Research Paper

ENHANCING ENERGY EFFICIENCY IN MOBILE ADHOC NETWORK USING AGGLOMERATIVE HIERARCHICAL CLUSTERING TECHNIQUE

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Abstract

Mobile Adhoc NETwork (MANET) is a multi hop wireless network which consists of mobile nodes that communicate with each other through wireless medium. Many researchers are proposed different solution to improve networks performance in terms of effective routing, transmission delay, throughput, Control overhead and stability. Existing research works are mainly focused for creating efficient collaboration between nodes of a network. In MANET, the mobility of nodes provides an opportunity to change network topology that increase control overhead of a network. Clustering mechanism is played crucial role in MANET to improve the networks performance. We proposed an Efficient Hierarchical Cluster based Routing scheme that uses agglomerative hierarchical clustering technique to form stable clusters. It used the various distance metrics like Unweighted Pair Group Method with Arithmetic Mean (UPGMA), Unweighted Pair Group Method using Centroids (UPGMC) Unweighted Pair Group Method using Centroids (WPGMC), Single linkage or Shortest distance, weighted pair group method with averaging (WPGMA) and Inner squared distance to form the efficient clusters that are close proximity. Efficient cluster head is selected based on weight metrics including transmission range, mobility and remaining energy of the nodes. Simulation results shown that the proposed scheme is achieved good performances with respect to Packet Delivery Ratio, routing overhead, total energy consumption.

Key Terms: Cophenet Correlation Coefficient, Energy efficiency, Linkage methods, Hierarchical Cluster, MANET

1. Introduction

MANET is formed arbitrarily by set of mobile nodes falling within the transmission range of each other [15]. MANET had lack of centralized infrastructure that causes numerous challenges [14]. Many researchers are focused for providing efficient and effective routing in MANET while considering the bandwidth and power constraints [3]. MANET could operate by two types of network architecture such as flat and hierarchical network architecture. In the flat network architecture, all nodes are participated in the routing process. In the hierarchical
network architecture, nodes are partitioned into a number of clusters each of which is managed by a cluster head. The main challenges with the cluster formation algorithms are not scale well in Mobile Adhoc environments. Various Clustering algorithms[1, 13] provides an effective solution to enhance the networks performance by using effective cluster functions such as power management, scheduling for channel access and coordination with other cluster.

We proposed a protocol; Energy Efficient Hierarchical Cluster based Routing Protocol (EHCRP) that uses hierarchical approach to form stable cluster. Its goal is to form a efficient clusters by using various distance metrics such as Unweighted Pair Group Method with Arithmetic Mean, Unweighted Pair Group Method using Centroids Unweighted Pair Group Method using Centroids, Single linkage or Shortest distance, weighted pair group method with averaging and Inner squared distance. We use a Cophenet correlation coefficient factor to measure the efficient and stable clusters in MANET. Cluster Weight factor such as highest remaining energy, mobility factor and Transmission range are considered to select energy efficient cluster head.

The remainder of the paper organized as follows. Section 2 summarizes related work and highlights the differences between it and our work. Section 3 describes our proposed work called as Efficient Hierarchical Cluster based Routing Protocol in MANET in terms of various distance metrics. Section 4 presents our simulation results and a relevant performance analysis. Finally, Section 5 presents our conclusions and discusses future direction.

