A Simple Hole-Resistant Technique for Reliable Geocasting in Wireless Sensor Networks

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Abstract

In wireless sensor networks, geocasting is one of the important transmission behaviors when the sink intends to send messages to sensor nodes in a specific area, typically identified by accurate two-dimensional location information (e.g., x- and y-coordinates). Unfortunately, this information is not always obtained at sensor nodes, and the network may have environmental holes (e.g., physical obstacles or areas without the functionality of communication). The challenges are more likely to cause a low packet delivery ratio. This paper proposes a Simple HOle-Resistant Technique, called SHORT, to improve the geocast packet delivery ratio in virtual coordinate wireless sensor networks with holes. Sensor nodes in virtual coordinate wireless sensor networks are positioned by two virtual coordinates, direction and distance, respectively represented by a directional code and hop count from sink. To select appropriate nodes to participate in relaying geocast packets, each candidate forwarder depends on its direction and distance to derive an ultimate forwarding probability when it receives geocast packets. As the proposed SHORT can assign a higher forwarding probability to a more appropriate candidate forwarder, it can efficiently resist environmental holes. Simulation results validate that SHORT achieves a higher packet delivery ratio compared with the simple direction-based forwarding scheme under virtual coordinate wireless sensor networks with holes.

Key Words: Forwarding Probability, Geocast, Sensor Network, Virtual Coordinate

1. Introduction

In recent years, the evolution of tiny and autonomous wireless devices, called sensor nodes, has possessed multiple functionalities, including computation, sensing, and communication. Typically, a large number of sensor nodes are randomly deployed and collected as a wireless sensor network (WSN) to achieve a variety of tasks, such as environmental monitoring, battlefield surveillance, object detection, and target tracking [1,2]. In WSNs, numerous applications rely on node location; thus, sensor nodes require to have accurate locations. Their locations can be obtained using a positioning hardware, such as Global Positioning System (GPS) [3] and range-based or range-free localization algorithms [4].

Previous research on protocol design in WSNs always assumes that all nodes have accurate physical locations [5−10]. Unfortunately, this assumption may be unreasonable because using the positioning hardware is costly and energy-consuming [3], and existing localization approaches may derive incorrect location of sensor nodes [4]. Our prior study designs a novel virtual coordinate system, in which the location of sensor nodes is indicated by a two-tuple, including direction and hop distance [11]. We call this kind of network the virtual coordinate wireless sensor network, termed VC-WSN.

For some WSN applications, sinks require to deliver messages to sensor nodes in the specific geographical

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area that users are interested in for querying sensing data or readings, assigning tasks, or updating commands. This area is called the area of interest (AOI.), which is generally identified by the geographic information. Thus, this kind of message delivery is called geocasting. Typically, geocasting is regarded as a variation of multicasting and differs from multicasting in the way of characterizing the destination nodes. Greedy forwarding [6,12] is a fundamental method to achieve geocasting. If a sensor node receiving packets is closer to the AOI than the sender of the packets, this node is responsible for relaying received packets. Nevertheless, in sparse WSNs, the greedy forwarding method is likely to incur the local minimum problem, in which no forwarders can be found because none of neighboring nodes is closer to the AOI than sender. An alternative strategy to geocasting is depending on the zone of forwarding (ZOF) [6,13−15]. Only sensor nodes in ZOF have to forward received packets. This ZOF can be constructed using multiple approaches based on different geographical information, such as distance, direction, and angle. Although ZOF-based techniques prevent packets from flooding in the whole network and guarantee that packets are transmitted towards AOI, the construction and maintenance of ZOF create a considerable amount of communication overhead. Additionally, most of existing approaches mainly construct a fixed ZOF. It is probably unsuitable for the network with multiple holes, which are formed by physical obstacle, environmental hole, and area without the functionality of communications.

The majority of existing geocasting protocols is always designed for WSNs in which all sensor nodes have accurate physical locations, and the AOI is identified by the accurate physical geographical information as well [5−10]. As mentioned above, this assumption is not applicable. Without accurate location information, most of proposed geocasting approaches are more unlikely to be directly used in VC-WSNs. In this paper, we propose a simple role-resistant technique, called SHORT, to provide reliable geocasting for VC-WSNs with holes.

The proposed SHORT aims to not restrain sensor nodes to participate in forwarding received packets and to increase the ultimate forwarding probability of sensor nodes which are closer to AOI than senders. In SHORT, sensor nodes receiving geocast packets become candidate forwarders. They calculate two probabilities based on direction and distance, and then use a weighted function considering these two probabilities to determine an ultimate forwarding probability. This function enables sensor nodes to determine its ultimate forwarding probability depending on the level of vicinity to AOI. That is, sensor nodes in the AOI region must forward packets, and sensor nodes farther from the AOI region will be assigned a smaller value of ultimate forwarding probability. Because candidate forwarders self-determine their ultimate forwarding probabilities, multiple routing paths will be discovered. In addition, the determined forwarders construct a virtual dynamic ZOF, which can inherently tackle with the problems resulted from holes. Simulation results validate that the proposed SHORT significantly improve the packet delivery ratio to guarantee reliable geocasting, and outperforms the fixed ZOF-based approaches in packet delivery ratio for VC-WSNs with holes, although generating a little bit more number of packets for lack of accurate as well as precise location information.

