International Journal of Future Generation Communication and Networking
Vol. 9, No. 12 (2016), pp. 17-28
http://dx.doi.org/10.14257/ijfgcn.2016.9.12.02

Mobility-Aware Node Clustering with Fuzzy Logic for Wireless Mesh Network

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Abstract

In recent times, Wireless Mesh Network (WMN) has received prominence worldwide due to the evolution of wireless networks as a ubiquitous and seamless broadband service provider. Routing on WMNs is one of the most prominent research issues on these days. Hierarchical clustering based routing protocols are proposed by the researchers for large networks. In these protocols, all the available nodes are grouped into clusters. Each cluster consists of cluster members, cluster head and gateway nodes where cluster head plays the most vital role to form an efficient cluster. Selection of a better cluster head depends on the decisions made from different parameters and their relations. In this situation, fuzzy logic suits better by providing better analysis and helps to make the right decision based on different parameter values and their relations. In this paper, a fuzzy logic based hierarchical clustering technique is proposed for WMN. The proposed technique along with the existing Fuzzy Logic Control Clustering Algorithm(FLCCA) are experimented using the simulation software NS3 and the simulated results are compared to establish the efficiency of the proposed technique.

***Keywords**: Wireless Mesh Network; Mobile Ad-hoc Network; Cluster Head; Cluster Based Routing;Fuzzy Logic*

1. Introduction

Wireless Mesh Network (WMN) is established as one of the most significant wireless technology for several applications, like broadband home networking, community and neighborhood networking, battlefield surveillance, Voice over IP(VoIP), intelligent transportation systems *etc*. Most importantly, it is gaining more attention as a tool for Internet service providers (ISPs) and the end-users to access efficient wireless broadband service at minimum cost. WMNs have the ability to self-organize and self-conFigure dynamically because the nodes in the network are capable of establishing automatically an ad hoc network with mesh connectivity [1]. There are three different kinds of mesh architecture, namely, Infrastructure WMNs, Client WMNs and Hybrid WMNs. This classification is based on the fact: whether the mesh clients are having any infrastructure created by mesh routers or not or it is the combination of both(hybrid) [2].

Scalable routing protocols are needed for providing last mile connectivity in WMNs. For scalable networks, Hierarchical routing technique produces good results as only a few of the nodes are involved in routing [3-4]. With the help of efficient clustering techniques, the important routing performance parameters like, throughput, bandwidth consumption, energy consumption, packet delivery ratio, end to end delay may be improved [5]. Efficient clustering protocols try to solve different design goals for the application they are designed for.

Clusterhead selection is a complex decision making process involving various parameters which are qualitative, inexact, or uncertain in nature. It is found that fuzzy logic can

ISSN: 2233-7857 IJFGCN

produce better results when uncertainty is considered. Therefore, in this paper a fuzzy logic based cluster head selection algorithm is proposed taking into consideration the fact that the mobility of the client nodes should be seamless from one cluster to another cluster.

In this paper, existing clustering and routing algorithms in wireless networks are discussed in Section 2 whereas Section 3 discusses about the proposed technique. Results and discussions are presented in Section 4 and the conclusion is made in Section 5.

2. Related Study

Over the years, various node clustering and routing algorithms are proposed by the researchers mostly for MANETs and WSNs whereas only two clustering schemes are available for WMN.

A good number of schemes are available in the literature which are primarily mobility based, viz, Mobility Prediction-based Clustering (MPBC) [6], Neighbor-stability based mobility prediction [7], Lowest Relative Mobility Clustering Algorithm (MOBIC) [8], Mobility-based d-hop Clustering Algorithm (MobDHop) [9]. These schemes are proposed for MANETs and WSNs.
The available clustering algorithms for WMNs are Hierarchical Cluster Based Routing for WMN [12] and Fuzzy Logic Control Clustering Algorithm (FLCCA) [13].

2.1. Hierarchical Cluster Based Routing for WMN [12]

This technique is an enhancement to the Cluster-based Routing Protocol (CRP) [10,11]. In CRP, Mesh point portal (MPP) is there on the top of the hierarchy and elects cluster head (CH) and members of each cluster.MPP keeps the information like CH id, CH neighbours *etc* in its own table. All the CHs have the information about neighboring CHs and therefore, in the time of routing neighboring CHs are sent path requests. In this scheme, the MPP is overloaded.

