

A Novel GPS-Based Quorum Hybrid Routing Algorithm (GPS-QHRA) for Cellular-Based Ad Hoc Wireless Networks

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This work presents a novel GPS-based Quorum Hybrid Routing Algorithm (GPS-QHRA), which is a cluster-based approach protocol for cellular-based *ad hoc* wireless networks. Each node equipped with GPS knows in which zones they are located. Based on the results reported in [12], cellular-based management can achieve better behavior in reducing the number of flooding messages, better bandwidth management and a smaller hops. A table-driven routing protocol is used for intra-cluster routing, and an on-demand routing protocol is used for inter-cluster routing. The node with the highest connectivity is selected as a cluster head in each zone to simulate the function of the Home Location Register (HLR) in a GSM system. It is called the Location Database Node (LDN). In the GPS-QHRA, LDNs are formed as part of a Uniform Quorum System (UQS), and they are disjoint and distinguishable from each other. This algorithm is divided into three parts: (i) a GPS-based routing algorithm, (ii) a mobility management scheme searching for a new substitute node while maintaining the LDNs, and (iii) a fault tolerance strategy that is initiated under specific circumstances. Simulation results show that the GPS-QHRA better optimizes the flooding overhead and the mean paths in highly mobility environments compared with Zone Hierarchical Link State (ZHLS) algorithm, which partitions each zone into a square and does not adopt the cluster head concept.

Keywords: GPS-QHRA, ad hoc wireless network, LDN, UQS, ZHLS

1. INTRODUCTION

An *ad hoc* wireless network is a temporary network formed by a collection of mobile nodes without the aid of any centralized coordinator. An *ad hoc* wireless network is adaptable to the highly dynamic topology that results from mobility, where predicting and managing routing information are difficult. An exclusive routing algorithm [1] is required to determine possible paths for data transmission. The architectures of such algorithms are categorized as being hierarchical or flat [2]. In a hierarchical architecture, nodes are aggregated into clusters, each of which is managed by a special node called *cluster head*. A flat architecture treats each node equally with no hierarchical differences.

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Experiments reported in [3] demonstrated that a hierarchical architecture outperforms a flat architecture.

Two kinds of path discovery algorithms exist: Table-Driven and On-Demand. In Table-Driven algorithms [4, 5], each node broadcasts periodically to distribute routing information among nodes. A table is requested to save the routing information and is updated as soon as the network topology changes. In On-Demand algorithms [6-8], the routing path is determined when data transmission is initialized. When a source node makes a request to transmit data, a routing discovery packet is forwarded to establish a routing path. The advantage of a Table-Driven algorithm is immediate transmission without preprocessing, but its drawback is that the routing table must be updated periodically, which increases the network flow overhead. Since path discovery is performed only during initialization of data transmission in an On-Demand routing algorithm, the amount of network resources consumed during regular information updating can be saved. However, a re-determination path is required for each data transmission. Some hybrid routing algorithms have been proposed to solve the drawbacks of the two algorithms, including the ZHLS (Zone Hierarchical Link State) algorithm [9], in which the Global Positioning System (GPS) technology [10] is applied. The network is divided into an arbitrary number of square zones and Table-Driven and On-Demand routing algorithms are adopted for intra-zone and inter-zone communication, respectively. A recent study on wireless *ad hoc* networks has introduced the UQS (Uniform Quorum System) [11], which dynamically searches for an appropriate node, called a Location Database Node (LDN), in each zone, which can be treated as a Home Location Register (HLR) in a GSM system. However, the UQS does not adopt GPS technology; thus, node locations are poorly controlled during accessing or updating of the database, possibly leading to high packet flooding overhead. Although the ZHLS algorithm is a hierarchical algorithm, it does not adopt the cluster head concept. Each node has two tables, one for recording information of other nodes in the same zone, and the other for storing information between zones. When a node wants to transmit data, packets are forwarded based on information in the first table using the Table-Driven routing algorithm. When the destination node is outside the zone, On-Demand broadcasting is performed to determine to which the zone belongs. Unfortunately, the amount of packets forwarded exceeds that of the UQS due to message overhead for duplicate information in routing tables. Experimental results in [12] show that system evaluation with hexagonal divisions is better than that with square ones based on the smaller number of flooding messages, better bandwidth management and smaller number of hops. The advantage of a hexagonal zone, like a cellular zone, is that it offers six directions of transmission, possibly increasing the number of routing alternatives and avoiding routing through unnecessary nodes.

GPS technology with the UQS in hexagonal zones is applied in a new algorithm, called the GPS-based Quorum Hybrid Routing Algorithm (GPS-QHRA). This algorithm is divided into three parts; a GPS-based routing algorithm; a mobility management scheme searching for a new substitute node while maintaining LDNs; and a fault tolerance strategy that is applied under specific circumstances.

This paper is organized as follows. Section 2 reviews related research on routing algorithms, including Table-Driven, On-Demand, Hybrid, and UQS routing algorithms. Section 3 introduces the system model and the GPS-Hybrid Quorum Routing Algorithm (GPS-HQRA). Section 4 describes the simulation environment and discusses simulation

results. The new algorithm is compared to and found to outperform the ZHLS algorithm based on the mean path, mobility effect, communication overhead, and dropping probability. A conclusion is given and future works summarized in section 5.

2. RELATED RESEARCH

Routing information can be distinguished as Proactive/Table driven, Reactive/On demand and Hybrid [1, 13, 14]. Proactive/Table driven always gets the latest information, but wastes a large amount of memory and bandwidth. Two drawbacks of Reactive/On demand are lower efficiency due the need to broadcast packets to collect routing information and to gain information not in real time. Reactive/On demand benefits, however, from the use of many routing paths to determine without continually updating the routing table and from a frugal use of memory. The advantage of Hybrid lies is link up with Proactive and Reactive for quick routing, economizing on the use of memory and bandwidth. Numerous Table-Driven routing algorithms have been proposed, such as Cluster Head Gateway Switch Routing (CGSR) [4]. This algorithm has a kind of hierarchical architecture in which some specific nodes are treated as a cluster head, which is responsible for recording information concerning each node within the cluster. Not every node inside the cluster must maintain a routing table, so the network overhead can be reduced. One trivial contribution to the network overhead is election or substitution of the cluster head. The Least Cluster Change (LCC) [4, 15] clustering algorithm is executed to reduce network overhead during election of the cluster head. When a node demands data transmission, a packet is firstly forwarded to the cluster head based on information in the routing table, and then the cluster head determines whether its destination is in its cluster range. If it is not, the packet is forwarded to the gateway node. Source-initiated on-demand routing algorithms are proposed, such as Communication-Aware Mobile Hosts Algorithm [7]. The Communication-Aware Mobile Hosts Algorithm is based on interaction among nodes and takes affinity as a variable to measure performance. Each node must know the moving directions of the other nodes to find stable routing path instead of the shortest path. That will reduce the probability of path failure for unexpected reasons, such as mobility, and overcome this problem may increase the overhead of the entire system. When the Table-Driven routing algorithm is applied to perform route maintenance, each node or cluster head must constantly maintain a complete routing table, where as the On-Demand routing algorithm requires table information only when a transmission is requested. The On-Demand routing algorithm has a flat routing architecture, whereas the Table-Driven algorithm has a hierarchical one.