The rest of this paper is organized as follows. Section 2 describes the network model. Section 3 presents the proposed SHORT in detail. Section 4 shows the performance evaluation results, followed by the concluding remarks in section 5.

2. Network Model

This paper considers a square VC-WSN introduced in [11]. Given the number of directions, say 2^m, a VC-WSN is partitioned into 2^m directional regions with the sink, which can be located anywhere. The location of sink only influences the number of sensor nodes in each directional region. Therefore, the proposed SHORT can still work because each sensor node in SHORT determines an ultimate forwarding probability depending on its direction-based and distance-based virtual coordinates only.

Each directional region is recognized by a unique code, called directional code. VC-WSNs use the Gray code to stand for the directional code of directional regions, and these directional codes are numbered counterclockwise. The reason of usage of the Gray code is that sensor nodes can effortlessly recognize whether received packets come from one of its adjacent directions or not. As this study intends to investigate the geocasting issue on VC-WSNs, we do not change the representation of direction code in VC-WSNs and preserve the network model to design a hole-resistant geocasting technique.

Figure 1 shows an example of VC-WSNs. The location of a sensor node in VC-WSNs is identified by two types of geographical information, direction and distance. The direction is represented by the code of the directional region in which this sensor node locates. The distance is represented by the hop count from the sink to this sensor node. Our prior work develops a directional-based localization scheme, called DLS, to determine the directional code and hop distance of sensor nodes [11]. In DLS, sensor nodes are randomly deployed and are well functional original (i.e., there is no hole in the network). The sink originates a Locating_Request (LREQ) packet flooding in the whole network after deploying sensor nodes. When receiving LREQ packets, a sensor node takes a reasonable duration to gather more packets from its neighbors, and uses a multi-message decision scheme, based on the spatial locality property, to determine its directional code. Meanwhile, the sensor node is able to obtain its hop count to the sink, as this information is carried in LREQ packets. If the sensor node determines its directional code and hop count, it then forwards the received LREQ packets. As sensor nodes waste its battery power for message transmission, receiving, and processing, they are more likely to consume the energy as time elapses. When numerous nearby sensor nodes exhaust the battery energy, they will form an environmental hole.

Suppose that N_s stationary sensor nodes are randomly deployed in a VC-WSN, and holes randomly appear in the network. We assume that sensor nodes, s_i (i = 1, 2, …, N_s), have accurate virtual coordinates which can be accomplished using DLS. Let c_i and h_i be the directional code and hop count of s_i, respectively, and thus we denote the virtual coordinate of sensor node s_i as (c_i, h_i). Let c_{AOI} and h_{AOI} respectively indicate the directional code and hop count of AOI. We denote the AOI, R_{AOI}, as (c_{AOI}, h_{AOI}). For example, if the AOI is in the region with directional code '011' and six hops from the sink, we denote R_{AOI} as (011, 6).

3. Proposed Simple Hole-Resistant Technique (SHORT)

This section elaborates the proposed probabilistic geocasting approach. We first give an overview of SHORT, and then address the assumptions in this study, followed by the proposed rules to determine the forwarding probability of candidate forwarding nodes.

3.1 Overview

Figure 2 gives an overview of SHORT. Suppose that R_{AOI} = (000, 4) (i.e., c_{AOI} = 000 and h_{AOI} = 4). This information is attached in the geocast packet disseminated by the sink. When receiving a geocast packet, sink's

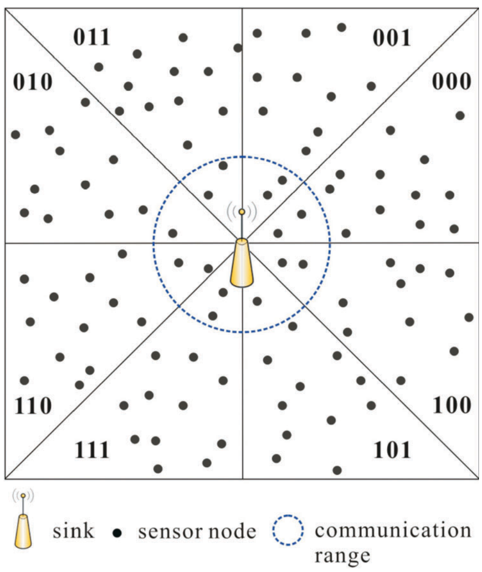


Figure 1. Example of a VC-WSN partitioned into eight directional regions (m = 3).

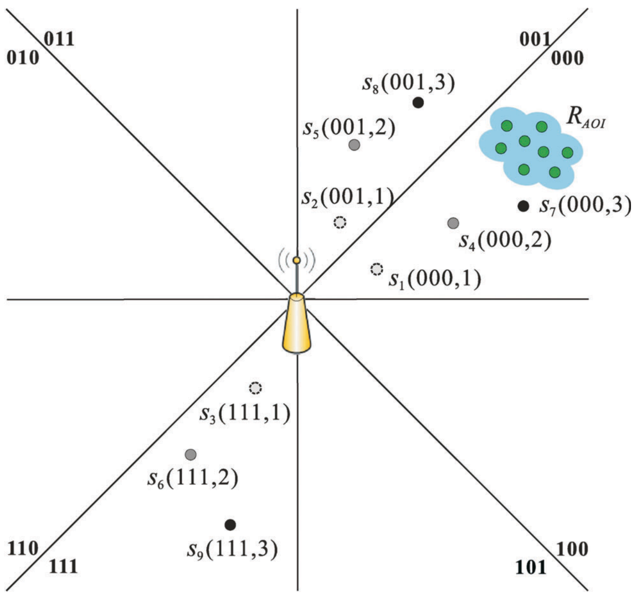


Figure 2. Overview of SHORT.

neighbors (e.g., s_1, s_2, and s_3) self-determine their ultimate forwarding probabilities. Because s_1 locates in the directional region identical to the directional region of AOI, i.e., $c_1 = c_{AOI}$, the proposed SHORT assigns s_1 to forward the received geocast packet absolutely. That is, its ultimate forwarding probability is determined as 1. Similarly, the ultimate forwarding probability of s_4 and s_7 are identical, and the value is 1.

