Application of GPS to Mobile IP and Routing in Wireless Networks

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Abstract— **In this paper,we discuss how the location information provided by a GPS can be used at different layers of the TCP/IP stack of a mobile host. Our discussion focuses an application of the two GPS based networking protocols we have designed and implemented.The Network topology we are considering is composed of fixed Internet with base station at the edges, ad hoc network and sensor network. In the network, base stations and mobile nodes are GPS equipped. The idea is to leverage the information of the mobile and base station positions ,obtained via the GPS, to improve performance of the ad hoc routing, to adaptively determine the appropriate base station capacity to be reserved strictly for handoffs, to collect data from sensors scattered to the medium and to inform mobile about the prospective future location.**

I. Introduction

GPS (Global positioning system) enables a device to determine their position (longitude, latitude, and altitude) by getting information from the satellites. GPS satellites first orbited in 1983 and from that time efforts have been under way to include GPS in everything from marine navigation to guided missiles to tracking golf balls. The GPS Industry Council has forecasted the markets for GPS applications at approximately $ 10 Billion by the year 2002.

Wireless networks have also experienced explosive growth. Different types of wireless networks are emerging. Second generation cellular networks which provided only voice services are evolving into third generation systems which also provide packet data services. Wireless LANs are becoming prevalent in buildings. There is significant interest in using multi-hop wireless networks for providing internet access to residences. Such multi-hop adhoc wireless networks are also being used for networking distributed control systems. Another type of ad hoc wireless networks are sensor networks where tiny sensors with radios are used to collect information about their environment.

In this paper we are going to investigate the application of the position information provided by GPS to wireless networks. Currently, most work concerning wireless networking has been done without using position information. Most protocols and algorithms used in wireless networks do not use position information. But as GPS receivers become cheap, they maybe embedded into cell phones, base stations and other wireless access devices. As we discuss in this paper, there are several advantages to using position information in the protocols and algorithms used in wireless networks.

We consider the application of position information provided by GPS in ad hoc wireless networks,cellular networks and in sensor networks. In Section 2, we present the network structure and scenario we aim to establish and our motivation on this subject and

In Section 3,we discuss the application of position information provided by GPS to ad hoc routing. We present a routing scheme that uses position information of the destination in making routing decisions. We show that our scheme has significant advantages over other methods that do not using position information.

In a cellular network,a mobile connects to a fixed base station. As the mobile moves, its connection needs to be handed off from one base station to another base station. Typically, the strength of radio signal that the mobile or the base station hears is used for this purpose. In Section 4, we show that the performance of such handoff schemes can be improved by using position information.

In Section 5,we discuss the application of position information in collecting information from sensor nodes.

In Section 6, we present the performance analysis to prove the better performance of our algorithms and In Section 7, we conclude the paper.

II. Motivation

Advanced Traveler Information Systems (ATIS) is one of the broad areas of the California Partners For Advanced Transit and Highways (PATH)research [1]. ATIS aim at collecting and processing useful information about transportation conditions and travel options in order to allow people to take full advantage of the transportation system. In addition to this traffic management, vehicle users want uninterrupted Internet service.We designed our scheme regarding these.

We propose a network structure that consists of sensor network, ad hoc network and cellular network as seen in Figure 1. Unlike the current sensor networks that sensors construct a large network in them selves in order to connect to a fixed base station, we consider GPS equipped mobile bases(vehicles) that roam in sensor scattered area in addition to the GPS equipped fixed bases. They form immediately a small scale sensor network in their roaming area and send sensor data multi-hop to the fixed bases stations by ad hoc routing. This overcomes the overhead of large sensor network formation and sensor locations are predicted more accurately. Sensor data is gathered in a Management Center, processed and sent to the mobiles for information about location they are reaching. Mobile IP is implemented for Internet connectivity, mobiles connect a fixed base (Foreign Agent) and register to its Home Agent. 1. Connection to a base is not restricted to be a one hop, it may be multi-hop. Since the users perform frequent hand-offs , our focus is to improve the handoffs with position information.

