Cluster Based Geo-Routing Protocol

Hatem Hamad[*]
hhamad@iugaza.edu.ps

Abdessalam Elhabbash[*] *ahabbash@iugaza.edu.ps*
Yousif Mansour[*] *ymansour@iugaza.edu.ps*
Fuad Abuowaimer[*] *fowaimer@iugaza.edu.ps*

[*]*The Islamic University of Gaza/ Computer Engineering Department, Gaza, Palestine*

Abstract

This paper addresses the problem of the overhead resulting from flooding the control packets in mobile ad hoc networks in searching for routes between the source and destination. We propose a location enhanced routing protocol for clustered MANETs based on the cluster based routing protocol (CBRP). Our protocol employs local position information obtained by smart antennas to discover routes and make routing decisions for the clustered MANETs. One of the CHs, named general manager (GM), is assigned the responsibility to maintain the local positions of the other nodes. The GM divides the space into four quarters and periodically sends HELLO messages that reach all the nodes. Then each node sends its location information to the GM when this information is changed. Also, the GM has the responsibility to route data from the source to the destination. Simulation results show enhancing the performance of clustered MANETs by decreasing the control packets overhead.

Keywords: *MANET, Cluster, smart antenna, CBGRP*

1. Introduction

A Mobile Ad hoc network (MANET) is a self-organizing multi-hop system of wireless nodes that can communicate with each other without pre-existing infrastructure. This type of networks has been used in several applications such as industrial, commercial, cultural and environmental. Ad hoc networks are characterized by limited battery power, limited bandwidth, frequent network topology changes, and rapid mobility. These characteristics make the design of routing protocols a great challenge [1].

Existing ad hoc routing protocols are classified either as proactive (Table-driven) or reactive protocols (On-demand) [2] [3]. Proactive protocols always know the routing information beforehand through periodic route updates. Each node maintains one or more tables to store routing information and refreshes these tables timely. Each node propagates its tables through the network to maintain a consistent network view. The advantage of proactive protocols is that each node has nearly a complete view about the network. Once a source wishes to transmit data to a destination, it immediately looks up the routing table for the needed route. However, proactive protocols do not perform well in high mobility or large networks since the amount of information maintained in tables becomes large. On the other hand, reactive protocols create routes only when needed by the source. When the source requires sending to the destination, it invokes the route discovery procedure to discover the route. Once the route is found, it is maintained by the route maintenance procedure until the destination becomes inaccessible. Although the source has to wait for node discovery delay, practical experiments show the reactive protocols perform better and more suitable for ad hoc networks than proactive ones.

The architecture of the ad hoc networks can be classified into flat or hierarchal architectures [4]. Flat architectures do not define any network structure. They encounter scalability problems especially with the increased network size. In these architectures each node has to maintain information about all nodes in the network which becomes significantly large with increasing the network size [11]. In hierarchal architectures nodes are dynamically grouped into clusters [5] [6] [7]. Each cluster has a representative called cluster head (CH). Every node has to join a cluster. A node that belongs to more than one cluster is called a gateway. Figure 1 shows clustered ad hoc network architecture. Routing traffic between clusters is done by the CH. The CH is responsible on collecting control packets, e.g. route discovery packets, and relaying them. On contrast, in flat architectures each node floods control packets which may overwhelm the network with these packets and consumes the limited capacity.

In this paper we present a location-enhanced routing protocol for clustered MANETs that employs smart antennas for estimating nodes' locations. The rest of this paper is organized as follows. Section II presents a

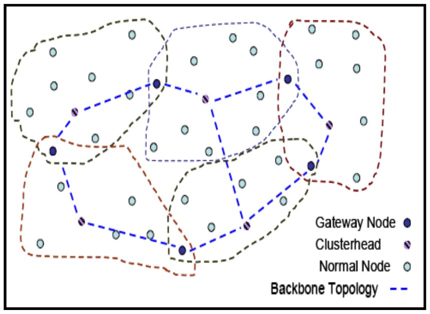

Figure 1: Clustered ad hoc Network

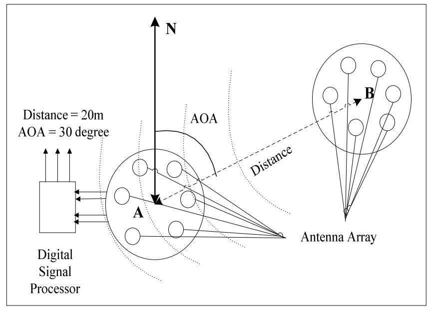

Figure 2: Locate mobile node with smart antenna.

