Dynamic Source Routing for Ad Hoc Networks Using the Global Positioning System

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Abstract— **This paper proposes a new routing protocol for ad hoc networks built around the source routing technique combined with the location (e.g., GPS coordinates) of nodes obtained by an energy and distance smart dissemination mechanism. The key new observation used is that the location information provides each node with a snapshot of the topology of the complete network from which a source route may be computed locally rather than through route discovery. The resulting protocol has reduced delay, and is more bandwidth and energy efficient, than both traditional (proactive and reactive) ad hoc routing protocols, as well as location based routing protocols.**

I. Introduction

Routing a packet from a source to a destination in an *ad hoc network*, i.e., a wireless network in which all the nodes are free to move randomly and organize themselves arbitrarily, is a challenging problem. The main source of the challenge comes from the fact that there are no base stations in these networks, and therefore the nodes themselves must also function as switches, forwarding packets to their destination while coping with the dynamically changing network topology.

Depending on how a route is determined, existing routing protocols for ad hoc networks fall into two main categories. In *proactive* protocols, a route between the source node S and the destination node D is immediately available because each node maintains a routing table giving the node that is the "next hop" on the route to D. Maintaining these routing tables requires each node to exchange routing tables with its neighborhood whenever a topology change is detected, and then recompute the routes based on the updated information. Protocols in which a *route discovery* phase precedes the transmission of a data packet are called *reactive.* In a reactive protocol, the route is determined only when needed. In addition to incurring delay due to the route discovery process, there is no guarantee that the route discovered is usable because of node mobility.

In both categories of protocols, the information on the route between S and D is given in terms of the topology of the network, meaning the route is given as a sequence of nodes. The route is explicitly specified in reactive protocols, whereas in proactive protocols it corresponds to a sequence of next hop table lookups at each node along the route. Since in ad hoc networks the topology may change rapidly and unpredictably, this implies that a large part of the network's limited bandwidth and, consequently, each node's limited energy, has to be used either for updating or gathering routing information.

In an attempt to overcome the drawbacks derived from the dependency between the routes and the topology of the network, routing protocols have recently been proposed in which each node stores information about the (geographic) *location* of each other node [1], [5]. In these solutions the source node S can compute the (geographic) area in which D is expected to be found and send the packet to all nodes in D's *direction.* Both these solutions assume that each node is aware of its current location through the use of, for example, Global Positioning System (GPS) receivers available at each node.

The routing protocol described in this paper combines the advantages of reactive protocols, such as the Dynamic Source Routing (DSR) protocol presented in [4], with the improved performance that is typical of the location based solutions. As in the DSR protocol, when the source node S of a data packet goes to transmit the packet to D, it includes the complete route the packet is to follow in the packet header ("source routing"). Each intermediate node on the designated route will forward the packet to the next node on the route itself until D, if possible, is reached.

Using the location dissemination mechanism described in our previous work [1], we maintain at each node a location table that contains for each other node it's location given as GPS coordinates. The key new observation used is that the location table may not only be used to determine the direction of a given node from the source, but it also provides a snapshot of the entire network topology. Given a bound on a node's *transmission radius*, i.e., the distance at which its transmissions can be received, each node not only knows the positions of all nodes, but can also compute the neighbors of each node at the time it

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sent its last location update. Thus, the route to the destination may be computed locally *without* the need for a route discovery phase and its associated delay.

Specifically, when a new data packet is ready to be sent from S to D:

- S constructs from it's location table a representation of the topology of the network, i.e., a graph representing the node connectivity;
- S locally computes a route to D (e.g., the shortest path, or the *best* path according to some routing criteria), and then, if a route physically exists between S and D,
- S transmits the packet, that includes the route the packet is to follow, to the first node on the computed route to D.

Through the use of simulation, we show that the average delay of routing a packet between any two nodes is always less than the average delay of the solutions mentioned above. The reduced delay occurs since we eliminate the overhead of reactive protocols. Specifically, no route discovery phase is ever needed and no route maintenance needs to be performed (reporting of broken links, i.e., edges that become unusable in the graph). There are several reasons why our solution is more bandwidth and energy efficient. Compared to location based routing methods, in our solution, a data packet is sent along a single route instead of to all the nodes in the direction of D. Therefore, fewer copies of the same packet are traveling through the network. As well, the location information that is disseminated is very small in terms of the number of bytes transmitted when compared with routing tables exchanged by proactive protocols. These properties make our protocol suitable for ad hoc networks with a higher packet arrival rate, where previous solutions become unstable.

