Mobility Based Clustering Algorithm and the Energy Consumption Model of Dynamic Nodes in Mobile Ad Hoc Network

Suchismita Chinara [1], Santanu Kumar Rath [2]
Department of Computer Science Engineering,
National Institute of Technology, Rourkela, Orissa, India.
[1] Suchi.nitrkl@gmail.com
[2] Rath.santanu@gmail.com

ABSTRACT

The mapping of cellular architecture into mobile ad hoc network (MANET) leads to the design of Linked Cluster Architecture (LCA), where every cluster has a head node associated with zero or more member nodes. In order to achieve a faster cluster setup, we consider mobility of nodes as the deciding parameter for selecting the heads and their associated members. A node having the lowest mobility among its neighbors becomes the cluster head. Selection of low mobile nodes as the cluster heads ensures better cluster stability. A new energy consumption model has been considered for the cluster heads that takes into account the network traffic, density of cluster members and the transmission power utilized to communicate the member nodes.

Keywords: Mobile ad hoc network, running average, node operating mode, energy consumption.

I. INTRODUCTION

With the recent advances in wireless communication and the development of low cost wireless devices like PDAs, laptops etc., people have a desire to stay connected with the outer world even on fly. Mobile ad hoc network (MANET) is a proven solution for such requirements which does not need any fixed infrastructure for deployment [13]. Situations like disaster recovery, battle field communication and law enforcement operations demand for setting up a network in no time. However, limited battery power and computing capability, scarce in radio resources and bandwidth, frequent node mobility and link failure perturbs the efficient network services [2].

One way to overcome these hindrances and to support efficient communication in a multi-hop environment is the development of virtual wireless backbone architecture [2] where few nodes are selected to form the virtual backbone of transmission. Thus the concept of mapping the base station design into ad hoc network results in the formation of cluster architecture [14]. The cluster head within each cluster acts as the local coordinator for its member nodes. The one-hop distance of member nodes from its cluster head guarantees faster communication [3].

Being the communication hotspots, cluster heads consume more battery power while serving other member nodes [8]. In this paper we propose a distributed clustering algorithm that makes a fair distribution of cluster headship among all the nodes. The algorithm aims to distribute the time for which a node is selected as cluster head in an uniform manner so that every node obtains nearly equal opportunity to act as a central router for its neighbor nodes. A faster cluster setup is aimed to achieve such that unlike [5, 12] the freezing time of motion for mobile nodes during clustering can be minimized. Further, energy consumption is a key factor that hinders the deploy ability of a real ad hoc and sensor network. It is due to the limited life time of the battery powered devices that motivates intense research into energy efficient design of operating systems, protocols and hardware devices. We consider the energy consumption of every node in a broadcast environment. Specially, we propose a new energy consumption model for the head nodes by considering the amount of data forwarded, the service cost for its members and the total transmission power utilized by it. The rest of the paper is organized as follows. Section II describes the work done in the related area followed by section III, which gives a brief description about the proposed algorithm with a suitable example. Section IV focuses on the energy consumption model of the nodes and section V explains the simulation carried out and its results obtained. Finally, section VI concludes the paper.

978-0-7695-3513-5/08 $25.00 © 2008 IEEE
DOI 10.1109/ICIT.2008.54

II. RELATED WORK

Cluster control structure is found to be a proven solution for efficient resource management in mobile ad hoc network. There exists some 1-hop clustering algorithms that emphasize either on minimizing number of cluster heads [1, 2] in the virtual back bone to reduce the routing delay or maximizing the cluster stability by un-altering the head nodes [3,7]. A combined metric clustering algorithm [5, 10] uses parameters like mobility, degree of connectivity, transmission power and available battery power of a radio to find its suitability as a head. But obtaining so much of information to compute the combined weight of individual nodes in the network itself needs a longer frozen period of motion before the cluster is actually formed. Moreover, a large number of message exchanges are required globally among all the nodes to yield a node with lowest weight.

The author in [4, 9] proposed a weight based distributed mobility adaptive algorithm DMAC that removes the non-mobility assumption of the hosts during clustering setup and maintenance. Heads are selected among the radio nodes with the knowledge of their local topology resulting in a faster cluster setup period. This algorithm adopts the topology change in the network during the cluster setup as well as maintenance period. This major advantage of DMAC makes it more realistic in ad hoc network. However, the criteria by which the nodes are selected as heads are not specified in it. Also, this algorithm does not allow two cluster heads to be neighbors of each other. That is when two head nodes come within the transmission range of each other; the node with the lower weight has to resign its role as head and is forced to become the member node of the node with higher weight. This restriction of non-neighborhood of two cluster heads increase the cost of cluster maintenance by increasing frequent reaffiliations of the member nodes and the rate of dominant set updates. Moreover, the condition of affiliation of member nodes to a head with higher weight than its present head (if it finds any at any time within its transmission range) further increases the reaffiliation rate reducing the clustering efficiency.