Research supported by the Office of Naval Research and National Semiconductor

In the next sections we will describe our protocols that we used in our scheme in detail and compare them with the previous proposed ones.

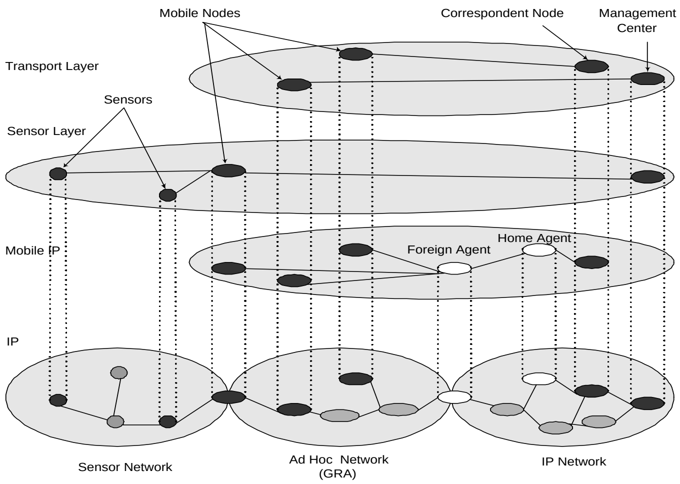

Fig. 1. Network Architecture

III. Ad hoc routing with GPS

Geographical Routing Algorithm (GRA) is a asynchronous, real-time distributed and scalable algorithm for ad hoc routing with incomplete knowledge of network topology. We assume that each node gets its geographical position from GPS and has the means to find the position of the destination node. When a node has a packet for a destination, it chooses from the nodes it knows about the one which is closest to the destination, and sends the packet on its way to that node. Along the path, a node may know of an even closer node to the destination. The packet then gets redirected to that node. On its way to that node, it may get redirected again, and so on until it reaches the destination.

The routing table consists of a *subset* of all nodes in the network, their positions (with time-stamps), and corresponding next-hop neighbors. Initially, nodes know about neighbors only, and later other nodes get added to the routing table till the tables are "complete", i.e routing to any node can be accomplished using the tables. When node S receives a packet for a node D at position $pos(D)$, it finds the p_i in its routing table which is closest to $pos(D)$ and forwards the packet to the neighbor S_i. When $pos(S)$ is closer to $pos(D)$ than any other p_i in the table, we then say that the packet is "stuck" at S. Then, a route discovery protocol is invoked that finds the route and updates the tables. Once, the tables are "complete", no more route discoveries are required.

1. Location Advertisement Protocol: Each node will periodically broadcast route advertisement packets. A route advertisement packet consists of an Ethernet header and a geographic header. When a node receives a route advertisement it will check its routing table and update it if necessary and it will not rebroadcast this packet.

2. Geographical Routing Protocol: When a node receives data packet it will first check the final destination, if the final destination is a neighbor it will forward the packet, else it will check its routing table, find the closest neighbor to this destination and then forward the packet to that neighbor

3. Route Discovery Protocol: If a node cannot send a packet to a destination because of a physical barrier it will use a Greedy DFS algorithm in order to find an alternate route to the destination. + Property 1 sentence

4. Tear Down Protocol:

Of course, for any routing algorithm, the packets forwarded according to the algorithm must not get caught in loops. The precise claim for GRA is:

Theorem 1: In a static network G, if the route discovery process works as explained above, then packets forwarded according to the GRA do not get caught in loops forever.

Of course, ad hoc networks are not static, but as we show in the paper [7], the packets may loop till the routing tables have not converged. But once they converge the packets reach the destination almost surely. This is proved using an inductive argument, and the key is the way RDP updates the routing tables (see [7] for details).

Moreover, the GRA initiates less than O(log n) route discoveries on average per node, and this makes the algorithm efficient in terms of routing table sizes, and hence communication overhead.

