A Stable Energy-Efficient Location Based Clustering Scheme for Ad Hoc Networks

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Abstract. *Clustering* is an approach applied in mobile ad hoc networks to organize the hosts in groups called *Clusters*. The paper focuses on implementing a Clustering technique that conserves *Energy*, provides *Stability* and keeps the *Communication Traffic* and *Overheads low* using *Location based approaches* by setting *Thresholds* for different parameters in dynamic ad hoc environment of uncontrolled movement of nodes, low bandwidth of wireless channel and energy limited nodes. The mechanism uses pools of Primary and Secondary cluster heads (CHs) to provide uninterrupted communication due to node mobility. The protocol saves network resources by reducing the information exchange amongst the nodes and limiting it to clusters and CHs. The paper includes a case that models different scenarios based on the proposed protocol. Also, characteristic analysis of our clustering scheme with some of the existing algorithms is done which shows the strength of this scheme over others.

Keywords: Clustering, Mobile Ad Hoc network (MANET), Stability, Location Services, GPS, Energy Conservation, ELS.

1 Introduction

A Mobile Ad-hoc Network (MANET) is a temporary self-configuring wireless network of autonomous mobile nodes that communicate without any preinstalled infrastructure or central administration over the wireless links. MANETs provide an efficient method for a dispersed set of nodes to establish communication without the need of an infrastructure [3].

Every Node acts as a router as well as a host and forwards the packets. Routers are free to move in an uncontrolled manner, thereby leading to constant topology change. Initial setup configuration, routing support and maintenance in mobile networks are some of the most significant challenges that make research in ad hoc networks very interesting. First, uncontrolled node mobility results in a highly dynamic network with rapid topological changes causing frequent route failures. A good network mechanism for this environment is required to dynamically adapt to the changing topology. Second, the underlying wireless channel working as a shared medium, provides much less and variable bandwidth than wired networks making available bandwidth per

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node even lower. Therefore, the right routing protocol should be bandwidth-efficient by expending a minimal overhead for computing routes so that much of the remaining bandwidth is available for the actual data communication. Third, nodes run on batteries which have limited energy supply. In order for nodes to stay and communicate for longer periods, it is desirable that the routing approach be energy-efficient as well. This provides another reason why overheads must be kept low. Thus a mechanism must be there in the network that meets the conflicting goals of dynamic adaptation and low overhead to deliver good overall performance [13].

Currently there is a growing interest in designing protocols for mobile ad hoc networks and one of the most researched topics in this respect is *Clustering*. It is an approach applied in mobile adhoc networks to organize the hosts in groups called *Clusters* in hierarchical or flat fashion. The interconnected Clusters communicate inside themselves as well as amongst themselves [6]. Its architecture makes it an extremely efficient approach which helps in improving the network performance; provide scalability in dynamic environment and reducing energy consumption of power limited nodes. The purpose of any clustering algorithm is to produce and maintain a connected cluster where every node can play a different role in different situation [8]. A *Cluster Head* (CH) is chosen for every Cluster using any of the various available schemes for CH Election, which acts as a Base Station for the cluster communication. Many Clustering schemes have been proposed for MANETs where they aim to meet certain needs of the system [7].

There are numerous *Advantages* of Clustering for MANETs [6]: Better *Protocol Performance* for MAC Layer; Improved *Power Consumption*; *Routing Tables' size minimized;* Reduced *Transmission Overhead*; *Aggregated* topology information; *Bandwidth and Energy conservation* are just a few of them. On the other hand, there are some areas of concern that draw the attention of researchers [6]: *High Maintenance cost* because of large message exchanges when topology changes; Some nodes are more *Power consuming* like Cluster Heads and Gateways leading to shutdown of the nodes; *Stability* of Clusters and *Location Management*.