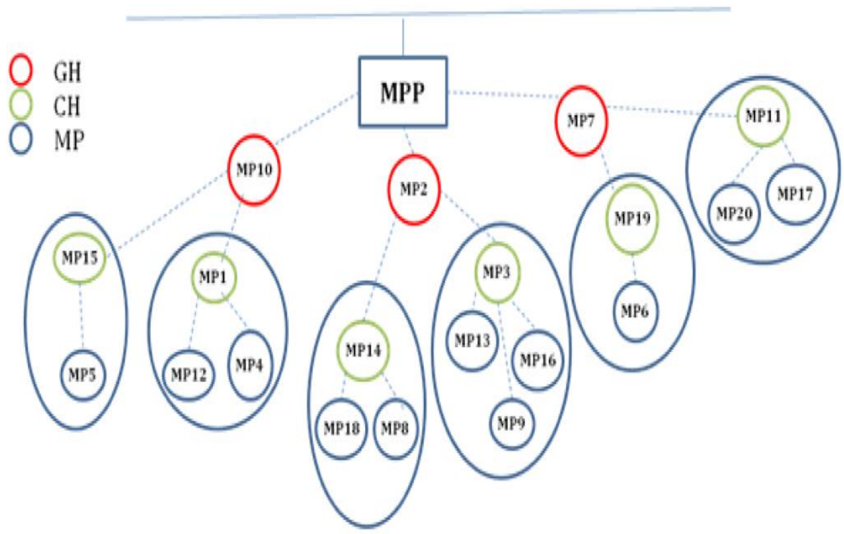

Figure 1. Domains in Wireless Mesh Network

As shown in Figure 1, in the hierarchical cluster based method, a Group Head(GH) is used to control the load on MPP and each GH controls some domains. Under each domain, there are a number of clusters. Each cluster will have one MP as the Cluster head (CH). Here, CH and MPs maintain the information of all the MPs within the same cluster. Information on its GH and other CHs is stored in each

CH. GH has the information about the MPP and also about the CHs under its supervision.

Information of all the GHs is maintained by MPP. A single node cannot be considered as both CH and GH simultaneously. Big oval shapes in Figure 1 are representing the domains in WMN, three nodes namely, MP10, MP2 and MP7 are considered as GHs. In the Figure, two clusters are maintained by every GH and MP15, MP1, MP14,MP3,MP19 and MP11 are shown as cluster heads.

2.2. Fuzzy Logic Control Clustering Algorithm (FLCCA)

In this paper the authors proposed a fuzzy based algorithm to select CH and gateway for mesh client networks. The method is based on the fuzzification of three parameters, namely, mobility, traffic delivery capacity and cost of service. Due to the traffic pattern of WMNs, Mesh Client (MC) with high traffic delivery capacity has better possibility for getting selected as a CH. Also, the cost of service metric can approximate the message overhead that each MC will produce. So, if the cost of service of an MC is higher, the less is the chance for selecting it as a CH. Similarly, a highly mobile node creates more re-affiliations and makes the cluster structure further unstable. Therefore, a CH should be having less mobility. Triangular membership function is used to represent these three parameters and the final fuzzy score for each node is calculated from these three input variables as represented by a trapezoidal membership function. FLCCA requires that every MC should get the fuzzy score value of its one hop neighbour. Once the fuzzy score values are acquired, an MC with highest score elects itself as CH among the set of MCs that falls within one-hop of its transmission range. Nodes which reside in the two adjacent clusters having minimal average distance between the two clusters are elected as cluster gateway nodes. The gateway nodes facilitate communication between adjacent clusters.

3. Proposed Method

In this paper, we have proposed a fuzzy based hierarchical clustering scheme which considers the hierarchy proposed in [12] where MPP is on the top of the hierarchy having group head (GH) in its lower level and then Cluster head(CH) and on the last level the cluster member MPs. It is assumed that the MPP elects the GHs in and around some particular co-ordinates. GHs are assumed to be static nodes.

3.1. Fuzzy Input and Output Parameters

The proposed Fuzzy Logic Controller (FLC) uses four input parameters Node degree, Node Mobility, Distance between GH and MP, Node Residual Power to evaluate the output parameter *i.e.* the fuzzy score of individual node.