In Figure 2, s_3 is farther from AOI than s_2 is, although the sensor nodes have the same hop count. Therefore, s_2 obtains a higher direction-based forwarding probability than s_3 does, and they have the same distance-based probability to the nodes. In general, if a node not in the directional region of AOI has a larger value of hop count, it is more likely to be farther from AOI. Based on this concept, the distance-based forwarding probability of s_5 should be smaller than that of s_2, although they have the same direction-based probability. Whenever a sensor node determines its direction-based and distance-based probabilities, it combines the two probabilities to obtain an ultimate forwarding probability. Then, the node depends on its ultimate forwarding probability to make a decision of relaying the received geocast packets depending on. If a sensor node whose distance (hop count) is less than that of AOI (i.e., c_{AOI}), it requires to calculate an ultimate forwarding probability to determine whether it has to forward received packets or not. On the other hand, sensor nodes in the AOI discard received geocast packets.

3.2 Assumptions

The proposed SHORT performs under the following assumptions.

(1) Each sensor node has a unique identifier.
(2) The communication ranges of sink and sensor nodes are a unit disk.
(3) Sensor nodes have the same communication range.
(4) The sink knows the accurate location information of AOI (i.e., c_{AOI} and h_{AOI}).

3.3 Determination of Forwarding Probability

In general, how to determine proper forwarders is a main challenge in designing an efficient geocasting approach. Recall that VC-WSNs use direction and distance to stand for sensor node's location. Motivated by the two virtual coordinates, SHORT reasonably enables each candidate forwarder to consider two kinds of probabilities, direction-based probability and distance-based probability, to derive its ultimate forwarding probability. Denote the direction-based probability and the distance-based probability of sensor node s_i as p_i^{dir} and p_i^{dis}, respectively.

In SHORT, all the candidate forwarders are divided into two categories, depending on the directional region they locate in. If a sensor node in the directional region of AOI receives geocast packets, and it has a smaller value of distance than AOI, this node requires to forward the received packet. We formulate this strategy as

Rule 1: For a sensor node s_i, if $h_i < h_{AOI}$ and $c_i = c_{AOI}$, then $p_i^{dir} = 1$ and $p_i^{dis} = 1$.

The advantage of considering Rule 1 is that sensor nodes not in the directional region of AOI are suppressed to forward received packets, and thus saving their energy. However, if there are holes in the directional region of AOI and the holes are between the sink and AOI, this constrained flooding approach is much more likely to cause sensor nodes in the AOI to fail to receive geocast packets, thereby decreasing the packet delivery ratio. If sensor nodes not in the directional region of AOI are given an opportunity to become forwarders, the packet delivery ratio may be improved because geocast packets detour round the holes. To identify the difference of forwarding probability of candidate forwarders in different directional regions, SHORT considers a direction-based forwarding probability, which is based on the difference of direction between the regions of AOI and a sensor node.

Given the directional code of s_i, c_i, and the directional code of AOI, c_{AOI}. We define the above difference of s_i, denoted as δ_i, as the minimum difference in direction between the directional regions of s_i and AOI. This difference can be obtained using a clockwise or a counterclockwise manner. We give an example to illustrate this difference, as shown in Figure 3. Suppose that the network is partitioned into eight directional regions. Given $c_{AOI} = 110$, $c_1 = 001$, $c_2 = 010$, and $c_3 = 000$, we obtain $\delta_1 = 3$, $\delta_2 = 1$, and $\delta_3 = 4$.

In this paper, SHORT takes this difference into account to derive the direction-based forwarding probability of candidate forwarders. We argue that the larger

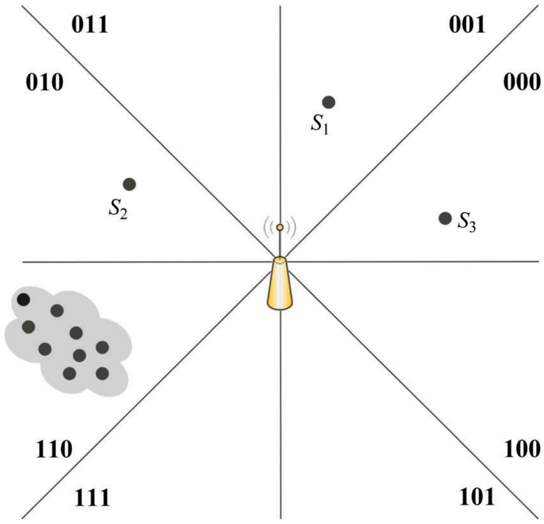


Figure 3. Example of determination of difference of direction between the region that sensor nodes locate in and the AOI.

value of difference a sensor node has, the lower direction-based forwarding probability this node obtains, and propose the following rule.

