

## An Intelligent and Energy Efficient Area Coverage Protocol for Wireless Sensor Networks

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### Abstract

*One major problem in the area of wireless sensor networks is the coverage problem. The coverage problem deals with the ability of the network to cover a certain area or some certain events. In this paper, we focus on the area coverage problem. We propose SRAHS, a sensing radius adjusting protocol, to deal with the problem of area coverage. In this protocol, proper sensing radius can be determined using the harmony search algorithm. Due to the proposed protocol accuracy in adjusting the nodes sensing radius, it is able to provide the full coverage in less densities. Moreover, as the result of increasing nodes density, the proposed protocol decreases both the nodes sensing radius and the energy consumption. We have simulated our protocol and simulation results show high efficiency of the proposed protocol*

**Keywords:** *Adjusting sensing radius, Area Coverage, Energy Consumption, Harmony Search algorithm, Wireless Sensor Networks*

### 1. Introduction

Wireless Sensor Networks (WSNs) are designed to conduct surveillance tasks, such as monitoring an area, several known/unknown targets and so on. Each sensor has a sensing area in which the interested events can be detected. Hence, the sensing area of a WSN is a decisive factor of the quality of surveillance [1]. Due to their portability and deployment, nodes are usually powered by batteries with finite capacity. Although the energy of sensor networks is scarce, it is always inconvenient or even impossible to replenish the power [2]. Therefore, the applications are hindered by limited energy supply, and one design challenge in sensor networks is to save limited energy resources to prolong the lifetime of the WSN [2] [3]. Power saving techniques can generally be classified in two categories [2]:

- Scheduling the sensor nodes to alternate between active and sleep mode
- Adjusting the transmission or sensing range of the wireless nodes

In this paper, we deal with the area coverage problem using adjusting sensing range of the sensor nodes. We use a cluster-based coverage control scheme and propose SRAHS<sup>1</sup>

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<sup>1</sup> Sensing Range Adjusting Harmony Search area coverage protocol

protocol. In SRAHS, proper sensing radius can be determined using Harmony Search (HS) algorithm. The remaining of the paper is organized as follows: In Section 2 we present the related work in the context of Area Coverage. In Section 3 we illustrate the HS algorithm briefly. Section 4 presents the model and the assumptions made and Section 5 describes the proposed algorithm. Section 6 presents some simulation results and evaluates the algorithm for different sensor field deployments. The paper concludes with Section 7.

## 2. Related Works

One major problem in the area of sensor networks is the coverage problem. This problem deals with the ability of the network to cover a certain area or some certain events [4]. Various coverage formulations have been proposed in literature among which following three are most discussed [4]:

- Area coverage: monitoring the whole area of the network is the main objective of area coverage problem.
- Point coverage: the objective of point coverage problem is to cover a set of stationary or moving points.
- Barrier coverage: barrier coverage can be considered as the coverage with the goal of minimizing the probability of undetected penetration through the sensor network.

In this paper, we focus on the problem of Area Coverage.

By allowing redundant sensors to go into the sleep mode, the energy consumption network is reduced [2]. Thus, an important method for the Area Coverage problem is to find the maximal number of covers in sensor network, where the cover is a set of nodes that can completely cover the target area [2]. The problem of finding the maximal number of covers in a sensor network is addressed by Slijepcevic and Potkonjak [5]. It is an NP-complete problem [5]. Tian et al. proposed a centralized solution to reduce the energy consumption network by turning on some redundant nodes in the sensor network [7]. But, their solution requires a large number of nodes to operate in the active mode. Also, a sensor network must provide satisfactory the network connectivity [8]. But the proposed solution by Wang et al. does not provide minimized number of active nodes. A straightforward solution is to use a transition range  $R_T$  that is at least twice the sensing range  $R_S$  (i.e.  $R_T \geq 2R_S$ ), such that Area Coverage guaranties the network connectivity of active nodes [9]. Yang et al. in 2006 [10] addressed the k-Connected coverage set problems in wireless sensor network with the objective of minimizing the total energy consumption while achieving k-coverage for reliability. Note that a sensor network that achieves k-coverage could be k-connected. In the proposed solution by F. Ye et al. [11], a set of nodes are made active to maintain coverage while others are put into sleeping modes to conserve energy. This algorithm called PEAS. In PEAS, by adjusting the sensing radius of nodes, it can achieve different coverage redundancy. But it cannot preserve the original sensing coverage completely after turning off some nodes. The problem of maintaining sensing coverage by keeping a small number of active sensor nodes and a small amount of energy consumption is studied by Jia et al. in 2009, and proposed NSGA-II algorithm [2]. NSGA-II uses a cluster-based coverage control scheme which is scheduled into rounds. The cluster-head has full control of the square and it will choose a set of nodes to do the sensing job and assign each working node with a different sensing radius. But, decreasing nodes density causes efficiency of NSGA-II algorithm to decrease. Also, NSGA-II keeps a

small number in active mode. Thus, it can't maintain balance in using nodes energy so that it causes the network lifetime to decrease.

