A Novel Beaconless Geographic Routing Protocol for Irregular Wireless Sensor Networks

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Abstract: Many beaconless geographic routing protocols have been proposed in the wireless sensor networks, and they could avoid the hidden problem by adopting restricted forwarding area, which is nested in the greedy area and includes only mutually communicable nodes. However, these protocols are designed for uniform sensor field, so they cannot be directly applied to practical irregular sensor fields with partial voids. If voids or hotspots are in the restricted small area, these restricted region-based approaches would be failed to find a forwarding node even if there exist appropriate candidates in the rest area. In this paper, we propose a beaconless geographic routing protocol to increase forwarding opportunities for practical sensor networks. By giving different contention priorities into the mutually communicable nodes and the rest nodes in the greedy area, every neighbor node in the greedy area can be used for data forwarding without any packet duplication.

1 INTRODUCTION

Geographic routing requires nodes to know positions of their neighbors for forwarding data, so each node periodically exchanges HELLO messages including its position with its neighbors. To reduce the control overhead due to these messages called beacons, beaconless routing strategy has been studied in the literature. Traditional beaconless routing (Heissenbuttel, 2004); (Turau, 2005); (Fubler, 2003) and (Sanchez, 2007) has the following process: a sender broadcasts data to its neighbors, and only neighbors in greedy forwarding area, closer neighbors to a destination, are eligible to become as next-hop forwarding candidates. Finally, only one neighbor is selected as a next-hop forwarder by a completely reactive method. To avoid collision among these neighbors, the sender includes a waiting function into the data packet which is related to the distance between each receiving neighbor and the destination. So, the fastest timer expiring node, the closest node from the destination among the neighbors, will become a next-hop forwarder by itself and begin to send the received data by broadcasting like the previous sender did. The rest of neighbors overhear this message, so they could cancel their own timer and release the received data.

However, some of neighbors in the greedy area cannot hear the message of other neighbors because any two nodes may be possibly out of radio range. It might lead to a large number of packet duplications in such overhearing-based beaconless routing protocols due to multiple winners among these neighbors. So, previous studies tries to adopt a completely conservative approach, which reduces a forwarding candidate area as a restricted region. This approach limits the greedy forwarding area into only mutually communicable nodes. It allows that only the nodes in the restricted forwarding area, which is nested in the greedy area, can be participated in the timer-based forwarding contention.

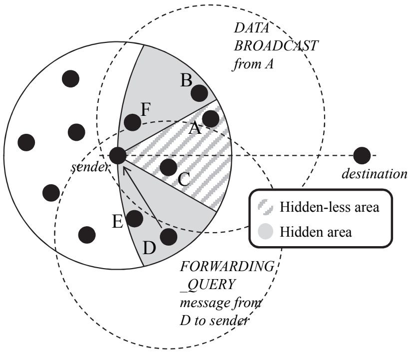

Figure 1: Data forwarding in the proposed protocol.

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This strategy is very simple and may be effective in uniformly and densely deployed WSNs, but forwarding opportunities can be loss in the practical WSNs. In most of applications of WSNs, very small and cheap sensor nodes are deployed to an interest field by a plane in the air. Therefore, the network commonly becomes an irregular shape that has lots of partial network holes due to obstacles such as buildings, lakes, or etc. If such holes are in the restricted small forwarding area, it would be failed to find a forwarding node even if there are appropriate candidates in the rest area. In this case, the sender has to send the data packet again or change its routing mode from the greedy mode to the recovery mode. Unfortunately, the neighbors cannot be guaranteed to successfully receive data packet again at the next time due to the error-prone nature of wireless links. Also, if the routing mode is changed, the protocol requires a number of control messages and wastes lots of node energy because it has to get the positions of all neighbors to detour the holes.

Therefore, in order to both increase forwarding opportunities and also prevent packet duplication due to the hidden problem, we propose a novel region-based beaconless routing protocol, which gives different contention priorities into each region in the sub-areas of the greedy forwarding area. In the proposed protocol, nodes in high prioritized region immediately find a next-hop forwarder in a fully distributed manner after receiving a sender's broadcast data. On the other hand, nodes in low prioritized region have to wait until contention of high prioritized region is done. Namely, our protocol has the two phase of contention process.

