ՀՀ ԳԱԱ ԻՆՖՈՐՄԱՏԻԿԱՅԻ ԵՎ ԱՎՏՈՄԱՏԱՑՄԱՆ ՊՐՈԲԼԵՄՆԵՐԻ ԻՆՍՏԻՏՈՒՏ

Համիդ Խոսրավի

ԱՆԼԱՐ ՍԵՆՍՈՐԱՅԻՆ ՑԱՆՑԵՐՈՒՄ ԾԱԾԿՈՒՅԹԻ ԵՎ ԿԱՊԱԿՑՎԱԾՈՒԹՅԱՆ ԱՆՀՐԱԺԵՇՏ ՄԱԿԱՐԴԱԿԻ ԱՊԱՀՈՎՄԱՆ ՕՊՏԻՄԱԼ ԿԱՐԳԸՆԹԱՑ

ՍԵՂՄԱԳԻՐ

ԵՐԵՎԱՆ 2013

INSTITUTE OF INFORMATICS AND AUTOMATION PROBLEMS OF NAS RA

Hamid Khosravi

OPTIMAL PROTOCOL FOR DESIRED LEVEL OF COVERAGE AND CONNECTIVITY IN WIRELESS SENSOR NETWORKS
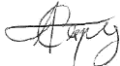
AUTHOR'S ABSTRACT

YEREVAN 2013

Ատենախոսության թեման հաստատվել է ՀՀ ԳԱԱ Ինֆորմատիկայի և ավտոմատացման պրոբլեմների ինստիտուտում:

Գիտական ղեկավար՝   ֆիզ. մաթ. գիտ. դոկտոր   Լ.Հ.Ասլանյան

Պաշտոնական ընդիմախոսներ՝   տեխ. գիտ. դոկտոր   Գ.Հ.Խաչատրյան
                             ֆիզ. մաթ. գիտ. թեկնածու   Հ.Ա.Սահակյան
Առաջատար կազմակերպություն՝ Երևանի պետական համալսարան

Պաշտպանությունը   կայանալու   է 2013թ. Դեկտեմբերի 10–ին ժ. 15:00-ին, ՀՀ ԳԱԱ Ինֆորմատիկայի և ավտոմատացման պրոբլեմների ինստիտուտում գործող 037 «Ինֆորմատիկա և հաշվողական համակարգեր» մասնագիտական խորհրդի նիստում (հասցեն՝ 0014, Երևան, Պ. Սևակի փ. 1)

Ատենախոսությանը կարելի է ծանոթանալ ԻԱՊԻ-ի գրադարանում:
Սեղմագիրն առաքվել է 2013թ. Նոյեմբերի 10-ին:

Մասնագիտական խորհուրդի գիտական քարտուղար,
ֆիզ. մաթ. գիտ. դոկտոր   Հ. Գ. Սարուխանյան

The subject of the dissertation has been approved in Institute Informatics and Automation problem of NAS RA

Scientific advisor: Doctor of phys. math. sciences   L.H. Aslanyan

Official opponents: Doctor of technical sciences   G.H.Khachaturyan
                                 Candidate of phys. math. sciences   H.A.Sahakyan
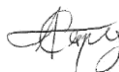Leading organization: Yerevan State University

The defense will take place on 10 December, 2013 at 15:00 in Institute for Informatics and Automation Problems of NAS RA, during the session of the special council "Informatics and computer systems" (address:1 P. Sevak str. 0014, Yerevan).

The dissertation is available at the library of the institute.
Author's Abstract is sent on 8 November, 2013

Scientific secretary of the specialized council,
Doctor of phys. math. sciences   H. G. Sarukhanyan

CHARACTERIZATION OF THE THESIS

Actuality of the subject. Recent developments in wireless communication and embedded computing technologies have led to the advent of wireless sensor network technology. Hundreds of thousands of these micro sensors can be deployed in many areas including health, environment and battlefield in order to monitor the domain with desired level of accuracy. When wireless sensors are deployed in an area, the lifetime of the network should last as long as possible according to the original amount of energy. Therefore, reducing energy consumption in WSNs is of primary concern. Wireless sensors generally consist of three main part, communication subsystem, processing subsystem and sensing subsystem, normally communication subsystem consume most of energy of a typical sensor this is as much energy that we can neglect the processing energy consumption. Energy consumption of the sensing subsystem depends on specific sensor type. Usually it's also much less than communication subsystem. Therefore in energy conservation scheme we generally consider only communication and sensing subsystem and neglect the processing subsystem. We can categorize energy conservation schemes in three main category, duty-cycling, data-driven approaches and mobility management. In duty-cycling we consider different approach to minimize communication subsystem energy consumption; in data-driven approach we consider ways to minimize sensing subsystem energy consumption such as data aggregation or energy efficient data acquisition. While the nodes are mobile, or we have some mobile nodes among sensors, we can use some mobility management techniques to reduce power consumption. In this thesis, we focus on duty-cycling; duty-cycling is divided to two main categories which are topology control and power management. Topology control is referred to using node redundancy for sensing or communication subsystem when we have more node than sufficient, to achieve desired level of connectivity or coverage in the network. Some of the work in the area of topology control has considered only connectivity of the network in the other hand some of them considered only coverage of the network and some considered both coverage and connectivity into account, some of these algorithm are centralized algorithm, and some are distributed. Centralized algorithm is a type of network protocol when all nodes data are gathered in a main node and node sleep scheduling is decided in this main node, then the schedules are send to the network nodes; in the other hand in distributed protocol each node decide by itself to remain active or not, or in some cases nodes sleep scheduling is done by local cluster heads. In this thesis, our focus is the coverage problem that occurs as the result of random and dense deployment of sensor nodes. The coverage problem indicates a disorganized placement of sensor nodes with plenty of sensing redundancy. It challenges the wireless sensor network in terms of energy and sensing efficiency. We have proposed a node scheduling solution that solves the coverage and connectivity problem in sensor networks in integrated manner. In this way, we divide network life time to some specified number of rounds and in each round we generate a coverage bitmap of sensors of the domain and based on this bitmap it will be decided which sensors remain active or go to sleep. We check the connection of the graph by using Laplacian of adjacency graph of active nodes in each round. Also by using Minkowski technique in generation of coverage bitmap, the network will be capable of producing desired percentage of coverage. We define the connected coverage problem as an optimization problem, which is NP-compete, and therefore, we seek a solution for the problem by GA Heuristic optimization methods in centralized fashion.

Objectives of the work are.

The main **goals** of this thesis are:

- ☐ Increasing life time of the sensor networks by an integrated coverage and connectivity topology control.
- ☐ Producing desired percentage of coverage over monitoring area to increase network life time.
- ☐ Increasing robustness of sensor network node failure.

The **presented statements** are:

- ☐ The Genetic Algorithm heuristic optimization method to solve the optimization problem at hand.
- ☐ We have used property of adjacency graph of the network to ensure connectivity.
- ☐ We have devised a method based on bitmap image of covered area of each sensor to estimate the percentage of covered domain by using Minkowski technique.
- ☐ We have used C++ language, LAPACK, BLAS, Armadillo and Genetic Algorithm Utility Library (GAUL) Packages and also MATLAB at some part to implement the presented algorithm.

Objective of the research.

To reach the specified goals, following **tasks** could be solved:
- ☐ Presenting node scheduling mechanism as constraint optimization problem.
- ☐ Devising a mechanism to identify percentage of domain which is covered by active sensors.
- ☐ Devising a mechanism to ensure the connectivity of the network.

Methods of research.

The **methods and research** used in the investigation are as follows:

First we have presented a formal representation of the problem as an optimization problem then we have solved this problem by Genetic Algorithm Heuristic method. The methods and resources used in the investigation are as follows: We have used Genetic Algorithm heuristic optimization method to solve the optimization problem at hand. We have used property of adjacency graph of the network to ensure connectivity. We have devised a method based on bitmap image of covered area of each sensor to estimate the percentage of covered domain. We have used C++ language, LAPACK, BLAS, Armadillo and Genetic Algorithm Utility Library (GAUL) Packages and also MATLAB at some part to implement the presented algorithm.

Scientific novelty

The **novelties** of this thesis are:
- ☐ The node-scheduling algorithm presented in this thesis ensures coverage and connectivity of

the sensor network in an integrated fashion.

- □ We have not found any record of using properties of adjacency graph of the sensor network for checking connectivity of the network in the literature.
- □ We have presented a novel idea based on Minkowski technique in generating a bitmap image of covered area for estimating desired percentage of coverage over monitoring domain.
- □ Many researchers estimate connectivity of the network based on coverage to offer integrated coverage and connectivity, therefore there is a limitation on ratio of sensing radius to communication radius of sensors; we have released such limitation in our new method.

