**Network Protocols and Algorithms**
ISSN 1943-3581
2014, Vol. 6, No. 4

# Grid Coverage Algorithm & Analysis For Wireless Sensor Networks

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Received: October 14, 2014 Accepted: November 24, 2014 Published: December 27, 2014

DOI: 10.5296/npa.v6i4.6449 URL: http://dx.doi.org/10.5296/npa.v6i4.6449

**Abstract**

The problem of having sufficient coverage is an essential issue in wireless sensor networks (WSN). A high coverage rate delivers a higher quality of service. The aim of coverage strategy is to ensure that there will be a minimum number of nodes (at least one node) with little redundant data to cover every point inside the interest area. This paper addresses the problems of coverage of WSN by proposing two grid-based algorithms: Grid Square Coverage version (1) and Grid Square Coverage version (2). Moreover, we have analyzed the performance of both algorithms and provided a compression between them. The results present that the Grid Square Coverage (1) algorithms has 78% coverage efficiency while the Grid Square Coverage (2) has 73%.

**Keywords**: WSN, WSN Coverage, Grid Coverage, Square Coverage, Coverage efficiency.

## 1. Introduction

WSN is a collection of nodes, which are low-cost, low power and small size, carrying out the task of sensing, performing simple data processing and communicating wirelessly over a short distance [1-12]. Each node contains three main subsystems: the sensing subsystem contains one or more physical sensor devices and one or more analog-to-digital converters as well as the multiplexing mechanism to share them. The processor subsystem executes instructions pertaining to sensing, communication, and self-organization [2]. The communication subsystem contains the transmitter and receiver for sending or receiving information. The sensed data by the sensor devices is generally highly important. Therefore, one of the primary issues that occur naturally in sensor networks is coverage (how to cover the whole interest field). The good coverage strategy provides a good way to evaluate the performance of whole network [3].

WSN like other distributed systems, it subjects to a variety of unique constraints and challenges such as restricted sensing and communication ranges as well as limited battery capacity [3]. These challenges affect the design of a WSN [2], and bring issues such as coverage, connectivity, network lifetime, self-managing and data aggregation [4-5]. Good coverage scheme helps a lot in getting the desired purpose of the network using the minimum economic costs; not only this, but also the data routing and transferring depending mainly on the sensors deployment in interest workplace. Many of coverage schemes have been proposed such as Target Coverage. The Target coverage means to watch a number of fixed targets, this type of coverage scheme mentioned in [6] has noticeable military applications, the authors extensive tests to not only detect targets, but to classify and track them , also the authors in [7] tried to detect targets while conserving energy. Barrier coverage scheme discusses the detection of movement across a barrier of node; this scheme explored in the reference [8] with details.

Most of researches assumed the nodes are static and stuck in their locations once they deployed. However, newer nodes are able to relocate themselves dynamically after deployment. The coverage of mobile nodes is more complex than static ones [3] because they need a dynamic geographic computation to get their location updates whenever detected a necessity to maximize the coverage. In the algorithm [9], each node has the ability to move in order to provide maximum coverage. In this paper, we have introduced two algorithms for WSN coverage; both are based on grid scheme.

The rest of this paper is organized as follows. Section 2, explained the definitions, and assumptions which our work is based on. In sections 3 and 4, the grid square algorithm: version (1) and version (2) are explained in details. In section 5, we have provided the results and discussion for both versions of the algorithm. And , in the last section 6, we conclude our work.

## 2. Definitions and Assumptions

**Work area $W_n$** :The interest area to be covered by the nodes is a set of point in **2D** space.

**Set of sensors $S_k$**: The sensors to be deployed in the working area, each sensor has a well know location.

$A_{ci}$: The area of regions which covered by $i$ sensors.

$f(v,h)_{ci}$: The number of $i$ covered regions, where $k = v\,x h$ , k is the number of sensors to be deployed , *v* and *h* are both integers greater than zero.