In this paper we focus on the design of an algorithm that implements Clustering while Conserving Energy of the nodes, providing Stability to reduce reclustering and keeping the Communication Traffic and Overheads low using Location Services. There have been many schemes that have implemented each of these features separately to achieve effective routing and adaptability for the vast application set of mobile ad hoc networks.

This paper focuses on a scheme that provides Energy Conservation and Stability in Clustering by managing the Power levels of information signals between the CHs and other members [1] [3]. Further we add Location Management Services to provide Efficient and Fast Routing along with Quick Recovery in case of Link Failures [2]. The algorithm uses a Hierarchical approach with Location services for attaining a Stable Clustered Network. To achieve Energy Conservation for every node the CH and the cluster are chosen depending on the proximity of the CH to the node, so that less power is used while sending and receiving packets. The protocol manages both Intercluster and Intracluster Location information using tables and also includes Path Activation and Deactivation process for accuracy. We assume that all the nodes are

GPS enabled. Also, Mobility parameters are included to achieve Stability in the network which is extremely critical in vehicular ad hoc applications [3].

In Section 2 we present some of the existing related clustering approaches for stability, location management and energy conservation in terms of their strengths and weaknesses. Section 3 describes the proposed clustering approach. In Section 4 we perform a case evaluation under different scenarios and verify the working of our protocol. Section 5 gives a characteristic analysis of our protocol and some previously proposed protocols. Finally, Section 6 concludes the paper.

2 Survey of Related Work

There have been previous works on Energy Conservation in Clustering like 'New Clustering Schemes for Energy Conservation in Two-Tiered mobile Ad Hoc Networks' by Ryu, in which hierarchical clustering schemes that optimize the configuration of the cluster in a way where every node has maximum energy conservation and minimum drop in communication rate are proposed [1]. The schemes designed take into account the *small size and battery supplied power characteristics of nodes* working in dynamic real time event–driven scenarios and reconfigurations. Two schemes have been designed in the paper- *Single Phase and Double Phase* Clustering. Both the algorithms are based on Paging from the Master Nodes and Acknowledgement from the Slave Nodes. Every Master node sends paging signal to all the Slave nodes at the same Power level. Every Slave Node will send an Acknowledgement to one Master Node from which it received highest power level because that Master must be nearest to that Slave, thereby saving the Transmitted Power. It is seen that the Power consumption of every node decreases with both less number and high number of nodes. Although these schemes provide a mechanism for energy conservation and lowering call drop rate. But they are designed assuming static topology which is quite unfeasible considering dynamic nature of mobile adhoc networks. Also, they consider Error-free conditions and no channel contention, which is again very difficult to achieve.

In another paper based on Location Services to improve network performance [2] the protocol manages Location information of a Source, a Destination or any in-between host. The proposed scheme works on single level because multilevel schemes require high Bandwidth because of high Communication overhead. Each CH acts as a Location Server for providing location information which results in Less Delay in searching for a Location. The protocol provides Intracluster management by maintaining two tables – Local Connection Table (LC) and Intracluster Routing Table (Intra R). For Intercluster management, Location State Table (LS) have been used in addition to LC and Intra R tables. But there are certain limitations like the direction and moving rate are considered constant. Also, the protocol works well when the numbers of clusters are less and Cluster Size is Large.

One of the stable clustering algorithms, is proposed in [3] for pseudo linear mobile ad hoc networks. In such networks the movement of the nodes is highly linear in one direction without much change in their motion parameters. It is designed on one-hop approach and based on *Doppler's Shift*. The working is in two phases – Initial stage Cluster Formation and Progressive stage Cluster Maintenance. Stability of the network is dependent on the estimated duration of the communication links which depends on DV which further depends on the ratio of the frequency of received signal to the frequency of known communication signal. It was shown that in Cluster maintenance stage, with increase in the speed of a node, the number of members leaving a cluster is more in case number of NULL nodes is less. Authors also found, with increase in the number of NULL nodes, number of clusters formed decrease but they become more stable. The schemes proposed manage CH Contention very well and Cluster size can vary depending on the application. But the schemes don't take Ripple effects of clustering are into account and won't work in case there are any changes in the direction of the nodes. Considering all these approaches, it is seen that though some of the issues are addressed but none of them meets all the requirements of an efficient clustering. In the next section we propose a protocol which implements all of the following: *Stability, Energy Conservation, Location Services and Low overhead.*