The remainder of this paper is organized as follows. Section II explains how a location table is maintained at each node using an energy and distance smart dissemination mechanism, and how a graph representing the network topology can be constructed from the contents of the location table. Section III describes the new routing protocol that combines the source routing technique with the graph obtained from the location table information. The simulation results showing the advantages of this combined approach are presented in Section IV. Finally, our conclusions are found in Section V.

II. GPS Based Topology Representation

As in other location based routing protocols, we assume that each node is aware of its own (geographical) location. Using a Global Positioning System (GPS) receiver, a node can receive GPS broadcasts and compute its three-dimensional coordinates (latitude, longitude, and altitude), velocity, and even the current "global" time, with extremely high precision.

In order for the nodes in an ad hoc network to become location aware, i.e., each node is aware of the location of *all* other nodes, each node floods the network with a *location packet* containing its current location. Upon reception of a location packet from a node B, a node A updates its *location table* that stores, for each other node, B's location. In order to meet the requirements of ad hoc networks, our dissemination mechanism is tailored to minimize bandwidth and energy usage. This is achieved by transmitting the small, constant size location packets at a frequency, and for a distance, that is locally optimized by each node depending on its velocity. The accuracy of our dissemination mechanism, as well as its effectiveness in supporting location based routing in ad hoc networks, has been studied and presented in [2] and [1], respectively.

Given the location table, and a bound on the transmission radius of each node[1], it is straightforward to compute which nodes are in the transmission range of each other node in the network. In graph theoretic terms, this means to construct from the location table the *undirected graph* $G = (V, E)$ representing the network topology (i.e., where nodes are positioned and how they are connected), where V is the set of network nodes, and E is the set of bidirectional radio links. An edge $(A, B) \in E$ between two nodes A and B means that the nodes A and B are in the transmission range of one another. Such a graph represents a "snapshot" of the network topology. Note that G can be constructed efficiently, in time polynomial in n, the number of the nodes of the network, and thus it only imposes a negligible overhead for a node.

III. Dynamic Source Routing Using GPS

Source routing is a routing technique that has been used in a number of contexts in wired networks (see, e.g., [3], [6]) as well as in wireless networks. The basic idea of source routing is that the sender (or "source") of the packet determines the complete sequence of nodes through which to forward the packet. The source then explicitly lists this route in the packet header, specifying each forwarding "hop" by the identifier of the next node to which to transmit the packet on its way to the destination.

In the Dynamic Source Routing (DSR) protocol [4] for ad hoc networks, due to the rapidly changing network topology, a route discovery is used to dynamically discover a route to any other node in the network in an "on demand" fashion. This is achieved by the source broadcasting a *route request* packet specifying the intended destination. On reception of a route request by a node that is not the intended destination, if this node has not already

[1]The transmission radius of a given node may also be included in the location packet without affecting the efficiency of the dissemination mechanism.

processed this packet before (to prevent looping and stop the flood associated with the route request), it will append its identifier onto the route in the packet header and re-broadcast the packet. If the receiver of the route request packet is the intended destination, then it returns a *route reply* packet to the initiator of the route discovery, following the newly constructed path in the reverse order.

In DSR, each node also maintains a route cache which is checked prior to initiating a route discovery in the case a route to the destination has previously been discovered and is still considered usable. Aggressive caching techniques, promiscuous learning of routes, and route maintenance (monitoring of the status of a source route while in use) are all used in order to reduce the overhead and delay associated with route discovery and improve the efficiency of the routes used.

We propose a dynamic source routing technique for ad hoc networks combined with network location awareness. Every time a node has a packet to transmit, it computes from its location table obtained through the dissemination mechanism, the graph G representing the "current" network topology. Then, it applies to G, *locally*, a (centralized) algorithm for the determination of a *minimum cost path* to the destination. We associate a cost of 1 with each edge of the graph. Thus, the total cost represents the total number of transmissions (hops) a packet must take to reach the destination. Therefore, a minimum cost path minimizes the overall transmission time, the related energy consumption and the overall needed bandwidth.

