# Heterogeneous Routing Protocol for Group Communication in Wireless Ad Hoc Networks

**Shou-Chih Lo, Jen-Chu Liu, and Wen-Tsuen Chen, *Fellow, IEEE***

***Abstract*--The mobile ad hoc network (MANET) becomes attractive in the areas of emergency relief and military. In a large-scale MANET with low density of nodes, the connection probability between a pair of arbitrary nodes becomes low. The introduction of the wireless overlay networks such as wireless LAN and GPRS into MANET can increase the connection probability. In this paper, we focus on the application of group communication in this kind of heterogeneous wireless networks. Our developed routing techniques can be divided into two parts: IntrA-group Routing Protocol (IARP) and IntEr-group Routing Protocol (IERP). The proposed routing protocol is different from the typical hierarchical ones by two points. First, our considered network environment is a heterogeneous one. Second, the node grouping is based on both the common interest and the geographical proximity. We provide the advantages of low maintenance cost on group clustering and high connectivity among nodes in a large and sparse MANET.**

***Index Terms*--Ad Hoc Network, Wireless LAN, GPRS, Routing Protocol**

## I. Introduction

The mobile ad hoc network (MANET) is a self-organizing and self-configuring multihop wireless network. The rapid and economy deployment in response to communication needs makes the MANET attractive in the areas of emergency relief and military. Node mobility makes the routing in MANET difficult. A variety of routing protocols have been proposed such as AODV [10], DSR [12], ABR [11], Fisheye [9], ZRP [3], LAR [5], etc. A good survey on these routing protocols was presented in [4], where the routing protocols are classified into three categories: flat, hierarchical and geographic position assisted routings.

In the flat routing, the routing information may be maintained regularly (called proactive or table-driven routing) or computed when needed (called reactive or on-demand routing). In the hierarchical routing, the mobile nodes (MN) are clustered into several groups. The routing information is maintained separately within a group and among groups. A typical route can be found in the group-level granularity first and then in the node-level granularity. In the geographic position assisted routing, each mobile node is equipped with the Global Positioning System (GPS). The routing information is computed based on the relative position between source and destination nodes.

In a large-scale MANET with low density of nodes, the connection probability between a pair of arbitrary nodes via the multi-hop path becomes low. The introduction of the cellular network into the MANET can increase the connection probability as studied in [13]. Two nodes out of the transmission range with each other can both attach to base stations nearby and communicate via the cellular network. The incorporation between MANETs and cellular networks, which is sometimes called a hybrid network, can have lots of benefits such as increased data rate, reduced transmission power, enhanced network capacity, better load balancing, and extended coverage area [7][8]. Most research efforts on this hybrid network are from the viewpoint of performance improvement on cellular networks by using the relaying of MANET.

In this paper, we focus on the application of group communication in the MANET overlaid by other wireless network systems. The MNs are classified into several groups based on the commonality of interests or tasks. Suppose there has a higher frequency in the intra-group communication than the inter-group one. This type of applications may be found in the battlefield or the outdoor teaching area where soldiers or students like to talk to each other of the same group. We are concerned about two issues in this application: how to efficiently connect two nodes in the same group and connect two nodes in different groups by using the wireless overlay networks if needed.

Our developed routing techniques can be divided into two parts: IntrA-group Routing Protocol (IARP) and IntEr-group Routing Protocol (IERP). IARP maintains routing information for nodes within the same group. IERP offers route discovery and route maintenance services for nodes within different groups. The proposed routing protocol is different from the typical hierarchical ones like CGSR[1], ZRP [3], HSR[6], and Landmark [2] by two points. First, our considered network environment is a heterogeneous one, where IERP might choose a route via the wireless overlay networks. Second, the MN grouping is based on both the common interest and the geographical proximity. The grouping zone, where the nodes of the same group locate, would be an arbitrary shape as opposed to the circular shape when only the proximity is used. Our proposed routing protocol has the advantages of low maintenance cost on group clustering and high connectivity in a large and sparse MANET.

The reminder of this paper is organized as follows. Section II

This work was supported in part by the Educational Ministry of the Republic of China under Grant No. 89-E-FA04-1-4.