Practical significance

The **significant points for practices** are:

- □ When wireless sensors are deployed in an area, there is usually no access to sensors to maintain or recharge, therefore the lifetime of the network should last as long as possible.
- □ Many researchers estimate connectivity of the network based on coverage to offer integrated coverage and connectivity therefore there is a limitation on ratio of sensing radius to communication radius of sensors; we have released such limitation in our new method.
- □ We have tried to find the maximum possible lifetime of the network by presenting this problem as a constraint optimization problem.

Practical implementation. We have studied most of the related work in this area and also different sleep scheduling techniques, further, we have implemented two of famous methods of providing Coverage and Connectivity, CCP and SPAN, CCP is distributed algorithm which capable of providing desired level of K_s-coverage and SPAN is also distributed algorithm which is capable of providing desired level of K_c-connectivity. We have simulated some networks of small, medium and large sizes and we have tried to find optimum node scheduling pattern to optimize network lifetime. Our centralized algorithm has been implemented with GA-Toolbox in MATLAB. For large size network we have developed a C++ code which uses Armadillo package (which itself internally uses LAPACK and BLAS) for eigenvalue computation and Genetic Algorithm Utility Library (GAUL) for optimization.

The following topics are presented to defense the thesis: Introduction; Methodology; Problem Definition; Coverage constraint; Connectivity constraint; Energy constraint; Implemented Algorithm; Postulation; Simulation Results.

Approbation of the thesis. The main results of the thesis have been presented and discussed at:

- ➢ International conference on Future Networks 7 to 9 March 2009 Bangkok, Thailand 2009(IEEE),
- ➢ International Conference of Computational Intelligence and Intelligent Systems Proceedings of the World Congress on Engineering 2009, WCE 2009, July 1 - 3, 2009, London, U.K.(IEEE),
- ➢ 3rd International Conference on Computational Intelligence-Modeling & Simulation, CIMSim2011 - Langkawi / Malaysia (IEEE),

➢ Scientific seminar of Institute for Informatics and Automation Problems, National Academy of Science, July 12,2012,Yerevan, Armenia.

Publications. Five scientific articles are published on the materials and result of the thesis; the list is presented at the end of the abstract.

The structure and volume of the work. Material results of this thesis which includes 132 pages, 13 tables and also 31 figures, **were published** in 5 scientific publications and **were reported** in IEEE 2011, institute seminar and Azad Abhar University 2011, Sama University 2011 and Elmikarbordi University workshop 2011.

CONTENTS OF RESEARCH

Introduction, which describes the actuality of the subject, objectives of the work, scientific novelty and practical significance of the work as well as the information about the practical implementation of the results.

Chapter 1 is dedicated to an overview of Introduction, Related Works, Problem Definition. It consists of 5 sections.

Section 1-1 gives an overview about different type of sensor networks taxonomy and requirements of sensor networks identifiers, sensor networks technologies, sensor networks operational mode and sensor networks applications.

Section 1-2 In this section, we reviewed main relevant research paper considering topology control and we Presented pros and cons of each method. And then in the same context, we proposed a PhD subject aiming at studying sleep scheduling topology control techniques to maximize the wireless sensor network lifetime, desired level of coverage (K_s-coverage) and connectivity (K_s-connectivity) will be considered in our work. The goal is to devise a technique to have a distributed optimal or sub-optimal algorithm. Also we took power management technique into account and we studied the effect of this feature on our algorithm. Finally, we evaluated the performance of this approach and compared it with existing ones.

Section 1-3 In this section, we defined our problem and we gave a formal representation of problem that should be solved so that the connected-cover problem as an optimization problem, which should be solved in centralized fashion, subjected to following type constraints (details are given below):

$$\forall p \in A, \sum_{s_i \in S_s} \delta_i(p) \geq K_s \quad \& \quad G_c = (S_c, E_c) \text{ is } K_c\text{-Connected}$$

Additionally to be operational, the network requires that:

$$\forall S_i \in S_a \exists S_j \in S_c \text{ such that } d(S_i, S_j) \leq R_c.$$

We assume that all active nodes participate in routing therefore:

$$S_a = S_s = S_c, \quad \sum_{k=1}^{r}(X_{ik} + (1 - X_{ik})\gamma)t_k e \leq E_i,$$

where e energy consumption of node in watt is, E_i is total energy of node i, and γ is ratio of energy consumption of a node in sleep mode to energy consumption of node in active mode.

Summary of chapter 1 is given in **section 1-4** and Bibliography of chapter1 is given in **section 1-5**

Chapter 2 consists of introducing some aspects of graph theory, which is useful in evaluating the connection of the sensor networks. Summary of chapter2 is given in **section 2-9** and Bibliography of chapter2 is given in **section 2-10**

Chapter 3 consists of some attributes of Numeric Computation used in this thesis such as:

☐ LAPACK and BLAS	☐ Armadillo (C++ library)

Summary of chapter3 is given in **section 3-3** and Bibliography of chapter3 is given in **section 3-4**

      Chapter 4: Our methodology is presented to tackle connected cover problem in sensor networks, we presented the problem as a constrained optimization problem, also we introduced each of problem constrains in mathematical form next we showed how to solve this optimization problem. The method we presented here is straightforward and it can be solved by any general optimization method. We have decided to use Genetic Algorithm as optimization method, and we have used one of publicly available tools for this purpose.

      In section 4-1 we assumed a set of sensors $S = \{s_1, s_2, ..., s_i, ..., s_n\}$ in a 2D plane and a target area A (basically supposed to be convex), and further assume that each sensor s_i is located at position (x_i, y_i), and has sensing radius R_s (the same for all sensors) therefore s_i can detect events located at maximum distance R_s to it (we have assumed a binary disk model for sensing) and so the S can cover or partial cover the target plane area A. We make no assumption regarding the ratio of sensing radius R_s to Communication (transmission) radius R_c that reflects the radio power of a sensor node. A particular point p in area A is said to be covered by s_i if it's within sensing range a_i of s_i, Euclidean distance $d(p, (x_i, y_i)) \leq R_s$. Given an integer K_s, a point p is said to be K_s-covered if it covered at least by K_s sensors. The sensor network $S_s \subseteq S$ is said to be K_s-covered if all points in area A are K_s-covered. If we define a membership function $\delta_i(p)$ such that $\delta_i(p) = 0$ if $p \notin a_i$ and $\delta_i(p) = 1$ if $p \in a_i$ we can represent K_s-covered sensor network by condition:

$$\forall p \in A, \sum_{s_i \in S_s} \delta_i(p) \geq K_s.$$

We define communication graph $G_c = (S_c, E_c)$ of network S_s, S_c, A, where S_c is the set of sensors participating in routing and E_c is the set of edges such that an edge exists between any two nodes of S_c - when they can communicate with each other. The degree of node $u \in S_c$ is defined as the number of its one-hop neighbors. The graph G_c is said to be K_c-connected if for any pair of nodes in S_c there exist at least K_c mutually node -disjoint paths connecting them.

K_c-Connected, K_s-Covered sensor network ((K_c-K_s)-CC): For set of sensors S and area A with sensing sensor set S_s and routing sensor set S_c where each sensor s_i has coverage area a_i and connection is symmetric (2 side), the sensing field/network is said pre-(K_c-K_s)-CC if A is K_s-covered by S_s and G_c is K_c-connected.Consider a particular set S_s of active sensor nodes and the set S_c of coordinator nodes, therefore $S_s \subseteq S$, and let $S_c \subseteq S_s$, and then area A is (K_c-K_s)-CC if: $\forall p \in A, \sum_{s_i \in S_s} \delta_i(p) \geq K_s$ & $G_c = (S_c, E_c)$ is K_c-Connected.

Additionally to be operational, the network requires that: $\forall s_i \in S_s \exists s_j \in S_c$ such that $d(s_i, s_j) \leq R_c$.

To simplify the problem at hand we assume that all active nodes participate in routing therefore: $S_a = S_s = S_c$.

After all descriptions brought above we need a set theoretic model of our problem so that it allows software coding and application. In this way we first introduce binary variables X_i to code the sensor state of activity. We define $X_i, i = \overline{1, n}$ such that X_i=1 if $s_i \in S_s$ otherwise X_i=0, so that binary vector $X = (X_1, X_2, \dots, X_n)$ forms the picture of sensor activities. We will apply to the Minimum Connected Sensor Cover Problem (MCSC) that is in fact a collection of problems similar to the following description:

Given a sensor network N over area A, the problem is to find $(K_c$-$K_s)$-CC subset S_a with minimum number of active nodes, $\min \sum_{i=1}^{n} X_i$.

