This full text paper was peer reviewed at the direction of IEEE Communications Society subject matter experts for publication in the WCNC 2007 proceedings.

On Providing Temporal Full-Coverage by Applying Energy-Efficient Hole-Movement Strategies for Mobile WSNs

Chih-Yung Chang, Hsu-Ruey Chang, Hsiao-Jung Liu, and Sheng-Wen Chang
cychang@mail.tku.edu.tw,{hrchang, judy, swchang}@wireless.cs.tku.edu.tw
Tamkang University, Taiwan

***Abstract*—This paper considers a mobile WSN that contains a big hole but there exists no redundant mobile sensor to heal the hole. To achieve the temporal full-coverage purpose or enhance the tracking quality, three distributed algorithms are proposed for moving the existing big coverage hole to a predefined location. Firstly, the sink chooses a promising direction for hole-movement. Then the Basic, Forward-only and Any-Direction movement mechanisms are proposed to move the hole along the promising direction in a manner of minimizing the total power consumption or balancing the energy consumption of the given WSN. Simulation results reveal that the proposed hole-movement mechanisms enhance the coverage of WSN and balance the energy consumption of mobile sensor nodes.**

Keywords-mobile sensor, WSN, power-balance, hole-movement, coverage.

I. INTRODUCTION

The diversity in applications present various design, operational, and management challenges for WSNs. In particular, both energy balancing and coverage maintenance designs are required at all levels of the system [1]. For most applications, the coverage percentage represents the quality provided by the WSN. However, WSNs may exist coverage holes due to several reasons including unbalanced deployment, a group of sensor failure after working for a long time, or unexpected accidents such as fire accident, a group of animals passing through, strong breeze and so on. The existence of coverage hole results in some portion of the monitoring area without functionality of sensing and communication as well as influence the accuracy of the sensing task. Therefore, how to maintain the WSN with full-coverage capability is one of the most important issues in WSN.

In literature, many researches have been proposed for achieving full-coverage purpose. Depending on the quality levels, full coverage can be classified into spatial and temporal types. The spatial full-coverage can be reached by dense deployment of static sensors [2]. However, the static sensors can't repair the coverage loss and hence the coverage quality can not be improved as some sensors are failure. To atone for the drawback of the static sensor, some other research [3] developed mechanism to relocate the mobile sensor for enhancing the coverage quality of the monitoring region. However, it requires redundant mobile sensors to achieve the spatial full-coverage purpose.

In addition to the spatial full coverage, previous studies [4][5] discuss how to reach the temporal full-coverage in static or mobile WSNs. The WSN is said to be temporal full-coverage if every point in the monitoring region has ever been covered by sensors during a specific period of time. Yet, these approaches did not take power balancing into account and hence results in a power-unbalanced WSN.

This paper motivates the coverage problem by those applications that require "hole-movement" when there exists no surplus mobile sensor in the WSN. Two application scenarios will be described in below to show the motivations of hole-movement in the considered network environment. First, consider the object tracking application which is one of the most popular issues and has been widely discussed in previous research [6]. When an object closed to the coverage hole, moving the hole to the other location can avoid the object entering the coverage hole. In this application scenario, hole-movement can increase the opportunity of detecting the target object. Second, the existence of coverage hole will cause some portion of the region without sensing functionality. Hole-movement enables the original uncovered region become covered and some covered region become uncovered. Hence hole-movement can balance the sensing precision of the whole sensing region.

II. NETWORK ENVIRONMENT AND PROBLEM STATEMENT

2.1 Network Environment

The considered WSN consists of several mobile sensors. Each mobile sensor is aware of its location and all sensors are synchronized. Let r_c and r_s denote the communication and sensing ranges of all sensor nodes, respectively. In [7], it is proved that the ideal deployment is achieved when any three neighboring nodes form an equilateral triangle. Under this deployment, the number of sensors required to maintain the full coverage is minimized and the side length of the equilateral triangle is $\sqrt{3}r_s$. Therefore, we assume that the communication range r_c is larger than $\sqrt{3}r_s$. We further assume that all mobile sensors are deployed over a WSN with a hexagonal lattice.

