Geometric Broadcast Without GPS Support in Dense Wireless Sensor Networks

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***Abstract*—For scalable information routing and dissemination, broadcast has been gaining tremendous interests of research in Wireless Sensor Networks (WSNs), where each sensor node has inherent resource constraints in terms of battery energy, and computing and communication capabilities. Since a blind broadcast can cause the broadcast storm problem, diverse broadcast strategies have been explored to increase the network coverage but to minimize the redundant rebroadcasts. In this paper, we propose a geometric broadcast scheme in dense WSNs. This scheme deploys a sender-initiated broadcast approach, where a sender approximates the location of its neighbor nodes without using an on-board global positioning system (GPS). Then the sender selects a set of forwarding candidate nodes located at the closest to the strategic positions based on a virtual hexagon-based coverage. A simple random backoff mechanism is also proposed to reduce the packet contentions and collisions. We develop a customized discrete-event driven simulator using the OMNeT++ to conduct our experiments. Two well-known broadcast schemes are modified to work in dense WSNs: Flooding and Ad Hoc Broadcast Protocol (AHBP). We conduct an extensive performance comparison study and the proposed scheme achieves a competitive and scalable performance in dense WSNs.**

***Index Terms*—Ad hoc broadcast protocol, dense wireless sensor networks, flooding, geometric broadcast.**

I. Introduction

Broadcast is a fundamental wireless communication operation and plays a vital role for scalable information routing and dissemination. Compared to point-to-point communication, broadcast communication has extensive applications in diverse wireless networks. For example, finding a routing path from a source to a destination in Mobile Ad hoc Networks (MANETs), forwarding an emergency alarm message to following vehicles in Vehicular Ad hoc Networks (VANETs), delivering a sensory data item from a node to a sink in Wireless Sensor Networks (WSNs), or invalidating a local cache of mobile node to opportunistically access data in cellular networks [1]. Due to the falling cost in accessing high-speed wireless Internet, broadcast has become increasingly popular.

As pointed out in the [2], however, broadcast has inherent operational constraints in terms of redundancy, contention, and collision in wireless networks. A blind broadcast followed by unconditional forwarding is inefficient and even harmful because it can cause redundant rebroadcasts and packet contentions and collisions. The redundant rebroadcasts can also negatively affect the communication performance such as the network lifetime. Note that unlike a wired network, when a node transmits a *unicast* packet, all of its neighbors can overhear the packet as if it broadcasts a packet [3].

In this paper, we investigate a geometric broadcast scheme in dense WSNs. Our contributions are two-fold:

- We first propose a sender-initiated broadcast approach, in which a sender approximates its neighbor nodes' location without using an on-board Global Positioning System (GPS). Then the sender selects a set of forwarding candidate nodes closely located at the boundary of the sender's communication range. The sender further searches the forwarding candidate nodes that are located at the closest to the strategic positions based on a virtual hexagon-based coverage. A simple random backoff mechanism is also proposed to avoid packet contentions and collisions.
- Second, a customized discrete-event driven simulator is developed to implement the proposed techniques by using the OMNeT++ [4]. Both *Flooding* and *Ad Hoc Broadcast Protocol* (AHBP) schemes are modified to work in dense WSNs.

Extensive simulation studies have been conducted for performance evaluation. The proposed scheme is compared with the Flooding and AHBP schemes in terms of packet delivery ratio, rebroadcast fraction, number of rebroadcasts, and packet propagation delay. In particular, the proposed scheme shows a scalable performance in terms of the number of rebroadcasts as the number of deployed nodes increases in the network. Overall simulation results indicate that the proposed scheme is a viable approach for dense WSNs.

The rest of paper is organized as follows. The prior work is reviewed and analyzed in Section II. The proposed non-geometric broadcast and simple random backoff techniques are presented in III. Section IV presents simulation results and analyses. Finally, we conclude the paper with future research direction in Section V.