The minimal selection of subset S_a will result in maximizing network lifetime. But we can further define optimization problems in term of network lifetime taking into account the difference of work intensity between the sensing and coordinating nodes. Further, given a collection Ξ of r $(K_c$-$K_s)$-CC subsets S_a, introduce rounds of activities of S_a and define the time duration t_k for this. The energy conservation problem requires maximizing the total time:

$$\max \sum_{k=1}^{r} t_k. \qquad (1)$$

Given $\Xi = \{ S_a \}$. S_a obey the conditions: $\forall p \in A, \sum_{s_i \in S_a} \delta_i(p) \geq K_s$ and $G_c = (S_a, E_c)$ is K_c-Connected Ξ Obey the energy maximization criteria:
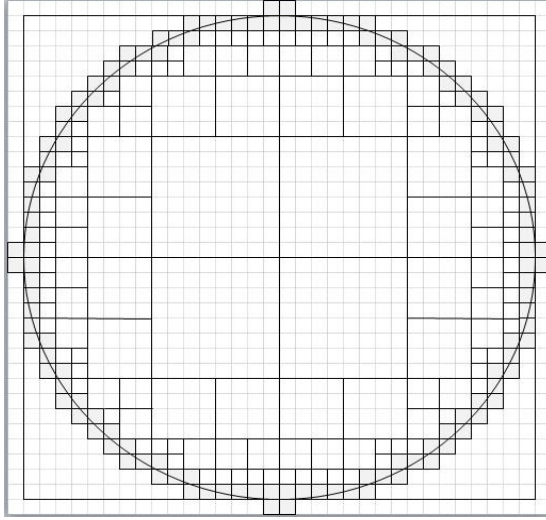
$$\sum_{k=1}^{r}(X_{ik} + (1 - X_{ik})\gamma)t_k\, e \leq E_i, \qquad (2)$$

Where e the energy consumption of a node in a time unit in watt is, E_i is total energy of node i, and γ is ratio of energy consumption of a node in sleep mode to energy consumption of node in active mode.

Section 4-2 shown that the optimization problems defined in the previous section are closely related to: combinatorial set cover problem, and to integer linear programming problem. Both these problems are known NP-compete/hard and therefore we will seek a solution for the problems by Heuristic optimization methods. We will consider centralized fashion vs. decentralized, when all information supposed existing in some point, sink ready for algorithmic analysis. Our model is in three components: a coverage problem in general terms of set cover that is still far from practical implementation, a graph connectivity check, to be completed by a related algorithmic solution, and an IP energy optimization problem with these constraints, which is to be solved in some way – sub-gradient optimization, random search or rounding, etc. The nature of wireless sensor network and the scalability requirement to these algorithms raise the issue of distributed algorithms. This also deals with node failure issue to set a more robust network. The distributed algorithm may be a sub-optimal one but we are able check the results comparing them with centralized heuristics finding suitable deterministic bounds for the algorithms both in terms of their runtime, communication overhead, and coverage and connectivity accuracy.

In subsection 4-2-1 we developed a centralized heuristic to solve the problem. As discussed earlier, the objective function is in (2) here we can consider number of rounds r and timedurations of rounds t_k is independent variables in general, but for simplicity we will assume a fixed number of rounds in an experiment. Let durations t_k choose any appropriate values. Optimization of criteria (1) is under the constraints:

Figure (4-1): Recursive split of rectangles

$$\forall p \in A, \sum_{s_i \in S_s} \delta_i(p) \geq K_s \qquad (3a)$$

$$G_c = (S_c, E_c) \text{ is } K_c\text{-Connected} \qquad (3b)$$

$$\sum_{k=1}^{r}(X_{ik} + (1 - X_{ik})\gamma)t_k e \leq E_i \qquad (3c)$$

The constraint number (3a) is coverage constraint against one particular sensor subset $S_s \subseteq S$. Constraint number (3b) is about connectivity of a particular sensor subset $S_c \subseteq S_s$. Further $S_s = S_c$ or connection of nodes of S_s to S_c is assumed. The last constraint (3c) requires a collection of r different sensor subsets, each with property of (4a) and (3b). So these subsets might be either variables or can be determined in a preliminary separate stage of the optimization procedure. We now explain how we compute each constraint and how we integrate them into the general procedure.

In subsection 4-2-2 we generated a bitmap of the domain. Then, by using this bitmap, we calculated coverage percentage as follows:

We consider a transformation of constraint (3a) into the discrete domain generating a bitmap structure over the area A. We consider 2 sub cases of digitization separately.

a) <u>**Single Sensing Disc Digitization**</u>

Consider a sensing disk a_i. Build the so-called quad tree. Start (root) from the bounding rectangle to a_i. Then split the rectangle into four smaller rectangles of the equal size (creating 4 leafs). This procedure might be recursively applied to all leafs in the tree until new leaf (recursive) rectangles reach certain size. Smaller rectangles in the picture approximate circle's border. They have 1, 2 or 3 corner points inside the

circle. Part of these rectangles form an inner area of the circle. These are rectangles having all 4 corners in circle. Milky color does not belong to the circle and might be removed from consideration. They have 0 vertices in the circle.

In order to make a decision if given leaf rectangle should be split to approximate the circle; we need to keep a functiont, which for a given rectangle r will return how many of its corners belong to the circle. There are obviously five cases mentioned above:

$$t(r) = 4 \quad \text{– Rectangle belongs to the sensing disk.}$$

$$t(r) = \overline{1,3} \qquad \text{– Rectangle intersects the circle.}$$

$$t(r) = 0 \qquad \text{– Rectangle is outside the disk.}$$

Function t is quite simple: $t(x_1, y_1, x_2, y_2) = \text{in}(x_1, y_1) + \text{in}(x_1, y_2) + \text{in}(x_2, y_2) + \text{in}(x_2, y_1)$, where $\text{in}(x, y) = 1$ if $x^2 * y^2 \leq R_s^2$, and 0 otherwise. $t(r) = 4$ Guarantees that rectangle r is covered by sensor s_i. Other cases provide partial cover which the given digitization scheme is unable to utilize. Approximation accuracy, determined through the number of rectangles intersecting with circle, will be considered below.

b) Integrated Digitization

Assume A is a rectangular area of length L_x and L_y. We divide this area to cells with dimension $\Delta_x *$ Δ_y and each cell a_{pq} (see Figure (4-2)) will be coded by its center, or the set of corner vertices. Simply let this will lead to $u * v$ cells in the domain so that $L_x = v \Delta_x$ and $L_y = u \Delta_y$ .We will create a $u * v$ bit matrix C such that each bit of the matrix c_{pq} will associate to the cell a_{pq} in real domain (see Figure (4-3)). In this way, each cell represent a small area in monitored domain therefore by increasing or decreasing these virtual cells dimension we can desirable lesser or higher accuracy for calculating the coverage.
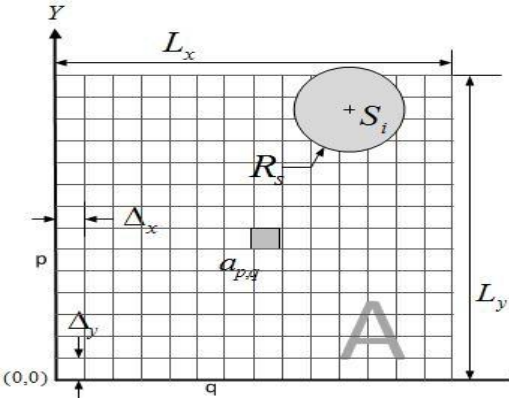

Figure (4-2): Area A divided to small cells
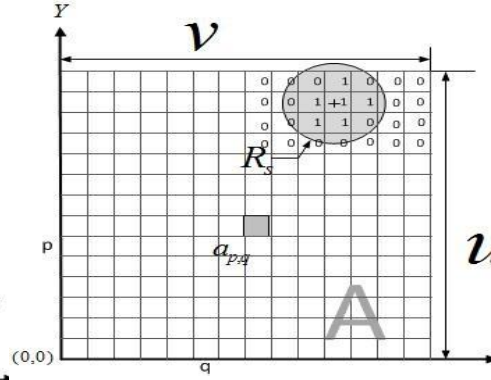
Figure (4-3): Matrix C represents covered area in Domain A

Next we will calculate the distance between each cell characteristic points and the sensor nodes, if distance from center of a cell to any active sensor was lower than sensor coverage radius, this cell will be marked intersecting with sensing disk. Further if all 4 angular points of cell are closer to the sensor than

the sensing radius then the cell is obviously covered. Depending on this coverage, the bit associated to the cell considered in Matrix C_i will become one.In this case we define the function $t(r)$ using the cell center. Let $(x_{a_{pq}}, y_{a_{pq}})$ is the position of the center of cell a_{pq}. Then, for sensor s_i:

$$t(a_{pq}) = \sum \text{true}\left(\left(\left|x_{s_i} - x_{A_{pq}}\right| \pm \frac{dx}{2}\right)^2 + \left(\left|y_{s_i} - y_{A_{pq}}\right| \pm \frac{dy}{2}\right)^2 \leq R_s{}^2\right). \qquad (4)$$

Matrix C appears as disjunction of all single sensor disc coverage's, achieved by the single sensing disk digitization model (4). The real coverage matrix is some $C_{(r)}$ so that $C \leq C_{(r)}$. The same time, if to consider the matrix of intersecting rectangles, $C_{(i)}$, then $C_{(r)} \leq C_{(i)}$. Further we develop analytics of approximating $C_{(r)}$ by C and $C_{(i)}$.

c) Terms of Minkowski geometry

In this section we continue with algorithmic analysis of the digitization process. Digitization through the small rectangles brings the continuous problem to the combinatorial domain but with this an error is introduced that appear in two levels: a) single sensing disk boarder coverage error, and b) error of missing rectangles that are covered in an integrity effort of several sensors. This is the cost of digitization but such error needs to be evaluated.