Theorem 2: Given that node locations come from a Poisson point process, the expected number of route discoveries initiated by a node is less than $O(\log n)$. And the mean routing table size is bounded above by $O(\bar{L}_1 \log n))$, where $\bar{L}_1$ is the mean length of the shortest path between any pair of nodes in a n-node random network.

The details of the proof can be found in [7].

In real networks, however, since GPS position has some error, and network topology is dynamic, information is never precise and complete. However, the GRA is actually quite robust to both errors in positional information as well as topological information, as long as there is consistency of information. This is argued in detail in the paper.

One problem that is particularly relevant to geographical networks is the problem of sending data to all nodes in a given region irrespective of their identity. For want of a better name, and not to confuse with multi-casting, we call it geo-casting as in [8].

Without loss of generality, we will assume that the region is convex (otherwise, it can be taken as a disjoint union of convex regions). Now, when a node S gets a packet with region R as destination instead of a destination node, it takes the intersection of its Voronoi view with the region R. Let $V_1, ..., V_l$ be the Voronoi cells with non-empty intersection with region R. Then, a copy of the packet is forwarded to the appropriate next-hop neighbor, N_i with destination region $R \cap V_i$. Then, the following shows that geographical routing can be naturally extended to geocasting.

Theorem 3: If the Voronoi views are complete, all nodes in the region R will receive the packet almost surely.

IV. Fast Handover with GPS

A major problem in Mobile IP arises in providing real-time services due to frequent handoffs resulting from mobility. During each handoff, the mobile registers to its home agent, which is the agent keeping mobile user current access point in the network, and loses the packets coming during the handoff. The most common way to make this handoff adjustment period faster is to send all packets to the potential future access points in addition to the current access point [4], [5], [6]. The assumption of these algorithms is the manual configuration of adjacent access points.

The usage of GPS in each access point together with the location advertisement messages eliminates the manual configuration of adjacent access points. Each access point contains a GPS device so knows its location. Location advertisement messages are used in order to send this location information to other access points. Each access point updates its table, the entries of which include the IP address and the location of each access point in the network, upon receiving location messages. The location advertisement messages are broadcasted either periodically or due to a change in the location of an access point or the addition of a new access point. We do not consider location messages as a burden on the network since the probability of a change in the place of an access point or the connection of a new access point is very low and the period of messages is very high, e.g. 1 day.

Putting GPS to mobile nodes in addition to the access points decreases the burden of extra data packets by decreasing the number of potential future access points. When the current access point of the mobile node knows the location of the mobile, it does not need to send to all of its neighboring access points. Instead, it can specify the access points that are in the direction of the mobile movement and only send to them.

This eliminates the packet loss in handoff and time interval between packets is reduced that is important for satisfying quality of service for real time data.

V. Integration of Sensor networks with GPS

Environmental monitoring through wireless sensor networks requires the determination of the physical location of each node. Naming sensor nodes with location instead of a particular ID is more suitable since the main focus will be on where instead of what is the ID of the sensor node the data, such as magnetic field data to detect car, is coming from.

Relying on GPS in all sensor nodes is impractical due to their power, cost and small size constraints. Clever localization techniques are essential to estimate the location of large proportion of sensor nodes based on RF communication with reference points containing a GPS receiver. These reference points, which can be mobile nodes with GPS receiver transmit a beacon signal containing their own location information in order that other sensor nodes can determine their approximate locations.

RF based localization can depend on either signal strength or connectivity. Signal strength based localization consists of measuring the signal strength of the received signals to estimate the distance from the transmitting end by using an outdoor radio signal propagation model[2]. This approach is discarded in sensor networks since at short ranges, fading, multipath and interference makes the signal strength uncorrelated to distance.

Connectivity based localization can be classified according to the density of reference points in the network. The reference points being dense means that their coverage include all the locations where the sensor nodes may be located with overlapping regions. As a result, each node hears at least one location information. One approach to this problem is to localize these nodes to the centroid of the reference points that they hear beacon[3].