We propose a novel sensing radius adjusting protocol based on harmony search algorithm, called SRAHS. In this protocol, proper sensing radius can be determined using harmony search algorithm. Due to the proposed protocol accuracy in adjusting the nodes sensing radius, it is able to provide the full coverage in less densities. Moreover, with increasing nodes density, the proposed protocol decreases both nodes sensing radius and energy consumption. Also, the number of active nodes is equal to the number of all nodes. Thus, the proposed protocol maintains more balance in using nodes energy so that it prolongs the network lifetime.

### 3. Harmony Search algorithm

Harmony Search (HS) algorithm, originated by Geem et al. [12], is based on natural musical performance processes that occur when a musician searches for a better state of harmony [13], [14], [15]. HS has several advantages with respect to traditional optimization techniques such as the following [13]:

- HS imposes fewer mathematical requirements.
- HS is free from divergence.
- HS does not require initial value settings of the decision variables, thus it may escape the local optima. Furthermore it may be easily adapted for multi-modal problems.
- As the HS uses stochastic random searches, derivative information is unnecessary. HS has novel stochastic derivative.
- HS can handle both discrete and continuous variables.
- HS algorithm could overcome the drawback of genetic algorithm building block theory by considering the relationship among decision variables using its ensemble operation. HS generates a new vector, after considering all of the existing vectors, whereas the genetic algorithm only considers the two parent vectors.

The HS algorithm optimization procedure consists of the following five steps [13], [14], [15]:

**Step 1:** Problem and algorithm parameter initialization

**Step 2:** Harmony memory initialization and evaluation

**Step 3:** New harmony improvisation

**Step 4:** Harmony memory update

**Step 5:** Termination criterion check

We give the pseudo-code for HS algorithm as follows:

**Step 1:**

- Initialize the problem parameters:
  - Objective function ( $f(x)$ )
  - Decision variable ( $x_i$ )
  - Number of decision variables ( $N$ )
- Initialize the algorithm parameters:
  - Harmony Memory Size (HMS)

Harmony Memory Considering Rate (HMCR)  
Pitch Adjustment Rate (PAR)  
The Number of Improvisations (NI)  
Distance bound wide (bw)

**Step 2:**

- Initialize the Harmony Memory (HM) with random vectors as many as the vectors of HMS
- Evaluate HM

**Step 3:**

With probability HMCR:

- Select a new value for a variable from HM

With probability  $1 - \text{PAR}$

- Do nothing

With probability PAR

- Choose a neighbouring value

With probability  $1 - \text{HMCR}$

- Select a new value from the possible value set

**Step 4:**

If New Harmony vector is better than existing harmony vectors in the HM then

- Update HM

**Step 5:**

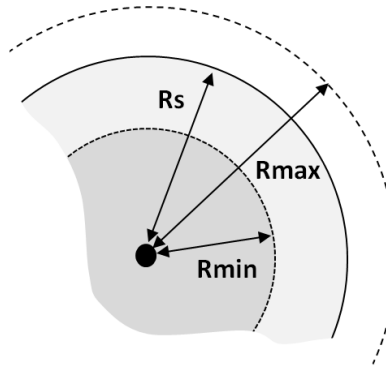
- Checking Termination criteria met and jump to step 3

## 4. The Network Model and the Assumptions

In this section, we present the model and the assumptions used in this paper.

### 4.1. Adjustable Sensing Radius

In this section, we assume that each node has adjustable sensing radius that can be between minimum and maximum area (see Fig. 1).  $R_{\min}$  is sensing radius with minimum power,  $R_{\max}$  is sensing radius with maximum power and  $R_s$  is selective sensing radius of node. The value of  $R_s$  should be between the  $R_{\min}$  and  $R_{\max}$  ( $R_{\min} \leq R_s \leq R_{\max}$ ). Value of sensing radius  $R_{\min}$  and  $R_{\max}$  will be calculated based on  $R_t$ . Value of sensing radius  $R_t$  identified proportionate with network density [6].



**Fig. 1: We assume that each node has adjustable sensing radius that can be between  $R_{\min}$  and  $R_{\max}$ .**

## 4.2. Coverage Problem Formulation

Define that the size of the target area is  $A_{total}$ , the size of the monitoring area is  $A_{area}$ , the sensor set is  $S = \{n_1, n_2, \dots, n_N\}$  and the sensing radius set is  $R = \{R_1, R_2, \dots, R_N\}$ , where  $R_i$  is the sensing radius of node  $n_i$ , and  $R_i \in [R_{min}, R_{max}]$  [2]. In this paper, we will deal with the nodes deployed randomly. We assume that the nodes are static once deployed, and each one knows its own location which can be achieved by using some location system [16].

Since the relationship of coverage and connectivity has been proved by Zhang et al. [9], the transmission range of sensor nodes is assumed to be at least twice the sensing range. Then coverage can imply connectivity [2]. Thus, we will only focus on the coverage problem.

