Home agent based location update and destination search schemes in ad hoc wireless networks

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Abstract: - Most previously proposed position based routing algorithms for wireless ad hoc networks were based on forwarding the actual message along multiple paths toward an area where destination is hopefully located. The significant communication overhead can be avoided if the routing strategy is changed. We propose that the source node issues several search 'tickets' (each ticket is a 'short' message containing sender's id and location, destination's best known location and time that location is reported, and constant amount of additional information) that will look for the exact position of destination node. When the first ticket arrives at the destination node *D*, *D* will report back to source with brief message containing its exact location, and possibly creating a route for the source. The source node then sends full data message ('long' message) toward exact location of destination. In this paper, we propose to use a home agent based strategy for location updates and destination searches. Each node designates a certain circular area as its home agent, and informs other nodes about it. It subsequently sends its location update messages only to the nodes located in its home agent (in addition to local updates of its position to neighboring nodes). Sending a query toward its home agent that will supply the latest available information about the position, and forward the request toward destination then performs destination search. Experiments confirm that proposed routing and location update schemes provide high success rates with reasonable communication overhead.

Key-Words: - Wireless networks, ad hoc networks, routing, location updates, home agent

1 Introduction

Mobile ad hoc networks consist of wireless hosts that communicate with each other in the absence of a fixed infrastructure. Routes between two hosts in network may consist of hops through other hosts in the network. The task of finding and maintaining routes in the network is nontrivial since host mobility causes frequent unpredictable topological changes. A number of position based protocols for achieving efficient routing have been recently proposed. The surveys of these protocols is given in [S4]. Among proposed techniques, the most interesting are request zone updates and routing [BCSW, KV], doubling circles updates [APL], Voronoi diagram and convex hull based updates [S2], depth-first search based destination search [SRV], and quorum based strategy [S1].

Macker and Corson [MC] listed qualitative and quantitative independent metrics for judging the performance of routing protocols. Desirable qualitative properties include: distributed operation, loop-freedom (to avoid a worst case scenario of a small fraction of packets spinning around in the network), demand-based operation, and 'sleep' period operation. Some quantitative metrics that are appropriate for assessing the performance of any routing protocol include [MC]: end-to-end data delay, and average number of data bits (or control bits) transmitted per data bits delivered. The review [S4] indicates that most proposed routing algorithms (more precisely, their performance evaluations) ignore one or more of these important metrics. The desirable properties will be here briefly elaborated.

Demand-based operation. Routing algorithms can be classified as *proactive* or *reactive*. Proactive protocols maintain routing tables when nodes move, independently of traffic demand, and thus may have unacceptable overhead when data traffic is considerably lower than mobility rate. For instance, shortest (weighted) path based solutions are too sensitive to small changes in local topology and activity status (the later even does not involve node movement). The communication overhead involved in maintaining global information about the networks is not acceptable for networks whose bandwidth are battery power are severely limited. Reactive algorithms, adopted in this article, are designing routes when they are needed, in order to minimize the communication overhead. They are adaptive to ‘sleep period’ operation, since inactive nodes simply do not participate at the time the route is established.

Distributed operation. We shall divide all distributed routing algorithms into *localized* and *non-localized*. Localized algorithms are distributed algorithms that resemble greedy algorithms, where simple local behavior achieves a desired global objective. In a localized routing algorithm, each node makes decision to which neighbor to forward the message based solely on the location of itself, its neighboring nodes, and destination. While neighboring nodes may update each other location whenever an edge is broken or created, the accuracy of destination location is a serious problem. This is the reason to study and develop appropriate location update schemes.

Location information. The distance between neighboring nodes can be estimated on the basis of incoming signal strengths (if some control messages are sent using fixed power). Relative coordinates of neighboring nodes can be obtained by exchanging such information between neighbors [CHH]. 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. We believe that the advantages of using location information outweigh the cost of additional hardware, if any. The distance information, for instance, allows nodes to adjust their transmission powers and reduce transmission power accordingly.

Single-path vs. multi-path strategies. There exist several *multi-path full message* strategies, where each node on the path sends full message to several neighbors which are best choices for all possible destination positions (e.g. [BCSW]). There is significant communication overhead, and lack of guaranteed delivery can make this approach inferior to even a simple flooding algorithm. Clever flooding algorithm may use about half of nodes only for retransmissions [SSZ], which often matches the number of nodes participating in routing in this method. In addition, flooding guarantees delivery and requires no prior location updates for improved efficiency. Multi-path methods [BCSW, KV, S2] may be regarded as flooding that is restricted to the request zone, and as such can be used for geocasting (where a message is to be delivered to all nodes located within a region). Multi-path algorithm that consisting of several single-paths are proposed in [SL]. *Single non-optimal path full message* strategy is proposed in [APL]. *Short message multi-path destination search, full message optimal single-path* method is discussed in this article.