Once the source route is computed, the packet is processed in a manner similar to any source routing protocol. Namely, the obtained source route is included in the header of the packet, and the packet is transmitted in a hop-by-hop fashion to those nodes on the path.

Our resulting routing protocol is simple and easy to implement, relying only on a bandwidth and energy efficient dissemination mechanism, rather than on the route request and reply control packets required by DSR. As well, our protocol does not require any complex route caching schemes, nor any route maintenance to be performed, without which DSR would not be a competitive routing protocol.

IV. Simulation Results

In this paper, we have simulated our dynamic source routing protocol that is combined with the location of nodes (henceforth, we will refer to our protocol as DSR-GPS) and compared it to a simplified version of the Dynamic Source Routing (DSR) protocol [4]. Specifically in DSR-GPS, when a packet arrives at a source node S with destination D, S computes the graph G representing the network topology, and then uses a breadth first search on G to find the shortest path to D (to minimize the number of transmissions). In DSR, the source node S initiates a route discovery to D by broadcasting a route request packet and waiting for the associated route reply. S buffers the packet while waiting for the route reply and can process other control and data packets during its wait. Route caching and route maintenance was not implemented in order to compare the performance of the two different forms of route discovery. After obtaining a source route, both DSR-GPS and DSR process the packet in the same manner.

We have developed a discrete event simulator of an ad hoc network, implemented in C++, and modeled the DSR-GPS and DSR routing protocols in the network.[2] Each of the $n = 30$ nodes of the ad hoc network can freely move around in a 1000×1000 meter region (modeled as a grid) according to the following "inertia" mobility model. (To ease the modeling, the node movements are discretized to grid units with a grid unit equal to 1 meter.) Each time a node moves, it determines its direction randomly, by choosing between its current direction (with 75% probability, i.e., it has a certain inertia to keep moving in its current direction) and uniformly among all other directions (with 25% probability). The node then moves in the chosen direction according to its current speed. When a node reaches a grid boundary, it bounces back into the region with an angle determined by the incoming direction.

Each node has a fixed transmission range of 350 meters since we found that this value results in high network connectivity, i.e., after network topology changes, the network was connected in more than 95% of the cases.

Each node is modeled by a store-and-forward queue, with buffer space that is 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 Mbps. Control packets (location packets in DSR-GPS, and route request and reply packets in DSR) and data packets share the same transmission channel. The control traffic has higher priority than data traffic and is always processed first. Thus, the control traffic may be affected by the network load, and the transmission of data packets may be slowed down by the transmission of control packets.

Each control (location) packet in DSR-GPS contains time-stamped, node identified, position coordinates. These packets are generated every time a node moves (i.e., at a frequency that is a function of the node velocity; see also [2]). Each control packet in DSR contains a source and destination identifier, a source route, and a unique identifier. In both protocols, data packets contain a payload that is 1K in size, as well as the source, destination, and source route in the packet header.

A data packet was considered to be successfully routed

[2]Currently, our study is limited to network-layer details, thus no link- or physical-layer are modeled.

if the source route discovered, and included in the packet header, could be followed in a hop-by-hop manner all the way from the source to the destination. If, because of a change in the network topology the next hop was unreachable (i.e., no longer in transmission range) then the packet was considered to be unsuccessfully routed. For DSR-GPS a routing failure could also occur if the source and destination were in different components in the topology graph G (i.e., no path existed between S and D in the graph). In DSR, a routing failure could occur if the route reply was never returned in response to a request. This is detected by having the buffered data packet time out. In both DSR-GPS and DSR, if the source route could not be obtained, the packet was simply dropped. In our simulations, data packet arrivals are distributed exponentially with a mean of 100ms.

Figure 1 shows the percentage of successfully routed packets in DSR-GPS and DSR for nodes whose velocity varies from 6m/s to 20m/s, i.e., from around 20 km/h to around 70 km/h. In DSR-GPS the routing success is always more than 99% due to accuracy of the dissemination mechanism and the fact that the local source route computation is performed with constant delay at the node. The routing success of DSR decreases with increasing node velocity since the source route becomes more vulnerable to failure with increasing network mobility.