The coverage model of the node  $n_i$  is supposed as a circle centered at its coordinates  $(x_i, y_i)$  with radius  $r_i$ . A random variable  $c_i$  is introduced to describe the event that the sensor  $n_i$  covers a pixel  $(x, y)$ . Then, the probability of event  $c_i$  denoted as  $P(c_i)$  is equal to the coverage probability  $P_{cov}(x, y, n_i)$ . This may degenerate to a two-valued function [2]:

$$P(c_i) = P_{cov}(x, y, n_i) = \begin{cases} 1 & \text{If } (x-x_i)^2 + (y-y_i)^2 \leq r_i^2 \\ 0 & \text{else} \end{cases} \quad (1)$$

We assume that any random event  $c_i$  is independent of the others, so  $c_i$  and  $c_j$  are unrelated,  $i, j \in [1, N]$  and  $i \neq j$ . Then the following two relationships can be concluded [2]:

$$P(c'_i) = 1 - P(c_i) = 1 - P_{cov}(x, y, n_i) \quad (2)$$

$$P(c_i \cup c_j) = 1 - P(c'_i \cap c'_j) = 1 - P(c'_i) \cdot P(c'_j) \quad (3)$$

Where  $c'_i$  is the complement of  $c_i$ , denoting that sensor  $n_i$  fails to cover  $(x, y)$ .

It can be considered that the pixel  $(x, y)$  is covered by the sensor set if any sensor node in the set covers it. As a result, the probability of the event that the pixel  $(x, y)$  is covered by the sensor set can be denoted as the union of  $c_i$  [2]:

$$P_{cov}(x, y, S) = P(\cup_{i=1 \text{ to } N} c_i) = 1 - P(\cap_{i=1 \text{ to } N} c'_i) = 1 - \prod_{i=1 \text{ to } N} (1 - P_{cov}(x, y, n_i)) \quad (4)$$

Also, we define the coverage rate of the sensor set,  $R_{cov}$ , as the proportion of the monitoring area  $A_{area}$  to the total area  $A_{total}$  [2]:

$$R_{cov} = A_{area} / A_{total} = \sum_{x=1 \text{ to } m} \sum_{y=1 \text{ to } n} P_{cov}(x, y, c) / (m \times n) \quad (5)$$

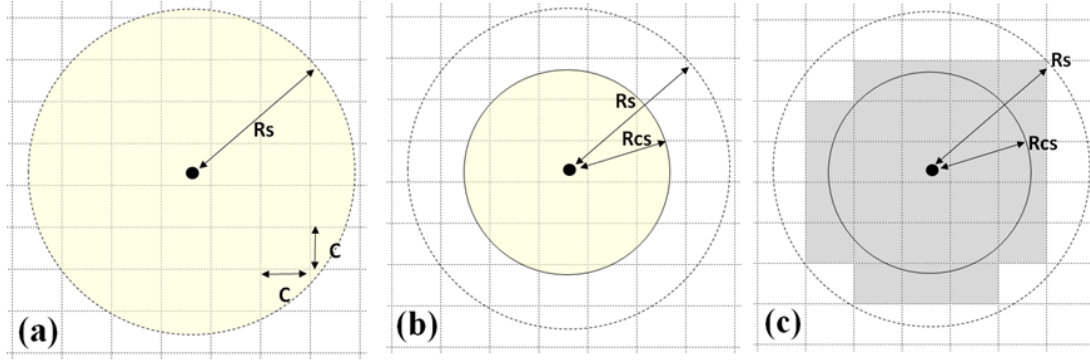
## 4.3. Cellular Method

Regarding that it is impossible to evaluate the coverage of all network points, we use the cellular network for doing Area Coverage. In this method, the target area with dimensions  $x \times y$  is divided in square cells with dimensions  $C \times C$ .

As mentioned before, the sensing radius of each node is showed by  $R_s$ . One cell is covered if it is completely within the sensing radius of a sensor node. We define a Calculated Sensing Radius ( $R_{CS}$ ) for each sensor node defined on the basis of real sensing radius and cell size as:

$$R_{CS} = R_s - (2C)^{1/2} \quad (6)$$

Where  $(2C)^{1/2}$  is the length of cell diameter. The reason for such definition is that if one of the cell vertices has the some overlap with the calculated sensing radius of node, it will be covered completely based on the real sensing radius of node. As a result, one cell is covered if it has some overlap with the calculated sensing radius of a sensor node as shown in Fig. 2. In this figure the dark cells are covered by sensor node based on  $R_S$  and  $R_{CS}$ .



