preloaded routers underscores the flexibility and unique nature of MANETs. Often dubbed as mobile packet radio networks or mobile multihop wireless networks, MANETs offer an innovative solution for service delivery in scenarios devoid of infrastructure. The "ad hoc" nature signifies its reliance on spontaneously formed connections without centralized infrastructure. Physically, a MANET comprises geographically dispersed mobile hosts sharing a radio channel, constructing the network dynamically as these hosts engage in communication. Within this setup, every participating node, also known as mobile nodes, assumes dual roles as both hosts and routers, fostering a decentralized network architecture. Addressing the limitations inherent in MANETs[1], cluster-based routing stands out as a promising approach. Central to this approach is the application of clustering algorithms, which organize the network hierarchically into overlapping clusters, each headed by a designated node selected based on specific criteria like mobility, power, and density. These clusters redefine pathways between clusters, reducing reliance on individual nodes. In MANETs, each mobile node equips an antenna-based wireless transmitter and receiver, facilitating dynamic communication within this infrastructure-less network.

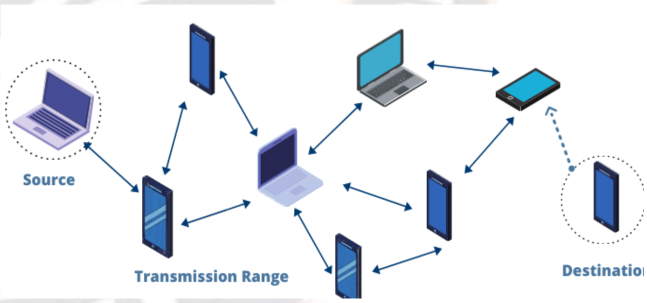

Figure 1. General structure of MANET

In the depicted Figure 1, the foundational architecture of the MANET is highlighted, showcasing the network's decentralized structure. Nodes within their respective wireless transmission ranges communicate directly, enabling peer-to-peer interactions. However, limitations such as signal fading, noise interference, and finite battery capacities restrict the transmission range and overall capacity of wireless networks in contrast to wired counterparts. Consequently, transmitting data across the network might necessitate multiple hops from one node to another. This requirement underscores the dual role each node assumes—functioning not only as a host but also as a router. Each individual node in the network undertakes the responsibilities of packet distribution, forwarding, routing, and various other critical network

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functions, ensuring the self-sufficiency and adaptability of the MANET's operational framework [2].

II. WORKING OF AD HOC ON-DEMAND DISTANCE VECTOR (AODV) PROTOCOL IN MANET

Wherever Ad Hoc On-Demand Distance Vector (AODV) is a reactive routing protocol for mobile ad hoc networks (MANETs) [8-11]. It works by discovering routes to destinations on demand, when needed. This makes AODV a good choice for MANETs, as it can conserve bandwidth and energy. It establishes and maintains routes between nodes on an as-needed basis. Let's break down how AODV works in detail with the help of a simplified diagram.

A. AODV Route Setup and Maintenance:

AODV uses a route request/reply mechanism to discover routes to destinations. When a node wants to send a packet to a destination that it does not have a route for, it broadcasts a route request (RREQ) packet. Neighboring nodes forward the RREQ packet until it reaches the destination node or an intermediate node that knows a route to the destination node.

a. Route Discovery:
b.

- Step 1: Node A (the source) wants to send a packet to node F (the destination) but doesn't have a valid route to F in its routing table.
- Step 2: Node A initiates a Route Discovery process by broadcasting a Route Request (RREQ) packet to its neighbors. The RREQ contains the source node's IP address, a broadcast ID, and the destination node's IP address. The broadcast ID ensures that nodes do not process the same RREQ more than once.
- Step 3: Neighboring nodes that receive the RREQ examine it. If they have a route to the destination or if they've already seen this RREQ before, they discard it. Otherwise, they create a reverse route entry in their routing tables.
- Step 4: The RREQ continues to propagate through the network, hop by hop, until it reaches either the destination node D or a node that has a route to F.

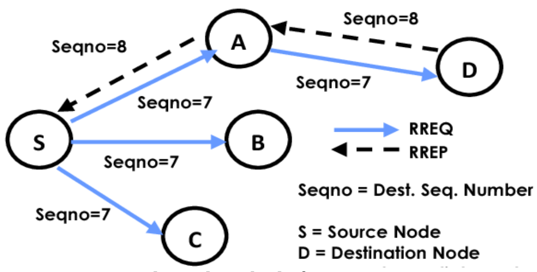

Figure2. Traditional Method of AODV Route Discovery

- Step 5: When the RREQ reaches F or a node with a route to F, that node generates a Route Reply (RREP) packet and sends it back to the source S. The RREP includes the route information. Along the reverse path, the nodes set up forward route entries in their routing tables.

c. ***Route Maintenance:***

- Step 6: After the source S receives the RREP, it can start sending data packets using the established route. As data packets traverse the network, intermediate nodes monitor the link quality.
- Step 7: If a node detects a link failure (e.g., if a link becomes unreachable), it generates a Route Error (RERR) packet and sends it to the source S. The RERR contains information about the broken link.
- Step 8: Upon receiving the RERR, the source S can initiate a new Route Discovery process to find an alternative route to the destination D. This process follows the same steps as Route Discovery described earlier.