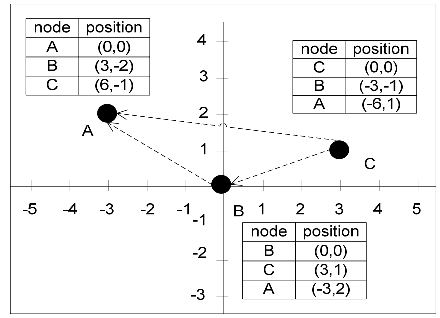

Figure 3: Location calculation.

description of the smart antenna and how to use it to estimate a location. Section III presents the related works. In section IV we state the problem definition. Section VI presents the proposed protocol in which we employ smart antennas to estimate nodes locations of the nodes relative to the GM. Based on this location information we limit the route discovery flooding to the region in which the destination exists. Section 5 discusses the simulation results and finally in section 6 we conclude the paper and outline future work.

2. Smart antennas

Smart antennas is a system of antenna arrays with smart signal processing algorithms that are used to identify spatial signal signature such as the direction of arrival (DOA) of the signal, and use it to calculate beamforming vectors, to track and locate the antenna beam on the mobile/target. Location estimation using smart antennas is more suitable in MANETs than the global positioning system (GPS). GPS has the following limitations to be used in MANETs:

- GPS is very useful outdoors, but it is ineffective indoors because GPS radio signal is blocked by walls inside building [13].
- The accuracy of current GPS lacks the precision required by MANETs [12].
- GPS consumes high power while mobile nodes are equipped with limited batteries [14].

When radio signals arrive at a smart antenna, the antennas in the array collects information on the phase of the signal. This information is processed by an embedded digital circuit. Location information is finally outputted to the host mobile station or terminal. Figure 2 shows two nodes A and B equipped with smart antennas [12]. When node A receives signals from B, the array of antennas estimates the Angle of Arrival (AoA). The power of the signals helps to estimate the distance from node B to node A. This information is processed by the digital signal processor to estimate the position of node B. By the AoA (θ) and distance (d) a node can easily estimate its neighbor position using the following formulas:

$$x = d\cos\theta, y = d\sin\theta \qquad (1)$$

In order to estimate the position of a non-neighbor node, relative position calculation is applied. In figure 3 node A can estimate the position of node C by summing the position of node B relative to A, (P^A_B), and the position of C relative to B, (P^B_C), as declared in (2).

$$P^A_C = P^A_B + P^B_C \qquad (2)$$

For example, in figure 3 node B estimates the position of its neighbor C as (3, 1) and node A estimates the position its neighbor B as (3,-2). Then, if B sends information about the position of C to A, A calculates the position of C as:

$$P^A_C = (3,-2) + (3,1) = (6,-1)$$

3. Related Work

Many routing protocols have been proposed for routing data in MANETs. In this section we present three related protocols AODV, CBRP, and LEOD.

1. Ad hoc On-demand Distance Vector protocol (AODV) is a reactive routing protocol that is designed for flat architectures [8, 9]. Each host maintains a routing table to store information on the mobile nodes in the network and how to reach each of them. Flooding is the way which a source finds a route to a destination. If a node A wishes to send to B, A creates a route request (RREQ) message and broadcast it to its neighbors. Each node receives the RREQ re-broadcasts it to its neighbors with increasing the sequence number of the message to prevent looping. When the RREQ reaches the destination B, B replies with a route reply message (RREP) to A. Then A stores the route in the routing table. An intermediate node can reply to node A if it has a valid route to B. Periodic HELLO messages are used to maintain the routes. By HELLO messages a node can discover its neighbors. When a node discovers a failure in a link it informs its neighbors. The neighbors also

inform their neighbors and so on and the corresponding routes will be deleted from the tables.