2.2 Problem Formulation

This paper considers a WSN that exists a big coverage hole. There are η mobile sensors in the sensing area and $S=\{s_1, s_2,\ldots, s_\eta\}$ denotes the set of η mobile sensors. We assume that the number of sensors is not enough to cover the coverage hole. The big hole in this paper is constituted by lots of small hexagonal hole cells. The size of the big hole is measured by the total number of the hexagonal cells. More specifically, we assume that the size of the big hole is $W\times H$ where W is larger than H. We further assume that the big hole requires to be moved with a distance x in direction d. Therefore, the hole-movement task T can be represented by T=(*Hole*, *direction*, *distance*), where the direction and distance of task T are d and x, respectively.

Here, we clarify the term "energy-balanced". One important concept in this paper is that the movement of mobile sensor can result the movement of the hole. The big hole moves from location a to location b only can be achieved by the movement of a number of sensors whose sensing coverage can cover the big-hole. A good hole-movement policy is to distribute the hole-movement task to as more mobile sensors as possible so that the work load for hole-movement on each mobile sensor is minimized. The term "energy-balanced" means that the energy consumption of each mobile sensor that participates in the hole-movement task can be minimized.

Let E and λ denote the total power consumption for a hole-movement task T and the number of mobile sensors participated in the task T, respectively. Let e_i denote the energy consumption of each mobile sensor s_i for all $1 \le i \le \lambda \le \eta$. Formula (1) defines the energy-balanced index B.

$$B = \frac{E = e_1 + e_2 + \ldots + e_\lambda}{\lambda} \qquad (1)$$

The goal of this paper is to develop energy-balanced hole-movement strategies that minimize energy-balanced index B.

III. Hole Movement Strategies

In this paper, a hexagon is used to represent the coverage of a sensor node and therefore any sensor s_i has exactly six neighbors $s_i.UL$, $s_i.Up$, $s_i.UR$, $s_i.DR$, $s_i.Down$, and $s_i.DL$ as shown in Fig. 1(a). Each sensor has six moving directions $\{UL, U, UR, DR, D, DL\}$ as shown in Fig. 1(b).

<u>Definition:</u> *detector u*

The mobile sensor who detects holes in its sensing range is referred to the *detector*.

<u>Definition:</u> *u.MD*

Notation *u.MD* denotes node *u*'s movable direction set which contains all possible moving directions of the detector *u*. The detector *u* finds the directions which correspond to the absent neighbors and records theses directions in *u.MD*.

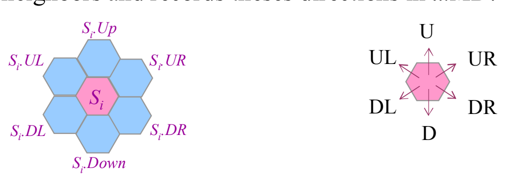


Fig. 1: (a) The six neighbors of sensor S_i. (b) The six moving directions of sensor S_i.

Three distributed hole-movement schemes are proposed. First, the *Basic* movement scheme enables each mover directly moves along the opposite direction of d. Though *Basic* movement scheme minimizes the total energy consumption, it results unbalanced energy consumption. The other two schemes aim to balance the energy consumption. They firstly decompose the original big hole into lots of small hole cells. Then the *Forward-Only* scheme moves each small hole cell only forward along direction d while the *Any-Direction* movement scheme enables some small hole cells have opportunity to move some steps backward the direction d to minimize the value of the balanced index.

A. Basic movement scheme

Let $\bar{d}$ denote the opposite direction of d. The basic idea of the Basic Movement scheme is quite straightforward. It enables that sensors nearby the longer side of the big coverage hole play the mover role and move along the direction $\bar{d}$. After all the sensors receive the hole-movement request from the sink node, the Basic movement scheme will be initiated. As time goes by, each detector will have two statuses. One is "detecting" status and the other is "moving" status. In detecting status, detector u will detect the direction of the hole cell and then check whether the direction $\bar{d}$ is in *u.MD*. If the direction $\bar{d}$ exists, the detector will switch its status to moving status and then move toward the direction $\bar{d}$. Once a detector changes its status to moving status, it is termed as a mover.