The ZHLS algorithm [9] not only combines the characteristics of On-Demand and Table-Driven routing algorithms, but also applies GPS technology. Unlike the Table-Driven routing algorithm, the ZHLS algorithm only records path information within a zone and maintains an external zone routing table. In contrast to the On-Demand routing algorithm, a path discovery packet needs not be broadcasted to all nodes of the network to find a routing path. If the destination node remains in the same zone, the broadcasting may be ignored and the transmission rate increased. Table 1 compares the performance of the three algorithms. The ZHLS algorithm clearly performs the best [16].

Table 1. Performance evaluation of routing algorithms.

Type of Routing Algorithm	Table-Driven	On-Demand	Hybrid
Overhead for routing maintenance	Crucial	None	Normal
Speed of path discovery	Fastest	Slow	Normal
Resource saving	Worse	Better	Normal
Network overhead for path discovery	Light	Crucial	Normal
Effect of host mobility on network	Crucial	Light	Normal
Large scale network topology	Bad	Bad	Good
Small scale network topology	Good	Good	Bad

The UQS [11] with a particular node, usually a cluster head or backbone node, is selected to simulate the function of the Home Location Register (HLR) in a GSM system. The main function of the HLR in a GSM system is to maintain the registration of mobile nodes at the base station. When communication between two nodes is requested, a signal is firstly emitted to the base station. Then, the location of the destination is determined via the HLR, and communication is established. Given the mobility of each node, a node used to simulate the HLR function must be determined dynamically since an *ad hoc* wireless network has no fixed base station. The entire network must be constructed with a virtual backbone topology [16, 17] to record the location of each node before this algorithm is applied. After a virtual backbone is established, a backbone node, called an Location Database Node (LDN), is chosen to simulate the HLR function. Each of the other, or common, nodes, must register its location with a neighboring LDN. LDNs form a set with the following characteristics: (i) they intersect each other, and (ii) elements of the set are distinct from each other. An LDN broadcasts a request packet to neighboring nodes and waits for a reply packet with the correct ID number, to enable the LDN to learn the locations of all neighboring nodes. An element of UQS is then selected by the LDN and is broadcasted to other LDNs. Then, when packet forwarding is requested, the corresponding LDN asks for the location of the destination node, multicasts to one of its neighboring zones, and sends routing information to the destination node. Distinct database location nodes may record different routing information due to the node's mobility. A time slot may be added to packets to distinguish the latest location information. Moreover, an LDN may leave its zone, and a new LDN must be dynamically re-determined. The LDN is inaccessible during discovery, and any data forwarded via this node will fail. UQS assumes that the number of observed inaccessible states exceeds number of searching or updating LDNs. In addition, even if an LDN fails, the exact routing information can be obtained from other proper LDNs since more than one such node knows the location.

3. GPS-QHRA

This section introduces the GPS-QHRA explains how GPS technology is combined with the UQS. A network may be divided into an arbitrary number of zones, and some nodes are selected dynamically to perform the UQS function of LDNs within each zone. A node's movement can be easily controlled with the assistance of GPS. A node learns

its physical location by means of geolocation techniques, and its zone ID can then be determined by mapping its physical location onto zone map. A candidate node can then be elected in advance, when an LDN is about to leave to reduce its inaccessibility. A cluster head (obtained by the LDN) is applied, so that the need for each node to maintain the same routing information can be eliminated and the network overhead can be reduced. The LDN only records inter-zone routing information and the locations of nodes of other Uniform Quorum sets. In addition, when packet forwarding to destination node outside the zone is requested, broadcasting to all other nodes may be avoided by the UQS. Routing table in ZHLS brings out duplicate information, while it can be avoided in GPS-QHRA. Instead of broadcasting, it multicasts to LDNs of other Uniform Quorum sets, possibly reduces packet flooding over the network.

3.1 System Assumptions and Definitions

The system assumptions of GPS-QHRA when applied to an *ad hoc* wireless network are as follows.

- (1) Each node has a unique ID.
- (2) Each node is equipped with a GPS receiver and emitter. A 2-D coordinate is obtained after emitting to the GPS satellite and receiving a response. The zone's location for a node is observed by referencing a zone map.
- (3) Each node has a synchronization clock which it uses to analyze the packet's sequence.
- (4) The emitting power of all the nodes is identical, and the signal fading problem is ignored.
- (5) An effective bandwidth management algorithm exists; thus, collision and bandwidth allocation problems are not considered in this paper.
- (6) If sufficient nodes cover the network, the probability that no node in a zone is low; however, if a zone is empty, the GPS-QHRA fault tolerance mechanism is applied.

• Zone Map Design

First, the entire map is divided into an arbitrary number of zones, n , in the UQS design (n, q, k, m, r) [18]. The transmission radius within one GPS-QHRA zone is shown in Fig. 1. Instead of square zones as in the ZHLS algorithm, our method divides the network into many hexagonal zones. The system evaluation [12] with hexagonal divisions as shown in Fig. 2, has better behavior than that with square zones based on fewer flooding messages, better bandwidth management, and a smaller number of hops. Moreover, the advantage of the hexagonal zone is that it offers six directions of transmission, thus possibly increasing the number of routing alternatives and avoiding routing through unnecessary nodes. After the number of zones is determined, each coordinate of the network is identified as a zone and stored in its corresponding zone map table, so that a node can know exactly in which zone it belongs after a coordinate obtained from the GPS satellite is matched to the zone map table. Moreover, the dotted line in the above figure defines the *danger zone* of the LDN. When a node moves toward the danger zone, this indicates that it has higher probability for leaving the zone, and a new LDN must be re-determined.

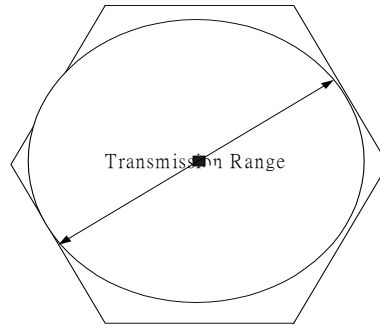


Fig. 1. Transmission radius within one GPS-QHRA zone.

