Cluster Based Topology Control in Dynamic Mobile Ad Hoc Networks

[1#]T. Parameswaran, [2*]Dr. C. Palanisamy, [3@] P. Kokila

1 & 3. Department of CSE, Anna University Regional Centre, Coimbatore, India

[#] tparameshse@gmail.com

[@] kokilait90@gmail.com

2. Department of IT Bannari Amman Institute of Technology, Sathy, India

[*] cp_samy@yahoo.com

Abstract: In Mobile Ad hoc NETworks (MANETs), mobility of nodes, resource constraints and selfish behavior of nodes are important factors which may degrade the performance. Clustering is an effective scheme to improve the performance of MANETs features such as scalability, reliability, and stability. Each cluster member (CM) is associated with only one cluster head (CH) and can communicate with the CH by single hop communication. Mobility information is used by many existing clustering schemes such as weighted clustering algorithm (WCA) Link expiration time prediction scheme and k-hop compound metric based clustering. In scheme 1) the CH election is based on a weighted sum of four different parameters such as node status, neighbor's distribution, mobility, and remaining energy which brings flexibility but weight factor for each parameter if difficult. In scheme 2) lifetime of a wireless link between a node pair is predicted by GPS location information. In scheme 3) the predicted mobility parameter is combined with the connectivity to create a new compound metric for CH election. Despite various efforts in mobility clustering, not much work has been done specifically for high mobility nodes. Our proposed solution provides secure CH election and incentives to encourage nodes to honestly participating in election process. Mobility strategies are used to handle the various problems caused by node movements such as association losses to current CHs and CH role changes, for extending the connection lifetime and provide more stable clusters. The conducted simulation results shows that the proposed approach outperforms the existing clustering schemes.

Keywords: Clustering, Intrusion Detection System, MANETs, mobility, resource level.

I. INTRODUCTION

MANETs are a completely autonomous wireless temporary network established using a group of mobile nodes suitable for environments where no fixed infrastructure is available. MANETs have received increasing attention in recent years due to their mobility feature, energy level, dynamic topology, ease of deployment. Grouping of nodes into clusters [15] has been considered as suitable method to improve the performance of MANETs. In a MANETs, CMs locally communicate with their CHs directly and CHs are responsible for routing and data forwarding.

CH election [10] process mainly considers nodes energy level, mobility [3] and trustworthiness. Energy level of nodes is kept as private information. Mobility is a special aspect that should be considered since it may cause frequent and dynamic topology changes that affect clustered network structure. As the topology changes, an individual node may move out of its cluster and losses the association with its current CH and it needs to join in a new cluster. This is referred to as reassociation. CHs also may no longer maintain relative stable communication n to its CMs. This is referred to as CH rotation.

MANET is formed as a set of 1- hop clusters and each node has at least one cluster head. The selected leader can run the IDS since nodes are energy limited. Nodes in each cluster should elect a node as leader which has low mobility and considerable energy level to serve as IDS for the entire cluster. Since the resource level is the private information of a node, unless sufficient incentives are provided, nodes might misbehave by acting selfishly and lying about their resources level.

Our proposed clustering scheme provides incentives in the form of reputation [1] to encourage encouraging selfish nodes, longer connection lifetime, fewer reassociation rates, shorter reassociation time. Doppler shift is used to estimate the relative speeds of nodes. The solution has two main stages. 1) Cluster formation stage 2) Cluster maintaining stage. In first stage each node estimates its average relative speed to its neighbors by periodically exchanged hello packets as well as cost of analysis based on energy level and reputation value. Based on the estimated results, nodes with the lowest relative mobility and low cost are selected as leaders.

In cluster maintaining stage, predicted mobility related information's are used to solve the problems caused by relative node movements, including the cases when a node moves out of its current CH coverage area, two CHs move into each other's coverage area and a CH is not qualified to keep serving its members. These approaches are further enhances the network stability [16].

