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HGRP: hybrid grid routing protocol for heterogeneous hierarchical wireless networks*†

by

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Abstract: The heterogeneous mobile terminals coexist in the next generation wireless networks. The most common routing schemes for mobile ad hoc networks are designed for homogeneous wireless networks. The heterogeneous wireless network routing protocols are needed urgently in many important applications. This paper improves the routing scheme utilizing different capability of terminals and the Hybrid Grid Routing Protocol (HGRP) is proposed. The network is organized in the grid form, that is, the network deployment area is divided into square cells according to the location. Each cell contains one backbone node and several ordinary nodes. This proposed protocol consists of four parts: grid construction, local routing, global routing, and routing correction. Analysis and simulation results indicate that the proposed protocol has the advantages of lower routing cost, lower energy consumption, smaller delay and higher throughput, compared to AODV and ZRP.

Keywords: hybrid grid routing protocol, mobile ad hoc networks, heterogeneous wireless networks, ad hoc on-demand distance vector routing protocol, zone routing protocol.

1. Introduction

The mobile ad hoc network is a self-organizing and self-configuring multi-hop wireless network, as presented by Jubin and Tornow (1987) in the DARPA Packet Radio Network (PRNet) and by Lauer (1995) in the SURAN project. Sesay et al. (2004) also showed that the mobile ad hoc network can provide rapid and cost effective deployment, which makes it very attractive for emergency relief and military applications.

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Liu and Kaiser (2005) suggested that a crucial issue for the mobile ad hoc network is routing protocol design, which is also a major technical challenge due to the dynamism of such networks. The routing protocols for mobile ad hoc networks can be classified into two categories: flat and hierarchical ones. This paper focuses on the hierarchical routing scheme. The network is divided into groups according to knowledge topology in the hierarchical setting. In each group, the nodes take turns to act as the leader through an election algorithm. The hierarchical routing protocols adopt proactive routing for intra-group communication and reactive routing for inter-group packet forwarding. Tchepnda et al. (2006) and Sun et al. (2003) showed that both the available flat and hierarchical routing protocols assume that the nodes are homogeneous, that is, all the nodes have the same capabilities, resources and transmission range.

With the fast growth of various mobile terminals, the heterogeneous terminals with different capabilities and resources are required and mixed in the deployment, see e.g., Andronache et al. (2006). The heterogeneous wireless networks are now needed urgently in many important applications. In the military field, the sensor nodes deployed in the ground collect information on the environment and send it to the nodes that can be carried by the soldiers. In the civilian applications, the mesh routers, which have improved computational, communication and power resources as compared with mesh clients, undertake global routing in wireless mesh networks. However, the available routing protocols do not take these heterogeneous application scenes into consideration. So, they will yield poor performance in such applications. The available routing protocols for mobile ad hoc networks are designed mainly for homogeneous wireless networks. Therefore, a new type of routing approach for the heterogeneous wireless networks becomes necessary, see Vukojevic et al. (2008) and Lee et al. (2005).

In this paper, we focus on the heterogeneous hierarchical wireless network and propose a new Hybrid Grid Routing Protocol (HGRP) for it. The main idea of HGRP is to deploy the network with the grid form, that is, the network deployment area is divided into square cells according to the location. Each cell contains one backbone routing node and some ordinary nodes, such that the expensive flooding data packages can be effectively restricted within each cell only. At the local level (within one cell), a proactive routing protocol provides a detailed and fresh view of each node's surrounding topology. At the global level (between cells), the slope ratio determined by the source cells and the destination cells significantly shrinks the search areas of global path. The proposed protocol promises to offer high efficiency in terms of routing cost, energy consumption, delay and throughput.

The rest of this paper is organized as follows: Section 2 describes our HGRP. Section 3 analyzes the advantages of HGRP and compares it with clustered routing. Section 4 presents a comparison among HGRP, AODV and ZRP based on an extensive simulation study. Section 5 presents some related works. Section 6 concludes this paper.

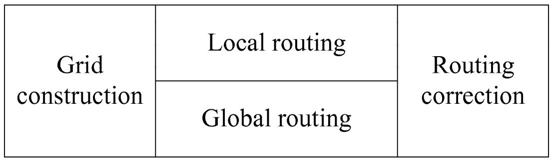

Figure 1. Illustration of the HGRP framework

2. HGRP: Hybrid Grid Routing Protocol

In this section, we introduce the new HGRP protocol, including its overall framework, the issues of grid construction, local routing within a cell, global routing among cells and also routing correction. First, the network deployment area is divided into cells with side length equal $\sqrt{2}R/4$. Then the table-driven routing protocol is used in the cell, limiting the expensive routing flooding data packages within a single cell. The global routing in HGRP is based on a simple plane geometry algorithm, and it does not require the complex path search process. At the same time, routing correction is presented to determine the backbone node and manage the node addition and subtraction. The pseudo-code of the main steps in local routing, global routing and routing correction algorithm is presented to establish the whole system.