The AODV RERR message is broadcasted by a node when it detects a link or route failure. The RERR message helps in quickly updating the routing tables of other nodes in the network, allowing them to find alternative routes and avoid using the failed route.

d. Route Expiry:

Routes in AODV have a finite lifetime. If a route is not used for a certain period, it expires and is removed from the routing table. When a source node tries to use an expired route, it will need to initiate a new Route Discovery process.

AODV aims to minimize routing overhead by creating routes only when they are needed, making it suitable for MANETs with frequently changing topologies. This reactive approach helps conserve bandwidth and reduce control message overhead.

It's important to note that this is a simplified explanation of AODV's operation. In practice, AODV may employ various optimizations, and the protocol handles multiple scenarios, such as route errors and network changes. Nevertheless, this overview should give you a good understanding of how AODV functions in a MANET.

III. UNSUPERVISED MACHINE LEARNING BASED K-MEANS CLUSTERING APPROACH FOR IMPROVING MOBILE AD-HOC NETWORKS ROUTING PROTOCOLS

In our solution we designed energy-based K-means clustering as a mechanism to enhance the AODV (Ad-Hoc On-Demand Distance Vector) routing protocol in MANETs is a strategy to improve energy efficiency and prolong the network's lifetime. [2-10]. Energy-aware clustering can help optimize routing decisions by considering the energy levels of nodes.

The flooding strategy used in AODV routing entails broadcasting route request (RREQ) packets to all nodes within a sender's transmission range in order to carry out route discovery. Frequently, the unnecessary retransmission of RREQ packets and the reply (RREP) packets sent in response causes packet collisions and network congestion. In this thesis, I have recommended an improved route-discovering method for AODV. The key idea is to use the K-Means clustering technique to select the optimal cluster of RREQ packet forwarders rather than broadcasting. In order to reduce network

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congestion and end-to-end delay, this strategy reduces the delivery of extra control packets. NS2.34 is used to simulate the network.

A. Proposed algorithm

i. Start by setting the number of nodes in the network and creating the nodes.
ii. Set the energy level for each node in the network.
iii. Implement the K-means clustering algorithm:
    a. Initialize cluster heads randomly.
    b. Iterate until convergence or maximum iterations:
        - Assign nodes to clusters based on distance from cluster heads.
        - Recalculate new cluster heads as centroids of their respective clusters.
iv. Implement cluster head selection based on centroid and maximum energy node:
    a. Sort nodes based on their energy levels in descending order.
    b. Select cluster heads based on centroid and maximum energy node.
    c. Set a flag to identify selected cluster head nodes.
v. Implement data routing from source to destination using CH-to-CH forwarding (AODV):
    a. If the source and destination are in the same cluster, route data within the same cluster using AODV routing protocol.
    b. If the source and destination are in different clusters, route data between different clusters using CH-to-CH forwarding (AODV).
vi. Run the simulation.

B. Proposed flowchart

There are four important steps performed in K-means clustering algorithm.

Step 1: In the beginning, the k clusters are originated from the SNs(Sample Node) by taking the k number of centroids at random places.

Step 2: The Euclidean distance from each SN to the centroid is computed for making the k initial clusters. Consider each node is closest to the centroid. The Euclidean distance from one node to another node is given in Eq. (1).

$$\textit{Eucildean distance} = \sqrt{(x1 - x2)^2 + (y1 - y2)^2}. \;\ldots\ldots(1)$$

Where, the co-ordinates of x and y axis is represented as $x1$, $x2$ and $y1$, $y2$ respectively.

Step 3: The position of each node is verified from the previous position and the each-cluster locations are again generated in a networks.

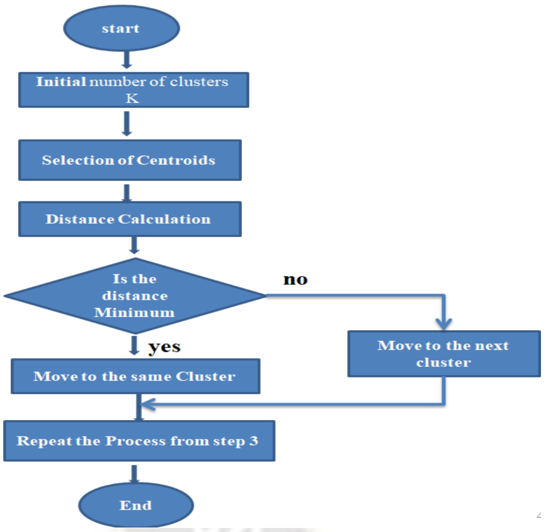

Figure 3: Flowchart of the K-means clustering algorithm

Step 4: If the locations of centroid changes, then again step 2 should be processed for creating the effective clusters or else the grouping process needs to be ended.