II.SYSTEM DESCRIPTION

The number of CMs in each cluster is limited to N_U. A CH is saturated if there are N_U CMs associated with it otherwise unsaturated. Each node broadcasts hello packets with a constant period T_B. Within βT_B ($\beta \geq 1$), no hello packets from any neighbor, that will be rejected from the neighbor list of node i. In this paper we focus on balancing resource consumption of IDS and stable one-hop relationship between CMs and CHs.

For leader election, Intrusion detection, Stable Clustering we formulate the following components.

1. Mobility Estimation
2. Cost of Analysis Function
3. Reputation system
4. Payment design

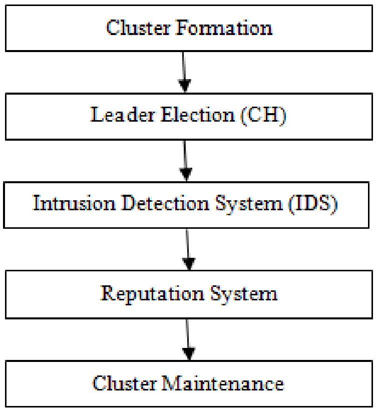

Fig 1. System model

A. Mobility Estimation

Relative position of node 'a' is X and for b is Y. Node b moves with a relative speed $V_{b \to a}$ toward a. In this model, average power of the received signal is

$$P_r = \frac{P_t G}{d^{\alpha}} = \frac{G'}{d^{\alpha}}$$

$$d = \sqrt[\alpha]{G'/P_r}$$

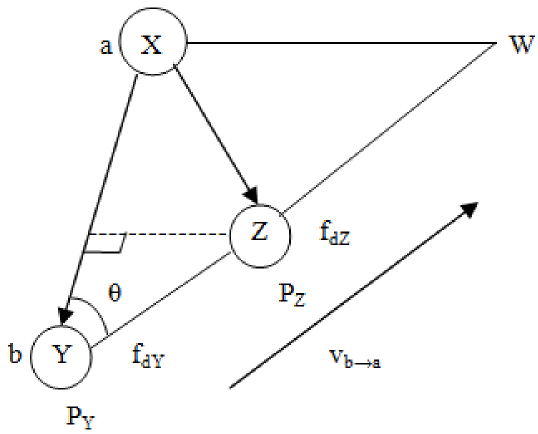

Fig 2. Relative node position in approaching scenario

where P_t is the transmission power, d is the distance between the two nodes, G is a constant, depends on the characteristics of radio transceivers, α is a path loss exponent.

The relative speed can be estimated after the node b receives two Hello packets from a at positions Y and Z with time interval t, f_{dY} and P_Y are Doppler shift & average power of received signal at position Y, f_{dz} and P_z are Doppler shift & average power of received signal at position Z. Difference between the average powers of received signals at two positions P is

$$P_\Delta = P_Z - P_Y$$

$$= \frac{G'}{\left(\overline{XY} - d_\Delta\right)^\alpha} - \frac{G'}{\overline{XY}^\alpha} \quad (1)$$

where $d_\Delta = \overline{XY} - \overline{XZ} \geq 0$

Expanding the right hand side of (1) using first order Taylor series,

$$P\Delta = G'\left(\frac{1}{\overline{XY}^\alpha} + \frac{d\Delta\alpha}{\overline{XY}^{\alpha+1}} + O(d\Delta) - \frac{1}{\overline{XY}^\alpha}\right)$$

$$\cong d_\Delta \alpha \left(\frac{P_Y}{G'}\right)^{\alpha+1} \quad (2)$$

Therefore

$$G' \approx P_Y \left(\frac{\alpha d_\Delta P_Y}{P_\Delta}\right)^{1/\alpha} \quad (3)$$