**Fig. 2: The Covered cells by the sensor node based on RCS and RS.**

Also, we define the Calculated Minimum Radius ( $R_{C \min}$ ) and the Calculated Maximum Radius ( $R_{C \max}$ ) as:

$$R_{C \min} = R_{\min} - (2C)^{1/2} \quad (7)$$

$$R_{C \max} = R_{\max} - (2C)^{1/2} \quad (8)$$

When one cell has some overlap with  $R_{C \max}$ , we assume it is one of cells in the sensing set of the sensor node. Because we sure that this cell covered by  $R_{\max}$ .

$$c_i \in \text{Sensing Set} \quad \text{if } c_i \text{ covered by } R_{\max} \quad (9)$$

$$\text{Sensing Set} = \text{all cells have overlap with } R_{C \max} \quad (10)$$

As shown in Fig. 3, cells of the sensing set are in three different subsets. Subsets of  $A_{\min}$ ,  $A_S$  and  $A_{\max}$  is calculated according to the following equations:

$$c_i \in A_{\min} \quad \text{if } c_i \text{ covered by } R_{\min} \quad (11)$$

$$c_i \in A_S \quad \text{if } c_i \text{ covered by } R_S \text{ and not covered by } R_{\min} \quad (12)$$

$$c_i \in A_{\max} \quad \text{if } c_i \text{ covered by } R_{\max} \text{ and not covered by } R_S \quad (13)$$

$$A_{\min} = \text{all cells have overlap with } R_{C \min} \quad (14)$$

$$A_S = \text{all cells have overlap with } R_{CS} - (A_{\min}) \quad (15)$$

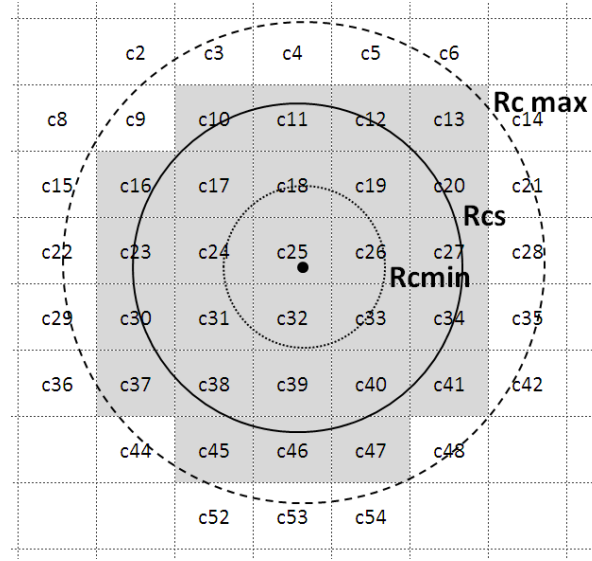
$$A_{\max} = \text{all cells have overlap with } R_{C_{\max}} - (A_S \cup A_{\min}) \quad (16)$$

$$A_{\max} \cup A_S \cup A_{\min} = \text{Sensing Set} \quad (17)$$

$$A_{\max} \cap A_S \cap A_{\min} = \{ \} \quad (18)$$

In (9), (11), (12) and (13),  $c_i$  is cell number.

The sensing area and set of cells is shown in Fig. 3. The main problem in this paper is choosing minimum sensing radius  $R_S$  between  $R_{\min}$  and  $R_{\max}$  for each node without decreasing the coverage.



$$A_{\min} = \{ c17, c18, c19, c24, c25, c26, c31, c32, c33 \}$$

$$A_s = \{ c10, c11, c12, c13, c16, c20, c23, c27, c30, c34, c37, c38, c39, c40, c41, c45, c46, c47 \}$$

$$A_{\max} = \{ c2, c3, c4, c5, c6, c8, c9, c14, c15, c21, c22, c28, c29, c35, c36, c42, c44, c48, c52, c53, c54 \}$$

$$\text{Sensing Set} = A_{\min} \cup A_s \cup A_{\max}$$

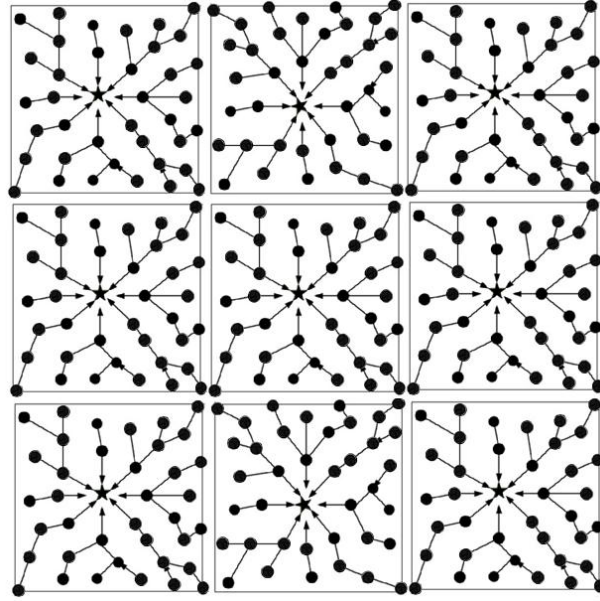
**Fig. 3: The covered cells by the sensor node based on RC min, RCS and RC max.**

#### 4.4. The Cluster-based Architecture

We use a cluster-based coverage control scheme in this paper, which is scheduled into rounds. In each round, firstly, the target area is divided into several equal squares. Then the node in each square having the largest energy will be chosen as the cluster-head. The procedure of selecting the cluster-head is the same works by Jia and Chena in 2006 and 2009 [2] [17].