Rule 2: For any two sensor nodes s_i and s_j, where $c_i \neq c_j \neq c_{AOI}$ and $h_i = h_j < h_{AOI}$, if $\delta_i \leq \delta_j$, then $p_i^{dir} \geq p_j^{dir}$, else $p_i^{dir} < p_j^{dir}$.

Let $\delta^{\max}$ be the maximal value of δ_i, where $i = 1, 2, \ldots, N_s$. If s_i locates in the directional region opposite to that of AOI (i.e., $\delta_i = \delta^{\max}$), it should obtain the minimal value of p_i^{dir}. Thus, SHORT assigns p_i^{dir} as 0. On the other hand, if s_i locates in the directional region of AOI (i.e., $\delta_i = 0$), it should obtain the maximal value of p_i^{dir}. Therefore, SHORT assigns p_i^{dir} as 1. We use the following to determine the direction-based forwarding probability of s_i.

$$p_i^{dir} = 1 - \frac{\delta_i}{\delta^{\max}} \quad (1)$$

where $\delta^{\max} = 2^{m-1}$.

In addition to direction, distance is another virtual coordinate used to represent the location of sensor nodes in VC-WSNs. This paper further considers distance as an impact factor to determine a distance-based forwarding probability associated with the direction-based forwarding probability to derive the ultimate forwarding probability of sensor nodes. The key concept of the strategy to determine this distance-based forwarding probability is that the larger value of distance a sensor node has, the lower distance-based forwarding probability this sensor node obtains. The rule that this strategy adheres to is as follows.

Rule 3: For any two sensor nodes s_i and s_j, where $c_i \neq c_{AOI}$, and $c_j \neq c_{AOI}$, if $h_i \leq h_j$, then $p_i^{dis} \geq p_j^{dis}$, else $p_i^{dis} < p_j^{dis}$.

According to Rule 3, the proposed PAG uses the following equation to determine the distance-based forwarding probability of s_i.

$$p_i^{dis} = 1 - \frac{h_i}{h_{AOI}} \quad (2)$$

In the proposed SHORT, we consider both direction-based and distance-based forwarding probabilities, and formulate the ultimate forwarding probability of candidate forwarders as a weighted combination of the two probabilities. Let p_i^f be the ultimate forwarding probability of s_i. It is derived as

$$p_i^f = \alpha \times p_i^{dir} + (1 - \alpha) \times p_i^{dis} \quad (3)$$

where $0 \leq \alpha \leq 1$.

Whenever a sensor node receives geocast packets that it never received, it determines an ultimate forwarding probability according to algorithm shown in Figure 4. Then, the node depends on this derived probability to make a decision of forwarding received packets.

4. Performance Evaluations

This section addresses the simulation parameters, followed by the simulation results.

4.1 Simulation Setup

To evaluate the geocasting performance of the proposed SHORT, this paper performs extensive simulations via C++. We consider a VC-WSN with 500 m × 500 m in size. The numbers of directional regions of the network are 4 and 8. All sensor nodes are randomly deployed in the network. The numbers of sensor nodes are

Algorithm 1: Algorithm to determine the ultimate forwarding probability.

/* To be performed by node s_i when it receives a geocast packet. */
Input: $m, \alpha, c_i, h_i, c_{AOI}, h_{AOI}$;
Output: p_i^f;
$\delta^{\max} \leftarrow 2^{m-1}$
if $h_i < h_{AOI}$ **then**
    if $c_i = c_{AOI}$ **then**
        $p_i^f \leftarrow 1$;
    else
        Determine δ_i;
        $p_i^{dir} \leftarrow 1 - \frac{\delta_i}{\delta^{\max}}$;
        $p_i^{dis} \leftarrow 1 - \frac{h_i}{h_{AOI}}$;
        $p_i^f \leftarrow \alpha \cdot p_i^{dir} + (1-\alpha) \cdot p_i^{dis}$;
    end
else
    $p_i^f \leftarrow 0$;
end

Figure 4. Algorithm of the proposed SHORT.

600, 700, 800, 900, and 1000. The communication range of sensor nodes is 50 m. We consider different weighted values to investigate their influence on geocasting performance. The weighted values, α, we consider are 0.3, 0.6, and 0.9.

The simulation assumes that only one hole appears in a specific directional region of AOI, and the hole is between the sink and AOI. The hole is represented by a lot of non-working nodes, including a sensor node and all of its 2-hop neighbors. Figure 5 illustrates an example of hole construction in the simulation. For ease of explanation, the hole is assumed to be in the "000" region. First, we randomly select a node, say *H*, and set this node as a node in the hole, represented by a white dot. Next, we set the nodes of *H*'s 1-hop neighbors as ones in the hole, represented by the light gray dot, and then set the neighbors of all the *H*'s 1-hop neighbors as ones in the hole, represented by the charcoal gray dot. Consequently, we regard these nodes as the hole.

