Mangai and Tamilarasi *EURASIP Journal on Wireless Communications and Networking* 2011, **2011**:18
http://jwcn.eurasipjournals.com/content/2011/1/18

EURASIP Journal on Wireless Communications and Networking
a SpringerOpen Journal

RESEARCH **Open Access**

A new approach to geographic routing for location aided cluster based MANETs

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Abstract

Routing has been the main challenge for *ad hoc* networks due to dynamic topology as well as resource constraints. Completely GPS(Global Positioning System) free as well as GPS scarce positioning systems for wireless, mobile, ad-hoc networks has been proposed recently by many authors. High computational overhead and high mobility of the nodes typically require completely GPS enabled MANETs for higher performance. In this article, Improved Location aided Cluster based Routing Protocol (ILCRP) for GPS enabled MANETs has been evaluated for performance metrics such as end to end delay, control overhead, and packet delivery ratio. Use of cluster based routing as well as exact location information of the nodes in ILCRP reduces the control overhead resulting in higher packet delivery ratio. GPS utility in nodes reduces the end to end delay even during its high mobility. Simulations are performed using NS2 by varying the mobility (speed) of nodes as well as number of the nodes. The results illustrate that ILCRP performs better compared to other protocols.

Keywords: MANET, GPS, Routing Algorithm, Location aided routing, Cluster based routing, Stable clustering

Introduction

'Resource Constraint' is an extreme challenge faced by a routing protocol designed for *ad hoc* wireless networks. Gadgets used in the *ad hoc* wireless networks in most cases require portability and hence they also have size and weight constraints along with the restrictions on the power source. Control overhead increases due to mobility of the nodes resulting in bandwidth constraint. Mobility also affects end to end delay as well as packet delivery ratio. Therefore, in real time applications there is a reduction in quality due to bandwidth constraint. As a result, *ad hoc* network routing protocols must optimally balance these contradictory aspects.

Many routing protocols [1] have been proposed to reduce the complexity of a flat structured routing either with help of the clustering schemes or using location information of the nodes. Through clustering, MANETs are partitioned into a group of nodes with a Cluster Head (CH). These clusters are dynamically rearranged with change in topology of the network. CH is the node which represents itself as a single entity and has specific responsibilities. Cluster members are simply nodes that join a cluster but cluster members that belong to more than one cluster are gateway nodes. The gateway nodes are used for communication between clusters. When there is more than one gateway to the same cluster, the CH chooses the best one for routing data by considering the node value of each gateway node. If two clusters are non-overlapping then each cluster will have separate gateway nodes. These gateway nodes will facilitate inter CH communication.

Related work

Many algorithms have been proposed to optimize the procedure for election of CH. Lowest-ID algorithm [2,3] uses minimum ID whereas Highest-Degree (HD) [4] uses degree of the node as a metric for CH election. The degree of a node is the number of neighbour nodes. LID biases the lower ID to drain their resource ultimately leading to node failure. Even though HD reduces the delay as well as the number of clusters, it increases reaffliation overhead resulting in higher number of re-elections.

Mobility Metric Based Algorithm (MOBIC) [5], a variation of Lowest-ID algorithm, uses the ratio of two consecutive signal strengths received by a node to know its

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relative motion with respect to its neighbors. MOBIC applies well only for group mobility of the nodes. MOBIC provides stability at the cost of higher delay and can be applicable only to group mobility of the nodes.

Node mobility as well as transmission range are taken for weight calculation in Distributed Mobility Adaptive Algorithm (DMAC) [6]. Most of the algorithms such as Weighted Clustering Algorithm (WCA) [7-9], Generalized Distributed Mobility Adaptive Clustering (GDMAC) [10] are derived from DMAC. WCA considers degree of connectivity, mobility, battery power and transmission power. WCA is extended to improve performances in IWCA [11], FWCA [12]. GDMAC improves the performance by introducing a cluster density parameter for the whole network. WCA and its derived algorithms provide better performance with compromised setup delay. Introduction of more parameters result in setup delay.

Similarly, many weighted algorithms are proposed for electing a CH. Apart from algorithms, protocols such as CEDAR, CBRP, etc. improve the scalability as well as performance of MANETs.

Cluster Based Routing Protocol (CBRP) [13,14], an on demand source routing protocol, divides clusters into nodes and decreases control overhead during route discovery. K-Hop CBRP [15] improves CBRP [14] with increase in number of nodes and its mobility. It modifies the existing WCA for the election of CH.