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***ICITA2004 ISBN 0-646-42313-4***

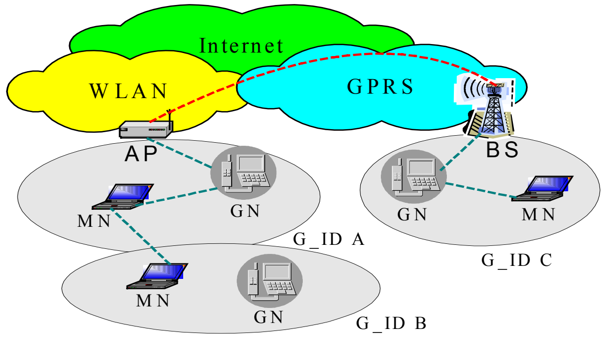


Fig. 1. Heterogeneous networking environment.

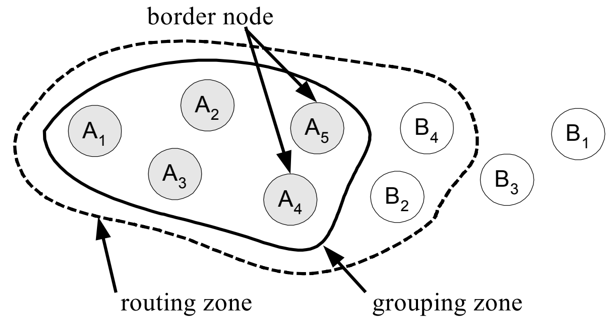


Fig. 2. Definitions of some notations.

describes the network model and data structures used in our developed routing protocol. Section III introduces our proposed heterogeneous routing protocol which contains the details of IARP and IERP. The issues about design and performance are discussed in Section IV. Finally, we present the conclusion in Section V.

## II. Preliminary

### A. Network Model

Our considered network environment includes MANETs with overlay networks of the WLAN (Wireless Local Area Network) and the GPRS (General Packet Radio Service) types. The MNs in this environment have group mobility by following the movement of group heads. The group head is a specific MN which equipped with a variety of wireless networking cards to the Internet. Suppose the group head can properly switch between the WLAN and the GPRS interfaces according to the wireless overlay network available. The group head can be viewed as a gateway to the Internet for other MNs and is called Gateway Node (GN) in the paper. Each group, which has a single active GN, is associated with a unique group identification number (G_ID). Any non-GN MN will join a GN as a group member. A communication scenario example in this kind of environment is shown in Fig. 1.

We define the grouping zone of a group of G_ID $x$ to be the neighborhood of the GN of G_ID $x$ where its member MNs can be reached. Border Nodes (BN) of a group are MNs one of immediate neighbors of which is an MN from another group. The immediate neighbor of a node is a neighboring node one hop away from the node. The routing zone of a group contains the MNs located in the grouping zone of the group and the external immediate neighbors (from other groups) of the BNs in the group. Fig. 2 shows an example for easily understanding these definitions. Nodes $A_1$ to $A_5$ constitute the grouping zone of the group of G_ID A. Nodes $A_4$ and $A_5$ are BNs in this group. The routing zone contains external nodes $B_2$ and $B_4$ from another group in addition to the nodes in the grouping zone.

An MN is called insider node if it is reachable from the GN of the same group. Otherwise, this MN is called outsider node. An outsider node happens when it moves outside the grouping zone due to lack of coordination in the group mobility. To keep connectivity to the outsider nodes, these nodes should re-attach themselves to other groups nearby.

### B. Data Structure

The packet formats of those control packets that will be used are shown in Fig. 3. The field ToP indicates the type of the control packet (hello, neighboring vector, etc.). The hello packet carries the information about a node itself such as IP address, type of the node (ToN) and G_ID. The ToN filed has one of the three values: GN, Insider, and Outsider. The neighboring vector carries the information about the node itself and its immediate neighbors. The member update packet is used to refresh the member list (list of MN's IP addresses) of a GN. The Action field has one of the three values: Add, Delete, and Purge. The overlap update packet contains a list of G_IDs the corresponding groups of which are overlapping with the designated group.

The route request packet can specify a set of intermediate nodes that should be routed to in sequence besides the designation node. The tuple (SN IP,DN IP,Session ID) is used to identify a unique session between nodes SN and DN. The Link field has one of the two values: Int(ernal) and Ext(ernal). Each MN maintains the routing information of on-going sessions using the structure shown in Fig. 4. The fields Previous and Next record the previous hop and the next hop of the corresponding session. The (IN IP, Link) field records the next intermediate node extracted from the route request packet received. The detailed usage of these data formats will be explained in the next session.

