"Direction" Assisted Geographic Routing for Mobile Ad Hoc networks

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Abstract—In Geographic Routing protocols (e.g., GPSR), a node makes packet forwarding decisions based on the coordinates of its neighbors and the packet's destination. Geo-routing uses greedy forwarding as a default; if this fails (e.g. the packet is trapped in a dead end caused by holes and/or obstacles), a recovery scheme based on perimeter routing is invoked. This however often leads to degraded performance.

In this paper, we present a hybrid routing scheme called Geographic Direction Forwarding Routing (Geo-DFR), which features efficient recovery from dead ends. Geo-DFR integrates on demand, table driven routing with geo-routing. During the data transfer, periodic routing advertisements from the destination help to track node motion and to update/maintain a feasible direction to the destination. Direction Forwarding in Geo-DFR is designed to complement and even replace perimeter routing in dead end recovery. With the help of a local coordinate system (e.g., GPS or virtual coordinate system), a node derives the direction of the arrival of the advertisements. A packet is first forwarded to the neighbor which yields the most progress towards the destination, i.e., greedy forwarding. If greedy forwarding fails, the packet is “directionally” forwarded to the “most promising” node along the advertised direction, i.e., direction forwarding. Moreover, the direction can be used proactively for “early dead end detection” to decide which forwarding scheme should be used to avoid getting stuck, which is opposed to GPSR in which perimeter routing is applied only after greedy forwarding fails. Through simulation experiments we show that Geo-DFR substantially improves the performance in large, mobile network scenarios.

I. INTRODUCTION

Network scalability is one of the critical challenges and requirements in designing routing protocols for wireless ad hoc networks. It is important to guarantee a good scalability to dynamic ad hoc networks when the number of nodes, the traffic load and the mobility rate increase. Many scalable approaches have been proposed [1, 2, 3], which are based on either table-driven forwarding or geo-forwarding. Table-driven routing (such as proactive link-state or distance vector routing protocol) permits the calculation of the best path towards the destination by knowing the network topology. The best path is in terms of different metrics such as the number of hops, delay, bandwidth, or link stability, etc. The drawback of table-driven routing schemes is that the increase in routing table size reduces the scalability when the number of nodes increases. In addition, the increase in link control overhead for a table-driven routing protocol results in a reduction of bandwidth availability.

On the other hand, geo-routing uses the physical positions of routers and the destination of packets to make decisions on packet forwarding [4]. Geo-routing only keeps the states of local topology, thus reduces control overhead effectively. Most geographic routing protocols use greedy forwarding as their basic mode of operation, where the next forwarding hop is the closest node to the destination among its neighbors. Greedy forwarding, however, fails in the presence of a void or an obstacle [1, 4]. In the presence of a void, face routing has been proposed to route around the void, which uses the perimeter mode packet forwarding via a planar graph traversal. Heavy control overhead is observed in perimeter mode forwarding and the need of Geo Location Service to learn the destination coordinates further degrades the performance of geo-routing. In summary, Geo-routing has two limitations to scalability: the difficulty in overcoming voids and obstacles, and the need to maintain and access a Geo Location Server. Either factor leads to extra overhead that eventually drives performance down as network size and traffic load increase.

To overcome the above problems, we propose a novel routing scheme Geo-DFR (Geographic Direction Forwarding Routing) which combines the advantages of geo-routing schemes and table-driven routing schemes. When a source initiates a communication session, it first discovers the destination in on-demand fashion. Once the destination is notified by the communication request, it initiates periodic routing updates and other nodes participate in propagating the updates in proactive fashion. There are two key features in Geo-DFR: 1) the geo-location of a destination is piggybacked by proactive routing updates so that a global coordinate system, or a Geo-Location Server, is not required; 2) when the routing update arrives, the node remembers not only the predecessor delivering the update but also the update direction of the arrival from proactive routing updates.