This cluster-based architecture is shown in Fig. 4. The nodes of cluster-heads are those asterisked ones. The black nodes represent the sensor nodes which are working in the target area. The cluster-head has full control of the square and it will choose a set of transition radii

to do the sensing job. In the next round, another sensor set will be selected as the cluster head. It is done in a random way, so the energy consumption among all the sensors can be balanced well [2].



**Fig. 4: The Cluster-based Architecture of SRAHS Protocol**

#### 4.5. Energy Consumption Analysis

For the brief of the energy consumption analysis, here we only consider the energy consumed by the sensing function, and do not include the power consumption of transmission and calculation. When the sensor node is sleeping, the consumed power is considered as zero [2].

According to different energy consumption models, the energy consumed by a sensor node to deal with a sensing task is proportional to  $R_s^2$  or  $R_s^4$ , where  $R_s$  is the sensing radius of the sensor node [2] [18]. In this paper, we take the sensing energy consumption as  $u \cdot R_s^2$ , where  $u$  is the factor.

Thus, the coverage energy consumption of the sensor set, which is related to the sum of the sensor's sensing radius squared, is defined as:

$$E_{\text{total}} = u \cdot \sum_{i=1 \text{ to } N} (f_i \times R_i^2) \quad (19)$$

In (19), the amount of function  $f_i$  is calculated according to (20):

$$f_i = \begin{cases} 0 & \text{if node } n_i \text{ is in sleep mode} \\ 1 & \text{else} \end{cases} \quad (20)$$

So, the energy consumption per area is shown as the following [2]:

$$E_{\text{cov}} = E_{\text{total}} / A_{\text{area}} = u \cdot \sum_{i=1 \text{ to } N} (f_i \times R_i^2) / A_{\text{area}} \quad (21)$$

## 5. Proposed Protocol

In this section, we propose an algorithm based on harmony search algorithm and try to decrease average of sensing radius of nodes without decreasing coverage of network.

In proposed algorithm, at first a primary population of sensing radii set, are selected randomly. Each the sensing radius set represents one configuration of sensor network. We consider the mentioned population as Harmony Memory. Then we try to improve the Harmony Memory by creating a new sensing radius set. If the new sensing radius set is better than the worst sensing radius set existing in Harmony Memory, the worst one will be replaced with it. The process of providing new sensing radius set and replacing the worst sensing radius set with the new one continue until meeting termination criteria. Algorithm continues until achieving a certain number of iteration or if the fitness value of one of the sensing radius sets exceeds the threshold value. Finally, the best sensing radius set existing in the Harmony Memory is selected as the response.

So, the proposed algorithm is presented briefly in five steps as follows:

Phase1. Initialization:

Step1: Initialize the problem and algorithm parameters.

Step2: Initialize the harmony memory with sensing radius sets randomly.

Phase1. Repeating main loop of algorithm until meeting termination criteria:

Step3: Improvise a new sensing radius set.

Step4: Update the harmony memory.

Step5: Check the stopping criterion.

These steps are described in the next five subsections.

### 5.1. Step1. Initialize the Problem and Algorithm Parameters

In Step 1, the optimization problem is specified as follows:

$$\text{Maximize } f(R) = \alpha \cdot (1/E_{\text{cov}}(R) + \epsilon) + \beta \cdot R_{\text{cov}}(R) \quad R = (R_1, R_2, R_3, \dots, R_N) \quad (22)$$

Where  $\alpha$  and  $\beta$  are two constant factors.  $R$  is the set of nodes sensing radius;  $N$  is the number of nodes,  $R_i$  is sensing radius of node  $n_i$ , that is  $R_{\min} \leq R_i \leq R_{\max}$ .  $R_{\min}$  and  $R_{\max}$  are the lower and upper bounds for sensing radius of each node. Also  $\epsilon$  is a constant number that should be selected properly such a way that  $f(R)$  function value doesn't exceed the threshold value.

As mentioned in section 4,  $E_{\text{cov}}(R)$  is the energy consumption per area based on (21). Based on (5),  $R_{\text{cov}}(R)$  is the coverage rate of the sensing radius set. Also, according to (22):

$$\text{If } \alpha=0 \Rightarrow f(R) = \beta \cdot R_{\text{cov}}(R) \Rightarrow \text{Maximum } f(R_{\text{MAX}}) \quad , R_{\text{MAX}} = (R_{\max}, \dots, R_{\max}) \quad (23)$$

$$\text{If } \beta=0 \Rightarrow f(R) = \alpha \cdot (1/E_{\text{cov}}(R) + \epsilon) \Rightarrow \text{Maximum } f(R_{\text{MIN}}) \quad , R_{\text{MIN}} = (R_{\min}, \dots, R_{\min}) \quad (24)$$

Therefore, according to (22), (23) and (24),  $f(R)$  function value is in direct ratio to coverage rate and in inverse ratio to the nodes sensing radius.

The HS algorithm parameters are also initialized in this step:

- HMS: the harmony memory size or the number of the sensing radius sets in the harmony memory
- HMCR: harmony memory considering rate
- PAR: pitch adjusting rate
- NI: the number of improvisations or stopping criterion.