None of the above algorithms emphasize on the energy constraint of the mobile radios. Though the authors in [5, 10] takes the residual power as one of the metric for computing the combined weight, but the cluster head serving time alone can not assure a good prediction for energy consumption. Recently, Yang and Zhang [12] have proposed a new weight based clustering algorithm WBCA that considers the mean connectivity degree and the consumed energy of a node to calculate its weight. As per the algorithm the consumed energy is dependent on the degree of connectivity of the nodes. Calculating the mean connectivity degree of a node also needs to calculate the degree of connectivity of its neighbor nodes. In a dynamic network where the topology changes frequently and the degree of connectivity changes rapidly, keeping the connectivity information of every node in a local proximity increases further complexity in computation as well as the freezing time prior to the cluster setup. The authors in [18] have proposed an energy efficient cluster design which is possible either in case of a static network or where the cluster head is known a priori. For a real ad hoc network these conditions are never satisfied.

III. PRELIMINARIES AND PROPOSED ALGORITHM

The mobile ad hoc network can be modeled as a unidirectional graph G = (V, L) where V is the set of mobile nodes and L is the set of links that exist between the nodes. We assume that there exists a bidirectional link L_{ij} between the nodes i and j when the distance between the nodes $d_{ij} < t_{range}$ (transmission range) of the nodes. In the dynamic network the cardinality of the nodes $|V|$ remains constant, but the cardinality of links $|L|$ changes due to the mobility of the nodes. A preliminary version of this algorithm appeared in [21]. The algorithm works with the following assumptions:

- Nodes in the network have equal transmission range
- Every cluster head has the information regarding the weight of its member nodes.

In a dynamic network the mobility of nodes can not be ignored. It has a vital role in maintaining the stable cluster structure. Thus we choose mobility of a node to be the deciding factor for initial cluster setup so that a better cluster stability can be achieved. A node with lower mobility has a higher chance of being a cluster head. The weights assigned to the nodes are reciprocal to their respective mobility. i.e. a node with lower mobility is assigned a higher weight and the node with higher mobility is assigned a lower weight.

Basically, we consider the mobility of a node by taking the average of the distances covered by it in last n time slots. That is

Total distance at time t is $D_t = \sum_{i=t-n}^{i=t} Dist_i$ where i= t is current time.

Thus, average Mobility M = Total distance D_t / n

Here, instead of taking the most recent mobility of a node we take a statistics of distances covered by it in last n unit of time. This gives a prediction of its mobility characteristics and identifies the node with minimum average mobility. Then the weights are calculated for individual node which is inversely proportional to its mobility. That is a node with higher running average is given lower weight and a node with lower running average is given a higher weight. In order to find the weight we take a very simple ratio as

$$W_i = \frac{k}{M_i}$$

Where, the value of k is a constant that can be decided depending on the network area. During the initial cluster setup phase every node broadcasts it's ID along with its weight W_i to the neighbors and stores the weights W_j that it hears from other nodes within its transmission range. If it does not receive any weight higher than its own weight then it declares itself as a cluster head and the entire 1-hop uncovered neighbor nodes (i.e. whose role is not yet decided) become the members of the currently formed cluster. A lower ID node is preferred for cluster head in case of a tie in the weights of the nodes. This process is repeated till all the nodes are assigned with their role either as a head or a member of the cluster. This ensures a fast cluster setup with minimum freezing time of motion by the nodes. Unlike [4] once a member node is affiliated with a cluster head, it does not re-affiliate to a new head unless it goes out of the range of its current head or the head drains out of battery power. This reduces the number of re-affiliations lowering the cluster maintenance cost.

We calculate the Cumulative Time T_i during which node i acts as a cluster head as

$T_i = \sum_{k=1}^{q} T$ where q indicates the times of period for which a node i acts as cluster head.

The steps of initial cluster formation in the network:

Step 1: Detect the neighbors of individual node v (i.e. detect the nodes within its transmission range).