3 Proposed Clustering Scheme: ELS

In our Clustering approach, in *the initial set up stage* every node connects to a CH only and not amongst themselves. The scheme utilizes the grouping approach and reduces the information updates by limiting it to a cluster and amongst CHs. Every Cluster is formed by two sets of nodes - Cluster Heads and Cluster Nodes that have unique id numbers. For every cluster our scheme makes use of *Primary* and *Secondary Cluster heads*. Pool of a predefined number of nodes are created for backup of both Primary and Secondary CH using election schemes like Lowest Id, Highest Degree, Weights etc. [8].

3.1 System

Every Cluster node sets up connection with a primary CH that is nearest to it i.e. sending maximum power so as to provide maximum *Energy Conservation*. The CHs work on a set of rules designed for efficient working of the network:

(i) During communication, the power of signal transmitted by the CH varies depending on the power left with the node. A minimum threshold value is set 'T_p' and if the power of the primary CH gets below that value, a new CH is made the primary CH from the pool of elected CHs. The size of any cluster depends on the distance till which minimum power 'P_{min}' of every CH is maintained. This helps in preventing breakdown of the CHs.

(ii) Also, the Bandwidth capacity 'B_c' allotted for communication to every CH is fixed. When a CH's majority communication channels are busy and the capacity left with it gets below the minimum set capacity value, we delegate the future communication tasks to the Secondary CH with again capacity 'B_c' and it also starts working as a CH in the cluster. It provides uninterrupted network through Load balancing.

3.2 Location Management

We assume that every node in the network is *GPS enabled* and therefore every CH is able to get and store Location Information of all the nodes in their Cluster and other Cluster Heads. In our approach every CH (Primary as well as Secondary) stores two tables: *Routing Location Table* and *Network Location Table*. The first table - Routing Location Table stores Intracluster information that includes id numbers of the cluster nodes, location coordinates available through GPS and distance to every cluster node (calculated using location coordinates). The other table – Network Location Table stores Intercluster information which includes other CHs' id numbers, shortest route to every other CH in terms of number of hops, node ids in every cluster and neighboring CHs that are one hop away.

Table 1. Cluster Head C-4 Intracluster Table

Node Ids	Node Location	Distance from CH
I-1	12,20,45	7.7'88deg N
I-2	30,60,20	10.3'120degN W
I-3	22,50,12	5.5'90degS

Table 2. Cluster Head C-4 Intercluster Table

CH Ids	Node Ids in Cluster	Shortest Path to CH	Neighboring CHs
C-1	I-1,I-3,I-8	C-3, C-9	C-3, C-12
C-2	I-9,I-5,I-4,I-6	C-2, C-5, C-6, C-9	C-2
C-3	I-2,I-7,I-10	C-8, C-10, C-15	C-8, C-9,C-14

3.3 Cluster Communication

The algorithm proposes the communication in the Clustered network through different types of messages.

(i) Any node that either wants to join a particular cluster or change its cluster membership will send a JOIN packet to the CHs of that cluster. In return, if the current CH (primary or secondary) has the required communication capacity, it will acknowledge the node by sending a JOIN-ACCEPT packet to that node. Also, the CH adds the node information in its tables.

(ii) If a node wants to leave a cluster or is moving to another cluster, it will see a decrease in the strength of the power signal from its current CH that will be below the threshold value set. Node will then send a BYE message to the CH, which in turn removes the node from it member list in the table and responds with a BYE ACCEPT packet.