Algorithmically we construct a binary matrix for each sensor

$$\forall s_i, c_{i,pq} = \begin{cases} 1 & \text{if } \left(\left|x_{s_i} - x_{A_{pq}}\right| + \frac{dx}{2}\right)^2 + \left(\left|y_{s_i} - y_{A_{pq}}\right| + \frac{dy}{2}\right)^2 \leq R_s{}^2. \\ 0 & \text{Otherwise.} \end{cases}$$

This process is repeated for each active sensor and finally all cells accumulate their associated bit values in an integrated matrix C, and if the value for certain cell is not set to one in the matrix C then in algorithmic level it declared uncovered by the given set of sensors. Bit value zero means partial cover or no cover by all sensors but in real picture several partial cover can complement each other providing complete cover of a cell (error (b)). The guaranteed coverage ratio provided by algorithm is calculated as follows: $\qquad \text{Coverage\_by\_alg} = \frac{\sum_{p=1}^{u}\sum_{q=1}^{v} C_{pq}}{u*v}$.

Our analytics applies the well-known Minkowski technique of approximation of convex bodies. This complements the algorithmic construction in two parts so that gives guaranteed approximation accuracy in analytic level.In terms of point a) structures suppose that coordinate axes are placed at the sensor position (x_i, y_i). We will consider the general case of convex figures that approximate the sensing disc. The key element is the use of recursive rectangles that are intersecting with the boundary of sensing disc a_i. Denote the body composed of all internal recursive rectangles by R_i. Let R_o is extension of R_i by the rectangles catting the sensing circle, and let R_{co} is the convex closure of R_o. $R_i \subset R_o \subset R_{co}$ in set theoretical domain.
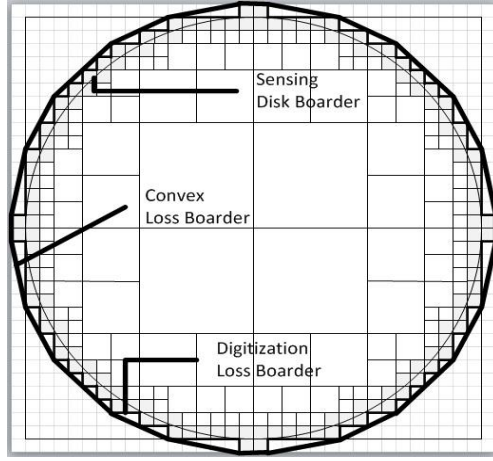
Figure (4-4): Approximation by recursive rectangles: Sensing disk boarder by a_i, Digitization loss boarder by R_{brd}, Convex shell R_{cnv}.

d) Approximation of digital coverage

Now we consider sensing disc a_i as the base convex figure. Other structures that we need are as R_i, R_o, R_{ci}, R_{co} see Figure (4-4). Without loss of generality we suppose that $\Delta_x = \Delta_y$, and then the diagonal of recursive rectangle become equal to $\rho = \sqrt{2}\,\Delta_x$. In zero step $\Delta_x = L_x = L_y = L$. In k-th step $\Delta_x = 2^{-k}L$. Approximation error of digitization can be estimated in different ways. One of the possible schemes is as follows. Theoretically the sensing surface is $O(a_i) = \pi r^2$. The digitized coverage equals $O(R_i)$. So the error is equal to $O(a_i \backslash R_i)$, and it hardly depends on k and position of (x_i, y_i). We do not hope to describe that error in exact terms and we will try to approximate the error. First we pay attention to an evident chain of relations: $a_i \backslash R_i \subset R_o \backslash R_i \subset R_{co} \backslash R_i$.

Now consider the related support functions as follows:

$$h_{R_{ci}} < h_{R_{co}} < h_{R_{ci}} + \rho \le h_{R_{ci}} + \rho \frac{h_{R_{ci}}}{r - \rho} = h_{R_{ci}}\left(1 + \frac{\rho}{r - \rho}\right) = h_{R_{ci}}\frac{r}{r - \rho}.$$

In terms of surfaces $\frac{O(R_{co} \backslash R_{ci})}{O(R_{ci})} \le \left(\frac{r}{r - \rho}\right)^2 - 1 = \frac{\rho(2r - \rho)}{(r - \rho)^2} \sim \frac{2\rho}{r} = \frac{\sqrt{2}L}{2^k r}$. Proper selection of k provides the desired approximation.

e) Guaranteed coverage domain in terms of a lesser sensing radius

Another simpler interpretation is in terms of coverage radiuses. Consider the radius $r - \rho$. It is evident that sensing disc of this radius is complete covered through the digitization map. The mining is that real sensing radius is r, energy consumption is in accord to this, but digitization brings some losses and then it guarantees only that the radius $r - \rho$ is covered completely. The loss can be computed and controlled similarly to the case d).

Subsection 4-2-3 has considered the connectivity constraint as follows:

For communication graph $G_c = (V_c, E_c)$ of the network to be connected the Laplacian of this graph should have just on zero eigenvalue, therefore in each round we will construct the laplacian of active nodes of the network and check to see if it's a connected graph or not. By definition the laplacian of graph is formed as follows:

$$L(G)_{pq} = \begin{cases} d_p, & \text{if } p = q \\ -1, & \text{if } p{\sim}q (p \text{ is adjacent to } q) \\ 0, & \text{Otherwise.} \end{cases}$$

If we sort eigenvalues of this matrix as follows: $\forall i, 0 \leq \lambda_i \leq 2\Delta$. We know that λ_0 is always zero, therefore we check for λ_1. In this way we will have one constraint in each round of network run time.

In subsection 4-2-4 Energy constraint has been attend so that when a node is in active state it will consume a power for sensing and communication, and when it goes to sleep it will consume small amount of energy, but total amount of energy that each node consume during network life time could not exceed its initial energy. We have written this constrain previously as follows:

$$\forall s_i \in S, \sum_{k=1}^{r} (X_{ik} + (1 - X_{ik})\gamma)t_k\, e \leq E_i$$

Therefore for each node of the network we will have one such constraint. Overall assuming that we have r round and n node in the network, we will have $(n + 1) * r$ independent variable to optimize and there is $r * n$ inequality constraint and r equality constraint.

We know that this is a NP-complete problem therefore we can use any heuristic optimization to solve this problem. For the present time we will use Genetic Algorithm to find the maximum life time of the network.

In section 4-3 we have implements our centralized algorithm. we have used GA-Toolbox in MATLAB, the flowchart of the algorithm is shown in figure (4-5). For large size network we have developed a C++ code which uses Armadillo package (which itself internally uses LAPACK and BLAS) for eigenvalue computation and Genetic Algorithm Utility Library (GAUL) for optimization. In the next section we simulate some network and we will discuss the results.