Loop-freedom. Interestingly, this basic criterion from [MC] was neglected in many papers. *Greedy* algorithm [F] is inherently loop-free [SL]. A counterexample showing that undetected loops can be created in directional based methods (e.g. [BCSW]) is given in [SL]. The method is therefore not loop-free. The algorithm in [BMSU] is loop-free which follows from its design properties.

Memorization of past traffic. Most reported algorithms require some or all nodes to memorize past traffic, as part of current routing protocol, or to memorize previous best path for providing future path to the same destination. Solutions that require nodes to memorize route or particular information about past traffic are sensitive to node queue size, changes in node activity and node mobility while routing is ongoing. One form of such memorization are routing tables, which memorize last successful path to each destination. Localized routing algorithms [BMSU, F] do not memorize past traffic at any node, while algorithms [BCSW, KV, S2, SL] require nodes to memorize past traffic, to avoid infinite mutual flooding between neighboring nodes. In flooding greedy algorithms [SL], message is flooded at nodes where basic algorithm fails, and these nodes refuse further copies of the same message. These algorithms guaranty delivery. Routing algorithms that use depth first search (DFS) in search for destination are discussed in [JPS, SRV]. Memorization there is imposed by DFS process. The algorithm guarantees delivery but the efficiency depends on the accuracy of destination information. Quality-of-service routing, where the path needs to satisfy delay, bandwidth, and connection time criteria [SRV] requires that nodes memorize the QoS-path, thus using DFS for its construction does not impose any memorization overhead. In this article, memorization is used for storing latest node positions, but not for routing algorithms.

2. Proposed approach

In [SRV, S1] and this article, we suggest to solve the routing problem in ad hoc network by dividing the problem into four components, as follows.

1) *Location update* messages are initiated by each node, which acts on its movement. Location updates are required by some other tasks as well (e.g. clustering, broadcasting, quality-of-service routing etc.).

2) *Destination search* messages, initiated by a source node, when it wants to route a message toward destination.

3) *Path creation* messages, initiated by destination upon receiving the first copy of a search

message. The destination learns the location of sender from the search message and is able to find the best path accurately. Since the transmission speed is far greater than node movement speed, the path creation phase in a localized routing may, to a large extent, be considered as the operation performed on a static network. Thus routing algorithms for static networks (with known location of destination), may be applied for the path creation phase. This assumption is justified since each node mountains the list of neighbors and learns the exact location of destination, which is the only information needed for making a routing decision at each node.

4) *Data traffic* messages, initiated by source upon receiving reply from destination containing its exact location, possibly together with the path toward destination. Alternatively, the source may attempt to create another path, knowing destination location accurately, by applying any localized routing algorithm defined on static networks.

In this routing scheme, we may also divide all messages into short and long ones. Short messages do not have the real information (to be forwarded to destination) as part of message (unless it is a very brief message, e.g. alarm), and therefore has much lesser number of bits than the message that contain the real information. Location update, destination search, and path creation messages are short messages. Location update messages are generated independently on routing request, as a preparation for successful destination search. Destination search and path creation messages are generated by routing requests. They are still a communication overhead. When the real message, containing data to be forwarded to destination, is long compared to first three kinds, this routing scheme is justified.

Note that, with this general routing scheme, the routing problem is divided into two components that may be investigated separately, as follows.

Component 1: *Location update and destination search schemes.*

Component 2: *Routing to a destination whose position is known* (includes path creation from destination to the source, and data traffic from source to destination).

Satisfactory localized solutions for path creation and data traffic phases are already proposed (see survey [GSB]). Because of drawbacks of existing solutions for the location updates and destination search schemes, we shall concentrate on these two components in this paper. We shall propose new solutions for them in the next two sections.

The main difference between described location update and destination search strategies and previously proposed analogous solutions (including non-GPS based route discoveries and route maintenance) is that full flooding was previously used as regular technique to construct the route, maintain the route or update the location in many cases. For example, when destination moves extensively but far way from the source, no solution other than full flooding was suggested. In [S1], we proposed to deal with such movement pattern by reducing full flooding to row and column paths of certain thickness. In this paper, we propose to use home agent circles instead.