In Location Aided Routing (LAR) [16] protocol the overhead of route discovery is decreased by utilizing location information of mobile nodes. Using GPS [17] for location information, LAR protocol reduces the search space for a desired route. Reducing the search space results in fewer route discovery messages. By contacting a location service provider which knows the positions of all the nodes, the source node should first get the position of the destination mobile node when it wants to send data packets to a destination.

To localize the *ad hoc* network, a wide variety of routing protocols [18-20] have been proposed over the years. Some techniques use GPS but for very few nodes. These nodes are often referred to as anchor nodes or reference nodes. 'Completely GPS Free Localization' [21-24] or 'Using Very Few Anchor Node' [25,26] are the two types of localization approaches that provide techniques to localize the network in a GPS Less or GPS-Scarce area (LACBER). The GPS-less localization [27] approaches, establish a virtual coordinate system and try to localize the network in that coordinate system. On the basis of distance measurement (using ToA or AoA or RSSI) or hop count these coordinate systems are established. Using the above coordinate systems, the exact location of the node cannot be determined due to absence of GPS.

Location Aided Cluster Based Energy-efficient Routing (LACBER) [28] is a location aided routing protocol proposed for GPS scarce *ad hoc* networks. In the network, only a few nodes are GPS enabled and are capable of finding their own location using GPS. A few special nodes are equipped with antennas which can measure RSSI and the angle of arrival (AOA) of received signals from other nodes. The rest of the network can find their positions in a process using either GPS enabled or special nodes.

The LACBER protocol requires that each cluster must have at least one GPS enabled node or antenna equipped node in it. Compared to other cluster based routing protocols [29] the formation of clusters in LACBER protocol results in high control overhead. Using LACBER protocol, determining the location of normal nodes with high mobility is a constraint.

Proposed protocol

This article proposes an ILCRP protocol where all the nodes in all the clusters are GPS enabled compared to few nodes in a cluster as in LACBER protocol. The proposed protocol makes use of clusters as well as location information intensively. The exact location information of the nodes is known to each other with the help of GPS. The protocol is divided into three phases. First phase is cluster formation followed by cluster maintenance. The last phase is route discovery phase.

In the proposed ILCRP protocol, the control overhead becomes less for route discovery due to its GPS capability. The proposed protocol delivers the packets more accurately with less end to end delays since the exact location of the source as well as destination nodes are known to respective CHs. Besides, the overhead decreases due to exact location information of the nodes at all CHs.

Cluster formation

Clusters are formed between nodes which are m-hops far away from the CH. All the nodes start in undecided stage. Since all the nodes are GPS enabled, all the nodes can become CH. Initially all the nodes in the network broadcast a HELLO (Table 1) message with node ID and location information. Location information is obtained using GPS utility with an assumption of location error e. Let node ID be the MAC address as stated in FWCA. Based upon the updated neighbour nodes' list, the node calculates its Node Value. Each node computes its node value based on the following parameters:

- The degree difference Δi: It is defined as the difference between the cluster's size 'N' and the actual number of neighbors. It allows estimating the remaining number of nodes that each node can still handle.

Table 1 Selection of cluster head

No. of nodes N_i in the cluster C_i	Weights W_1, W_2, W_3	Degree difference	Mobility M in m/s	Remaining battery power in J	Node value NV	Selected node as cluster head
3 (N_1, N_2, N_3)	(0.09, 0.38, 0.53)	7,5,2	2,4,6	200,150,150	106,78, 77	N_1
5 (N_4, N_5, N_6, N_7, N_8)	(0.27,0.31, 0.42)	2,6,4, 8,5	3,1,3,1,7	174,190,188, 200,182	73,81,79, 86,76	N_7
6 (N_9, N_{10}, N_{11}, N_{12}, N_{13}, N_{14})	(0.33,0.24, 0.43)	3,4,9, 8,7,2	2,3,1,5,4,2	130,156,195,169,179,120	56,68,87, 74,78,52	N_{11}

$\Delta i = |di - N|$ where di is the degree of the node and N is the threshold for number of nodes in the cluster

- The mobility of the node M.

Mobility of the node at time t_2 is calculated using the below formula:

$$M = \frac{1}{(t_2 - t_1)}\left(\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}\right) \quad (1)$$

Where x_1, y_1 and x_2, y_2 are the co ordinates of the node at time T_1 and T_2 respectively.