(iii) Whenever a Cluster node changes its location, UPDATE-NODE packet is sent to the CH with the new information. The CH updates its tables and sends an acknowledgement through UPDATE-NODE ACCEPT packet.

(iv) Whenever there is a change in the CH like a change in the location of CH or its members, change in the membership of nodes or a new CH assignment, UPDATE-CH packet is broadcasted by the CH to all other CHs in the network with aggregated information of the cluster over a fixed time period. Also, if a new CH is designated it gets the copies of all the tables with the previous CH.

(v) Any node that wants to send a message to any other node in the same cluster or a node outside will send a REQUEST message to the CH to get the information of the destination node. If the destination node is within the cluster, CH provides the location info and the next hop in a REQUEST REPLY message. The node then uses Dijkstra's algorithm for calculating shortest path to its destination. The communication of information between cluster nodes of the same cluster is then done through a NODE-MSG packet.

(vi) On the other hand if the node is outside the cluster, CH asks the source node to send it the information that needs to be sent to the destination in REQUEST REPLY message.

Node then sends a NODE-MSG packet to it CH, which sends all the information to the head of that cluster in which destination node is present in a PASS-INFO packet. CH uses CH-MSG to pass the information to the required node. In the packet, source will be the original node that actually sent the message.

Any message can be sent via any alternate intermediate CH in case the intermediate CH on shortest path fails. This is possible because all CHs have the clustered network map.

3.4 Stability

To prevent duplication of packets and loops, we attach a *Sequence Number* with every packet. If Acknowledgement of any form is not received, nodes resend the message after lapse of a time period 'T_{rep}'. To maintain a stable cluster, our algorithm sets up *a Minimum Connection Time, a Maximum and a Minimum Mobility Factor.*

For every node that wants to join a cluster, its estimated Connection time to the CH and its mobility is calculated by using the algorithm in [10]. If the predicted Connection time of that node satisfies the Minimum set Threshold, only then it is allowed to be a part of the Cluster. Also, if any node or a CH has mobility factor is higher than the Maximum set value, it means it will not allow the network to stay stable. Therefore, the node is not made a part of that cluster. On the other hand if two CHs which are extremely close to each other, if their mobility factor is lower than the Minimum value, it means they will stay in each other's vicinity for a large amount of time and thus only one of them is required to service all the nodes. CH with higher power level at that point of time is allowed to stay a CH and the other becomes a node under it.

4 Case Evaluation

In this section, to better understand the proposed scheme, we consider a MANET environment and implement our protocol under various scenarios.

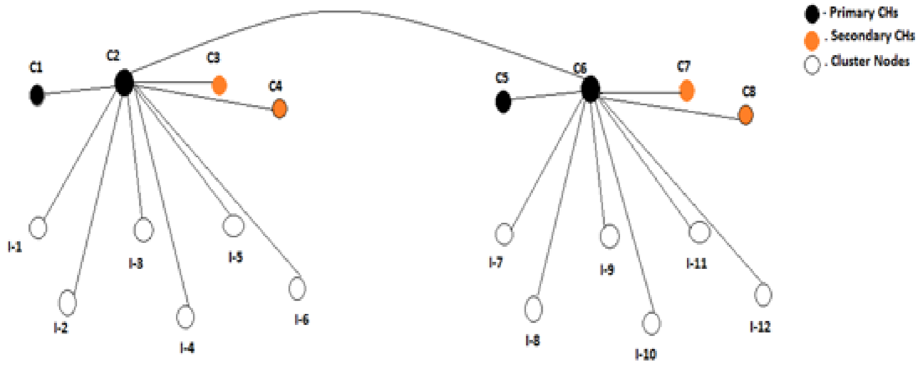

Fig. 1.

As we can see in *Fig. 1*, our network is divided into two clusters. In every cluster there are two primary CHs - (C1,C2,C5,C6) and two secondary CHs - (C3,C4,C7,C8) with currently C2 and C6 being the currently designated CHs. I-1 to I-6 are the members of Cluster 1 and I-7 to I-12 form Cluster 2.