2.1. The framework of HGRP

The heterogeneous hierarchical wireless networks consist of various wireless terminals (nodes) with different capabilities and resources, and these nodes are divided into two kinds: backbone nodes and ordinary nodes. The nodes whose energy is limited and transmission scope is small are regarded as ordinary nodes, and the nodes whose energy is high and transmission range is large are regarded as backbone nodes. The overall framework of our new HGRP, including its main modules of grid construction, local routing, global routing and routing correction, is illustrated in Fig.1.

In the HGRP, the coverage area of a heterogeneous hierarchical wireless network is first divided into cells, as shown in Fig.2. Here, local routing is responsible for communication between backbone node and ordinary nodes within a single cell, while global routing is responsible for communication among the backbone nodes of different cells. When faults occur in the routing, the routing correction process is used to correct them.

In the HGRP protocol we assume that the backbone nodes and ordinary nodes are deployed in an evenly mixed proportion, and the backbone node has a higher reliability than a ordinary node, as described by Xie et al. (2005). Also, we assume that each node can obtain its own location by the node location mechanism and determine the cell it belongs to, following Zhang et al. (2007)

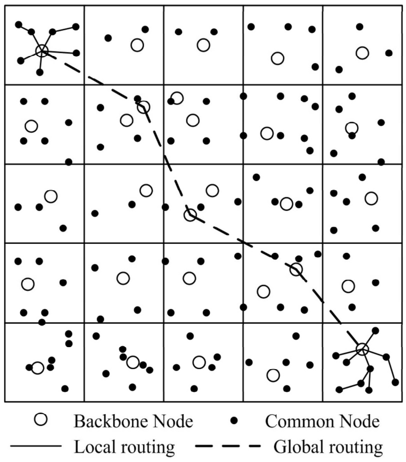

Figure 2. The architecture of a heterogeneous hierarchical wireless network

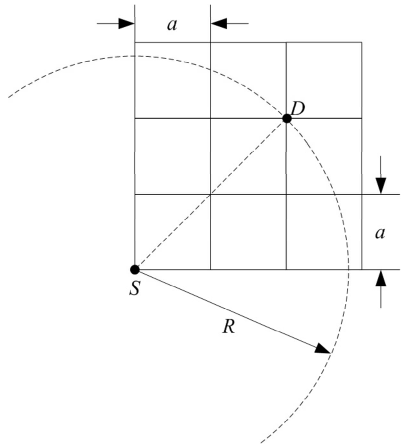

Figure 3. Diagram of parameters a and R

and Chou et al. (2007).

Using the difference between the nodes and the knowledge of the local topology, HGRP improves the wireless network routing. The wireless mesh networks use the routing protocols for MANET or their improvement. The wireless mesh network routing function implemented in MAC layer has high efficiency, but is not suitable for large-scale wireless networks. The HGRP can also be used in mesh networks.

2.2. Grid construction

The first important issue of the HGRP is grid construction, i.e., how to properly divide the network deployment area into cells. For grid construction, we need to determine two parameters: the cell side length and cell coordinate (or cell *ID*).

Let the minimum transmission ranges of backbone and ordinary nodes be R and r, respectively, and let the cell side be a. To ensure that the backbone nodes of two adjacent cells communicate directly, the transmission range R of the backbone node is $2\sqrt{2}a$ at least, which is just the possible greatest distance between the backbone nodes of two adjacent cells, as illustrated in Fig.3. Hence, the cell side length should be $\sqrt{2}R/4$.

As the transmission range R of backbone nodes should be $2\sqrt{2}a$, so each backbone node can cover from 13 to 16 cells, as shown in Fig.4.

The unique cell *ID* is represented by the coordinates of the cell, as shown in

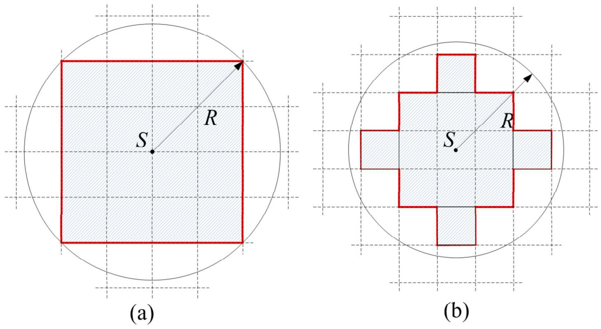

Figure 4. The coverage range of backbone node signal. (a) The maximal number of full-cover cells. (b) The minimum number of full-cover cells.

Fig. 5. When the cell *ID* is determined, the optional backbone node in each cell broadcasts a message to declare itself as the backbone node, and others as the ordinary nodes, which is recorded by the backbone nodes. In each cell, only one node can be selected and sustained as the backbone node of this cell. If there are several optional backbone nodes and the messages of the competitive backbone nodes conflict, the optional backbone nodes wait for a random time and declare them to be the backbone nodes. The backbone node declared earlier will be selected as the backbone node, and other nodes are regarded as the candidate backbone nodes.

When the backbone node of a cell moves out of the cell, its qualification of being the backbone node is lost. Then, the nodes inside the cell will initiate the selection of backbone node again and choose a new backbone node. When no nodes in the cell can be considered as the backbone nodes, the cell uses flooding to transmit data.