The aim of the coverage is to ensure that every point $p_i \in W_n = \{(x_1, y_1), (x_2, y_2), \dots (x_n, y_n)\}$ is covered by a set of sensors $S_k = \{s_1, s_2 \dots s_k\}$ and satisfied the following constraints:

1) **Connectivity**: There is at least one path $s_i s_{i+1} s_{i+2} \dots B_s\,; s_{i+j} \in S_k, i, j > 1, i + j < k + 1$ from the current node $s_i$ to the base station $B_s$.
2) **Minimum nodes**: **k** is the minimum number of nodes; get the maximum coverage area with the minimum number of nodes.
3) **Less redundant data**: the larger the overlapped area between the sensors in the network the more amounts of redundant data to generated and more power to consumed and busier the network will be.

**Definition 1:**

We can calculate the Node Coverage Redundancy with reference to the sum of the intersection areas within overlapped sensors (the area would be covered by more than one sensor at onetime) between adjacent nodes.

**Assumption 1:**

All the sensors inside the network are Homogeneous, that is to say, they have the same sensing range and communication range, which can monitor the whole direction around, and we say the coverage is **r** radius of a circular area A. $A = \pi r^2$.[10]

**Assumption 2:**

The sensors of the network have the same transmission power, that is to say, they have the same ability to detect the target when it moves within sensing range.

**Definition 2:**

Calculation of maximum effective of area coverage of the whole network is the effective coverage area of all node inside the network it can be calculated as below.[10]

$$S_e = \bigcup_{i=1,N} E_{si} \qquad (1)$$

**Definition 3:**

Calculation of Coverage Efficiency of the whole network is the ratio of the union of (in the definition 2) effective coverage area of all the nodes and their sum. Coverage efficiency is determined using the following equation.[10]

$$C_E = \frac{S_e}{\sum_i^N A_i} \qquad (2)$$

## 3. Grid Square Coverage : Version(1)

### *3.1 Deployment strategy*

As shown in figure 1, the work area is divided into rows and columns. The sensors are deployed in rows and columns with no overlapping among them, but there will be a gap region -not covered- as indicated by red shadow in figure 1, its area as calculated exactly is occupying 5% of the working area. To ensure the maximum coverage, we have to deploy a sensor in the gap region, this sensor to be called the leader. Thus, the algorithm of grid square coverage (1) runs in two steps: the first step will locate the sensors in the rows and columns respectively such no sensor overlapped with others. As well as, the distance between the centers of any two adjacent nodes is $2r$ exactly . The second step is to deploy the leaders sensors. They deployed such that the vertical distance from the leader center point to other adjacent nodes -not the other leaders nodes- is 70% of $2r$, and the horizontal distance to adjacent leader nodes is $2r$.

**Grid Square Coverage (1) Algorithm.**

**input**: Work area $W_n$, Set of sensors $S_k$, double _2xr

```
Double w=width( Wn);
Double h= height( Wn);
Integer count =  k;
Integer s=0;
for (Integer x = 1; x < w - (_2xr / 2); x += _2xr)
        {
                for (Integer y = 1; y < h - (_2xr / 2); y += _2xr)
                 {
                    if (s < count)
                     {
                        setposition(Ss(x, y));
                        s++;
                      }
                      Else
                      Break;
                  }
           }
for (Integer xx = _2xr; xx < w - (_2xr / 2); xx+= _2xr)
        {
                for (Integer yy = _2xr; yy < h - (_2xr / 2); yy += _2xr)
                 {
                    if (s < count)
                     {
                        setposition(Ss(xx/2, yy/2));
                        s++;
                      }
                      Else
                      Break;
                  }
           }
```

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In line 11, the function $setposition(S_s(xx/2, yy/2))$ provided the X and Y positions for the location of sensor in 2D space.