- According to the proposed algorithm, the CHs C2 and C6 have a fixed power level 'PWR'. While communicating let us assume for CH- C2 : $PWR < T_p$
  As a result, the other primary CH- C1 is designated the task of communication and all nodes of the cluster (I-1 to I-6) are now connected to C1. The Intercluster and Intracluster tables from C2 are then passed on to C1 for future communication.
- The currently designated CHs- C1 and C6 are allocated a fixed Bandwidth Capacity B_c such that : $B_c1 + B_c2 + B_c3 + B_c4 + B_c5 + B_c6 + B_cRemaining = B_c$ *(for C1)*
  Let us suppose that $B_cRemaining$ < *Minimum Capacity*, therefore we make secondary CH 'C3' a designated CH of Cluster 1 *(Fig. 2)* and it is also assigned a Bandwidth Capacity – B_c to handle the future connections. Again, the new CH gets copies of the tables.

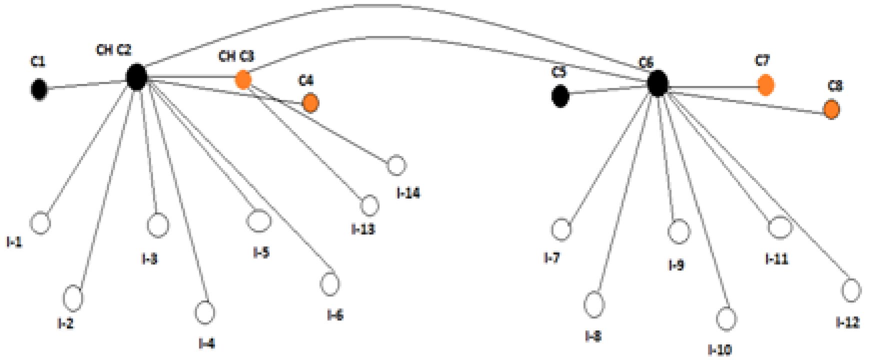

Fig. 2.

- In Fig. 2, Nodes I-13 and I-14 want to join cluster1 and will send JOIN packet to the secondary CH 'C3'. In return, C3 will establish connections with them as it has the required communication capacity and then it will acknowledge the request by sending a JOIN-ACCEPT packet to I-13 and I-14. Also, the CH adds the node information in its tables.
- Next let's consider a scenario where I-8 moves to a position where it finds that CHs of Cluster 1 are closer than that of Cluster 2. According to the energy conservation principle of our algorithm, it will now join Cluster 1.
- The power received by I-8 from CH 'C6' is below the minimum threshold value. So, a BYE message is sent to C6 which in turn acknowledges the request with a BYE ACCEPT. C6 also removed I-8 from its table.

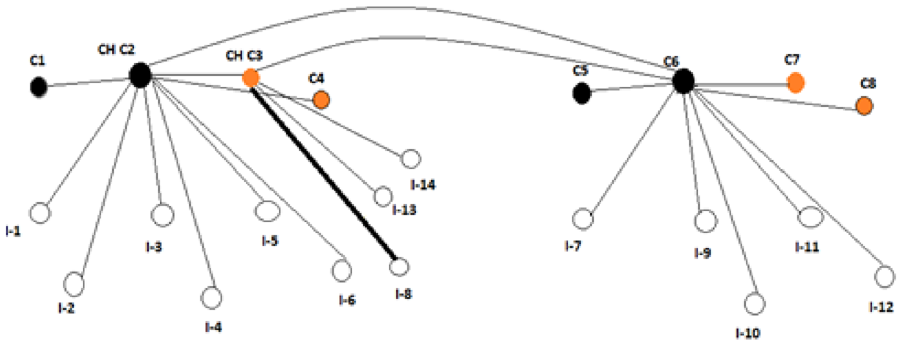

Fig. 3.