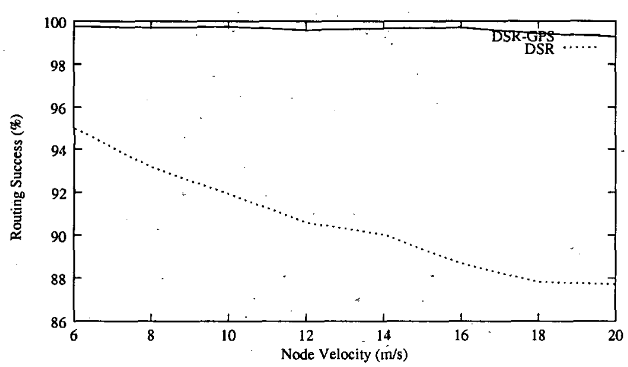

Fig. 1. Percentage of successful routing as a function of node mobility.

The delay experienced by a data packet was computed by subtracting the arrival time of the packet at the source node S from the time of its delivery at the destination node D. Since a source route must be obtained before the data packet can be transmitted, this delay measure also includes the delay incurred by the route discovery (a constant time in DSR-GPS, and a variable time in DSR). The global average delay was computed by simply averaging the delay for each successfully routed data packet. Figure 2 shows the global average delay of successfully routed data packets in DSR-GPS and DSR again for nodes whose velocity varies from 6m/s to 20m/s. The global average delay for DSR-GPS is roughly 40ms for all node speeds whereas the delay for DSR ranged from 10 to 50ms higher. This is, in part, due to no attempt being made to build or return the shortest source route during route discovery. As a result, significantly longer routes than that obtained by the shortest path algorithm resulted, with the associated transmission delay for each hop in evidence in the delay.

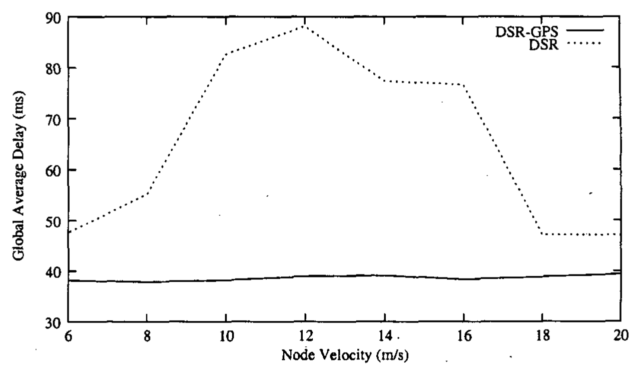

Fig. 2. Global average delay as a function of node mobility.

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

V. Conclusions and Future Research

In this paper we have described how network location awareness, obtained through GPS receivers and the efficient dissemination of location information, can be combined with source routing to obtain a new routing protocol (DSR-GPS) for ad hoc networks. The route discovery is performed locally at the source when a data packet arrives. The source first computes a graph that represents the the network topology using its location table, and then computes the shortest path to the destination on the resulting graph as the source route. This route is then included in the packet header, with the route followed in a hop-by-hop manner as in all source routing techniques.

Through the use of simulation, we have shown that the global average delay of routing a packet between any two nodes in DSR-GPS is always less than the global average delay of a simplified DSR, a source routing protocol for ad hoc networks, for varied network speeds. The reduced delay occurs since the overhead associated with the route discovery, implemented by flooding the network with a route request, followed by a route reply that follows the discovered path in reverse, is eliminated. The success rate of routing is also higher in DSR-GPS than in DSR since the likelihood that the source route discovered is usable is reduced by the delay of the route discovery process itself and node mobility.

Our solution more bandwidth and energy efficient since in DSR-GPS we disseminate very small, constant size location packets compared to control packets bearing variable length source routes in DSR. When compared to location based routing methods, DSR-GPS is also more bandwidth and energy efficient since a data packet is sent along a single route instead of to all the nodes in the direction of the destination.

Finally, variations and optimizations of the basic DSR-GPS protocol can be studied to further improve its performance in case of route failure due to node movement. Here, we can apply techniques similar to those found in reactive approaches, namely, route caching, route recomputation at intermediate nodes, and route repair—all done as local computations. The resulting protocol should be compared to to DSR with similar enhancements.

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