2. Literature Review

Recently many research works have been done on mobility based cluster formation [2, 8] in MANET. These works are mainly focused on form the clusters with the maximum stability against the node mobility. Jiang et al [7] proposed a Cluster based routing protocol (CBRP) which used the variation of the min-ID algorithm to form the small stable clusters using local information. CBRP used two data structures for routing process including the cluster adjacency table and the two hop topology database that provide the features of route shortening and local repair. Torkestani et al [18] proposed weighted learning automata based clustering algorithm for finding node's relative mobility with respect to all its neighbors. The highest expected weight is selected as the cluster head that ensures the stability of the clusters. Bheemalingaiah et al [3] proposed an Energy Aware Cluster Based Multipath Routing (EACMR) which incorporated functions like Cluster formation, cluster maintenance, route discovery, route selection and route maintenance and congestion control. Gomathi et al [5] proposed a fuzzy cost enabled cluster based routing algorithm that select appropriate path on cluster based multipath routing at fuzzy cost. Valentini et al [20] reviewed the comprehensive survey on the energy efficient cluster based power management technologies including static power management systems which utilized low power components and dynamic power management systems for optimizing the energy consumption in the networks. Sudipta Shana et al[17] presented a Weight based Hierarchical Clustering algorithm(WBHCA) for MANET that leads cluster formation and its stability by using combined weight metrics like highest heuristic degree, largest transmission range and low mobility factor. Saha et.al [16] proposed a Cluster Based Mobility Routing Protocol (CBMRP) for MANET that use two metrics such as node mobility parameter and load balancing mechanism to elect a cluster head. Yong Li et al [9] presented a Cluster Cache Based K-hop Routing protocol which is used the cluster head cache to form clusters. Majumder et al[10] presented a Mobility aware Clustering Scheme in MANET in which node degree, energy and mobility are taken into account to cluster formation. They used priority based mechanism to elect the cluster head. Mohammed et al [11] proposed a protocol in which mechanism design theory is used to encourage mobile nodes for participating honestly in the election process to balance the energy consumption among all nodes. Haidar Safa et al [6] presented a cluster based trust aware routing protocol (CBTRP) that used weighted clustering algorithm to form clusters. The weighted degrees are taken into consideration of battery power, number of neighbors, transmission power and mobility of the nodes to form optimal cluster head. Pushpita Chatterjee et al [13] proposed a Secure Trusted Auction oriented Clustering
based Routing Protocol that organized the network into 1-hop clusters and elects the trustworthy nodes as Cluster head by using a secret voting scheme. Tselikis et al [19] proposed a Degree Based Clustering Algorithms for MANET in which node degree, energy related fairness factor and security component and node’s Euclidean distance are taken into the account to form clusters.

3. Research Design and Methodology

In this paper, agglomerative hierarchical clustering technique is used to partition the group nodes over a variety of scales. Multilevel hierarchy is formed by creating a cluster tree where clusters at one level are joined as clusters at the next level. This allows to decide the scale of clustering that is most suitable for hierarchical routing which lead routing overhead. Agglomerative clustering technique creates the efficient clusters that incorporates the distance calculation, linkage methods, and cluster formation. MANET is set up with n nodes that consists of n*(n – 1)/2 pairs in the network. Agglomerative hierarchical cluster formation consists of three phases including (i) Find the similarity or dissimilarity between every pair of nodes in the network; (ii) Group the nodes into hierarchical cluster tree (iii) form the hierarchical tree into clusters. In first phase, distances between nodes are calculated by using the Euclidean similarity measures metric. Dissimilarity matrix is calculated between every pair of nodes in a network by Eq.(1)

\[ d^2_{st} = (x_s - x_t)(x_s - x_t)' \] (1)

Where \( x_s \) and \( x_t \) are the x-axis and y-axis of two nodes. Distances \( d_{st} \) are arranged in the order \((2, 1), (3, 1), \ldots, (n, 1), (3, 2), \ldots, (n, 2), \ldots, (n, n-1)\), then it formatted as a vector to save space and computation time. The Euclidean distance between node1 and node2 is shown in Fig (1).

In second phase, pairs of nodes are linked that are in close proximity by using the linkage methods such as UPGMA, UPGMC, single linkage, WPGMA and Inner squared distance. The linkage method used to find the similarity between pair of nodes that determine the proximity of nodes to each other. Then nodes are grouped into clusters that are having similarities. The newly formed clusters are grouped into larger clusters until a hierarchical tree is formed. The following notation is used to describe and implement the linkage methods: Cluster \( r \) is formed from clusters \( p \) and \( q \), \( n_r \) is the number of nodes in cluster \( r \), \( x_{ri} \) is the \( i \)th nodes in cluster \( r \).