II. Related Work

In this section, we categorize and analyze prior broadcast technique in terms of threshold-, structure-, probability-, and geometry-based approaches.

Threshold-based Approach: When a node sends a packet, due to a promiscuous receiving mode, all of its neighbor nodes can overhear the packet. A following unconditional forwarding (i.e., flooding) can incur redundant transmissions and lead to the broadcast storm problem [2]. To avoid the redundant rebroadcasts resulting in the packet contentions and collisions, several threshold-based schemes have been proposed and their threshold values are adjusted based on the local connectivity information [2], [5]. Under the consideration of distance- and counter-based schemes [2], receiver's signal strength can be measured to approximate the distance to a packet sender [6]. The node located at the farthest from the sender rebroadcasts the packet to increase the coverage area. This approach is further extended to a heterogeneous network topology in the presence of obstacles [7], where nodes are non-uniformly deployed in the network. In [8], since the packet loss is unavoidable (i.e., a predefined rebroadcast probability, $p = 0.55 < 1$) during a broadcast period, each node buffers failed broadcast packets and periodically rebroadcasts them to compensate any missed packet.

Structure-based Approach: A broadcast tree between a source and multiple destinations is built to improve energy efficiency or reliability, i.e., a flood tree [9], [10], [11]. Depending on the connectivity in the tree, each node can decide whether to rebroadcast or drop a packet. In [10], a connected dominating set (CDS) is constructed in a localized and distributed manner: constructing independent DSs (i.e., dominators) and connecting all nodes (i.e., connectors) in DSs. Then the dominators create a virtual backbone for efficient broadcast. In [11], a single node is elected (i.e., single-initiator) in a distributed manner and it grows a dominator tree to form a CDS by using the timers. Multiple-initiators are considered to avoid a single-point of failure at single-initiator. As pointed out in the [9], however, the problem of finding a minimum tree that has the minimum number of forwarding nodes is proven to be NP-complete. Frequent constructing and maintaining the tree can also occur non-negligible communication overhead because of the mobility and energy constraints in MANETs and WSNs.

Probability-based Approach: Each node decides whether to forward a packet with a retransmission probability p, i.e., a gossip probability [12], [13], [14], [15]. The probability is calculated under the consideration of dissemination coverage, redundant retransmission, latency, and communication overhead. To adaptively calculate the p, a hybrid scheme [13] is proposed by combining the counter-based [2] and probabilistic approaches. Each node estimates a time-varying local density of network by counting the number of received packets, and then adjusts the p accordingly with a set of predefined thresholds in MANETs. In [14], each node uses an adaptive gossip probability based on local topological properties (i.e., parent, child, and sibling nodes) in WSNs, where the probability can be changed by unpredictable node and link failures. A. Gaba et al. further analyze prior GOSSIP3 scheme [12] in terms of the key parameters (i.e., p, m, and k), and propose a probabilistic forwarding scheme [15] based on a heuristic approach in MANETs. Each node periodically estimates its local network density (i.e., a number of neighbor nodes) and dynamically adjusts its gossip probability with the Weibull model, which is formalized by empirical results.

Geometry-based Approach: Each node is equipped with a GPS and a set of forwarding nodes is optimally selected in the network. A hexagon-based coverage is popularly deployed and the forwarding nodes located at the strategic positions (i.e., hexagons' vertices) are selected to increase the network coverage but to minimize redundant rebroadcasts and packet collisions. In [16], [17], unlike the flooding, either three or six nodes located at hexagon's vertices are selected as the forwarding nodes. [16] proposes an adaptive-geometric scheme, in which a next forwarding node is self-selected based on the distance. The selected forwarding nodes should be located at the closest to the strategic location as well as farthest from the previous packet sender.

In summary, relatively little effort has been made for developing a geometric broadcast approach without using a GPS in dense WSNs.