*3.2 Coverage Efficiency*

The coverage efficiency analysis is based on equation (1) and (2) explained in section 2. Grid Square Coverage (1) algorithm contains only two coverage degrees, one-covered regions and two- covered regions.it ensures that 78% of whole area is covered without overlapping, which means less redundant data will be generated during routing or monitoring targets processes. Whereas 22% of whole interest area is covered by more than one node (two-covered regions). Mathematically, the area of gap region in the figure 1 is equal to the area of square subtracting the area of four equal circle's sectors.

The area of square is:

$$A_{sq} = 2r * 2r = 4r^2 \qquad (3)$$

The area of red start shape is:

$$= A_{sq} - 4\left(\frac{\theta r^2}{2}\right) = 4r^2 - \pi r^2 = r^2(4-\pi) \approx 0.85r^2 \approx 27\%\ of\ Leader\ sensor$$

$$\approx 5\%\ of\ total\ area \qquad (4)$$

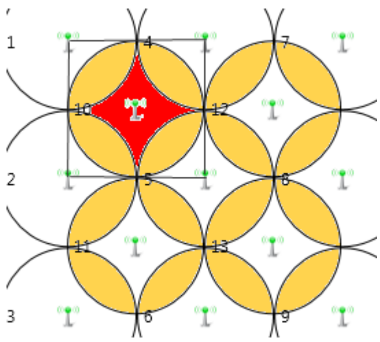


Figure 1: Grid square (1) sensors deployment scheme

For each leader node, the total area of two-covered regions is equal to the circle area subtracting the area of red gap region (Yellow regions of figure 1).

$$A_{c2} = \pi r^2 - r^2(4-\pi) \qquad (5)$$

$$A_{c2} = r^2(\pi - (4-\pi)) \qquad (6)$$

$$A_{c2} = r^2(2\pi - 4) \approx 2.28r^2 \quad (7)$$

Therefore, the intersection area between any two sensors is $2.28r^2/4$=$0.57r^2$, hence the total overlapping area of two-covered regions is $9.12r^2 = 22.33\%\ of\ total\ coverage.$

Generally, the total overlapping area of two-covered regions is equal to: the number of leader sensor multiply by $r^2(2\pi - 4)$.

$$A_{c2} = l \times r^2(2\pi - 4) \quad (8)$$

The total area of one-covered regions is equal to the whole area of interest subtracting the total area of two-covered regions.

$$A_{c1} = 13(\pi r^2) - 9.12r^2 \approx 31.72r^2 \approx 77.66\%\ of\ total\ area \quad (9)$$

Generally, the total overlapping area of one-covered regions is equal to:

$$A_{c1} = k(\pi r^2) - A_{c2} \quad (10)$$

$$A_{c1} = k(\pi r^2) - lr^2(2\pi - 4) \quad (11)$$

The Coverage Efficiency for Grid Square Coverage (1) algorithm is 78%. The Node Coverage Redundancy is 22%. In addition, The Maximum effective of area coverage ($A_{max}$) is the area covered by one sensor. Say we have $\boldsymbol{S_k}$, and $k = h \times v$ sensors deployed in a sensing field using the algorithm Grid Square Coverage (1), the exact area covered by one sensor is:

$$A_{max} = A_k - A_{c2} \quad (12)$$

Where $A_k$ is the total area covered by $k$ node. According to topology of coverage Grid Square Coverage (1), the Coverage Redundancy will be generated within the range of leader node only. Each leader holds redundancy of 4 regions. The number of leader nodes is $\leq h - 1 \times v - 1$. For facility we will assume $h = v$, so there will be $(v-1)^2$ of leaders. Then,

$$A_{max}(v, r) = v^2(\pi r^2) - (v-1)^2 r^2(2\pi - 4) \quad (13)$$

It is easy to find the number of regions that are one covered by:

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$$f(v,h)_{c1} = 2v + (h-2) + \sum\left(\prod_{\substack{i\geq v-2 \\ j\geq h-2}} ((v-i)(h-j))\right) \qquad (14)$$