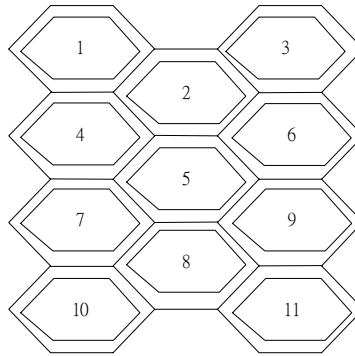


Fig. 2. Hexagonal zone map of GPS-QHRA.

• Definition of Uniform Quorum Arguments

The simulation results were obtained based on the number of nodes, the size of zone, and the set of intersects. The optimum parameters of the Uniform Quorum System were identified by means of simulation as described in section 4.

3.2 GPS-QHRA

This section describes the proposed algorithm, including the determination of the LDN, routing rules, updating the location of nodes, re-determination of the LDN and the fault-tolerance mechanism.

• Determination of the LDN

In this paper, a cluster head is selected as the LDN, based on connectivity. The node with the highest connectivity, which may be routed with the smallest hop count and transmission distance, is selected since the LDN must record the location of other nodes. If more than two nodes have the same highest level of connectivity, then only one node is randomly selected as the LDN. First, an NF (Neighbor Found) packet <node ID, Zone ID> is broadcasted to all neighboring nodes to determine each node's connectivity. Nodes within its communication range reply, in turn, with link responses <node ID, Zone ID>. For example, in Fig. 3 (a), node *d* broadcasts the NF packet to nodes *b*, *c*, *e*, *f*, and *g*.

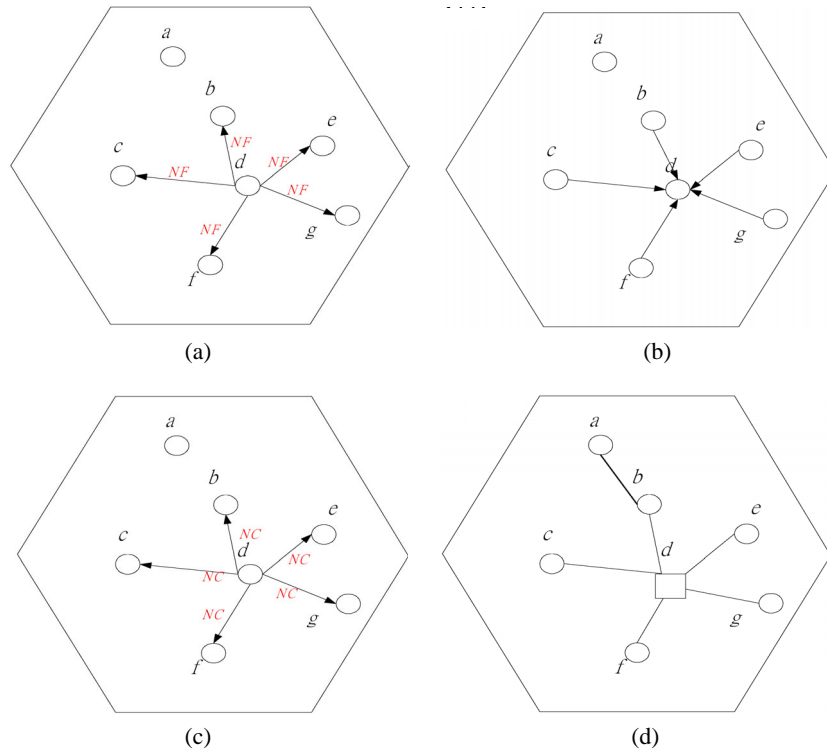


Fig. 3. Determination of the location database node in GPS-QHRA.

In Fig. 3 (b), nodes b , c , e , f , and g respond to node d . Here, the connectivity obtained by node d is 5. Then, an NC (Neighbor Connectivity) packet is broadcasted to inform all neighbors about the connectivity of the node, as shown in Fig. 3 (c). This node initializes a counter, and waits for other neighboring nodes' NC packets. After all nodes have completed the activity described above, the node d with the highest level of connectivity is selected as the LDN, which is shown in Fig. 3 (d) as a square node. The connectivity of nodes within the danger zone is set to zero since nodes in the danger zone may not be able to serve as the LDN due to possibly leaving the zone. The algorithm for determining the LDN, *GPS-Database Formation Algorithm (GPS-DFA)*, is described as follows:

GPS-Database Formation Algorithm (GPS-DFA)

For each node x in the network, an NF packet $\langle \text{nodeId}, \text{zoneId} \rangle$ is broadcasted to its neighbors

If x 's node Location is within the Database Danger Region (DDR), then

Set $\text{conn\#} = 0$

Once all replies have been received, broadcast a NC $\langle \text{nodeID}, \text{conn\#} \rangle$ to its neighbors,

$\text{count} = \text{conn\#}; \text{maxconn\#} = \text{conn\#}$

$\text{databaseID} = x$'s nodeID

```

DO While count! = 0
  Wait for any neighbor NC packet; count = count - 1
  if neighbor's maxconn# > x's maxconn# and neighbor zoneID = x's ZoneID then
    maxconn# = neighbor's maxconn#
    databaseID = neighbor's ID
  end if
LOOP
End if
Node x with database = databaseID

```

• Generating Routing Tables in GPS-QHRA

Three types of routing tables are needed in GPS-QHRA. The first one is used for intra-zone routing. The second one is used for partial inter-zone routing and simply records the zones of the Uniform Quorum. The last one is the location table of nodes within the Uniform Quorum.

- (1) **The Intra-Zone Routing Table:** After GPS-DFA is executed, each zone has an LDN, as shown in Fig. 4. Meanwhile, the LDN has the routing information of other nodes within the zone. The LDN may learn about other nodes and their connections to other zones by broadcasting the GPS-DFA. A zone includes three types of nodes: (i) **LDNs**, which constantly monitor the movement of other nodes, (ii) **direct nodes**, which communicate directly with the LDN, and (iii) **in-direct nodes**, which cannot communicate directly with the LDN. In Fig. 5, taking zone 1 in Fig. 4 as example, node v is an LDN; nodes b , c , s , and z are within node v 's transmission range called direct nodes. Nodes x and y are outside node v 's transmission range and must route via other nodes to reach node v ; they are, therefore, called indirect nodes.