2 NETWORK MODEL

In the proposed protocol, the greedy forwarding area is divided into two sub-areas: Hidden-less area and the rest area, hidden area. The hidden-less area is similar to the restricted forwarding area of the previous protocols in the way that includes only mutually communicable nodes. However, instead of the previous protocols, the position of the hidden-less area can be moved within the greedy forwarding area by a learning mechanism. In order to switch the hidden-less area with simple calculation, we choose a 60' radian area for the hidden-less area which is a radial region that includes a 30' radian area around the line connecting the sender and the destination on both sides. Except the hidden-less area, we call the rest area as a hidden area. Note that all nodes in the greedy forwarding area have been given data packet from its previous sender at the same time, but their relaying or answering times have to be different from each other in order to prevent collisions. So, we exploit the modified waiting function which is based on both the distance from the destination (closer node from the destination has lower timer) and the priority value related to its geographic position in the greedy forwarding area (higher prioritized node has lower timer).

3 PROPOSED PROTOCOL

As shown in Fig. 1, a sender broadcasts its data to its neighbors, so all nodes in the greedy forwarding area can receive the sender's data. The data packet contains the original message, the position of the sender and the destination, the maximum waiting time, and the region information for the hidden-less area. So, each neighbor in the greedy forwarding area could realize whether it is in the hidden-less area, or not. In this case, only the nodes *A*, *B*, *C*, *D*, *E*, and *F* have been received the data successfully among neighbors in the greedy forwarding area. These nodes start to keep the received data into their memories. Among these nodes, only both *A* and *C* are in a high prioritized hidden-less area (fan-shaped dashed region). After receiving the data, nodes in the hidden-less area get higher priority than the hidden area, and it immediately begins to find a next-hop forwarder. These nodes have their own timer only related to the distance from the destination by using a predefined maximum time of *T_max* seconds. So, in the hidden-less area, the closest node A from the destination wake up first, becomes a next-hop forwarder by itself, and broadcasts the received data to its neighbors. Among all neighbors in the greedy forwarding area, nodes that overhear this broadcast data release its timer and received data. However, if the node density is extremely high, this forwarding message might be generated simultaneously among neighbors because timers expire almost concurrently. It might lead to lots of collisions, so the proposed protocol exploits Distance and Angle based Collision Avoiding Scheme, called *DACAS*.

On the other hand, nodes in the hidden area set their own timer as a sum of distance-based value and the *T_max*. Namely, every nodes in the hidden area has to wait during *T_max* seconds first, it then begins to start its distance-based timer. If the timer is expired, the node in the hidden area sends a *FORWARDING_QUERY* message to the sender. If only there are no node that successfully rebroadcast the data in the hidden-less area, the sender replies the *FORWARDING_PERMIT* message to the node immediately. After that, the node becomes a next-hop forwarding node, and broadcasts the received data to its neighbors. Except the node, other neighbors release their timers and received data when they overhear the *FORWARDING_PERMIT* message. In this figure, the node *A* in the hidden-less area becomes a next-hop forwarding node by itself. The other nodes *B*, *C*, and *F* that can overhear a broadcast data from *A*, give up their contention process for becoming the next-hop forwarder. Since the node *D* and *E* are out of transmission range from the *A*, they cannot overhear the broadcast data message. When the timer of node *D* is expired, it sends *FORWARDING_QUERY* messages to the sender *S*. However, the sender *S* already overheard the broadcast data from *A*, so the *S* ignores the message from the node *D*. Also, the node *E* can releases its timer when it overhears a *FORWARDING_QUERY* message from the node *D*.

When a sender broadcasts its data to its neighbors, neighbors which is closer to the destination than the sender (in greedy forwarding area) set their own timer as the following equation:

$$W(c) = f(c) + f'(c) + f''(c), \tag{1}$$

where *W(c)* represents the total waiting time (ms) for the current node between 0 and *T_max*. The greedy area of a sender which is closer to the destination than the sender can be divided into multiple sector areas. Each sector is made by using the *Maximum_Radio_Range (MRR)* and the sector size α given by the application. The function *f* represent the waiting time for each sector, and the *f'* represents the local waiting time for each node in a sector according to its position in the sector. The f'' represents the priority time delay. If the node *c* is in the hidden-less area or out of the greedy area, the function *f''* returns 0. Otherwise, it returns *T_max*. For the function *f*, it uses the following equation:

$$f(c) = T_{\max} \cdot \frac{\beta + MRR}{MRR}, \tag{2}$$

where *dist(a,b)* represents the Euclidean distance between the position of the node *a* and *b*. β can be presented as the following equation:

$$\beta = \alpha \cdot \left\lfloor \frac{dist(c,d) - dist(s,d)}{\alpha} \right\rfloor, \tag{3}$$

where the values *s*, *c*, and *d* are the geographic location of sending node that broadcasts data packet, the current node that successfully receives the data packet, and the destination node, respectively. According to the sector size α, similarly located sensor nodes have the same waiting time for the sector. The function *f'* can be presented as the following equation:

$$f'(c) = T_{\max} \cdot \frac{\gamma \cdot \alpha}{MRR}, \tag{4}$$

where the value γ falls between 0 and 1 according to the angle ratio of a sensor node in a sector area. The lower γ means the node is closer to the line which is connecting the sender and the destination. Namely, the closest node from the source-destination line has the shortest timer in each sector area. Also, every sensor node has another timer called *T_interval* for the adoptive collision avoidance. After a sender node broadcasts data packet, if the node realizes a collision among its neighbors by MAC device or receives two or more packets from its neighbors within *T_inverval*, it determines there might be a collision among neighbors and rebroadcast data with increased *T_max*.

