GEOGRAPHIC MESSAGING IN WIRELESS AD HOC NETWORKS

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Abstract – This paper presents a network layer mechanism for the efficient dissemination of Global Positioning System (GPS) based node position in *ad hoc networks*, and shows its application to problems involving geographic awareness. In particular, we describe how, based on a "position database" maintained through the dissemination mechanism, a node of the network can direct messages to all the nodes currently present in a precise geographic area. The effectiveness and accuracy of the dissemination mechanism is demonstrated through the use of simulations. We show that for ad hoc networks with up to 60 nodes, the position database correctly determines which nodes are actually in the expected geographic area the 97% of the time.

I. INTRODUCTION

Given the rapid commercial growth and the decreasing size and cost of Global Positioning System (GPS) devices, it is reasonable to expect that nodes of future mobile networks will be equipped with GPS receivers by default. Every node in the network will, therefore, be constantly aware of its own position with respect to the coordinate system defined by GPS with a precision down to 100 meters (for general public use, and even better in military applications). As a consequence, the position of a node will become information that is as common as a node's unique identifier, its speed, or the current date.

A myriad of position dependent applications are emerging in which geographic awareness is the key ingredient. Among these applications, *geographic messaging* is the sending of a message selectively to only those nodes located in a specific geographic area. For example, if there has been a multi-vehicle accident on a freeway then, in order to allow emergency vehicles quick and easy access to the area, and to begin rerouting other traffic around the area, a message to take a specific detour is only of interest to those vehicles in the area approaching the position of the accident. In *geographic multicast*, the message is targeted to only a subset of nodes in the geographic area. For example, perhaps a specific message is intended to be received only by all medical services units in an area, rather than all vehicles in an area, to enable the fastest response to the life-and-death situation.

Having a geographic messaging capability also enables a service provider to advertise to nodes within its proximity. Here, it is assumed that the service is of local interest. For example, is it likely that people within close proximity of a particular restaurant would eat there. On the other hand, geographic messaging also opens up the possibility to query a particular area in order to search for a particular service, such as the closest automatic teller machine. This could include a query to identify the nodes located in a given area. For instance, in a military scenario, a brigade commander may wish to know which ground troops have penetrated a certain area. Or, in the field of wildlife management, scientists may monitor endangered species by fitting animals with GPS receivers and tiny transmitters in order to study their population distribution patterns.

In networks with a fixed infrastructure, the fixed part of the network must be made "geographically aware," i.e., configured in such a way that a router's service area is defined to correspond to a geographic area. This is the case in the GPS based geographic addressing and routing described in [1]. This work focuses mainly on the integration of the concept of physical position into the current design of the Internet, thus assuming fixed geographic routers. The routers are hierarchically organized, with the service area of routers higher in the hierarchy defined as the union of the service areas of its children. When a message is sent to a geographic area, the router receiving it intersects the destination area with its own service area to determine if it services (all or part of) the destination area. If the intersection is

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empty, the message is forwarded up the hierarchy. Otherwise the specific child routers that service the destination area are identified and the message is passed down the hierarchy.

When no fixed infrastructure is available, as in *ad hoc* networks, a mechanism distributed among all the mobile nodes of the network has to be provided for maintaining position awareness. This requires that the (GPS) position coordinates of each node be disseminated throughout the network. The term ad hoc networks refers to a mobile network in which each node can move, and is willing to forward packets for other nodes that cannot communicate directly with each other (namely, each node is also a router). These networks are critical for defense applications (tactical networks) and are starting to fill an ever increasing role in commercial environments in which traditional networks are not viable. It is easy to see that, due to the absence of fixed routers, the position awareness techniques and protocols proposed for geographic messaging in existing solutions are no longer usable.

This paper proposes a reliable network layer mechanism for the efficient dissemination of the GPS position information in ad hoc networks, and shows its application to problems involving geographic awareness. In Section II, after briefly introducing the Global Positioning System and the information obtainable through its use, we describe our dissemination mechanism for building a position database that takes into account the specific operational characteristics and system issues of ad hoc networks. Specifically we describe how our mechanism achieves efficiency in terms of the bandwidth and energy used for dissemination since each node establishes its update frequency locally depending on its own velocity, as well as using information about the distance separating nodes for propagation of the position. Section III shows how we provide solutions to two position dependent problems through the effective use of the position database, namely, to implement querying a geographic area to determine the identity of the nodes in the area, and geographic messaging. Through the use of simulation, Section IV shows the effectiveness and accuracy of our mechanism in determining which nodes are actually in the expected geographic area. For a wide range of node mobility rates and with different network loads we always obtain that more than 97% of the nodes are actually in the expected area. Finally, Section V concludes the paper.