- The remaining battery power of the node is P_a.

Therefore, Node Value $NV = W_1 \times \Delta i - W_2 \times M + W_3 \times P_a$ where W_1, W_2, W_3 are the weights used and are in a relation such that $W_1 + W_2 + W_3 = 1$. Maximum node value of a Node can be calculated by considering the mobility of the node as NULL. The threshold value is the value till which the elected CH retains the head of the cluster and is approximately given by forty percent of the maximum node value.

All the nodes, after finding its node value NV, broadcasts NV using an INFO (Table 1) message to its 1-hop neighbors. Depending upon the node values, the node with the highest node value and greater than the threshold value of the maximum node value elects itself as CH by sending CH_INFO. Table 1 shows the method of selection of the CH for three clusters.

CH_INFO (Table 2) is the packet broadcasted by CH on its self election as CH containing its ID and the neighbor table. Neighbor table is a conceptual data structure for formation of a cluster whereas Cluster Adjacency Table (CAT) is used for keeping information about the adjacent clusters. In CAT, CH stores the IDs of the adjacent CHs, gateway node IDs to reach adjacent CHs, whereas nodes store NULL. Gateway node is the node through which the CH communicates with an adjacent cluster. Neighbor Table is used for intra cluster routing and CAT is for inter cluster routing. Adjacency cluster discovery and gateway node selection are done as per the CBRP IETF MANET draft. All other nodes store node IDs, location information and its node values in its neighbor tables. In Figure 1, the cluster C1 has one CH, one gateway node and four member nodes.

Cluster maintenance

The clusters have to be reorganized and reconfigured dynamically due to the mobility of nodes in the *ad hoc* network. There are three major scenarios in a cluster for reconfiguration. The scenarios are:

- Reduction in the node value of the CH
- Mobility of a node
- Mobility of CH

Reduction in the Node Value of the Cluster Head

The CH determines its node value from time to time. When its node value falls below threshold value, the CH sends CH_RELEIVE (Table 2) to all its nodes in its cluster. After receiving CH_RELEIVE, all the nodes calculate the respective node values and convey them to the CH.

Table 2 Summarizes the messages used for formation as well as maintenance of the clusters

Message	Description
HELLO	Contains broadcaster's ID, location information, node status, neighbour table, cluster adjacency table and sender's node value
INFO	Contains node value
CH_INFO	Contains cluster head ID and cluster neighbour table
CH_ACK	The new node's HELLO message is acknowledged by cluster head (CH)
JOIN	A new node joins as member in the cluster after cluster head (CH) is activated by sending JOIN message
CH_NEWNODE	The new node's JOIN is acknowledged by cluster head.
CH_NACK	The new node's HELLO is rejected by cluster head
CH_RELIEVE	Notifies the members about its intention to resign as cluster head
CH_RACK	Present cluster head relieves finally after broadcasting new cluster head ID

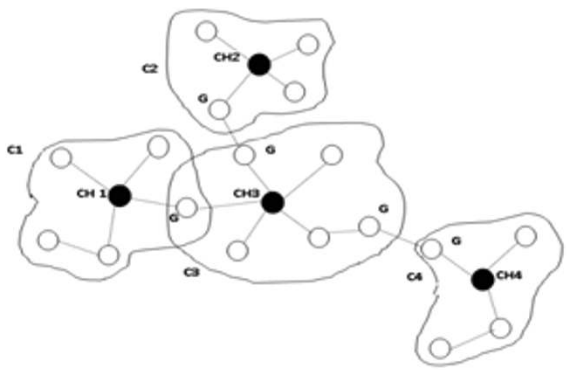

Figure 1 ILCRP cluster formation.

Now the CH decides the next succeeding CH with CH_RACK (Table 2) with node ID of the new CH.

Mobility of a node

When a node goes from one cluster to another, the state becomes undecided and it floods the new network with HELLO message containing important information regarding the sender such as sender's ID, location information, node status, neighbour table, CAT and its node value. On receiving the HELLO message, the CH verifies whether it has reached the threshold value of number of nodes in the cluster. If the threshold has not been reached, it acknowledges the new node with CH_ACK (Table 2). The new node sends back JOIN (Table 2) with its node value. CH replies with CH_NEWNODE (Table 2) and broadcasts CH_INFO with updated neighbour node. Beyond threshold level, the CH replies with negative acknowledge CH_NACK (Table 2) to the new node. The new node repeats the above process with other CHs. It is explained in Figure 2.

