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Design and Evaluation of a Fuzzy Hierarchical Location Service for Mobile Ad Hoc Networks

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Abstract

Location services are used in mobile ad hoc and hybrid networks to locate either the geographic position of a given node in the network or a data item. One of the main usages of position location services is presented in location based routing algorithms. In particular, geographic routing protocols can route messages more efficiently to their destinations based on the destination node's geographic position, which is provided by a location service. In this paper, we propose an adaptive location service on the basis of fuzzy logic called FHLS (Fuzzy Hierarchical Location Service) for mobile ad hoc networks. The adaptive location update scheme using the fuzzy logic on the basis of the mobility and the call preference of mobile nodes is used by the FHLS. The performance of the FHLS is to be evaluated by a simulation, and compared with that of existing HLS scheme.

Keywords : Fuzzy Logic, Location Service, Mobile Ad Hoc Networks

1. Introduction

Mobile ad hoc networks (MANETs) enable wireless communication between mobile hosts without relying on a fixed infrastructure. In these networks the mobile hosts themselves forward data from a sender to a receiver, acting both as router and end-system at the same time. MANETs have a wide range of applications, e,g., range extension of WLAN access points, data transmission in disaster areas and inter-vehicular communication. Due to scarce bandwidth, varying network connectivity and frequent topology changes that are caused by

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node mobility and transient availability, routing algorithms tailored for wired networks will not operate well if directly transposed to MANETs.

Since no fixed infrastructure of servers is assumed in MANETs, it is useful to devise a scheme through which various services offered within the network may be located. With the availability of such location services, it is tempting to adapt and exploit them for storing routing information. By storing the geographic location of mobile nodes in designed location servers in the network, it is possible to introduce a new family of routing algorithms that may potentially perform better than the traditional approach of discovering and maintaining end-to-end routes.

In this paper, we present an adaptive location service on the basis of fuzzy logic called FHLS (Fuzzy Hierarchical Location Service) for MANETs. FHLS divides the area covered by the network into a hierarchical of regions. The top level region covers the complete network. A region is subdivided into several regions of the next lower level until the lowest level is reached. We call a lowest level region a cell. Using the hierarchy as a basis, the FHLS uses the adaptive location update scheme using the fuzzy logic on the basis of the mobility and the call preference of mobile nodes. The performance of the FHLS is to be evaluated by a simulation, and compared with that of existing HLS scheme.

The remainder of this paper is organized as follows. The next section provides an overview of related work. In Section 3, we present the FHLS algorithm, which serves as a basis for a routing algorithm. In Section 4, we undertake a simulation study for the FHLS. We finally conclude and describe future work in Section 5.

2. Related Works

In routing protocol of MANETs, the location service uses the location information of a node for packet routing. So, many researches for location management in MANETs were performed recently. A location service that uses flooding to spread position information is DREAM (Distance Routing Effect Algorithm for Mobility) (Basagni et al. 1998). With DREAM, each node floods its position information in the network with varying flooding range and frequency. The frequency of the flooding is decreased with increasing range. Thus, each node knows the location of each other node, whereas the accuracy of this information depends on the distance to the node.

The GLS (Grid Location Service) (Li et al. 2000) divides the area containing the ad hoc network into a hierarchy of square forming a quad-tree. Each node selects one node in each element of the quad-tree as a location server. Therefore the density of location servers for a node is high in areas close to the node and becomes exponentially less dense as the distance to the node increases. The update and request mechanisms of GLS require that a chain of nodes based on node IDs is found and traversed to reach an actual location server for a given node. The chain leads from the updating or requesting node via some arbitrary and some dedicated nodes to a location server.

DLM (Distributed Location Management Scheme) (Xue et al. 2002) partitions the mobile node deployment region into a hierarchical grid with square of increasing size. The location service is offered by location servers assigned across the grid, storing node location information. Nodes that happen to be located in these regions offer the location service. The selection mechanism for the predetermined regions is carried out through a hash function, which maps node identifiers to region addresses. DLM distinguishes between a full length address policy and a partial length address policy. Under the full length address policy, location servers store the precise position of nodes. When nodes change regions due to mobility, it is necessary to update all location servers. Under the partial length address policy, the accuracy of node location information stored at the location servers increases along with the proximity of the location servers to the nodes. To the contrary of the full length address policy, several queries are necessary to locate a node. Nevertheless, the partial addressing scheme offers overall increasing performance, since it reduces the scope and frequency of location server updates due to node mobility.