The main performance metric this paper considers is the packet delivery ratio, as we argue that it is an important issue that all the nodes in the AOI require to successfully receive geocast packets. Denote the number of sensor nodes in the AOI as N_{AOI}^{Total} and the number of sensor nodes successfully receiving geocast packets as N_{AOI}^{Rcv}. The packet delivery ratio of SHORT, denoted as R_{SHORT}, can be determined by

$$R_{SHORT} = \frac{N_{AOI}^{Rcv}}{N_{AOI}^{Total}} \tag{4}$$

Generally speaking, large numbers of packets flood-

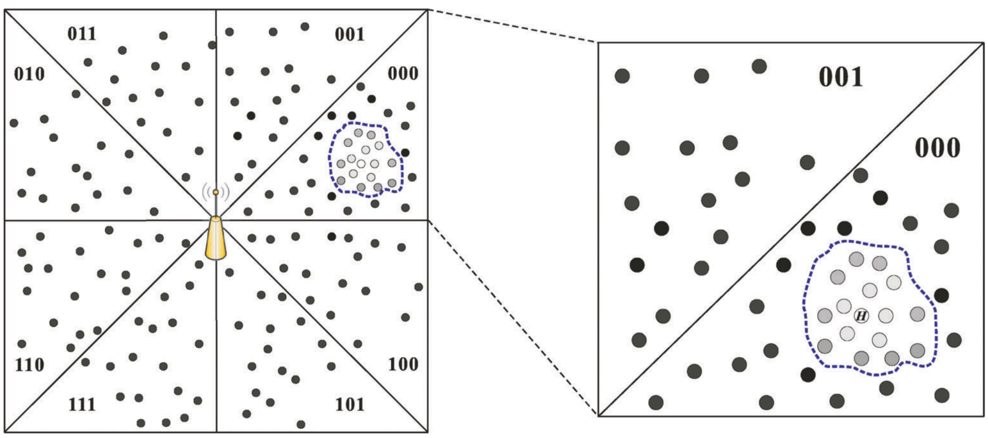


Figure 5. Example of hole construction in the simulation. The are bounded by the blue dotted edge is the hole.

ing in the network are most likely to cause serious collisions, thereby resulting in retransmissions. In addition, frequent retransmissions further consume the residual energy of sensor nodes. Thus, this paper also simulates the number of packets generated during geocasting, as this metric can effectively stand for the level of energy consumption. In order to show the performance of the proposed SHORT, this study compares SHORT and an approach, in which only sensor nodes in the directional region of AOI require to forward the received packet. Because this comparative approach constructs a fixed ZOF (i.e., the directional region of AOI is regarded as a fixed ZOF), it is denoted as "Fixed-ZOF" in the simulations. For brevity, we use "SHORT (α)" to indicate the SHORT using the weighted value α.

4.2 Simulation Results

4.2.1 Packet Delivery Ratio

This subsection discusses the influences of network density on the packet delivery ratio under the scenarios with different h_{AOI}. In Figures 6 and 7, the proposed SHORT exhibits a better performance than Fixed-ZOF in different numbers of h_{AOI} and sensor nodes. The average packet delivery ratio of SHORT is about 90% in all cases. Note that increasing the number of directional regions does not show a significant influence on packet delivery ratio in SHORT. Moreover, the packet delivery ratio decreases as the number of directional regions increases, especially for the scenario with smaller value of h_{AOI} and low network density. Obviously, if the number of directional regions increases, the number of determined forwarders decreases because each directional region becomes small in size. Although the number of forwarders in the non-AOI regions increases, this shows a slight influence on the packet delivery ratio.

On the other hand, if $m = 3$ and the network density is low, i.e. the number of sensor nodes is 600, Fixed-ZOF has a low packet delivery ratio, as shown in Figures 6(a), (b), and (c). In this case, only the sensor nodes in the forwarding zone forward the received packet, so sensor nodes in the directional region of AOI are probably unable to receive packets from sender. If the number of sensor nodes increases, the packet delivery ratio increases as well. This is significant if $h_{AOI} = 6$. That is, Fixed-ZOF does not work well in case of low network density and large value of h_{AOI}. For SHORT, all sensor nodes in the network may help to forward the packets from the sender. Thus, sensor nodes in the directional region of AOI have a higher probability to receive the packets. However, R_{PGA} does not further increase when the number of sensors increases, as all sensor nodes are involved in the packet forwarding no matter what the sensor density or the value of h_{AOI} is.