Figure 2 shows how the Basic movement scheme works. There is a big hole with size 4×3 in the WSN. The big hole will move toward 'Down' direction according to the request from the sink node. Therefore detector whose *MD* has the 'Up' direction will change its status to moving status and move one hop distance along 'Up' direction to help the hole cell migrate toward down direction. As shown in Fig. 2(a), detectors u_i, $0 \le i \le 3$, will switch from detecting status to moving status since their $u_i.MD$ contains 'Up' direction. The number labeled on the sensor represents how many hops the mover has walked. All movers participate in the hole-movement task by applying the Basic movement scheme have moved 4 hops.

The Basic movement scheme is effective for minimizing the total power consumption of all movers because the decomposed small hole cells always move toward the direction d directly. However, the power consumption of each mover increases with the hole height. An obvious drawback here is that when the height of the coverage hole is very large, each mover will consume significant energy in executing the hole movement task and the value of the balanced index B increases accordingly, which indicates that the power consumption of all sensor nodes in the WSN are unbalanced.

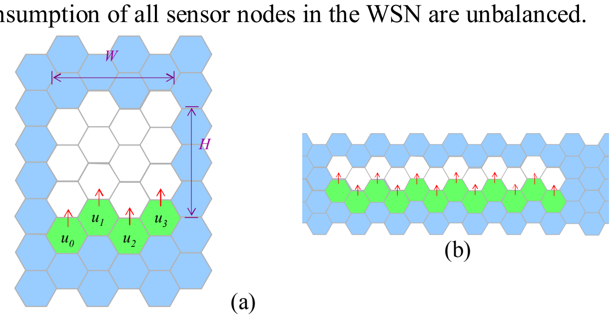


Fig. 2: (a) An example of the Basic movement scheme. (b) An example of the Basic movement scheme with hole size 12 x 1.

We notice that the movers can consume less energy in executing the hole-movement task as long as the height H of the coverage hole is minimized. Figure 2(b) is taken as an example to illustrate this argument. We consider a big hole with size 12×1 which equals to the size of hole shown in Fig. 2(a). Applying the Basic movement scheme, each mover only move one hop in executing the hole-movement task. The total

This full text paper was peer reviewed at the direction of IEEE Communications Society subject matter experts for publication in the WCNC 2007 proceedings.

power consumption of all movers in Fig. 2(b) is identical to that in Fig. 2(a). According to Formula (1), we conclude that under the fixed total power consumption of movers, the more movers participate in the hole-movement task the more power balanced of all sensors in the WSN. Based on this reason, we are motivated to change the hole shape into a belt to enable more movers to share the workload of hole-movement task, balancing the energy consumption of all sensors. Two mechanisms, named Forward-only and Any-Direction mechanisms, are proposed to change the hole shape into a belt during the execution of hole-movement task.

B. Forward-Only movement scheme

The Forward-Only movement scheme moves the hole by taking both energy-balancing and total power consumption into consideration. The Forward-Only movement scheme aims to simultaneously move the big hole forward along the direction d and change the hole shape into a belt. This scheme decomposes the original big hole into lots of smaller hole cells and each hole cell always moves forward along direction d. Sensors in the WSN can only move along one of the three directions that are closest to the direction $\overline{d}$. For example, if the sink determines the hole moving direction d is 'Down', each sensor in the WSN can only move along 'up-left', 'up', or 'up- right' directions which are closest to the 'up' direction. Figures 3(a) depicts the moving trajectories by applying the Forward-Only mechanism on the hole-movement task for a big hole with size 4×3 hole cells.