• Single linkage method used to determine the smallest distance between nodes in the two clusters, is given by Eq.(2) which is also called nearest neighbor:

\[ d(r, s) = \min(dist(x_{ri}, x_{sj})), i \in (i..n_r), j \in (i..n_s) \] (2)

• UPGMA method used to determine average distance between all pairs of nodes in any two clusters, is given by Eq.(3)

\[ d(r, s) = \frac{1}{n_r n_s} \sum_{i=1}^{n_r} \sum_{j=1}^{n_s} dist(x_{ri}, x_{sj}) \] (3)

• UPGMC method used to determine the Euclidean distance between the centroids of the two clusters given by Eq.(4)

\[ d(r, s) = \| \overline{x}_r - \overline{x}_s \| \] (4)
where

\[ \bar{x}_r = \frac{1}{n_r} \sum_{i=1}^{n_r} x_{ri} \]  

(5)

- WPGMC method used to determine the Euclidean distance between weighted centroids of the two clusters that expressed from Eq.(6)

\[ d(r, s) = \|\bar{x}_r - \bar{x}_s\| \]  

(6)

Where \( \bar{x}_r \) and \( \bar{x}_s \) are weighted centroids for the clusters \( r \) and \( s \). If cluster \( r \) was created by combining clusters \( p \) and \( q \), \( \bar{x}_r \) is defined recursively from Eq.(7)

\[ \bar{x}_r = \frac{1}{2}(\bar{x}_p + \bar{x}_q) \]  

(7)

- Inner squared distance method is used to determine the incremental sum of squares given by Eq.(8)

\[ d(r, s) = \frac{\sum_{i,j}(n_r n_s)}{\sqrt{n_r n_s}} \|\bar{x}_r - \bar{x}_s\|_2 \]  

(8)

Where \( \| \|_2 \) is Euclidean distance, \( \bar{x}_r \) and \( \bar{x}_s \) are the centroids of clusters \( r \) and \( s \), \( n_r \) and \( n_s \) are the number of nodes in clusters \( r \) and \( s \)

- WPGMA uses a recursive definition for the distance between two clusters. If cluster \( r \) was created by combining clusters \( p \) and \( q \), the distance between \( r \) and \( s \) is another cluster defined as the average of the distance between \( p \) and \( s \) and the distance between \( q \) and \( s \) from Eq.(9)

\[ d(r, s) = \frac{d(p, s) + d(q, s)}{2} \]  

(9)

In third phase, the cluster algorithm prunes the branches from the bottom of the hierarchical tree, and then assigns all the nodes below each cut to a single cluster. This creates a cluster of nodes. The clusters are formed by the following procedure

Step1: Initially, put each node in its own cluster. Item Among all current clusters, pick the two clusters with any of the linkage methods.

Step2: Replace these two clusters into a new cluster, formed by merging the two original ones.

Step3: Repeat the above two steps until form only one cluster.

We applied Cophenetic Correlation Coefficient (CCC) to measure the dissimilarities among nodes in cluster tree which might not consider for making cluster. If the linking of nodes in the cluster tree achieves strong correlation, then the clustering is valid. If the closer value of the CCC is to 1, the clustering solution is more accurate. The CCC between \( Z \) and \( Y \) is expressed as follows

\[ c = \frac{\sum_{i,j}(Y_{ij} - y)(Z_{ij} - z)}{\sqrt{\sum_{i,j}(Y_{ij} - y)^2 \sum_{i,j}(Z_{ij} - z)^2}} \]  

(10)