II. GPS AND DISSEMINATING POSITION INFORMATION

The Global Positioning System (GPS)

GPS, which stands for Global Positioning System, is a satellite-based radio-navigation system developed and operated by the United States Department of Defense (DoD) [2, 3]. Using the signals sent by the satellites, users with a GPS receiver can compute their three-dimensional position, velocity, and time with very high accuracy.

The system consists of three segments: space, control, and user. The *space segment* consists of 24 satellites placed in orbit so that at any time a minimum of 6 satellites are in view to users anywhere in the world. Each satellite continuously broadcasts position and time data. The *control segment* continuously receives satellite control and monitoring signals, and uses the information collected to compute extremely precise satellite orbits. Updated navigation messages are then transmitted to each satellite in view in order to ensure the whole system keeps operating properly.

The *user segment* consists of the receivers, processors, and antennas allowing the users of these devices to receive the GPS satellite broadcasts and compute their precise position, velocity and time as follows. The user's GPS receiver measures the time delay for the signal to reach the receiver, which even though traveling at the speed of light, takes a measurable amount of time to reach the receiver. The distance to the satellite is calculated from the difference between the times the signal is sent and received, multiplied by the speed of light. Such measurements collected simultaneously from four satellites are then used to solve for the three dimensions of position (latitude, longitude, and altitude), velocity and time.

GPS provides two levels of service. The *precise positioning service* (PPS) is intended for use by the DoD, whereas the intentionally degraded accuracy of the *standard positioning service* (SPS) is intended for general public use. The accuracy of the SPS is to within 100 meters horizontal, 156 meters vertical, and 340 nanoseconds time.

Position Dissemination

Given that each of the nodes in an ad hoc network is equipped with a GPS receiver, each node is aware of its own position. Using a dissemination mechanism tailored for ad hoc networks, each node distributes its own position in control packets throughout the network. From these control packets, each node builds a position database with entries for all other nodes, and maintains the entries up to date. (This mechanism is different from that introduced in [4] since there is no associated probabilistic model. This is obtained by transmitting the creation time of a "position packet" along with the GPS coordinates. In this way, given the maximum speed of a node, the area within which it can be surely found is easily determined.)

Since bandwidth and energy use are important concerns in ad hoc networks, it is critical for the dissemination mechanism to be efficient. Control packets carrying the position information are small (only 16 bytes are needed for the node's latitude and longitude, 4 bytes for the node identifier, and 2 bytes for the packet creation time), thus requiring very little of the available bandwidth and associated energy to transmit.

Rather than periodically flooding the network with these control packets, we use two observations to further improve the efficacy of dissemination in ad hoc networks. The first observation is that the frequency a node needs to disseminate a control packet should depend on its speed, since a node's position changes more rapidly at higher speed. Thus, each node can adapt its own dissemination frequency locally, according to its own mobility rate. In particular, in the event a node is stationary it would stop disseminating control packets entirely.

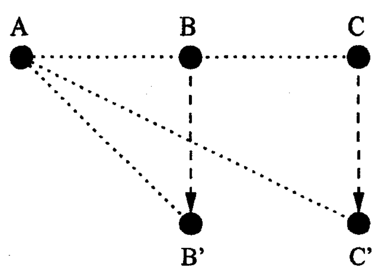

Figure 1: The distance effect: although B and C have moved the same distance, from A's perspective, $\widehat{BAB'} > \widehat{CAC'}$.

The second observation is the *distance effect*. This is the simple but fundamental observation that the greater the distance separating two nodes, the slower they appear to be moving with respect to each other (as Figure 1 illustrates). Thus, nodes that are far apart, need to update each other's position less frequently than nodes closer together. This is accomplished by a packet aging technique, wherein control packets are sent more often to nodes close by, and less often to more distant nodes.