3.1.1. Node Degree: Node degree of a node is the number of 1-hop neighb or of a mesh node. The node which is having maximum number of neighbors in its vicinity is capable of communicating with highest number of nodes in its neighborhood. An MP with higher capacity to transfer data packets should have higher preference to be chosen as CH because it can decrease control overhead and increase cluster stability in the network. The number of one hop neighbours of v_i is called the node degree of v_i represented as:

$$n\ deg(v_i) = \sum_{d=1}^{n} (v_d) \quad (1)$$

Node degree membership function is shown in Figure 2(a) as input variable and is made up of three membership functions (Low, Medium and High) which are represented as Low [x: 0.0 , 0.0 , 0.15 , 0.5], Medium [x : 0.2 , 0.5 , 0.8], High[x : 0.5, 0.9, 1.0, 1.0] .

3.1.2. Node Mobility: Node mobility is the most important parameter in the proposed method. It is assumed that the MP nodes in the WMN may be having low, medium or high mobility. More preference is given to the nodes which are having low mobility for getting selected as CH. Therefore, when fuzzy input variable mobility is defined, it is assumed that the nodes which are actually having moderate mobility may be regarded as having high mobility (Figure 2b).The distance between node *x* and node *y* can be found by the formula presented in equation 2:

$$Dist(x,y)=\sqrt{(x_i-x_j)^2-(y_i-y_j)^2} \quad (2)$$

where (x_i, y_i) and $(x_j, y_j)$are the coordinates of node *i* and *j* respectively. The mobility for each MC from one place to another place is represented as the average speed at current time *t* as shown in Equation 3 :

$$M_v=1/T\{\sum_{i=1}^{T} \sqrt{(x_i-x_{i-1})^2-(y_i-y_{i-1})^2}\} \quad (3)$$

Node mobility input variable is made up of three membership functions (Low, Medium and High). The variables are organized as Low [*x : 0.0 , 0.0 , 0.2 , 0.4*], Medium [*x : 0.2, 0.4, 0.6*], High [*x : 0.5, 0.8, 1.0, 1.0*].

3.1.3. Distance between Group Head and MP (DGM): The distance between MP and GH is also a very important criterion for hierarchical clustering. The MP which is nearer to the GH has better chance to deliver the packets to the MPP with minimum error. The distance can be found by using Equation (2), where (x_i,y_i) is the co-ordinate of mesh point and (x_j,y_j) may be the co-ordinate of GH. The membership function of DGM as shown in Figure 2c is also defined similar to the node degree variable *i.e.*, with three values having similar ranges.

3.1.4. Residual Energy: Every node is capable of measuring its own residual energy. Residual energy is presented by 3 triangular membership functions as shown in Figure 2(d). It is also same as Node degree and DGM. All these three variables are represented by triangular membership function specified by three parameters $\{a_1, a_2, a_3\}$ as follows:

$$\text{triangular}\{x: a_1, a_2, a_3\}=\begin{cases} 0 & x<a_1 \\ (x-a_1)/(a_2-a_1) & a_1 \le x \le a_2 \\ (a_3-x)/(a_3-a_2) & a_2 \le x \le a_3 \\ 0 & x > a_3 \end{cases} \quad (4)$$