Step 2: For individual v, compute the total distances covered by it in last n unit of time (i.e. $Dist(v)_{t=n} = \sum Dist(v)_{t=n-1} + \sqrt{(x(i)_{t_n} - x(i)_{t_{n-1}})^2 + (y(i)_{t_n} - y(i)_{t_{n-1}})^2}$).

Step 3: Compute the average mobility of individual node v (i.e. $M_v = \frac{Dist(v)_{t=n}}{n}$).

Step 4: Compute the weights of the nodes as explained earlier.

Step 5: For node v, If $w_v \rangle w_i$ where $i \in \text{neighbor}(v)$, then Set head= v.

And,

If dist ($v, i_{uncovered}$) $\leq v_{trange}$ then HEAD ($i_{uncovered}$) $= v$.

Step 6: Repeat step 5 till all the nodes are covered with a status of either a cluster head or a member node.

The example of cluster setup phase of the proposed algorithm is demonstrated with the help of Figure 1 and Figure 2. To start with the Fig.1 every node is identified with a unique ID and its associated weight in parenthesis. We assume that the weights are already being computed for every node.

The link between every pair of nodes denotes that they are within the transmission range of each other and establish a bidirectional link among each other.

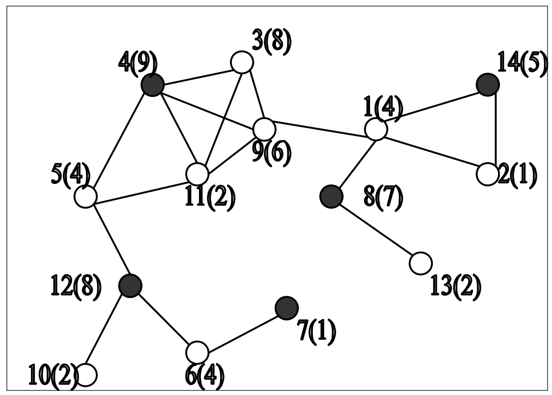

Fig. 1 Initial cluster heads are identified

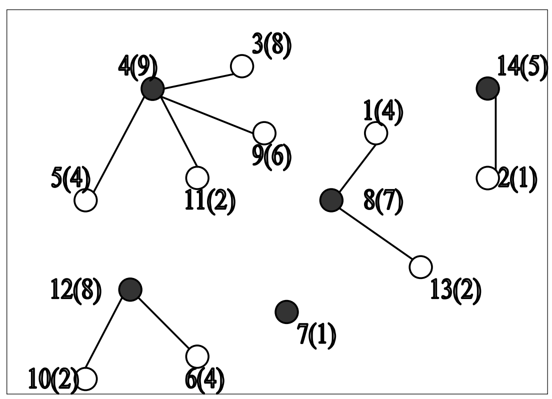

Fig.2 Clusters are formed

Above Figures show the network with the cluster heads identified after the exchange of their weights within the local topology. A node having the higher weight among its one-hop neighbors become the head and its immediate uncovered neighbors become its members. Fig. 2 shows the network with the corresponding head and its associated members. Here, the dark circled nodes indicate the cluster heads and the ordinary circles denote the member nodes. As we know this is only the virtual partition of the nodes. And this structure changes with every topology change in the dynamic network.

IV. ENERGY CONSUMPTION MODEL

The effect of ad hoc operation on power consumption has been explained in [17]. According to 802.11, wireless network interface can work in either base station mode (BSS) or ad hoc mode. In BSS mode, every mobile host remains in the transmission range of one or more base station, which are responsible for buffering and forwarding traffic between hosts. Similarly, nodes can send outgoing traffic to the base station anytime and to receive the incoming traffic it can poll the base station periodically. The rest of the time the node can enter into sleep state, from which the interface must wake up in order to send or receive traffic. The guaranteed availability of fixed infrastructure like base station for buffering and traffic management supports this kind of energy conserving functionality.

In contrary, ad hoc mode of operation does not use any base station. So nodes communicate directly with all other nodes which are in its transmission range. This demands nodes to remain ready to receive traffic from their neighbors and does not allow a node to enter into sleep state. However, a node can enter into idle mode when it constantly listens to the wireless media and consumes energy which is almost same as the energy consumption in receiving traffic. Thus, energy consumption of the mobile devices depends on the operating mode of its wireless network interfaces.

Considering a broadcast communication between the nodes of the dynamic network, wireless interfaces can be in any of the following operating modes:
(i) **transmit:** for transmitting data
(ii) **receive:** for receiving data
(iii) **idle :** a default mode when the node is ready to transmit or receive
(iv) **sleep:** the low power consumption state when a node can not transmit or receive until woken up.