Since $\overline{XY} = \sqrt[\alpha]{G'/P_Y}$ from (3) we approximately have

$$\overline{XY} = \left(\frac{G'}{P_Y}\right)^{\frac{1}{\alpha}}$$

$$= \frac{\alpha d \Delta P Y}{P \Delta} \quad (4)$$

Similarly, $$\overline{XY} = \left(\frac{G'}{P_Z}\right)^{\frac{1}{\alpha}}$$

$$= \frac{\alpha d \Delta P_Z}{P \Delta} \quad (5)$$

The law of cosines in ΔXYZ can be stated as,

$$\overline{XZ}^2 = \overline{XY}^2 + \overline{YZ}^2 - 2\overline{XY}\,\overline{YZ}\cos\theta \quad (6)$$

where $\overline{YZ} = V_{b\to a}t$, when t is very short, ΔYXZ is very small and d_Δ is

$$d_\Delta = \overline{XY} - \overline{YZ} \quad (7)$$

Since $f_{dY} = f\, V_{b\to a} \cos\theta / s$, where s is the speed of light, we have

$$\cos\theta = \frac{sf_{dY}}{V_{b\to a}} 2 = XY \quad (8)$$

Substituting (8) in (6), we have

$$\overline{XZ}^2 = \overline{XY}^2 + \left(V_{b\to a}\right)^2 - 2\overline{XY}\frac{ts\, f_{dY}}{f} \quad (9)$$

From (4), (5) and (9), $V_{b\to a}$ can be solved as

$$V_{b\to a} = \frac{\sqrt{s\, f_{dY}\sqrt{\alpha}}}{P_\Delta f}\sqrt{2P_\Delta P_Y - \alpha P_Y^2 + \alpha\left(\frac{P_Y^{\alpha+1}}{P_Z}\right)^{\frac{2}{\alpha}}} \quad (10)$$

Node lifetime within a cluster is

$$\gamma_{b,a} = \frac{\overline{YW} - \overline{YZ}}{V_{b\to a}} \quad (11)$$

1) Effective neighbor set of a node:

Let N_i be the total number of neighboring nodes of node i. If $N_i > N_U$ the N_U nodes that have the lowest relative speed to node i forms the effective neighbor set of node I, which is denoted as $N_{e,i}$. If $N_i \le N_U$, the effective neighbor set of node i includes all its neighboring nodes. Effective Average Relative Speed (EARS) of node i is defined as

$$\overline{V_i} = \frac{1}{\left|N_{e,i}\right|}\sum_{j\in N_{e,i}} V_{i\to j} \quad (12)$$

Where $\left|N_{e,i}\right|$ is the number of nodes in $N_{e,i}$.

B. Cost of Analysis

Cost of analysis design is based on node's energy level and its reputation value. It provides two properties: Fairness and Privacy. The former is to allow nodes to increase their reputation by less resource to serve as leaders. The latter is to avoid malicious use of resource level.

E_i is energy level of node i. nT_i is number of timeslots alive in a cluster. PF_i power factor of node i. TV_i is trust value of node i. PS is percentage of sampling.

$$PS_i = \frac{TV_i}{\sum_{i=1}^{N} TV_i} \quad (13)$$

Cost of Analysis of node i,

$$c_i = \begin{cases} \infty, if\left(E_i < E_{ids}\right) \\ \frac{PS_i}{PF_i}, otherwise \end{cases} \quad (14)$$

C. Reputation system

Each node in a cluster has the following components:

1) Monitor or watchdog:

Set of nodes are selected as checkers to monitor the behavior of leaders by mirroring a small portion of the computation done by leaders.

2) Information Exchange:

Reputation exchanged with other nodes in other clusters and information about leaders are exchanged by checkers.

3) Reputation Table:

It contains ID of other nodes and their respective TV. The node with highest reputation is most trusted node and is given priority in the cluster service.

4) Threshold Check:

If Node's reputation is predefined threshold then nodes services are offered based on its reputation. Leaders behavior is greater than the predefined threshold then punishment system will be called.

5) Service System:

The amount of service provided to each node is based on node's reputation so nodes are motivated to participate in every election round and try to increase their reputation by becoming the leader in order to increase their services.

6) Punishment System:

Checkers are catching and punishing misbehaving leaders by decrasing its reputation value using many detection levels.