4.2.2 Number of Generated Packets

In this subsection, we compare the numbers of gen-

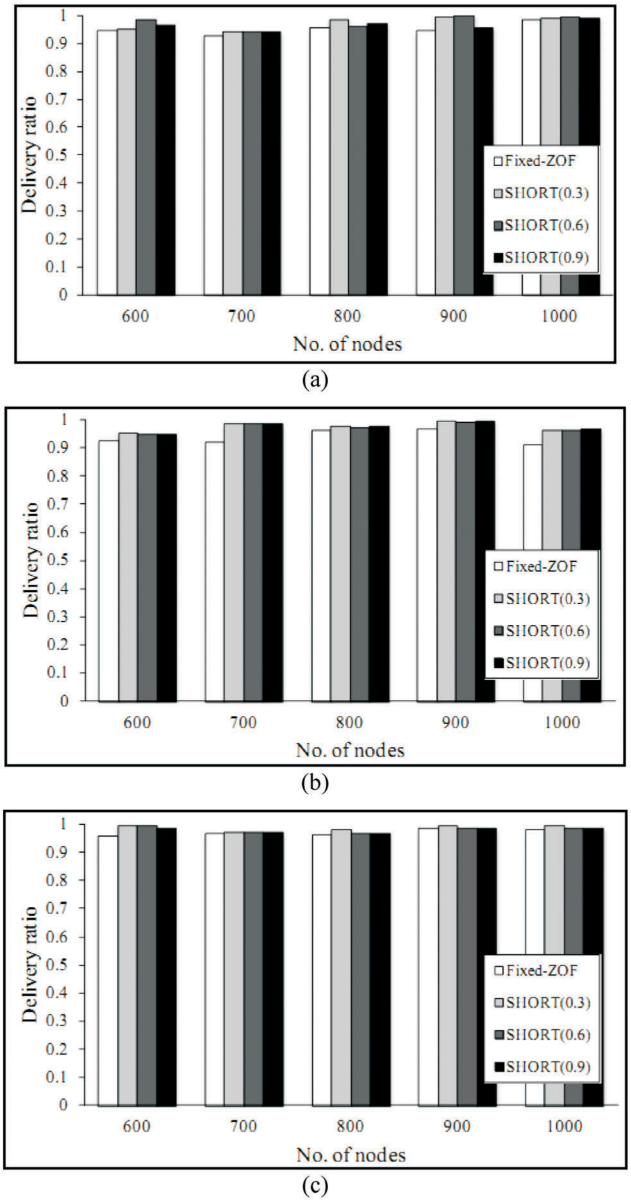
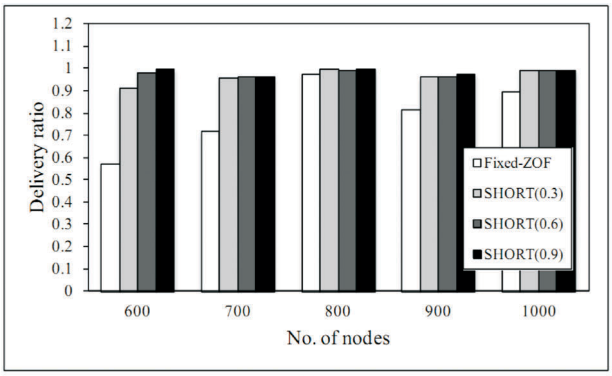
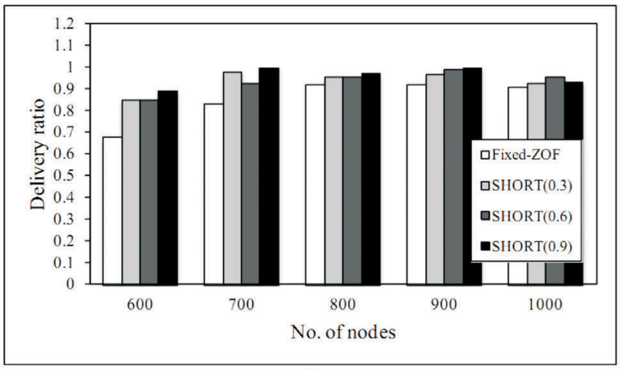


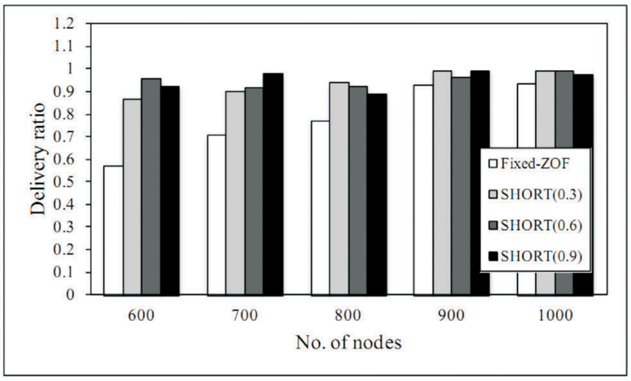
Figure 6. The influence of the network density on the packet delivery ratio under the network with 4 directional regions. (a) $h_{AOI} = 4$, (b) $h_{AOI} = 5$, (c) $h_{AOI} = 6$.



(a)

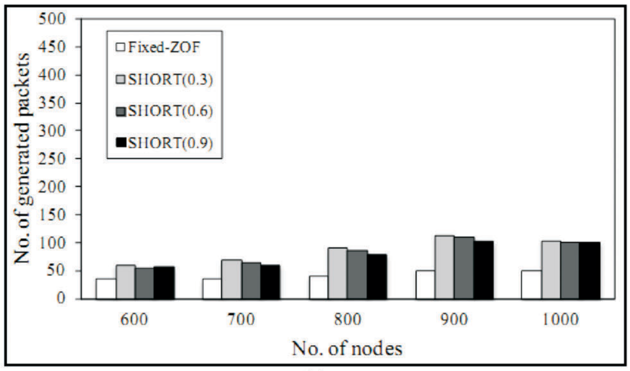


(b)

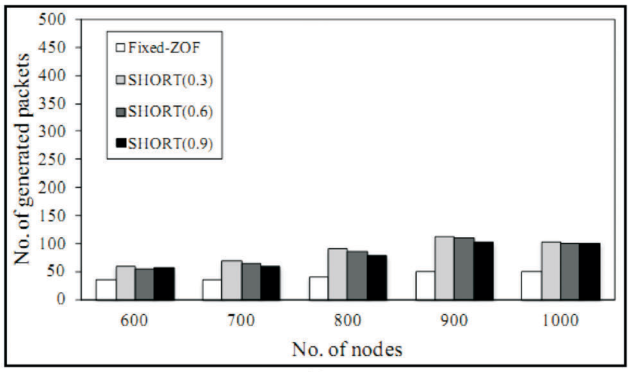


(c)