Geo-DFR uses greedy forwarding as its basic mode of operation to handle high mobility scenarios in ad hoc networks. However, if the selected next hop is not satisfied with the “Direction” condition due to the presence of holes/obstacles, Geo-DFR switches to “Direction” Forwarding Routing (DFR) for forwarding packets to the destination. DFR [5] is initially designed to overcome the “stale” next hop problem. In DFR, when a packet is forwarded to destination, it is first forwarded to the node ID found in the routing table. If the node has moved and ID forwarding fails, the packet is “direction” forwarded to the
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GOAFR [14], try to use geographic information (typically
from GPS) to achieve scalability [1]. In geo-routing, packets
are forwarded to the next hop which yields the most progress
towards the destination (greedy forwarding). When the
greedy process fails, it switches to the face routing in
perimeter mode which forwards the packet using a planner
graph traversal. Position-based routing does not require the
establishment or maintenance of routes. The nodes neither
have to store routing tables nor need to transmit messages
within the overall network to keep routing tables up-to-date.
The above features provide the scalability of geo-routing
protocols and robustness to mobility. But the huge overhead
with face routing and the request of geo location service limit
its further applications.

Recently several new hybrid protocols, which use the
geographic information to forward packets to a remote
destination and use proactive routing to a local destination,
are proposed. Terminodes routing [15] is a good example of
this class of protocols. In Terminodes routing, the link state
routing is applied for the local routing within the local scope
of two hops, while geo-forwarding is used for long distance
routing. This protocol presents more accurate information in
the local view and less accurate information for long
distances. Geo-LANMAR [16] is similar to Terminodes

routing, which also combines proactive schemes in the local
scope and long haul distance geo-routings. It achieves good
scalability by exploiting group mobility in large ad hoc
networks.

However, none of the above routing protocols
overcome the "stale" next hop problem in table-driven
routing or the "void" problem in geo-routing. None of them
uses Directional Forwarding which is the main component of
Geo-DFR. Direction Forwarding (DFR) [5] is initially
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indicated direction.

Geo-DFR extends such characteristics of the DFR to
handle the "void" problems of geo-routings to avoid the
"perimeter re-routing", which is one of the main purposes
of the paper. Compared to initial DFR, the default operation of
Geo-DFR applies the greedy location-based packet
forwarding, the main benefit offered by position-based
routing protocols in terms of network scalability. Geo-DFR
also uses on-demand route discovery, which reduces the
overhead of proactive route discovery in DFR. The
extension of virtual coordinate system without GPS makes
Geo-DFR more practical than DFR.

III. GEO-"DIRECTION" FORWARDING PROTOCOL

There are two kinds of packet forwarding modes in the
Route Forwarding phase of Geo-DFR: geo packet
forwarding (Greedy forwarding) and direction packet
forwarding (Direction forwarding, DF). Greedy forwarding
is used as the default mode of operation and Direction
forwarding is used when greedy forwarding fails or is not
suitable. The direction information (from rough knowledge
of network topology) is also utilized to decide which
forwarding mechanism is proper to forward packets
efficiently and correctly.

A. Greedy Forwarding

Geo-DFR makes a greedy forwarding decision based on
location information of neighbors and the packet's
destination. Packets are forwarded to the next hop which
yields the most progress towards the destination along the
direction for the destination. The position of the destination
is obtained via routing updates.

B. Direction Forwarding

When a routing update in Geo-DFR arrives, the node
records not only the predecessor delivering the update, but
also the direction of the arrival. If Greedy forwarding fails,
the packet will be forwarded by Direction Forwarding, i.e.,
the packet will be forwarded to the most promising node in
the indicated direction. If the network is sufficiently dense,
direction forwarding will be able to find next hop along the
indication to the destination so as to recover from Greedy
forwarding failures.
It is worth noting that Geo-DFR learns the direction from the routing updates, instead of being computed from the destination coordinates. Thus, Geo-DFR itself does not require destination coordinates, global coordinate system, or Geo Location Server.

1) Computation of the direction to the predecessor.

Once a node receives an update of a destination from a neighbor with minimum hop distance, the node simply learns geo coordinates of the predecessor from the update, or consults a cache named “neighbor coordinate cache” to get the coordinates of the predecessor. If GPS is not available, a virtual coordinate system can be used. The neighbor coordinate cache is maintained with information extracted from local routing updates. The direction to the predecessor is computed based on the node’s current coordinates and the predecessor coordinates.

