Coverage Providing in Directional Sensor Networks through Learning Algorithms (Learning Automata)

Cobertura que brinda redes de sensores direccionales a través de algoritmos de aprendizaje (autómatas de aprendizaje)

Cobertura Fornecendo em Redes de Sensores Direcionais através de Algoritmos de Aprendizagem (Autômatos de Aprendizagem)

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Abstract

Today, wireless sensor networks due to application development are widely used. There are significant issues in these networks; they can be more effective if they would be fixed. One of these problems is the low coverage of these networks due to their low power. If coverage increases only by increasing the power of sending and receiving power, it can increase network consumption as a catastrophic disaster, while the lack of energy is one of the most important constraints on these networks. To do this, the antenna coverage is oriented in some sensor networks to cover the most important places. This method tries to improves the efficiency and coverage of directional sensor networks by providing a mechanism based on the learning algorithm of the machine called learning automata. Results show this method outperform the before methods at least 20%.

Keywords- Directed Wireless Sensor Network; Increased coverage; improved energy consumption; machine learning; learning automata

Resumen

hoy en día, las redes de sensores inalámbricos debido al desarrollo de aplicaciones son ampliamente utilizadas. Hay problemas importantes en estas redes; pueden ser más efectivos si se solucionan. Uno de estos problemas es la baja cobertura de estas redes debido a su baja potencia. Si la cobertura aumenta solo elevando la potencia de envío y recepción de energía, puede aumentar el consumo de red como un desastre catastrófico, mientras que la falta de energía es una de las limitaciones más importantes de estas redes. Para hacer esto, la cobertura de la antena está orientada en algunas redes de sensores para cubrir los lugares más importantes. Este método intenta mejorar la eficiencia y la cobertura de las redes de sensores direccionales al proporcionar un mecanismo basado en el algoritmo de aprendizaje de la máquina denominado autómatas de aprendizaje. Los resultados muestran que este método supera los métodos anteriores al menos un 20%.

Palabras clave- Red de sensores inalámbricos dirigidos; incremento de cobertura; consumo de energía mejorado; aprendizaje automático; aprendizaje autómata

Resumo

hoy en día, as redes de sensores inalámbricos debitaram o desenvolvimento de aplicações sonoras extensamente utilizadas. Obras do feno importantes nas redes; pueden ser más effectivos y se solucionan. Uns de esos protes es la baja cobertura de es redes debido a su baja potencia. Se a porta leva sozinho a aumentar a potência de envio e a recepção de energia, aumentar o consumo de energia como um desastre catastrófico, a falta de energia de energia é uma das limitações mais importantes destas redes. Para hacer esto, la cobertura de la antena está orientada nas algunas redes de sensores para cubrir os lugares mais importantes. This method intenta mejor a eficiencia and the coverage of the networks of sensors directionals are provided in engine based on the algorithm of aprendizado of the machine denominado autómatas de aprendizaje. Los resultados muestran que este método supera os métodos anteriores a menos de 20%.

Palabras clave- Red de sensores inalámbricos dirigidos; Prefeito cobertura; consumo de energia mejorado; aprendizaje automático; aprender autómatas

Introduction

One of the most important challenges on the way of using sensor networks is energy consumption and cost. Considering the definition and basic nature of wireless sensor networks caused by using too many sensors forming such networks, effort has been made for selection of affordable sensors, with no need for energy source to be very large. Otherwise, cost, size, and weight of network nodes will be increased in a way that using them would become less possible. In fact, until now production and manufacturing cost of such sensors have been referred to. From among other costs in relation to usage of such networks, reference could be made to maintenance costs. The more cost of using wireless sensor networks reduces, the more they would be used in various fields; and, outcome would be better. So, effort has been made in the project to present an algorithm based on learning automata algorithm so that cost of applying such networks including energy consumption reduces; and, using it in various industrial, agricultural and animal husbandry sections, and most importantly in military applications becomes realized. In fact, the proposed algorithm has been presented upon maximum coverage, with energy consumption taken into consideration.

Deployment strategies, and coverage principles in directional sensors

A directional sensor network is formed of N sensors, each having W directions; while, they work on just one direction with one-dimensional sensing area. All sensors are randomly dispersed, covering M targets in two-dimensional space.