2. Cluster Based Routing Protocol (CBRP) is a routing protocol that clusters the network to reduce the flooding of control packets. CBRP groups the nodes in clusters and elects a CH for each cluster. At any time, a node is in one of three states: a cluster member, a cluster head, or undecided, meaning still searching for its host cluster [8, 10]. Each node starts in the undecided state and periodically broadcasts a HELLO message. Upon receiving a HELLO message, the CH responds to the node and joins it to the cluster. The node then changes its state to member.
3. Location Enhanced On-demand routing protocol (LEOD) is an evolution from the AODV protocol [12]. LEOD uses smart antennas to localize neighbor mobile nodes. This information is used to estimate the location of the mobile nodes in order to reduce the flooding of the control packets. Assume node A wishes to send to B. Initially A has no location information about B. A floods a RREQ and puts its location information in the RREQ. This location in formation is updated hop by hop till the RREQ reaches B. Then, B will reply with a RREP message back to A. Also, intermediate nodes will store location information about B. When A wishes to send again to B, a will benefit from the location information of B. A will restrict flooding to the request area in which node B exists. Nodes that are outside the request area ignore the RREQ.

Our work is most related to LEOD protocol. The main difference is that we restrict gathering location information to the backbone nodes in clustered MANETs, i.e. the GWs and CHs. Benefiting from smart antennas in clustered MANETs we significantly reduce the flooding of control packets. Simulation results show the CBGRP outperforms the LEOD protocol.

4. Statement of the problem

Mobility in ad hoc networks is the main factor affecting stability of routes. Movements of nodes lead to many disconnections in the routes established between these nodes. In ad hoc routing protocols, flooding of control packets is the only mechanism to discover and maintain routes. Flooding overwhelms the network with high number of control packets which puts serious questions about the scalability and reliability of the network. Flooding overhead appears clearly in dense networks due to the high number of nodes that broadcast the control packets. Consider figure 4 and assume the source A wishes to establish a route to the destination B. A will overwhelm the whole network with control packets to maintain the route to B. A significant question arises here; why do we flood the whole network to find a certain route? Can we limit the flooding to a specific area of the network in which B is expected to exist thus reduce the flooding overhead?

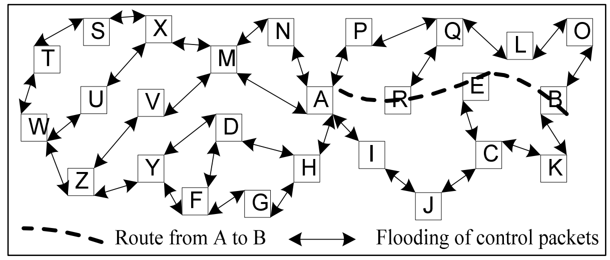

Figure 4: flooding the whole

5. Geo-Routing Protocol (CBGRP)

In this section we introduce our proposed solution to reduce the network control overhead in clustered MANETs as much as possible and enhance routing. In our solution, we benefit from both (1) clustering the ad hoc network by CBRP [10] and (2) estimating the location of the nodes by employing smart antennas. As a cluster-based on-demand routing protocol, CBGRP is an evolution from CBRP, where local position information are employed to aid routing and enhance the performance of the basic protocol. The main idea is to divide the network into four regions, namely R00, R01, R10, and R11. Each node has to indicate in which region it exists. In searching for a route, flooding of control packets occurs only in one region which is the one where the destination exists. In the ideal case the network is divided into four equally-spaced regions and thus flooding of control packets is reduced by 75%. The center of the network is indicated by one of the CHs called the General Manager (GM). For simplicity, the lowest-ID CH is elected to act as GM. The main role of the GM is to maintain a table, called location table (LT), to manage the locations of the member nodes. Periodically, the GM sends HELLO messages that reach all the nodes. Then each node estimates its position relative to the GM by formula (2) and indicates in which region it exists. Figure 5 shows the four regions. The boundaries of these areas are defined according to the values of the x and y components as shown in figure 5. A node sends its location information to the GM only when it moves to a new region. A source node S wishes to send data to a destination D sends route request message to its CH, called source CH which sends this route request to GM. The GM looks up the location table to indicate in which region the destination D exists. Then the GM floods the corresponding region to find a route to D. The advantage here is that flooding the control packets is restricted to a certain region resulting in reducing about 75% of overhead. When the GM finds a route to D, it responds to the source CH. Then data flows from S to D through the GM. The CBGRP has five major components: cluster