2.3. Local routing

At the local level (within one cell), the proactive routing protocol provides a detailed and fresh view of each node's surrounding topology. The knowledge of local topology will be used to support services of proactive route maintenance, unidirectional link discovery, guided message forwarding and distribution.

Each ordinary node in a cell needs to establish and maintain a routing sheet, by which the ordinary node can reach the backbone node of the cell. The process of routing sheet establishment is as follows: each ordinary node first floods a route request package in its cell to find the nearest backbone node. Every node which receives the route request package will extract the cell *ID* included in the route request package, and determine whether the *ID* is the same as the *ID* of its cell. If it is the same, the node will be added to the path, and the

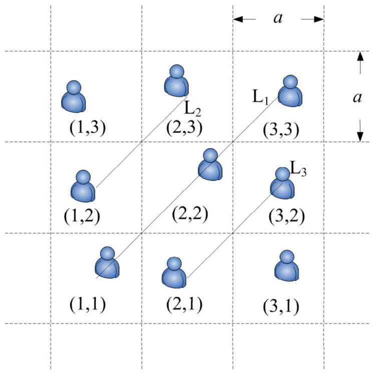

Figure 5. Routing cells and their *IDs*

route request package will be further flooded until the backbone node receives the route request package. If the *ID* is not the same, the package is abandoned. Since the backbone has a large transportation range, when receiving the route request package, it can include the route in the route responds package and send it directly to the source node. Then, the source node can follow the route and send the data package to the backbone node.

The pseudo-code of the main steps in local routing algorithm can be summarized as follows:

```
Path search
   {
     For each ordinary node in network do
       While (routing table= =Null OR routing message is expired)
         Cell ID and its node identifier are used to build reque-
sted routing data package and broadcast it.
         Monitor the routing messages sent by backbone nodes.
         If (in the given time, the routing messages are received
by backbone nodes)
           Fill the received path in the routing sheet.
         End if
       End While
     End for
   }
   Transfer the routing messages
   {
     For each ordinary node in network do
       Monitor routing data packages.
       Extract the cell ID in the routing data packages.
```

```
      If (cell ID of routing data packages = = cell ID in which
the nodes are located)
        Add its identifier in the routing data package path and
new data packages are formed.
        Broadcast this new data package.
      Else
        Discard the data package.
      End if
    End for
    For each backbone node in network do
      Monitor routing data packages.
      Extract the cell ID in the routing data packages.
      If (cell ID of routing data packages = = cell ID in which
the nodes are located)
        Send directly the path in the data package to the source
ordinary node.
      Else
        Discard the data package.
      End if
    End for
  }
```

It should be noted that in the above local routing process, the cell *ID* is used to ensure that the scope of the route updates (flooding) is restricted to the range of the node cell only, so the HGRP can greatly decrease the route flooding cost.

2.4. Global routing

Another key issue of the HGRP protocol is how a backbone node discovers other backbone nodes in the routing process. The shortest communication distance between two cells is the straight-line distance that links then. Since the *ID* of each cell is the coordinate of the cell, so from the *IDs* of the source and destination cells we can determine the straight line of the shortest path.

Let S be the backbone node of the source cell with *ID* (S_x,S_y), D be the backbone node of the destination cell with *ID* (D_x,D_y), C be the current cell with *ID* (C_x,C_y). Then the line L linking the source and destination cells can be represented as:

$$Y = \frac{D_y - S_y}{D_x - S_x}X + \frac{S_y D_x - S_x D_y}{D_x - S_x}. \tag{1}$$

Let

$$k = \frac{D_y - S_y}{D_x - S_x} \tag{2}$$

$$b = \frac{S_y D_x - S_x D_y}{D_x - S_x}. \tag{3}$$

Formula (1) can be represented as:

$$Y = kX + b. \tag{4}$$

The vertical distance from the cell with *ID* (x,y) to the line L of (4) is

$$d = \sqrt{(\frac{kx - y + b}{2k})^2 + (\frac{y - kx - b}{2})^2}. \tag{5}$$

Substituting (2) and (3) into (5) , we have

$$d = \frac{yD_x - yS_x - xD_y + xS_y - D_xS_y + S_xD_y}{2(D_y - S_y)(D_x - Sx)} \sqrt{(D_y - S_y)^2 + (D_x - S_x)^2}. \tag{6}$$

The next hop cell is determined by two steps: direction search and distance computation. The direction of the next hop cell in which data are sent from S to D is determined by (C_x,C_y) and (D_x,D_y). In the direction of X, if $D_x>C_x$, the next hop cell is searched along the direction in which X becomes larger, and vice versa. Similarly, in the direction of Y, if $D_y>C_y$, the next hop cell is searched along the direction in which Y becomes larger, and vice versa. In the distance computation, the distance from the searched cell to line L is computed. Then, according to the pre-defined path width w, the protocol determines whether data are transmitted through the cell. If the computed distance is less than w, the searched cell is selected as the next hop cell. Otherwise, the protocol continues to search.

