Proximity-Based Overlay Routing for Service Discovery in Mobile Ad Hoc Networks*

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Abstract. We propose a proximity-based overlay routing algorithm for accelerating the service discovery using the distributed hash table (DHT)-based peer-to-peer (P2P) overlay in mobile ad hoc networks (MANET). DHT systems are useful for resource restrained MANET devices due to the relatively low communication overhead. However, the overlay routing for service discovery is very inefficient, since overlay structure is independent of physical network topology. Our proximity-based overlay routing utilizes the wireless characteristics of MANETs. The physically closer node to destination is preferred to the logical neighbors, using information collected by 1-hop broadcast between a node and its physical neighbors. More enhancement is achieved by the shortcut generated from the service description duplication. In a detailed ns-2 simulation study, we show that the proposed scheme achieves approximately shortest physical path without additional communication overhead, and also find that it works well in the mobile environment.

1 Introduction

Mobile ad hoc network (MANET) is a network of self-organized wireless mobile hosts, which is formed without help of the fixed infrastructure. Service discovery protocol (SDP) enables services (which may be network devices, applications or resources) to advertise themselves, and clients to issue queries and discover appropriate services needed to properly complete specified tasks. SDP is an important and challengeable component in the application layer for ad hoc communication and collaboration, because the MANET does not assume any centralized or publicly known fixed server, and the network topology incessantly varies during the lifetime. SDP for MANETs are usually based on the network-wide broadcasting and matching algorithms, and some improving mechanisms, such

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as caching and grouping, have been developed because the broadcasting cost is very high when the size of network gets larger.

On the other hand, peer-to-peer (P2P) overlay networks, which have been proposed for the mutual information exchange among Internet users, are very similar to the MANET in the nature of self-organized and distributed networks. Early stage P2P protocols were based on the all-to-all broadcasting like SDPs in MANETs, but they suffered from the data redundancy, large amount of traffic, and so on. Now, the structured approach using distributed hash table (DHT) is gaining the popularity in the research community, and the P2P strategy has been being accepted as a novel technique for distributed resource management. We consider the structured P2P protocols as a good candidate for the SDP for MANETs to alleviate the redundancy and performance degradation.

On applying the DHT-based system to the MANETs, there are some difficulties caused by MANET's dynamic property, resource restraints, and wireless characteristics. Of those problems, we focus on the routing inefficiency of service query and retrieval process. The DHT overlay structure and its routing algorithm don't take the physical topology into account at all, so the shortest logical path may be a longest physical path. Some topology-aware DHT routing algorithms [1] have been proposed, but they are not applicable for MANETs because they usually exploit the fixed Internet topology information.

In this paper, we propose an overlay routing scheme on the DHT-based overlay in MANETs to reduce the length of physical routing path using the dynamic feature and wireless characteristics.

2 Related Work

Service discovery protocols for distributed environments have been mainly designed for the static networks including Internet, and they usually adopted the centralized directory-based approach as shown from SLP (Service Location Protocol), UDDI (Universal Description, Discovery & Integration), and Jini. In MANETs, every node including server nodes and directory nodes has possibility to change its location and the state, so the assumption for the designated centralized component is not appropriate or reasonable.

The simplest approach for the distributed service discovery is flooding-based algorithm, such as SSDP (Simple Service Discovery Protocol) of UPnP (Universal Plug and Play) and JXTA. Every node advertises its own services to all other nodes periodically (push model), or every query message floods into the network whenever a service is requested (pull model). The push model suffers from the requirement for large storage and outdated advertisements, and the pull model has to pay for the excessive communication overhead. These drawbacks are more problematic in MANETs because devices in MANETs usually have the limitations in the storage, computing and communication capability, and power capacity.

Some works have been proposed to reduce the storage or communication overhead by compromising the pull and push model. One approach is caching and the other is grouping. In caching approaches [2,3], some intermediate nodes satisfying specific conditions store the service advertisements in their storage. The request message outside the range arrives at a cache node, the service description can be returned to the requester without reaching the service providers. Lanes [4] follows the grouping approach under the assumption of IPv6 addressing. A group of nodes forms a Lane, and the members of a lane share their service descriptions and have the same anycast address. Search message floods from a Lane to another Lane by anycasting. GSD [5] is another grouping method using ontology information of service description.

On the other hand, P2P networking mechanism, which has been developed for the mutual information exchange among Internet users, is emerging as a MANET SDP or resource sharing method because it is very similar to the MANET in the nature of self-organized, distributed, and ever-changing topology. Early stage P2P protocols based on the directory server approach (e.g. Napster) or all-to-all broadcasting (e.g. Gnutella) also have the resemblance and the same problems with the SDPs for MANET.