While the number of two covered regions is:

$$f(v,h)_{c2} = 4(v-1)(h-1) \qquad (15)$$

The total number of regions will be:

$$f(v,h)_t = f(v\,xh)_{c1} + f(v\,xh)_{c2} = 4(v-1)(h-1) + 2v + (h-2) + \sum\left(\prod_{\substack{i\geq v-2 \\ j\geq h-2}} ((v-i)(h-j))\right) \qquad (16)$$

Hence**,**

$$A_{c2} = f(v,h)_{c2} \times r^2(2\pi - 4) \qquad (17)$$

$$A_{c2} = 4(v-1)(h-1) \times r^2(2\pi - 4) \qquad (18)$$

## 4. Grid Square Coverage: Version (2)

*4.1 Deployment strategy*

As shown in figure 2, the work area is divided into rows and columns. The adjacent sensors deployed in the same rows are overlapped such the horizontal distance between their centers, 70% of $2r$, it is the minimum distance to guarantee the covering of every point with less redundant data. In other hand, the vertical distance between the centers of any adjacent sensors located in the same columns is 70% of $2r$.here we call this distance parameter by intersection parameter. As shown in the figure 3, the greater the intersection parameter is, the less the coverage efficiency will be, and the smaller the intersection parameter is, the more the redundant data will be generated. When the intersection parameter is 70%, it ensures every point is covered, also the coverage efficiency is 73% of whole area, at the same time it guarantees the possible minimum data redundant 27%. As shown in figure 3(a), the black regions are generating more data redundant. In other hand, in figure 3(b), the red regions are not covered. Actually, the reader can notice that the intersection parameter of

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Grid Square Coverage (1) algorithm is 100% and red gap in the figure 1 is the maximum geographic shape can be created which occupies 5% of total area, which ensures less redundant data and more coverage efficiency.

**Grid Square Coverage (2) Algorithm.**

**input:** Work area $W_n$, Set of sensors $S_k$, double _2xr

```
Double w=width( Wn);
Double h= height( Wn);
Integer count = k;
Double inter_para =_2xr*0.7;
Integer s=0;
for (Integer x = 1; x < w - (inter_para / 2); x += inter_para)
    {
        for (Integer y = 1; y < h - (_inter_para / 2); y += inter_para)
        {
            if (s < count)
            {
                setposition(Ss(x,y));
                s++;
            }
            Else
            Break;
        }
    }
```

*4.2 Coverage Efficiency*

Two coverage degrees are provided by Grid Square Coverage (2) algorithm, one-covered regions and two- covered regions. This algorithm ensures that 73% of whole area is covered without overlapping which means less redundant data will be generated during routing or monitoring targets processes. Whereas 27% of whole interest area is covered by more than

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one node (two-covered regions). Mathematically, the total area of two-covered regions is calculated as below:

We will start by computing the area of square shape showed in figure 2, then computing the area of one sector inside the square and finally computing the area of triangle. Actually, the intersection area of two overlapped circles is made of two chords.

The area of square is:

$$A_{sq} = r * r = r^2 \qquad (19)$$

The square is divided into two triangles, the area of each triangle is:

$$A_{tr} = \frac{A_{sq}}{2} = \frac{r^2}{2} \qquad (20)$$

The square shape contains two sectors, the area of each sector is:

$$A_{sec} = \frac{\pi r^2}{4} \qquad (21)$$

The overlapping area of two sensors is equal to the area of one sector subtracting the area of one triangulate, since we have two chords then the area is:

$$A_{over} = 2(A_{sec} - A_{tr}) = 2\left(\frac{\pi r^2}{4} - \frac{r^2}{2}\right) = \frac{r^2}{2}(\pi - 2) \approx 0.57r^2 \approx 18.1\%\ of\ sensing\ range. \qquad (22)$$