III. The Proposed Geometric Broadcast

In this section, we first analyze sender- and receiver-initiated broadcast approaches. Then we propose an approximation method for neighbor location without using a GPS to minimize the overlapped broadcast areas in dense WSNs. A simple random backoff mechanism is also proposed to avoid the packet contentions and collisions.

A. Sender- Vs. Receiver-initiated Broadcasts

In multi-hop broadcasts, either a single node or a set of nodes is often selected as a forwarding candidate node. A blind broadcasting followed by unconditional forwarding may cause redundant broadcasts and increase the network traffic, resulting in the broadcast storm problem [2]. Thus, it is critical to select an appropriate forwarding node for efficient broadcasting. Generally either a sender- or receiver-initiated broadcast approach is considered. In a sender-initiated broadcast, a packet sender selects a set of forwarding candidate nodes based on its local policy. Here, each node (e.g., n_i) can aware of its one-hop neighbor nodes (G_i) and also count the number of one-hop neighbor nodes ($|G_i|$) by exchanging one-hop *Hello* and *Hello_Ack* packets piggybacked with its id. In addition, each node can aware of its one-hop neighbor nodes' neighbor nodes, if its one-hop neighbor nodes' ids are piggybacked with the *Hello* and *Hello_Ack* packets. The sender unicasts the packet piggybacked with the forwarding nodes' ids. Only designated nodes rebroadcast the packet and others keep quiet. Note that the sender sends a unicast packet aiming at the designated receivers only, but all the sender's adjacent nodes can still overhear it. In a receiver-initiated

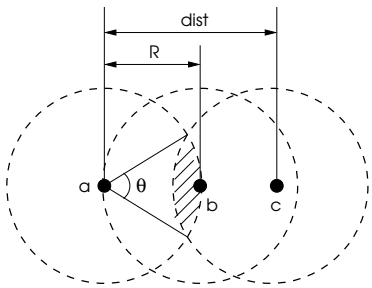

Fig. 1. Each node shares a communication range with its neighbor. Nodes n_a and n_b are located at the boundary of each other's communication range. Here, a dashed line represents a communication range.

broadcast, however, the sender simply broadcasts a packet and its one-hop neighbor nodes will decide whether to rebroadcast based on their local policy. For example, each node may use a gossip probability for rebroadcasting. The sender can know whether its neighbors rebroadcast the packet through either an implicit or explicit acknowledgment.

In this paper, we deploy a sender-initiated broadcast approach. The basic idea is to select a set of forwarding candidate nodes that is closely located at the boundary of the sender's communication range without using a GPS. A virtual hexagon-based coverage is considered to minimize the overlapped broadcast areas in dense WSNs. In prior hexagon-based broadcast approach [17], [18], each node is often assumed to equip a GPS and thus, a sender can select a set of forwarding nodes closely located at the boundary of the sender's communication range. Since the sender selects the nodes located at the furthest from it and spaced widest each other, the overlapped broadcast areas can be minimized in the network. Although GPSes have been deployed in diverse networking areas and become increasingly popular, the accuracy of GPSes can significantly affect the communication performance, i.e., NAVSTAR GPS has about 50 to 100m of error bounds [19].

B. Approximation of Neighbor Location

To select a set of forwarding candidate nodes, nodes closely located at the boundary of communication range are searched to maximize the broadcast coverage. In Fig. 1, each node shares a communication range with its neighbors. Nodes n_b and n_c are located at the radius (R) and $dist$ distances apart from n_a, respectively. Generally, an overlapped area (i.e., shaded area) between two nodes located at the $dist$ distance apart can be calculated as,

$$A_{dist}^{overlap} = 2(\pi R^2 \frac{\theta}{2\pi} - \frac{dist}{2}\sqrt{R^2 - \frac{dist^2}{4}}). \quad (1)$$

