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ORZBP: An Obstacle-Resistant Zone-based Broadcasting Protocol for Wireless Sensor Networks

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***Abstract*—Wireless Sensor Networks (WSNs) comprise a few sink nodes and a large number of sensor nodes. The WSN environment contains unpredictable obstacles, such as mountains, lakes, buildings, or regions without any sensor node, impeding or blocking message relay. Broadcasting is an essential operation broadly used in WSNs. However, the blind flooding results in the large-scale waste of energy and bandwidth resources even though it is the simplest way to overcome obstacle-resistant problems. On the other hand, the blind flooding also raises the amount of packet collisions and contentions. This paper proposes a distributed obstacle-resistant broadcasting protocol, called as ORZBP, to reduce the number of forwarding nodes and to overcome the obstacle problem. Experimental results reveal that ORZBP reduces the redundant bandwidth and power consumptions, avoids the possible packet collision as well as achieves the high success rate.**

Keywords- wireless sensor network; obstacle-resistant; packet collision; zone-based; broadcasting

I. INTRODUCTION

In a WSN, broadcasting is an essential operation which will be applied at different nodes when the sink node intends to deliver the query request to all sensor nodes. In the blind flooding mechanism, the sink node initiates a broadcasting request to the entire network. On receiving the packet, each sensor rebroadcasts the packet to its neighbors so that the packet could be delivered to all nodes in the network [3][5][6] [10-13]. Although blind flooding is simple and commonly used in WSNs, however, it consumes plenty of bandwidth resource and raises packet collision and contention problems as well as reduces the packet delivery rate [2]. To reduce the number of flooding packets, previous researches [1, 7-9] partition the network area into several equal-sized zones. For each partitioned zone, nodes located in the same zone will vote for a manager, who is responsible for performing the message exchange with the other neighboring managers. The number of broadcasting packets is significantly reduced since only the zone managers participate in the task of packet forwarding. However, the collision problem is still existed at the zone-level managers. If the neighboring managers simultaneously broadcast the message, the collision will be occurred and hence results in the low accuracy of data collection at the sink node.

In literatures, a zone-based broadcasting protocol [8], called as *ZBP*, aims at preventing the transmissions from packet collision. In addition to partitioning the network area into a number of equal-sized zones, *ZBP* further partitions the network into bands. The zone-level managers on the band boundary will be selected as forwarding nodes which will be arranged to relay packets to avoid collisions as well as improve the accuracy of information collection. However, *ZBP* did not take the unpredicted obstacles into consideration in WSNs. When the packet transmissions encounter the unpredictable obstacle, they will be blocked, resulting in low packet delivery ratio.

The objective of this paper is to propose an *Obstacle-Resistant Zone-based Broadcasting Protocol*, called as *ORZBP*, to send a message from source to all nodes in the WSN without collision, even though the network contains unpredicted obstacle. The reminder of this research is outlined as follows. Section II illustrates the previous works and the basic concept of *ORZBP*. Section III presents the detail of *ORZBP*. Meanwhile, section IV shows the performance evaluation of *ORZBP*. Conclusions are finally made in section V.

II. RELATED WORKS

Broadcasting is an essential operation applied in WSNs. To reduce flooding overhead, a number of zone-based management protocols [4, 8, 9] are proposed. Based on the location information, *Cellular-Based Management* (*CBM*) [4] was proposed to alleviate the phenomenon of packet collision and contention. The *CBM* geographically partitions the area of monitoring region into several equal-sized zones. As shown in Fig. 1(a), each partitioned zone is assigned with a unique zone ID as the coordinates system of the *CBM*. Fig. 1(b) depicts the general rule of the coordinates system in *CBM*. In each zone, a manager will be selected for executing the information exchange with its neighboring managers.

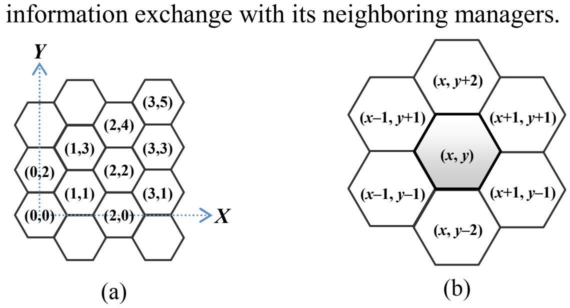

Figure1: Coordinate system of cellular-based management.
(a) Each cell has a unique ID in *CBM* system.
(b) Coordinate system of *CBM* is defined.

The concepts of zone-based partition and manager-level broadcast in *CBM* systems cause that only the zone managers participate in the packet flooding. However, packet collisions are still occurred at zone-level nodes when the neighboring managers broadcast the received message at the same time. To improve the collision problem of cellular-based management, a *zone-based broadcasting protocol* (*ZBP*) [8]

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was proposed to improve *CBM* [4]. The *ZBP* not only selects representative managers but also schedules their broadcasts to avoid the potential collisions. As shown in Fig. 2, the network region is partitioned into six areas A_n, for $1 \le n \le 6$, according to the six directions X_i of source cell S where the sink or the mobile sink node is located, for $1 \le i \le 6$. *ZBP* then further partitions the network into bands with a width of three cells.