For simplicity we have considered a linear model for the energy consumption cost of mobile nodes for sending or receiving a packet. The linear model [19] consists of a incremental cost **m** and a fixed cost **c** that is represented for a broadcast communication as

$$Energy_{member} = m_{send/receive} \; X \; size_{packet} + c_{broadcast}$$

In a broadcast traffic, the sender listens briefly to the channel. If the channel is found to be free then the packet is sent and is received by all nodes in wireless range. If the channel is found easy, the sender has no choice but to back off and retry later. In order to avoid the complexity of retransmission, we have ignored the situation of retransmissions; acknowledgements as well as discarding cost of overhear packets by the hidden and exposed terminals.

The situation is little bit different for the cluster heads. In addition to the job of forwarding the packets to and from the cluster, it has an additional job of resource management for its members. Thus the cost of consumption of energy is proportional to the number of member nodes served by the cluster head. Again the radio range coverage by the head node has a considerable effect on its energy consumption. Depending on the RF environment the energy consumption can vary from p_v^2 to p_v^4 [20], where p_v is the transmission power utilized by the head node in communicating a 1-hop neighbor v within its cluster. As we consider the distance between the nodes in a cluster is very small, so we setup a linear relation between the transmission power and the energy consumption of the head node. As a whole, we consider the energy consumption of a head node basically depends on the following parameters:

(i) The traffic forwarded by the head
(ii) No. of members served by the head
(iii) Total transmission power utilized by the head in serving the members.

and proposed a simple linear equation as

$$Energy_{head} = \alpha * |n_i| + \beta * Traffic_{bcast} + \gamma * \sum_{v' \in n_i} dist(v, v')$$

Where $|n_i|$ represents the cardinality of the cluster, $Traffic_{bcast}$ is the cost of energy consumption in traffic forwarding and $\sum_{v' \in n_i} dist(v, v')$ is the total transmission power utilized in communicating the member nodes of the cluster head. α, β and γ are the weighing factors for the corresponding network parameters. These values are kept flexible so that they can be changed as per the network scenario. For example, when the network traffic is very high β can be given more weight age than the other two. Similarly, in a dense network where the cardinality of clusters are more, the weight age of α dominates the other factors. All three parameters are chosen so that $\alpha + \beta + \gamma = 1$.

V. SIMULATION RESULT AND DISCUSSION

We simulate our mobility based algorithm using the Random Walk mobility model. This mobility model [14, 15] represents the most erratic and unpredictable movement of an entity. Here, a mobile node (entity) moves from its current location by choosing a random speed between (speedmin, speedmax) and a random direction between (0, 2π) respectively. In random walk model when a mobile node reaches a simulation boundary it bounces back with an angle determined by the incoming direction. This is a memory less mobility pattern as it retains no knowledge about its past location and speed value.

We simulate a system of M nodes in a 100 x 100 grid area. And the simulation time is kept for 10000 seconds. The maximum mobility of nodes is kept between 0 m/sec to 5 m/sec. Equal transmission range for all the nodes are taken between 25 to 30 grid units. In our simulation the value of K was taken as 1000 and the running average of every node is calculated for 5 unit of time (i.e. n=5) elapsed. The simulation result for the cumulative time of a node acting as a cluster head is shown in Fig.4 where M is considered as 35. We made a comparison with the well known lowest ID algorithm and the recent WBCA algorithm.

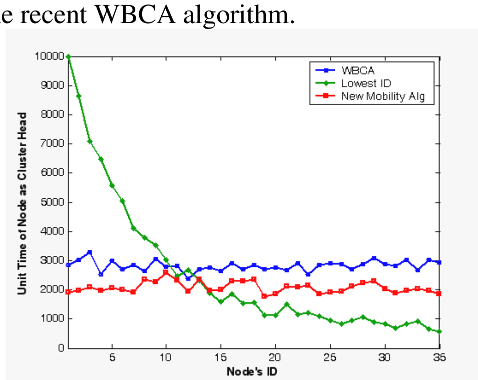

Fig. 4 The time of a node acting as a cluster head

It can be seen from the result that the distribution of cumulative time T_n for every node to act as a cluster head is not uniform in the Lowest ID algorithm. The nodes with lower ID get the opportunity to remain as head for a longer period of time. But the situation is different in other algorithms. The proposed algorithm and the WBCA algorithm gives almost equal chance to every other node to act as a cluster head which is clearly visible in figure 4.