The K-means algorithm iterates through the assignment and update steps until convergence occurs. This means that the cluster memberships and centroid positions remain stable between iterations

Finally, the node which is near to centroid and whose energy is greater than other nodes in cluster is selected as an optimum CH for a cluster group. After clustering of the network, routing process takes place using K-means clustering techniques.

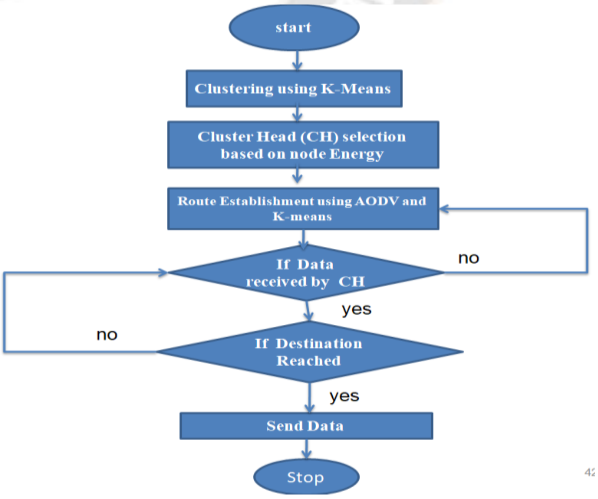

Figure 4: Flow chart of overall method

c. Mathematical equations for proposed energy based K-means clustering

1. Distance Function:
    - Euclidean Distance:

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$d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$

where:

- d_{ij}: Distance between data points i and j
- (x_i, y_i): Coordinates of data point i

2. Cluster Assignment:

Each data point is assigned to the cluster with the closest centroid based on the chosen distance function:

$c_i = \text{argmin}_k(d_{ik})$ for all k = 1, ..., K

where:

- c_i: Cluster assigned to data point i
- K: Number of clusters
- d_{ik}: Distance between data point i and centroid k

3. Centroid Update:

The centroids of the clusters are updated iteratively as the average of all data points within each cluster:

$mu_k = (1/N_k) * \Sigma(x_i)$ for all $x_i \in C_k$

where:

- mu_k: Centroid of cluster k
- N_k: Number of data points in cluster k
- Σ: Sum over all data points in cluster k

4. Objective Function:

The K-means algorithm minimizes the total squared distance between each data point and its assigned centroid:

$J = \Sigma(d_{ik})^2$ for all i = 1, ..., N and k = 1, ..., K

where:

- J: Objective function
- N: Total number of data points

5. Node Energy Calculation:

For each node i, its remaining energy level is represented by E_i.

6. Cluster Head(CH) Selection:

We want to find the node with the highest remaining energy to act as the cluster head.

Formula:

$CH = \text{argmax}_i(E_i)$ for all nodes i

where:

- CH: Index of the node selected as the cluster head
- E_i: Remaining energy of node i
- argmax: Function that returns the index of the element with the maximum value

7. Interpretation:

This formula iterates through all nodes and compares their remaining energy levels. The node with the highest energy level ($\text{argmax}_i(E_i)$) is chosen as the cluster head (CH).

8. Route setup and Data Routing:

The remaining steps involve utilizing AODV for intra-cluster and CH-to-CH forwarding for inter-cluster communication.

Figure 3 and Figure 4 shows overall method of Energy-based K-means clustering .This approach is used to reduce the number of RREQ packets that are being broadcast. By clustering the nodes in the network based on their energy levels, the nodes with the highest energy levels can be selected as cluster heads (CH). The cluster heads are then responsible for routing data packets for the other nodes in their cluster. When a node wants to send a data packet to a destination for which it does not have a route, it first sends a RREQ packet to its cluster head. The cluster head then checks to see if it has a route to the destination. If the cluster head has a route to the destination, it sends a RREP packet back to the source node. If the cluster head does not have a route to the destination, it forwards the RREQ packet to the cluster head of the neighboring cluster. This process continues until a cluster head is found that has a route to the destination. The cluster head that has a route to the destination then sends a RREP packet back to the source node via all the other cluster heads in the route. By using energy-based K-means clustering, the number of RREQ packets that are broadcast can be reduced. This is because RREQ packets are only broadcast by cluster heads. As a result, the amount of energy that is consumed by the routing process can be reduced, which can increase the lifetime of the network.