The Harmony Memory (HM) is a memory location where all sensing radius sets are stored. Here, HMCR and PAR are parameters that are used to improve the sensing radius sets. Both are defined in Step 3 (i.e. improvise a sensing radius set).

## 5.2. Step2. Initialize the Harmony Memory

In this step, we consider a Harmony Memory consists of one HMS group of the sensing radius sets according to Fig. 5. Each the sensing radius set,  $R^i = (R_1^i, R_2^i, R_3^i, \dots, R_N^i)$ , represents one configuration of sensor network such a way that the sensing radius of each  $j^{\text{th}}$  node equals to  $R_j^i$ . The fitness value of this configuration is shown by  $f(R^i)$ .

$$HM = \left[ \begin{array}{ccccc|c} R_1^1 & R_2^1 & \dots & R_{N-1}^1 & R_N^1 & f(R^1) \\ R_1^2 & R_2^2 & \dots & R_{N-1}^2 & R_N^2 & f(R^2) \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ R_1^{HMS-1} & R_2^{HMS-1} & \dots & R_{N-1}^{HMS-1} & R_N^{HMS-1} & f(R^{HMS-1}) \\ R_1^{HMS} & R_2^{HMS} & \dots & R_{N-1}^{HMS} & R_N^{HMS} & f(R^{HMS}) \end{array} \right]$$

**Fig. 5: The Harmony Memory (HM) is a memory location where all sensing radius sets are stored.**

So, one  $N \times HMS$  matrix of sensing radii will be obtained. These sensing radii are initialized randomly according to (25):

$$R_j^i = R_{\min} + \text{rand}() \times (R_{\max} - R_{\min} + 1) \quad i = 1, 2, \dots, HMS, j = 1, 2, \dots, N \quad (25)$$

Where  $\text{rand}()$  is a random number between 0 and 1. HMS is harmony memory size (i.e. the number of the sensing radius sets in the harmony memory) and N is the number of nodes.

The fitness value of each sensing radius set  $R^i$  is represented by  $f(R^i)$  and it is calculated by (26). So:

$$f(R^i) = \alpha \cdot (1/E_{\text{cov}}(R^i) + \varepsilon) + \beta \cdot R_{\text{cov}}(R^i) \quad R^i = (R_1^i, R_2^i, \dots, R_N^i), i = 1, 2, \dots, HMS \quad (26)$$

As mentioned in section 4,  $E_{\text{cov}}(R^i)$  is the energy consumption per area based on (21). Also, based on (5),  $R_{\text{cov}}(R^i)$  is the coverage rate of the sensing radius set.

### 5.3. Step3. Improvise a Sensing Radius Set

Generating a new harmony (a new sensing radius set) is called ‘improvisation’. A new sensing radius set,  $R'=(R'_1, R'_2, R'_3, \dots, R'_N)$ , is generated based on three rules:

- Memory consideration
- Pitch adjustment
- Random selection

In the memory consideration, the value of the first sensing radius ( $R'_1$ ) for the new sensing radius set is chosen from any of the values in the specified HM range ( $R_1^1, R_1^2, R_1^3, \dots, R_1^{HMS}$ ). Values of the other sensing radiuses ( $R'_2, R'_3, \dots, R'_N$ ) are chosen in the same manner. The HMCR, which varies between 0 and 1, is the rate of choosing one value from the historical sensing radius values stored in the HM, while  $(1 - HMCR)$  is the rate of randomly selecting one value from the possible range of values (i.e. one value between  $[R_{min}, R_{max}]$ ).

$$R'_i \leftarrow \begin{cases} R'_i \in \{R_i^1, R_i^2, \dots, R_i^{HMS}\} & \text{with probability HMCR} \\ R'_i = R_{min} + \text{rand}() \times (R_{max} - R_{min} + 1) & \text{with probability (1-HMCR)} \end{cases} \quad (28)$$

For example, a HMCR of 0.85 indicates that the HS algorithm will choose the sensing radius value from historically stored values in the HM with an 85% probability or from  $[R_{min}, R_{max}]$  with a (100-85)% probability.

Every sensing radius obtained by the memory consideration is examined to determine whether it should be pitch-adjusted. This operation uses the PAR parameter, which is the rate of pitch adjustment as follows:

Pitch adjusting decision for  $R'_i \in R'=(R'_1, R'_2, \dots, R'_N)$ :

$$R'_i \leftarrow \begin{cases} \text{Yes} & \text{with probability PAR} \\ \text{No} & \text{with probability (1-PAR)} \end{cases} \quad (28)$$

The value of (1-PAR) sets the rate of doing nothing. If the pitch adjustment decision for  $R'_i$  is YES,  $R'_i$  is replaced as follow:

$$R'_i \leftarrow R'_i \pm \text{rand}() \times (R_{max} - R_{min} + 1) \quad (29)$$

Where  $\text{rand}()$  is a random number between 0 and 1. Also, as already stated,  $R_{min}$  and  $R_{max}$  are the lower and upper bounds for sensing radius of nodes.

In Step 3, HM consideration, pitch adjustment or random selection is applied to each variable of the new sensing radius set in turn.