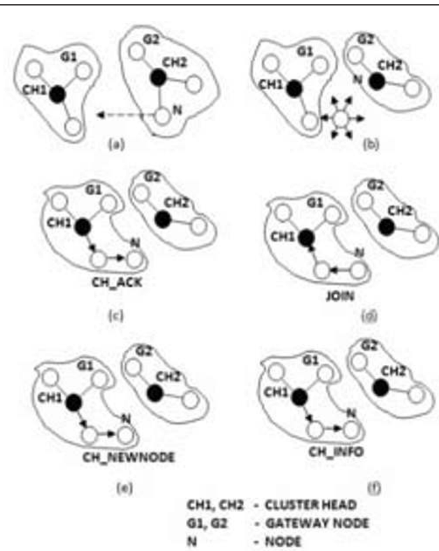

Figure 2 Mobility of a node.

Mobility of Cluster Head

When the CH moves away from the farthest node in the cluster, the farthest node waits for HELLO messages after a period of refresh time T_{ref}. If the node receives the message, it still maintains the member state of the cluster. If it does not receive, it goes to undecided state. In the undecided state, it floods the neighboring node with HELLO message indicating its presence. Upon receiving the acknowledgement from any reachable CH or any other nodes in an m-hop cluster, it sends with its INFO message. Any reachable CH replies with its neighbor table and updates all the members in the cluster about the new node. The previous CH updates the neighbor table after every T_{ref} and informs all the nodes.

Route discovery

The route discovery is done using source routing in cluster based routing protocols, whereas in ILCRP protocol it is done using location information. So control overhead becomes extremely high in cluster based routing protocols compared to location based routing protocols for source routing. Now, there are two instances of route discovery. The two instances are routing within a cluster known as intra cluster routing and routing between clusters known as inter cluster routing.

Intra cluster routing

In intra cluster routing, each and every node's GPS utility is made to sleep for reduced power consumption. All nodes in a cluster know about the location of other nodes in its cluster. Therefore, the source node forwards packets to the receiver node using the location information. If the destination node is one hop away from the receiver node, then source node sends the packet towards the destination node either using CH or using another node as shown in Figure 3. This process is explained in Algorithm 1.

Algorithm 1 as shown in Figure 3 is used for intra cluster routing in one hop cluster *Node S (source) checks its neighbour table for location information of Node D (destination)*

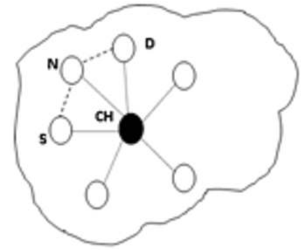

Figure 3 Intra cluster routing algorithm.

Calculate the distance D_{diff} *between the nodes having coordinates* $S(x_1, y_1)$ *and* $D(x_2, y_2)$

$$D_{diff} = \left| \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \right| \quad (2)$$

If D_{diff} *is greater than* D_{txRg} *where* D_{txRg} *is the maximum transmission range of the node.*

Find one or more hop neighbours in the cluster

If found

Find the nearest neighbour node with less number of hops using the distance equation (2) and
Forward the packet to the node N and
N forwards the packet to Node D

Endif
Endif
Else

Node S forwards the packet towards Node D

Endif

When there is mobility of a node inside a cluster for a multi hop cluster, the use of LAR protocol results in higher efficiency. From Figure 4, Node D moves with an average speed of v m/s from known location at t_0. All the messages are routed to node D through N1 at t_0. After a time interval of t_{diff}, the node D is expected to be at a radius distance of vt_{diff} units from the location at t_0. As shown in the Figure 4, Node D is not reachable via node N1. Using LAR, expected region is reachable via node N2. This process is explained in Algorithm 2.

Algorithm 2 as shown in Figure 4 is used for intra cluster routing in multihop m (= 2)cluster *Follow the Algorithm 1 till the Node N1.*

On receiving the packet, N1 verifies whether the destination node is reachable

If (Not Reachable)

Find the estimated distance R travelled by Node D in time Δt

$$R = v\Delta t \quad (3)$$

Find the recent direction of node D with deviation angle β *due to mobility M*
The area of the circle shaped Request zone with radius R is πR^2
Find the expected zone with same radius R and deviation angle β.

$$\text{Area of expected zone} = \frac{\beta}{360}\pi R^2 \quad (4)$$

Find the new node (N2) through which D is reachable
Forward the packet through Node N2
N2 forwards the packet to Node D
Endif
Else

Node N1 forwards the packet towards Node D

Endif

The direction of destination node can be known by time differentiated GPS Coordinates (i.e., Direction, Latitude and Longitude). Therefore, the location of the destination node is identified and the beacon signal is transmitted within the expected zone by initially considering the value of $\beta = 15°$. If we are unable to catch up with the required destination node we increase the value of β by +/-10°. This procedure is repeated until the destination node is located.