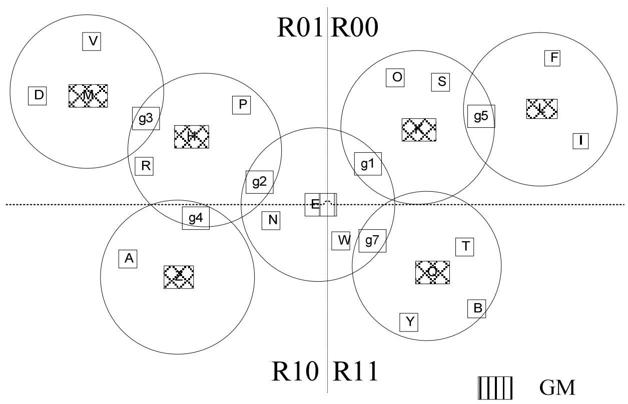

Figure 5: GM divides the clustered network into four regions

Table 1: Region boundary conditions

Area	x-component	y-component
R00	positive	Positive
R01	negative	Positive
R10	positive	Negative
R11	negative	Negative

formation, adjacency cluster discovery, general manager election, indicating regions, and routing. The routing process is divided into two phases, route discovery (RD) and the actual packets routing. The RD phase is divided into two steps, route request and route reply. Next we present the above components of CBGRP.

5.1. CBGRP components

1. Cluster formation

The election of the CH in CBGRP follows the same criteria as the basic CBRP. The nodes wake up in undecided state, exchange HELLO messages and elect a CH. When a new undecided node receives a HELLO message from a CH, it joins this cluster.

2. Adjacent cluster discovery

Each CH keeps Cluster Adjacency Table (CAT) that records information about its entire neighboring CHs. Periodically each node sends a HELLO which contains a neighbor table (NT) and the CAT. Using the HELLO messages alone, a CH is able to discover the adjacent CH. An entry in CAT contains the adjacent CH and the gateway node ID through which the neighboring CH could be reached.

3. General Manager election

After building the CAT, a CH has a complete view about the adjacent CHs and their IDs. The general manager (GM) is elected as the lowest-ID CH. Each CH compares its ID with those in its CAT. If its ID is the lowest, it sets its role as GM and broadcasts a HELLO message to all CHs in the network to advertise itself as the GM. When a CH or a gateway receives a HELLO message with role field set to TRUE, it passes this HELLO message to the adjacent clusters so the GM HELLO messages reach all the CHs in the network. Then each CH broadcasts this message to its members. If more than one CH advertise their selves as GMs, the one with the smallest ID will continue to act as GM while the others will back down this role.

4. Indicating regions

Periodically, the GM broadcasts a HELLO message every HELLO_INTERVAL seconds that reaches all the nodes. The GM includes its default position (0, 0) in the HELLO message. Upon receiving the HELLO message from the GM, each node computes its position relative to the GM by formula (2). By comparing the x and y components of the computed position with conditions shown in figure 5, each node indicates in which region it exists. For the first time, each node sends its location information, i.e. region ID, to the GM. The GM maintains this location in the LT. After that, with the next HELLO messages received from GM, a node sends it region ID to the GM only when it moves to a new region. Since HELLO messages are periodically sent, the GM periodically updates the location information of the nodes, so it always has a complete view about the locations of the nodes.