III. GEOGRAPHICALLY AWARE APPLICATIONS

In the sequel, a ***geographic area*** is defined by a closed (convex) polygon whose vertices are represented by GPS latitude and longitude coordinates. Examples of such areas include a single point, a circle specified by the point representing its center together with its radius, and an n-sided polygon specified by n points $(p_0, p_1, \ldots, p_{n-1})$, where line segments connect p_i and $p_{i+1}, i = 0, \ldots, n-1$.

Area Query Application

One geographically aware application includes querying a specific geographic area in order to determine the identity of nodes in the area (also called a "who's around?" service). In a fixed network architecture [1], this can be implemented by sending a query to all nodes in the geographic area using geographic routing, and waiting for each node within the area to return its identifier to the node that initiated the query.

In ad hoc networks, given the position database that is constructed and maintained at each node by our dissemination mechanism, we obtain an immediate response to such an area query without the need to transmit any messages. Indeed, a node needs only to query its position database in order to obtain the identity of the nodes in the geographic area.

Geographic Messaging Application

Another geographically aware application is geographic messaging, the problem of how to direct traffic to the correct position of a node or to the nodes that reside in a specific area. To solve this problem in ad hoc networks, there are two distinct scenarios to consider according to whether or not the source of the message is inside or outside the destination geographic area (see Figure 2).

When the source is inside the destination geographic area, the packet containing the message is simply broadcast. Any node that receives the packet first determines whether it is within the destination geographic area. If so, it will process the message within the packet, and re-broadcast the packet. Otherwise, the packet is ignored. Of course, nodes must maintain a cache of packet identifiers in order to prevent processing of a broadcast packet more than once.

When the source of the message is outside the destination geographic area the packet must be handled differently. In fact the source node, which knows whether it is inside or outside the destination geographic area, must mark the packet accordingly, in order for nodes outside the geographic area to handle the packet properly.

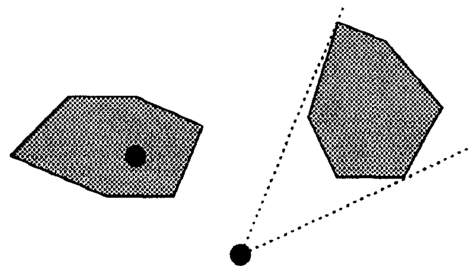

Figure 2: Geographic messaging initiated by a node inside (left) and outside (right) the destination geographic area.

Being aware of its current geographic position, a node S outside the destination geographic area can easily calculate in which direction it should send the packet in order to reach all the nodes in the area. (The direction is defined by the two tangent lines "drawn" from S to the geographic area. See Figure 2.) Once the direction is computed the packet is sent to all S's one-hop neighbors in that direction, and the forwarding of the packet is repeated accordingly. Following this directional approach, the packet is naturally driven towards the selected destination geographic area. When the packet finally reaches a node within the area, the packet is then broadcast to ensure that the packet will be received by all nodes within the destination geographic area. (This is done in the same manner as described above when the source node is within the destination geographic area.)

One valid concern in using any directional approach in an ad hoc network is whether a node will have any one-hop neighbors in the direction of the destination geographic area. The position database can be effectively utilized to address this concern. Assuming an upper bound on the transmission range of the nodes is known (this information can also be disseminated along with the position information), the position database also provides a "snap-shot" of the network topology.

In particular, any node outside the destination geographic area, processing a geographic message initiated by a node outside the area can use the position information to determine whether it has any one-hop neighbors in the direction of the destination geographic area. If it does, then it will forward the packet to these one-hop neighbors. Otherwise, the node should "open up" the angle covering the destination geographic area until it has one-hop neighbors that can forward the message. Here again, two possibilities arise. In the worst case, the angle will open up to the maximum of 360° in which case the network is flooded. Alternatively, the node will have no neighbors, even in this extreme case, meaning it is disconnected from the rest of the network. In this case the geographic message cannot be successfully delivered by any protocol. In all cases, a cache must be utilized to prevent packet looping.

We finally notice, that following our directional approach, there is no need for geographic routers or major modification to the structure of a message as required in existing approaches [1]. Moreover, while existing solutions focus mainly on the integration of geographic coordinates into the Internet, our approach is completely general, and can possibly be applied also to networks with a fixed infrastructure.

IV. SIMULATIONS RESULTS

A discrete-event simulator of an ad hoc network, implemented in C++, was used to evaluate the performance of our dissemination mechanism for use in the area query and geographic messaging applications. Currently, our study is limited to network-layer details, thus no link- or physical-layer are modeled.