The pseudo-code of the main steps in the global routing algorithm can be summarized as follows:

```
// The source cell S with ID (S_x, S_y).
// The destination cell D with ID (D_x, D_y).
// The current cell C with ID (C_x, C_y).
// The next cell N with ID (N_x, N_y).
Direction Search (C,D)
{
  If (D_x > C_x)
      N_x = C_x + 1;
   Else if (D_x < C_x)
      N_x = C_x - 1;
    Else
      N_x = C_x
  end if
```

```
  If (D_y > C_y)
       N_y = C_y + 1;
   Else if (D_y < C_y)
       N_y = C_y - 1;
     Else
       N_y = C_y
  end if
  return (N_x, N_y)
}
Determine hop cell(S,N,D,w)
{
```

$$d = \frac{yD_x - yS_x - xD_y + xS_y - D_xS_y + S_xD_y}{2(D_y - S_y)(D_x - Sx)}\sqrt{(D_y - S_y)^2 + (D_x - S_x)^2}$$

```
  If (d ≤ w)
    N is determined as the next hop cell.
  Else
    Direction search is done again.
  End if
}
```

Take Fig. 5 as an example, and assume that cell (1,1) is ready to communicate with cell (3,3). Although the backbone nodes are both moving, the two cells will not change within a certain time. Assume that line L_1 goes through the center of the cells (1,1) and (3,3). The line goes through (1,1), (2,2) and (3,3). Lines L_2 and L_3 are parallel to L_1, at distance w to L_1 . All the cells through which lines L_1, L_2 and L_3 pass can be defined as routing cells.

The value of w depends on the density of candidate backbone nodes in the network. The path width determines the number of the searched paths. The greater the value of w, the higher the number of the potential next hop cells. The increase of w allows more cells to be the next hop ones. Hence, the cells with backbone nodes are preferentially selected as the next hop cells.

When w=0, the cells, through which line L passes are only the middle cells. When w>0, the cells from which the vertical distance to line L is less than w act as the middle cells. In Fig. 5, if w=0, the routing cell is the cell, through which L_1 goes. If there are no backbone nodes in some cells, the value of w must be increased. If w is set as $\sqrt{2}a/2$, the next hop routing cells will be the ones between L_2 and L_3.

2.5. Routing correction

When backbone nodes move out of the cell, or in the case of invalidation of backbones, the route must be corrected. Again, take Fig. 5 as example, suppose that in the process of discovering the route it is found that the route is (1,1) → (2,2) → (3,3). If, after finding the route, one backbone in the path (suppose (2,2)) moves out of the range of its cell or the backbone is invalid, and at the same time there is no new backbone node to be selected, then it means that the known route is invalid.

When the backbone node sends data to the next hop, if it does not intercept the retransmitted data of the backbone node in the next cell, it is believed that there is no backbone node in the next hop. If the cell (1,1) finds out that the cell (2,2) is invalid, cell (1,1) will flood a route repair package of the direct predecessor (itself) and direct successor ((3,3) in the example) to the routing cell (cell (1,2)/(2,3) in the example), in order to find a route leading to direct successor backbone node (3,3).

Route repair package floods in the cells of route direction. After the backbone nodes of successor cells receive the first route repair package, they send a response route package to the correcting cell (1,1) along the source route, so that cell (1,1) can find a correction route.

The pseudo-code of the main steps in the routing correction algorithm can be summarized as follows:

```
Routing correction
   {
     For correcting backbone node do
       Detect that the next hop cell does not transfer data.
       Flood route repair package.
       While (monitor the response of route repair package)
         Repair routing.
       End while
     End for
     For the routing cell do
       Receive the routing repaired data packages.
       If (the path existed in the subsequence cell)
         Return the response of route repair package.
       Else
         Discard the data packages.
       End if
     End for
   }
```

3. The analysis of HGRP

In this section, we introduce in more details the advantages of using HGRP over the typical ones, like AODV, ZRP, and clustered routing.

3.1. Comparison with AODV and ZRP

Basically, the HGRP is different from the typical routing protocols (like AODV and ZRP) in two points. First, the HGRP adopts cells to avoid the complicated leader selection and group generator processes, and it also restricts the expensive routing flooding data packages within a single cell. Second, global routing in HGRP is based on a simple plane geometric algorithm, and it does not need the complex path search process.

Due to above differences, the HGRP offers the following the advantages:

1) More efficient route: Since the backbone nodes in HGRP have large transmission distance, so the shortest path with small number of hops can be found through the simple geometry algorithm.

2) Smaller routing delay: The global routing in HGRP is simply based on the backbone nodes with longer transmission range and cell location coordinates, while the traditional routing protocols need to execute complex on-demand routing algorithm. Therefore, HGRP results in a smaller routing delay.

3) Lower routing cost: In HGRP, the flooding in both initial phase and route correction route is restricted within a single cell, so it will not result in a large routing cost. The global routing there is accomplished not by the flooding but by a the simple geometric algorithm, so the global routing also has low cost compared with the traditional methods.