5. Routing

Routing in CBGRP is based on source routing as in the base CBRP. It has two phases RD and actual packet routing.

a. Route discovery (RD)

RD is the mechanism whereby a node S wishing to send a packet to a destination D obtains a source route to D. RD is the main operation that requires flooding of control packets. However, because of clustering the network and determining nodes locations, the number of times a control packet is forwarded is much less in general. In CBGRP, data flows from the source to the destination through the GM. So, the route from S to D is divided into two sub-routes, from S to GM and from GM to D. Since the GM HELLO messages reach all the nodes, each node always has a valid route to the GM, so there is no need to search for the sub-route from S to GM. CBGRP applies limited flooding in searching for the destination. The GM defines the request area, i.e. the area in which control packets are flooded, as the region in which the destination exists as indicated in the LT.

To perform a RD to D, the source node S sends out a RREQ message with the target node address set to D's

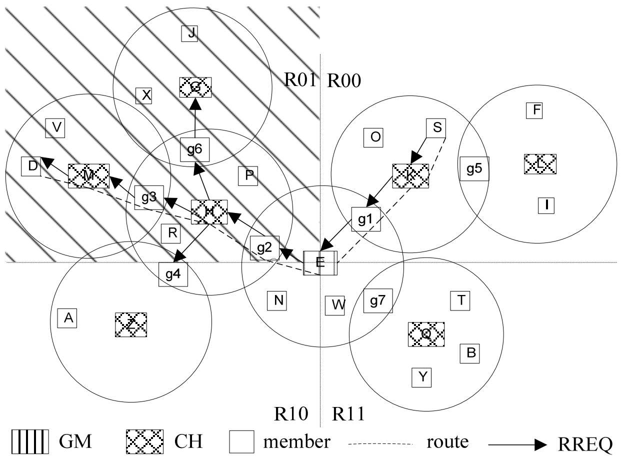

Figure 6: Operation example

address. The source CH, the CH of node S, receives this RREQ and contacts the GM, i.e. forwards the RREQ to the GM. The GM looks up the LT and obtains the region in which D exists. Then the GM forwards the RREQ to its gateways and includes the destination's region ID, in the RREQ packet. The gateways forward the RREQ to the adjacent CHs. When a gateway/CH receives the RREQ, it compares its region ID and the destination's region ID which is included in the RREQ packets. If they are the same, the gateway/CH determines that it is inside the request area and forwards the RREQ to the next CH/gateway. Otherwise, it simply discards the RREQ packet. This process prevents the RREQ from propagating outside the request area, so limits the flooding of the control packets. This process continues until the RREQ reaches D. When the target of the Request, node D, receives the RREQ, D sends out a route reply (RREP) packet to the GM. The RREP packet includes the list of Cluster Addresses the RREP should traverse in order to reach the GM. While forwarding the RREP packet, intermediate CHs will calculate the hop-by-hop route according to the information contained in the list cluster addresses and put it in the calculated route field.

b. Actual packet routing

When the GM obtains a route to the destination, it notifies the source CH to begin sending data. Then the source node sends data to the GM which forwards this data to the destination through this route. When a forwarding node finds out that the next hop along the source route is no longer reachable, it will create a route error (RERR) packet and send it back to the GM to notify it of the link failure. Then the GM will repeat the RD process again.

5.2. Example

The example shown in figure 6 clarifies the above steps assuming node S wishes to send to D. The figure shows the placement of the nodes in clusters and node *E* is elected as the GM since it is the CH with the lowest ID. Node *S* sends the RREQ to its CH, *K*, which sends it to the GM through a pre-known route. GM looks up the LT and finds that D exists in region R01. Then GM floods the request area, which is shaded in the figure. Note that gateway *g4* discards the RREQ since it is outside the request area. The figure shows the route obtained to the destination through which the data flows from S.