We consider a case that n_a and n_b are located at the R distance apart. Here, the $dist$ and θ become R and $\frac{2\pi}{3}$, respectively. Then the overlapped area can be calculated based on Eq. 1,

$$A_R^{overlap} = 2R^2(\frac{\pi}{3} - \frac{\sqrt{3}}{4}). \quad (2)$$

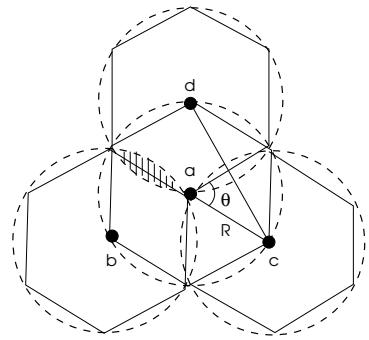

Fig. 2. Three forwarding candidates are selected based on the distance among nodes, closely located at the border of communication range.

Compared to the area of n_a's communication range (A_{n_a}), $A_R^{overlap}$ shares approximately 39.1% expressed as below,

$$\frac{A_R^{overlap}}{A_{n_a}} = \frac{2R^2(\frac{\pi}{3} - \frac{\sqrt{3}}{4})}{\pi R^2} = \frac{2}{3} - \frac{\sqrt{3}}{2\pi} \approx 0.3910\ldots \quad (3)$$

Since we consider a dense WSN where nodes are uniformly distributed in the network, each node shares the same or similar number of neighbor nodes. For example, if two nodes are located at the same location, each node shares 100% of its communication range with the other. If two nodes are located at more than $2R$ distance apart, no communication range is shared. In Eq. 3, if both n_a and n_b share about 39.1%, each node is then most likely located at the border of the other node's communication range.

To identify the nodes located at the communication boundary (B_s) of a sender (e.g., n_s), n_s first counts its one-hop neighbor nodes (e.g., n_i), $|G_s|$. The number of one-hop neighbor nodes' neighbors but located within n_s's communication range is also counted, $|G_i \cap G_s|$. Then n_s calculates whether $\frac{|G_i \cap G_s|}{|G_s|}$ is about 39.1% or 39.1% + ϵ, as shown in Eq. 4. If n_i satisfies this equation, it is most likely located at the boundary of n_s's communication range and becomes a forwarding candidate node. Here, the ϵ is a system parameter and provides a margin to flexibly select the nodes closely located at the communication boundary.

$$B_s = \{n_i \in G_s | \ \frac{|G_i \cap G_s|}{|G_s|} \approx 39.1\% \text{ or } 39.1\% + \epsilon\}. \quad (4)$$

Because multiple nodes can satisfy Eq. 4, we consider a hexagon-based coverage approach to further refine the forwarding candidate nodes for minimizing the overlapped broadcast areas in dense WSNs, as shown in Fig. 2. Each node establishes a virtual hexagon within its communication range. In this paper, three forwarding candidates (i.e., n_b, n_c, and n_d) located at $\sqrt{3}R$ apart each other are considered to minimize the overlapped broadcast areas. Here, the $dist$ and θ become $\sqrt{3}R$ and $\frac{\pi}{3}$, respectively. Then the overlapped area (i.e., shaded area) can be calculated based on Eq. 1,

$$A_{\sqrt{3}R}^{overlap} = 2(\pi R^2 \frac{1}{6} - \frac{\sqrt{3}R}{2}\sqrt{R^2 - \frac{3R^2}{4}}) = \frac{\pi R^2}{3} - \frac{\sqrt{3}R^2}{2}. \quad (5)$$

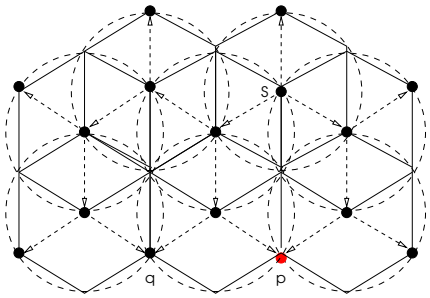

Fig. 3. A node may receive multiple broadcast packets. Here, a dashed arrow indicates the direction of packet propagation in the network.