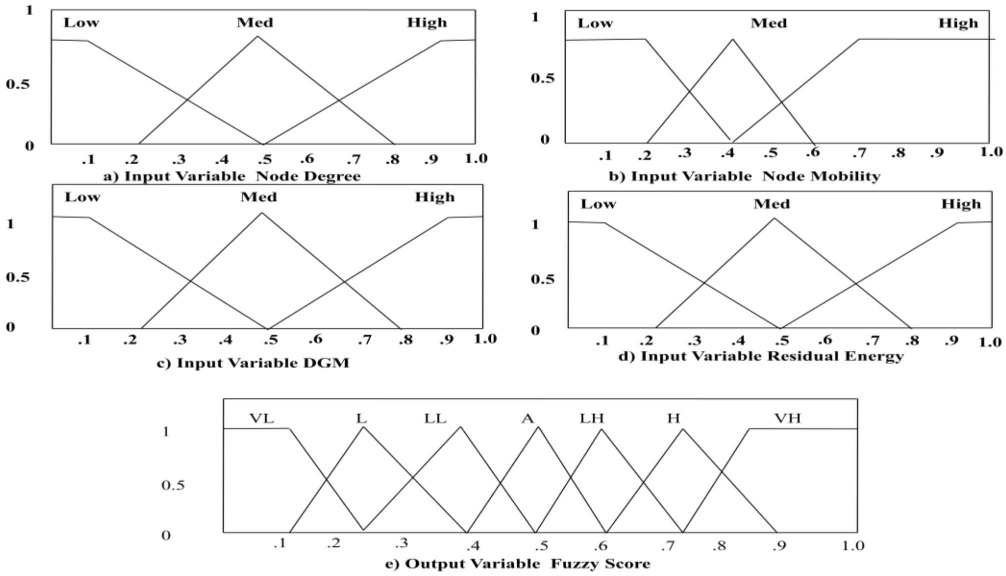

Figure 2. Fuzzy Input and Output Variables

3.1.5. Output Fuzzy Score: Output fuzzy score of each node that gives the final value for MPs to determine its suitability for election as CH is an output variable that consists of seven membership functions [VeryLow (VL), Low (L), LittleLow (LL), Average (A), LittleHigh (LH), High(H), and VeryHigh (VH)] respectively (Figure 2e). The variables are represented as follows: VL [*x : 0.0, 0.0, 0.1, 0.2*], L [*x : 0.1, 0.25, 0.4*], LL [*x : 0.25, 0.4, 0.5*], A [*x : 0.4, 0.5, 0.6*], LH [*x : 0.5, 0.6, 0.7*],H [*x : 0.6, 0.7, 0.9*], VH [*x : 0.7, 0.85, 1.0, 1.0*]. The output variable fuzzy score is represented by trapezoidal membership function specified by four parameters$\{a_1, a_2, a_3, a_4\}$ as follows

$$\text{trapezoidal}\{x: a_1, a_2, a_3, a_4\} = \begin{cases} 0 & x < a_1 \\ (x-a_1)/(a_2-a_1) & a_1 \le x \le a_2 \\ 1 & a_2 \le x \le a_3 \\ (a_4-x)/(a_4-a_3) & a_3 \le x \le a_4 \\ 0 & x > a_4 \end{cases} \quad (5)$$

3.2. Fuzzy Logic Inference Engine and Fuzzy Rule Base

Mamdani fuzzification model is used in our proposed method as was applied in [14] by Gupta *et al* to find the CH in sensor networks. Figure 3 shows the general Fuzzy logic controller structure with fuzzifier, Fuzzy Inference Engine, Fuzzy Rule Base and defuzzifier. Firstly, the crisp input is fuzzified using predefined membership functions. Then the Fuzzy Rule Base is applied to the fuzzified input. The crisp out- put is finally generated by applying defuzzification to the output of the inference engine.

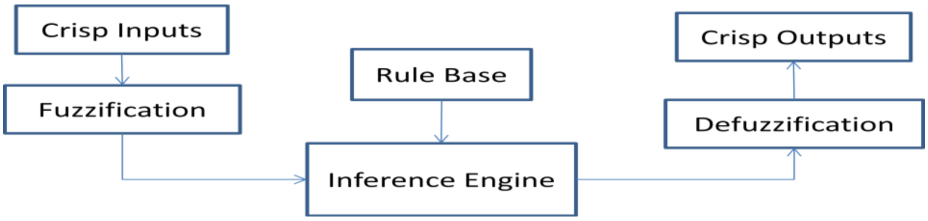

Figure 3. Fuzzy Logic Controller (FLC) Structure

Table 1. Fuzzy Rule Base

Sl. no.	Node degree	Residual Energy	DGM	Node Mobility	Fuzzy Score
1	H	H	L	L	VH
2	H	H	L	M	A
3	H	H	L	H	VL
4	H	H	M	L	H
5	H	H	M	M	LL
6	H	H	M	H	VL
7	H	H	H	L	LH
8	H	H	H	M	L
9	H	H	H	H	VL
10	H	M	L	L	VH
11	H	M	L	M	A
12	H	M	L	H	VL

The inference engine takes the decisions like the human reasoning process by applying IF-THEN rules from the fuzzy rule base. There are 81 (3x3x3x3) rules in our fuzzy rule base as our every fuzzy input variable has 3 values (low, medium & high).Table 1 presents some rules that were designed for the fuzzy inference engine which takes the form IF *u* AND *v* AND *w* AND *x* THEN *z*. The *u*, *v*, *w*, *x*, *z* represent node degree, residual energy, distance between MP & GH (DGM), node mobility and output fuzzy score respectively. Here, utmost importance is given to node mobility as mentioned before. Therefore, whenever there is a high mobility node, there will be very little chance for that node to be selected as CH.

3.3. Defuzzification

After fuzzification, the input data are converted into linguistic values .Now, the defuzzification step will be used to convert the range of output values into Crisp output values. In the defuzzification process, we would like to represent the possibility distribution of an inferred fuzzy control action to a non-fuzzy control action [15]. In the proposed scheme, centroid defuzzification method is used. This method finds out the center of area below the curve considered.