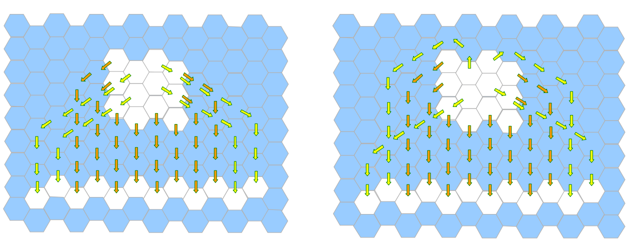


Fig. 3: (a)The moving trajectory by applying the Forward-Only movement scheme on the big hole with size 4×3 hole cells. (b)The moving trajectory by applying the Any-Direction movement scheme on the big hole with size 4×3 hole cells.

The developed movement strategies must satisfy the following three properties:

P1: Distributing the hole cells into different columns.

P2: The detector that has the maximal remaining energy moves first.

P3: The hole is moved only along the forward direction.

To change the shape of the big hole into a belt, we let each column maintains one hole cell. Property *P1* is proposed to make sensors help the hole cells in the same column distribute to different columns. To implement property *P2*, the Forward-Only scheme maintains a hop value in each mover which records how many hops the mover has moved. Then the scheme enables detectors who have smaller hop value to help the hole cells migrate in the WSN to minimize the maximal energy consumption of movers and obtain a better balanced index *B*. Property *P3* takes the total power consumption into consideration.

The following proposes two checking rules for detectors to determine whether or not it should change its status from a detector to a mover and which direction it should move. In the following rules, we assume the big hole will move toward the 'Down' direction. Therefore the detector only can migrate toward either up-left (UL), up(U), or up-right(UR) directions. To avoid two movers helping the same cell migrate, the detector, say a, who is located below the hole cell will be the arbitrator which has to decide the movement direction of the hole cell in this round. In other words, the arbitrator need to choose one of its neighboring detectors $a.UL$, a and $a.UR$ to heal the hole cell that is located above the arbitrator.

The following presents the Forward-Only rules for those detectors located at the left side of the big hole. Similar rules can be easily derived for the Right side detectors.

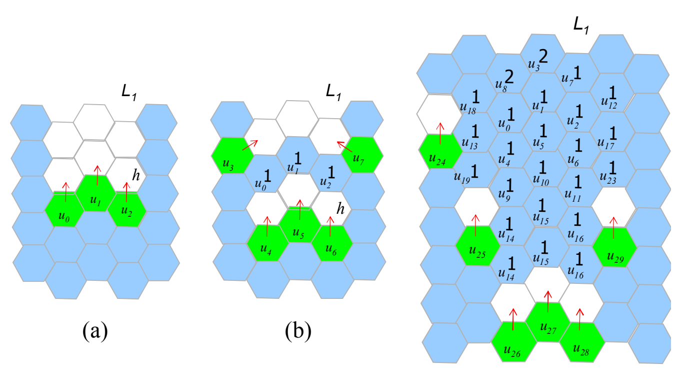
Rule 1: Detector s who has never moved before and detects $s.up$ = hole will select the up direction as its moving direction.

Rule 2: Detector s who has ever moved and detects $s.up$ = *hole* will choose an appropriate neighboring detector to move based on the following algorithm. Detector s should send a packet to inform the selected neighbor about its decision.

Mover Selection Algorithm for Rule 2
Left side rule

```
1.    if (s.hop >= s.UL.hop )
2.         s.UL. moving direction = up-right
3.    else
4.         s. moving direction = up
5.    end if
```

Since the most efficient movement is to directly move the hole toward the direction *d*. Rule 1 is designed accordingly. Because that the big hole is composed by lots of small hole cells, in the procedure of changing hole shape into a belt, we try to make the hole cells located at the left and right sides of the big hole move toward left and right and balance the number of the hole cells walking to the left and right sides, respectively. Lines 1 to 5 of Rule 2 algorithm discuss the circumstance when the arbitrator is located at the left side. The right side rules can be similarly derived.



(a) (b) (c)

Fig. 4: An example of the Forward-Only movement scheme. The hole size is 3 x 2.