$A^{overlap}_{\sqrt{3}R}$ shares approximately 5.8% compared to A_{n_a},

$$\frac{A^{overlap}_{\sqrt{3}R}}{A_{n_a}} = \frac{\frac{\pi R^2}{3} - \frac{\sqrt{3}R^2}{2}}{\pi R^2} = \frac{1}{3} - \frac{\sqrt{3}}{2\pi} \approx 0.0577\ldots \quad (6)$$

Based on Eq. 6, n_s further searches the nodes closely located at the boundary of its communication range (i.e., B_s), whether they are located at $\sqrt{3}R$ apart. For example, two nodes (e.g., n_i and n_j) are first selected in B_s, in which both n_i and n_j are in G_s. The number of both n_i's and n_j's common one-hop neighbor nodes is counted, $|G_i \cap G_j|$. Then n_s calculates whether $\frac{|G_i \cap G_j|}{|G_s|}$ is about 5.8% or 5.8% + δ, as shown in Eq. 7. If both n_i and n_j satisfy this equation, two nodes are mostly likely located at $\sqrt{3}R$ apart each other. The distances of all the pairs of nodes in B_s are estimated. Here, the δ is a system parameter and provides a margin to flexibly select a pair of nodes located at about $\sqrt{3}R$ apart each other.

$$F_s = \{n_i, n_j \in B_s \ \wedge \ n_i, n_j \in G_s | \ \frac{|G_i \cap G_j|}{|G_s|} \approx 5.8\% \text{ or } 5.8\% + \delta\}. \quad (7)$$

In case of multiple forwarding candidates in F_s, the best three forwarding nodes estimated as close as 5.8% are selected.

The network density can affect the validity of the relation between the approximated area and the number of neighbor nodes in such as a sparse or non-uniform network. To find enough number of nodes that satisfy Eqs. 4 or 7, n_s increases the ϵ or δ. In this paper, both ϵ and δ are initially set to zero and they are linearly incremented.

C. Random Backoff Procedure

In Fig. 3, a sender, n_s, initially broadcasts a packet that is propagated to the three selected forwarding nodes. Then each forwarding node executes a backoff procedure before forwarding the packet to avoid possible packet contentions and collisions. Since n_s piggybacks the forwarding nodes' id in the packet, packet collisions can be minimized within the n_s's communication area. But the nodes located at the three overlapped areas (i.e., about 5.8% of n_s's communication range each) will be affected. A forwarding node may receive multiple broadcasts, i.e., n_p and n_q. Multiple broadcasts can be collided at n_p after three propagation hops via different forwarding nodes. n_q may receive multiple broadcasts but most likely they will not be arrived at the same time because of the different number of hops and the different propagation directions. Thus, n_q will discard the later arriving packet for duplication. In this paper, we deploy a simple CSMA/CA MAC protocol for the link layer and propose a random backoff mechanism to prevent each forwarding node from sending a packet simultaneously. For example, when a node n_i receives a packet, its random backoff period is, $t_i^{boff} = \text{Uniform}(0, \kappa \cdot |F_i|) \cdot t_{slot}$, where $|F_i|$ and t_{slot} are the number of forwarding nodes of n_i and slot time, respectively. Each slot time is on the order of tens or hundreds of microseconds. The κ is a system parameter to reduce the probability of choosing the same backoff period.

In summary, we propose an approximation scheme of neighbor nodes' location and a simple random backoff technique for a geometric broadcast in dense WSNs. Without one-hop neighbor nodes' precise location information, a sender may not find a set of forwarding nodes located at the closest to the strategic positions (i.e., hexagon's vertices). But nodes located at the boundary of the sender's communication range as well as $\sqrt{3}R$ apart each other are comprehensively searched to avoid a distorted coverage. The pseudo code of the proposed geometric broadcast is shown in Fig. 4.