D. Payment Design

Payments are computed using the VCG mechanism where truth telling is the dominant strategy. Payment is given to the elected node and it is based on per packet price that depends on the number of votes the elected node gets. Payment of node m is

$$P_m = \sum_{i \in N} vt_m(c,i) B \rho_m \tag{15}$$

Where

$$\rho_m = \min \sum_{j \in -n_m} v_j\left(\theta_j, o\left(\theta_j, \theta_{-j}\right)\right) \tag{16}$$

III. CLUSTERING

A. Effective Leader Election (ELE) Algorithm

Initially, each node starts the election procedure by broadcasting Hello message to all its neighbors. This message contains its ID and hash value of the cost.

Algorithm 1 (Executed by every node)

/* On receiving Hello, all nodes reply with their cost */

1. if (received Hello from all neighbors) then
2. Send Begin-Election (ID_k ; $cost_k$; EARS);
3. else if(neighbors(k)=Ø) then
4. Launch IDS.
5. end if

After receiving all the hash values from all its neighbors each node send the Begin-Election message. This message contains the original values, ID of the node and Effective Average Relative Speed. If a node does not have any neighbors it can launch its IDS.

Algorithm 2 (hash Executed by every node)

/* Each node votes for one node among the neighbors */

1. if ($\forall$ n $\in$ neighbor(k), $\exists$ i$\in$n : $c_i \leq c_n$) then
2. Send Vote (ID_k ; ID_i ; $cost_{j \neq i}$);
3. leadernode(k) := i;
4. end if

After receiving the Begin-Election message each node compares hash values to verify the least cost and lowest speed. Each node send Vote message to the corresponding node. The Vote message consists of ID of the node, ID of the leader node to which it sends the vote and second least cost.

Algorithm3 (Executed by Elected leader node)

/* Send Acknowledge message to the neighbor nodes */

1. Leader(i):= TRUE;
2. Compute Payment, P_i ;
3. update service_table(i);
4. update reputation_table(i);
5. Acknowledge = P_i + all the votes;
6. Send Acknowledge(i);
7. Launch IDS.

The leader node calculates its payment and sends an Acknowledge message to all the serving nodes. The Acknowledge message contains the payment and all the votes the leader received. The leader node then launches its IDS.

Each ordinary node verifies the payment and updates its reputation table according to the payment. All the messages are signed by the respective source nodes to avoid any kind of cheating. At the end of the election, nodes are divided into two types: Leader and ordinary nodes. Leader nodes run the IDS for inspecting packets, during an interval T_{ELECT} , based on the relative reputations of the ordinary nodes. We enforce reelection every period T_{ELECT} since it is unfair and unsafe for one node to be a leader forever. Even if the topology remains same after T_{ELECT} time, all the nodes go back to initial stage and elect a new leader according to the above algorithms.

IV.CLUSTER MAINTENANCE

Stability of cluster structure is reduced by problems caused by node movements. In cluster maintenance, predicted mobility information used to deal with problems like CM moves out of its coverage area, a CH rotation is needed, or two CHs moves into each other's coverage area.

A. CM moves out its CH coverage area

When a CM realizes that it is moving away from its CH then it starts to predict the stay time $\gamma_{a,b}$. If CM receives Hello packet from an unsaturated CH then it predicts $\gamma_{a,b}$, to which CH has highest staytime, the CM associate it with association request. If any node in orphan state after leader election and if it does not receive any CH announcement after βT_B time, then the node itself can become a CH.

1) Adding a new node:

Four messages are needed to include a new node. At first, Hello message is used by a new node intimate its presence. Upon receiving the Hello message neighbor node replies. If it is a leader node it sends the Status message with its cost otherwise ordinary node sends the ID of its leader node.