The simulations of the new energy consumption model for the algorithms are shown in the following figures. For the member nodes the measurements of the energy consumption during different operating modes are considered [17, 19] as:

Broadcast send= 1.9 μ W.s/byte * size $_{packet}$ +250 μ W.s

Broadcast recv= 0.50 μ W.s/byte * size $_{packet}$ +56 μ W.s

Idle = 808 mW

and the packet size is taken as 1024 for the simulation. Figure 5 represents the result for the bench mark Lowest ID algorithm for different transmission ranges. It is clear from the figure that higher transmission range of a node consumes more energy than that of in lower transmission range. Moreover, the nodes with the lower IDs consume maximum energy where as the energy consumption of higher ID nodes is almost negligible. The result shown in figure 5 is a proof of the result of figure 4 that the period of time for a node to serve as a cluster head is directly proportional to its energy consumption.

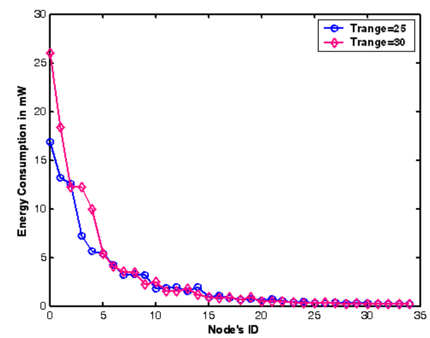

Fig. 5 Energy consumption of Lowest ID algorithm.

As the lower ID nodes remain as heads in most of the simulation time, so the energy consumption is greater for them. The energy consumption of nodes of our proposed algorithm is shown in figure 6. Here, the period of getting the headship by the nodes is randomly distributed among them. So the energy consumptions by the nodes are also randomly distributed. The spikes of the graph represent the consumption by the head nodes as they do the traffic forwarding as well as the member management within a cluster.

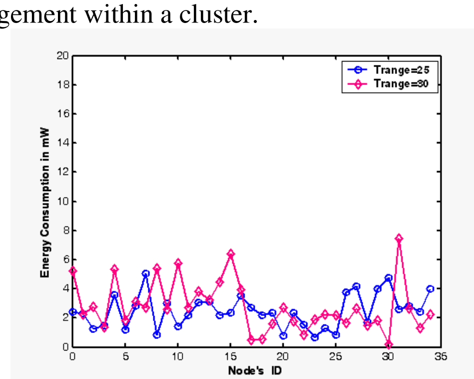

Fig. 6 Energy consumption of proposed algorithm.

The comparison of the simulation result for both the algorithms is shown in figure 7. It is clearly visible that in the lowest ID algorithm the nodes with lower IDs are biased for the headship and drain their energy sooner reducing the network lifetime as well as cluster stability. Our proposed algorithm makes a random selection of head nodes according to their average speed in previous n seconds. This removes the biasness of any node to act as a head so that the consumption of energy is fairly distributed among them. This improves the network lifetime as well as cluster stability by preventing a single node to become overloaded and finally dead.

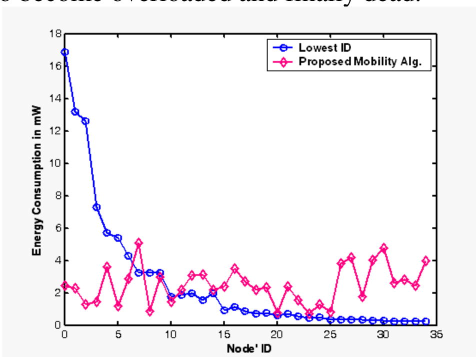

Fig. 7 Energy consumption of nodes for Trange=25

VI. CONCLUSION

A mobility based distributed clustering algorithm is proposed in the dynamic network in order to reduce the freezing time of motion of mobile nodes during the initial cluster setup. We keep a record of previous n set of movements of every node to predict their average mobility. Another solution could be the GPSs installed in the wireless devices that provide their current location information from which the mobility could be calculated with respect to their displacement information. A node with lower mobility is assigned higher weight value. Choosing low mobile nodes to act as cluster heads ensure better cluster stability as head nodes rarely move. As indicated in the simulation result the nodes become cluster heads in a uniformly distributed fashion. A new energy model has been proposed for the cluster heads that considers several factors like the traffic load, network density and the total transmission power utilized by them in handling their members.

REFERENCES

[1] M.Gerla and J.T.C.Tsai, "multicluster, mobile,multimedia radio network", *wireless networks*, 1,3,pp.255-265,1995.