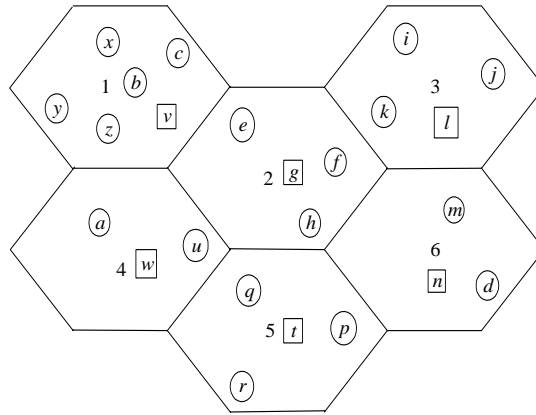


Fig. 4. Entire topology of GPS-QHRA.

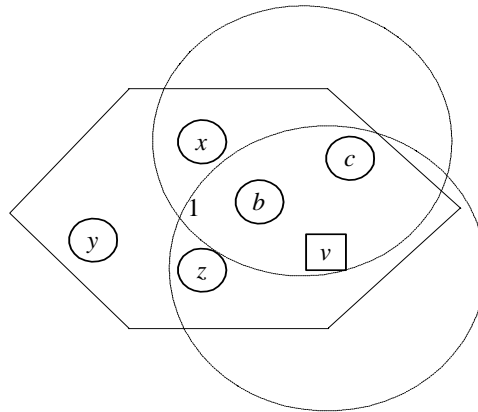


Fig. 5. Intra-zone topology of GPS-QHRA.

Table 2. Intra-zone routing table of node v in zone 1 generated from Fig. 5.

Destination	Next Node	Remark
b	b	Direct
c	c	Direct
x	b	Indirect
y	z	Indirect
z	z	Direct

The LDN creates a routing table according to the following steps. First, direct nodes are detected, and a list of the direct nodes is broadcasted to all the direct nodes. A direct node will forward an INP (Indirect Node Probe) packet to search for indirect nodes within the zone. Nodes not included in the list of direct nodes are indirect nodes. Information about indirect nodes is sent to the LDN. Since the size of each zone is defined as transmission range, which has at most 2 hops, all nodes are included in this step. It is probable that two distinct direct nodes that are found will have the same indirect node; then, a routing table is created based on the shortest distance of a direct node to that indirect node (this distance can be obtained by means of the GPS coordinate). In the meantime, a gateway node is recorded for inter-zone routing and the intra-zone routing table for node v in zone 1 generated from Fig. 5 is depicted as Table 2.

- (2) **The Inter-Zone Routing Table:** Similar to the ZHLS algorithm, a partial inter-zone routing table is required to record a routing table of other Uniform Quorum sets. Since the indirect node's information is recorded during the establishment of the intra-zone routing table, the LDN may recognize its neighboring zones and corresponding intermediate nodes. Indirect nodes are responsible for multicasting to other LDNs of Uniform Quorum sets. Table 3 shows the partial inter-zone routing table of node v in zone 1. For example, nodes within zone 1 want to communicate nodes within zone 2 and zone 3 and node e is gateway node of zone 1, zone 2, and zone 3 from Fig. 4.

Table 3. Inter-zone routing table of node v in zone 1 generated from Fig. 4.

Destination zone	Next zone	Next node
2	2	e
3	2	e

Table 4. The LDN contains the information of zones.

LDN	Information
g	1, 2, 3, 4, 5, 6
v	1, 2, 3
l	1, 2, 3, 4, 5
w	2, 3, 4, 5, 6
t	2, 3, 4, 5, 6
n	2, 4, 5, 6

Table 5. Routing information table of LDN g generated from Fig. 4.

Zone	Node Resident
1	b, c, v, z, x, y
2	e, f, g, h
3	i, j, k, l

- (3) **Node's Location Table:** This table records the other LDNs of Uniform Quorum sets. For instance, in Fig. 4, the presumed Uniform Quorum sets are $((g, l, v), (g, n, t), (l, t, w), (g, n, w))$. Referring to [11], the LDN should contain the information of zones after it multicasts its Uniform Quorum set which is shown in Table 4. Of course, with route packets multicasted to all Uniform Quorum sets, each LDN contains the information of zones is 1, 2, 3, 4, 5, and 6. Thus, the intra-zone table of LDN g is constructed, and information about nodes within the zone is sent to all Uniform Quorum databases. It is assumed that the information selected is (g, l, v) , and that the LDN g , based on the partial inter-zone routing table, multicasts the zone's information to database location nodes l and v . After all database nodes have completed this step, LDN g may have the node's location table including LDNs l and v , which are shown in Table 5.

• GPS-QHRA Routing Rule

Following table construction, any source node will have sufficient information to forward packets to its destination. Two cases are considered in the following.

- Case 1.** When source and destination nodes are in the same zone, the Table-Driven routing algorithm is used. Before forwarding data, each source node will check its LDN to determine whether its destination node is in the same zone. If it is, then data is forwarded along the route given in the database node's routing table.
- Case 2.** If the source and destination nodes are in distinct zones, then the On-Demand

routing algorithm is applied, the node broadcasts to one of the distinct zones based on the partial inter-zone table, and examines the LDNs to determine the zone of its destination. Then, the packet is routed to the destination via the database node of the destination and completes the forwarding process by referencing the routing table.

- **Location Update Rule of GPS-QHRA**

In an *ad hoc* wireless network, the routing table must be periodically examined to ensure that its information is up-to-date since nodes may move at any time due to its mobility. Two location update rules are defined in GPS-QHRA: **Regular update** and **Update on transmission**. (i) **Regular update**: a LDN will periodically examine other nodes within its zone and corresponding routes, and periodically inform about the zone's residents since nodes invariably move. (ii) **Update on transmission**: If data forwarding is requested and the GPS determines that a node has left its original zone, then the node must register to its new LDN. The new zone's LDN will update its routing table with routing information corresponding to this new member, and a new UQS will be selected from this new node's location. The new UQS will then be informed of other LDNs.

- **Rule for Re-Determining the LDN**

Management of the zone is impossible since the LDN is mobile and may leave its original zone. The re-determination mechanism is automatically initiated when the LDN moves into the danger zone. A new node is re-determined and becomes the LDN. When the database node is already in the danger zone during a regular update, a packet chosen from the database is broadcasted to inform all other nodes within its zone. After some time, all nodes are reset and the re-determination procedure is initialized just as in the DFA algorithm. The newly selected database location node then informs the old LDNs of UQS. The intra-zone routing must be recalculated, and the information is then multicast to other members of UQS.