Below is a series of three diagrams illustrating how the Forward-Only movement scheme works by applying the two rules. For simplicity, we use the hole with size 3×2 as the example. In Fig. 4(a), u_0, u_1, u_2 employ *Rule 1* to move along

This full text paper was peer reviewed at the direction of IEEE Communications Society subject matter experts for publication in the WCNC 2007 proceedings.

up direction. And then u_0 and u_2 use *Rule 2* to enable u_3 move toward up-right and u_7 move toward up-left as shown in Fig. 4(b). Finally, as shown in Fig. 4(c), when executing the algorithm repeatedly, all hole cells that constitute a big hole will be distributed into different columns and there is only one hole cell in one column. At this time, the shape of the big hole is likely to become a belt. From now on, the big hole will be migrated in an optimal energy-balanced manner.

Once a detector determined its moving direction by applying Rule 1, it will not change its decision even if it receives another detector's informed packet later.

C. Any-Direction movement scheme

As the name indicates, each hole cell can move along six different directions in the Any-Direction movement scheme. In this scheme, we only extremely take the energy-balancing energy consumption into consideration in executing the hole-movement task. Different from the Forward-Only movement scheme, this scheme enables some hole cells have opportunity to move some steps backward the direction d to balance the power consumption of all movers. Figure 3(b) depicts the moving trajectories by applying the Any-Direction movement mechanism in executing the hole-movement task for a big hole with size 4×3. The main difference from the Forward-Only movement scheme lies in the checking rules.

The following proposes five checking rules for detectors to determine whether or not it should change its status from a detector to a mover and determine which direction it should move. In the following rules, we assume the big hole will move toward the 'Down' direction. The Any-Direction movement also tries to make the hole cells located at the left and right parts of the big hole move toward left and right and balance the number of the hole cells walking to the left and right sides, respectively, as shown in Fig. 3(b). Next we define the hole cell moving direction priority order at first and then illustrate the five rules and make them match the priority order.

Consider a hole cell located at the left side of the big hole and there exists a moved sensor below the hole cell. Figure 5 shows the moving direction priority of the hole cell. They are 'down-left', 'up-left', 'down', 'up' in order. Based on the property *P1*, the hole cell moves down-left has higher priority than the hole cell moves downward since the sensor below the hole has moved. And then the 'up-left' direction will be the second priority because that when the hole cell moves toward up-left, it can migrate to other different column. Since the hole cell moving along 'up' direction will increase the total energy consumption of a hole-movement task, the Any-Direction movement mechanism arranges the 'up' direction as the last priority for movement. The movement priority for the hole cells located at the right side of the coverage hole is similar to that of hole cells located at the left side.

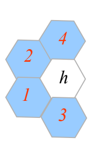


Fig. 5: The movement priority of the hole cell *h* which belongs to the left side of the big hole is labeled on each detector.

In the Any-Direction movement mechanism, the detector who has the maximal remaining power should help the hole cell migrate, even though the detector is located above the hole. To avoid more than one mover helping the same hole cell migrate, the movement direction of a hole cell is determined by the negotiation among those detectors located around the same hole. For example, in Fig. 5, the four detectors will negotiate and determine a mover from themselves which should help the hole cell *h* migrate. The five rules designed in Any-Direction movement scheme implement the priority and the negotiations mentioned above.

Rule 1: Detector *s* who has never moved before and detects *s.up* = hole will select the up direction as its moving direction.

Rule 2: Detector *s* simultaneously detects *s.down* = hole, *s.down-left* = hole and *s.down-right* = hole will select the down direction as its moving direction.

Mover Selection Algorithm for Rule 2

if (*s.Down==hole*)
    if ($s.hop < \lceil width/2 \rceil - 1$ && *s.DL==hole* && *s.DR==hole*)
        s.moving direction = down
    end if
end if

In the hole movement procedure, we prefer the hole cells moves toward down. That is to say, we prefer the detector moving upward. For this reason, the mechanism let detectors located at the down side of the big hole have more one row to move upward than detectors located at the up side of the big hole. That is why we allow that the detector can only move downward when its hop value is less than half of the height of the big hole minus one.