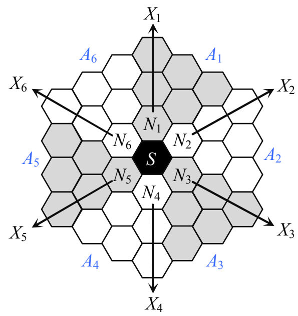


Figure 2: *ZBP* partitions the area of WSN into six regions, $A_1,\ldots,A_6$.

Consider the region A_1 as an example in Fig. 3. A_1 can be partitioned into several bands along direction X_2. Zone Managers on the sub-axis S_j, for $j>0$, are responsible to forward the broadcast message so that all managers can receive the message.

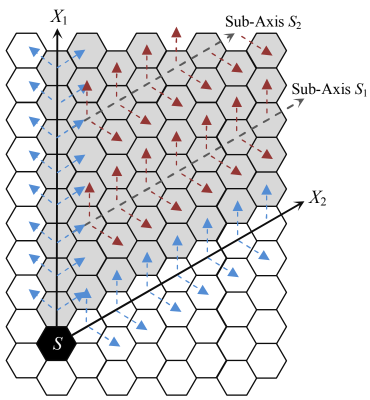
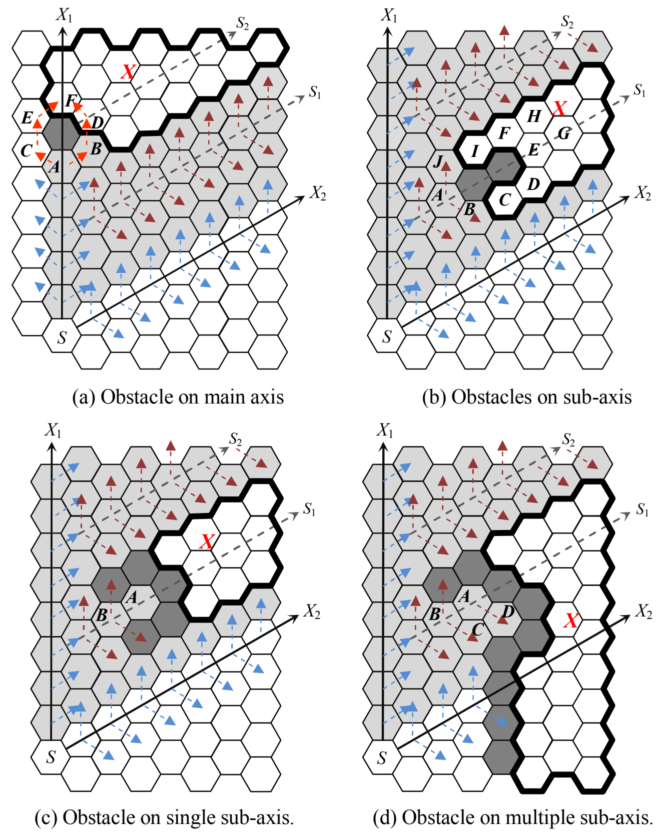


Figure 3: *ZBP* partitions each region A_n into bands with three-cell width.

In *ZBP*, a dynamic coordinate system is applied to help managers to calculate their coordinates relative to the sink node. Managers determine whether they should broadcast the received message while the mobile sink node moves. A delay mechanism to schedule the packet transmission is proposed for avoiding packet collisions in the axis-leveled cells. Though *ZBP* resolves the packet collision problem on the main axis or sub-axis, however, some problems will be happened in the network environment with unpredictable obstacles. While the packet transmission transmitted by the selected managers encountered the unpredictable obstacles, message relaying will be blocked and results in follow-up managers unable to receive the message.

For example, Fig. 4 depicts the impact of unpredicted obstacles on packet delivery. In Fig. 4(a), there is an obstacle marked as dark-gray color on the main axis that results in the region X surrounded with the thick-black line can not receive any packet from the sink node. Similarly, as shown in Fig. 4(b), the obstacle existing on sub-axis causes the same problem of packet blocking. If the obstacle occupies a large area across one or more main-axes or sub-axes, the block range which packets can achieve will be extended. As shown in Fig. 4(c) and 4(d), it depicts more complicate obstacles which lie on single sub-axis and cross multiple sub-axes. Following the TDMA scheduling, these unpredicted obstacles block the packet transmission and finally reduce the accuracy of data collection at the sink node.



(a) Obstacle on main axis

(b) Obstacles on sub-axis

(c) Obstacle on single sub-axis.

(d) Obstacle on multiple sub-axis.

Figure 4: Obstacles block packet transmissions.

To address the message blocking problem caused by the unpredicted obstacles, this paper develops a broadcasting protocol (*ORZBP*) for zone-based WSNs. According to the location of mobile sink, *ORZBP* selects managers to representatively relay the messages to neighboring managers so that all managers in sensor network can receive the sink's message to avoid packet collision, contention and blocking and increasing the success rate of packet receiving in the WSN with unpredicted obstacles.