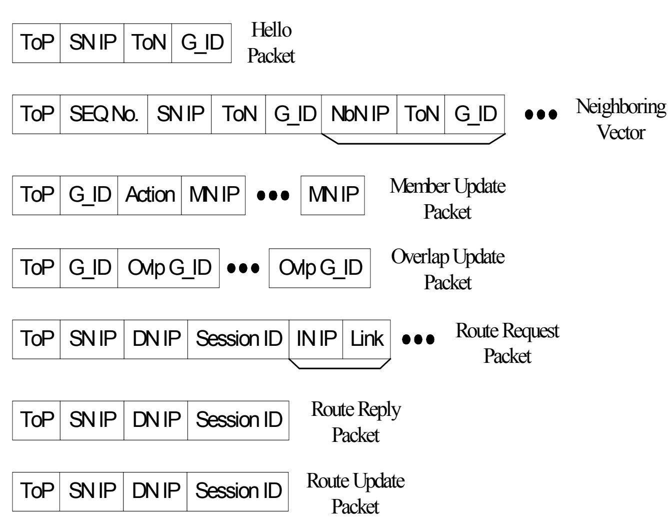


Fig. 3. Internal structure of control packets.

| SN IP | DN IP | Session ID | Previous | Next | (IN IP, Link) |
|---|---|---|---|---|---|

Fig. 4. Fields in the routing table at MN.

## III. Heterogeneous Routing Protocol

### A. Intra-Group Routing Protocol

IARP is a family of group-based proactive routing protocols. The MNs in the same grouping zone will exchange the link state information periodically. The following procedures are involved in neighborhood maintenance:

1. Neighbor Announcement: Each MN periodically broadcasts a hello packet to its immediate neighbors to advertise its information.
2. Neighbor Discovery: Each MN discovers all its immediate neighbors by listening to the up-to-date hello packets. The carried data in the hello packets will be recorded in the link table of this MN which stores the information of its immediate neighbors.
3. Neighbor Propagation: Each MN constructs a neighboring vector based on the link table and broadcasts the vector to all peer members in the same grouping zone. The vector broadcast message can be restricted within the grouping zone if each node only re-broadcasts the vectors coming from the nodes of the same group. The neighbor propagation is performed each time when there have significant changes in the link table.

After the above three phases, each MN can discover the current network connectivity within the routing zone. Moreover, each MN can derive the routing path based on the shortest path to any neighbor in the routing zone. For example, the routing paths from $A_i$ to $A_j$, $A_i$ to $B_2$, and $A_i$ to $B_4$ in Fig. 2 will be available ($1 \le i, j \le 5$).

IARP has the same advantage on efficient route discovery and recovery as the pure proactive routing protocol. This feature facilitates the intra-group communication. However, our group-based IARP suffers from the less control overhead on flooding the link state information (in the neighbor propagation) into the entire network as compared with the pure proactive one. We can limit the maximal size of a group to limit the control overhead on information flooding.

### B. Inter-Group Routing Protocol

IERP is a family of group-based reactive routing protocols. A route discovery for any two arbitrary nodes belonging to different groups is performed by first issuing the route request packet to the GN the source node attaches to. Then the GN computes a routing path to the GN the destination node attaches to according to the situation of group overlapping and the wireless overlay networks available. The routing path from the GN to the destination node is maintained by IARP.

Three procedures are involved in IERP: membership maintenance, route discovery, and route recovery.

#### 1) Membership Maintenance

The group clustering algorithm plays an important role in the hierarchical routing protocol. In the homogeneous network environment, all nodes have the same chance to be a group head. The group head can be dynamically elected based on smallest ID, highest connectivity, or smallest relative mobility [16]. However, the frequent changes of group heads due to node mobility will degrade the performance of the routing protocol. In the heterogeneous network environment we are concerned here, only the GN can be the group head. Each MN should join a GN nearby as a group member and follows the movement of the GN. Members in the same group led by a GN have the same task or interest on communication. An MN remains in the same group if it is reachable from the leading GN. Hence, the group clustering is more stable in the heterogeneous environment than in the homogeneous one.

An MN recognizes itself as an insider node if the leading GN is reachable. Otherwise, this MN is an outsider node. An outsider node can attach to a new group by simply changing its G_ID to that of the node which is one of its immediate neighbors and is an insider node of another group. An outsider node becomes isolated if all its immediate neighbors are outsider nodes. The isolated nodes can form a new group if one of these nodes announces the node itself to be a GN.