Algorithm 4 (Executed by new node)

```
/* The neighboring nodes send 'Status' to new
 node*/
1. if (leader(k) = TRUE) then
2. Status:=(cost_k, EARS) ;
3. else
4. Status:=leadernode(k);
5. end if;
6. send Status(k,n);
```

On receiving the Status messages from the neighbors, the new node n sends Join to the leader node. If two of its neighbors are leaders with the same cost, then the new node can send Join to any of the nodes depending on its physical location (i.e., signal strength). We assume that an ordinary node has no interest to be a leader during the service time since it will not receive any payment from others. The algorithm does not make the new node as a leader for others before the new election (i.e., to reduce the performance overhead). Detailed analysis is presented in Section 6. If the new node has the least cost, it can either send Join to the leader node or launches its own IDS. After getting the Join message, the leader node adds the new node to its service list.

2) Removing a node:

Due to many reasons such as mobility or battery depletion, a node is disconnected from the network. Whenever a node dies, a Dead (n) message is circulated to all neighbors. After receiving the Dead (n) message, the neighbor node checks whether node n is its leader node or not. If node n is the leader node, then it announce a new election and updates its reputation table. Otherwise the leader node updates its serving list.

Algorithm 5 (Executed by neighboring nodes)

```
 /* The neighboring nodes the network and*/
/* declare new election if necessary*/
1. if (leadernode(k)=n) then
2. leadernode(k) := NULL;
3. update reputation(k);
4. send Begin_Election as in Algorithm 1;
5. end if;
6. if (leader(k)=TRUE) then
```

7. if (n ∈ service(k)) then
8. update service();
9. end if;
10. end if;

B. CH Rotation

The relative mobility of CH and all its CMs may change with time. The average relative speed of CH a node at time t is defined as,

$$\overline{V_{a,t}} = \frac{1}{|M_a|} \sum_{m \in M_a} V_{b \to a}^{t} \tag{17}$$

To reduce unnecessary rotations, we use sliding average of $v_{b,t}$ to check whether CH b is still qualified to remain as a CH. The sliding average is calculated as

$$\overline{V_{n-ave}} = \frac{\left(\overline{V_{n,t-(\rho-1)}} + \overline{V_{n,t-(\rho-2)}} + \ldots + \overline{V_{n,t}}\right)}{\partial} \tag{18}$$

∂ is length of sliding window. When Va-ave reaches v_{max} CH broadcasts a cluster rotation announcement. Again leader election takes place.

C. CH Contention

Two CHs may move into each other's coverage area due to nodes continuous movement. That movement leads to degradation of CH to a CM of other CH. a' It starts a countdown timer, When CH a receives a Hello packet from CH. If no more Hello packet is received from CH a' before timer reaches zero, CH contention is not triggered. If second Hello packet is received CH contention is triggered based on the stay time.

V. PERFORMANCE ANALYSIS

We used Network Simulator-2 (ns2) as simulation tool to analyze the performance of the proposed algorithm.

A. Performance Metrics

We use the following metrics to evaluate our algorithm against others: percentage of alive nodes, energy level of nodes, average cluster size, average connection lifetime and average association change rate.

B. Simulation Environment

We randomly assign 60 to 100 joules to each node and energy required to running the IDS for one time slot as 10 joules. We set the transmission radius of each node to 200 meters. Besides, we deploy different number of nodes, which varies from 10 to 100 in an area of 500x500 square meters. Table 1 summarizes our simulation parameters.

Table 1. Simulation Parameters

Parameters	Value
Simulation Time	200 seconds
Simulation Area	500 x 500 m
Number of Nodes	10 to 100
Transmission range	200 m
Movement Model	Random Waypoint Model
Maximum Speed	20 meters/sec
Pause Time	50 seconds
Initial Energy	60 to 100 joules
Traffic Type	CBR/UDP
Packet Rate	5 packets/sec
T_{ELECT}	20 sec
T_B	1 sec
N_U	15

C. Experimental Results

Nodes movement in network will affect the association between CH and CMs. Nodes can behave selfishly before and after the election. Both kinds of selfishness and connection breaks between nodes have serious impact on the normal nodes.