- **Fault-Tolerance in GPS-QHRA**

Some nodes may be unable to connect their LDNs under some circumstances. However, their LDNs always exist. For instance, Fig. 6 (a) shows that node *a*, initially located within transmission range of LDN *m*, changes its location to overstep its LDN's transmission range. To differentiate between before moving and after, an alternative given name of node *a* is node *a'*. Node *a'* effect solidifies node *b* and *c* isolated and to be defined as a "**free node**." Thus, even if the network is proper, node *a'* cannot communicate with node *m* any more. That is to say, free nodes cannot communicate with any other nodes. When a free node requests permission to deliver data and perceives the unavailability of the LDN, the fault-tolerance mechanism is initialized after a period of time. The free node initiates the DFA to select a new LDN. In Fig. 6 (b), node *b* is chosen as the new LDN as relevant information is sent to other sets of UQS. Although this may cause two LDNs to exist simultaneously within a zone, the manipulation of the algorithm is unaffected. While two LDNs connect within a zone, one of them is chosen as the proper LDN based on connectivity. The existence of two LDNs is anomaly case that increases network flow, but the probability of occurrence is low. Hence that will not be much greatly affected the performance of GPS-QHRA in the network with large number of nodes.

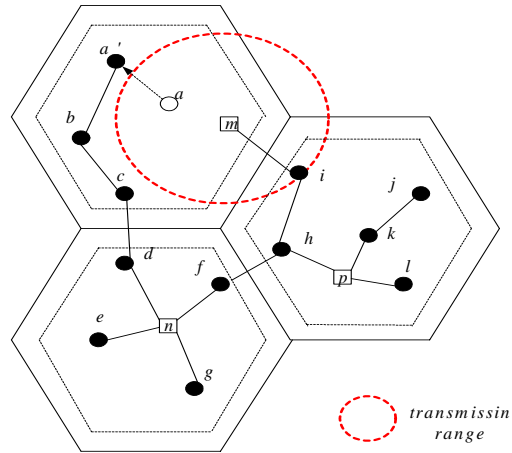
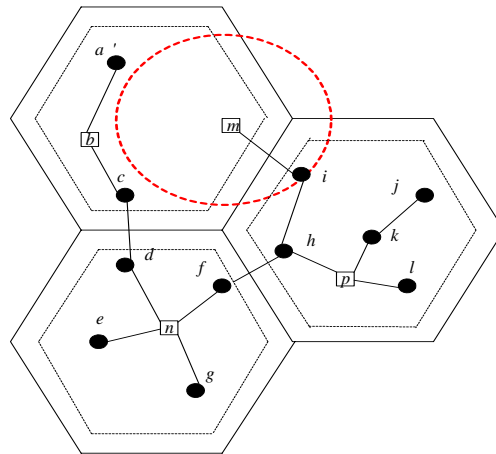


Fig. 6. (a) Fault-tolerance in GPS-QHRA.

Fig. 6. (b) Node b becomes the new database node.

4. SIMULATION EVALUATION

This section evaluates the system performance of the ZHLS algorithm and GPS-QHRA in terms of the mean path length, the number of LSPs (Link State Packets) generated, the mobility effect, the overhead of path discovery, and the packet loss rate.

4.1 Simulation Environment

The simulation environment of the ZHLS algorithm used in [7] was applied, as shown in Fig. 7. The network was a square composed of 999×1000 units, and is divided into six zones, each composed of 333×500 units. Two simulation environments were

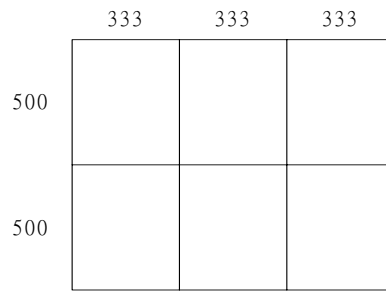


Fig. 7. Simulation environment of the ZHLS algorithm.

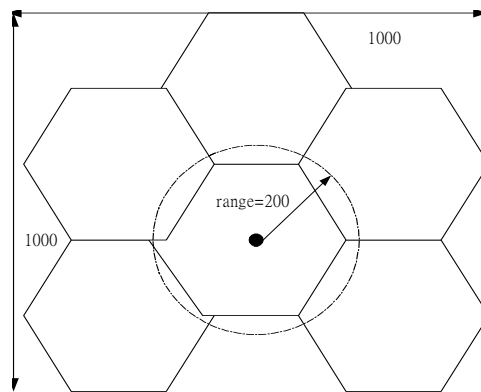


Fig. 8. (a) Simulation environment composed of six zones with a 200-unit transmission range.

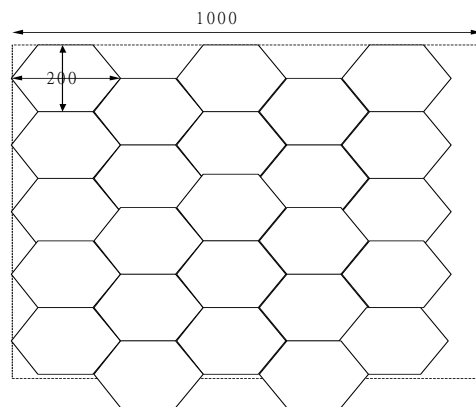


Fig. 8. (b) Simulation environment composed of 25 zones with a 100-unit transmission range.

designed for GPS-QHRA with two different transmission diameters: Fig. 8 (a) shows a network composed of six zones with a 200-unit transmission range, while Fig. 8 (b) shows a network composed of 25 zones with 100-unit transmission range. The moving

speed of nodes is random generated from 1, 5, 10, 20, 40 units/cycle. The arbitrary distributed node numbers are 50, 100, 150, 250, and 500. The transmission radii are 100, 200, 250, and 300.

4.2 System Parameters

• **Mean Path Length:** Fifty, 100, 150, 200, 250, and 500 nodes with transmission radii of 100, 200, 250, and 300 were used to compare the mean path length in GPS-QHRA with that in the ZHLS algorithm. Two environments for GPS-QHRA were used, shown in Figs. 8 (a) and (b). A particular node is picked and used to search for a route to other nodes. Path lengths of 2000 unit time simulations, removing losing route, are averaged. Fig. 9 shows that, for a fixed transmission range, the longest mean path length was obtained when the node count was 50, while mean path lengths for node counts of 100, 150, 200, 250, and 500 did not show significant differences. The number of alternatives was small when the number of nodes was small, so the shortest path obtained was longer, and vice versa. The number of routes obtained fell as the transmission range increase due to the large number of possible routes, which was caused by the wide transmission range, leading to a decrease in the mean path length. Remarkably, the simulation results obtained in GPS-QHRA environment (b) with 25 zones were better than those obtained in GPS-QHRA environment (a) with 6 zones, since the number of routing alternatives increased with the number of network subdivisions. Furthermore, the number of LSPs generated increased as the number of network subdivisions increased.