The DHT-based P2P system constructs an application level overlay network on top of the physical network. Each resource or service is associated with a key, and each DHT node is responsible for a certain range of keys (zone). The basic function of DHT is efficient key lookups, thus to route the query to the node that stores the corresponding resource of a key. This involves the construction and maintenance of topology among peers, routing in the overlay network. Several topologies such as ring (e.g. Chord), hypercube (e.g. CAN), and tree (e.g. Pastry, Tapestry) and the overlay routing algorithm based on each topology were proposed. Most of them maintain the information of $O(\log N)$ neighbors and logical route length of $O(\log N)$ hops for N participating peers. Participating nodes periodically exchange control messages with the neighbors and keep the overlay routing table up-to-date. When a node joins or departs the overlay network, some special process should be performed to maintain the structure in order to support full virtual key space. A query message travels the route established on the logical structure, though each overlay hop may consist of a number of hops in underlying IP network.

There have been some previous attempts to use DHT-based overlay for resource sharing in MANETs [4,7,8,9], paying attention to the similarities of two networks - both are self-organizing and decentralized. [7] proposed an integrated architecture for P2P and mobile applications, and investigated the expected challenges. They pointed out the logical versus physical routing is a critical issue in the integration. In [4] and [8], the cost for maintaining the strict overlay structure is said as the biggest obstacle, because of highly dynamic feature and resource limited devices. [4] weakened the condition of overlay structure, and [8] proposed an on-demand structuring and routing. [9] proposed an IP layer routing protocol integrating a representative MANET routing algorithm DSR and an application layer P2P protocol, Pastry.

3 Proximity-Based Overlay Routing

Distributed service trading process in MANETs consists of service advertisement and discovery. Each node advertises its own services to be shared to the other nodes by sending messages with service descriptions, and the client nodes flow service request messages into the network. The nodes that own the matching service or store the advertised service descriptions reply with the requested service descriptions, so that the client node can access the server node.

In DHT-based P2P overlay networks, the basic functions are *join*, *leave*, *insert*, *update*, and *lookup* as described in Sec. 2. Our DHT-based service discovery follows the same process and rules as the given overlay structure except a few differences. Main resource to be shared is not service itself, but service description (SD). Each SD generates a key by hashing, and each node stores and maintains the (key, SD) pairs as well as the overlay routing table. *Service advertisement* is performed by the insertion of (key, SD) to the node that takes charge of a zone. Participating nodes exchange routing information periodically, and keep the routing table updated just as the way of overlay maintenance. When a service is requested, the overlay routing table is referred and the requesting message travels along the route constructed from the overlay routing table. *Service discovery* is performed by the lookup process on the overlay.

The logical overlay routing does not consider the physical topology at all, so unnecessarily longer paths often introduce the inefficiency and waste of limited resource of MANET devices. We propose a scheme to shorten the route utilizing the wireless characteristics of MANETs.

In the wired networks, only a part of nodes joins in the P2P overlay networks and the overlay construction and routing are performed among the participating peers only, while the underlying IP networking enables the real communication. However, every node which dwells in a MANET takes part in the overlay network, we assume, because each node in a MANET functions as a router as well as a working peer. Service description language and the hashing mechanism are not described because they are beyond the scope of this paper.

3.1 Consult Physical Neighbors

The first modification of overlay routing uses information from physical neighbors. The wireless devices in MANETs have limited radio range, so only the devices within the transmission range can hear the messages. Before forwarding a service discovery request message, a node sends a request for neighbor information to its own physical neighbors by 1-hop broadcast. The neighbors look up their routing table, compute the logical distance between the destination and each entry in the routing table, and reply with the information on the closest node and the distance. If one of the neighbors is responsible for the requested key, then it replies with its own address and the distance 0. The requester collects the replies for certain period, and selects the node that declares the shortest distance. That is, each node considers the physical neighbors' routing information prior to its own logical neighbors, so increases the possibility of choosing the physically shorter routes. We call this scheme as **CPN** (Consult Physical Neighbors).

Figure 1 shows a very simple example. The distance is computed based on the structure of key space, and a threshold is set to prevent too many replies in the case that the node density is high. In this example, the threshold value is 0.2. Though node `B` and `E` send the same response, `E` is chosen because the packet from `E` contains `E` as a source address. If the CPN is not used, the physical path length is 3 (`A` → `B` → `A` → `E`).