Notations:
- G_s, $|G_s|$: A set of one-hop neighbors of n_s and its number of nodes.
- B_s, $|B_s|$: A set of forwarding candidates located at the boundary of n_s's communication range and its number of nodes.
- F_s, $|F_s|$, κ: A final set of forwarding nodes $\sqrt{3}R$ apart each other and its number of nodes, and a system parameter.
- t_s^{boff}, t_{slot}: A random backoff time and a duration of time slot.
- ϵ, δ: System parameters for providing a margin in finding a set of forwarding candidates and a set of final forwarding nodes, respectively.

◇ When a node, n_s, receives a packet, pkt, for transmission:

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B_s, F_s = ∅;
for each n_i ∈ G_s do
    if ( |G_i∩G_s|/|G_s| ≈ 39.1% ∨ |G_i∩G_s|/|G_s| ≈ 39.1% + ε)
    then B_s = B_s ∪ n_i;
end do
for each n_i, n_j ∈ B_s ∧ n_i, n_j ∈ G_s do
    if ( |G_i∩G_j|/|G_s| ≈ 5.8% ∨ |G_i∩G_j|/|G_s| ≈ 5.8% + δ)
    then F_s = F_s ∪ n_i, n_j;
end do
t_s^boff = Uniform(0, κ · |F_s|) · t_slot;
Broadcast the pkt[F_s] after t_s^boff;
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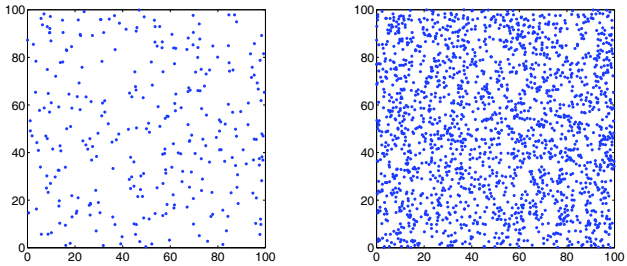
Fig. 4. The pseudo code of the proposed geometric broadcast scheme.

IV. Performance Evaluation

A. Simulation Testbed

In this paper, we develop a customized discrete-event driven simulator by using the OMNeT++ [4] with extended library functions for WSNs, Castalia [20], to conduct our experiments. We use a 100×100 m^2 rectangular network area, where a set of nodes is randomly distributed in the network. For example, Fig. 5 compares the network topologies with 300 and 2,000 deployed nodes respectively. The radio model simulates CC2420 with a nominal data rate of 250 Kbps. The radio propagation model is based on the free-space model. A single



(a) 300 nodes (b) 2,000 nodes

Fig. 5. Network topologies.

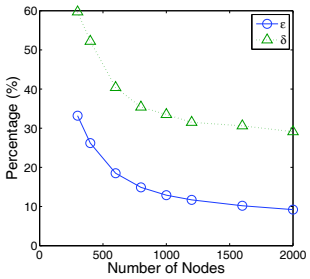


Fig. 6. Changes of ϵ and δ.

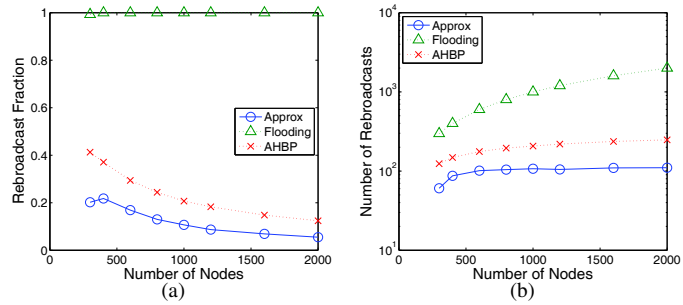


Fig. 7. Rebroadcast fraction and number of rebroadcasts.