This article has been originally published as a technical report [S3] in September 1999, but was not submitted for publication due to the lack of experimental results. Since then, variations of the home-agent based scheme have been described by four different groups [BBCGHL, MJKLD, PG, WS], with March 2000 as earliest dated report among them. Three of them [MJKLD, PG, WS] present detailed experimental results that show the advantages of home-agent based scheme over all other competing schemes.

3. Location update

The location update idea proposed in this paper is similar to the one used in cellular phone networks and mobile IP [P]. When a phone user moves away from his home server (agent) to a new place (e.g. new city), it sends periodically the message from visitors location to home agent, giving its current coordinates. When a phone call is made to that user, the call is first sent toward the user's home agent. Home agent then directs the call toward his visiting position. This idea is adapted for the use in mobile ad hoc networks.

The basic update procedure is performed by each moving node whenever it observes that, due to its movement, an existing edge will be broken (that is, the distance between two nodes becomes $>R$). The node will broadcast a message containing its new location information to all neighbors which are at distance tR. For $t=1$, the radius is same as the radius for transmitting data traffic. For $t>1$, the message will be either retransmitted, using optimized flooding algorithm [SSZ], or transmitted with increased transmission radius, if nodes may adjust transmission radius. Spending larger power for update may be justified by better destination search efficiency. Each node which is, at the moment of transmission, located inside that circle (of radius tR) is assumed to receive the new location accurately, without acknowledging the message. Location update message is also sent in response to a location update message received from a new neighbor. However, $t=1$ is suggested in that case, since the new neighbor may be the only one in need of accurate position of updating node.

To decide whether edge is made or broken, node may use last available information about its direct neighbors and other nodes in the network. However, when two nodes are moving in the same direction, such procedure may result in unnecessary updates. To reduce overhead in such scenarios, connection time can be used as follows. The availability of GPS enables nodes to estimate the connection time with other nodes, as proposed in [SRV, SLG]. The connection time is defined as the estimated duration of a connection between two neighboring nodes. Neighboring nodes frequently update their location to each other, and this information may be used to estimate the direction and speed of their movements. In turn, this suffices to estimate the connection time. Let A and B be the two neighboring nodes which move at speeds a and b, respectively. Here, A and B are position vectors while a and b are directional vectors. At time t, they move to new positions $A'= A+at$ and $B'= B+bt$. They will loose their connection when the distance between them becomes $>R$, where R is the radius of corresponding unit graph (or the smaller of their transmission radii in case of minpower graphs). The time t when the connection will be lost can be estimated by solving quadratic equation $|A'B'|=|B-A+(b-a)t|=R$ [SRV,SLG]. When the time expires, edge is assumed broken and location update is sent to all neighbors. Similar criteria can be used to estimate the time a connection will be made, and act accordingly.

The main location update is performed by each node as follows. At the beginning, each node informs every other node about its initial position, which will be its home agent. More precisely, home agent will consist of all nodes that are currently located inside a circle with radius pR, where p is network parameter, centered at the initial position of the node. Each node A uses a counter to count the number of previously made changes in edge existence (the number of created or broken edges). When the counter reaches a fixed threshold value e, node A sends a location update message to its home agent, using greedy algorithm [F] which works well in dense networks, or a routing algorithm that guarantees delivery [BMSU, SL]. In greedy routing, node A and each intermediate node B will send the update message to one of the neighbors that is closest to the center C of home agent circle (using radius R for transmission). Each neighbor of current node B also hears the location update, and will update its information about both A and B. That is, each node, transmitting anything, will use the opportunity to broadcast its own new location as well. If B has no closer neighbor to home agent than itself, it can stop [F], apply neighbor flooding with withdrawal [SL] or routing in planar Gabriel graph [BMSU]. If current node B is inside home agent base, the condition will be stricter, and the message will be forwarded only if a neighbor closer to the center C (of home agent circle) than B is found. Let B be the node that stops the transmission (for whatever reason). Node B may optionally transmit the location update message about A using larger transmission radius pR.

4. Destination search

Suppose now that source S wants to route a message to a destination D. Destination search messages will be issued, looking for D. S sends exactly two such messages (thus D may receive two search messages). One is sent toward D using the location information about D currently available to S, applying one of routing algorithms [BMSU, F, SL]. More recent location information will be taken on the way to destination (if any is available). The second routing type message is sent toward the center C of home agent circle of D, which may be at completely different region than current position of D. Node B, where routing stops, will then issue request for the destination location to all nodes located inside circle of radius pR, centered at B. B will also inform, in the same message, about the most recent location information collected on the way to it by that destination search message. All nodes inside the circle that have more recent location information will reply. Node B will then act on the basis of best information obtained, and redirect the message toward the location reported with that latest information, also applying one of routing algorithms [BMSU, F, SL].