3.2. Comparison with clustered routing

The available clustered routing procedures, including those by Jiang et al. (1999), Iwata et al. (1999) and Chiang et al. (1997), involve high costs of cluster heads selection and substitution. Also, the scale of clusters is usually uneven, which makes routing maintenance very difficult. Hence, the current clustered routing usually consumes more energy. The HGRP is different from the current clustered routing. The HGRP functioning is based on the cell and the simple selection of backbone node according to its transmission capability and location. The HGRP needs a node location, which can be implemented by various available node location systems, such as presented by Zhang et al. (2007) and Chou et al. (2007). The general comparison between HGRP and clustered routing is shown in Table 1.

4. The simulation results

In this section, ns-2 based simulation is used to demonstrate the performance of the new HGRP protocol in terms of routing cost, energy consumption, throughput and delay.

Table 1. Comparison between HGRP and clustered routing

	HGRP	**Clustered routing**
Initialization	Simple, low cost	Complex, high cost
Leader selection	Simple,low cost	Complex,high cost,impractical
Leader update and maintenance	Simple,low cost	Complex,high cost,impractical
Cell/cluster size	Uniform	Not uniform
Local routing	Low cost	Low cost
Global routing	Low cost	High cost
Routing correction	Simple,low cost	Complex,high cost,re-establish
Node location	Necessary	Unnecessary

4.1. Simulation setting

There are 100 nodes deployed in the range of $1000m * 1000m$, among which 25 nodes are optional backbone nodes, the transmission range of the backbone node is $200m$, the transmission range of the usual node is $100m$. The nodes are moving randomly, the range of moving velocity is $0-50m/s$. The length a of the cell is supposed to be $R/1.6$, so there are 16 cells and at most 16 backbone nodes in the range of the route area. The width w of the route cell set at 0, which means that the route cell is the cell through which line L passes. The simulation time is 600 seconds. The communication nodes use CBR (Constant Bit Rate) to generate data stream for communication. The source node generates 4 data packages every second, and the size of every data package is 512 Bytes.

In the simulation, we compared the HGRP, AODV and ZRP protocols in the routing cost, energy consumption, throughput and delay, because AODV is the most typical wireless network routing protocol and ZRP is the most typical region-based routing protocol. In AODV and ZRP protocol simulation, the backbone nodes have strong capacities, and both routing protocols work in accordance with the appropriate routing.

4.2. The routing cost

A. The routing cost under different moving velocities

When the node sends 100 data packages, the number of its route control packages is defined as the routing cost. The routing cost of nodes of HGRP, AODV and ZRP moving at different velocities is shown in Fig. 6.

When the velocity of the node increases, the routing cost of HGRP, AODV and ZRP also increase. The faster the node moves, the higher invalidation frequency will be, thus increasing the routing cost. But the routing cost of HGRP is much smaller than that of AODV and ZRP. When the node is not mobile, the routing cost of AODV and ZRP is generally equal to that of HGRP; but when the largest velocity of the node is $50m/s$, the cost of AODV is nearly 5 times larger than that of HGRP.

The cause of the previous phenomenon is that the backbone nodes have larger transmission range, and thus the number of hops of HGRP and the delay

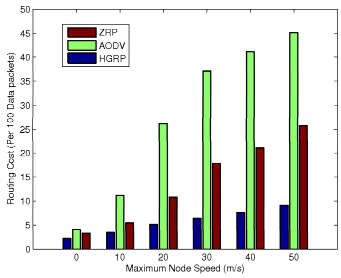

Figure 6. Routing cost at different moving velocities

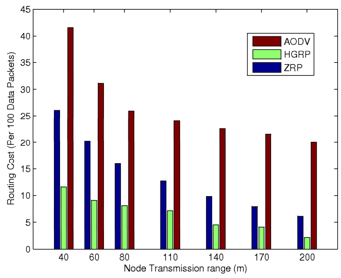

Figure 7. Routing cost at different transmission ranges

are lower. The smaller route delay means that the interval between the process of discovering route and sending data is smaller. Consequently, when the data packages come, the location of middle nodes will not be far away from their previous locations, so the invalidation of route is smaller.

B. The routing cost at different transmission ranges

For different transmission ranges, the mean routing cost is shown in Fig. 7.

The distance of transmission of ordinary node is from 40 meters to 200 meters. The simulation results show that the cost of HGRP is much smaller than that of AODV and ZRP. When the range of transmission is more than 140 meters, the cost of HGRP is very small and there will be less than 5 routing control packets per 100 data packets which are transmitted. The reason is that if the distance of transmission is large enough, the source node and the goal node can communicate with each other through the backbone nodes nearby directly. Thus, there is no need to use flood routing request and acknowledge packets, the cost of routing is reduced significantly.

C. The routing cost for different network scales

To test the routing cost in different network scale of HGRP, we have designed a large-scale test scenario. In a scope of $2000m * 2000m$ and $1000m * 1000m$, there are 400 nodes distributed evenly, within which 100 are optional backbone nodes. The routing cost of HGRP, AODV and ZRP is shown in Fig.8.