Rule 3 is designed for the detector who is located at down-left or down-right locations of the hole cell *h*. For simplicity, we only discuss the detector who located at the left side of the big hole. Rule for the detector who is located at the right side can be derived similarly. If the detector *s* has up-right direction in *s.MD*, it has the highest priority to help the hole cell *h* move down-left. Therefore, when its hop value is less than that of the neighboring detector who is located above *s*, it indicates that either the detector *s* or the detector *s.DR* who is located below the hole cell *h* has to move to the location of hole cell *h*. In this case, the detector will compare the hop values of itself and the neighboring detector *s.DR*, and then select the one that has smaller hop value to be the mover.

Rule 3: Detector *s* who detects *s.up-left* = hole will choose an appropriate neighboring detector to move based on the following algorithm. Detector *s* then sends a packet to inform the selected neighbor other than itself about its decision.

Mover Selection Algorithm for Rule 3
Left side rule

if (*s.up-right==hole*)
    if (*s.hop* <= *s.Up.hop* or *s.Up is absent*)
        if (*s.hop* <= *s.DR.hop* && $s.DR.hop \neq 0$ **or** *s.DR is absent*)
            s. moving direction = up-right
        end if
        if(*s.hop* > *s.DR.hop*)
            s.DR. moving direction = up
        end if
    end if
end if

This full text paper was peer reviewed at the direction of IEEE Communications Society subject matter experts for publication in the WCNC 2007 proceedings.

Rule 4 is designed for the detector who is located at the left-up or right-up locations of the hole *h*. For simplicity, we only discuss the detector who is located at the left side of the big hole.

Rule 4: Detector *s* who detects *s.down-left* = hole will choose an appropriate neighboring detector to move based on the following algorithm. Detector *s* then sends a packet to inform the selected neighbor other than itself about its decision.

Mover Selection Algorithm for Rule 4
Left side rule

```
if ( s.down-right==hole )
    if (s.hop < s.Down.hop or
        (s.Down is absent && s.hop==0))
        if (s.hop <= s.UR.hop &&
            s.UR. moving direction ≠ down
            or s.UR is absent)
            s. moving direction =down-right
        end if
        if (s.hop > s.UR.hop)
            s.UR. moving direction = down
        end if
    end if
end if
```

Consider a detector *s* located at the left side of the big hole. If the detector *s* has down-right direction in *s.MD*, it has the second priority to help the hole cell *h* move along up-left direction. Therefore when its hop value is less than the neighboring detector who is located below *s*, it indicates that either the detector *s* or the neighboring detector *s.UR* who is located above the hole cell *h* can move to the location of hole cell *h*. In this case, the detector *s* will compare the hop values of itself and the neighboring detector *s.UR*, and then select the one who has a smaller value to be the mover.

Rule 5 is mainly designed to prevent the hole from the back-and-forth movements. The following lists the forbidding moving directions of detector *s* in all kinds of last moving direction. Since *Rules 1* to *4* may cause the hole cell moving back and forth, *Rule 5* is proposed to avoid the hole cell moving back-and-forth.

Rule 5: Detector *s* who has ever moved before will be forbade to move along some directions in this round according to the last moving direction of *s*.

Table 1: The forbidding moving direction.

The last moving direction	The forbidden moving directions
up	Down
up-left	up-right, down-right
up-right	up-left, down-left
down-left	up-right, down-right
down-right	up-left, down-left
down	up-left, up, up-right

Each detector checks its moving direction by these five rules in order. Once the detector determines its moving direction in any of these rules, it will not change its decision even if it receives another detector's informed packet later.

IV. PERFORMANCE EVALUATIONS

This section examines the performance study of the developed Energy-Balanced Strategies for the hole-movement task in WSNs. We arbitrary generate a big hole that contains several hole cells. Then we apply the proposed three hole-movement mechanisms, namely Basic, Forward-Only, and Any-Direction movement mechanisms to execute the hole-movement task. Performance comparisons of the proposed three hole-movement mechanisms are examined in terms of the maximal power consumption, the total power consumption, and the balanced index.