3.4. Clusterhead Selection and Cluster Maintenance Algorithm

Pseudocode for Proposed Method.

```
Input : N(x) number of MPs
Output: CH of MPs based on fuzzy score
NeighbourInfo(N(x)) {
   for any u < N(x)  {                                        // u is a counter variable
       if N(u) and time==0   {
             N(u).BroadcastHello_msg;             /* any Node or MP "u" from MP's Broadcast message
               return bNode_id,                   this Node or MP ID has been returned, named as bNode_id */
        }
       if( time<=thresholdTime){
                  N(u).ReceivedHello_msg          /* any Node or MP "u" from MP's Broadcast message
                  return rNode_id;                this Node or MP ID has been returned, named as rNode_id */
             }
Compute Degree( bNode_id,rNode_id) )
Compute MobilityInfo( u_x , u_y , u_x-1, u_y-1 , thresholdTime)
Compute GH distance( u_x , u_y , u_x-1, u_y-1 )
Compute Residual Energy(get.N(u))
f(u)=N(u).Fuzzify( Degree, MobilityInfo, GH distance, Residual Energy)
    }
    return list of nodes
   NeighbourInfo(N(x-1))
}
 ClusterHead( (N(x))){                        // N(x) list of neighbors
          if(f(N(x)) > f(N(x-1))              // compare fuzzy score of two neighbor nodes and return max CH
              return N(x)
          else if (f(N(x)) = f(N(x-1)) {               /*if fuzzy score of two neighbor nodes are same then
                                              varify which one having less Mobility and return as CH */
                    if(N(x). MobilityInfo < N(x-1). MobilityInfo){
                       return N(x )
                     else
                       return N(x-1)
                 }
  ClusterHead(N(x-1))                   // recursive call to check the condition for each and every node of the list
}
ClusterMaintenance(N(x)){                  // N(x) list of cluster
   for(u<N(x)){
        if(f(u)< thresholdvalue){                      /*Fuzzy Score is less than for any node, Move
               moveout(N(u))                  that node and determine neighbors with remaining
               return  ClusterHead(N(x-u))    nodes in the given list */
              exit
           } else
               return N(x)
        }
 }
```

The pseudo code of proposed algorithm for CH selection and maintenance is given above. Based on the received hello message and response, we can generate list of neighbors for each node. Then we can find the fuzzy score of each node by applying the above algorithm. For determining CH, we find the maximum fuzzy score of a mesh node from the list of neighbours and elect this mesh node as a CH of this given neighbour list. In any circumstance, if two clients are having same fuzzy score within a list then identify the MP having less mobility and select that node as a CH. To maintain the cluster, we determine fuzzy score of all the nodes in a cluster and determine which client is having fuzzy score less than threshold value and move out that client from that cluster and find the cluster head from the remaining nodes.

4. Results and Discussion

The proposed clustering algorithm is simulated using NS3 network simulator. A number of MPs are simulated within a network area of 1000x1000 square meters. FLCCA [13] is also simulated in the same environment and the results are compared with the proposed one. Three performance evaluation parameters were checked, namely, number of cluster formed, stability of clusters and overhead. The different parameters of simulation environment of our experiment are given in Table 2.

Table 2. Simulation Environment

Parameter	Value
Simulator	NS 3.24
Network Area	1000m x 1000m
Number of Nodes	20-150
Simulation Time	382 sec
Mobility Model	Random Direction 2D model
Node placement	Random
Transmission Range	50-100 m
Mobility Speed	0-20m/s
Packet Size	512 bytes
Buffer Size	50B

4.1. no. of Clusterheads (CHs)

Number of CHs with increased node density (Figure 4) shows better result for our algorithm compared to the FLCCA. The number of CH decreases with the increase in transmission range (Figure 5) and the proposed method performs better.

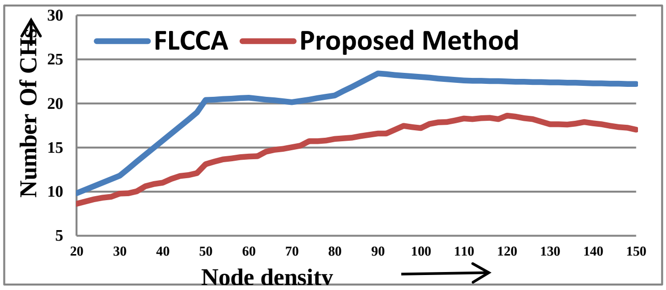

Figure 4. Node density Vs Number of Clusterheads (CH)