Inter cluster routing

Using the CAT, the CH sends an inter-cluster Routing REQuest (RREQ) packet to its gateway nodes to obtain routing information between clusters in the form of source flooding. Routing REPly (RREP) Packet received from the destination contains the location information of the destination node, destination CH, intermediate gateway node and source CH.

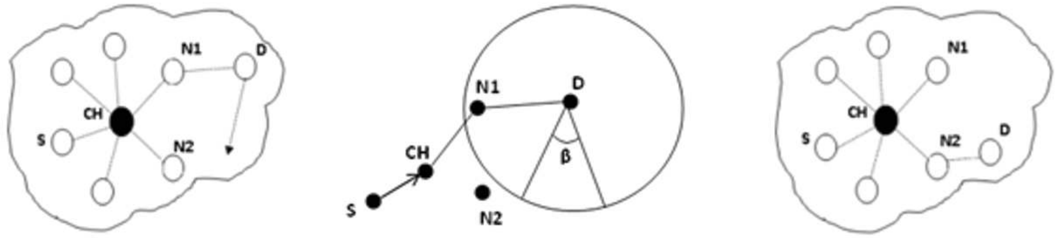

Figure 4 Intra cluster routing.

Consider the routing between adjacent clusters as shown in Figure 5. In a network of 2 clusters, routing is done using clusters as well as location information. Using the location information in RREP packet, the source node sends the packet directly towards the destination node through its gateway node. Gateway node forwards the packet to next cluster's gateway node. Gateway node calculates the expected and request zone for the destination node. If the expected zone does not fall in the transmission range of the gateway node, it forwards the packet to its CH. Then the cluster forwards the packet to destination node through other nodes. This process is explained in Algorithm 3.

Algorithm 3 as shown in Figure 5 is used for inter cluster routing between adjacent clusters *Source S sends the RREQ (Route REQuest) packet to its CH (Cluster Head)*

CH forwards the RREQ to adjacent cluster head via Gateway nodes G in both the clusters.

On receiving the RREQ, CH checks its neighbour table and replies with RREP (Route REPly) packet containing the location information of destination Node D.

On receiving the location information of Node D, Node S forwards the data packet to G as per directional flooding.

After the data is received by the next cluster gateway node G, it calculates the expected zone as well as request zone as given in algorithm 2.

If Node D is reachable

Node G forwards the packet to the node D

Else if Node D is reachable via other nodes

Node G forwards the packet to Cluster Head of the destination node D

CH forwards the packet to Node D via other nodes in the cluster

Else

Node G replies NACK to Node S

Node S requests the CH to reinitiate the route discovery process.

End

If the source cluster and destination clusters are *m* clusters away, then the location information obtained by using initial source routing can be used for direction flooding. Consider the formation of clusters as shown in Figure 6, where Node S needs to send packet to Node D. Source CH forwards the packet using directional flooding with an angle of α via its gateway node. Now the packet hops from one cluster to another cluster by keeping closer to the axis of imaginary line between node D and source CH. Transmission time of RREP from destination cluster CH to source CH is considered as Δt_1 whereas Δt_2 is the time taken by the packet to travel from source CH to the destination CH.

Total time difference after finding the location information of the node is $D = \Delta t_1 + \Delta t_2$. The velocity ($v$) of the node D have already been obtained for calculation of the node value. This process is explained in Algorithm 4.

Algorithm 4 as shown in Figure 6 is used for inter cluster routing between clusters which are m clusters away *After obtaining RREP, Node S sends the packet to its CH.*

Source CH floods the packet directionally with an angle of α via its gateway Node.

After reaching the Destination CH, it calculates the expected zone and request zone of the node D.