III. NETWORK ENVIRONMENT

The considered WSN contains an extremely large amount of randomly deployed sensor nodes. A mobile sink moves around the monitoring region for network patrolling and information collecting. The network region is assumed to be geographically partitioned into several equal-sized zones. In each zone, sensor closest to the zoning central point is elected as the zone manager. Some definitions in this paper are given as following.

Definition: ***Manager*** M_K

Cell-ID K or simply *cell K* denotes the cell whose ID is K. Notation M_K denotes the manager of cell K. ■

Let *cell S* denote the source cell where the sink node located and M_S denote the manager of cell S. Herein, the *Cell-ID* presents the coordinates of each cell relative to the source cell. The coordinates of the source cell are dynamically assigned with (0,0) and a dynamic coordinate system [8] is applied for each manager to derive the relative coordinates with the source cell since the sink node is mobile.

Definition: **Neighboring Cells** N_i

Six neighboring cells of each cell K, starting with north neighboring cell, are defined as N_1, N_2, N_3, N_4, N_5 and N_6 in the counterclockwise direction. In addition, let $K.\boldsymbol{N_i}$ denote i-th neighboring cell of cell K. ■

Definition: **Main Axis** X_i **and Area** A_n

Extending from source cell S to its six neighboring cells, there are six main axes X_1, X_2, X_3, X_4, X_5 and X_6 that partition the network region into six disjoint areas A_1, A_2, A_3, A_4, A_5 and A_6, respectively. ■

Definition: **Sub-Axis** S_j:

Lines parallel to Main Axis X_i partition the region A_n into several bands. Each parallel line is defined as *Sub-Axis* S_j, for $j \geq 1$ and the distance of three cells is existed between Sub-Axis S_j and S_{j+1}. Cellular managers on Sub-Axes will perform the operation of packet broadcasting if receiving a querying message from the sink node. It is guaranteed that all managers in WSNs will receive the packet without collision. ■

When the sink intends to deliver a query to all sensors of the monitoring region for data collection, cellular managers the axes are responsible to forward the query message so that the message could be transmitted to all managers in each band. However, once the appearance of the obstacles, packet routing will be blocked or inefficient. In this paper we assume that each manager as able to identify whether or not the obstacle exists at its neighboring cells. Rather than *ZBP*, this paper prevents the packet transmission from impeding or blocking of obstacles.

IV. OBSTACLE-FREE BROADCASTING PROTOCOL

In *ORZBP*, the managers that receive the broadcasting packet derive new coordinates from the source zone. Managers can determine whether it participates in the packet flooding based on the dynamic coordinate system. To overcome the unknown obstacle, the manager nearby the obstacle also participates in the operation of packet forwarding. In addition, managers will evaluate the timing for delivering the broadcasting packet so that the collision problem could be avoided. When the packet transmission passes by the selected managers and encounters the obstacle, the obstacle-handling rules are applied. The manager that satisfies one of the following criteria will perform the broadcasting operation.

- Manager located on the main axis $\boldsymbol{X_i}$: A manager will execute the broadcasting operation if the new coordinate (*my_x*, *my_y*) of the manager's zone satisfies *my_y*=0.
- Manager located on the sub-axis $\boldsymbol{S_i}$: A manager will execute the broadcasting operation if the value *my_x* is a multiple of three.
- Neighboring zone without manager: A manager whose neighboring zone is lying on the main axis or sub-axis that the neighboring zone has no manager existing will participate in the broadcasting operation.

The sink node typically broadcasts a request demand to WSNs. Based on the dynamic coordinate system [8], the managers make a decision that whether it should forward the packet. The managers located on the main axis or sub-axis will relay the request demand. The packet, called as *Forwarding Broadcast Packet*, is transmitted by the scheduled managers to give a query over the WSNs.

Definition: ***Forwarding Broadcast Packet (FP)***

As shown in Fig. 5, broadcasting packet transmitted on $\boldsymbol{X_i}$ or $\boldsymbol{S_i}$ without obstacles in its forwarding direction is called *Forwarding Broadcast Packet.* ■

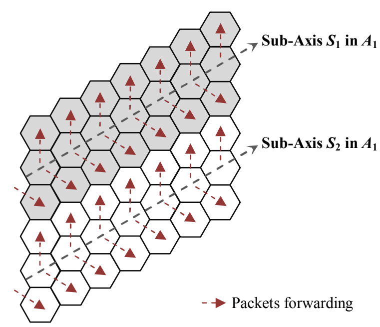


Figure 5: *FP* is transmitted by the packet forwarding direction.

Since the packet transmission encounters the obstacle and no other non-scheduled manager exists, the packet transmission may be blocked by the obstacle. To address this, some non-scheduled managers should be dynamically scheduled to participate in the broadcasting task. The role is defined as below.