Where \( Y_{ij} \) is the distance between nodes \( i \) and \( j \) in \( Y \), \( Z_{ij} \) is the cophenetic distance between nodes \( i \) and \( j \), \( y \) and \( z \) are the average of \( Y \) and \( Z \) respectively. EHCRP achieved efficient clusters because it having optimal CCC value. Inconsistency coefficient is computed for each link of the hierarchical cluster tree that characterizes each link in a cluster tree by comparing its height with the average height of other links at the same level of the hierarchy. By default the depth is considered as 2. Each link of nodes \( k \), the inconsistency coefficient is calculated from Eq. (11)

\[ Y(k,3) = \frac{(z(k,3) - Y(k,1))}{Y(k,2)} \]  

(11)

In this hierarchy cluster formation, the inconsistency coefficient is set to 0 when nodes have no further nodes under them that represented as cutoff value. This makes efficient cluster formation because far away nodes are not participated to form cluster.

3.1 Cluster Head Selection
We proposed a methodology to energy efficient cluster head. Cluster Weight factor is calculated for mobile node based on the following metrics such as highest remaining energy, mobility factor and Transmission range.

3.1.1 *Highest Remaining energy (HR)*

The highest remaining energy of all nodes is calculated by

\[ E_{HR} = E_T - (E_I + E_T + E_R) \]  

(12)

Where \( E_{HR} \) – Highest remaining energy, \( E_T \) – Total energy, \( E_I \) – Initial Energy, \( E_T \) – Transmission energy, \( E_R \) – Receiving energy

3.1.2 *Mobility Factor (MF)*

Mobility factor is calculated as the rate of position of mobile node with respect to time. Nodes update packets frequently at high speed during travel. Here, node with less mobility is considered as factor. Source node knows the mobility of all nodes. Mobility is computed from Eq.(13)

\[ M_f = \frac{1}{T} \sum_{i=1}^{T} \sqrt{(x_i - x_{i-1})^2 + (y_i - y_{i-1})^2} \]  

(13)

\( M_f \) – mobility of a node, \( \sqrt{(x_i - x_{i-1})^2 + (y_i - y_{i-1})^2} \) – Distance between sender and all nodes.

3.1.3 *Transmission range (TR)*

During route request phase, sender node calculates the distance between sources nearest nodes. Transmission range is calculated by Eq.(14)

\[ TR = \prod \sqrt{(x_i - x_{i-1})^2 + (y_i - y_{i-1})^2} \]  

(14)

The procedure for selecting cluster heads as follows

**Step1:** Identify a node with high remaining energy, less mobility and large transmission range

**Step2:** Finds the percentile value of nodes

**Step3:** Identify the nodes with percentile value above 80 percent

**Step4:** Calculate weighted factor

\[ W_i = (w_1 E_{HR} + w_2 M_f + w_3 TR) \]

A node with highest weighted factor is selected as cluster head

4. **Results and Discussion (Important for research paper)**

The performances of the proposed EHCRP are evaluated in Network Simulator (NS-2). The simulation result provides an effective solution to form cluster. Table 1 summarizes the simulation parameters to form clusters. The results and observations of the EHCRP are compared with CBMRP and WBHCA protocols in terms of Packet delivery ratio and routing overhead.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation Area</td>
<td>800 × 800 m</td>
</tr>
<tr>
<td>Simulation Time</td>
<td>900 Sec</td>
</tr>
<tr>
<td>No of nodes</td>
<td>25, 50, 75, 100</td>
</tr>
<tr>
<td>Transmission range</td>
<td>200 m</td>
</tr>
<tr>
<td>speed</td>
<td>2.5 ms</td>
</tr>
<tr>
<td>Packet size</td>
<td>512 bytes</td>
</tr>
<tr>
<td>Pause time</td>
<td>200 Sec</td>
</tr>
<tr>
<td>Initial Energy</td>
<td>100 joules</td>
</tr>
</tbody>
</table>