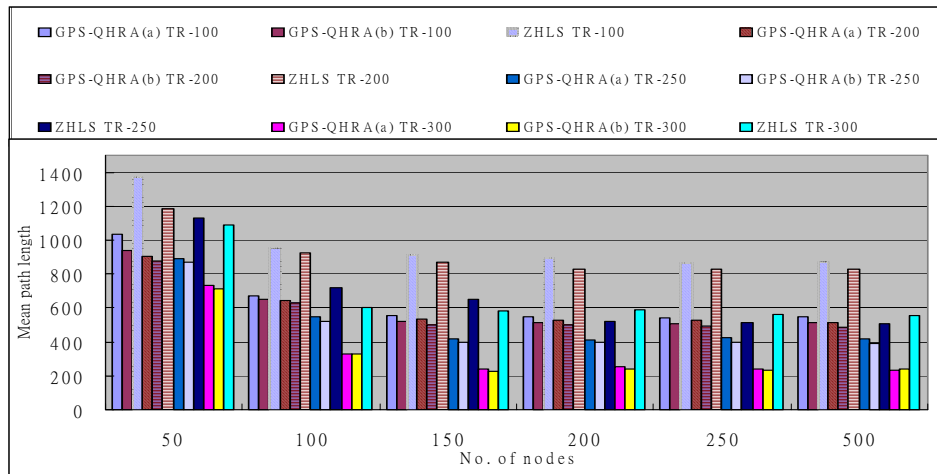


Fig. 9. Comparison of mean path lengths in GPS-QHRA and the ZHLS algorithm for various node counts and transmission ranges.

Fig. 10 compares the mean path lengths in GPS-QHRA, ZHLS, and ZHLS with hexagonal zones for various node counts and transmission ranges, and shows that a shorter mean path length is achieved with hexagonal zones. Fig. 10 shows that the mean

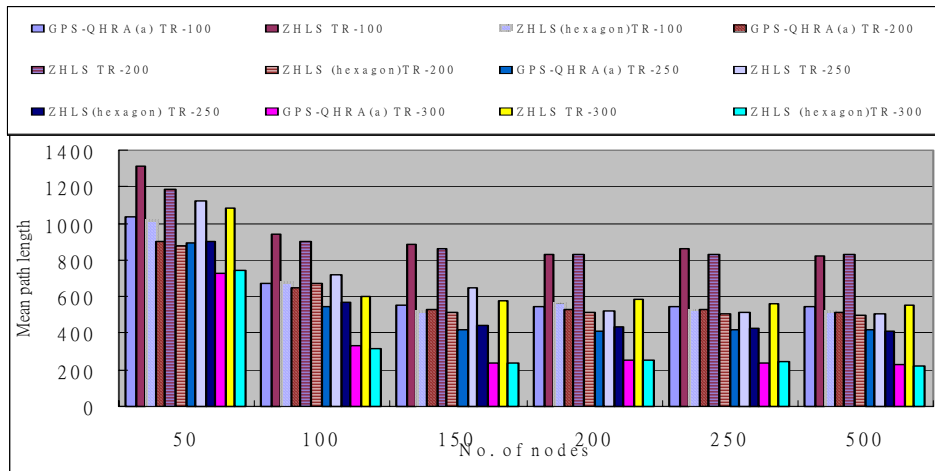


Fig. 10. Comparison of mean path lengths in GPS-QHRA and the ZHLS and ZHLS with hexagonal zones for various node counts and transmission ranges.

path length obtained for both GPS-QHRA and ZHLS with hexagonal zones is almost the same. However, adoption of the quorum concept will be shown later to reduce system overhead.

- Comparison of the LSP Packets Generated:** Two kinds of packets are generated in GPS-QHRA and ZHLS algorithm to search for a routing path: Zone LSP and Node LSP. Fig. 11 compares the total number of LSPs for both ZHLS algorithm and GPS-QHRA for various numbers of nodes. The number of LSP packets generated by GPS-QHRA and the ZHLS algorithm was determined through simulations with 50, 100, 150, 200, 250, and 500 nodes. For equally distributed nodes in the ZHLS algorithm with six zones, the number of Node LSP packets generated is $(\text{node counts})^2/(\text{number of zones})$ since each node in an arbitrary zone will broadcast its Node LSP packets to all other nodes within the zone. The GPS-QHRA simulation was conducted under two environments: (a) with six zones and (b) with 25 zones. Only LDNs are responsible for generating Node LSP packets. Node LSP packet generation is completed with the assistance of direct nodes and indirect nodes, and they are sent to the LDNs of UQS via Gateway nodes. The simulation results showed that Node LSPs were generated by GPS-QHRA than by the ZHLS algorithm. With respect to Zone LSP packets and the number of packets generated in environment (a), there was no difference between GPS-QHRA and the ZHLS algorithm. Fig. 11 indicates that the number of Zone LSPs generated by GPS-QHRA with 25 zones was large, while for node counts of 50 and 100, the total LSP counts for the ZHLS algorithm were larger. However, the number of Node LSPs generated by the ZHLS algorithm grew quickly, since it is governed by the ratio of $(\text{node counts})^2/(\text{number of zones})$. GPS-QHRA generate fewer LSPs.

- Mobility Effect:** Fig. 12 shows the overhead of GPS-QHRA and ZHLS algorithm for different mobility rates. The simulation was based on mobility rates of 1, 5, 10, 20, and