While in larger circumstances, HGRP routing cost is in an acceptable range, the AODV routing cost for $2000m * 2000m$ is much higher than for $1000m * 1000m$. When the network scales expand, AODV routing of the flooding area will also expand, the number of nodes involved in routing discovery greatly increases as well, and so, AODV routing cost for $2000m*2000m$ is far greater than for $1000m * 1000m$. In addition, in large-scale networks, when transmitting a data packet, AODV needs more intermediate nodes, any failure and mobility of

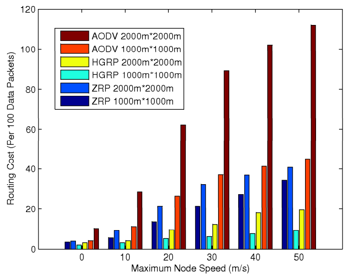

Figure 8. Routing cost for different scale scenes

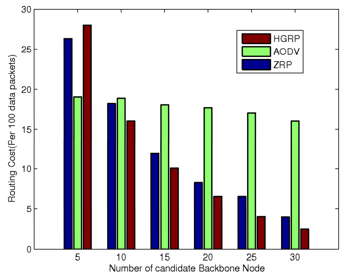

Figure 9. Routing cost for different densities of backbone nodes

intermediate nodes will lead to amending or re-routing, causing higher routing cost. For the same source target nodes, as HGRP uses backbone nodes which have greater transmission scales to transmit data packets, it needs less intermediate nodes than AODV, thus routing failure probability in HGRP is much lower. The simulation results also show that HGRP routing cost for different scale scenes is lower than for ZRP.

D. The routing cost for different densities of backbone nodes

For deploying different numbers of backbone nodes in a network, the average routing cost is shown in Fig. 9.

The less the backbone nodes, the higher the HGRP overhead. When the number of candidate backbone nodes increases, HGRP overhead decreases rapidly.

4.3. Energy consumption

At different moving velocities, total energy consumption of transmitting 100 data packages in the network is shown in Fig. 10.

The major energy consumption of the network is the energy consumption of sending data. At different moving velocities, energy consumption of AODV and ZRP is much higher than that of HGRP. The reason is that the higher routing cost of AODV and ZRP related to the fact that when transmitting the same data, AODV and ZRP have to send more packages than HGRP, thus consuming more energy.

4.4. The throughput

A. The throughput at different transmission loads

We measure the throughput and delay of different transmission loads. The transmission load in simulation ranges from $50kbit/s$ to $300kbit/s$, the largest

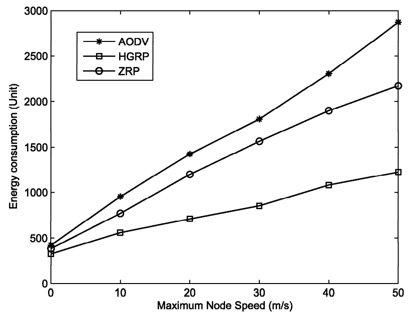

Figure 10. Energy consumption at different velocities

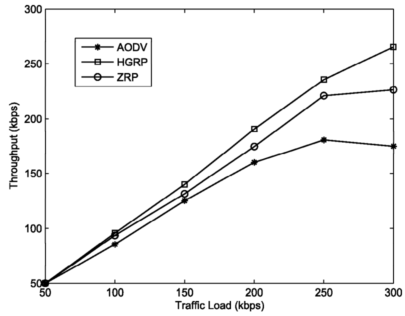

Figure 11. Throughput at different transmission loads

speed of node is $10m/s$. The comparison of throughput is shown in Fig. 11.

When the transmission load is over $250kbit/s$, the throughput of the network using AODV begins to decline. That is, in the case of a heavy transmission load, AODV network has already reached the saturation point because the flooding method of routing in AODV results in a large cost of network routing. So, in a heavy load, the network begins to jam and packets are discarded, which leads to the decline of throughput.

B. The throughput for different network scales

To test the throughput for different network scales of HGRP, we have designed the same framework as for routing cost. The throughputs of HGRP, AODV and ZRP are shown in Fig. 12.

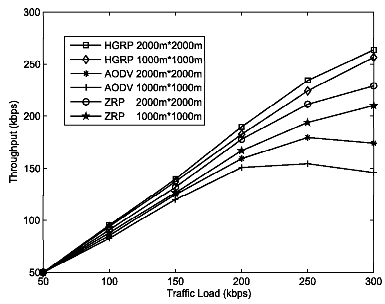

Figure 12. Throughput for different scale networks

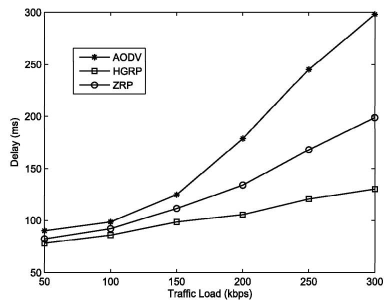

Figure 13. Delay under different transmission loads

The throughput of HGRP is almost the same, indicating that the efficiency of HGRP in large-scale networks is still high. However, performance of AODV at large-scale deteriorated sharply compared with small-scale networks, especially, when the network load exceeds $200bit/s$, the throughput of AODV decreases rapidly.