### 5.4. Step4. Update Harmony Memory

If the new sensing radius set,  $R'=(R'_1, R'_2, R'_3, \dots, R'_N)$  is better than the worst harmony in the HM, judged in terms of the objective function value  $f(R')$ , the worst one will be replaced with it:

$$((\forall R^j \in \text{HM} \quad f(R^{\text{worst}}) \leq f(R^j)) \text{ and } f(R^{\text{worst}}) \leq f(R')) \Rightarrow$$

$$R^{\text{worst}} = (R_1^w, R_2^w, \dots, R_N^w) \leftarrow R' = (R'_1, R'_2, \dots, R'_N) \quad (30)$$

### 5.5. Step5. Check Stopping Criterion

If the stopping criterion (maximum number of improvisations) is satisfied, computation is terminated. Otherwise, Steps 3 and 4 are repeated. According to (31), after ending the main loop of algorithm, the sensing radius set with most objective function is selected among sensing radii sets existing in Harmony Memory.

$$R^{\text{Best}} = (R_1, R_2, R_3, \dots, R_N) \in \text{HM} \text{ is answer if: } \forall R^j \in \text{HM} \quad f(R^{\text{Best}}) \geq f(R^j) \quad (31)$$

## 6. Simulation Results

In this section, our proposed mechanism is simulated using NS2 simulator. To evaluate the proposed protocol, it is compared with NSGA-II [2] and OGDC protocols [9]. In the simulation, we assume an area with a size of 150×150 which is divided in cells with size of 1×1. We deploy the sensor nodes randomly in the area. The number of nodes, N, in different configurations are considered as 110, 120, 130, 140, 150, 160, 170, 180, 190 and 200 respectively. In the proposed protocol and NSGA-II protocol, the nodes sensing radius is considered as  $R_s \in [8, 23]$ . Also, regarding the ability of proposed protocol to adjust the sensing radius of nodes, it is compared with OGDC protocol with three sensing radiuses with size of 8, 10 and 12m. Other assumptions are shown in Table 1.

**Table 1. Parameters Values**

NI	HMS	HMCR	PAR	$\alpha$	$\beta$	$\epsilon$
300	50	0.85	0.02	N	5N	1

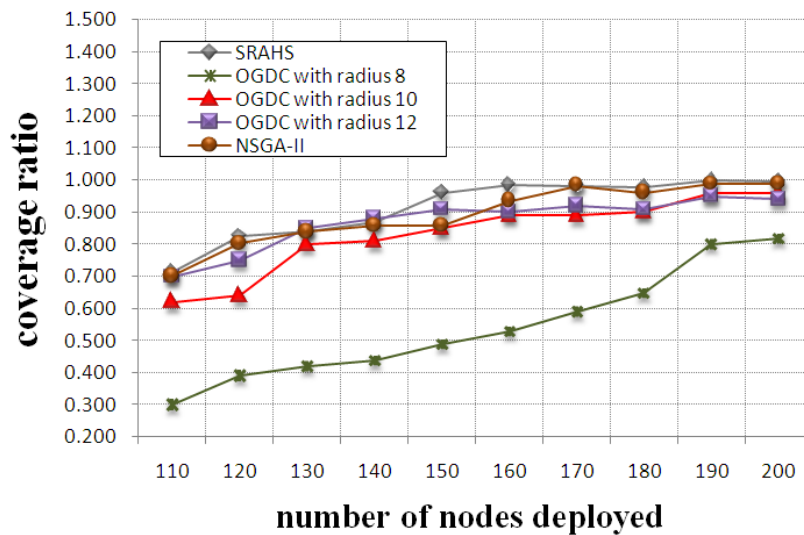
As shown in Fig. 6 and Table 2, due to its ability to adjust sensing radius, the proposed protocol is able to provide higher coverage rate in comparison with OGDC and NSGA-II protocols. On the other hand, as shown in Fig. 7 and Table 3, the energy consumption per area in different configurations of our protocol is less than the OGDC and NSGA-II protocols.

Due to the proposed protocol accuracy in adjusting the nodes sensing radius, it is able to provide the full coverage in less densities. Moreover, as the result of increasing nodes density, the proposed protocol decreases both nodes sensing radius and energy consumption, but OGDC protocol is not able to decrease energy consumption and to provide the full coverage in low density because of using fixed sensing radius. Also, NSGA-II protocol selects a few numbers of active nodes, using the energy of nodes will not be balanced. Furthermore, the performance of NSGA-II protocols in low densities will decrease.

Another noticeable point in the proposed protocol is the number of active nodes. As shown in Fig. 8 and Table 4, the number of active nodes is equal to the number of all nodes while the energy consumption in the proposed protocol is less in different configurations. As a result, the proposed protocol maintains more balance in using nodes energy so that it prolongs the network lifetime.