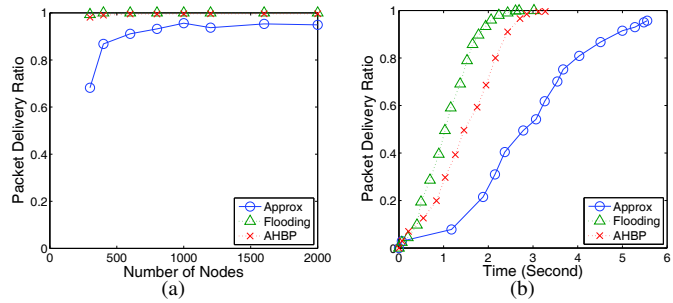


Fig. 8. The packet delivery ratio and packet propagation delay.

source node located at the center of network broadcasts a 2 KByte data packet. The transmission range of each node is 10 m. The simulation results are the average of 50 simulation runs.

B. Simulation Results

For the performance comparison study, we modify two broadcast schemes to work in a dense WSN: *Flooding* and *Ad Hoc Broadcast Protocol* (AHBP) [21]. Let us denote the proposed scheme as *Approx*. The AHBP scheme deploys a sender-based broadcast approach and maintains two-hop neighbor knowledge by periodically exchanging an one-hop *Hello* message. A sender selects a set of forwarding nodes (called as a broadcast relay gateway) that can efficiently cover the nodes located within two-hop radius. We embed the proposed simple backoff mechanism into Flooding and AHBP schemes. Unless otherwise specify, we use 15 time slots (i.e., κ = 5) and each slot is 70 ms.

In this paper, four performance parameters are evaluated: packet delivery ratio (PDR), rebroadcast fraction, number of rebroadcasts, and packet propagation delay. In addition, the Approx scheme is evaluated in terms of PDR and rebroadcast fraction either with or without backoff mechanism.

We first show the average values of ϵ and δ depending on the network density in Fig. 6. When 300 and 600 nodes are deployed in the network, the average number of neighbor nodes is 9.4 and 18.8 respectively. To find the enough number of nodes that satisfy Eqs. 4 and 7, both ϵ and δ increase. For example, when 300 nodes are deployed in the network, both ϵ and δ are 33.2% and 59.7% respectively. As the number of deployed nodes increases in the network, both ϵ and δ decrease because more number of nodes located at the strategic locations are found. The δ shows higher values than ϵ for entire number of deployed nodes, because it is harder to find the number of nodes satisfying the Eq. 7 compared to that of the Eq. 4.

Second, we compare the performance in terms of rebroadcast fraction and the number of rebroadcasts in Fig. 7. In Subfig. 7(a), rebroadcast fraction is measured as the fraction of nodes involved in rebroadcasting and indicates redundant broadcast operations. As we can expect, the Flooding scheme shows 100% because every node can be a forwarding node. As the number of deployed nodes increases in the network, the Approx scheme shows the lowest and decreasing rebroadcast fractions. This is because a sender can select forwarding nodes located at more closely to the communication boundary and thus, the less number of nodes is involved in rebroadcasting. Subfig. 7(b) shows comparisons of the number of rebroadcasts. In the Flooding scheme, the number of rebroadcasts is same as the number of deployed nodes in the network. As the network becomes dense, the AHBP scheme increases the number of rebroadcasts because more number of nodes are selected as a forwarding node. Since the maximum three forwarding nodes are involved in each rebroadcasting, however, the Approx scheme shows a scalable performance for the number of deployed nodes in the network.

Third, Fig. 8 shows both PDR and packet propagation delay with 1,000 deployed nodes in the network. In Subfig. 8(a), the PDR is measured as the fraction of nodes that receive a broadcast packet at least once. Both Flooding and AHBP schemes show almost 100% PDR and the Approx scheme also can show more than 95% PDR in dense networks, i.e., when the number of deployed nodes are more than 600. Since the PDR of Approx scheme is directly affected by the number of neighbor nodes, it shows the lowest performance in 300 nodes. Subfig. 8(b) shows both PDR and packet propagation delay. The Approx scheme shows more delay than that of the AHBP and Flooding schemes. Since both Flooding and AHBP schemes involve more number of forwarding nodes in