2) Update the direction to a destination

A node may receive more than one update from different predecessors with the same minimum hop distance and sequence number for the same destination. Thus, we need to aggregate the updates to get an accurate direction to the destination. The order of addition does not matter since unit vectors are used in Geo-DFR to combine the directions. If a distance vector update with a new sequence number or same sequence number but smaller hop distance to the destination is received, the direction of the destination will be reset.

C. Geo-DFR based on Fisheye State Routing (FSR)

In this paper FSR is the protocol “hosting” Geo-DFR. FSR protocol is a proactive routing protocol based on Distance Vector (DV). FSR features gradually reduced propagation frequencies of DVs to nodes further and further away. In our design, each remote destination broadcasts DV routing updates periodically using different frequencies depending on the destination’s distance. The location of the destination is also embedded into routing updates. Moreover, proactive Link State (LS) routing is applied in a local scope. Within local scopes, each node broadcasts its topology information at most K hops away. The neighbor’s coordinates are piggybacked in local routing updates. Thus, each node has accurate routing information, including neighbors’ coordinates, of all nodes up to K hops away. In order to reduce local update routing packet size, the local scope size K is set to 2 in Geo-DFR and each routing update only includes its neighbor information.

In Geo-DFR, each node has one neighbor coordinate cache, one Direction cache, and one local routing table. The neighbor coordinate cache at a node keeps the coordinates of all of its neighbors within its scope. The Direction cache keeps the directions to all remote destinations computed based on DV updates and neighbor coordinates. It also keeps positions of remote destinations discovered through propagated DV routing updates. The direction cache is refreshed periodically and its entries are expired after a pre-specified timeout. The refresh time of these entries is related to the mobility of nodes in the network. If the nodes seldom change their position, long refresh time can be used so that the Direction cache is refreshed less frequently. Positions of remote destinations are only used for greedy forwarding. The local routing table is built / maintained by the local scoped proactive routing protocol. It provides exact routing information to any nodes within the local scope.

D. Choice of the Greedy Forwarding and Direction Forwarding

In previously proposed geo-routing protocols, greedy forwarding is used when possible, which means that a packet is always forwarded to the neighbor geographically closest to the packet’s destination until either its destination or a local maximum (hole/obstacle) is reached. Obviously, when a packet reaches a local maximum, a recovery strategy is needed. The recovery procedure degrades the performance if this procedure is frequently applied. The drawback of this approach includes failure to find the shortest path around the hole/obstacle, and the inability to utilize the global topology knowledge. In Geo-DFR, since a node not only keeps the predecessor delivering the update but also tracks the update direction of the arrival, which helps to select an optimal next hop around an obstacle or a hole by utilizing the direction towards the destination. For example, in Geo-DFR, the greedy forwarding is only applied when the direction of candidate next hop is consistent with the direction computed from the destination coordinates. Practically, in our implementation, Geo-DFR uses greedy forwarding to route packet if and only if the difference of the two directions is not less than p/2. Otherwise, DFR is used to forward a packet to its destination. A simple example of switching between greedy forwarding and direction forwarding is illustrated in Figure 1. Here, a packet from node G travels through path (G→H→B→...→D) to its destination, instead of path (G→H→E→F→...→E→B→...→D) since the difference of the two directions at node H is greater than p/2 that detects a hole/obstacle ahead. Thus, node H switches to direction forwarding from greedy forwarding.

Figure 1. Greedy forwarding fails. F is a local maximum in its geographic proximity to D.
E. DFR without GPS

In general, location information can be obtained by using GPS. But GPS is expensive and does not work indoor environment. Recently several localization schemes have been proposed to compute virtual coordinates to replace real coordinates for sensor networks where nodes rarely move. Those schemes induce the locations of nodes from their local interactions, such as the detection of local neighbors and/or distances between neighbors. Many of them assume the existence of a number of anchor nodes whose positions are already known. In order to generate a set of virtual coordinates inside a shaded area, say indoor where GPS is not available, we design a simple local reference system with a number of anchor nodes. An anchor node periodically broadcasts beacons including its ID without its position information. Beacons from different anchor nodes partition the shaded area into sections. Based on received beacons, a node can distinguish which section it is participating. We use a list of anchor node ID to represent a section. A simple example of a local reference system is illustrated in Figure 2. There are 5 designed anchor nodes and beacons from those anchor nodes cover the entire shaded area. Thus, the shaded area is partitioned into 14 sections.

