Customizing GPSR for Wireless Sensor Networks

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Abstract— **Several problems are required to be fixed in order to apply geographical routing protocol Greedy Perimeter Stateless Routing (GPSR) in wireless sensor networks. First, GPSR is designed under the assumption of symmetric links (i.e., *bidirectional reachability*) which is not realistic for many practical sensor networks. Second, in sensor networks, packet destinations are often marked with locations instead of identifiers like IP address and therefore packets are routed to the *home node* which is the node geographically closest to the destined location. GPSR is not efficient in identifying the home node when the target location is outside the exterior perimeter of the sensor network. Third, due to the dynamic nature of sensor networks, maintaining *data consistency*, that is, data retrieved from the home node for a location should be consistent with the data sent to the same location, becomes a challenge when home nodes change. We propose *On-demand GPSR* (OD-GPSR), a data driven geographical routing protocol customized for sensor networks with solutions to the above three problems. Simulation results show that OD-GPSR performs well in terms of energy efficiency and packet delivery rate at the cost of a little bit more packet delivery delay.**

Keywords: Sensor Networks, Geographical Routing Protocol, Energy-efficient, Link Asymmetry.

I. Introduction

As a strongly geographical routing protocol allowing nodes to send packets to a particular location, GPSR[3] is holding promise in providing routing support in sensor networks. However, several problems are required to be fixed before it can be applied in sensor networks.

- First, GPSR is designed under the assumption of symmetric wireless links. That is, whenever a node receives a beacon from another node, it considers that node as its neighbor as it assumes they are *bidirectional reachable*. Such an assumption may not be realistic for practical sensor networks, since wireless links in sensor networks often are asymmetric.
- As in some applications built atop GPSR in sensor networks, packet destinations are often marked with locations and packets finally reach the *home node* of the target location. When the target location in a packet is located outside the exterior perimeter of the sensor network, GPSR's Planar Perimeters Algorithm does not work well in that each packet has to visit all nodes on the border of the network topology before returning and recognizing the home node. This process is very energy expensive.
- *Data consistency* problem, which means data retrieved from a location in sensor networks should be consistent with data sent to the same location, becomes a challenge because of the dynamic nature of sensor networks.

Based on the implementation of GPSR, we propose a data-driven geographical routing protocol called *On-demand GPSR*(OD-GPSR), which routes a packet to the home node of its target location more efficiently. OD-GPSR not only works well under the situation where non-uniform transmission ranges exist but also is able to take advantage of the unidirectional links in sensor networks, which would be very useful in practical sensor networks. In OD-GPSR, the destination in a packet is identified with location rather than node IP address. Neighbors still need to be distinguished via identifiers like MAC address. The node nearest to a location(i.e. the *home node* for that location) is actually the destination of all packets sent to that location. Let's briefly explain how OD-GPSR works.

OD-GPSR is a data driven reactive routing protocol under which, only those nodes with data flowing over solicit location information from neighbors. As a result, unnecessary communication between neighbors is avoided and the valuable energy is saved. A node broadcasts a one-hop *beacon-request* packet to all neighbors requesting neighbor information when necessary. The node specifies the type of beacon packets its neighbors use to reply. *Unicast* beacon packet is used to discover potential unidirectional links to neighbors.

The routing decision for packets is made using the same algorithm as of GPSR but based on different neighbor information. Packets are forwarded greedily whenever possible based on both bidirectional and unidirectional neighbor information. When a packet reach a dead end with no closer neighbor, the packet switches to *perimeter forwarding* mode and uses right-hand rule to take tours of enclosed cycles in a planarized network graph. This planarized graph is constructed only based on information of bidirectional neighbors.

As GHT[5], OD-GPSR uses perimeter traversal method to identify the home node to a location. To maintain data consistency and improve robustness to node failures, OD-GPSR recruits all neighbors of a home node as replica to deal with the dynamic property of sensor networks. OD-GPSR uses a *temporary boundary* method to deal with the boundary problem. By building a temporary boundary, following packets targeted to locations outside are able to identify its home node

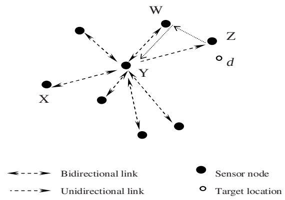

Fig. 1. An example of unidirectional links

at a border node without extra traversals of the border.