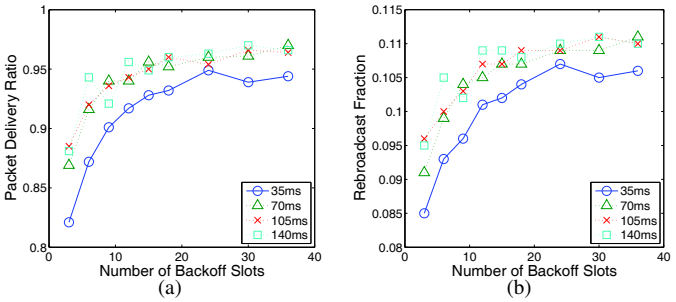


Fig. 9. Packet delivery ratio and rebroadcast fraction.

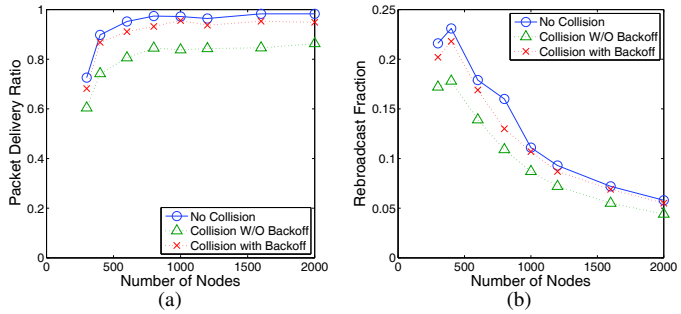


Fig. 10. Packet delivery ratio and rebroadcast fraction.

rebroadcasting than that of the Approx scheme, they achieve higher PDR with less delay compared to the Approx scheme.

Fourth, the proposed backoff mechanism for the Approx scheme is evaluated in terms of PDR and rebroadcast fraction by changing the slot time against the number of backoff slots in Fig. 9. In the Approx scheme, three backoff slots would be ideal because the number of forwarding nodes is at most three. However, more number of backoff slots and a long slot time are preferred to reduce the possible packet collisions. As both slot time and the number of slots increase, slightly higher PDR and rebroadcast fraction are witnessed in Subfigs. 9(a) and (b).

Finally, we evaluate the performance of the Approx scheme in terms of PDR and rebroadcast fraction either with or without backoff mechanism in Fig. 10. The no collision case is shown as a performance upper bound, which shows the highest PDR and rebroadcast fraction. With the backoff mechanism, the PDR shows a competitive performance to the upper bound, while lower rebroadcast fraction than that of the upper bound is witnessed in Subfigs. 10(a) and (b) respectively. Since more nodes are involved in rebroadcasting, both no collision and with backoff cases show higher PDR and rebroadcast fraction than that of the without backoff case.

V. Conclusion and Future Work

In this paper, we proposed a geometric broadcast scheme and a simple backoff mechanism in dense WSNs. This scheme deploys a sender-initiated broadcast approach and a set of forwarding nodes located at closest to the strategic positions is selected without using a GPS. Compared to the Flooding and AHBP schemes, the proposed scheme shows a competitive performance with respect to the PDR, rebroadcast fraction, and number of rebroadcasts. In particular, as the number of deployed nodes increases in the network, the proposed scheme shows a scalable performance in terms of the number of nodes involved in rebroadcasting.

We plan to extend the proposed scheme to see its full potential. In this paper, we implicitly assume that all nodes have the same communication range in dense WSNs. We need to relax this assumption because of the fluctuating signal power and ambient noises. Although each node can estimate its neighbor nodes' distance based on the receiving signal strength without using a GPS, there is a non-negligible error for estimating the distance. We also plan to investigate time-varying communication ranges for the proposed scheme in energy harvesting WSNs [22]. Each node can switch from its normal communication range to extended communication range whenever it harvests energy from environment resources (i.e., solar, wind, vibration, etc.).

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