$S = \{s_1, s_2, \dots s_N\}$ is defined as a set of N sensor and $R = \{r_1, r_2, \dots, r_M\}$ is defined as M targets. Contrary to a multi-directional sensor network, in directional sensor network, recognition of sensors' direction and communication with them have to be also considered.

j is D^{th} direction of si sensor where, (j= 1,2,…,W) and (i=1,2,…,N). It is supposed that a si sensor has no overlapping with its two adjacent directions.

D= set of j and Di for (j= 1,2,…,W) and (i=1,2,…,N).
CK ($\subseteq$D): k^{th} set of directions which covers all people in R; the same as each member of CK which covers at least one member of R. Meanwhile, each element in CK may not belong to a similar sensor in S. This set is called cover set.

Rm ($\subseteq$D: set of directions covering rm (m=1, 2, …, M).
Li: considered as a si sensor's lifespan. It is supposed that si sensor consumes a uniform energy in terms of direction and number of targets coverage, when it is active.
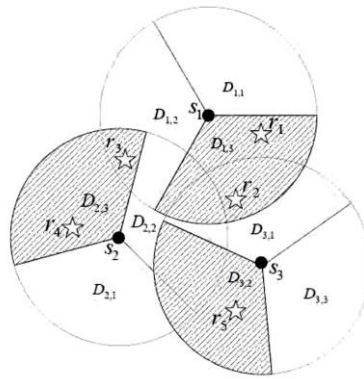tK: Active time for K^{th} set of allocated coverage.

Figure 1- A view of a sensor network with 3 sensor nodes, and 5 targets considered
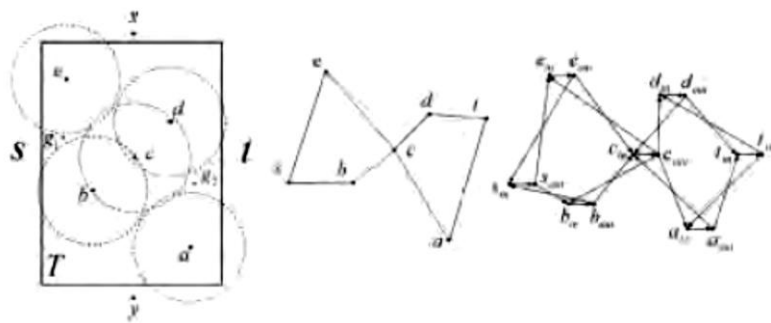

Figure 2- A view of a directional sensor network and its flow

Directions are organized in D within K cover set, where K is maximum number of cover sets to cover the area between S and R. j, Dj may end to several cover sets till lifespan (Li) of a si sensor is completely finished. A Boolean variable of k, j, and xi is defined as:

$$x_{i,j,k} = \begin{cases} 1 & \text{if } D_{i,j} \in C_k \\ 0 & \text{otherwise.} \end{cases}$$

$$\text{Maximize} \quad \sum_{k=1}^{K} t_k$$

$$\text{subject to} \quad \sum_{k=1}^{K} \sum_{j=1}^{W} x_{i,j,k} \cdot t_k \le L_i, \forall s_i \in S$$

$$\sum_{j=1}^{W} x_{i,j,k} \le 1, \forall s_i \in S, k = 1, 2, \ldots, K$$

$$\sum_{D_{i,j} \in R_m} x_{i,j,k} \ge 1, \forall r_m \in R, k = 1, 2, \ldots, K$$

$$\text{where} \quad x_{i,j,k} = \{0,1\} \text{ and } t_k \ge 0.$$

Above equation guarantees that the time allocated to each s_i sensor all over the cover sets is not bigger that Li; because, it is lifespan of each sensor. One directional sensor in one cover set is more dependent on one direction, despite being active or inactive. The formula also guarantees that each target is covered by minimum number of directions in a cover set.

Status of sensors and their arrangement affects such parameters as energy consumption, and also verification of coverage quality. Deterministic and random deployments are considered as two methods of deployment of directional sensor networks. In deterministic deployment, position of directional sensors is pre-adjusted according to the plan. The approach is aiming at providing maximum coverage with minimum

number of sensors, which may affect cost reduction in sensor network. This deployment strategy has to be applied in outdoor applications.