If some sensor nodes cannot hear beacon from any reference point, more constraints are required on their location pattern in order to determine their position. For instance, in a parking lot, the pattern in which the sensor nodes are placed is predetermined in addition to the location of the base stations. The interesting problem here is to find the tradeoff between decreasing the density of the reference points and increasing the constraints on the location pattern of the nodes.

VI. Integration of the algorithm for the Scenario

The scenario consists of two threads; One of them is collecting information from sensors and sending them to the management center (see Figure 1.) and the other is performing handover.

When collecting data handover is not necessary because it is going to be one way from mobile to the foreign agent. Foreign agents advertise their presence by geo-casting to specific area, mobile roaming in the area learn its new care of address and GPS position.Mobile send their registration and connect to a foreign agent via GRA. When registered, mobile is ready to send and receive packets. While mobile is roaming mobile initiate wake up process for the sensors. This is same as advertisement messages but small scale. This procedure is used to form the ”mesh” network between sensors and the mobile. Since it is small scale, movement does not cause trouble. Each sensor who gets the message sets its gateway route and duplicate the messages. Message is limited by a hop-count number. Hop-count also used to eliminate loop route formation by assigning the hop count number as a level number for each sensor [3],[2]. Sensors send their data with these network to the mobile and mobile send them to its current foreign agent by using GRA. Sensor information is processed in management center and sent back to the mobiles who need information.

Mobiles periodically update their registration, in each registration update foreign agent learns the mobiles current position and estimate the prospective base stations on the mobiles way in order to send the packets. Foreign agent duplicate the mobiles packet to the adjacent foreign agents. When mobile reaches to another foreign agent‘s responsible area , it hears the beacons and send registration. If mobile hears more than one beacon, it select the one near.Foreign agent reduce the wireless bandwidth consumption, by suspending the packet transmission to a mobile, if the mobile reaches the vicinity of another foreign agent responsible area.It only sends the packets to the next foreign agent via wired network.

VII. Performance Analysis

In this section, we are going to investigate more the performance of GRA and FASTMIP. The performance of a routing algorithm can be measured in terms of the memory requirement at the nodes, and the bandwidth used due to the communication overhead. We quantify the performance of the algorithm by simulating the GRA running over random graphs of varying size. In each case, we sample enough random graphs to put our results

in a 95% confidence interval.
On the other hand, the performance of a handoff scheme can be measured in terms of the packet loss, throughput,time interval between packet reception in a handoff.

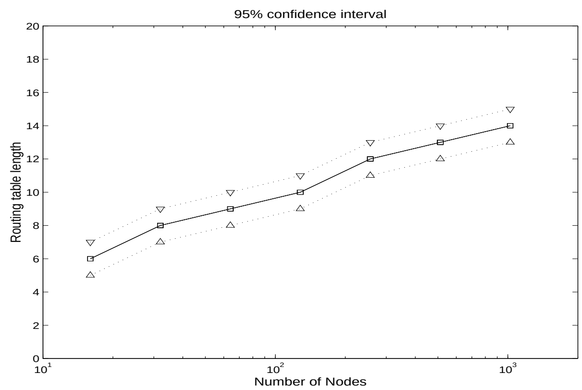

Fig. 2. Mean routing table size

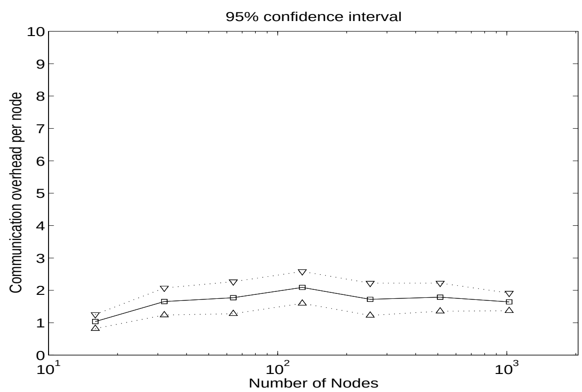

Fig. 3. GRA protocol packets per node

Figure 2 shows that the mean routing table size is small. In fact, for a 1024 node network, the mean routing table length is only 12.1. The plots show the 95% confidence interval for the mean with 50 simulation experiments.As expected, it grows with the size of the network. Some of this growth is the simply the growth in the number of neighbors.