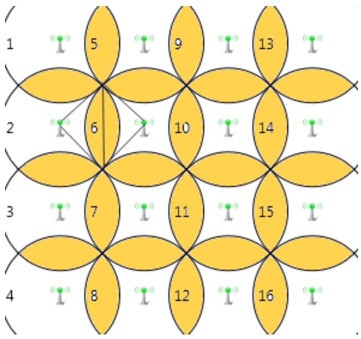


Figure 2: Grid square (2) sensors deployment scheme

The total area of two-covered regions is equal to the sum of yellow parts multiply by $0.57r^2$

$$A_{c2} = 13.68\, r^2 \approx 27\ \%\ of\ total\ area \qquad (23)$$

While the number of two covered regions is:

$$f(v,h)_{c2} = v(v-1) + h(h-1) \qquad (24)$$

The total area of one-covered regions is equal to the whole area of interest subtracting the total area of two-covered regions.

$$A_{c1} = 16(\pi r^2) - 13.68\, r^2 = 50.26 r^2 - 13.68\, r^2 = 36.58\, r^2 \approx 73\ \%\ of\ total\ area \qquad (25)$$

While the number of one covered regions is:

$$f(v,h)_{c1} = 2v + (h-2) + ((v-2)(h-2)) \qquad (26)$$

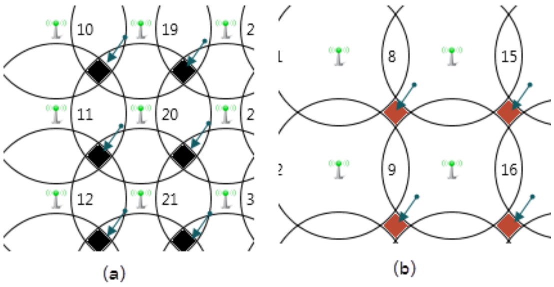


Figure 3: (a) intersection parameter is 60% (b) intersection parameter is 80%

## 5. Performance evaluation

The values of redundant data and maximum coverage efficiency for both Grid Square Coverage (1) and Grid Square Coverage (2) as calculated are not similar. Both algorithms during implementing shows different performance. We will try to make compression between the two algorithms from energy consumption, deployment space, communications messages and sensor lifetime points of views. For this purpose, we have develop a special software using c# visual studio 2012. We have implemented that in 2D space. The work area 896px **x** 590px.

### *5.1 Deployment space*

Considering the cost and economical situations, some users consider the coverage schemes that expands and covers the whole interest area with minimum number of nodes. According to our experiment indicated in the figure 4 and 5, it shows that the Grid Square

Coverage (1) express economical deployment space better than the Grid Square Coverage (2).

Table 1: different sensing rage deployment for coverage (1, 2)

| Exp. | r | Coverage (1) | Coverage (2) | Difference |
|---|---|---|---|---|
| 1 | 15 | 1151 | 1176 | 25 |
| 2 | 25 | 403 | 425 | 22 |
| 3 | 35 | 188 | 206 | 16 |
| 4 | 50 | 94 | 104 | 10 |
| 5 | 60 | 59 | 67 | 8 |
| 6 | 70 | 39 | 45 | 6 |
| 7 | 80 | 30 | 35 | 5 |