In IARP, each GN can discover all its members from the collected routing information. Also, a GN can discover which group is overlapping with it according to the information provided by the BNs. All GNs should exchange the information about membership and group overlapping with each other by issuing the member update and overlap update packets via the wireless overlay networks. The membership data can be updated incrementally by specifying the Action field in the member update packet. As a result, any GN can know the leading GN of a given MN.

#### 2) Route Discovery

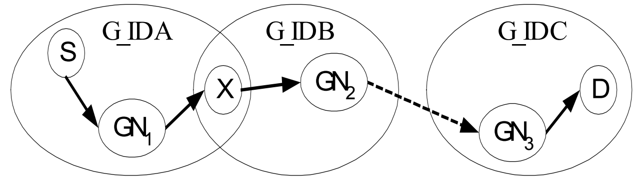


Fig. 5. Example of the route discovery by IERP.

We show the route discovery of IERP by using an example in Fig. 5. Suppose we have three groups (A, B, and C) with GNs 1, 2, and 3, respectively. First, node S sends a route request packet containing the data {(S,D), ($GN_1$,Int)} to node $GN_1$ which is the GN of the currently attached group. The tuple (S,D) is simply used to identify the session. The tuple ($GN_1$,Int) indicates that the next intermediate node the route request packet should be sent to is node $GN_1$. The state Int indicates that an internal path should be used. The external path through the wireless overlay network is indicated by the state Ext. The nodes between S and $GN_1$ will forward this route request packet to node $GN_1$ based on IARP.

After receiving the route request packet, node $GN_1$ starts computing a route to node D based on the membership and group overlapping information collected. Node $GN_1$ decides to

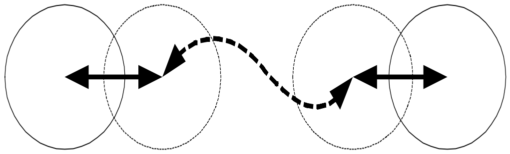


Fig. 6. One extreme case of routing among groups.

send the route request packet to node $GN_2$ of group B by an internal path and then to node $GN_3$ of group C by an external path. According to the routing information of the routing zone of group A, node $GN_1$ discovers that the nearest node to group B is node X. Node X is one of the nodes locating in the overlapping area of groups A and B. Therefore, node $GN_1$ updates the route request packet to {(S,D), (X,Int), ($GN_2$,Int), ($GN_3$,Ext)}. The route request packet is forwarded from node $GN_1$ to node X through the path discovered by IARP.

After node X receives the route request packet, it updates the packet to {(S,D), ($GN_2$,Int), ($GN_3$,Ext)}. Then, the route request packet is forwarded to node $GN_2$ using the routing information of this routing zone. Node $GN_2$ updates the route request packet to {(S,D), ($GN_3$,Ext)} and tunnels the route request packet to node $GN_3$ through the wireless overlay network. Finally, node $GN_3$ decapsulates such tunneled packet and forwards the route request packet to node D. Node D sends a route reply packet along the reversed route selected.

When the route request packet is delivered toward the destination node, the related routing information is maintained in the routing table of each node along the path. For example, the corresponding previous and next hops will be recorded to allow transmission forward and backward. The (IN IP, Link) fields of the routing tables at nodes S, $GN_1$, X, $GN_2$, and $GN_3$ would be ($GN_1$, Int), (X, Int), ($GN_2$, Int), ($GN_3$, Ext), and (D, Int), respectively. This information will be used in the route recovery as introduced latter.

The routing path among groups is decided by a simple criterion that there are at most four groups being involved in the routing. That is, we extend the routing path by first using the overlapping groups and then using the wireless overlay networks. One typical case of the routing using this criterion is shown in Fig. 6. We extend the routing paths at the two end nodes (source and destination nodes) by using the overlapping groups (solid line in the figure). Then the paths are connected using the wireless overly network (dotted line in the figure).

Using the overlapping groups can reduce the burden of GNs on the transmissions over the wireless overlay networks with possibly limited bandwidths. However, a long multi-hop path through several overlapping groups may cause performance degradation if the underlying medium access control (MAC) protocol is a contention-based one like IEEE 802.11 [17]. A more complex routing approach by considering the issues of load balance and quality-of-service (QoS) will be designed in the future.

### 3) *Route Recovery*

The routing path discovered may become failed after a certain period of time due to node mobility. We perform the route recovery procedure from the path errors by using a scheme similar to the source-initiated one. In the source-initiated scheme, the source node initiates the rerouting process to discover an alternative rout to the destination when triggered by other nodes. This scheme has the benefit of easy control, but the overhead may be high especially when only parts of the routing path are error. However, in our routing approach which combines both IARP and IERP can suffer less overhead than what we discussed before when something error occurs in the path.