HLS (Hierarchical Location Service) (Kieb et al. 2004) divides the area covered by the network into a hierarchy of regions. The lowest level regions are called cells. Regions of one level are aggregated to form a region on the next higher level of the hierarchy. Regions on the same level of the hierarchy do not overlap. For any given node A, one cell in each level of the hierarchy is selected by means of a hash function. These cells are called the responsible cells for node A. As a node moves through the area covered by the network, it updates its responsible cells with information about its current position. When another node B needs to determine those cells that may potentially be responsible for A, it then queries those cells in the order of the hierarchy, starting with the lowest level region. There are two different methods for HLS to update location servers, the direct location scheme and the indirect location scheme. To update its location servers according to the direct location scheme, a node computes its responsible cells. Position updates are then sent to all responsible cells. The location information in the responsible cells is represented as a pointer to the position of the node. The network load can be reduced with the indirect location scheme where the location servers on higher hierarchy levels only know the region of the next lower level a node is located in. More precise location information is not necessary on higher levels.

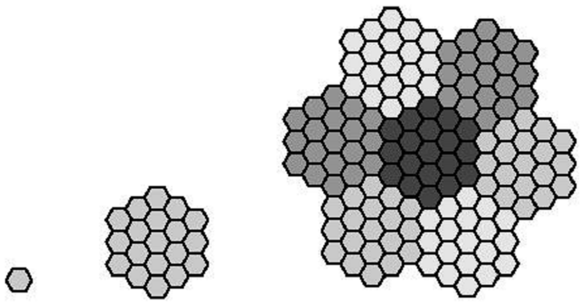
3. Fuzzy Hierarchical Location Service

We present an adaptive location service on the basis of fuzzy logic called FHLS (Fuzzy Hierarchical Location Service) to minimize the sum of location update cost and paging cost. FHLS is adapted to the location update rate and call arrival rate in an environment where the characteristic of nodes movement is changed all the time. The fuzzy control logic for location update is used in the FHLS. The input parameters of the fuzzy logic are the linguistic variables of location update rate and call arrival rate for a mobile node, and the output is a direct location update scheme or an indirect location update scheme on the basis of a different level in hierarchical region.

3.1 Area Partitioning

FHLS partitions the area containing the ad hoc network in cells. This partitioning must be known to all participating nodes. The shape and size of the cells can be chosen arbitrary according to the properties of the network. The only prerequisite is that a node in a given lowest level cell must be able to send packets to all other nodes in the same cell.

The cells are grouped hierarchically into regions of different levels. A number of cells form a region of level one, a number of level 1 regions forms a level 2 region and so on. Regions of the same level must not intersect, i.e., each region of level n is a member of exactly one region of level n+1. An example for the area partitioning is shown in Figure 1.



<Figure 1> Grouping cells to form regions: cell, region on the level-1 and region on the level-2

3.2 Location Service Cells

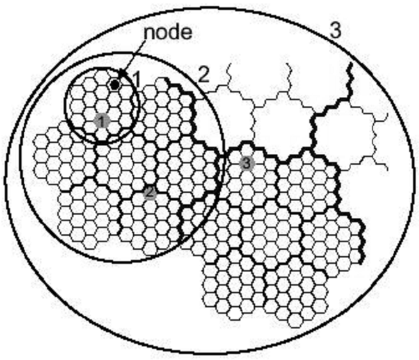
For any given node A one cell in each level of the hierarchy is selected by means of a hash function. The hash function takes a node ID (e.g. an IP Address), the level of the hierarchy and the node's position as an input and determines the LSC (Location Service Cell) for a node with this ID on this level of the hierarchy as an output. As a node moves through the area covered by the network, it updates its location service cells with information about its current position. When another node B needs to determine the position of node A it uses the hash function to determine those cells that may potentially be responsible for

A.

FHLS places location information for a node T in a set of cells. We call these cells the LSC of T. A node T selects one LSC for each level in the hierarchy. For a given level n, the LSC is selected according to the following algorithm:

(1) Compute the set S(T, n) of cells belonging to the region of level n which contains T.
(2) Select one of these cells with a hash function based on the characteristics of S and the node ID of T.