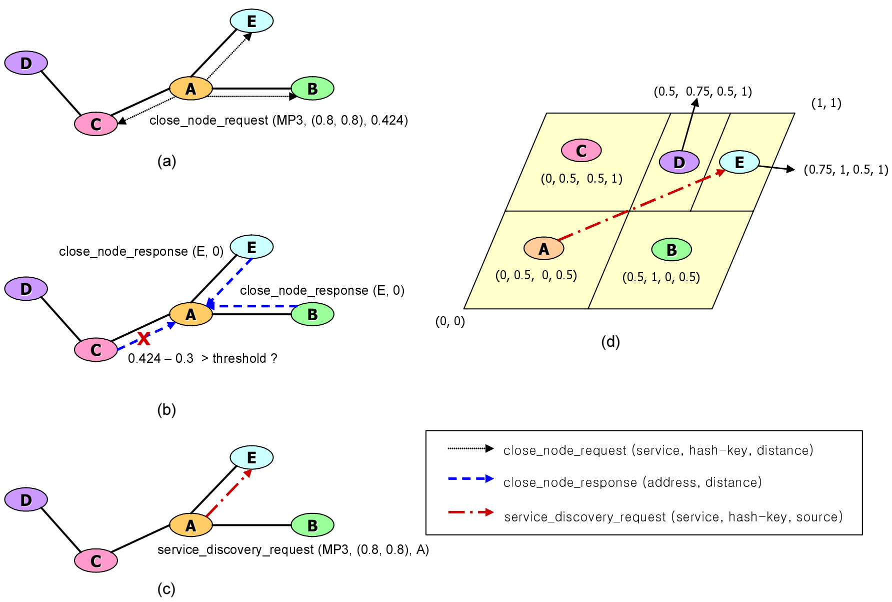

Fig. 1. Use of physical neighbors' routing information

3.2 Use Duplicated Description

The second modification utilizes the fact that the service descriptions are duplicated and stored in the node in charge of the key zone as well as the service provider. In addition to the advertised (key, SD) pairs (*Ad_SD_table*), each node maintains the (key, SD) directory of its own services (*My_SD_table*). When a SD request message arrives, the node looks up the *My_SD_table* first. So, the requester can be replied by the physically closer SD of the duplicated ones (see Fig. 2). We call this scheme as **UDD** (Use Duplicated Description). UDD can be used with the usual overlay routing, but more effective with CPN. In usual overlay structure of N nodes, the possibility to meet the service provider on the route to the designated key space is $1/N'$, where N' is $N-$(number of predecessors). In CPN routing, all physical neighbors are checked before forwarding so the possibility goes up to k/N'', where N'' is $N-$(total number of predecessors and their neighbors) and k is the number of current neighbors. The higher node density gives the higher possibility.