- I-8 will then send a JOIN packet to C3 and C2. Since C2 has no more capacity, C3 sends a JOIN-ACCEPT packet and I-8 becomes a part of Cluster 1 (Fig. 3)
- Since I-8 has left Cluster 2, C6 sends the UPDATE-CH packet after a fixed time interval containing this information about node I-8 to C2 and C3, so that they can update their tables. On the other hand, since I-8 after leaving Cluster 2 has joined Cluster 1, C3 will also send an UPDATE-CH to C6.
- In another scenario, let us suppose I-4 in Cluster-1 wants to send a message to I-10 in Cluster-2. I-4 will send a REQUEST message to C-2. Since destination is not in the same cluster, C-2 will send a REQUEST REPLY message to I-4 asking for the message it wants to send to I-10.

  I-4 sends all the information in NODE-MSG packet to C-2 which further passes on this information to C-6 through PASS-INFO packet. C-6 will look up its Intracluster table, get the location of the destination and use the shortest path to deliver the message in CH-MSG packet to I-10.

5 Characteristic Analysis

In this section we provide a characteristic analysis of the proposed algorithm along with some other representative algorithms that address the problems of stability, energy conservation and location management individually. The table provides comparison of performance and other characteristic features of each protocol.

It is seen that the Transmission overhead in the network is Highest in case of [1] because of the use of paging signals for energy conservation, and Lowest in case of [2] when the cluster size is not too large because of the availability of location of all nodes and therefore less location updates. Our proposed algorithm also doesn't require high overhead because of the Location Tables with every CH. Also, Single & Double Phase Clustering Protocol [1] provides faster processing and computing power along with Less Call Drops. But, it works on static topology during the clustering process, which is quite unfeasible. KCLC & KCMBC Protocol [2] takes into account Duplicate copies and Delivery Loops by adding sequencing and in case of Inter-cluster, link failure the packet can still reach the destination as the new route information can be provided by intermediate CHs and so it acts as a Self-Recovery protocol. Again, this protocol assumes an environment in which direction and moving rate are considered constant. Therefore, the results that have been derived don't model the real time scenarios that closely. In DDVC & DDLC Protocol [3] Cluster size can vary depending on the application and they manage CH Contention very well, but won't work in cases where there are any changes in the direction of the nodes.

The proposed algorithm ELS takes into consideration the dynamic nature of the network and the direction and moving rate are not taken constant. In addition, the protocol uses a very efficient mechanism for CH management which ensures Energy and Bandwidth conservation along with fault free working of network. The tables managed by CHs help in achieving Less Delay in searching for a Location, thereby reducing overhead and allowing self recovery with the help of alternate redundant nodes. It is suggested that Single & Double Phase Clustering Protocol [1] takes care

Table 3. Characteristic Analysis

S.No	Characteristics	Single & Double Phase Clustering Protocol [1]	KCLC & KCMBC Protocol [2]	DDVC & DDLC Protocol [3]	ELS Protocol [4]
1	Basis of Protocol	Energy based	Location based	Stability based	Energy, Location & Stability based
2	QOS Metric	Power	Mobility	Mobility	Power & Mobility
3	Route Discovery	Proactive	Proactive	Reactive	Reactive
4	Mobility Support	Low	Medium	Medium	High
5	Architecture	Hierarchical multi hop	Flat k hop	Hierarchical single hop	Hierarchical multi hop
6	Route Redundancy	No	Yes	No	Yes
7	Reclustering	Required	Required	Not Required	Not Required
8	Transmission Overhead	High	Less	Medium	Medium
9	Bandwidth Conservation	Achieved to quite an extent	Limited	Limited	Achieved to quite an extent
10	Stability	No	No	Yes	Yes
11	Energy Conservation	Yes	No	No	Yes
12	Maintenance	No Mechanism	Effective Mechanism	Effective Mechanism	Effective Mechanism
14	Call Drop Rate	Very Low	Medium	Medium	Low
15	Fault Tolerance	Good	Excellent	Less	Good
16	Environment	Static Topology	Constant Direction & Moving Rate	Fixed Direction	Dynamic Topology
17	Self Recovery	To some extent	Yes	Yes	Yes