A possible hash function is the simple, modulo based function: $H(T,n) = ID(T) \bmod \| S(T,n) \|$. With the number of calculated with this hash function, one of the cells in S(T, n) is chosen. As a result of the above selection, T has exactly one location service cell on each level n and it is guaranteed that the LSC for T of level n and node T share the same level n region. An example for the selection of LSCs for the level-3 is shown in Figure 2. All location service cells are candidates for the location service. These candidate cells, tree like structure are called candidate tree.

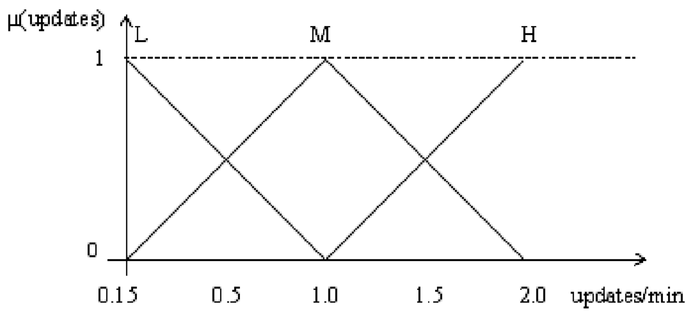


<Figure 2> Example for location service cells of a node

3.3 Location Updates

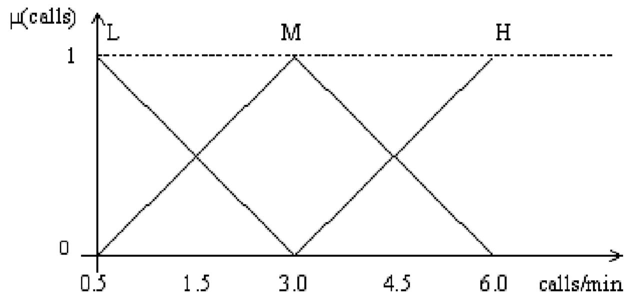
We propose the adaptive location update scheme using the fuzzy logic on the basis of the mobility and the call preference for mobile nodes. The input parameters of the fuzzy logic are the linguistic variables of location update rate and call arrival for a mobile node, and the output is a direct location update scheme or an indirect location update scheme on the basis of a different level in the hierarchy.

The mobility of a mobile node is measured by location update rate per minute. We map the update rate to the linguistic variable for the node mobility using the membership function as shown in Figure 3.



<Figure 3> The membership function and the linguistic variables for node mobility.

The call preference of a mobile node is measured by call arrival rate per minute. We map the call arrival rate to the linguistic variable for the node preference using the membership function as shown in Figure 4.



<Figure 4> The membership function and the linguistic variables for node preference.

Fuzzy logic uses linguistic variable to map the input fuzzy variable to the output variable. This is accomplished by using IF THEN rules (Baldwin 1981 and Bae 2004). We use 9 fuzzy rules described in Table 1. According to the mobility and the preference for a mobile node, a direct location update scheme or an indirect location update scheme on the basis of a different level in the hierarchy is used for updating the location information of the mobile node. For a mobile node, if the linguistic variable for node mobility is M and the linguistic variable for node preference is M, FHLS uses the level i indirect location update scheme for updating the location information of the mobile node, where the input parameter for FHLS, the level i represents the level of the first location service cell in the hierarchy.

<Table 1> Fuzzy control rules for location update

Preference \ Mobility	L	M	H
L	level-(i+1) direct location update scheme	level-(i+1) indirect location update scheme	level-(i+1) indirect location update scheme
M	level-i direct location update scheme	level-i indirect location update scheme	level-i indirect location update scheme
H	level-(i-1) direct location update scheme	level-(i-1) direct location update scheme	level-(i-1) indirect location update scheme

(Input variables)
L - Low, M - Medium, H - High
(Output variables)
a direct location update scheme or an indirect location scheme on the basis of a different level in the hierarchy

3.4 Location Requests

To successfully query the current location of a target node T, the request of a source node S needs to be routed to a location server of T. When querying the position of T, S knows the ID of T and therefore the structure of the candidate tree defined via the hash function and T's ID. It furthermore knows that T has selected a LSC for each region it resides in. Thus, the request only needs to visit each candidate cell of the regions containing S.