Definition: ***Around Manager*** (M_a)

The around manager is defined as the manager nearby the obstacle participating in the broadcasting process to overcome the unpredictable obstacle, such as M_A, M_B, M_C, M_D, M_E, M_F as shown in Fig. 4(a). ■

Each manager periodically exchanges the beacon messages from neighboring managers and updates its neighboring information to make a decision if it treated as the role of M_a. A direction table is one kind of neighboring information to record the existence of the obstacle. The direction table is defined as follows.

Definition: ***Direction Table***

As shown in table I, the table records whether or not the existence of obstacle nearby each manager. A direction is marked as 'T' means that there is not exist the obstacle, whereas is marked as ‘F’ while the occurrence of the obstacle in that direction. ■

TABLE I: Information in Direction Table.

Packet ID	Dir. 1	Dir. 2	Dir. 3	Dir. 4	Dir. 5	Dir. 6	Received *from*
A001	F	F	T	T	T	F	B
…	…	…	…	…	…	…	…

An example of cellular A in Fig. 4(d)

Managers in the zones and located on $\boldsymbol{X}_i$ or $\boldsymbol{S}_i$ are responsible to forward packets. To overcome the existed obstacles, all managers M_a are additionally responsible to forward the received packets, avoiding the packets are blocked on main axis or sub-axis. To easy describe the proposed protocol and overcome the unknown obstacle, the *promising* and *non-promising forwarding zones* are defined.

Definition: ***Promising Forwarding Zones and Promising managers*** $\boldsymbol{P_t}$

The promising forwarding zones are the three adjacent zones that in the face of the previous data flow direction. The managers located at the promising forwarding zones are treated as promising managers denoted by P_t. The middle manager of three promising managers is depicted by P_1. In the face of the previous data flow direction, the left-hand and right-hand sides of the promising manager P_1 are denoted by P_2 and P_3, respectively. ■

Definition: ***Non-Promising Forwarding Zones and Non-Promising managers*** $\boldsymbol{NP_s}$

The other zones not belong to the *Promising Directions* of a hexagon is called non-promising forwarding zones and the non-promising managers is located at these three zones is denoted by NP_s. ■

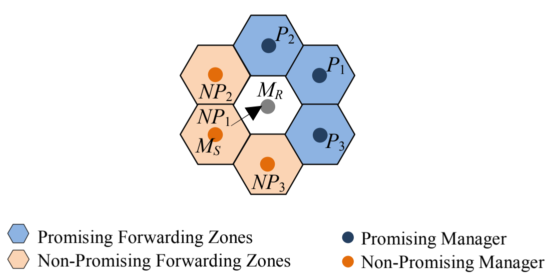


Figure 6: Promising and non-promising forwarding zones of R.

As shown in Fig. 6, three adjacent zones of the manager M_R that in the face of the data flow direction $\overline{SR}$ where the manager M_R received the broadcast packet from the manager M_S will be treated as the *Promising Forwarding Zones*. The other three zones are treated as *Non-Promising Forwarding Zones*. To overcome the unknown obstacle, the manager M_a located on the main axis or sub-axis initializes the obstacle-handling process. Upon receiving the packet, the scheduled manager will firstly forward to the *Promising Managers*. Since all of the *Promising Forwarding Zones* occupied by the obstacles cause the packet transmission blocking, the scheduled manager further makes a decision to delivery the packet to *Non-Promising Managers*. By this way, the success rate of packet delivery will be increased. However, the deadlock of packet transmission will existed if the original broadcast packet is applying in the obstacle-handling process without any modification.

As shown in Fig. 4(c), the manager M_B relays the query packet to *Promising Managers*. Upon receiving the packet from M_B, M_A subsequently deliveries to *Promising Managers* but the packet transmission blocked due to the obstacles surrounded by the manager M_A. Transmitting the packet back to the manager to solve this predicament is one of the solutions. However, the packet has already received by the manager M_B will be treated as the abandoned packet without handling, causing the messages do not received by the managers in region X.

Since the broadcast packet encountered obstacle in the transmission process, the packet will be automatically split as several types of packets, each works for special function to overcome the different types of obstacles. The possible packets will be split is given as following.

Definition: ***Around Broadcast Packet* (*AP*)**

One of the broadcast packet types that the manager will transmit when meets obstacle and this packet is in order to surround the obstacle. ■

Definition: ***Back Broadcast Packet* (*BP*)**

This type of broadcast packet will be produced when no other direction to forward *Around Broadcast Packet* excepting the pre-transmission direction. ■

Broadcast packets *AP* and *BP* are used to surround the unknown obstacle. Since the manager M_a located on the main axis or sub-axis will initialize the obstacle-handling process to overcome the obstacle by transmitting *AP* broadcast packet which is unlike the original broadcast packet. Only the scheduled manager M_a is responsible to relay this kind of packets to the *Promising Managers*. The packet transmission on manager M_a may encounter the obstacle which surrounded nearby it, if it applies the *BP* broadcast packet to find the possible transmission routes. Since *AP* is transmitted by the M_a that turns back to the axis $\boldsymbol{X}_i$ or the Sub-axis $\boldsymbol{S}_i$ will divide into two types of broadcast packets. One packet is *AP* continues to surround the obstacle and the other packet is transmitted *FP* by the method of the broadcast protocol without obstacle. In the following, we will discuss the detail of the protocol.