4.1 **Cophenet Correlation Coefficient (CCC)**
The Cophenetic Correlation for a cluster tree is defined as the linear correlation coefficient between the Cophenetic distances obtained from the cluster tree. Cophenetic Correlation Coefficient is computed for the hierarchical cluster tree which indicates the efficiency of cluster formation in MANET. The CCC is evaluated for varying number of nodes for different linkage methods. In this simulation, inconsistency or cutoff value is also calculated for preventing the nodes to participate cluster formation those who are in far away distance. These nodes are not participated in routing phase because it is not within the transmission range. Table 2 shows that the summary of Cophenetic Correlation Coefficient of various Linkage methods. Fig 2 shows that magnitude value CCC for different linkage methods for cluster formation including Single, Ward, UPGMC, UPGMA and WPGMC. In this analysis, all linkage methods are providing with consistence CCC value except single method about 0.7696. It is proved that efficient cluster formation in networks.

![Consistency of Cluster Formation with cutoff < 0.7071](image)

**Fig 2: Consistency of Cluster Formation with cutoff < 0.7071**

**Table 2: Cophenetic Correlation Coefficient of various Linkage methods**

<table>
<thead>
<tr>
<th>No of nodes</th>
<th>Cophenetic Correlation Coefficient of various Linkage methods</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Single Cutoff&lt;0.7071</td>
</tr>
<tr>
<td>25</td>
<td>0.6742</td>
</tr>
<tr>
<td>50</td>
<td>0.6538</td>
</tr>
<tr>
<td>75</td>
<td>0.5907</td>
</tr>
<tr>
<td>100</td>
<td>0.5782</td>
</tr>
</tbody>
</table>

### 4.2 Packet Delivery Ratio (PDR)

In this simulation, Packet Delivery Ratio is evaluated for varying number of nodes like 25, 50, 75 and 100. Fig.3 noticed that the EHCRP continuously maintained higher PDR about 90% compared to WBHCA and CBMRP. WBHCA protocol suited for small networks so it reduces the PDR when increase the number of nodes and CBMRP could be performed control packet and hello packets transmission during routing phase which causes congestion that reduces the PDR.
4.3 Routing overhead

In this simulation, the routing overhead is evaluated for EHCRP, WBHCA and CBMRP while varying nodes in different linkage methods. Fig 4 shows that the minimal routing overhead caused by EHCRP than other two protocols because far away nodes are not participating in cluster formation. WBHCA is also reducing the flooding traffic during route discovery and Inter cluster routing process. It exchanges the limited routing control message to form the clusters. Where as CBMRP caused routing overhead because this is making more flooding traffic in routing phase.

4.4 Total Energy Consumption

Each Adhoc node is initialized with a limited energy source of 100 J to evaluate the energy efficiency performance. The number of nodes varied from 25 to 100. Fig.5 shows that total amount of energy consumption in which EHCRP consume less energy. Each node exchanges control packets with its neighbours every 500ms. WBHCA and CBMRP show higher energy consumption of the all nodes in terms of mobility factors. The EHCRP has minimum hop counts for end to end data delivery than CBMRP because it has heavy message exchange overhead and high computational complexity. EHCRP consumes lower energy compare to related schemes.
5. Conclusion

In this paper, we proposed an Efficient Hierarchical Cluster based Routing scheme for improving the network performance in MANET. This work used an agglomerative hierarchical clustering to form clusters that achieved efficient cluster formation. EHCRP applied various distance metrics like UPGMA, UPGMC, WPGMC, Shortest distance, WPGMA and Inner squared distance to form the efficient clusters and these are analyzed. The Cophenet Correlation Coefficient is proven that these distance metrics are providing efficient cluster which reduces the routing overhead and control overhead. Efficient cluster head is selected based on weight metrics including remaining energy of a node, transmission range and mobility of the nodes. The simulation results of EHCRP are compared with WBHCA and CBMRP. The numerical results shown that the EHCRP outperforms for creating efficient clusters compare to other two approaches. In addition, the EHCRP also reduces the energy consumption to form the clusters. In future work genetic algorithm may apply to select optimum cluster head in each cluster.

Reference