Simulation results show that OD-GPSR performs better than the GPSR version used in GHT[5] in terms of energy efficiency and packet delivery success rate at the cost of a little bit more packet delivery delay.

The rest of the paper is organized as follows. Section 2 presents related work. In section 3, we describe in detail the algorithm and implementation of our protocol. Section 4 gives simulation results. Section 5 is discussion and some future directions.

II. Related Work

GPSR[3] is one of the most well known geographic routing algorithms in wireless networks. GHT[5] modifies GPSR to fit the needs by marking the packet destination with location instead of identifiers and identifying the home node for the target location after a traversal of the perimeter around the target location. [6], [7] study the impact of radio irregularity on wireless sensor network including geographic routing protocols. [2] points out the impact of non-uniform transmission range on GPSR. [1] proposes methods to guarantee successful perimeter routing for those geographic routing methods based on planar graph by adding virtual edges in cases of instable transmission ranges. [4] extends this result towards efficiency.

III. Algorithms and Implementation

We consider a network of *static* (e.g. immobile) energy-constrained sensors with each node knowing its own location.

A. Greedy Forwarding and Right-Hand Rule

OD-GPSR is a reactive data-driven routing protocol and only those nodes over which data is flowing solicit neighbor information for making routing decisions. A node broadcasts a beacon-request packet to neighbors seeking location information. In response, a neighbor node sends back a beacon including its location via either a broadcast packet or a unicast packet as specified in the request packet. Bidirectional neighbors are discovered by specifying *broadcast* beacon packets. Unicast beacon packets are used for detection of unidirectional links. When a neighbor receives notification of delivery failure for unicast beacon packets(we assume the MAC layer has such capability) for several times, the neighbor sends a special *unidirectional_notification* beacon via a local broadcast packet for notification. Fig. 1 shows an example of the process to discover unidirectional links. Therefore, in a node, there are two neighbor tables, one for neighbors of bidirectional links and the other for neighbors of unidirectional links.

Greedy forwarding in OD-GPSR uses the same algorithm as GPSR. A forwarding node is always trying to make a greedy choice, selecting the neighbor geographically closest to the destination as the next hop. The neighbor information is from both neighbor tables which include neighbors of unidirectional links and bidirectional links. Greedy forwarding fails when reaching a node which has no neighbors closer to the destination. Then the packet is forwarded using the *right-hand rule* to circumnavigate this region. OD-GPSR routes *perimeter forwarding* mode packets on a planarized subgraph of the network connectivity graph, in which there are no crossing edges. This planarized graph is constructed only based on neighbor information of bidirectional links.

B. Data Consistency Problem

With the destination marked with location, a packet reaches the home node of the destination. Home nodes are categorized into two types: *transient home node* and *persistent home node*. For transient home node, it does not matter if the same data can be retrieved from the same location in different time. In contrast, data consistency is required for persistent home node, meaning that the same data sent to a location before should be retrieved later from the home node of the same location regardless the possible changes of the home node for the location.

A transient home node is identified when a packet reaches a node whose distance from the target location is less than half of its radio range and no neighbor nodes are closer to the destination. The other way to identify a transient home node is the perimeter traversal method as [5]. After the packet returns to the nearest node to the destined location and finds itself traversing a loop, the node is recognized as the home node for the location.

For persistent home node, the first time a packet is sent to a location, OD-GPSR identifies the target home node using the perimeter traversal method. Following packets to the same destination reach destination as they arrive at the marked home node for the target location without the traversal of the perimeter. Due to the dynamic nature of sensor networks, OD-GPSR has special mechanism for persistent home node to keep the data consistency. The first time a node is identified and marked as a persistent home node for a location, it recruits all neighbors as replica nodes. Each replica node has a timer associated with it. The primary home node broadcasts refresh packets periodically to refresh timers on all neighbors. When the home node is dead, the timer in a replica node will expire and the replica node will keep sending a special packet to the target location reporting the death of the primary home node until receiving response. To handle the problem of new emerging home node for persistent home node, the current primary home node sends packets to the target location periodically to check the existence of new home node.