Summary of chapter 4 is given in **section 4-4** and Bibliography of chapter4 is given in **section 4-5.**

Chapter 5 shows some simulated networks of small, medium and large sizes and we have tried to find optimum node scheduling pattern to optimize network life time. We have shown that small decrease to domain coverage percentage will result in large increase of network life time which may be very beneficiary in some sensor network applications and that coverage of all points of monitoring area is not critical. Also we have shown that increasing number of deployed nodes in monitoring area will increase the network life time and, although this relationship is not linear, it's very close to linear one. It should be noted that we have tried to find maximum life time extension which is possible as a result of slight decrease in percentage of monitored area by selecting disjoint sets of sensors at each round of network life time. But in actual implementation of distributed protocol, this level of optimization may not be

possible and thus we expect that in that situation network life time will be less than results we obtained in these simulations. But still these results help us in evaluating the performance of any distributed
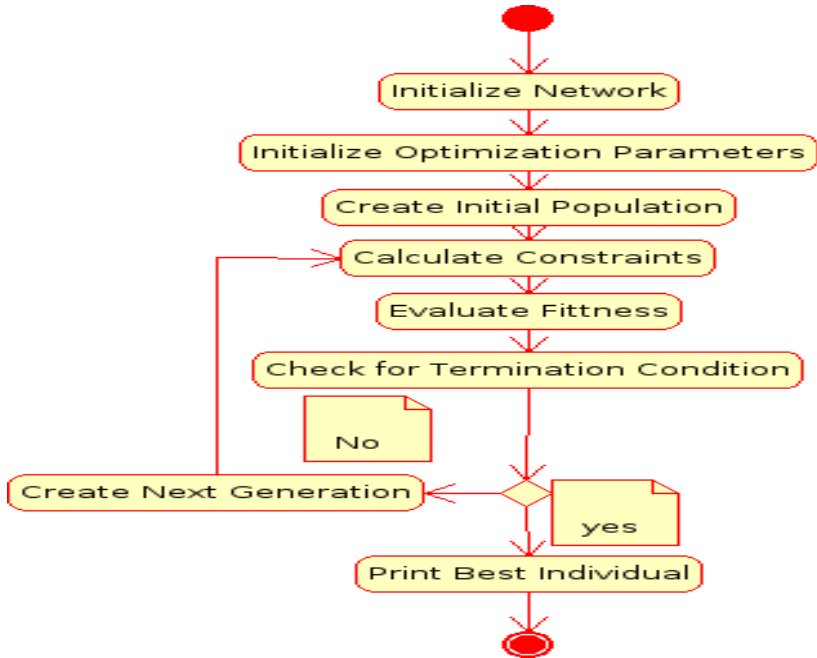
Figure (4-5): Flow chart of implemented algorithm.

protocol which may be implemented for this purpose later. First we have used MATLAB software to calculate eigenvalues of the Laplacian and also to optimize the problem with GA Toolbox provided in MATLAB. But because the MATLAB is to slow for large size network we have developed a C++ code which uses Armadillo package (which itself internally uses LAPACK and BLAS) for eigenvalue computation and Genetic Algorithm Utility Library (GAUL) for optimization.

In section 5-1 illustrates the algorithm functionality we will model a small size network. For this purpose we consider a network of 5 nodes at each corner of $100 * 100$ rectangular domain and in the middle of the domain, further we will assume sensing radius of network nodes $R_s = 100$ and communication radius of each node $R_c = 2.5R_s$, Initial energy of each node is considered as 3J and ratio of sleep power consumption to active power consumption gamma=0.1.

In section 5-2 we consider three networks of 16, 25 and 50 nodes uniformly distributed over the area of $100 * 100$ m^2. Further we will assume sensing radius of network nodes R_s=50 m and communication radius of each node R_c=2R_s, Initial energy of each node is considered as 30J and ratio of sleep power consumption to active power consumption gamma=0.1 complete parameters of this network are listed in table (5-2) and GA Optimization parameters of this example are listed in table (5-3).
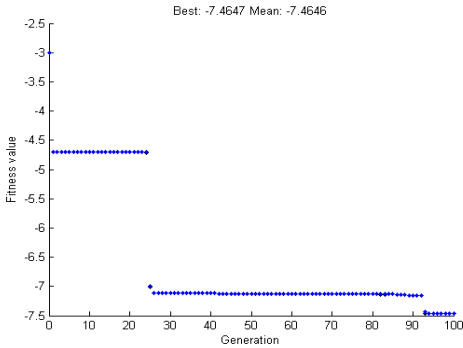
14

Best: -7.4647 Mean: -7.4646

Figure (5-1): the fitness function
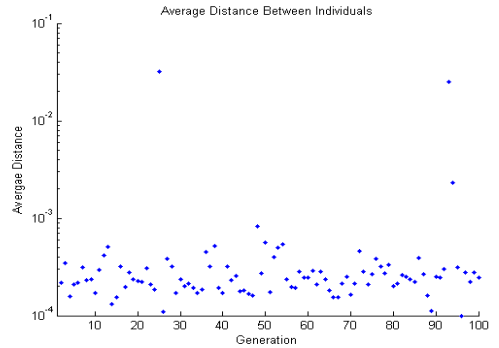

Average Distance Between Individuals

Figure (5-2): shows the average distance between members of ech generation

Figure (5-1) shows the fitness function of this example vs. number of generation, and figure (5-2) shows the average distance between members of population in each generation. Figure (5-3) shows a histogram of last generation. In figure (5-4) we have the same graph for another run, because GA is random algorithm each run of the program will produce different set of population but all this population will finally converge to the minimum fitness.
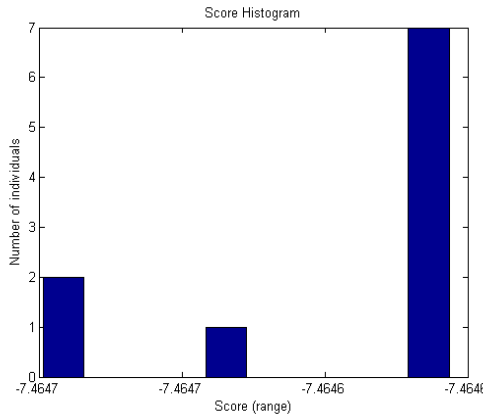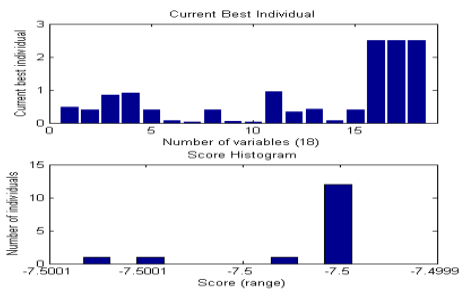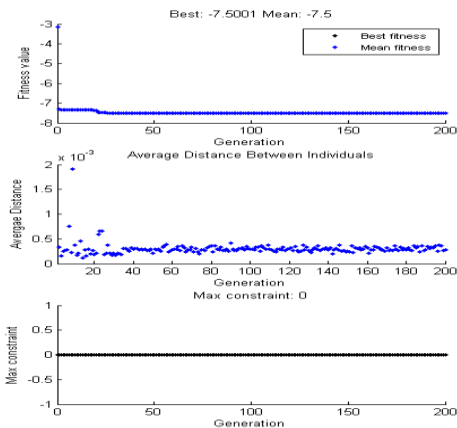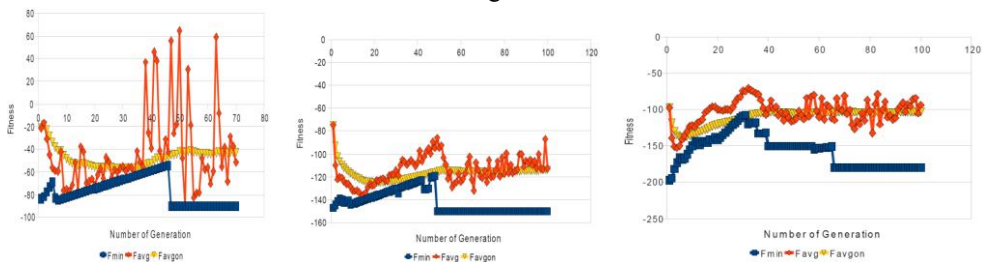

Score Histogram

Figure (5-3): histogram of last generation

Figure (5-4): fitness function vs. number of generation, average distance between members of population in each generation, max constraint value vs. number of generations, histogram of last generation

Figure (5:5-7): the fitness function for 16 node network 100%, 90%, and 80% coverage, respectively

Figure (5-5) to (5-7) shows the fitness function of this network vs. number of generation for 16 nodes network when the desired coverage percentage is 100%, 90% and 80% respectively. In these figures F_{min} is the minimum fitness and F_{avg} is the average of fitness in each generation, also F_{avgon} is average of F_{avg} from the first generation until current generation. It can be noted in figure (5-5) to (5-7) that F_{avgon} after fast drop in initial generation's increases steadily with number of generations but at the same time F_{min} and F_{avg} have more random pattern. F_{min} is the best individual at each generation, and at the end of optimization this individual will be reported as a best result.

In figure (5-8) we have plotted network life time vs. desired percentage of coverage. As can be seen in figure (5-8) network life time increases when percentage coverage slightly decreases from 100 percent, but there is not linear relationship between desired percentage of coverage and network life time. The rate of increasing network life decreases with the decreases of desired percentage of coverage. Therefore the designer should choose between the more life time and percentage of coverage based on specific application of the sensor network. In figures (5-9) and (5-10) we have plotted the network life time vs.