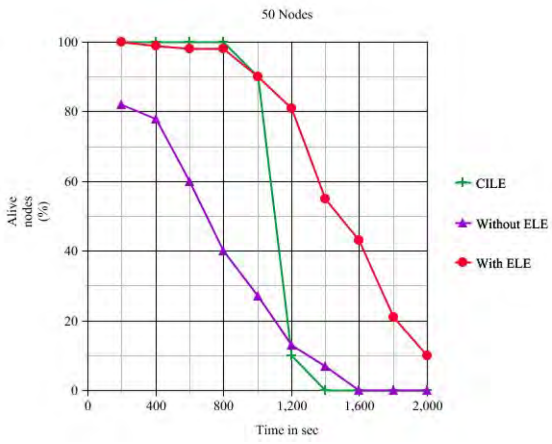

Fig. 3. Percentage of alive nodes

Figure 3, shows the percentage of alive nodes with respect to time. The nodes repeatedly elect a set of leaders every T_{ELECT} seconds. The election is based on proposed scheme. The experiment indicates that our model results in a high percentage of alive nodes. As the number of nodes increases, the life of nodes also increases since there are more nodes to act as leaders. Thus, the detection service is distributed among the nodes which prolong the lifetime of the nodes in MANET.

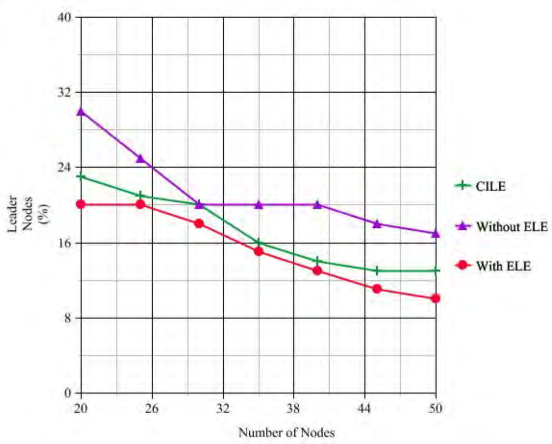

Fig. 4. Percentage of leader node

We compare some of the cluster characteristics of our model with those of the connectivity model. Figure 4, shows the percentage of leader nodes. The percentage of leaders for our model is less that saves the energy of nodes.

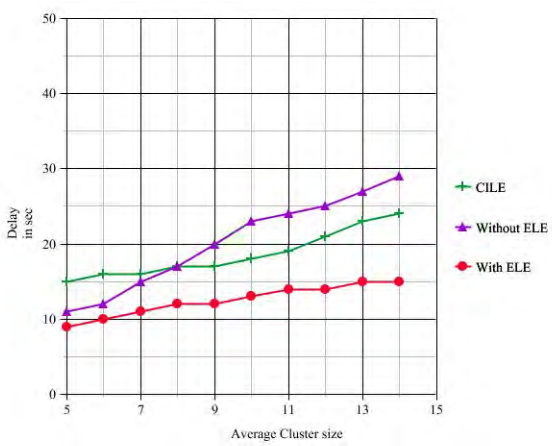

Fig. 5. Average cluster size vs Delay

Above figure compares the average cluster size and reachability delay for nodes. As the cluster size increases the delay also increases.

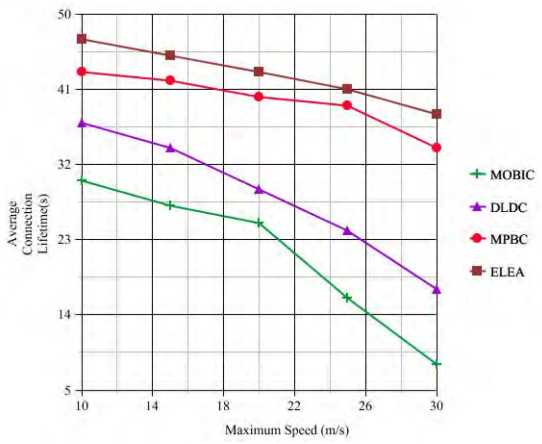

Fig. 6. Average connection lifetime versus v_{max}

Next we compare the average connection lifetime with different v_{max}. Figure 6, shows the simulation result which provides a much longer average connection lifetime that indicates better adaptability of the proposed scheme to dynamic node mobility.