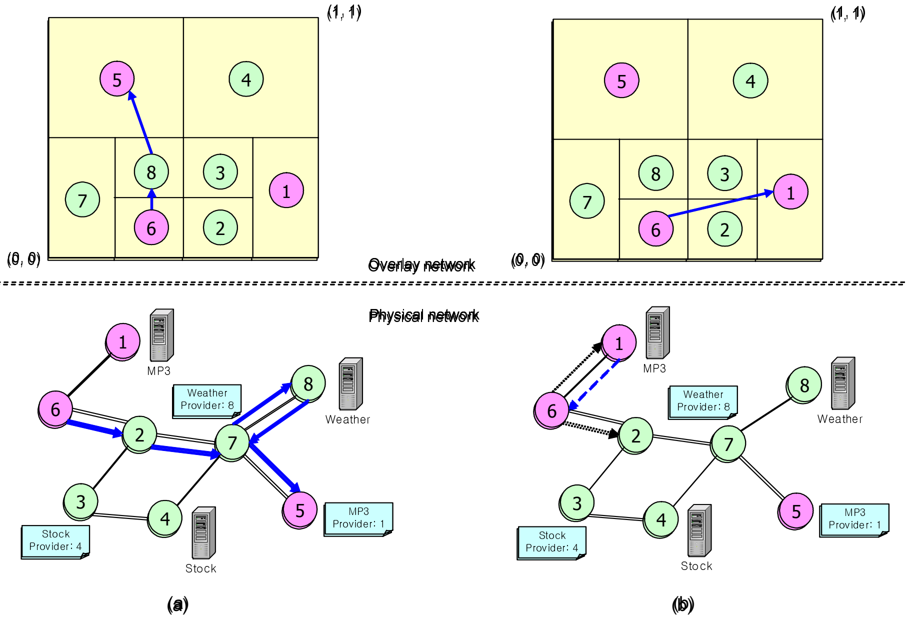

Fig. 2. Shortcut to physically close service descriptions

Integrating both acceleration methods, each node performs following algorithms as a sender or a receiver.

```
void retrieveService (char *serviceRequest) {
  ...
  key = makeKey(serviceRequest);
  if (zone.IsContain(key) || lookupMyService(serviceRequest)) {
     retrievalSuccess();
  } else if (neighbor = zone.isNeighborContain(key) >= 0) {
      forwardTo(neighbor, msg);
  } else {
      logicalDistance = zone.distance(key);
      sendCloseNodeRequest(serviceRequest, key, logicalDistance);
      setBroadcastTimer();
  }
  ...
}
```

```
void broadcastTimerExpire(Event *) {
  ...
  closest = selectCloseNode();
  forwardTo(closest, msg);
  ...
}

void recMsg(int size, char *msg) {
  ...
  switch(msgType) {
    case SERVICE_RETRIEVAL_REQUEST:
      if (zone.isContain(key) || lookupMyService(serviceRequest) {
         sendRetrievalResponse (serviceRequest, serviceDescription);
      } else if (neighbor = zone.isNeighborContain(key) >= 0) {
           forwardTo (neighbor, msg);
      } else {
           sendCloseNodeRequest (serviceRequest, key, logicalDistance);
      }
      break;
    case SERVICE_NODE_REQUEST:
      if (lookupMyService (serviceRequest)) {
         sendRetrievalResponse (serviceRequest, serviceDescription);
      } else if (neighbor = zone.isNeighborContain (key) >= 0) {
           sendCloseNodeReponse (serviceRequest, neighbor, 0);
      } else {
          myDistance = zone.distance (key);
          if (myDistance < msg->logicalDistance - threshold)
             sendCloseNodeResponse (serviceRequest, address, myDistance);
      }
      break;
    case CLOSE_NODE_RESPONSE:
      addReply (msg);
      break;
      ...
}
```

4 Simulation Results and Discussion

We implemented the prototype of our scheme based on the IEEE 802.11 MAC and AODV [10] routing protocol in the ns-2 simulator with the CMU wireless extension. Two-dimensional CAN [6] was chosen as the basic construction algorithm for peer-to-peer structure. In DHT-based P2P overlay, periodical exchange of routing information is essential for the structure maintenance, but it is a large burden for limited communication capacity of MANET wireless channel. Whereas most of DHT structures maintain $O(\log n)$ neighbors, d-dimensional CAN requires only $2d$ neighbors. For implementation simplification and efficiency, we chose 2-dimensional CAN.

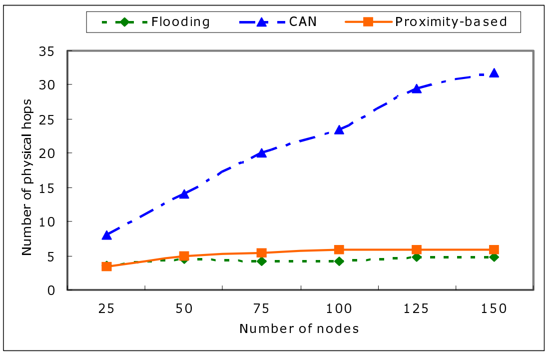

Fig. 3. Route length with respect to the number of nodes

For comparison, we also implemented the basic flooding approach and the original CAN algorithm which doesn't use proximity-based acceleration in the retrieval. The transmission range of each node is 250m, and the channel bit rate is 2 Mbps. The simulation area of 1500m x 1500m is used, and the number of nodes varies from 25 to 150 increased by 25, which are randomly placed in the area. In the initial stage, every node configures a MANET and an overlay, and 50% of nodes registers 3 services with 60 second interval. During the total simulation time of 20000 seconds, they periodically reregister their services and 30% of nodes discovers randomly selected 10 services in every 50 seconds.

Figure 3 shows the route length of service discovery. The more nodes join the network, the longer routes are needed in the original CAN algorithm, because the request message flows according to only the logical structure. In the case of flooding, a request message reaches all other nodes, so the shortest route was established between the requester and the service provider. Our algorithm achieves the similar route length with the flooding because the physically close node is chosen first and the logical structure is inspected next.

We estimated the communication overhead by counting the number of messages. Fig. 4(a) shows the number of received messages by all nodes, and (b) the number of sent messages from all nodes. As the number of nodes increases, the number of messages in the flooding scheme increases in geometrical order. Structured schemes show the superiority in reducing the number of messages. The interesting point is that the number of messages of our algorithm is not more than that of original CAN in spite of the 1-hop broadcast overhead. The reduced route length also reduces the total number of messages, so our algorithm can achieve the shorter routes without excessive communication overhead.