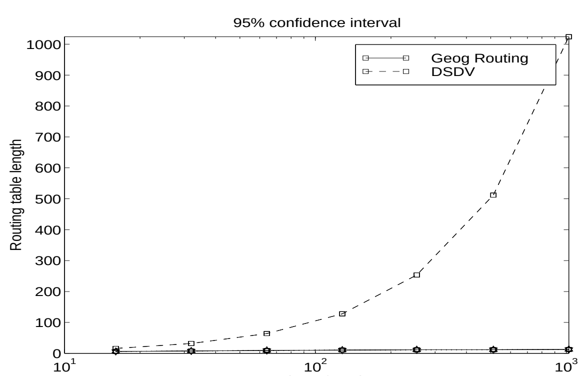

Fig. 4. Comparison of GRA with DSDV

Figure 3 shows that the small routing table sizes are achieved at very little communication overhead. The overhead in communication is because of the bandwidth used due to the route discovery packets and the updates.Figure 2 shows that geographical routing algorithm in a non-mobile network, achieves complete routing tables with communication overhead of less than two route discovery packets per node. The average number of protocol packets per node is approximately constant. Therefore the growth in the number of protocol packets is linear in the size of the network.

Figure 4 compares the mean routing table length of the GRA routing algorithm with other routing algorithms such as DSDV which need to keep all nodes in their routing tables.

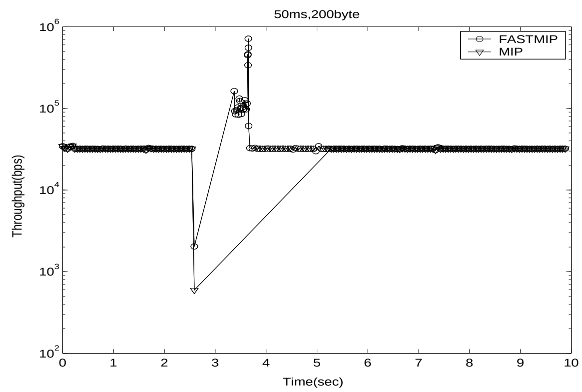

Fig. 5. Instantaneous Throughput vs Time packet rate=50ms

Figure 5 shows the instantaneous throughput during a handoff when the packet size is 200byte, which is an average real-time audio packet size, and inter-sending time is 50ms. This figure shows that basic Mobile IP (MIP) loses all the packets during handoff, which causes an unrecoverable throughput decrease for 3 seconds. These 3 seconds include the time necessary for the detection of the new access point, which is equal to beacon period(100ms) of access points at maximum, the time necessary for the registration request to reach home agent and for the registration request to reach the access point back. On the other hand, our scheme (FASTMIP) buffers the packets at the prospective access points and send the packets that the mobile missed during the handoff when mobile is connected. The period during which the throughput decreases is around 300ms, which is less than 3 sec in MIP since FASTMIP registration is done only to a specific foreign agent in the local region instead of the home agent in a far away network. In FASTMIP, although the instantaneous throughput decreases during handoff, it is compensated after the handoff by sending back the packets that mobile host has missed. Since this forwarding operation inter-sending time is less than 50ms(they are already in the buffer) the throughput is above the average throughput for about 500ms.

Figure 6 shows the instantaneous throughput during a handoff when the packet size is 200byte and inter-sending time is 20ms. The throughput graph behaviour for Mobile IP is the same as that with 50ms inter-sending time. The reason is that the handoff time 3 sec does not depend on sending rate and the inter-arrival of packets reaches the average value since there is no compensation for packets lost. However, the fast MIP behaviour ????????