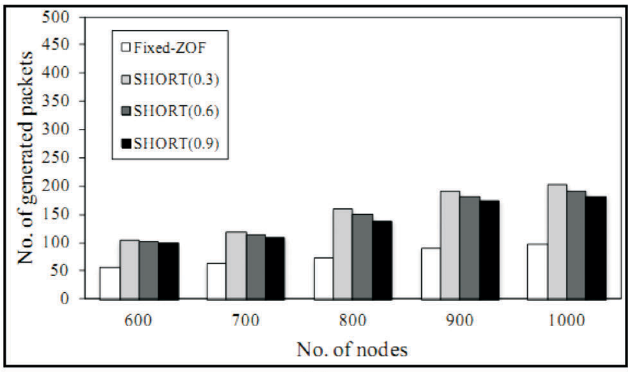
Figure 7. The influence of the network density on the packet delivery ratio under the network with 8 directional regions. (a) $h_{AOI} = 4$, (b) $h_{AOI} = 5$, (c) $h_{AOI} = 6$.



(a)



(b)



(c)

Figure 8. The influence of the network density on the number of generated packets under the network with 8 directional regions. (a) $h_{AOI} = 4$, (b) $h_{AOI} = 5$, (c) $h_{AOI} = 6$.

erated packets in different network density and the numbers of h_{AOI}. In general, the number of generated packets increases as the number of sensor nodes increases, as depicted in Figures 8 and 9. In our evaluations, Fixed-ZOF generates a less number of packets than SHORT because only the nodes in the directional region of AOI are involved in packet forwarding. On the other hand, SHORT needs more sensors to help to forward the packets from sender, which results in the increase of the number of generated packets. Recall that, in this paper, we mainly focus on the improvement of the packet delivery ratio in VC-WSNs. Therefore, it is worth the additional overhead to efficiently improve the packet delivery ratio.

Additionally, Figures 8 and 9 show that less number of packets is generated for the packet forwarding in the network with less number of directional regions. Because only the nodes locating in the directional region of AOI has to become forwarders, Fixed-ZOF incurs less number of sensor nodes required to forward the received

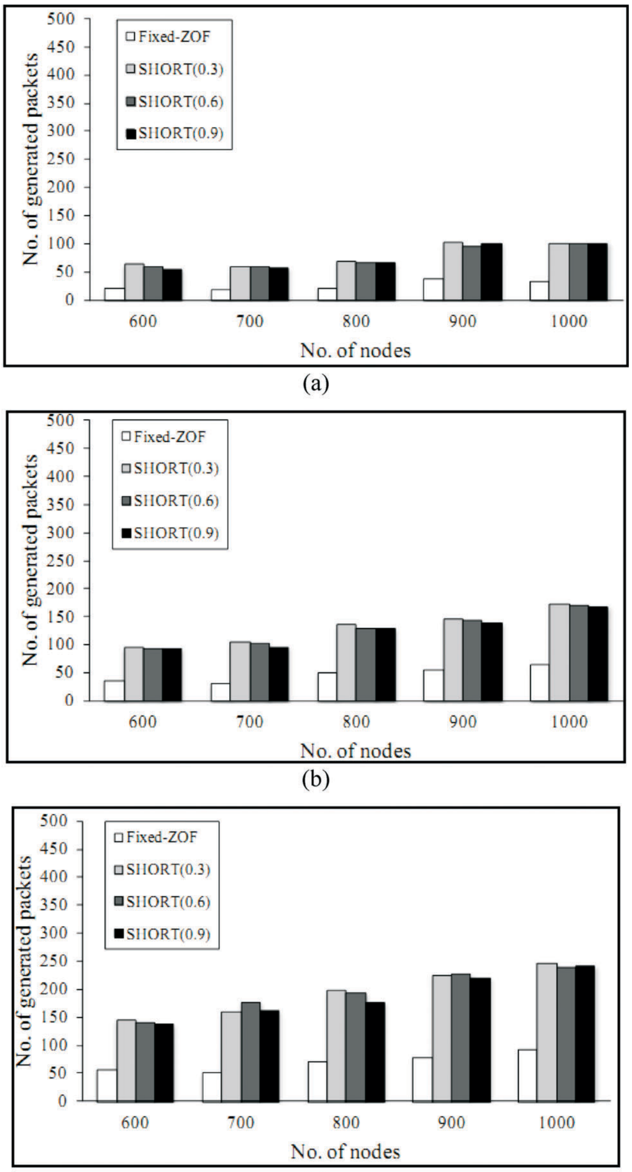


Figure 9. The influence of the network density on the number of generated packets under the network with 4 directional regions. (a) h_{AOI} = 4, (b) h_{AOI} = 5, (c) h_{AOI} = 6.

packet compared with the proposed SHORT. In SHORT, because the wireless sensor network is divided into several directional regions, only sensor nodes in the specified regions have a high chance to participate in forwarding received packets. As a result, the number of generated packets increases significantly. Actually, the proposed SHORT can efficiently improve the packet delivery ratio, although generating a little bit more packets during geocasting.