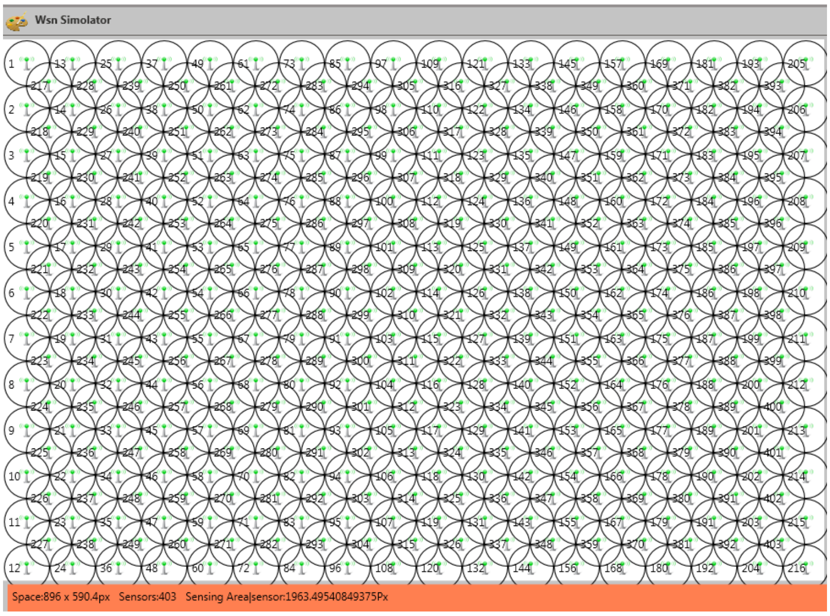


Figure 4: deployment space of Grid Square Coverage (1)

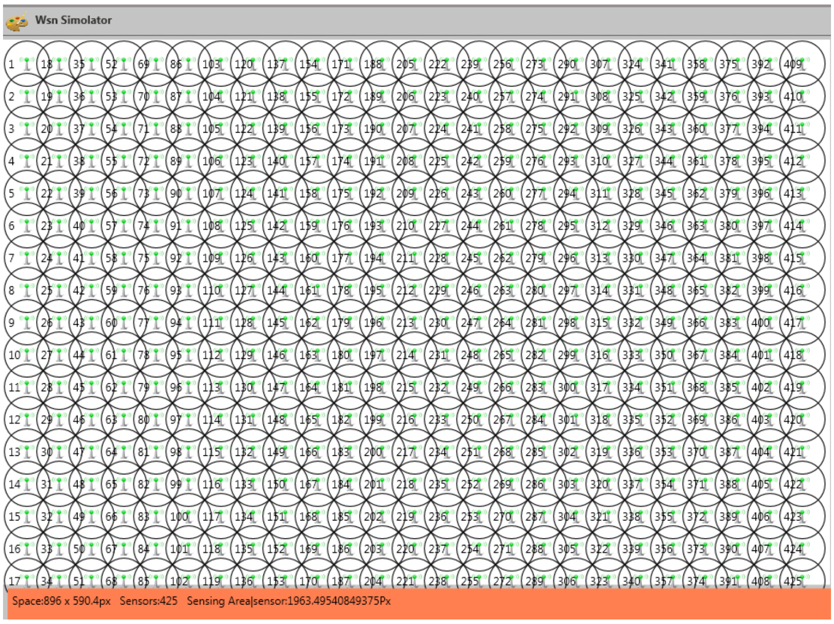


Figure 5: deployment space of Grid Square Coverage (2)

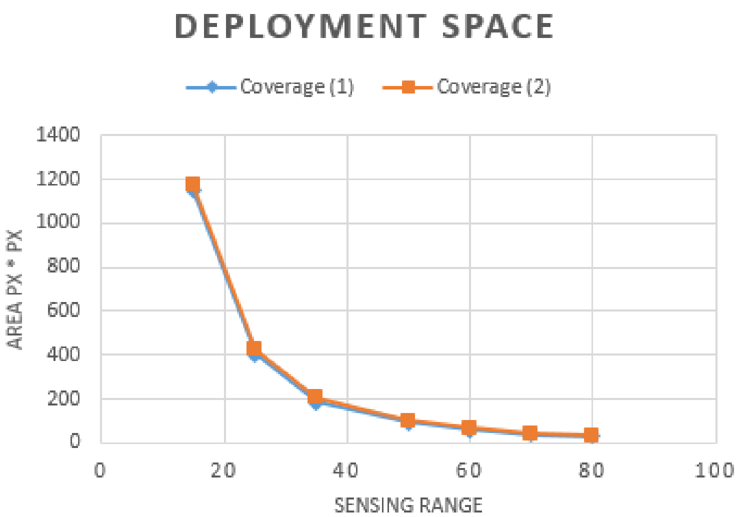


Figure 6: Deployment space compression

### *5.2 Network lifetime*

The Grid Square Coverage (1) expresses shorter lifetime because of the leader sensors, they carry out more tasks during routings processes and communications processes. The leader sensors will die before any other sensors in the network. For Grid Square Coverage (2) it shows balance lifetime for all sensors.