Each manager received the broadcast packets firstly check the *Direction Table* to detect whether the obstacle is nearby it. After that the scheduled managers M_k on $\boldsymbol{X}_i$ or $\boldsymbol{S}_i$ are responsible to transmit the *FP* packet to *Promising Managers* until the packet transmission encounters the obstacle. The obstacle located on the axis causes the packet blocked transmission should be overcome.

However, since the obstacle is occupied cross multiple axes, multiple *AP* packets will be initialized, resulting in the packet collisions. Therefore, when the packet transmission on manager M_a which located on the main axis or sub-axis encounters the obstacle, it intends to initialize the obstacle-handling process and selects one of the underside managers M_a to transmit the *AP* packet. If no direction to forward *AP* due to obstacles, the *BP* packet will be applied to overcome the obstacle. Upon receiving the *AP* or *BP*, the manager M_a intends to forward packets to *Promising Managers*, whereas it relays packets to *Non-Promising Managers* if all of the *Promising Forwarding Zones* are occupied by the obstacles. The manager makes a decision that whether it should relay the broadcast packets and what kinds of packet should be broadcasted by check following three rules.

Rule 1*: *designed for scheduled transmission

Managers located on the main axis or sub-axis are responsible to rebroadcast the *FP* packet without obstacles.

Rule 2*: *designed for surrounding the obstacle

Packet transmission by the manager located on the main axis or sub-axis encounters the obstacle or receives the *BP*, the manager firstly selects the underside manager to transmit the *AP* packet. If both of the underside neighboring zones are occupied by obstacles, the manager will transmit the *BP* packet back to the previous sending manager.

Rule 3*: *designed for surrounding the obstacle

Since the manager M_a receives the *AP* or *BP*, it firstly checks the direction table and intends to transmit to the *Promising Managers* if no obstacle occupied the *Promising Forwarding Zones*. In case of all of the *Promising Forwarding Zones* are occupied by the obstacles, it then transmit the packet to *Non-Promising Managers*. Otherwise, the manager M_a transmits BP packet to the previous sending manager.

Each manager will apply the preceding three rules. Noted that the manager receives the same type of the broadcast packet will terminate to transmit. The manager M_a that is not located on the Axis or the Sub-Axis will only deal with the *AP* and *BP* packets. Consider the example in Fig. 7. The broadcast process is initialed by the manager M_S. After receiving the broadcast packet, each manager firstly checks its *Direction Table* and applies *Rule* 1 if no obstacle exists occupied at the next scheduled zone. The *FP* packet will be transmitted step by step until encountering the obstacle. At the timestamp 6, the manager located on the sub-axis received the *FP* packet, the manager intends to forward packets to its *Promising Managers* but failure due to the obstacle. Then the manager M_a executes *Rule* 2 and sends the *AP* packet to the underside manager M_A. To further overcome the unknown obstacle, the *Rule* 3 is executed and the *AP* and *BP* packets are forwarded by the manager M_a. The manager M_A forwards the *AP* packet to the *Promising Managers*, M_B, M_C and M_D. Only the manager M_D which plays the role of M_a has responsibility to retransmit the *AP* packet whereas the other two managers M_B and M_C ignore the *AP* packet.

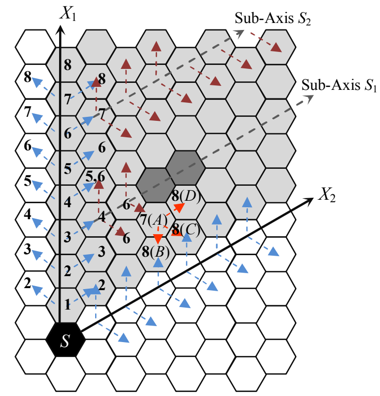


Figure 7: Timestamps that the manager received the broadcast packet.

Nevertheless, the collision problem may still occurred with the existence of unknown obstacle by applying the above-mentioned three rules. Since more than one M_a have responsibility to transmit the *AP* packet received the *AP* packet, the collision may occurred while the received managers M_a retransmit the packet at the same time. Fig. 8 depicts that the managers M_C, M_D and M_E received the *AP* packet and rebroadcast the packet at the same time, causing the packet collision at the managers M_F and M_G. To avoid this collision problem, the managers are responsible to relay the *AP* packet received the packet at the same time should wait for different slot according to the location which the manager lied on. When the manager M_a transmits the *AP* packet to the *Promising Managers* P_1, P_2 and P_3, the different delay time of three *Promising Managers* will be assigned. The *Promising Manager* P_1 can immediately transmit the *AP* packet without any delay. The *Promising Managers* P_2 and P_3 should wait for δ and 2δ time slot, respectively. As a result, the *Rule* 3 should be modified by the *Rule* 3' to avoid collisions.