16

percentage of coverage for 25 and 50 nodes networks respectively. It is obvious that there is a similar relationship between life time and percentage of coverage in these networks too.
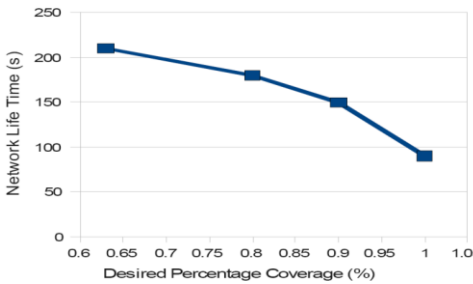

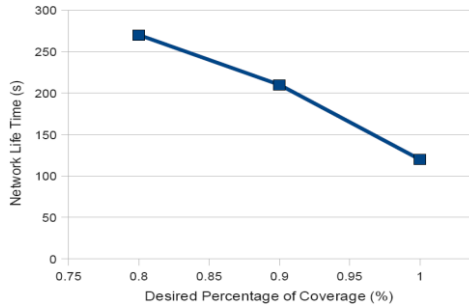Figure (5-8) network life time vs. desired coverage percentage for this 16 node network.

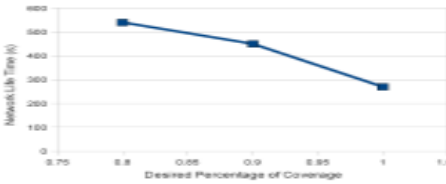**Figure (5-9)** Network life time vs. desired coverage percentage for this 25 node network.

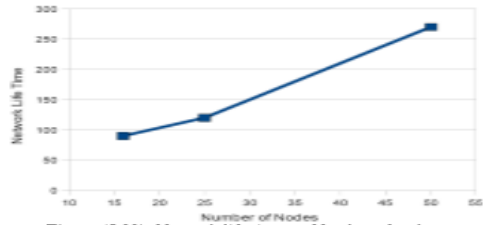**Figure (5-10)** Network life time vs. desired coverage percentage for this 50 node network.

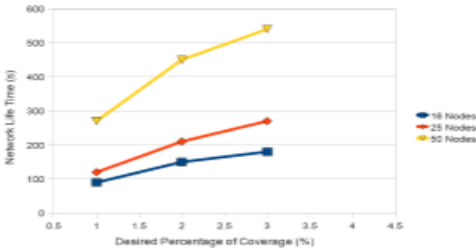**Figure (5-11):** Network life time vs. Number of nodes.

Figure (5-12): Network life time vs. desired percentage of coverage for three medium sized networks

Figure (5-13): Network life time vs. desired coverage percentage for 100 nodes network.

In figure (5-11) we have plotted the network life time versus number of deployed nodes when desired percentage coverage has been 100%. In figure (5-11) it has shown when number of deployed nodes increases the network life time also increases but the relationship may not be linear.

In figure (5-12) we have plotted the network life time versus desired percentage of coverage for all these networks in one graph it is obvious that the same pattern is repeated in all networks

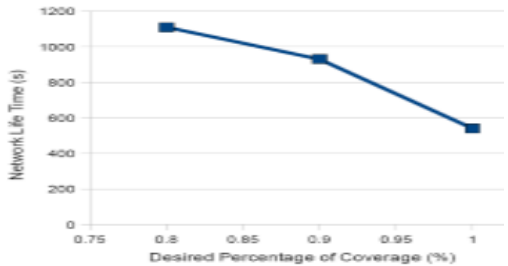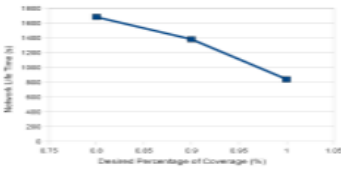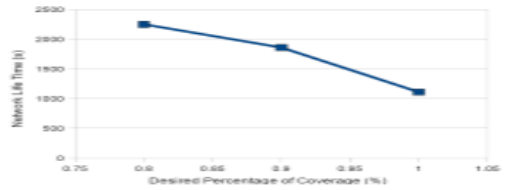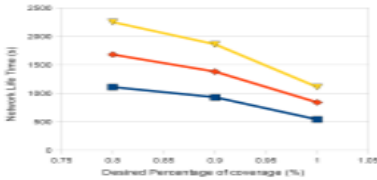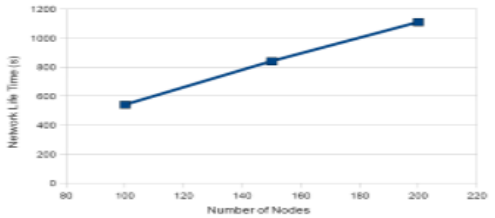**Figure (5-14):** Network life time vs. desired coverage percentage for 150 nodes network.

Figure (5-15): Network life time vs. desired coverage percentage for 200 nodes network.

Figure (5-16): Network life time vs. desired coverage percentage for 100,150 and 200 nodes network.

Figure (5-17): Network life time vs. Number of nodes

In section 5-3 we consider three dense networks of 100, 150 and 200 nodes uniformly distributed over the area of $100 * 100$ m^2. Further we will assume sensing radius of network nodes $R_s = 50$ m and communication radius of each node $R_c = 2R_s$, Initial energy of each node is considered as 30J and ratio of sleep power consumption to active power consumption gamma=0.1.

Figure (5-13) to (5-15) shown the network life time vs. desired percentage of coverage for these networks. And in figure (5-16) all these curves are plotted in the same figure for comparison. As it can be seen in figure (5-13) slight decrease in percentage of coverage from 100 percent to 90 percent will nearly doubled the network life time. In figure (5-16) it is shown that in all network decreasing the percentage of coverage will increase the network life time, and for all network this relationship is not linear and the rate of increasing network life time will be decreased with decreasing percentage of coverage. In figure (5-17) the network life time is plotted vs. number of deployed nodes. It's shown that the network life time will be increased with increasing number of deployed nodes and although this relationship is not linear it is close to linear one. In Figure 5-18 we have compared some other coverage and connectivity methods with GA optimization results. Clearly the GA method gives us the minimum number of nodes required to cover the monitoring domain with connected sensor network. As can be seen in the figure CCP requires the same minimum number of nodes as GA represents but it does not guarantee connectivity of the network and when it integrates with SPAN to produce connectivity it requires far more active nodes. In any case if we consider this optimization method as a new tool it can tell us how well a new coverage and connectivity protocol does perform. GA gives us minimum number of active nodes which is possible to cover a monitoring area with connected sensor network. And for any number of deployed nodes algorithms which are closer to GA are performing better.

Summary of chapter 5 is given in **section 5-4**

Chapter 6 consists of the Conclusion and Future Work.

In section 6-1 we have Summary of Contributions. When wireless sensors are deployed in an area usually there is no access to sensors to maintain or recharge, therefore the lifetime of the network should last as long as possible. Many researchers estimate connectivity of the network based on coverage to offer integrated coverage and connectivity therefore there is a limitation on ratio of sensing radius to communication radius of sensors. We released the ratio limit between sensing radius and communication radius which many protocols require to provide integrated coverage and connectivity. In addition we devised a mechanism for producing desired percentage of coverage over monitoring area to increase network life time and we further showed that by small decrease in percentage of covered area in monitoring domain we can increase network life time considerably. We can list some of the distinguished aspects of this work as follows:

- The node scheduling algorithm presented in this thesis ensures coverage and connectivity of the sensor network in integrated fashion.
- We have not found any record of using properties of adjacency graph of the sensor network for ensuring connectivity of the network in literature.
- We have presented a novel idea based on generating a bitmap image of covered area for estimating desired percentage of coverage over monitoring domain
- Many researchers estimate connectivity of the network based on coverage to offer integrated coverage and connectivity therefore there is a limitation on ratio of sensing radius to communication radius of sensors, but we have released such limitation in our new method.