4.5. The delay

At loads of less than $150kbit/s$, the delays of HGRP, AODV and ZRP are similar. In this case, congestion of network is not serious, packet loss rate is low, the packet delay of HGRP, AODV and ZRP is not large, so they have similar performance. The delays for different transmission loads are shown in Fig. 13.

When the transmission load increases heavily, the delay of AODV and ZRP rises rapidly, showing a lot of congestion and loss of packets in the network. A large number of data packets leads to increasing delay or even packets being discarded. HGRP routing load is much smaller than for AODV, even for a heavy load there is less congestion and acceptable packet loss in HGRP. This is the reason why the delay of HGRP rises slowly when network load increases.

5. Related works

In this section, we discuss in more details some routing approaches proposed recently for mobile ad hoc networks, especially the routing schemes of the hierarchical wireless networks.

Besides the hierarchical routing protocols, a lot of flat routing protocols are proposed, e.g. Perkins et al. (2002) proposed the AODV (Ad Hoc on demand distance vector), Johnson et al. (1998) presented the DSR (Dynamic Source Routing Protocol), and so on. The routing information may be maintained regularly (called proactive or table-driven routing) or computed on-demand (called reactive or on-demand routing) in these protocols.

The hierarchical routing scheme can be classified into two categories: the zone based routing protocols and the cluster based routing protocols. In the zone based routing protocols, the proactive routing approach is used inside routing zones and the reactive routing protocol is used between routing zones. However, they use different methods for zone construction, which has critical effect on their performance. Haas et al. (2002) proposed ZRP (Zone Routing Protocol), in which the network is divided into overlapping zones according to the topology knowledge for neighboring nodes of each node. Nikaein et al. (2001) proposed the HARP (Hybrid Ad Hoc Routing Protocol). The network is dynamically divided into non-overlapping zones. For each node in HARP, the topology knowledge for neighboring nodes is also needed and the zone level stability is used as a QoS parameter to select more stable route. The ZHLS (zone-based hierarchical link state) protocol is proposed by Mario and Lu (1999). The network is geographically divided into non-overlapping zones, and it is assumed that each node has a location system such as GPS and the geographical information is well known. Examples of cluster based routing protocols include CBRP (Cluster Based Routing Protocol) proposed by Jiang et al. (1999), HSR (Hierarchical State Routing) proposed by Iwata et al. (1999) and CGSR (Clusterhead Gateway Switch Routing) proposed by Chiang et al. (1997). Different clustering algorithms have been introduced to group mobile nodes and elect cluster heads in cluster based routing protocols, as proposed by Ma et al. (2008), and Maatta and Braysy (2009). In HSR, hierarchical addressing is used and the network may have a recursive multi-level cluster structure. Moreover, a location management mechanism is used in HSR to map the logical address to the physical address. The CGSR is based on DSDV (proposed by Perkins and Bhagwat, 1994), a proactive routing protocol for mobile ad hoc networks, and every node keeps routing information for other nodes in both the cluster member table and the routing table. In CBRP, every node keeps information about its neighbors and a cluster head maintains information about its members and its neighboring cluster heads. The CBRP exploits the source routing scheme and the addresses of cluster heads along a route are recorded in the data packets.

Cheekiralla and Engels (2007) discussed the routing and MAC issues that arise in a heterogeneous network consisting of omnidirectional and directional antennas. They proposed and evaluated a novel power-controlled multiple expected number of transmissions metric for such heterogeneous networks.

6. Conclusion

In this paper, we propose a hybrid grid routing protocol for heterogeneous hierarchical wireless networks. The heterogeneous wireless networks are composed of nodes with different capabilities and resources. During the communication, these nodes are divided into different layers according to their capabilities. Hybrid Grid Routing Protocol (HGRP) is proposed based on the location knowledge. HGRP divides the network deployment area into cells according to the location. There are a backbone routing node and several ordinary nodes in each cell. The local routing, global routing and routing correction methods of HGRP are presented. The cells restrict the flooding data packages within the cell. Global routing consists of the next hop cell search and distance computation, and restricts the middle cell within a certain range. Our analysis and simulation results indicate that HGRP has the advantages of high efficiency, low routing cost, low energy consumption, low delay and high throughput.

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7. References

Andronache, A., Brust, M.R. and Rothkugel, S. (2006) Multimedia content distribution in hybrid wireless networks using weighted clustering. In: *Proceedings of the 2nd ACM international workshop on WMuNeP 2006*, Torremolinos, Malaga, Spain. ACM Press, 1–10.

Cheekiralla, S. and Engels, D.W. (2007) Routing in Heterogeneous Wireless Ad Hoc Networks. In: *Proceedings of the 16th International Conference on CCN 2007*, Honolulu, Hawaii, USA. IEEE Communications Society, 951–956.