The overall throughput graph for different rates, as given in Figure 7, shows that the throughput increases as the sending rate increases and FASTMIP performs better than MIP. The reason for the throughput increase is that more packets are sent overall although the number of packets lost increases as the sending rate increases. FASTMIP performs better than MIP since the number of packets lost is smaller in FASTMIP as we have seen in instantaneous throughput graph.

The number of packets lost depends both on the size of buffer used to store packets for potential handoffs and the sending rate as seen in Fig. 8. The number of packets lost is constant for MIP since no buffer is used and increases as the sending rate increases since more packets are sent while mobile is unable to receive during handoff. On the other hand, the number of packets sent decreases as buffer size increases for FASTMIP. This means that the packet loss can be totally eliminated if the buffer size is chosen large enough. Furthermore, this buffer size can be adjustable to the sending rate since the number of packets lost increases as sending rate increases for constant buffer size.

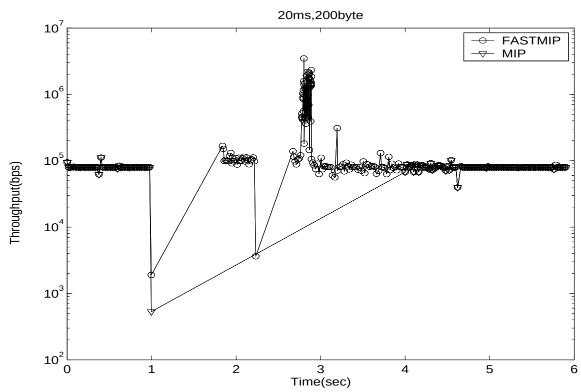

Fig. 6. Instantaneous Throughput vs Time packet rate=20ms

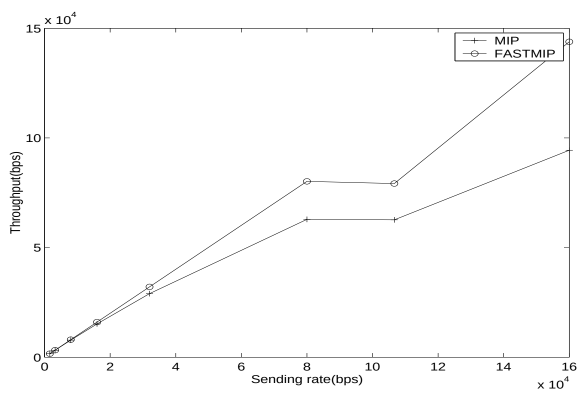

Fig. 7. Throughput vs Rate

VIII. Conclusion

In this paper, we have proposed novel routing and fast handover protocols for ad hoc networks using geographical information of the nodes.The basic intuition behind the routing algorithm is that to route a packet far away from the destination, only a ”coarse” knowledge of the network topology is required. As the packet reaches near the destination, nodes in that area are expected to know the topology around the destination in greater detail and will be able to route the packet to the destination.

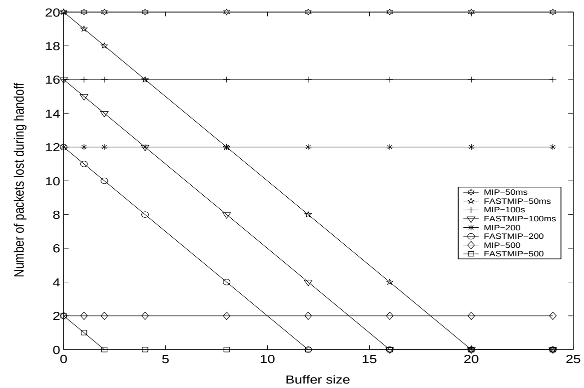

Fig. 8. Packet Loss vs Buffer Size

Fast handover protocol leverage the position information and eliminates the packet loss during a handoff by sending multiple copies to the prospective bases.

This algorithms are integrated to a scenario where sensor network , ad hoc network and Mobile IP is involved. Sensors form a ”mesh” network and connect to a mobile node.Mobiles form an ad hoc network connect to a fixed base station. This network is intended to satisfy traffic management and Internet service for mobiles.

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