The path errors can be classified into local and global ones. Take Fig. 5 as an example. In the local errors, the main intermediate nodes in the routing path (i.e., $GN_1$, $GN_2$, $GN_3$, X, and D) remain unchanged. This kind of errors can be recovered directly by using IARP, since IARP refreshes the new routing information automatically. In the global errors, some of the intermediate nodes become unreachable. The recovery procedure may be triggered by nodes S, $GN_1$, $GN_2$, $GN_3$, or X if one of these nodes found that the next intermediate node recorded in the (IN IP, LINK) filed of the routing table becomes unreachable. For example, S to $GN_1$, $GN_1$ to X, and X to $GN_2$, etc.

In the global errors, we explain the recovery procedure under three cases separately. The first case is when the source node S detects the global error (i.e., $GN_1$ is unreachable). Node S performs the route recovery procedure by initiating a new route discovery. The second case is when a GN in the routing path detects the global error (e.g., $GN_3$ found that D is unreachable). The GN sends a route update packet to the GN the source node currently attached to (say $GN_1$) via the wireless overlay network. If the GN the source node attached to has a record in the routing table which has the same identifier (SN IP,DN IP,Session ID) as the route update packet received, the GN (say $GN_1$) performs the route recovery procedure by re-computing a routing path to the destination node. The identifier checking is to conform that the source node is in the same group with the GN. If the source node has attached to a new group, the old attached GN will ignore any route update packet with respect to the source node.

If a GN receives multiple route update packets within a short time period, the recovery procedure will be initiated once only. Receiving of multiple route update packets happens as a result of concurrent movements of intermediate nodes. The last case is when a BN detects the global error (e.g., X found that $GN_2$ is unreachable). The BN sends a route update packet to the nearest GN (say $GN_1$) along the upstream nodes. A GN performs the same recovery procedure when detecting the global error or receiving a route update packet from a BN.

## IV. Implementation Issue and Performance Evaluation

In the implementation of our proposed routing protocol, we have the following configuration on mobile devices. Each non-GN MN equips with one WLAN card configured as the ad hoc mode. Each GN equips with three wireless networking cards: one GPRS card, two WLAN cards configured as the infrastructure mode and the ad hoc mode, respectively. The

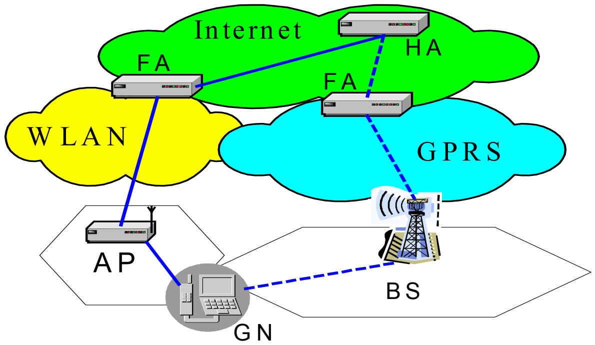


Fig. 7. Switching between WLAN and GPRS.

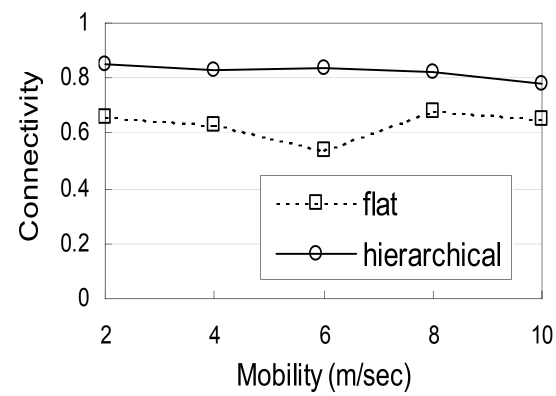
pure ad hoc communication is through the WLAN card configured as the ad hoc mode. The other types of networking cards are used to access to the Internet.