It is worthy of consideration that those networks formed upon above strategy have not to confront obstruction and/or overlapping issues. On the other hand, random deployment is more affordable and easier than deterministic deployment in a large scale directional sensor networks. Moreover, for harsh and distant environments, random deployment is considered as the only functional alternative. The reason is that, there is no exact location and sensor nodes are dispersed in too many numbers to increase error tolerance, which results in environment overlapping, additional sensor nodes and obstructed environments. As a result, coverage problem in such random deployment mode of directional sensor network has been lately considered a lot; and, several methods have been proposed to solve the problem (Kim et al, 2013; More, 2016; More & Raisinghani, 2017; Mini et al, 2014; Yang, Qianqian, et al, 2015). In directional sensor networks, high coverage rate may be obtained through the followings (Guvensan & Yavuz, 2011a).

1- Deployment of large number of directional sensors;
2- Using motility feature of directional sensors;
3- Using mobility feature in directional sensor nodes;
4- Re-deployment; and
5- Using a combination of methods.

Directional sensor networks have some problems, including coverage which produces a new and specific challenge in random deployment networks. A number of coverage holes (an area which has not to be covered), and overlapped areas (an area covered by more than one sensor) may happen, through primary deployment. However, self-oriented node is needed for random deployment of directional sensor networks. Basically, there are two approaches regarding self-oriented sensor nodes in directional sensor networks: irritability and motility.

Irritability refers to physical movement of nodes; whereas, motility concerns adjustment of working direction of nodes. In directional sensor networks, motility of a directional sensor node considerably affects coverage. Motility may solve overlapped visibility and obstructed areas which occur in some stages of initial deployment. It should be noted that, adjustment of working directions may not always solve the problem of cover hole. However, there are two main constraints in using them: physical movements of mobile sensors result in high energy consumption and cost (Guvensan & Yavuz, 2011b; Guvensan & Yavuz, 2013).

Previous Works

For the purpose of coverage and its maximization in directional sensors, some mechanisms and algorithms have been proposed, among which reference could be made to studies (Y. Cai, 2007) calling for a set of sensor's direction as a cover set; and, suggesting a centralized algorithm (DCS-Greedy), and a distributed algorithm (DSC-Dist) which specify working directions of directional sensor nodes. Basically, both proposed algorithms accept a number of M points under consideration, a number of N sensors, and a number of directions in each pair of W sensors as input. Two sets are defined by them: set of targets and set of directions which cover at least one point on set of intended targets. Their policy is to find a direction to cover target so that it could be covered by minimum number of directions.

CGA (Centralized Greedy Algorithm) is a centralized solution regarding MCMS (maximum coverage with the minimum sensors) problems. In each repetition, an inactive sensor and its status will be searched in an environment with maximum covered numbers of targets. Then, their work directions will be specified by selected nodes. Afterwards, ties will be randomly selected. The algorithm in mind will be executed within a restricted location and loop when there are not much targets to be covered and/or high numbers of directional sensors have been remained unselected. The reason is that, eventually n loops will remain, and time complexity of CGA is $O((m+1) n^2 P)$.

Centralized greedy algorithm is a developed solution regarding MCMS (Hochbaum, 1997). which only puts local information in the report. Although the algorithm is not capable of acting as well as centralized

methods, surely it will be very satisfactory in operation; and, traffic of messages requested by it would be less. In CGA, each node adopts a unique variable having priority of their neighbors, located within $2R_s$ range. In those sensors with high levels of priority, their work direction would be selected first. These nodes look for those directions with maximum number of covered targets. In each repetition, priority, location and data regarding status of nodes will be changed by them, within their communication scope. A transition timer will prevent sensor's decision making to be ended with zero value.

paper (More & Raisinghani, 2017), propose a method naming *Optimized Discharge-Curve-based Coverage Protocol* (ODCP) to handlen coverage problem in sensor network. ODCP determines sleep schedules for redundant nodes using their neighboring active nodes' battery discharge rate, failure probability, and coverage overlap information.

In (Yang, Qianqian, et al, 2015) authors suggested that first study the sensing probabilities of two points with a distance of d and obtain the fundamental mathematical relationship between them. If the sensing probability of one point is larger than a certain value, the other is covered. Based on such a finding, probabilistic area coverage has been transformed into probabilistic point coverage. Then, authors design the ε-full area coverage optimization (FCO) algorithm to select a subset of sensors to provide probabilistic area coverage dynamically so that the network lifetime can be prolonged.