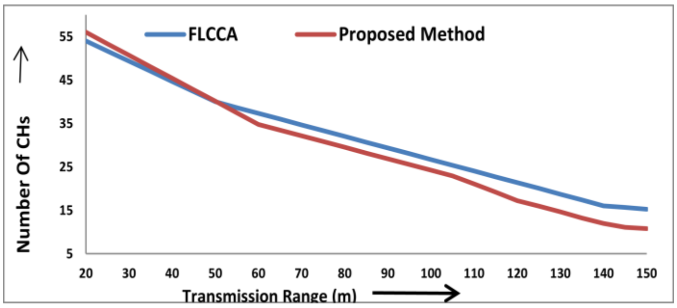

Figure 5. Transmission Range Vs Number of Clusterheads (CH)

4.2. Cluster Stability

Cluster stability is also evaluated for both the algorithms. The mobility speed of the mesh nodes is changed to find the simulation results in Figure 6. With increasing mobility of the nodes the proposed algorithm shows slightly better result.

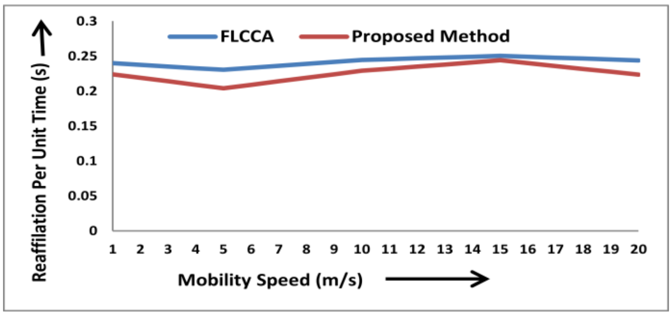

Figure. 6. Mobility Speed Vs Number of Re-affiliations

4.3. Clustering Overheads

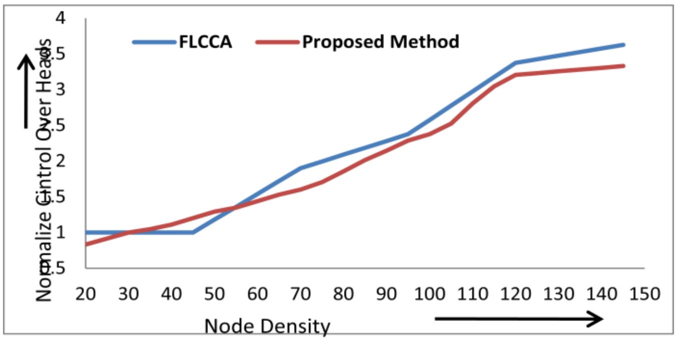

Figure 7. Node Density Vs Control Overhead

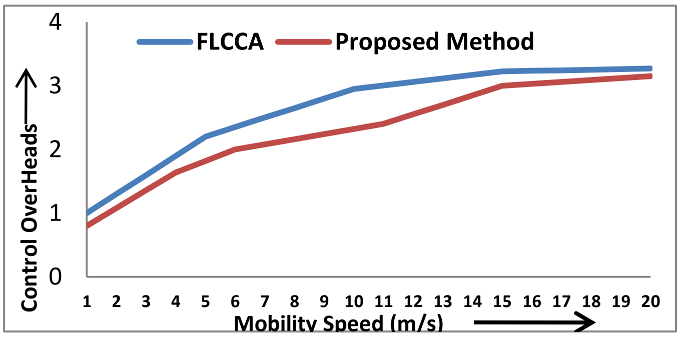

Figure 8. Mobility Speed Vs Control Overhead

An increase in node density results in an increase in clustering overheads (Figure 7). This is happening because with increasing number of nodes, traffic generated by the MPs also increase due to the exchange of different messages like Hello messages for initialization, cluster update and maintenance. Increase in mobility speed (Figure 8) increases the overhead a bit as re-affiliation chances may increase slightly. In both the cases the proposed method shows slightly better results.

5. Conclusion

In this paper, a new fuzzy based node clustering technique for wireless mesh network is proposed. The method works with four variables: node degree, node mobility, distance between GH and MP and residual energy of MP. The proposed algorithm is implemented in NS3.The results are compared with FLCCA algorithm and the method gives slightly better result in all the performance evaluation parameters. In future, the membership function values may be changed as well as some new parameters may also be checked to find out the change in the output. Other soft computing techniques may also be explored to find out best results.

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