### *5.3 Coverage and data redundant*

Both square coverage (1) and (2) perform different data redundant and coverage efficiency, as shown in the figure 7 (a-d).

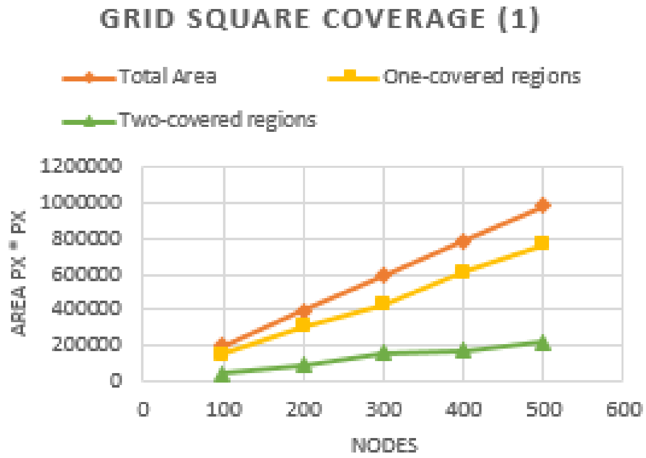


Figure 7: (a) Area coverage efficiency for grid square coverage (1)

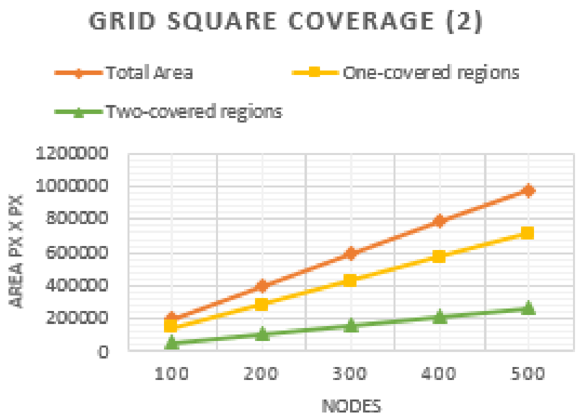


Figure 7: (b) Area coverage efficiency for grid square coverage (2)