IV. EXPERIMENTAL SETUP AND RESULTS

The flooding strategy used in AODV routing entails broadcasting route request (RREQ) packets to all nodes within a sender's transmission range in order to carry out route discovery. Frequently, the unnecessary retransmission of RREQ packets and the reply (RREP) packets sent in response causes packet collisions and network congestion. In this project, I have recommended an improved route-discovering method for AODV. The key idea is to use the K-Means clustering technique [25] to select the optimal cluster of RREQ packet forwarders rather than broadcasting. In order to reduce network congestion and end-to-end delay, this strategy reduces the delivery of extra control packets. Ns2.34 is used to simulate the network.

Figure 5 : Cluster head selection using K-means clustering algorithm

Figure 6: Route Establishment and Data forwarding using K-means clustering algorithm

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Figures 5 and 6 illustrate the cluster head selection process and the route establishment along with data forwarding process using the K-means clustering algorithm.

The following features are employed in K-Means clustering:

- transmission error rate,
- distance to destination
- available buffer room

These characteristics of the neighbors are used to select the best cluster. Clusters are assessed by comparison to an ideal forwarder with the following characteristics.

- Maximum buffer size = free buffer space
- distance to destination = Zero
- number of transmission errors = Zero
- Number of nodes : 10, 20, 30, 40, 50
- Number of packets per second : 10, 20, 30, 40, 50

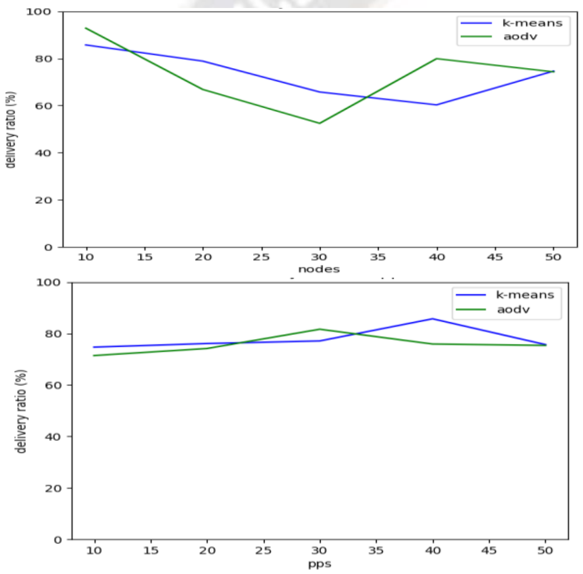

Figure 4. K-Means and AODV a) Delivery Ratio Vs Node b) Delivery Ratio Vs pps

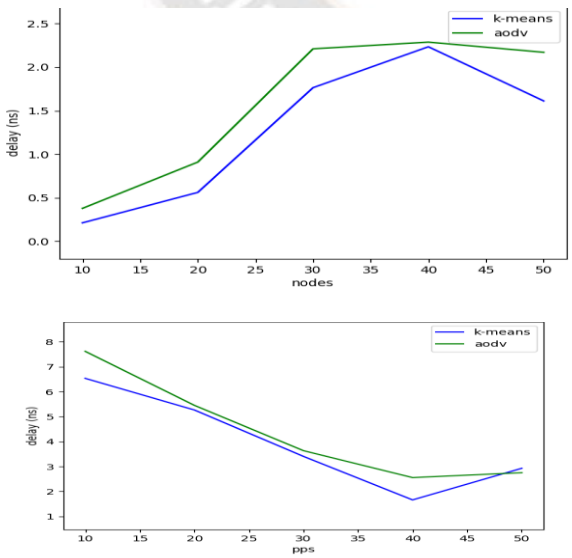

Figure 5. K-Means and AODV a) Delay Vs Node b) Delay Vs pps

The statistics show that the updated algorithm's delivery ratio is marginally lower than AODV. However, given that the updated approach employs a somewhat lower number of forwarders for route identification, the difference in delivery ratio is not particularly noteworthy. On the other hand, we can see that the updated technique has a far lower end-to-end delay than utilizing solely AODV. This is because the improved technique uses less RREQ and RREP packets, which speeds up the route finding process. Therefore, even if selective forwarding utilizing K-Means clustering lowers the delivery ratio slightly, the updated strategy shortens the network's end-to-end delay.

V. Conclusion and Summary

The proposed work will include a demonstration of the use of k-Means machine learning method,which is basically a clustering technique. This section describes the conclusion of the proposed energy conservation mechanism. The energy is calculated based on the prediction of the energy consumption level of the node. The energy computation method is performed using the K Means clustering along with the AODV routing with optimization by selecting the shortest path in the network. In this study, we provide an enhanced AODV route-discovery mechanism. The basic concept is to avoid broadcasting by choosing the best cluster of RREQ packet forwarders using the K-Means clustering technique. By limiting the delivery of unnecessary control packets, this method lessens network congestion and end-to-end delay.

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