6. Simulation results

The performance of the jobs-distribution solution is evaluated via simulations using JIST-SWANs simulator [15][16]. The simulation attempts to compare the performance of CBGRP, CBRP, AODV, and LEOD. Our evaluation is based on the simulation of 200 mobile nodes in 2000*2000 square meters. Random way point mobility model is used in our experiments with pause time of 5s [17]. In this model, a node travels towards a randomly selected destination in the network. After the node arrives, it pauses for the predetermined pause time and travels towards another selected destination. The data traffic simulated is constant bit rate (CBR) traffic [18]. 30% of nodes, CBR sources, generate 512-byte data packets every 25 seconds. The simulation counts the number of control packets propagated during the 10,000 sec. and the number of the overall packets then calculates the overhead percentage. Simulation results show that CBGRP outperforms CBRP, AODV, LEOD protocols. Figure 7 shows control overhead percentage over simulation time during 10,000 seconds. The control overhead in CBGRP is also much smaller than CBRP, LEOD, and AODV protocols. Figure 8 shows the impact of speed on control overhead percentage during 10,000 seconds. The control overhead increases as the speed of the nodes increases since more topology changes occur and more RREQ messages are propagates to maintain the routes. However, control overhead in CBGRP is much smaller than CBRP, LEOD, and AODV protocols. Figure 9 shows control overhead percentage during 10,000 seconds for 50, 100, 150, 200, 250, 300 nodes. The control overhead increases when the network is dense. As the number of nodes increases, more data and control packets are sent over the links resulting in more congestion. Consequently, more control packets are sent to maintain routes and re-send data. However, the figure shows CBGRP costs less overhead than CBRP, LEOD, and AODV.

7. Conclusion and future work

In this paper we presented a novel cluster-based geo-routing protocol, the CBGRP. CBGRP provides the advantages of both clustering and local positioning. As a