C. Boundary Problem

We propose *temporary boundary*, a solution to boundary problem, which is composed of three steps. The first is the

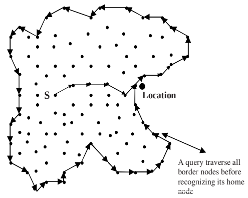

Fig. 2. Destination located outside of the network topology

detection of a packet with outside target location. Such a packet traverses the boundary of the network topology in counterclockwise direction before identifying the home node, as shown in Fig. 2. Next is to collect boundary information after a packet is determined with outside destination. The third is to inform all border nodes of the collected boundary information. The border node state is *soft* state and removed after a certain period of time because of the dynamic nature of sensor networks. After a temporary border is formed, when a packet in *greedy* mode reaches a border node, the node is able to make a decision whether or not the target location is outside the current boundary based on its boundary knowledge. If the target location is outside the network topology and no other border nodes are geographically closer to that location, the current node is recognized as the home node for that location. Otherwise, the packet is forwarded. As a result, energy is saved by avoidance of unnecessary traversal of the boundary.

Under OD-GPSR, when a packet switches to perimeter forwarding mode, it starts recording coordinates of several special hops(actually at most 8 hops which include the nodes located at the top, bottom, left and right of the boundary of the perimeter it travels) and their visited time until switching back to greedy mode or identifying the home node. If it switches back to greedy mode, all records are discarded. Otherwise, if a packet finally identifies the home node for its destination, it is easy to determine its traversal direction and then figures out whether it traverses the boundary or not.

After a packet with outside destination is detected, a *border_collect* packet marked with the same target location, is sent to visit all nodes on the boundary in perimeter forwarding mode and returns with all border nodes' location in the sequence of visited time. Afterwards, a *border_set* packet is sent to inform all border nodes of the boundary information. This method works efficiently when the topology change of the network is not much and therefore the time to keep the border state can be set longer.

IV. Simulation Results and Evaluation

We implement the modified version of GPSR proposed in [5](We use the term GPSR to refer this modified version of GPSR.) in ns-2 to compare its performance with OD-GPSR.

From Fig. 3, ODGPSR-bint10 expends less energy than GPSR-bint10 when the traffic is less, even though the delivery rate of ODGPSR-bint10 is higher than GPSR-bint10 as shown in Fig. 4. The difference of the energy consumption is incurred by those unnecessary communications among nodes in GPSR. This result is also demonstrated by comparing ODGPSR-bint15 and GPSR-bint15. In OD-GPSR, only nodes with

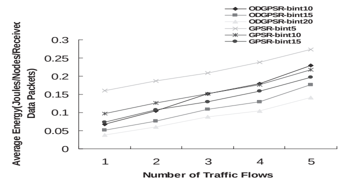

Fig. 3. Average Energy Consumption

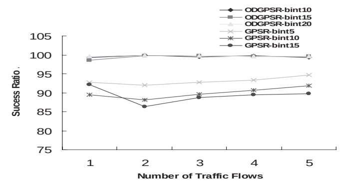

Fig. 4. Packets Delivery Success Rate

traffic solicit neighbor information and thus saves energy by avoiding unnecessary communications. Imagine a large-scale sensor network with not much traffic at most time, the energy saving is significant. As traffic involves more nodes, the saving becomes less as shown in Fig. 3, in which, when the number of traffic flows increases, the difference between GPSR-bint10 and ODGPSR-bint10 decreases.

V. Discussion and Future Work

OD-GPSR distinguishes the bidirectional links from the unidirectional links. The planarized graph for perimeter routing to circumnavigate the void is constructed based on bidirectional links only. Even the graph composed of bidirectional links is connected, using the algorithm as that in GPSR to construct the planar subgraph could lead to partition of the graph. To tackle this problem, we consider two potential solutions as our future work. The first is using methods proposed in [1] by adding virtual edges to those edge not existing to guarantee the correctness of the planar subgraph. The second is to make use of unidirectional links to help in solving this problem.

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