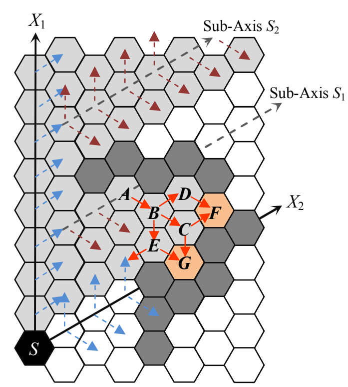


Figure 8: Packet collisions at the managers M_F and M_G. (*Rules* 1-3)

***Rule 3'*:** Since the manager M_a receives the *AP* or *BP*, it firstly checks the direction table and intends to transmit to the *Promising Managers* if no obstacle occupied the *Promising Forwarding Zones*. In case of all of the *Promising Forwarding Zones* are occupied by the obstacles, it then transmit the packet to *Non-Promising Managers*. Otherwise, the manager M_a transmits *BP* packet to the previous sending manager. Since the manager Ma transmits the *AP* or *BP* packet to the *Promising managers* P_1, P_2 and P_3 or *Non-Promising managers* NP_1, NP_2 and NP_3, the manager P_1 and NP_1 can immediately transmit the *AP* or *BP* packet without any delay. The managers P_2 or NP_2 and P_3 or NP_3 should wait for δ and 2δ time slot, respectively.

Based on three rules, some sensors originally cannot receive the broadcast packet due to the unpredictable obstacle. As shown in Fig. 9, the *FP* packet derived from manager M_S is subsequently transmitted to the manager M_A. On receiving the *FP*, the packet transmission on manager M_A forwards the packet to its neighboring managers but encounters the obstacle. By applying Rules 2 and 3', the *AP* will be transmitted to M_A passing through M_B, M_C, M_D, M_E, M_F, M_G and M_H. However, sensors located within the region *X* can not receive the packet. To solve this problem, this paper applies the *Rule* 4 for each manager located on the main axis or sub-axis

<u>Rule 4</u>: Designed for keeping on scheduled transmission with the existence of the obstacle

The managers which located on the main axis or sub-axis without nearby the obstacle receive the *AP* packet are responsible to broadcast the *FP* packet. Based on these four obstacle-handling rules, the *ORZBP* algorithm develops an efficient broadcasting protocol to avoid collision and contention problems with the existence of unpredictable obstacles. The query packet initialed by the sink node can be successfully transmitted to the entire sensors with minimal message cost and packet collision. Following takes a complete example to run the aforementioned four rules.

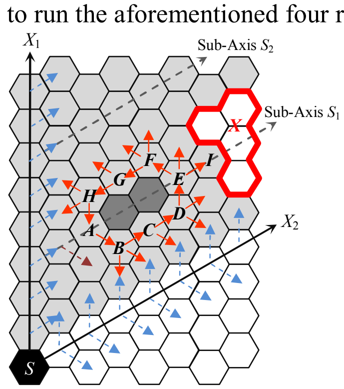


Figure 9: Broadcast holes in the region *X*. (*Rules* 1-3')

As shown in Fig. 10, the broadcast process is initialed by the manager M_S where the sink node is located and typically sends a request demand to the sensors in WSNs. Upon receiving the request demand, the managers whose location lies on the main axis or sub-axis apply *Rule* 1 to rebroadcast the request packet until the obstacle is encountered. The manager M_A receives the request packet and then forwards the packet to *promising managers* but encounters the obstacle. The *Rule* 2 is applied to find the possible broadcast path to overcome the obstacle and the *AP* packet is derived and transmitted to the manager M_B. Upon receiving the *AP* packet, the manager M_B applied *Rule* 3' to resolve the deadlock problems and the *AP* packet subsequently transmitted to the manager M_C. To avoid the broadcast packet can not received by the further sensors located on the sub-axis S_1, the *Rule* 4 will applied for keeping on scheduled transmission and surrounding the obstacle. As a result, the request demand can be successfully transmitted to the entire sensors in WSNs.

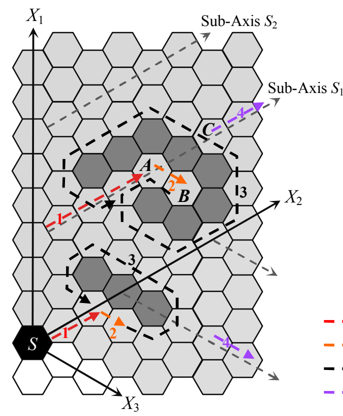
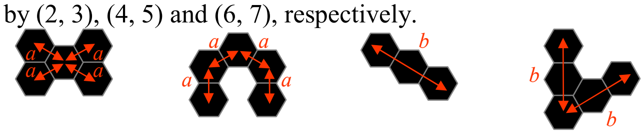


Figure 10: A complete example to run the aforementioned four rules.