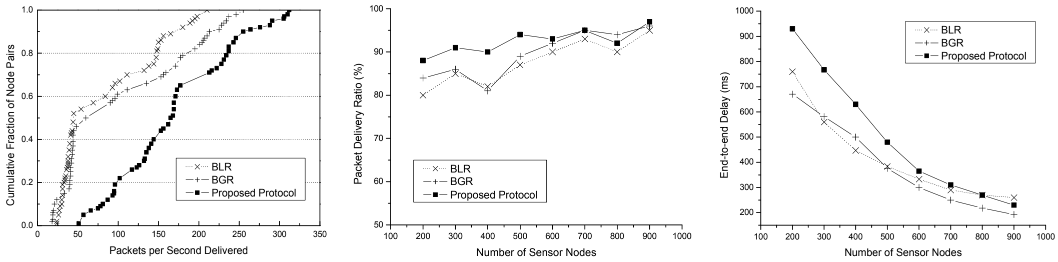
4 PERFORMANCE EVALUATION

We implement the three schemes by Qualnet Network Simulator 4.0 and utilize IEEE 802.15.4 as the MAC protocol. The model of sensor nodes are followed by the specification of MICA2. The transmission range of sensor nodes is set to 50 m. The simulation scenario is a 500 x 500 m^2 area in which a varying number of nodes (from 200 to 900 nodes) are deployed. To make a fair comparison, each protocol sets *T_max* as 300 ms. For the proposed protocol, *T_inverval* is set to 10 ms. For each scenario the results presented here are average of 10 separate simulation runs.

4.1 Path Throughputs

Figure 2 (a) shows the distribution of throughputs of the three protocols. In this simulation, 500 sensor nodes are randomly deployed into the sensor fields. Each curve shows the throughput CDF of the geographic routes for the same randomly selected 50 node pairs. A point's x value indicates throughputs in packets per second. The size of a packet is 100 bytes. The y value indicates what fraction of pairs has fewer throughputs.

The left two curves are the throughput CDF



(a) (b) (c)

Figure 2: Simulation results in terms of (a) cumulative fraction of randomly selected 50 node pairs, (b) packet delivery ratio according to node density, and (c) end-to-end delay according to node density.

achieved by using traditional beaconless routing protocols, BLR and BGR. The right curve is the throughput CDF achieved by the proposed protocol. The proposed protocol provides almost three times as much throughput as traditional beaconless routing for the median pair. It is because that BLR and BGR have more number of routing failures than our protocol. In the traditional protocols, only a few number of neighbor node could get a chance to be a next forwarding node. Unfortunately, this routing failure is related with the performance of the data throughput because of unnecessary time-loss.

4.2 Impact of the Number of Sensor Nodes

Fig. 2 (b) shows a packet delivery ratio (PDR) among three different protocols. As the node density increases, PDR of each protocol also increases. It is because that each protocol has shorter path as increasing node densities. Therefore we can find that PDR is strongly related with the number of hops. In general, the proposed protocol shows higher PDR than other protocols. The reason is that our protocol fully uses a forwarding candidate area like beacon-based protocols; however other protocols use only limited area that consists of mutually communicable sensor nodes. These protocols can guarantee a desired data throughputs by destination only when the network has an enough sensor node.

Fig. 2 (c) shows the end-to-end delay for each protocol. The graph shows that the density is strongly correlated with the end-to-end delay. Namely, the lower density shows a large amount of end-to-end delay. In fact, routing in perimeter mode is the main cause. In this simulation, a large part of end-to-end delay is made by perimeter routing. However, although the proposed protocol has smaller perimeter packets than other protocols, we observe that the proposed protocol has the more delay than others with low densities.

5 CONCLUSIONS

This paper propose a novel beaconless geographic routing protocol that can be used in irregular wireless sensor networks, which could increases forwarding opportunities by giving different contention priorities into the mutually communicable nodes and the rest nodes in the greedy area. Our various experimental results show that the proposed protocol has better performance than the previous protocols.

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