[2] A.K.Parekh, "Selecting routers in ad hoc wireless network", *Proceedings of the SBT/IEEE international telecommunication symposium*, August 1994.

[3] D.J.Baker, J.E.Wieselthier and A. Ephremides, "A design concept for reliable mobile radio networks with frequency hoping signaling", proceedings of IEEE vol. 75, no.1 Jan, 1987.

[4] S.Basagni, "Distributed and mobility-adaptive clustering for multimedia support in multi-hop wireless networks", in: *proceedings of vehicular technology conference*, *VTC*, vol.2, pp. 889-893, 1999-Fall.

[5] S.Das, M.Chatterjee, D.Turgut, "Wca: A weighted clustering algorithm for mobile ad hoc networks", *Journal of Cluster computing (special issue on mobile ad hoc networks)*, vol. 5, no. 2, 4, pp. 193-204, 2002.

[6] S. Basagni, I. Chlamtac, A. Farago, " A generalized clustering algorithm for peer-to-peer networks", *Proceedings of Workshop on Algorithmic aspect of communication* (satellite workshop of ICALP) July 1997.

[7] D.J.Baker and A. Ephremides, " The architectural organization of a mobile radio network via a distributed algorithm". *IEEE Transactions on Communications COM-29*, pp. 1694-1701, 11(Nov.1981).

[8] J.H. Chang, L. Tassiulas, "Energy conserving routing in wireless ad hoc networks," *Proceedings of INFOCOM 2000*, Tel-Aviv, Israel, March 2000.

[9] S. Basagni, "Distributed clustering for ad hoc networks", in: *Proceedings of International Symposium on Parallel Architectures, Algorithms and Networks*, June 1999, pp. 310–315.

[10] S.Das, M.Chatterjee, D.Turgut, "An on demand weighted clustering algorithm(WCA) for ad hoc networks", *in proceedings of IEEE GLOBECOM 2000*, San Francisco, pp.1697-1701, Nov. 2000.

[11] T.Ohta, S.Inoue, Y.Kakuda, "An adaptive clustering scheme for highly mobile ad hoc networks", *in proceedings of sixth international symposium on autonomous decentralized systems(ISADS'03)*, April 2003.

[12] Wei-dong Yang and G-z Zhang, "A weight-Based Clustering Algorithm for mobile Ad Hoc Network", *proceedings of Third International Conference on Wireless and Mobile Communication* (ICWMC'07), 2007.

[13] S.Basagni, M. Conti, S.Giordano and I.Stojmenovic, "Mobile ad hoc networking" A John Wiley & Sons Inc. publication, 2004

[14] T.Camp, J.Boleng, V.Davies. "A Survey of Mobility Models for Ad Hoc Network Research" Wireless Communications and Mobile Computing (WCMC): Special issue on *Mobile Ad Hoc Networking: Research, Trends and Applications* 2(5): 483-502, 2002.

[15] G.Lin, G.Noubir and R. Rajaraman, "Mobility models for ad hoc network simulation", IEEE INFOCOM 2004.

[16] E. Lochin, A. Fladenmuller, J-Y Moulin and S. Fdidda, "Energy consumption models for ad-hoc mobile terminals", Paris Cedex 05, France.

[17] L.M. Feeney and M Nilsson, " Investigating the Energy Consumption of a Wireless Network Interface in an Ad Hoc Networking Environment", Proceedings of IEEE INFOCOM 2001, Anchorage, Alaska, 3, pp. 1548-1557, 2001.

[18]] C-F Chiasserini, I. Chlamtac, P. Monti, A. Nucci, " Energy Efficient Design of Wireless Ad Hoc Networks", in proceedings of European wireless, February 2002.

[19] L.M. Feeney, " An Energy Consumption Model for Performance Analysis of Routing Protocols for Mobile Ad Hoc Networks" , Mobile Networks and Applications , Kluwer Academic Publishers, vol. 6, pp. 239-249, 2001.

[20] Q. Gao, K.J.Blow, D.J. Holding , I.W.Marshall and X.H.Peng, " Radio range adjustment for energy efficient wireless sensor networks" , Ad hoc networks , vol4, pp.75-82, 2006.

[21] S. chinara, S.K.Rath, P. Bhattad and A. Dey, " Mobility Based Distributed Clustering Algorithm for Mobile Ad Hoc Network", Proceedings of NCNTE-2008, Vashi, Mumbai, pp. 169-172, 2008.