of the Energy Conservation aspect of Clustering, KCLC & KCMBC Protocol [2] works on Location Management, DDVC & DDLC Protocol [3] tries to achieve stable clustering and ELS protocol incorporates all three aspects of clustering by implementing Location services, Energy efficient CHs and high Stability. Thereby achieving higher QOS than the other protocols.

6 Conclusion

In this paper we have presented an improvised clustering protocol that gives better network performance by combining various QOS metrics together. In MANET scenarios the algorithm works on energy conservation and high stability of clusters with location management that provide efficient and fast routing along with quick recovery in case of Link Failures. Our scheme makes use of two sets of Cluster heads - Primary and Secondary with unique ids. Thresholds have been set for Power level, Capacity and Link duration to achieve Energy Conservation. All nodes are GPS enabled and every CH stores Intercluster and Intracluster table to manage the Location services. Updates are required to be sent only to the CHs, thereby reducing the pressure on Network Bandwidth. This algorithm is well suited for dynamic environment and scenarios where direction and moving rate are not constant. The proposed scheme shows better performance than the previous algorithms because it combines reduced overhead, self recovery, Less Delay in searching along with energy efficient nodes. In the future, we plan to further analyze the mobility and link duration characteristics of our proposed algorithm in multihop Ad-Hoc Environment.

References

1. Ryu, J.-H., Song, S., Cho, D.-H.: New Clustering Scheme for Energy Conservation in Two-Tiered Mobile Ad Hoc Networks. IEEE Transaction on Vehicular Technology 51(6), 1661–1668 (2002)
2. Leng, S., Zhang, L., Fu, H., Yang, J.: A Novel Location-Service Protocol Based on k-Hop Clustering for Mobile Ad Hoc Networks. IEEE Transaction on Vehicular Technology 56(2), 810–817 (2007)
3. Sakhaee, E., Jamalipour, A.: Stable Clustering and Communications in Pseudolinear Highly Mobile Ad Hoc Networks. IEEE Transaction on Vehicular Technology 56(8), 3769–3777 (2008)
4. Rodoplu, Meng, T.H.: Minimum energy mobile wireless networks. IEEE J. Select. Areas Commun. 17, 1333–1344 (1999)
5. Anupama, M., Sathyanarayana, B.: Survey of Cluster Based Routing Protocols in Mobile Ad Hoc Networks. International Journal of Computer Theory and Engineering 3(6), 806–815 (2011)
6. Yu, J.Y., Chong, P.H.J.: A survey of clustering schemes for mobile ad hoc networks. Commun. Surveys tuts. 7(1), 32–48 (2005)
7. Umamaheshwari, Radhamani, G.: Clustering Schemes for Mobile Adhoc networks: A Review. In: International Conference on Computer Communication and Informatics, pp. 1–6 (2012)
8. Camp, T., Boleng, J., Wilcox, L.: Location information services in mobile ad hoc networks. In: Proc. IEEE ICC, pp. 3318–3324 (2001)
9. Su, W., Lee, S.J., Gerla, M.: Mobility prediction in wireless networks. In: Proc. IEEE MILCOM, Los Angeles, CA, pp. 491–495 (2000)
10. Stojmenovic, I.: Position-based routing in ad hoc network. IEEE Commun. Mag. 40(7), 128–134 (2002)
11. Basu, P., Khan, N., Little, T.D.C.: A mobility based metric for clustering in mobile ad hoc networks. In: Proc. ICDCSW, Mesa, pp. 413–418 (2001)
12. Inspirenignite routing for MANETS, http://www.inspirenignite.com/routing-in-mobile-ad-hoc-networks/