Here, we discuss the effect of weighted value on geocasting performance. The simulation results show that more packets are generated in most cases if $\alpha = 0.3$. This indicates that the influence of distance-based forwarding probability is more significant than that of direction-based forwarding probability in SHORT. Although the nodes locating in the non-AOI directional regions will become candidate forwarders, the total number of sensor nodes needed to forward the received packet increases, as more sensor nodes locating in the directional region of AOI may have a higher probability to become forwarders.

5. Conclusion

In this paper, we have proposed a probabilistic geocasting approach (SHORT) to mainly improve the packet delivery ratio in virtual coordinate wireless sensor networks with environmental holes. The main idea of SHORT is to construct a dynamic zone of forwarding by candidate forwarders which self-determine an ultimate forwarding probability according to its direction-based and distance-based forwarding probabilities. To investigate the influence of direction and distance on geocasting performance, the proposed SHORT introduces a weighted combination function of the two probabilities. As selecting multiple forwarders, the SHORT can discover many paths to deliver geocast packets so as to increase the packet delivery ratio. Simulation results validate that SHORT outperforms the fixed ZOF-based method in packet delivery ratio under VC-WSNs with environmental holes, although slightly incurring a little bit number of packets. Our on-going research is to investigate the possibility of reducing the number of candidate forwarders to save energy of sensor nodes. The future research can focus on the important issues such as tracking and coverage for VC-WSNs, and explore the solutions to these issues.

References

[1] Akyildiz, I. F., Su, W., Sankarasubramaniam, Y. and Cayirci, E., "A Survey on Sensor Networks," *IEEE Communications Magazine*, Vol. 40, pp. 102–114 (2002).

[2] Kahn, J. M., Katz, R. H. and Pister, K. S., "Next Cen-

tury Challenges: Mobile Networking for Smart Dust," *Proc. of the ACM International Conference on Mobile Computing and Networking (MOBICOM)*, Seattle, U.S.A., Aug. 15-20, pp. 271–278 (1999).

[3] Hofmann-Wellenhof, B. H., Lichtenegger, H. and Collins, J., *Global Positioning System: Theory and Practice*, 5^{th} ed., Springer (2001).

[4] Priyantha, N. B., Chakraborty, A. and Balakrishnan, H., "The Cricket Location-Support System," *Proc. of the ACM International Conference on Mobile Computing and Networking (MOBICOM)*, Boston, U.S.A., Aug. 8-11, pp. 32–43 (2000).

[5] Karp, B. and Kung, H., "GPSR: Greedy Perimeter Stateless Routing for Wireless Networks," *Proc. of the ACM International Conference on Mobile Computing and Networking (MOBICOM)*, Boston, U.S.A., Aug. 8-11, pp. 243–254 (2000).

[6] Zamalloa, M. Z., Seada, K., Krishnamachari, B. and Helmy, A., "Efficient Geographic Routing over Lossy Links in Wireless Sensor Networks," *ACM Transactions on Sensor Networks*, Vol. 4, pp. 1–33 (2008).

[7] Jiang, Z., Ma, J., Lou, W. and Wu, J., "An Information Model for Geographic Greedy Forwarding in Wireless Ad-Hoc Sensor Networks," *Proc. IEEE INFOCOM, Pheonix*, U.S.A., Apr. 15-17, pp. 825–833 (2008).

[8] Lian, J., Liu, Y., Naik, K. and Chen, L., "Virtual Surrounding Face Geocasting in Wireless Ad Hoc and Sensor Networks," *IEEE/ACM Transactions on Networking*, Vol. 17, pp. 200–211 (2009).

[9] Park, S., Lee, E., Park, H., Lee, H. and Kim, S.-H., "Mobile Geocasting to Support Mobile Sink Groups in Wireless Sensor Networks," *IEEE Communications Letters*, Vol. 14, pp. 939–941 (2010).

[10] Park, S., Lee, E., Yim, Y., Yu, F. and Kim, S.-H., "X-Geocasting: Data Dissemination to Mobile Sink Groups in Wireless Sensor Networks," *Proc. IEEE International Symposium on Personal Indoor and Mobile Radio Communications (PIMRC)*, Toronto, Canada, Sep. 11-14, pp. 2259–2263 (2011).

[11] Wang, S.-S., Shih, K.-P. and Chang, C.-Y., "Distributed Direction-Based Localization in Wireless Sensor Networks," *Computer Communications*, Vol. 30, pp. 427–442 (2007).

[12] Xing, G., Lu, C., Pless, R. and Huang, Q., "On Greedy Geographic Routing Algorithms in Sensing-Covered Networks," *Proc. ACM International Symposium on Mobile Ad Hoc Networking and Computing (MOBIHOC)*, Tokyo, Japan, May 24-26, pp. 31–42 (2004).

[13] Chang, C.-Y., Chang, C.-T. and Tu, S.-C., "Obstacle-Free Geocasting Protocols for Single/Multi-Destination Short Message Services in Ad Hoc Networks," *Wireless Networks*, Vol. 9, pp. 143–155 (2003).

[14] Stojmenovic, I., "Geocasting Protocol with Guaranteed Delivery in Sensor Networks," *IEEE Wireless Communications*, Vol. 11, pp. 29–37 (2004).

[15] da S. Araújo, de Castro, W. L. T. and Filho, R. H., "WSN Routing: A Geocast Approach for Reducing Consumption Energy," *Proc. IEEE Wireless Communications and Networking Conference (WCNC)*, Sydney, Australia, Apr. 18-21, pp. 1–6 (2010).

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