S computes the cell that T would choose as a location service cell. If the location service cell were in the same level one region, the S sends its request to this cell. When the request packet arrives at the first node A within the boundaries of the candidate cell, it is processed as follows:

(1) Node A broadcasts the request to all nodes within the candidate cell. This is called cellcast request.
(2) Any node that receives this cellcast request and has location information in its location database sends an answer to A.
(3) If A receives an answer for its cellcast request, the request is forwarded to the target node T.
(4) Otherwise A forwards the request to the corresponding candidate cell the next level.

With this mechanism, the request is forwarded from candidate cell to candidate cell until a location server for T is founded or the highest level candidate cell has been reached.

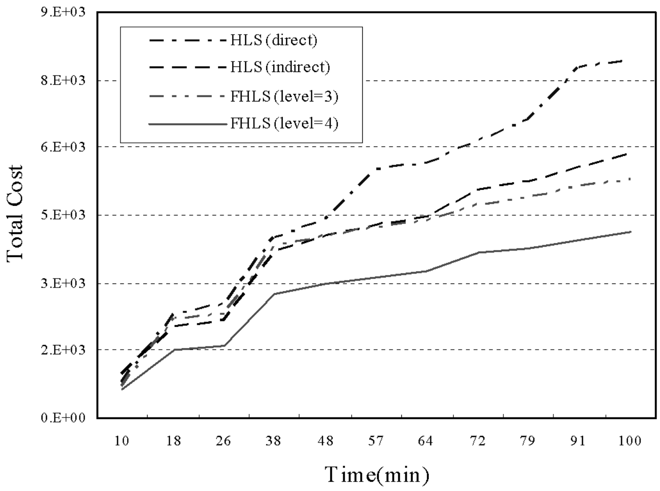
4. Performance Evaluation

Location-based routing significantly reduces routing overheads in MANETs by utilizing position information of mobile nodes in forwarding decisions. Location service is therefore critical to location-based routing. The total cost associated with the location service includes two components: (a) update cost, the cost of updating the location of the mobile user due to user movement; and (b) query cost, the cost of searching for the user in response to a call. In this section, we evaluate the performance of the FHLS in terms of the total cost. Table 2 shows the parameter values for the simulation.

<Table 2> Simulation parameters

Parameters	Values
The number of cells	64
Cell size (kilometer×kilometer)	2×2
Update rate per minute	random (0.15~2.0)
Call rate per minute	random (0.5~6.0)
Simulation time (minute)	100

The simulation result of total cost over time is illustrated in Figure 5. As shown in the Figure 5, the performance of the proposed FHLS is better than that of existing HLS. This is because the FHLS uses an adaptive location update scheme according to the characteristic of mobile node that is location update rate and call arrival rate. Also, the performance of the FHLS (level=4) that places the first location service cell on level 4 in the hierarchy is superior to that of the FHLS (level=3) that places the first location service cell on level 3 in the hierarchy. This is because as the level of the first location service cell increasing, the number of location service cells is decreased and the paging cost is reduced by the spatial locality in location query.



<Figure 5> Total cost for location service

Additionally, we know that the performance of the HLS (indirect) that uses indirect location update scheme is better than that of HLS (direct) that uses direct location update scheme.

5. Conclusions

In this paper, we have presented the Fuzzy Hierarchical Location Service (FHLS) for MANETs. The adaptive location update scheme using the fuzzy logic on the basis of the mobility and the call preference for mobile nodes is used in the FHLS. The input parameters of the fuzzy logic are the linguistic variables of location update rate and call arrival rate for a mobile node, and the output is a direct location update scheme or an indirect location update scheme on the basis of a different level in the hierarchy.

The performance of the FHLS has been evaluated by using a simulation. Because the FHLS uses an adaptive location update scheme according to the characteristic of mobile node that is location update rate and call arrival rate, the performance of the proposed FHLS is better than that of existing HLS. Also, we know that the performance of the FHLS (level=4) that places the first location service cell on level 4 in the hierarchy is superior to that of the FHLS (level=3) that places the first location service cell on level 3 in the hierarchy.

As part of our future work, we plan to evaluate our proposed FHLS in terms of various factors i.e., the number of cells, cell sizes, etc.

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