# TOWARDS MIDDLEWARE SUPPORT FOR PERVASIVE COMPUTING

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Abstract: Mobile ad hoc networks (manets) are dynamically reconfigurable multi-hop wireless networks with no fixed infrastructure, consisting of radio-equipped mobile hosts. Each host acts as a router and moves in an arbitrary manner. Under such a network environment routing becomes a challenging task that can be significantly supported and facilitated by the exploitation of location information, as this paper argues. More specifically, after a brief introduction to routing in manets, a location discovery algorithm is proposed. Then, the paper focuses on location-aware routing and after presenting briefly the most important related protocols attempts to compare them based on a number of qualitative properties. Finally, the emergence of location aware services is discussed, a service discovery scenario based on Jini technology is proposed and important related deployment challenges are highlighted.

## 1 INTRODUCTION

Mobile communication and wireless networking attract an increasing interest due to recent improvements in microprocessor and radio technologies, and are becoming more and more popular as they eliminate the disadvantage of having the user restricted in a particular location. Wireless systems constitute a mature solution that can be deployed easily, decreasing the overall cost and extending the working environment to a global one, utilising different wireless access technologies, interworking with each other transparently.

In most mobile communication environments there are base stations, which directly keep track of the mobile hosts. Although two mobile hosts are in a transmitting range of each other, they must communicate with each other by some base station. However, under some circumstances (e.g., due to low cost effect, poor performance or low usage), the mobility support offered by base stations is not available. In this environment the mobile hosts must form an ad hoc network.

Broadly defined a mobile ad hoc network (manet) is temporarily formed by a group of autonomous wireless nodes / hosts that communicate with each other over wireless channels and cooperatively form a network that operate without the support of any fixed network infrastructure and centralized administration (Mauve, 2001).

Routing in manets affects directly the efficiency of the network and is more challenging than in traditional networks because of the dynamic character of the network topology. In the last few years, a large number of routing protocols have been proposed for manets (Royer, 2004). Two different routing approaches can be distinguished: topology-based and position-based (or location-aware) routing. For this reason, this paper after discussing important matters related to the enabling of location awareness, examines the exploitation of location information in manets, including ways that this information can assist manet routing and methods for providing and supporting location-aware services.

## 2 ENABLING LOCATION AWARENESS

A widely accepted theoretical model for manets is the unit graph model, which represents the mobile hosts of the manet spread out in some environment by a set of points in the Euclidean plane. According to this model two nodes A and B in the network are neighbors (and thus joined by an edge) if the



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distance between them is at most R, where R is the transmission radius which is equal for all nodes in the network and specifies the maximum (Euclidean) distance between two mobile hosts at which they are able to directly communicate (Stojmenovic, 2004).

The use of the nodes' position for routing purposes in a manet represented as a unit graph, assumes that each node is aware of its own position (its x- and y- coordinates) in the plane. The distance between neighboring nodes can be estimated on the basis of incoming signal strengths or time delays in direct communications. Relative coordinates of neighboring nodes can be obtained by exchanging such information between neighbors (Capkun, 2005). Alternatively, the location of nodes may be available directly by communicating with a satellite, using GPS (Global Positioning System), if nodes are equipped with a small low power GPS receiver.

Independent of the exact positioning technology used location-aware routing protocols make forwarding decisions based on the geographical position of a packet's destination. Therefore, the main prerequisite for location-aware routing is that a sender can obtain the current position of the destination, assuming that it already knows its own position. In order to satisfy this need a location discovery algorithm is proposed, which can be used as is in simple routing scenarios or adjusted and in an integrated manner in the framework of various position-based packet forwarding strategies and location-aware routing protocols (Mauve, 2001).

It is assumed that the geographical area of a manet is divided into rectangular regions, as can be seen in Figure 2. All of these regions have well-defined IDs that are concatenations of the x and y coordinates of the bottom-left and upper-right corners. Furthermore, all nodes have a unique ID (such as an IP address). Next, it is assumed that there exists a static mapping f that maps a node's ID into a specific region (called its home region):

$$f(\text{Node ID}) \rightarrow \text{Region ID}$$

The function f represents a many-to-one mapping that is static and known to all nodes of the manet. It is necessary to satisfy the following properties:

- Every region should have the same node density in order to evenly distribute the queries throughout the manet.
- The entry or the departure of nodes from the manet should be transparent to f.
- The shape or size of the geographical area covered by the manet should not affect f.