The simulation environment is described in below. The network size is 1500m×1500m. A big hole with various sizes may exist in any location of the network and to be moved in various distances according to different scenarios. The parameters used in our simulation refer to the typical parameters in Berkeley motes [8]. The communication and sensing range are set at 40m and 20m, respectively. The energy consumptions for packet transmission, packet reception, and idle listening are set at 0.075J/s, 0.030J/s, and 0.025J/s, respectively. The initial energy of each sensor is set at 324000J. The movement cost in energy consumption is set by 8.267J/m (286.38J/hop) which refers to the parameters in [9]. To simplify the discussion of the performance results, the following arguments are given based on the assumption that the hole-movement task intends to move for a distance x= 70 hops$\times 20\sqrt{3}$ m$=1400\sqrt{3}$ m and the size of the big hole is varied from 2×2 to 7×7. The following depicts the results of our performance study.

A. The maximal power consumption

The maximal power consumption of movers is used to evaluate the degree of power balancing. The smaller value of the maximal power consumption is, the more energy-balanced among all movers in the WSN. Figure 6 depicts the maximal power consumption of movers by applying the three proposed hole-movement mechanisms. In general, the maximal power consumptions of the three mechanisms increase with the size of the big hole. However, the Basic hole-movement mechanism has poor performance compared with the other two mechanisms. By applying the Basic hole-movement mechanism, the maximal power consumption totally depends on the height of the big hole. In the Forward-Only mechanism, detectors that are located at the bottom, left and right sides of the big hole will participate in the hole-movement task and share the task workload. Therefore, the maximal power consumption of the Forward-Only mechanism is smaller than that of the Basic mechanism. Compared with the Forward-Only mechanism, the Any-Direction mechanism involves more detectors that are located at the top side of the hole to participate the hole-movement task. Consequently, the Any-Direction mechanism outperforms the other two mechanisms in terms of the maximal power consumption.

B. The total power consumption

Figure 7 investigates the total power consumption of the three proposed movement mechanisms. The hole-movement task intends to move the big hole for a distance *x*. In other words, each hole cell has to move a distance *x* to its destination. In the Basic movement mechanisms, each hole cell walks along the direction *d* directly. However, the Forward-Only and Any-Direction movement mechanisms aims to change the hole shape into a belt. They distribute the hole cells into different columns which cause some hole cells have the opportunity to move along the other directions other than the direction *d*. Therefore the total moving power consumption of the Basic mechanism is less than the other two movement mechanisms. In addition, Fig. 7 also reveals that the Any-Direction movement mechanism has poor performance in terms of the total power consumption since the mechanism allow some hole cells to have opportunity to move along the direction $\overline{d}$.

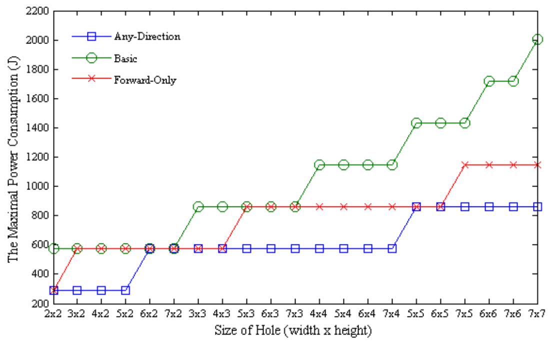


Fig. 6: The maximal power consumption of movers for moving a hole sizes for a fixed distance.

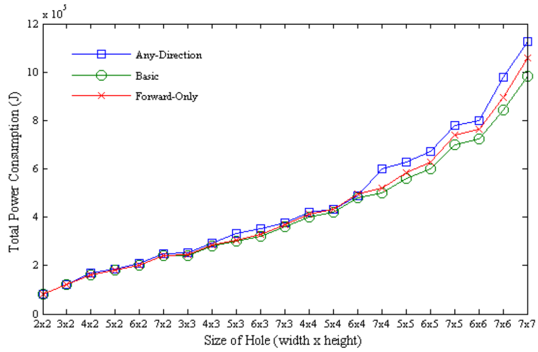


Fig. 7: Performance evaluation of the three proposed movement mechanisms in terms of the total power consumption.