V. SIMULATION

ORZBP is compared with *ZBP* [8], *CBM* [4], and flooding in terms of in terms of success rate, overhead index, the percentage of participated nodes and collision number.. The variation in number of sensor nodes is utilized as control factor in simulations. The number of sensor nodes is controlled ranging from 1500 to 4500 and nodes are randomly placed in a 1500*1500 rectangular region. All nodes in the network are stationary with transmission radius of 100. Each round of simulation is performed for 100*s*. The source node is randomly selected from sensor nodes to initiate the broadcasting service. Four different shapes of obstacles are considered in simulations as shown in Fig. 11. The obstacles are randomly located in the simulation and may be cross one or more axes or region. For each obstacle shape, the sizes are categorized into small, middle and large which are controlled by the parameters *a* and *b*. The parameters (*a*, *b*) of small, middle and large obstacle are set by (2, 3), (4, 5) and (6, 7), respectively.



(a) X-shape (b) C-shape (c) Rectangle (d) V-shape

Figure 11: Obstacles with various shapes are considered.

Table II shows the threshold δ impacts *ORZBP* on the success rate and delay time. The number of sensor nodes is 3000 and multiple different shapes of obstacles are considered in the environment. The success rate of packet delivery in case of δ=1 is 98% because that more than one managers have to transmit *AP* packet; the collision may occurred while the received managers M_a retransmit the packet at the same time so that some sensors cannot receive the broadcasting packet. As the increment of the threshold, the success rate of *ORZBP* can achieve 100%. On the other hand, the average completed time may increase with larger threshold. As a result, δ=2 is the better choice that the success rate = 100% and *Average Completed Time* is low. In the following, we set the threshold δ=2.

Table II: The threshold δ impacts *ORZBP* on the success rate and delay time.

	δ=1	δ=2	δ=3	δ=4
Success Rate (%)	98	100	100	100
Average Completed Time (Unit time)	28	30	33	35

In following, *ORZBP* is compared with the other three broadcast mechanisms in term of success rate. The number of sensor nodes is 4000. In the environment, multiple middle-sized obstacles with different shapes are randomly generated. The existence of obstacles will block the packet transmission and hence decreases the packet success rate. As shown in Fig. 12, the *ORZBP* outperforms other three mechanisms and achieves 100% success rate. The major reason is that the *ORZBP* selects the manager nearby the obstacle participated into the broadcast process so that the obstacle can be overcome and achieves high success rate.

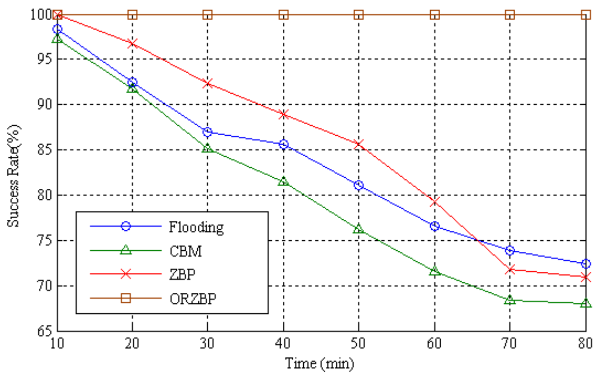


Figure 12: Success ratio with middle-sized obstacles (*One Kind*).

Fig. 13 compares four broadcast mechanisms in terms of success rate and various shapes of obstacles in Fig. 11 are generated. The *All Kinds* environment is obtained by mixing four different shapes of obstacles whose size is middle. *ORZBP* achieves 100% of packet success rate in all cases because that the selected forwarding managers are scheduled without collision.

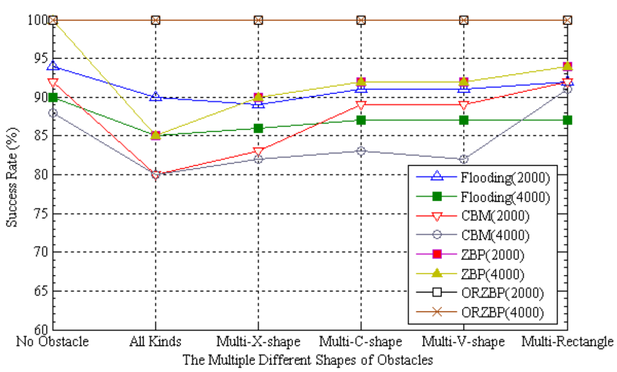


Figure 13: Success rate with various shapes of obstacles (*All Kind*).

The following applies *Overhead Index* to measure the efficiency of the broadcast message transmission, which is the ratio of the total broadcast messages and the success rate.

$$Overhead\ Index = \frac{total\ broadcast\ messages}{success\ rate}$$

The message overhead increases with the number of sensor nodes as the uncontrolled flooding mechanism is applied whether the environment contains multiple obstacles with different shapes. The collision and contention problems are significantly occurred and decrease the packet success rate. As shown in Fig. 14, *flooding* has a poor *Overhead Index* which is increased with the number of sensor nodes. *CBM* partitions the entire network into several disjoint and equally sized cellular zones and the sensors located near the center of the cellular treated as the managers which are responsible for forwarding the packet. However, the packet flooding is still existed on managers. Both *ZBP* and *ORZBP* select proper managers to forward the packets and hence maintain a constant *Overhead Index* in the environment without obstacles. Although the message overhead can be significantly reduced in *ZBP*, however, multiple obstacles may locate at the main-axis and sub-axis, decreasing the success rate.