![Figure 2. Local reference system with 5 anchor nodes](image)

In Geo-DFR, if the geo-location of a destination which locates inside a shaded area can not be obtained, the packets to the destination would be forwarded by using DFR purely. Moreover, inside a shaded area, the direction learned form the routing updates should point to the section from which the node first receives a routing update with a minimum hop distance. A packet is first forwarded to the node ID found in the routing table. If the node has moved and ID forwarding fails, the packet is forwarded to the most promising node in the indicated section. As for handling the "boundary" between indoor (no GPS) and outdoor (GPS) the simplest way is to consider only two directions (for the nodes that can hear both GPS and non-GPS nodes): into the building (tunnel etc) and out of the building. In other words, if an internal node gets the advertisement from an external node, it will mark the direction as pointing out. So, if a packet arrives from the interior to a boundary internal node, the node should seek an external node whenever possible.

F. Packet Forwarding Procedure

In this subsection, we describe the procedure of data packet forwarding in Geo-DFR. As we discuss above, Geo-DFR is able to make the best choice of the forwarding method between greedy forwarding and direction forwarding.

In Geo-DFR, when a data packet needs to be routed, the node will first consult with the local routing table which provides accurate, up-to-date routing information to nodes within local hops. If a route is found, the packet is routed directly by using the local routing table. If its destination is a remote node which is not in the local routing table, the source initiates the routing discovery in an on-demand fashion. Once the destination receives the request, it starts to advertise its existence (via periodic location beacon) to its neighbors. Upon receiving the beacon update, the neighbors update their route information, (i.e. next hop ID and direction) to the destination. In turn, every node periodically beacons to its neighbors if it has heard advertised routes from destinations, and it also updates its routing information when receiving such advertisements from neighbors. Thus, a proactive procedure is started by the destination when the source initiates the communication session. The proactive beacon stops if the destination receives no data for a predefined timeout since the source may have already finished the data transfer. By the above discovery procedure, the source or any intermediate node can check its local routing table or caches for grabbing geo-coordinates of destinations and directions to destinations in order to route packets towards remote destinations by greedy forwarding. If there is a dead-end or no next-hop for the destination (e.g. the link to the next-hop is broken), the "direction" cache still can be used to forward the packet (direction forwarding). Once the packet closes to its destination, it will be forwarded via the local routing table.

IV. PERFORMANCE EVALUATION

A. Simulation Environment

We use QualNet simulator [17], a packet level simulator to evaluate the proposed Geo-DFR routing scheme. The main purpose is to verify its scalability and flexibility in various scenarios. In our simulations, standard IEEE 802.11 radios are adopted with a channel rate of 2Mbps and transmission range of 367 meters. Randomly generated UDP based Constant Bit Rate (CBR) traffic is used for evaluation. The routing protocols selected for comparison are GPSR and AODV routing. In our experiments, the random waypoint mobility model [18] is used with varying speed from 0, 5, 10, 15, to 20m/s. Also a short pause time of 10 seconds is applied in the mobility model to ensure frequent topology changes. All experiments run 600 seconds.

B. Traffic pattern

The Constant Bit Rate (CBR) traffic pairs are spread randomly over a network. 80 source-destination pairs are randomly selected among all nodes in all experiments and the duration of each traffic is about 580 seconds. The size of data payload is 512 bytes and the inter-arrival time of the...
data packets on each source/destination connection is 1 second to model an interactive environment.

C. Performance Metrics

Performance Metrics selected include 1) Data packet delivery ratio: the ratio between the number of data packets received and those originated by the sources; 2) Average end-to-end packet delay: the average time from when the sources generate the data packets to when they reach the destination nodes; 3) Routing overhead: the total routing control overhead in bits/sec; and 4) Aggregated throughput: the aggregate of the throughput of all CBR connections, computed at each destination node.