**Table 2. Area Coverage Ratio**

Protocol	The number of nodes (N)									
	110	120	130	140	150	160	170	180	190	200
SRAHS	0.713	0.824	0.840	0.870	0.960	0.984	0.983	0.979	0.998	0.997
OGDC R=8	0.300	0.390	0.420	0.440	0.490	0.530	0.590	0.650	0.800	0.820
OGDC R=10	0.620	0.640	0.800	0.810	0.850	0.890	0.890	0.900	0.960	0.960
OGDC R=12	0.700	0.750	0.850	0.880	0.910	0.900	0.920	0.910	0.950	0.940
NSGA-II	0.704	0.804	0.838	0.860	0.860	0.934	0.984	0.959	0.899	0.990



**Fig. 6: The Coverage Rate of the Sensor Set in Different Configurations**

**Table 3. Energy Consumption per Area**

Protocol	The number of nodes (N)									
	110	120	130	140	150	160	170	180	190	200
SRAHS	0.440	0.460	0.460	0.450	0.490	0.500	0.491	0.475	0.480	0.470
OGDC R=8	0.558	0.560	0.561	0.587	0.580	0.590	0.590	0.588	0.600	0.600
OGDC R=10	0.660	0.672	0.674	0.673	0.675	0.677	0.688	0.681	0.683	0.685
OGDC R=12	0.700	0.697	0.710	0.743	0.740	0.743	0.745	0.749	0.750	0.750
NSGA-II	0.530	0.525	0.470	0.560	0.561	0.550	0.520	0.540	0.530	0.510

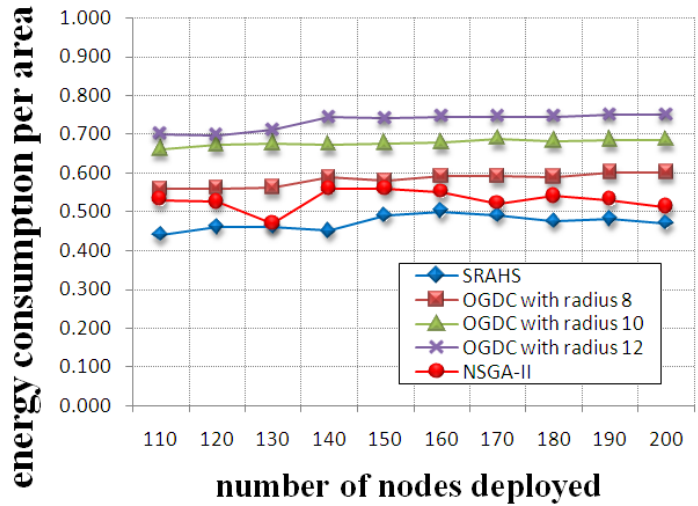


Fig. 7: The energy consumption per area in different configurations

Table 4. The Number of Active Nodes

Protocol	The number of nodes (N)									
	110	120	130	140	150	160	170	180	190	200
SRAHS	110	120	130	140	150	160	170	180	190	200
OGDC R=8	103	113	120	125	136	148	153	162	170	164
OGDC R=10	105	108	119	122	130	135	140	150	152	150
OGDC R=12	97	110	118	119	127	128	138	149	142	139
NSGA-II	100	100	116	119	117	118	120	139	129	132

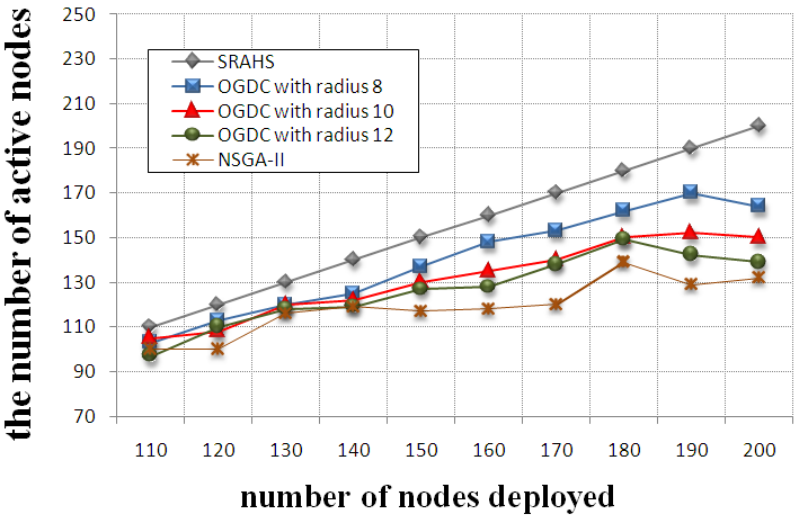


Fig. 8: The Number of Active Nodes in Different Configurations

## 7. Conclusion

In this paper, we have proposed SRAHS, a sensing radius adjusting protocol based on Harmony Search algorithm, to deal with the problem of area coverage. In this protocol, proper sensing radius can be determined using Harmony Search algorithm. Due to the proposed protocol accuracy in adjusting the nodes sensing radius, it is able to provide the full coverage in less densities. Moreover, as the result of increasing nodes density, the proposed protocol decreases both the nodes sensing radius and the energy consumption. We have simulated our protocol and simulation results show high efficiency of the proposed protocol.

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