Under these conditions the proposed location discovery algorithm, which is executed by every node in a manet, can be represented using pseudocode in the following way:

```
LocationDiscoveryAlgorithm
{
  if (the current node wants to move) then
  {
    Move the Current Node (CN);
    if (the CN moves out of its current
        region) then
    {
      Use function f to find the home
      region of the CN;
      Broadcast a location update message to
      all nodes in the home region of the CN;
      Inform all nodes in the home region of
      the CN about the new location of the CN
      - its new region;
    }
  }
  if (the CN wants to send a packet to
      another node) then
  { // determine the current location of the
    // recipient node
    Use function f to find the home region of
    the recipient node;
    Send a message to this region enquiring
    about the current location of the
    recipient node;
    Wait for the desired respond;
    Send the packet to the target node
     (e.g. using a location-aware routing
    protocol);
  }
}
```

A function f that can be used together with the proposed location discovery algorithm and satisfies all the necessary criteria is:

$$f(ID) = g(ID) \bmod k,$$

where $g(ID) \rightarrow [0, \ldots, N]$ is a random number generating function that uses the node ID as a seed and outputs a random number. The number of home regions that are present in the manet is denoted by k.

## 3 LOCATION-AWARE ROUTING

In a manet each node communicates directly with nodes within wireless range and indirectly with all other destinations using a dynamically determined multi-hop path via other nodes in the network. In this multi-hop scenario several hosts may need to relay a packet before it reaches its final destination. Therefore, the task of finding and maintaining routes in manets in order to send a message from a source node to a destination node is nontrivial because of the constantly and dynamically changing topology of the network triggered by node mobility.

One prospective approach to assist routing in a manet leverages the data available from location information. Since it is not necessary to establish or maintain explicit routes, the nodes have neither to store routing tables nor to transmit messages to keep routing tables up to date, and thus location-aware routing does scale well even if the network is highly dynamic. This is a major advantage in a manet where the topology may change frequently.

The location information that mobile hosts in manets provide can exploit the geometric relationship among those hosts optimising significantly the routing process. The most important manet routing protocols that feature location awareness are the following (Mauve, 2001)(Tseng, 2001): Location-Aided Routing (LAR), Distance Routing Effect Algorithm for Mobility (DREAM), Geographic Distance Routing (Gedir), Grid and Zone-based two-level routing.

Table 1: Comparison of location-aware routing protocols.

| Protocol Name | Path Strategy | Loop Freedom | Performance Metrics | Memory |
|---|---|---|---|---|
| LAR | Flooding | No | Hop count | Yes |
| Gedir | Single path | No | Hop count | No |
| Grid | Single path | Yes | Hop count | Yes |
| Zone-based 2-level | Single path | Yes | Hop count | No |
| DREAM | Flooding | No | Hop count | Yes |
| Power aware | Single path | Yes | Power | No |
| Cost aware | Single path | Yes | Cost | No |
| Power-cost aware | Single path | Yes | Power, cost | No |

| Protocol Name | Distributed operation | Scalability | Guaranteed Delivery | Robustness |
|---|---|---|---|---|
| LAR | Localised | No | No | No |
| Gedir | Localised | Yes | No | No |
| Grid | Localised | No | No | No |
| Zone-based 2-level | Zonal | No | Yes | No |
| DREAM | Localised | No | No | No |
| Power aware | Localised | Yes | No | No |
| Cost aware | Localised | Yes | No | No |
| Power-cost aware | Localised | Yes | No | No |

Location-aware routing protocols can be compared according to the following qualitative properties / characteristics (Macker, 2004) (Stojmenovic, 2004): Path strategy, loop freedom, performance metrics, memorization, distributed operation, scalability, guaranteed message delivery and robustness:

Table 1 compares important existing location-aware routing protocols based on the proposed qualitative properties / characteristics. Some of these protocols are fully location aware (e.g., Grid) as they exploit location information in route discovery, packet relay and route maintenance. Some others are only partially location aware (e.g., LAR is location aware only in terms of route discovery). Table 1 includes two power / cost aware routing protocols (Royer, 2004), because of their importance. While the computational power of the devices used in the network is rapidly increasing, the lifetime of batteries is not expected to improve much in the future. From this table is also obvious that robustness is not inherently supported by current location-aware routing protocols.