D. Performance as a function of speed

In the first set of experiments, we investigate the stabilization of the Geo-DFR scheme under various motion speeds to see the impact of mobility on performance. We run simulations with 225 nodes. The 225 nodes are equally distributed in 9 groups and all groups are deployed in a 2250m by 2250m network field. The simulation results are presented from Figure 3 to Figure 7.

First, let us compare the results shown in Figure 3 and Figure 4. In Figure 3, there is no distinction between packet delivery failure due to routing failure and topology disconnection. Clearly the latter is not the responsibility of routing. We have run another set of experiments in which we didn’t count the drop in the latter case. The results in Figure 4 show that Geo-DFR obtains above 95% delivery ratio even for the scenario with mobility of 20 m/s when the network disconnected cases are not counted. This is an enormous improvement with respect to all other routing protocols that deliver less than 70% packets! At high speed, a local planarized graph used in GPSR changes frequently, which may degrade GPSR performance as reported in Figure 4. AODV gives the worst performance since it generates more routing overhead to recover link failures.

The aggregate throughput results in Figure 5 confirm these findings. Note that the lower delay (see Figure 6) is due to lower overhead (see Figure 7).
In the second set of experiments, we further investigate the stabilization of the Geo-DFR scheme in a network with an obstacle as shown in Figure 8. In this scenario, the number of mobile nodes increases to 500. All nodes are equally assigned to 20 groups and all groups are deployed in the open space in 3750m by 3750m network field. The nodes can not travel in/throughout the obstacle and they move following random waypoint mobility model described above. The simulation results are presented from Figure 9 to Figure 11.

The higher efficiency of Geo-DFR is also shown in the scenarios with the increasing network size and with an obstacle. From Figure 9, we observe that Geo-DFR always obtains the best packet delivery ratio no matter which motion speed is. Compared with the first set of experiments, GPSR degrades its performance when an obstacle exists. The perimeter mode is used more frequently to overcome the obstacle. During our experiments, we also note that the average of path length in GPSR is 14.5 which is extremely higher than 7.8 in Geo-DFR at speed = 0m/s.

In this subsection, we repeat the first set of experiments in the network with shaded area as shown in Figure 12. In a shaded area (e.g. in a building), nodes can travel around, but can not obtain their geo-coordinates via GPS since the signal of GPS is not available. In order to make geo-routings work in such area, we apply a local reference system with 5 anchor nodes in each shade area, respectively as shown in Figure 2. So nodes in the shaded area can obtain their virtual coordinates by processing received beacon messages.

Figure 13 shows the packet delivery ratio as a function of speed. Geo-DFR still performs better than GPSR as we expected. However, Geo-DFR degrades its performance from 95% (in subsection IV-E) to 87% due to the simple local reference system used in our experiments. In the future, we may need to do more study to explore local coordinate techniques for improving Geo-DFR performance.
In this paper, we have identified the problems associated with current widely deployed MANET routing protocols. Routing protocols in geo-routing category, which based on local planarized graphs, may not work well in networks where holes and/or obstacles present; on the other hand, table-driven routing schemes are vulnerable to high mobility scenarios where an entry easily goes stale if a node moves away. To overcome the above problems, we have proposed a more robust routing protocol called Geo-DFR (Geo-Direction Forwarding Routing), which combines Greedy Forwarding scheme and a novel table driven routing scheme called Direction Forwarding Routing (DFR). DFR makes forwarding decision not only based on predecessor IDs but also based on directions of arrivals (obtained from routing updates). We have extensively tested the new scheme and have reported impressive performance improvements. The delivery ratio jumps to 95% in a moderately dense network at mobility of 20 m/s. With the existence of an obstacle, Geo-DFR also greatly beats GPSR in term of delivery ratio and control overhead. Another huge advantage of the Geo-DFR is that, by applying the new scheme, it eliminates the requirement of distributed location database for annotating packets with destinations' positions, which is necessary for all previously proposed Geo-routing protocols and may hinder real system deployment enormously.

References