Since a GN can dynamically switch between GPRS and WLAN interfaces to the Internet, we use the Mobile IP [15] to support this function. As shown in Fig. 7, each GN is associated with a *Home Agent* (HA) in the Internet. The *Foreign Agent* (FA) in each serving area (usually a cell) of wireless overlay network will periodically broadcast the agent advertisement to advertise its present. The GN can detect what type of the wireless overlay network is available by listening to the agent advertisement. When the GN wishes to switch to a different wireless overlay network, it sends a registration update request to the corresponding FA. Then the FA forwards this request to the HA. The HA will intercept any packet destined to the GN and tunnels the packet to the FA the GN registered. The FA then decapsulates such tunneled packet and forwards it to the GN. To facilitate the propagation of membership related data among GNs, we can establish a multicast tree rooted at per GN to other GNs. We need a centralized server on the Internet to coordinate the join and leave of any GN in the multicast tree.

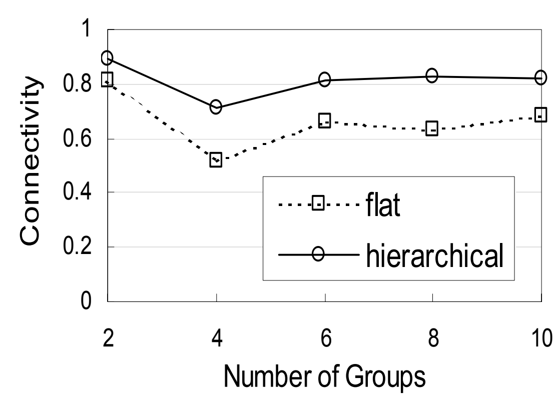
Our protocol evaluations are based on the simulation of 50 MNs forming the MANET, moving about over a square field (1500m×1500m) for 5000 seconds of simulation time. The MNs (including the GNs) are assumed to have constant radio range of 150m. The node mobility is based on the reference point group mobility model [2] in a square field. An MN randomly picks a destination within the grouping scope (150m×150m) of the attached GN and moves towards that destination at a fixed speed. Once the MN reaches the destination, it picks another destination randomly after a pause time of 10 seconds. The GN follows the similar move-pause model but within the whole field.

We study the connection probability between a pair of arbitrary nodes based on the flat and the hierarchical routing approaches. In the hierarchical one, the GNs are assumed to always connect to the Internet via the wireless overlay network. In the simulation period, 100 randomly chosen connection pairs are generated. In Fig. 8a, we found that the hierarchical one has higher connection probabilities than the flat one under different mobility speeds and fixed 5 groups. In Fig. 8b, we found the similar result under different number of groups and the constant speed with 6 m/sec. Moreover, the gap between the connection probabilities becomes large when the number of groups is large. The reason is that the probability of inter-group communication becomes large.

We compare our proposed protocol with other ones like CGSR [1], ZRP [3], Landmark [2], and HSR [6]. Each node should maintain the member table in CGSR, while only the GN maintains the member table in our protocol. We have the similar group-head-to-gateway routing approach to CGSR with one exception of the gateway-to-gateway route over the wireless overlay network. In Landmark and HSR, groups are constructed into a hierarchical architecture. The hierarchical IP address is used to locate the MN. However, the dynamic changing of the IP address due to node mobility makes the application limited. In ZRP, a logical group is formed by centering at each node. The routing zone includes the neighboring nodes of k-hop away from the center node. Therefore, two nodes with common interest locate in the same group using our grouping algorithm may locate in different groups in ZRP. The reason is that only the geographical proximity is considered in ZRP. Moreover, IERP using in ZRP is based on the bordercast Resolution Protocol (BRP). BRP can be viewed as a limited flood-based protocol to find the group the destination node locates in. However, we exchange the member information through the wireless overlay network to facilitate the group finding of the destination node.



(a)



(b)

Fig. 8. Connection probability.

## V. Conclusion

In this paper, we consider the application of group communication in wireless networks. Members within the same group can communicate with each other using the packet relaying of the MANET. However, in a large field, groups may be separated far away from each other. In this situation, the communication between groups is broken. Here, we use the wireless overlay network like GPRS with large radio coverage area to be the communicating bridge between groups. Our work focuses on the decision of an appropriate routing path between a pair of arbitrary nodes in the MANET environment overlaid by other wireless network systems.

The proposed routing protocol can be viewed as a hierarchical one and can function in a heterogeneous wireless network. The mobile nodes are first clustered into several groups. Each group is led by a specific mobile node which has the capability of accessing the Internet via the wireless overlay network. We develop our routing protocol by dividing the communications into intra-group and inter-group ones. We maintain the group clustering in a low cost and provide efficient route discovery and route recovery procedures within the same group and among different groups. In the future, a QoS capable routing protocol will be developed to meet the different needs of resource for users.

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