We have tried to find the maximum possible life time of the network by presenting this problem as a constraint optimization problem. Therefore the results obtained here could be an upper band to life time extension possible by using node scheduling in topology control. In this project we have focused on Topology control duty-cycling which is referred to using node redundancy for sensing or communication subsystem when we have more node than sufficient, to achieve desired level of connectivity or coverage in the network. Our focus is the coverage problem that occurs as the result of random and dense deployment of sensor nodes. The coverage problem indicates a disorganized placement of sensor nodes with plenty of sensing redundancy. It challenges the wireless sensor network in terms of energy and sensing efficiency. We have proposed a node scheduling solution that solves the coverage and connectivity problem in sensor networks in an integrated manner. In this way we have divided network lifetime to some specified number of rounds and in each round we have generated a coverage bitmap of sensors of the domain and based on this bitmap it has been decided which sensors remain active or go to sleep. We have checked the connection of the graph by using Laplacian of adjacency graph of active nodes in each round. Also by using Minkowski technique in generation of coverage bitmap, the network is capable of producing desired percentage of coverage. We have defined the connected coverage problem as an optimization problem which is NP-compete problem and therefore we have sought a solution for the problem by GA Heuristic optimization methods in centralized fashion. We have simulated six network of medium and large size and we have tried to find optimum node scheduling pattern to optimize network lifetime. We believe that these results are theoretical band to this optimization problem

and it can be used as performance measure for distributed node scheduling protocols. Also we have shown that small decrease in domain coverage percentage will result in large increase of network lifetime which may be very beneficiary in some sensor network applications that coverage of all points of monitoring area is not critical. Also we have shown that increasing number of deployed nodes in monitoring area will increase the network lifetime and although this relationship is not linear it's very close to linear one. It should be noted that we have tried to find maximum lifetime extension which is possible as a result of slight decrease in coverage percentage of monitored area by selecting disjoint sets of sensors at each round of network lifetime. But in actual implementation of distributed protocol this level of optimization may not be possible and thus we expect that in real situation network lifetime will be less than result we obtained in these simulations. But still these results help us in evaluating the performance of any distributed protocol which may be implemented for this purpose.

Future Work is given in section 6-2.

Main results of the dissertation

- We have studied most of related work in this area and also different sleep scheduling techniques [1].
- We have implemented two of famous method of providing Coverage and Connectivity, CCP and SPAN, CCP is distributed algorithm which capable of providing desired level of K_s-coverage and SPAN is also distributed algorithm which is capable of providing desired level of K_c-connectivity [4].
- The node scheduling algorithm presented in this thesis ensures coverage and connectivity of the sensor network in integrated fashion [2].
- We have not found any record of using properties of adjacency graph of the sensor network for checking connectivity of the network in literature [1].
- We have presented a novel idea based on generating a bitmap image of covered area for estimating desired percentage of coverage over monitoring domain [5].
- Many researchers estimate connectivity of the network based on coverage to offer integrated coverage and connectivity therefore there is a limitation on ratio of sensing radius to communication radius of sensors; we have released such limitation in our new method [3].
- We have found the maximum possible life time of the network by presenting this problem as a constraint optimization problem [5].

LIST OF PUBLICATIONS ON THE TOPIC OF THE THESIS

1. Arash Dana, AmirMansour Yadegari, Ahmad Salahi, Soroush Faramehr, Hamid Khosravi, *"A new scheme for on-demand group mobility clustering in mobile ad hoc networks"* Feb. 17-20, ICACT IEEE 2008, pp.1370-1375

2. Hossein Ashtiani, Shahpour Alirezaee, seyed mohsen mir hosseini, Hamid Khosravi,*"PNR: New Position based Routing Algorithm for Mobile Ad Hoc Networks",* Proceedings of the World Congress on Engineering 2009, July 1 - 3, 2009, London, U.K., Vol I, pp. 196-200.

3. MohammadReza Heidarinezhad, Mohsen Mirhoseini, Hamid Khosravi, Azam Kazemi, *"A Connection Selection Method and Vertical Handoff in Hybrid Wireless Environment",* International Conference on Future Networks, IEEE Computer Society 2009, pp. 161-165.

4. Hamid Khosravi, Levon Aslanyan,*"SOCCP: Self Organize Coverage and Connectivity Protocol",* 2011 Third International Conference on Computational Intelligence, Modeling & Simulation, Malaysia, IEEE Computer Society, 2011, pp. 317-322.

5. Hamid Khosravi *"Optimal Node scheduling for Desired Percentage of Coverage in Wireless Sensor Networks",* Wireless Sensor Network Journal, 2012, No 4, pp. 127-132 doi:10.4236/wsn.2012.45018 Published Online May 2012 (http://www.SciRP.org/journal/wsn)

Համիդ Խոսրավի

ԱՆԼԱՐ ՍԵՆՍՈՐԱՅԻՆ ՑԱՆՑԵՐՈՒՄ ԾԱԾԿՈՒԹԻ ԵՎ ԿԱՊԱԿՑՎԱԾՈՒԹՅԱՆ ԱՆՀՐԱԺԵՇՏ ՄԱԿԱՐԴԱԿԻ ԱՊԱՀՈՎՄԱՆ ՕՊՏԻՄԱԼ ԿԱՐԳԸՆԹԱՑ

ԱՄՓՈՓԱԳԻՐ

Անլար կապի և ներդրված համակարգչային տեխնոլոգիաների ոլորտում վերջին զարգացումների շնորհիվ մշակվեցին անլար սենսորային ցանցերի (այսուհետ՝ ԱՍՑ) տեխնոլոգիաներ։ Հարյուր հազարավոր միկրո սենսորներեր կարող են կիրառվել մի շարք ոլորտներում, ներառյալ առողջապահության, շրջակա միջավայրի ոլորտներում և մարտադաշտերում՝ ճշգրտության ցանկալի աստիճանով տիրույթը վերահսկելու նպատակով։ Նման ոլորտներում անլար սենսորների կիրառմամբ, ցանցի շահագործման ժամկետը պետք է որքան հնարավոր է երկար լինի՝ էներգիայի սկզբնական քանակին համապատասխան։ Հետևաբար, ԱՍՑ-ի ներսում էներգածախսի նվազեցումը համարվում է գլխավոր և առաջնային խնդիրներից մեկը։ Անլար սենսորները ընդհանուր առմամբ բաղկացած են երեք հիմնական մասերից. կապի ենթահամակարգից, մշակման ենթահամակարգից և սենսորային ենթահամակարգից։ Սովորաբար կապի ենթահամակարգը ծախսում է տիպիկ սենսորների առավելագույն քանակությամբ էներգիա, այսինքն, այնքան շատ էներգիա, որ մենք կարող ենք անտեսել մշակման էներգածախսը։

Սենսորային ենթահամակարգի էներգասպառումը ամբողջությամբ կախված է հատուկ (կոնկրետ) սենսորային տեսակից։ Սովորաբար, այն նույնպես շատ ավելի քիչ է, քան կապի ենթահամակարգինը։ Հետևաբար, էներգիայի պահպանման սխեմայում մենք ընդհանրապես ուշադրություն ենք դարձնում միայն կապի և սենսորային ենթահամակարգի վրա և միևնույն ժամանակ անտեսում ենք մշակման ենթահամակարգը։ Մենք կարող ենք էներգիայի պահպանման սխեման բաժանել երեք հիմնական կատեգորիաների. շրջափուլի ռեժիմ, տվյալների հիման վրա կառավարվող մոտեցում և շարժականության կառավարում։

Շրջափուլի ռեժիմի ժամանակ մենք ցուցաբերում ենք տարբեր մոտեցումներ՝ կապի ենթահամակարգի էներգասպառումը նվազագույնին հասցնելու ուղղությամբ։ Տվյալների հիման վրա կառավարվող մոտեցման դեպքում, մենք մշակել ենք տարբեր եղանակներ՝ սենսորային ենթահամակարգի էներգասպառումը նվազագույնին հասցնելու ուղղությամբ, ինչպիսին է, օրինակ. տվյալների կամ էներգապես արդյունավետ տվյալների ձեռքբերումում։ Քանի որ ցանցի հանգույցները շարժունակ են կամ սենսորների միջև առակ են մի շարք շարժունակ հանգույցներ, մենք կարող ենք կիրառել մի շարք շարժականության վերահսկման եղանակներ՝ էներգասպառումը նվազագույնին հասցնելու նպատակով։ Սույն ատենախոսության մեջ մենք անդրադառնում ենք շրջափուլի ռեժիմին։ Շրջափուլի ռեժիմը

բաժանված է երկու հիմնական կատեգորիաների, որոնք են. տոպոլոգիական վերահսկում և էլեկտրասնուցման ռեժիմի կառավարում:

Սույն ատենախոսության մեջ մենք անդրադառնում ենք ծածկույթի խնդրին, որը առաջանում է սենսորային հանգույցների պատահական և հաճախակի օգտագործման արդյունքում: Ծածկույթի խնդիրը կայանում է նրանում, որ սենսորային հանգույցները անկայուն և աննախատեսված տեղերում են տեղադրված՝ սենսորային ավելցուկներով: Ատենախոսությունում շոշափվում են անկար սենսորային ցանցի խնդիրները՝ կապված էներգիայի և սենսորային արդյունավետության հետ:

Մենք լուծման եղանակներ ենք առաջարկել հանգույցների պլանավորման խնդրի հետ կապված, որի միջոցով կկարգավորվեն ծածկույթի և միացման հետ կապված խնդիրները սենսորային ցանցում միասնական եղանակով: Նման եղանակով մենք բաժանել ենք ցանցի շահագործման ժամկետը մի քանի սահմանված փուլերի: Յուրաքանչյուր փուլում մենք ստացել ենք տիրույթի սենսորների բիտային ծածկույթ: Հաշվի առնելով տվյալ բիտային մատրիցան որոշվեց, որ նման սենսորները կմնան ակտիվ կամ հանգստի ժամերին կանջատվեն:

Ատենախոսության հիմնական նպատակներն են.