## 4 LOCATION-AWARE TELECOMMUNICATIONS SERVICES

The available location-tracking technologies and the position-based routing protocols, combined with the massive adoption of pervasive computing devices enable location-aware services in manets, forming an important and very promising class of mobile commerce applications..

In a manet environment, location-aware services and other more general telecommunications services (e.g., name resolution, file system management, mail, Web services) cannot be centralized, because the network population and topology are not known in advance. Nor can they be preconfigured, since much of the configuration will not be determined until the network is instantiated and may need frequent updating due to its unpredictable nature. Therefore, service discovery is an important component for ad hoc communications and collaboration in ubiquitous computing environments, since it enables the participating entities to provide services to peers and to be aware of and use the available services from peers.

In order to enable services to be offered and found in a manet environment the use of Jini technology (Kumaran, 2006) is proposed. More specifically, the desired functionality originates by the combined use of three Jini protocols called, discovery, join and lookup. The discovery protocol is used when a service is in need of a lookup server to register. The join protocol is used when a service has located a lookup server and wishes to join it. The lookup protocol is used when a client / user needs to locate and invoke a service described by its interface type (written in Java) and possibly, other attributes.

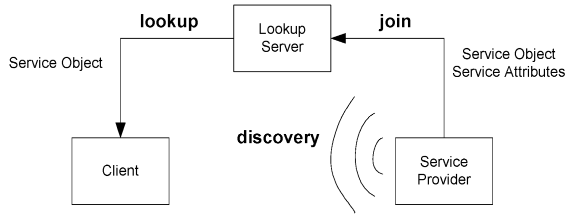


Figure 1: Service discovery in a manet.

The proposed service discovery scenario is illustrated in Figure 1. Initially, a service has to be added in a Jini system. The service provider, which is the originator of the service, locates a lookup server by multicasting a request on the manet for any lookup server to identify itself (discovery process in Figure 1). Then, a service object corresponding to the service is loaded into the lookup server (join process in Figure 1). This service object contains a Java interface for the service including the methods that clients will invoke to execute the service, along with any other descriptive attributes. The service is now ready to be looked up and used. A client locates an appropriate server by its type (interface and descriptive attributes). Then, the service object is loaded into the client to be invoked.

This service discovery approach needs optimization in order to encounter the overhead caused by the dynamic network topology of the manet. Explicit multicast packets for service discovery are necessary to be sent frequently in addition to the multicast control packets. In this way, bandwidth and battery resources are wasted and extra traffic is caused.

## 5 CONCLUSIONS

The recent availability of efficient GPS receivers and the improvement of the techniques for finding relative coordinates based on signal strengths, together with the need for the design of power efficient and scalable networks, provided justification for applying location-aware routing methods in ad hoc networks. However, the search for new such routing methods that have excellent delivery rates, short hop counts, small flooding ratios and power efficiency is far from over.

On the other hand, location-aware telecommunications services promise enhanced end-user experience and new commercial opportunities. However, further research is necessary for providing infrastructural support (mostly at the middleware level) in order to alleviate the need for services to handle issues like service discovery, privacy, context awareness, personalization and the constrained interfaces available on mobile devices in an ad hoc manner, and to simplify service creation.

The field of mobile ad hoc networks is rapidly growing and changing, and while there are still many challenges that need to be met (collective communication, QoS support, power-aware routing, efficient location updating congestion avoidance, improving network capacity), it is likely that such networks and the corresponding telecommunications services will see widespread use within the next few years.

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