Figure 5 depicts the probability of meeting the service owner in the middle of routing. As we predicted, our UDD scheme raises the probability as the number of nodes increases.

The next result shows the effect on the route length in the mobile environment, for 100 nodes. Random waypoint mobility model is used with the maxi-

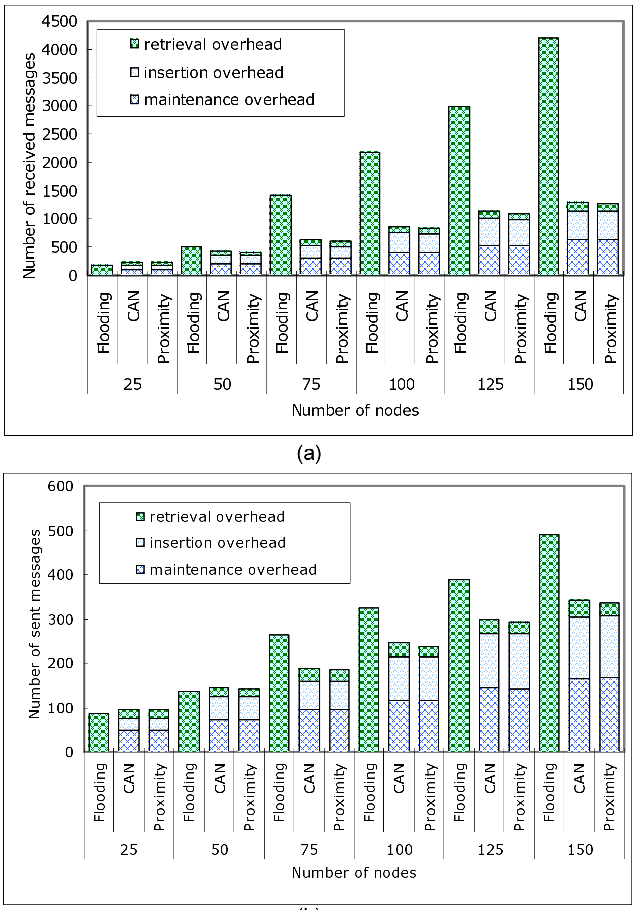

Fig. 4. Communication overhead

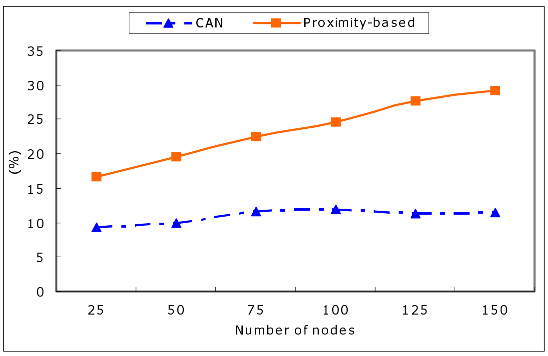

Fig. 5. Probability of meeting service provider in the mid of routing

mum speed of 40 m/s, and the maximum pause time varies from 0 to 40 seconds. Regardless of the degree of mobility, all 3 schemes show the similar result with that of the static network. The number of messages doesn't show any difference either because the messages for maintenance are counted for only logical structure, but the underlying IP routing messages increased due to the node mobility.

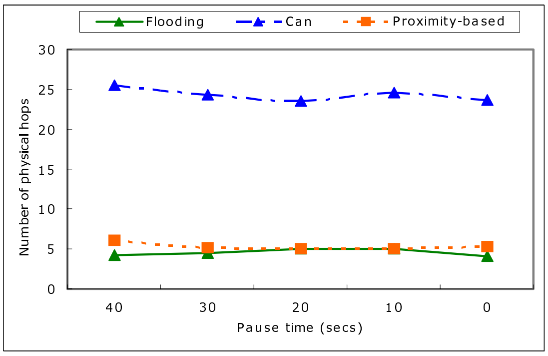

Fig. 6. Route length in the mobile environment

5 Conclusion

We proposed a scheme for accelerating the service discovery based on the DHT-based P2P overlay network in MANETs. Using the physical neighbor information which can be easily obtained in MANETs, the proposed algorithm could achieve the significant performance gain in terms of the routing distance. The overhead due to the 1-hop broadcast messages could be offset by the decreased number of hops. Our algorithm was implemented and evaluated with the CAN overlay network, and also applicable for other DHT-based P2P overlay structures.

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