The location update and destination search schemes are illustrated in Figure 1. It shows an ad hoc network with radius R as indicated. Destination D is the only node that moves (for clarity), and let $D1$, $D2$, $D3$ be its positions during the move. Upon every link change (making or braking), D informs its neighbors (indicated by arrow in Fig. 1). At position $D2$, it decides to inform its home agent, drawn as a circle in Fig. 1, about its current position. The location update message follows the path *D2-U-V-W* (indicated in bold line), and is broadcast from W to most nodes inside home agent circle (e.g. to nodes B and C, indicated by dotted lines). Suppose now that source S initiates destination search when destination is at position $D3$. The destination search message is forwarded toward the center of home agent circle, and follows path *S-K-I-H-G-L-M-N-B*. Node B then forwards the search message toward position $D2$, for which node *P* is the best neighbor. On the path *B-P-Q-D3* (indicated as bold and 'long' dashed line), node *Q* has more recent location of *D* and destination is found. The destination *D* then initiates path creation phase following a *GEDIR*-like method and finds the source *S* using the path *D3-A-E-F-G-H-I-K-S* (indicated in bold lines). The source *S* may then send the data toward *D*.

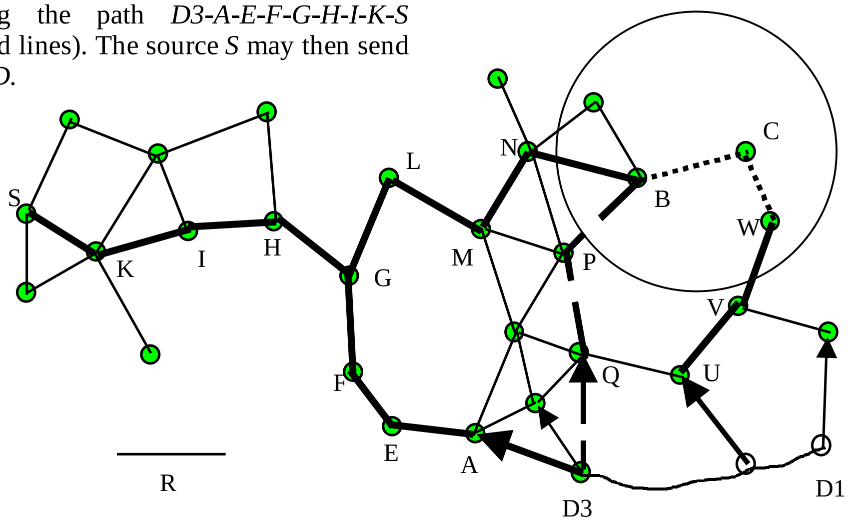

Figure 1. Location update from D2 and destination search from S

5. Performance evaluation and future work

Three of the articles that proposed independently variants of home-agent based schemes [MJKLD, PG, WS], also reported detailed experimental results on its performance. All of them report that the method is better than any other that was used for comparison, especially in terms of reducing communication overhead which is achieved by avoiding flooding. The advantage is especially notable for large network, and scalability appears to be the main advantage of home agent based scheme.

The method, however, is not without drawbacks, and the main drawback was not reported in [BBCGHL, MJKLD, PG, WS]. It is possible in some scenarios, such as rescue missions or military actions, that all nodes move out of the region where all home agents are located. In such scenario, all homes are ineffective, and new homes need to be created. If movement is intensive, the method becomes ineffective. It is possible to design some repair techniques, such as designing new home agent upon certain number of inefficient destination searches, but their effectiveness is also limited to ‘small’ movement.

In order to address the issue of moving region, we have proposed two other competing schemes, depth-first search based [SRV], and quorum based [S1], and also adopted proposed location update and destination search scheme for improved request zone scheme [S2]. All of them adapt well to mobility of whole region. Nevertheless, on a more positive note, it appears that all of them have more communication overhead in scenarios with limited node movements and movements that is restricted inside a region, e.g. a building. Thus we believe that home based idea for routing in ad hoc networks has the potential to be very efficient, in terms of small hop counts, almost guaranteed delivery, and small communication overhead, in such scenarios.

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