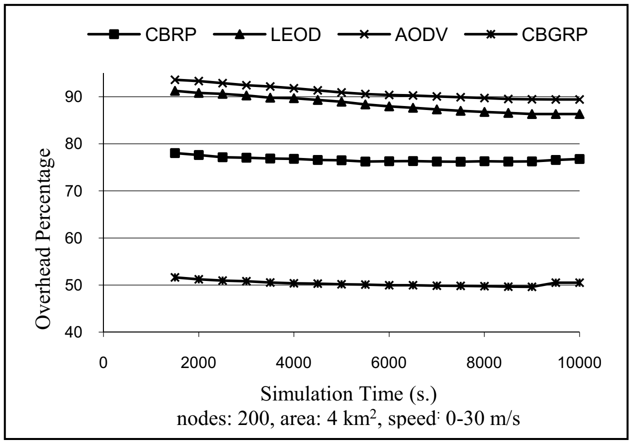

Figure 7: Control overhead vs. simulation time

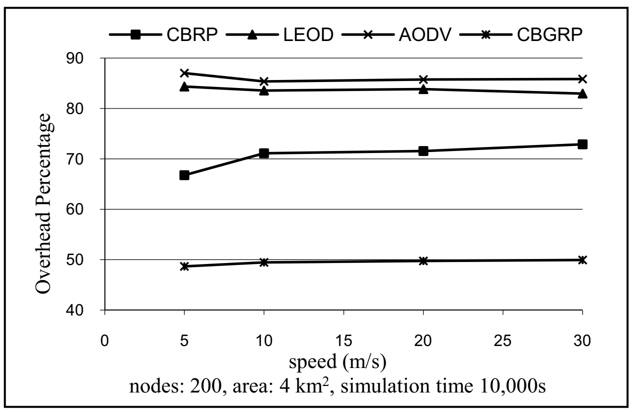

Figure 8: Control overhead vs. speed

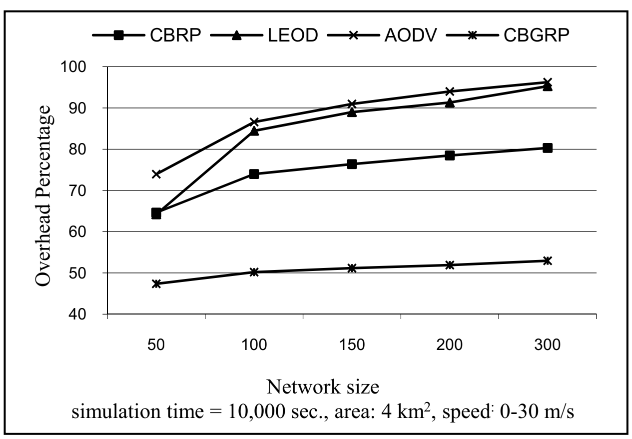

Figure 9: Control overhead vs. network size

cluster-based protocol, CBGRP provides a structure for ad hoc networks which makes it more scalable. Both clustering and location estimating help to reduce the control overhead. Simulations show that this novel protocol improves the performance of ad hoc networks. For simplicity, we proposed that the CH divides the space into four areas in order to form the request area. Our future work will be to develop a mechanism to dynamically determine how to divide the space around the CH based on the service to mobility ratio.

References

[1] A. Mukherjee, S. Bandyopadhyay, and D. Saha, "Location Management and Routing in Mobile Wireless Networks," *Artech House*, Boston, London, 2003.

[2] E. Royer and T. Chai-Keong, "A review of current routing protocols for ad hoc mobile wireless networks," *IEEE Personal Communications*, vol. 6, Issue 2, page(s): 46 – 55, 1999.

[3] M. Marina and S. Das Ad hoc networks Technologies and Protocols: ROUTING IN MOBILE AD HOC NETWORKS, *Springer*, 2005.

[4] J. Haas, and S. Tabrizi,, "On some challenges and design choices in ad-hoc communications," *IEEE MILCOM'98*, Bedford, MA, vol 1, Page(s): 187 - 192, 1998.

[5] R. Lin and M. Gerla, "Adaptive clustering for mobile wireless networks," *IEEE Journal on Selected Areas in Communications*, Vol. 15, No. 7, P: 1265-1275, 1997.

[6] M. Chatterjee, S. K. Das, and D. Turgut, "WCA: A Weighted Clustering Algorithm for Mobile Ad Hoc Networks," *Cluster Computing*, Vol. 5, No. 2, Pages: 193-204, 2002.

[7] M. Gerla and J. Tsai, Multicluster, "Mobile, Multimedia Radio Network," *ACM-Baltzer Journal of Wireless Network*, vol. 1, no. 3, pp. 255–265, 1995.

[8] A. Boukerche, "A Simulation Based Study of On-Demand Routing Protocols for Ad hoc Wireless Networks," *Proceedings of the 34th IEEE Annual Simulation Symposium (SS01)*, Page(s):85-92, 2001.

[9] E. Perkins, "Ad Hoc On-Demand Distance Vector (AODV) Routing," Internet Draft, Nov. 1997.

[10] M. Jiang , J. Li, and Y.C. Tay, "Cluster Based Routing Protocol(CBRP)," Internet Draft, July 1999.

[11] J.Y. Yu, and P.H.J. Chong, "A survey of clustering schemes for mobile ad hoc networks," *IEEE Communications Surveys & Tutorials*, vol. 7, Issue 1, Page(s): 32-48, 2005.

[12] A. Quintero A., D. Li ,and H. Castro , "A location routing protocol based on smart antennas for ad hoc networks," Journal of Network and Computer Applications, Elsevier, vol. 30, Page(s): 614–636, 2007.

[13] P. Enge, and P. Misra, "Special Issue on Global Positioning System," *Proceedings of the IEEE*, vol. 87, no. 1, 1999.

[14] D. Niculescu and B. Nath "Ad Hoc Positioning System (APS)," unpublished.

[15] Barr R., March, "*JiST– Java in Simulation Time User Guide"*, Department of Computer Science, Cornell University, Ithaca, NY 14853, 2004.

[16] Barr R., "*JiST SWANS– Scalable Wireless Ad hoc Network Simulator User Guide"*, Department of Computer Science, Cornell University, Ithaca, NY 14853, 2004.

[17] W. Navidi and T. Camp. "Stationary distributions for the random waypoint mobility model". *IEEE Transactions on Mobile Computing*, 3(1), 2004.

[18] C. Perkins "Ad Hoc Networking," *Addison-Wesley*, January 2001.