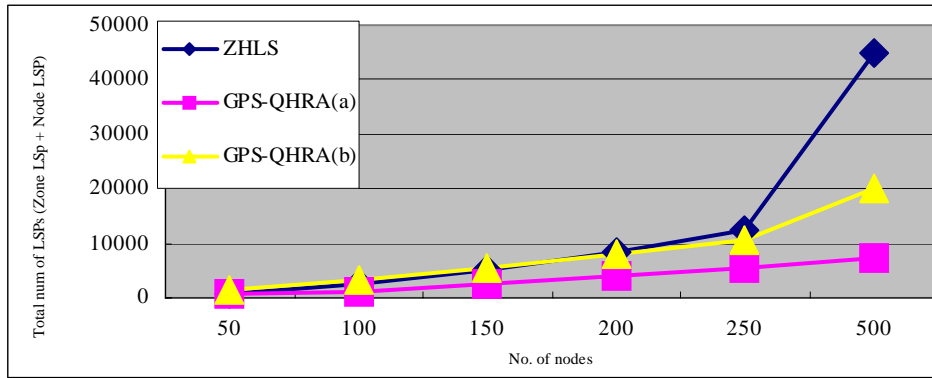
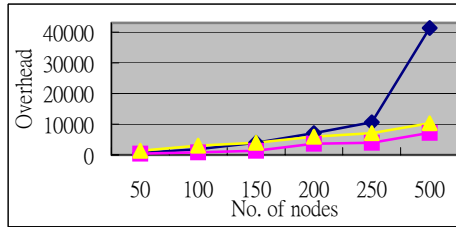
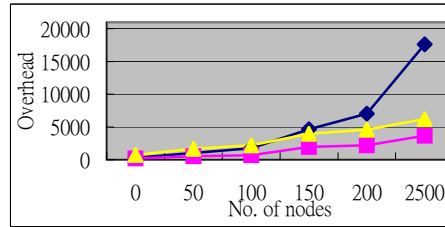


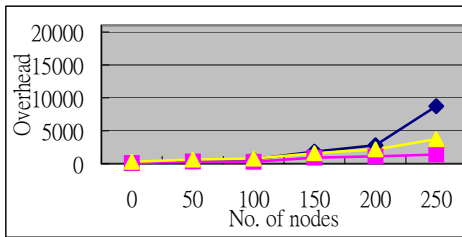
Fig. 11. Comparison of the number of LSPs generated by the ZHLS algorithm and GPS-QHRA for various numbers of nodes.



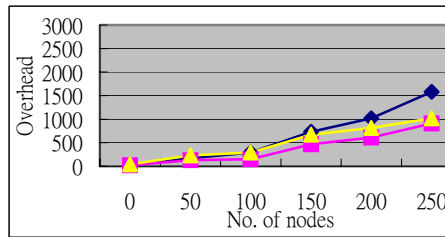
(a) Mobility = 40 units/cycle.



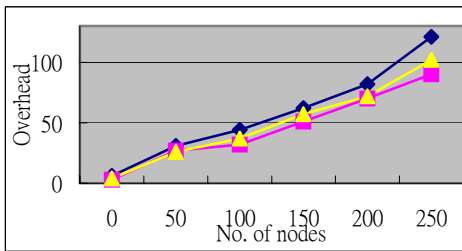
(b) Mobility = 20 units/cycle.



(c) Mobility = 10 units/cycle.



(d) Mobility = 5 units/cycle.



(e) Mobility = 1 unit/cycle.

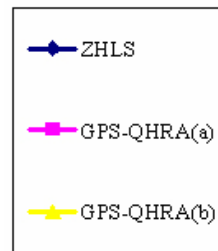


Fig. 12. Overhead of the mobility effect in GPS-QHRA and the ZHLS algorithm.

40 units/cycle and 50, 100, 150, 200, 250, and 500 nodes randomly distributed over the network. The nodes were assumed to move in a definite way, moving y units in a new direction after x units of time. A new direction was randomly selected for a node when the node moved toward a boundary. The topology changes slowly as the number of nodes increases since the number of Zone LSPs was not affected when an enormous number of nodes were involved. The number of Node LSPs increased with the number of nodes. GPS-QHRA with six zones performed better than the ZHLS algorithm for any number of nodes, while the performance of GPS-QHRA with 25 zones gradually surpassed that of the ZHLS algorithm for node counts 150 or above. GPS-QHRA outperformed the ZHLS algorithm for both six zones and 25 zones. As shown in Fig. 12, GPS-QHRA with six zones had the smallest overhead, followed by GPS-QHRA with 25 zones and then the ZHLS algorithm. When mobility was extremely low, the overhead was small for all three algorithms. However, our algorithm performed better when the speed was high and the number of node was large.

• **Overhead of Path Discovery:** Fig. 13 shows the simulation results for packet generation during path discovery for 50, 100, 150, 200, 250, and 500 nodes. A particular node was picked and used in searching for a route to other nodes. Path lengths of over 1000 units of time were averaged. With the ZHLS algorithm, broadcasting to all zones is required when a node requests permission to transmit data. The GPS-QHRA outperformed the ZHLS algorithm since it requires only partial broadcasting, that is, broadcasting to the LDNs of UQS. GPS-QHRA with six zones performed better than GPS-QHRA with 25 zones, because the former has fewer alternatives for path discovery. The overhead decreased as the number of nodes increased, since the retransmission rate was low because the number of nodes was adequate. The simulation results show that adoption of using UQS concept may reduce the network overhead during path discovery.

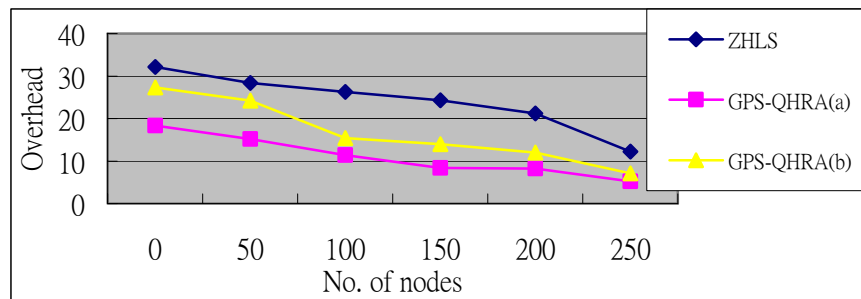


Fig. 13. Effect of path discovery.

• **Comparison of the Dropping Probability:** Fig. 14 compares the dropping probability of both the ZHLS algorithm and GPS-QHRA were compared for 50, 100, 150, 200, 250, and 500 nodes, and transmission ranges of 100, 200, and 250. A particular node was randomly selected as the destination for path discovery. A route was regarded as dropped if it could not be properly determined. A path could be dropped for the following reasons:

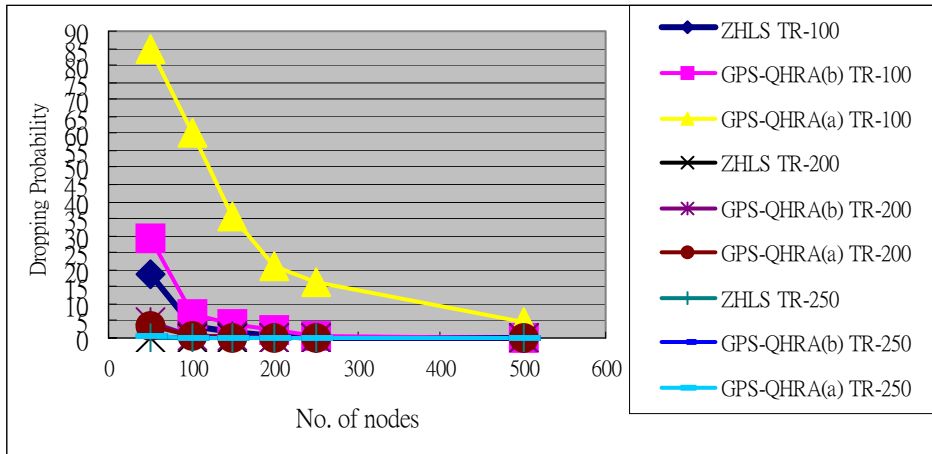


Fig. 14. Comparison of the dropping probability.