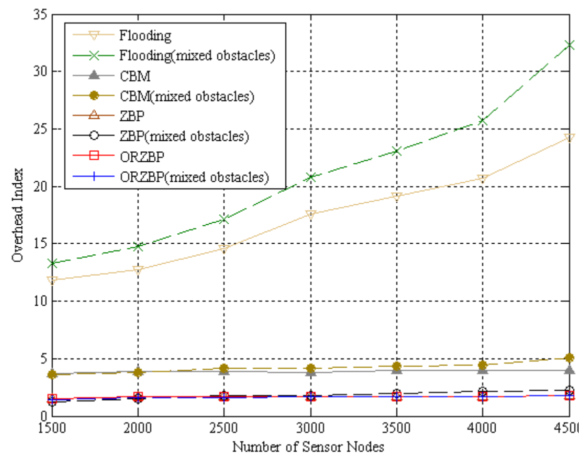


Figure 14: *Overhead Index* with multiple middle-sized obstacles.

Fig. 15 demonstrates that *ORZBP* can effectively control the percentage of nodes participating transition and overcome the different shapes of obstacle. In comparison, the number of participating nodes of *ZBP* fewer than 10% is the least than other three broadcast protocol in the environment. The participating nodes of *ORZBP* are more 1% to 2% than *ZBP* because that the managers nearby the obstacle should be participated the broadcasting operation to overcome the obstacle. Although the participating nodes of *ORZBP* are slightly more than *ZBP*, the number of nodes is 1/3 of *CBM* and 1/8 of Flooding in each case. Therefore, the proposed *ORZBP* efficiently overcome different shapes of obstacles and select fewer managers to participate in the broadcasting operation.

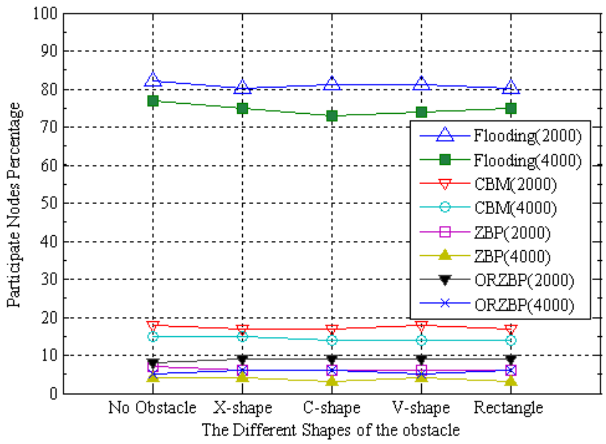


Figure 15: Percentage of sensor nodes that broadcast messages.

Fig. 16 displays the effect of packet collision on the number of sensor nodes with the existence of obstacle. Different shapes of small-size obstacle are mixed in the simulation. As the number of sensor nodes more than 1000, the packet collision of *ORZBP* and *ZBP* schemes is a constant since the number of managers is a constant in a fix-sized region. *CBM* performs better than Flooding scheme because only header of each cell participate the rebroadcast operation. However, applying *CBM* also introduce packet collision among neighboring managers. In the proposed *ORZBP*, only those managers that are located on main-axis, sub-axis and nearby the obstacle participate the rebroadcast operation. Thus, in the obstacle environment, *ORZBP* avoids packet collisions, saves the overhead in packet re-transmission and increases the accuracy of information collected by sink node.

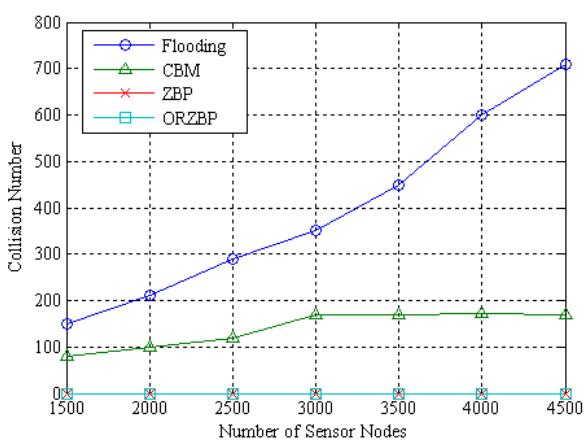


Figure 16: Number of collisions associated with the number of sensor nodes.

VI. CONCLUSIONS

Broadcasting is an essential function required in wireless sensor networks. However, all sensor nodes broadcast the broadcasting message raise problems of collisions and power consumption. This paper applies *CBM* model to reduce the flooding phenomenon from node-level flooding to manager-level flooding. This paper further proposes an efficient broadcasting protocol (*ORZBP*) to reduce the number of managers executing broadcasting operations so that broadcasting packet can be successfully transmitted to all sensor nodes in WSNs. A new coordinate system is introduced so that each manager can derive the new coordinate of its zone and determine whether and when it should broadcast the received message to neighboring managers. Simulation results show that the proposed broadcasting protocol efficiently reduces collisions and consumptions of power and bandwidth.

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