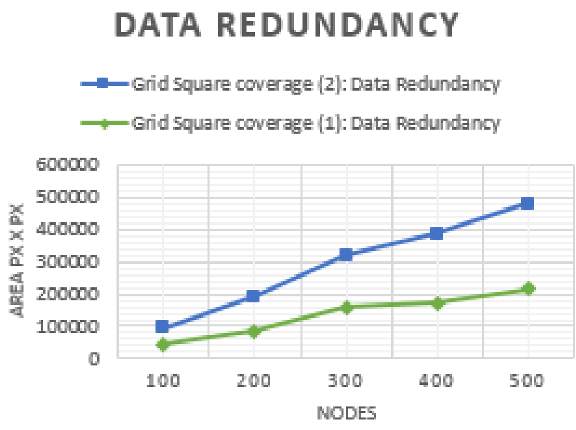


Figure 7: (c) Data Redundancy

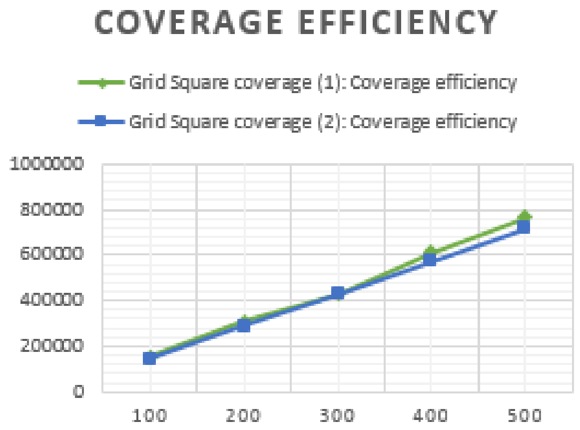


Figure 7: (d) Coverage efficiency

### *5.4 Communication and energy consumption*

The number of messages depends on the degree of overlapping. The more the degree of coverage is, the more the overlapped regions would be. Therefore, the more messages will be flooded [13]. Using the theorem 4 in reference [14-15]: The number of regions generated within the sensing range of sensor $s_i$ witch overlaps with a group of sensors $G^k$ can be calculated by solving the recursive relation:

$$Q_n(s_i) = \begin{cases} f(n) = n + f(n-1) - 1 \\ n \geq 1 \\ f(1) = 1 \end{cases} \qquad (27)$$

$$Q_n(s_i) = 1 + \frac{n(n-1)}{2} \qquad (28)$$

When the sensor belongs to multiple groups the number of regions can be gotten by the equation below:

$$Q^*(s_i) = \left( \sum_{(G_i^k \in G_i^*)} Q_k(s_i) \right) - \vartheta + 1 \qquad (29)$$

where $\vartheta$ is the number of groups.

As shown in figure 8 (b) and (d), the sensing ranges have the same overlapping regions inside. However, (a) and ( c) are not the same, which means the number of distributed messages generated by Square Grid coverage (2) are more than those generated by Square Grid coverage (1).

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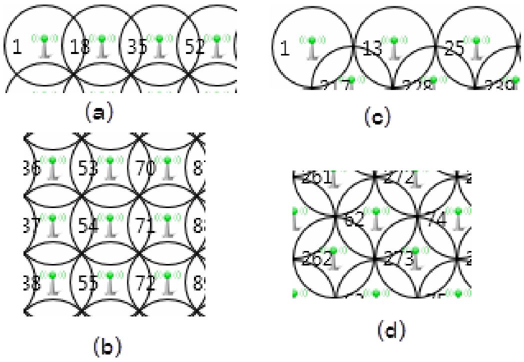


Figure 8: (a) borders sensors of Grid Square coverage (2), (b) central sensors of Grid Square coverage (2), (c) borders sensors of Grid Square coverage (1), (b) leader sensors of Grid Square coverage (1).

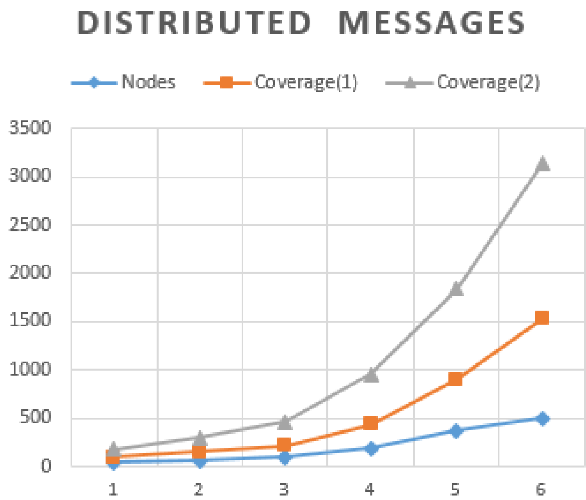


Figure 9: distributed messages generated by Grid Square coverage (1) and Grid Square coverage (2)

## 6. Conclusion

We have presented two algorithms based on grid coverage. Grid Square Coverage (1) and Grid Square Coverage (2), they express 78% and 73% of coverage efficiency respectively. WSN Grid based coverage algorithm generates more data redundancy and less coverage efficiency comparing with our previous work [15].

Due to simplicity of Grid Based Deployment Algorithms and less coverage efficiency, thus we will try to improve more efficient coverage algorithm in our coming researches.

**Acknowledgements**

The authors would like to express their appreciation to The National Natural Science Foundation of China, the National Science Technology Major Project and the China Scholarship Council for their supports.

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