Chiang, C.C., Wu, H.K., Liu, W. and Gerla, M. (1997) Routing in clustered multihop, mobile wireless networks with fading channel. In: *Proceeddings of the IEEE SICON 1997*, Singapore. IEEE Singapore Section, 197–211.

Chou, L.D., Lu, C.C. and Lu, C.Y. (2007) Design of Location Management for Heterogeneous Wireless Networks. **LNCS 4773**, 306–315.

Haas, Z.J., Pearlman, M.R and Samar, P. (2002) The Zone Routing Protocol (ZRP) for Ad Hoc lnternet Draft. *IETF Internet draft*, draft-ietf-manet-zone-zrp-04.txt.

Iwata, A., Chiang, C.C., Pei, G., Gerla, M. and Chen, T.W. (1999) Scalable routing strategies for ad hoc wireless networks. *IEEE Journal on Selected Areas in Communications*, **17**(8), 1369–1379.

Jiang, M., Li, J. and Tay, Y.C. (1999) Cluster Based Routing Protocol (CBRP). *IETF Internet draft*, draft-ietf-manet-cbrp-spec-01.txt.

Johnson, D.B., Maltz, D.A. and Broch, J. (1998) The dynamic source routing protocol for mobile ad hoc networks. *IETF Internet Draft*, draft-ietf-manet-dsr-01.txt.

Jubin, J. and Tornow, J.D. (1987) The DARPA packet radio network protocols. *Proceedings of the IEEE*, **75**(1), 21–32.

Lauer, G.S. (1995) Packet-radio routing, In: *Routing Communications Networks*. Prentice-Hall, Englewood Cliffs, New Jersey.

Lee, K.H., Han, S.B., Suh, H.S., Lee, S.K. and Hwang, C.S. (2005) Authentication based on multilayer clustering in ad hoc networks. *EURASIP Journal on Wireless Communications and Networking*, **2005**(5), 731–742.

Liu, C. and Kaiser, J. (2005) A Survey of Mobile Ad Hoc network Routing Protocols. *University of Ulm Tech. Report Series*. TR-4, 1–36.

Ma, X., Sun, M., Zhao, G. and Liu, X. (2008) An Efficient Path Pruning Algorithm for Geographical Routing in Wireless Networks. *IEEE Transactions on Vehicular Technology*, **57**(4), 2474–2488.

Maatta, J. and Braysy, T. (2009) A novel approach to fair routing in wireless mesh networks. *EURASIP Journal on Wireless Communications and*

Networking, 1–13.

Mario, J.N. and Lu, I.T. (1999) A peer-to-peer zone-based two-level link state routing for mobile ad hoc net-works. *IEEE Journal on Selected Areas in Communications*, **17**(8), 1415–1425.

Nikaein, N., Bonnet, C. and Nikaein, N. (2001) HARP - Hybrid Ad Hoc Routing Protocol. In: *Proceeding of International Symposium on Telecommunications*, Tehran, Iran. EURECOM Institute, 1–8.

Perkins, C.E. and Bhagwat, P. (1994) Highly dynamic destination-sequenced distance-vector routing (DSDV) for mobile computers. In: *Proceeddings of the ACM SIGCOMM 1994*, London, UK. ACM Press, 234–244.

Perkins, C.E., Belding, R.E. and Das, S. (2002) Ad Hoc on demand distance vector (AODV) routing. *IETF Internet draft*, draft-ietf-manet-aodv-10.txt.

Sesay, S., Yang, Z. and He, J. (2004) A Survey on Mobile Ad Hoc Wireless Network. *Information Technology Journal*, **3**(2), 168–175.

Sun, Y. and Royer, E.M. (2003) Application-oriented routing in hybrid wireless networks. In: *Proceedings of the IEEE ICC 2003*, Anchorage, AK, USA. IEEE Communications Society, 1–5.

Tchepnda, C., Moustafa, H. and Labiod, H. (2006) Hybrid Wireless Networks: Applications, Architectures and New Perspectives. In: *Proceeddings of the 3rd Annual IEEE Communications Society on SECON 2006*, Hyatt Regency, Reston, VA, USA. IEEE Communications Society, 848–853.

Vukojevic, B., Goel, N., Kalaichevlan, K., Nayak, A. and Stojmenovic, I. (2008) Depth first search-based and power-aware geo-routing in ad hoc and sensor wireless networks. *International Journal of Autonomous and Adaptive Communications Systems*, **1**(1), 41–54.

Xie, B., Kumar, A., Cavalcanti, D., Agrawal, D.P. and Srinivasan, S. (2005) Mobility and routing management for heterogeneous multi-hop wireless networks. In: *Proceedings of the IEEE International Conference on MASS 2005*, Washington, DC. IEEE Computer Society, 73–80.

Zhang, Y., Yang, L.T., Ma, J., Zheng, J., Zhou, M. and Xiao, S. (2007) Quantitative Analysis of Location Management and QoS in Wireless Mobile Networks. In: *Proceedings of the 21st International Conference on AINA 2007*, Niagara Falls, Canada. IEEE Computer Society, 573–579.