Each of the nodes of the network can move around in a rectangular region (modeled as a grid) according to the following mobility model. (To ease the modeling, the node movements are discretized to grid units with a grid unit = 1 meter.) Each time it moves, a node determines its direction randomly, by choosing it between its current direction (with 75% probability) and uniformly among all other directions (with 25% probability). The node will then move in that direction according to its current speed. When a node hits the boundary, it bounces back into the region with an angle determined by the incoming direction. The final position of the nodes is a function of its initial position and of its current speed.

Each node has a fixed transmission range of 350m (we found that this value gave the network good connectivity, i.e., always more than 90% of the time, after network topology changes, the network was connected). Each node is modeled by a store-and-forward queuing station, and is characterized by parameters such as buffer space which is assumed to be adequate for packets that are awaiting transmission. Each link is modeled by a FCFS queue with service time as the packet transmission time characterized by a bandwidth of 1 Mbits/s. Position (control) packets and data packets share the same transmission channel (which implies that the accuracy of the dissemination mechanism is affected by the network load).

Each position packet contains time-stamped, node identified, position information and are 22 bytes long. They are transmitted every time a node moves (i.e., at a frequency that is a function of the node velocity).

Data packets are 1K in size (plus a header). Data packets are used to introduce load into the network in the area query application, and represent the message to be transmitted to the destination area in the geographic messaging problem.

In order to test the accuracy of our dissemination mechanism, we have simulated the area query application ("who's around?" service), in which the destination area is a circle defined by a center point chosen randomly and uniformly within the grid, and a radius chosen randomly and uniformly in the range from 100 to 500 meters. The node that requires the "who's around?" service is also chosen randomly and uniformly from the set of all nodes. We query the position database at the requesting node in order to obtain the expected identity of nodes in the queried area, and compare the result to the actual nodes in the area itself. In all our experiment, the "who's around?" request arrivals are distributed exponentially, with a mean of 100ms.

Our first set of simulations (see Figure 3) concerns an ad hoc network with 30 nodes in a 1000m ×1000m grid. In this case, independently of the speed of the nodes (which varied from 6m/s to 20m/s, i.e., from around 20 km/h to around 70 km/h), the position database at each node returned the list of the nodes actually in the query area for more than the 99% of the queries. The results were obtained for two different network data loads, namely, those obtained by generating geographic multicast packets according to an exponential distribution with means 2500ms and 1000ms, respectively.

The same result, 99% accuracy, is obtained in the second set of simulations, which apply to the same scenario (30 nodes in 1000m ×1000m grid) when the maximum speed of each node is 10ms and the network data load varies from 800ms down to 100ms.

The third set of simulations (see, again, Figure 3) concerns an ad hoc network with 60 nodes on a 2600m ×1000m grid, which gives us networks with a larger diameter (maximal "hop distance" among each pair of nodes). In this case the position table accuracy is always more than 97%, independently of the speed (again from 6m/s to 20m/s), and of the two network loads considered (exponential distribution of geographic multicast arrivals with means 2500ms and 1000ms).

All the simulations run for a time long enough to achieve a confidence level of 95% with a precision within 5%.

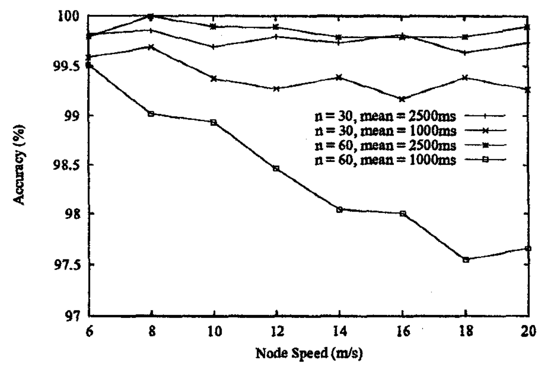

Figure 3: Accuracy of the nodes' position database at each node of ad hoc networks with $n = 30$ and $n = 60$ nodes.

V. CONCLUSIONS

This paper presented a mechanism for the efficient dissemination of geographic (GPS) coordinates in ad hoc networks, and described its use for applications involving geographic awareness. The mechanism is demonstrated to be highly effective in supporting services as the "who's around?" service, for the accurate determination of the nodes in a specific geographic area, and geographic messaging.

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