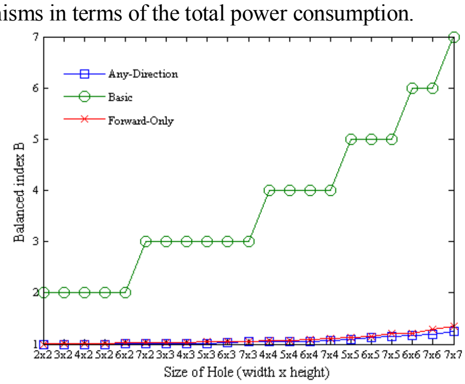


Fig. 8: Performance evaluation of the three proposed movement mechanisms in terms of balanced index.

C. The balanced index

In the experiments, the balanced index is measured by the average moving power consumption of all the movers. Therefore a small value of the balanced index represents the energy balanced. In Fig. 8, we compare the balanced index of three proposed mechanisms. The Basic movement mechanism increases with the size of the big hole owing to the power consumption of the each mover in the Basic movement highly depends on the height of the hole. Figure 8 reveals that the balanced indices of Forward-Only and Any-direction movement mechanism are closed to the optimal value of the balanced index since they allow more movers to participate in the hole movement task and results in good values of balanced index.

V. Conclusions And Future Work

Given a mobile WSN that contains a hole but the number of mobile sensors is insufficient to cover the hole, the hole-movement can prevent the bias information collection and achieve the purpose of temporal full-coverage. This paper develops three distributed hole-movement strategies to move the existing big hole in a way that either the total power consumption is minimized or the power consumptions of sensors are balanced. Future work will investigate the integration of the proposed mechanisms, developing a hybrid mechanism which takes full advantages from the three mechanisms and extends their usages to a random deployed WSN.

References

[1] A. Chandrakasan, R. Amritaharajah, S. Cho, J. Goodman, G. Konduri, J. Kullik, W. Rabiner, and A. Wang, "Design considerations for distributed microsensor systems," *IEEE Custom Integrated Circuits Conference*, pp. 279-286, 1999.

[2] S. Slijepcevic and M. Potkonjak, "Power Efficient Organization of Wireless Sensor Networks," *Pervasive Computing and Communications Wirkshop (PerCom)*, pp. 406-410, March 2005.

[3] Y. Zou and K. Chakrabarty, "Sensor Deployment and Target Localization in Distributed Sensor Networks," *ACM Transactions on Embedded Computing Systems (TECS)*, vol. 3, pp. 61-91, 2004.

[4] C. Gui, and P. Mohapatra, "Virtual Patrol: A New Power Conservation Design for Surveillance Using Sensor Networks," *Information Processing in Sensor Networks (IPSN)*, pp. 246-253, April 2005.

[5] B. Liu, P. Brass, and O. Dousse, "Mobility Improves Coverage of Sensor Networks," *International Symposium on Mobile Ad Hoc Networking & Computing (MobiHoc)*, pp. 300-308, 2005.

[6] J. Xu, X. Tang, and W. C. Lee, "EASE: An Energy-efficient In-network Storage Scheme for Object Tracking in Sensor Networks," *Second Annual IEEE Communications Society Conference on Sensor and Ad Hoc Communications and Networks (IEEE SECON)*, pp. 396-405, 2005.

[7] X. Bai, S. Kumar, Z. Yun, D. Xuan and T. H. Lai, "Deploying Wireless Sensors to Achieve Both Coverage and Connectuivity," *Proc. of the Seventh International Symposium on Mobile Ad Hoc Networking and Computing (ACM MobiHoc)*, 2006.

[8] J. Hill and D. Culler, "A Wireless Embedded Sensor Architecture for System-level Optimization," *Technical report*, Computer Science Department, University of California at Berkeley, 2000.

[9] S. Ganeriwal, A. Kansal, and M. B. Srivastava, "Self Aware Actuation for Fault Repair in Sensor Networks," *IEEE International Conference on Robotics and Automation* (ICRA), 2004.