The request zone is given by the πR^2 where

$$R = v(\Delta t_1 + \Delta t_2) = 2v\Delta t_1 \quad if \quad \Delta t_1 = \Delta t_2 \qquad (5)$$

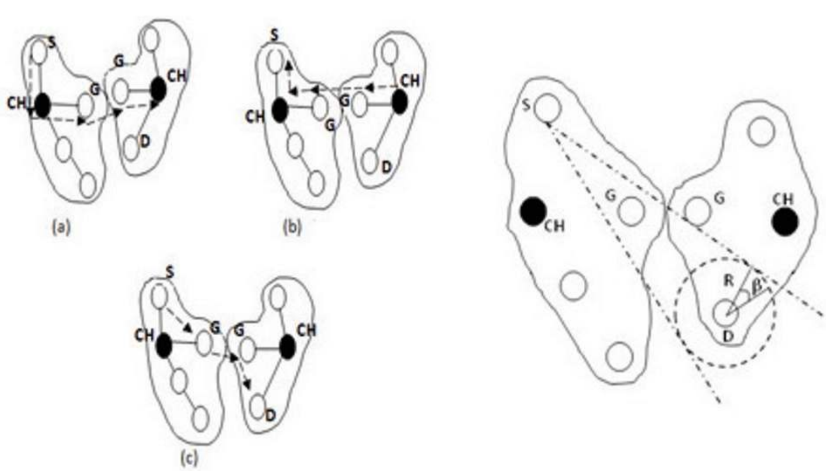

Figure 5 Inter cluster routing. (**a**) Flow of RREQ. (**b**) Flow of RREP. (**c**) Flow of data. (**d**) Intercluster routing between adjacent clusters.

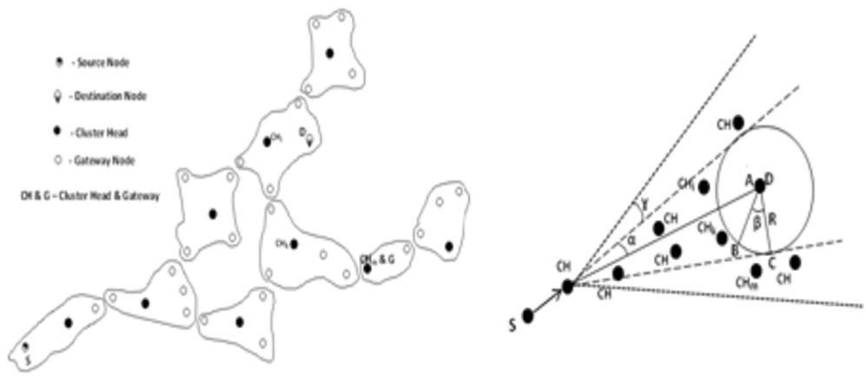

Figure 6 Inter cluster routing between clusters which are *m* clusters away.

As the direction of the node D is known, Area of the expected zone is calculated by

$$\frac{\beta}{360}\pi\left(2v\Delta t_1\right)^2 \quad (6)$$

If Node D is present in the cluster
CH forwards the packet to Node D
Else

CH forwards the packets directionally to the clusters

End

Route recovery

If a route failure occurs due to movement of the nodes in the intermediate clusters, the path should be reinitiated either from the local node where route failure is detected or from the source CH. Initially the path rediscovery starts from the local node by directional flooding. If the local rediscovery fails, the local nodes inform the source CH. The source CH increases the directional flooding angle α by γ as shown in Figure 6.

Simulation results

Simulation parameters

• Performed using NS-2 network simulator [30] with MANET extensions.

• IEEE 802.11 is used as the MAC layer protocol.

• The radio model simulates with a nominal bit rate of 2 Mbps.

• Nominal transmission range is 125 m.

• The radio propagation model is the two-ray ground model.

• First 100 nodes are deployed for one experiment and then 100 nodes are used for another experiment in a field of 1000 m × 1000 m.

• The traffic pattern is CBR (constant bit rate) with a network traffic load of 4 packet/s and the packet length are 512 bytes.

• The mobility model used is the Random Waypoint Model

• The pause time of the node reflects the degree of the node mobility. The small pause time means intense node mobility and large pause time means slow node mobility. The pause time is maintained as 5 s.

• The simulation time is 900 s.

• The first set of simulations are performed by varying the *speed* from 2 to 10 m/s with an increment of 2 m/s keeping number of nodes constant to 40.

• The second set of simulations are performed by creating 20, 40, 60, 80, 100 nodes, keeping speed constant to 5 m/s.