- Սենսորային ցանցերի շահագործման ժամկետի բարձրացում ինտեգրված ծածկույթի և միացման տոպոլոգիայի վերահսկման միջոցով,
- Վերահսկման տարածքի ծածկույթի ցանկալի տոկոսի ապահովում՝ ցանցի շահագործման ժամկետի բարձրացման նպատակով,
- Սենսորային ցանցի հանգույցների ճախողման կայունության բարձրացում

Ատենախոսության հիմնական արդյունքներն են.

- Մենք ուսումնասիրել ենք ուսումնասիրության տիրույթի մի շարք հայտնի աշխատանքներ, ինչպես նաև հանգստի ռեժիմի կառավարման ուսումնասիրման տարբեր եղանակները,
- Մենք իրականացրել ենք երկու հայտնի եղանակներ՝ Ծածկույթն ու Կապակցվածության ապահովման համար, CCP և SPAN: Առաջինը դա տեղաբաշխված ալգորիթմ է, որը ընդունակ է ապահովել K_s-ծածկույթի ցանկացած մակարդակ, իսկ երկրորդը իրենից ներկայացնում է տեղաբաշխված ալգորիթմ, որը ընդունակ է ապահովել K_c միացման ցանկալի մակարդակ,
- Ատենախոսության մեջ ներկայացված է սենսորների ակտիվության կառավարման ալգորիթմ որը ապահովում է սենսորային ցանցի ծածկույթն ու միացումը ինտեգրված եղանակով,

- Ցանցի միացումը ստուգելու համար աշխատանքում օգտագործվել է սենսորային ցանցի հարևանության դիագրամայի հատկանիշների կիրառումը, և գրականության մեջ որևէ նշում չկա այդ մասին`,

- Մենք ներկայացրել ենք մի զագափար, որը հիմնվում է ծածկույթով ընդգրկված տարածքի բիտային պատկերի ստացման վրա` վերահսկման տիրույթի ծածկույթի ցանկալի տոկոսը հաշվարկելու նպատակով,

- Շատ հետազոտողներ գնահատում են ցանցի միացումը` հիմնվելով ծածկույթի վրա` ինտեգրված ծածկույթն ու միացումն առաջարկելու նպատակով: Ուստի, սահմանափակումներ են գործում սենսորային շառավիղի գործակցի և սենսորային կապի շառավիղի նկատմամբ: Նման սահմանափակումների կիրառումը մենք բացառել ենք մեր նոր մեթոդում:

- Մենք հայտնաբերել ենք ցանցի առավելագույն շահագործման ժամկետը` ներկայացնելով տվյալ խնդիրը որպես սահմանափակումներով օպտիմալացման խնդիր:

Хамид Хосрави

ОПТИМАЛЬНЫЙ ПРОТОКОЛ ДОСТИЖЕНИЯ ЖЕЛАЕМОГО УРОВНЯ ПОКРЫТИЯ И СВЯЗНОСТИ В БЕСПРОВОДНЫХ СЕНСОРНЫХ СЕТЯХ

РЕЗЮМЕ

Новейшие разработки в области беспроводной связи и встроенных вычислительных технологий привели к появлению беспроводной технологии сенсорных сетей. Сотни тысяч этих микросенсоров могут найти применение во многих областях, включая здравоохранение, защиту окружающей среды, военное дело, давая возможность следить за доменом наблюдения с желаемым уровнем точности. При использовании беспроводных сенсоров в какой-либо области, срок службы сети должен максимально увеличиться в зависимости от первоначального количества энергии. Таким образом, сокращение потребления энергии в БСС имеет первостепенное значение. Беспроводные сенсоры обычно состоят из трех основных частей: подсистемы связи, подсистемы обработки и подсистемы зондирования. Подсистемы связи обычно потребляют большую часть энергии. Энергия обработки от типичного сенсора это такое количество энергии, что мы можем пренебречь потребление энергии при обработке.

Энергопотребление подсистемы зондирования зависит от типа конкретного сенсора. Обычно оно также намного меньше, чем энергопотребление подсистемы связи. Поэтому в схеме энергосбережения мы в целом рассматриваем только подсистемы связи и зондирования и пренебрегаем подсистемой обработки. Мы можем классифицировать схемы энергосбережения по трем основным категориям: управление активности, управления данными и управления мобильностью.

В первой категории, мы рассматриваем разные подходы к минимизации потребления энергии подсистемой связи, в категории управления данными мы рассматриваем способы минимизации потребления энергии подсистемой зондирования, такие как агрегирование данных либо энергоэффективный сбор данных. Поскольку узлы подвижны либо среди сенсоров имеется несколько мобильных узлов, мы можем использовать некоторые методы управления мобильностью для снижения энергопотребления. В данной работе мы ориентируемся на управления активности. Он делится на две основные категории: контроль топологии и управления электропитанием.

Контроль топологии относится к использованию избытка узлов для подсистемы зондирования или связи, когда у нас имеется более чем достаточно узлов для достижения желаемого уровня связности либо покрытия в сети. Некоторые работы в области контроля топологии рассматривают только связность сети, другие, напротив, рассматривают только покрытие сети, третьи рассматривают как охват, так и связность. Некоторые из этих алгоритмов являются централизованными, а некоторые - распределенными. Централизованный алгоритм является одним из видов сетевого протокола, когда данные со всех узлов собираются в основной узел и планирование режима работы активности осуществляется в этом узле, затем решения направляются в сетевые узлы. С другой стороны в распределенных протоколах каждый узел самостоятельно решает, оставаться ему активным или нет. В некоторых случаях планирование режима работы активности узлов осуществляется местными кластерными управляющими.

В настоящей работе наши усилия направлены на проблему покрытия, которая возникает в результате случайного и плотного распределения сенсорных узлов. Проблема покрытия указывает на неорганизованное размещение сенсорных узлов с большим избытком чувствительности. Он ставит под сомнение эффективность беспроводных сенсорных сетей с точки зрения энергопотребления и чувствительности.

Мы предложили решение планирования узла, которое решает проблемы охвата и подключения в сенсорных сетях в комплексе. Таким образом, мы делим срок службы сети на несколько этапов, на каждом из которых мы создаем битовые карты сенсоров покрытия домена и на основе этих битовых карт выносится решение о том, какие сенсоры должны остаться активными, а какие нет. Мы проверяем связанность сети с помощью графика смежности Лапласа активных узлов на каждом этапе. Также с помощью битовых карт покрытия, сеть будет способна обеспечивать желаемый процент покрытия. Мы определяем проблему охвата, как связанную с проблемой оптимизации, которая является NP-сложной и, следовательно, мы будем искать решение задачи при помощи Эвристических методов оптимизации GA в централизованной форме.

Цели работы: Основными целями настоящей работы являются:

- Увеличение срока службы сенсорных сетей с помощью интегрированного покрытия и контроля топологии связи;

- Производство желаемого процента охвата области мониторинга для увеличения срока

службы сети;

- Повышение надежности сенсорного сетевого узла.

Основные результаты диссертации

- Мы изучили большое множество работ в рассматриваемой области и различные методы планирования режима активности сенсоров.

- Мы реализовали два из известных методов обеспечения покрытия и связи: CCP и SPAN. CCP представляет собой распределенный алгоритм, который способен обеспечить желаемый уровень K_s-покрытия. SPAN также представляет собой распределенный алгоритм, который способен обеспечить желаемый уровень K_c-соединения.

- Алгоритм планирования узла, представленный в настоящей диссертации, обеспечивает покрытие и связность сенсорной сети в комплексе.

- Мы используем свойства графика смежности сенсорной сети для проверки ее связности и не нашли аналогичную технику в литературе.

- Мы представили новую идею, основанную на создании битовой карты зоны охвата для оценки желаемого процента охвата области мониторинга.

- Многие исследователи оценивают связность сети на основе показателей охвата чтобы рассмотреть охват и подключение в комплексе. Поэтому существует ограничение в соотношении радиуса восприятия к радиусу связи сенсоров. С помощью нашего нового метода мы избавляемся от такого ограничения.

- Мы нашли максимально возможный срок службы сетей, представив эту проблему как проблему оптимизации ограничения.