First, when the number of nodes was extremely small, the nodes from the source to the destination are too few to form a route. Second, the transmission range could cause a path to be dropped. As shown in Fig. 14, no dropping occurred with the ZHLS algorithm for a transmission range of 200 or 250 (dropping probability = 0), while for a transmission range of 100, some paths were dropped. The dropping probability increased as the transmission range decreased. Third, with GPS-QHRA, dropping occurred when an LDN could not find a destination or when it found an incorrect destination for the source node. The simulation results show that the dropping probability for GPS-QHRA under a transmission range of 100 is critical, but that the situation improved under a transmission range of 200. The ZHLS algorithm performed better than GPS-QHRA with respect to the dropping probability. However, as noted above, increasing the number of nodes or the transmission range had little effect.

5. CONCLUSIONS

This paper has proposed a hierarchical, hybrid GPS-QHRA that employs hexagonal zones, resulting in fewer flooding messages, better bandwidth management and fewer hops. GPS-QHRA combines the location tracking technology of GPS with the UQS concept, both of which are applicable to *ad hoc* wireless networks. With LDNs used to perform central management, each zone requires only one node to maintain a routing table and update it regularly. Simulation results show that the proposed algorithm can result in shorter paths and achieve better performance in a high mobility environment. In addition, the system overhead can be reduced, since GPS-QHRA only needs to multicast, not broadcast to LDNs of UQS. GPS-QHRA outperforms the ZHLS algorithm, since the latter more packets flooding overheads. The overhead caused by the large number of LDNs is compensated by an increased dropping probability when the database is faulty, which may influence performance. Future works may address the following issues. (i)

QoS: the goal will be to improve the system delay due to packet loss caused by topological changes. (ii) We will develop another location aware mechanism with smaller packet overheads than GPS. (iii) The limited bandwidth problem: this work will assume that a proper bandwidth management algorithm exists in this paper.

REFERENCES

1. E. M. Royer and C. K. Toh, "A review of current routing protocols for ad hoc mobile wireless networks," *IEEE Personal Communications Magazine*, 1999, pp. 46-55.
2. D. Baker *et al.*, "Flat vs. hierarchical network control architecture," *ARO/DARPA Workshop on Mobile Ad-Hoc Networking*, 1997.
3. L. Kleinrock and F. Kamoun, "Hierarchical routing for large networks, performance evaluation and optimization," *Computer Networks*, Vol. 1, 1977, pp. 155-174.
4. C. C. Chiang, H. K. Wu, W. Liu, and M. Gerla. "Routing in clustered multihop mobile wireless networks with fading channel," in *Proceedings of IEEE Singapore International Conference on Networks (SICON '97)*, 1997, pp. 197-211.
5. C. Perkins and P. Bhagwat, "Highly dynamic destination-sequenced distance-vector routing (DSDV) for mobile computers," in *Proceedings of ACM SIGCOMM '94 Conference on Communications Architectures, Protocols and Applications*, 1994, pp. 234-244.
6. C. E. Perkins, E. M. Belding-Royer, and I. Chakeres, "Ad hoc on demand distance vector (AODV) routing," IETF Internet draft, draft-perkins-manet-aodvbis-00.txt, 2003 (Work in Progress).
7. K. Paul, S. Bandyopadhyay, D. Saha, and A. Mukherjee, "Communication-aware mobile hosts in ad-hoc wireless network," in *Proceedings of IEEE International Conference on Personal Wireless Communication*, 1999, pp. 83-87.
8. V. D. Park and M. S. Corson, "A highly adaptive distributed routing algorithm for mobile wireless networks," in *Proceedings of IEEE INFOCOM '97*, 1997, pp. 1405-1413.
9. M. Joa-Ng and I. T. Lu, "A peer-to-peer zone-based two-level link state routing for mobile ad hoc networks," *IEEE Journal on Selected Areas in Communications*, Vol. 17, 1999, pp. 1415-1425.
10. T. Moore, "An introduction to the global positioning system and its applications," *IEE Colloquium on Developments in the Use of Global Position Systems (GPS) in Power Systems*, 1994, pp. 1/1-1/8.
11. Z. J. Haas and B. Liang, "Ad hoc mobility management with uniform quorum systems," *IEEE/ACM Transactions on Networking*, Vol. 7, 1999, pp. 228-240.
12. C. Y. Chang and C. T. Chang, "Hierarchical cellular-based management for mobile hosts in ad hoc networks," *Computer Communication Journal*, Vol. 24, 2001, pp. 1554-1567.
13. S. J. Lee, M. Gerla, and C. K. Toh, "A simulation study of table-driven and on-demand routing protocols for mobile ad hoc networks," *IEEE Network*, Vol. 13, 1999, pp. 48-54.
14. S. R. Das, C. E. Perkins, and E. M. Royer, "Performance comparison of two

- on-demand routing protocols for ad hoc networks”, in *Proceedings of IEEE Computer and Communications Societies Conference on Computer Communications (INFOCOM '00)*, Vol. 1, 2000, pp. 3-12.
15. S. Basagni, “Distributed clustering for ad hoc networks,” in *Proceedings of the International Symposium on Parallel Architectures, Algorithms, and Networks (I-SPAN '99)*, 1999, pp. 310-315.
 16. R. C. Lin and J. S. Liu, “Bandwidth routing in ad hoc wireless networks,” *IEICE Transactions on Communications*, Vol. E83-B, 2000, pp. 1497-1508.
 17. A. Ephremides, J. E. Wieselthier, and D. J. Baker, “A design concept for reliable mobile radio networks with frequency hopping signaling,” in *Proceedings of the IEEE*, Vol. 75, 1987, pp. 56-73.
 18. B. Das and V. Bharghavan, “Routing in ad-hoc networks using minimum connected dominating sets,” in *Proceeding of International Conference on Communications (ICC '97)*, 1997, pp. 376-380.



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