• The value of weights W_1, W_2 W_3, for simulation are (0.09, 0.38, 0.53), (0.27, 0.31, 0.42) and (0.33, 0.24, 0.43), respectively.

Performance metrics

For evaluating the performance of ILCRP, the metrics chosen are packet delivery ratio, control overhead and end to end delay.

End to end delay

End to end delay indicates the time lapse between the source and destination nodes in the network. Figures 7 and 8 shows that the end to end delay reduces if the exact locations of all the nodes are obtained. On increasing the mobility of the nodes, the delay increases due to reconfiguration of the clusters. The end to end delay also increases due to increase in the number of nodes due to more number of hops.

Packet delivery ratio

It is defined as the ratio of total number of packets that have reached the destination node to the total number of packets originated at the source node. The location information of the nodes make the packets route, loop free which results in high packet delivery ratio. On increasing the mobility or speed of the nodes, the delivery ratio decreases since most of the nodes move away

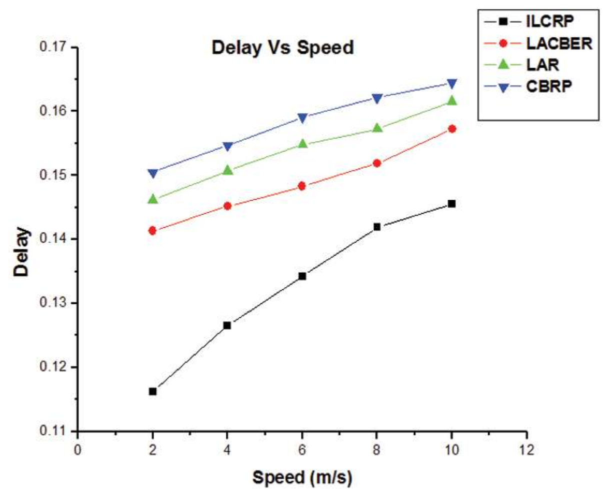

Figure 7 Comparison for delay vs. speed.

Figure 9 Comparison for packet delivery ratio vs. speed.

from each other. Increasing the number of nodes decreases the delivery ratio due to tightly coupled cluster configuration. Figures 9 and 10 confirms the packet delivery ratio between ILCRP and LACBER, LAR, CBRP.

Control overhead

It is defined as the ratio of the number of control packets transmitted to the number of the data packets delivered. Usage of cluster based routing protocol for clustering and exact location information for route discovery reduces the control overhead in the network. Figures 11 and 12 shows the control overhead ratio between ILCRP, LACBER, LAR and CBRP. It increases when the mobility of the nodes as well as number of nodes increases.

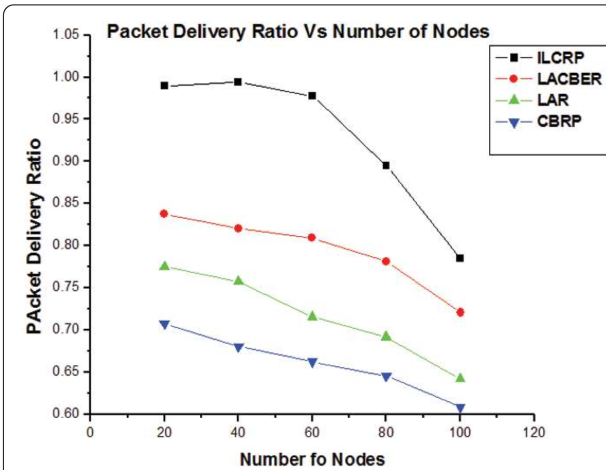

Figure 10 Comparison for packet delivery ratio vs. number of nodes.

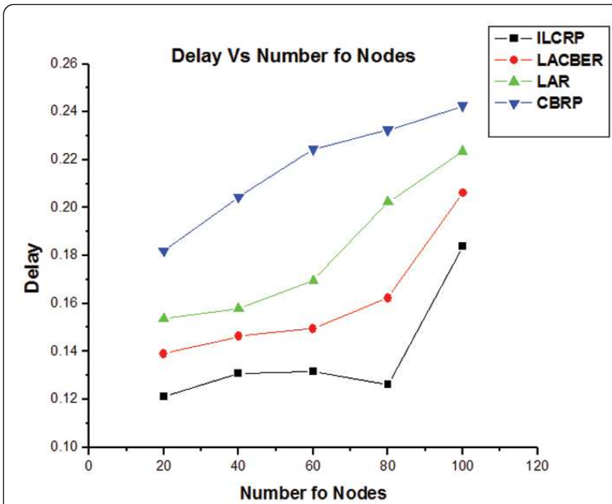

Figure 8 Comparison for delay vs. number of nodes.