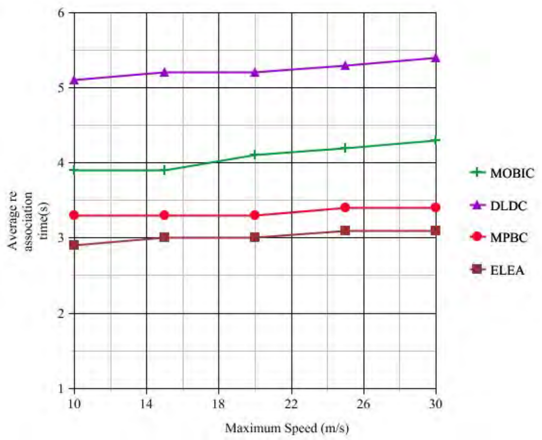

Fig. 7. Average reassociation time v_s v_{max}

The above figure shows the average reassociation time of the proposed scheme and the other clustering schemes in the literature. The average reassociation time using the proposed scheme is much shorter and less sensitive to moving speed changes. This is because of the utilization of the mobility prediction methods, particularly by keeping updated information about the reachable CHs (e.g., relative speeds and predicted stay times). In the high transmission failure scenario, the required average reassociation time increases since a node needs to wait for a longer time before it can receive sufficient information about the nearby CHs.

VI. CONCLUSION

The proposed clustering scheme is based on the estimated mobility information and reputations. Simulation results show good performance of the scheme in terms of providing longer connection lifetime in the presence of selfish node, lower reassociation rate, shorter re association time, balanced resource consumption among all nodes in the network. Moreover we are able to decrease the percentage of leaders, maximum cluster size and average cluster size. The solution motivated nodes are truthfully elect the most cost efficient and low mobility nodes as leaders that handle the detection duty on behalf of others.

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Authors Biography

Parameswaran. T has received his B.E degree in Electronics and Communication Engineering from Vellalar College of Engineering and Technology, Erode, and M.E degree in Software Engineering from College of Engineering Guindy, Anna University Chennai in 2005 and 2008 respectively. He is currently pursuing his Ph.Dfrom Anna University, Regional Centre Coimbatore. He is currently working as Assistant Professor in the Department of Computer Science and Engineering, Regional Centre Anna University, Coimbatore, India. He has published more than 10 research papers in various journals and conferences. He has organized 3 national level workshops. He is a student member of IEEE.

Palanisamy. C has received his B.E degree in Electronics and Communication Engineering from University of Madras, Chennai and M.E degree (Gold Medalist) in Communication Systems from Thiagarajar College of Engineering, Madurai, Madurai Kamaraj University in 1998 and 2000 respectively.He has received his Ph.D from the faculty of Information and Communication Engineering, Anna University, Chennai in 2009. He has more than 13 years of academic and research experience and currently he holds the post of Professor and Head of the Department of Information Technology, Bannari Amman Institute of technology, Sathyamangalam and Tamilnadu, India. He has published more than 30 research papers in various journals and conferences.He has organized more than 10 workshops and holds 2 Funded projects. He is a lifetime member of ISTE. He won Best M.E thesis award at Thiagarajar College of Engineering, Madurai and best paper award titled, "A Neural Network Based Classification Model Using Fourier and Wavelet Features," Proceedings of thr 2nd Int. Conf. on Cognition and Recognition 2008, (ICCR 2008), Organized by P. E. S College of Engineering, Mandaya , Kastrnataka, India, pp. 664-670, 2008. His research interests include Data mining, image processing and mobile networks.

Kokila. P has completed her B.E degree in Information Technology from Maharaja Institute of Technology, Coimbatore in 2011, and currently she is a PG scholar at Anna University Regional Centre , Coimbatore with a specialization of Network Engineering.