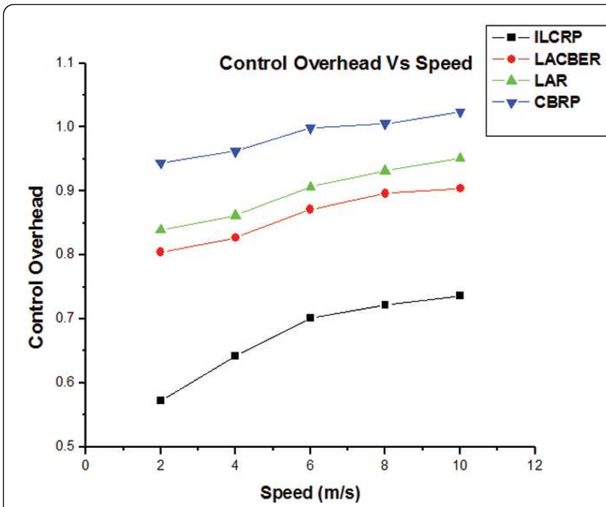

Figure 11 Comparisons for control overhead vs. speed.

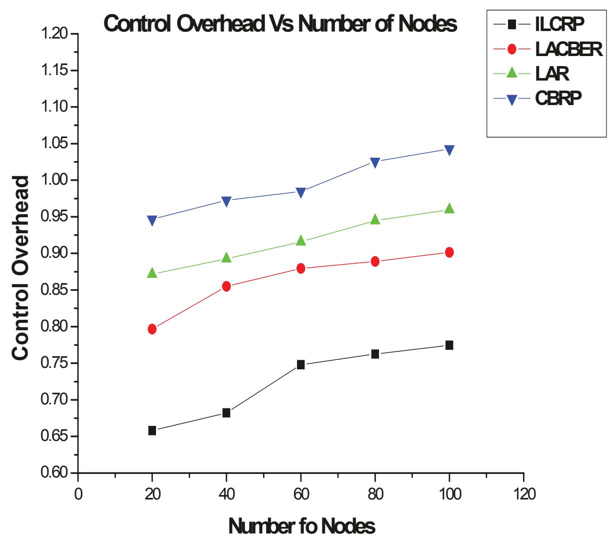

Figure 12 Comparisons for control overhead vs. number of nodes.

Conclusion

This paper introduces a new stable clustering scheme that are applicable in highly mobile *ad hoc* networks. Use of location information in the m-hop cluster based routing forms the basis of ILCRP. The exact location information of nodes in ILCRP increases the delivery ratio and reduces the control overhead and makes the route, loop free. Location information of all the nodes keeps the exchange information as well as the end to end delay very low in ILCRP compared to other protocols. From the results, it can be seen that the proposed scheme performs better than GPS free as well as GPS Scarce MANETs as the proposed scheme forms stable clusters containing members that remain within their associated clusters for a longer period of time, despite the targeted system having node speeds exceeding normal MANET scenarios. It is hoped that the geographic routing based clustering scheme presented would form the foundation for the possibility of reliable data sharing and communication between highly mobile vehicles i.e., VANETs for the present and in the future.

List of Abbreviations

AOA: angle of arrival; CAT: Cluster Adjacency Table; CBRP: Cluster Based Routing Protocol; CH: cluster head; DMAC: Distributed Mobility Adaptive Algorithm; GDMAC: Generalized Distributed Mobility Adaptive Clustering; HD: Highest-degree; ILCRP: Improved Location aided Cluster based Routing Protocol; LAR: Location Aided Routing; LACBER: Location Aided Cluster Based Energy-efficient Routing; MOBIC: Mobility Metric Based Algorithm; RREP: Routing REPly; RREQ: Routing REQuest; WCA: Weighted Clustering Algorithm.

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Competing interests

The authors declare that they have no competing interests.

Received: 23 September 2010 Accepted: 17 June 2011
Published: 17 June 2011

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doi:10.1186/1687-1499-2011-18
Cite this article as: Mangai and Tamilarasi: A new approach to geographic routing for location aided cluster based MANETs. *EURASIP Journal on Wireless Communications and Networking* 2011 **2011**:18.