Also in some research, researchers have tried to provide methods that can solve the problem of coverage in sensor networks in a desirable manner (J. Ai, A.A. Abouzeid, 2006; J. Wang et al, 2009; Yang, Jianjun, et al, 2013; Wang, Bang, 2011; Wang, Bang, 2010; Qu, Nan, et al, 2013; Zou & Chakrabarty, 2004; Zou & Chakrabarty, 2005; Xing, 2005; Zhang & Hou, 2005; Xia, Junbo, 2016; Singh, Devesh Pratap, et al, 2016). In this research, authors suggest coverage problem under consideration according to priority (J. Wang et al, 2009). This way, they may select minimum set of directional sensors which monitor overall targets; and, this way they may specify some priorities. A genetic algorithm has been proposed to solve minimum subset. The said algorithm has been executed in MATLAB, because the software provides strong toolboxes. Simulation results show effects of various factors including, sensing radius, view angle, and targets from subset sensors. Number of sensors decreases through increase in sensing radius so that uniform covered scope would be obtained. On the other hand, increase in view angle reduces number of sensors. However, this is relatively less than increase in scope of sensing. Directional sensor deployment is studied through a different method. They present an ILP (integer linear programming) model which includes a set of control points, a set of sensor deployment locations, as stated before. That is, placement of sensors in sensor field in a way that each control point is covered at least by one sensor, and overall cost of sensors becomes minimized.

In this research, authors have created coverage in wireless sensor networks through particle intelligence algorithm. The algorithm is in fact a combination of the two particle swarm optimization and artificial fish swarm optimization algorithms (Xia, Junbo, 2016). When particle swarm optimization is imposed for optimizing wireless sensor network coverage, the coverage speed level is high. Anyway, the algorithm is easily trapped by local optimization which leads to early response phenomenon. Using artificial fish swarm algorithm in optimizing wireless sensor network coverage has the same advantages of effective public search efficiency. However, its convergence speed repeats slowly; and, it is hard to use it for finding desirable solution. In the research, effort has been made to integrate the two algorithms and to use advantages resulted from both. General coverage of artificial fish swarm algorithm is used to search for domain of satisfactory solution. Then, particle swarm optimization has been made compatible for quick local search, WSN status and direction adjustment, and removing repetitive and blind areas coverage. This improves obtaining desirable response; however, there are some problems also in terms of complications created in solving the problem.

In this research, an analytical method has been proposed for increasing wireless sensor network lifespan while maintaining those groups separated from sensors (Devesh Pratap, et al, 2016). Accordingly, a unique group may provide coverage for area as a whole, at any time. Therefore, only one group may be activated at a time, in WSN. Coverage is in regular rectangular form, after placement of a group of sensors. This way, the research has been capable of increasing coverage lifespan in sensor network and to extend it to a considerable level. Although in general, rectangular coverage has some heterogeneities with covering

features of nodes in the network; it seems to be improvable. Various coverage forms will be considered in the next section.

In these researchs, we and other coworkers performed some research about different scopes of WSN include reduce energy consumption, routing, data storage and security of wireless sensor networks. These works cover many challenges on WSN and help to better performance for these networks (Sharifzadeh et al, 2015; Porkar et al, 2015a; Porkar et al, 2015b; GhadakSaz et al, 2012; Gheisari et al, 2012; Gheisari et al, 2012; Porkar et al, 2011a; Porkar & Gheisari, 2011; Porkar et al, 2011b). We used some of the the researches results in this paper.

Coverage Model

In this section, introduction of those coverage models are aimed at, in which nodes are capable of covering the whole network. This is why; various strategies have been studied regarding the procedure. The result is that, the proposed idea concerns using implementable virtual grid solution. Using virtual grids will somehow partition the network into certain cells. Nodes inside each cell are considered as its members and will be used in membership decision making. Decisions made may play a significant role in terms of optimized coverage, multiple coverage, and active and inactive mechanisms of sensor nodes. Proposed protocol (CPLA[71]) will be explained in this chapter.

Performance optimization of those protocols using grid

Energy shortage is the most important challenge of sensor networks. So, presented protocols for these networks try to optimize energy usage. Using virtual grid on the network is one of effective strategies in terms of reducing energy consumption in sensor networks. Numerous protocols use such concept. In these protocols, a virtual grid will be assumed over the network. Usually, one node from those located in each cell will be placed in active status; and, other nodes in the cell will remain inactive. This way, network energy will be stored and its lifespan would become increased. In most of those protocols which use virtual grid, the grid is considered to have square shape cells. Meanwhile, nodes in a cell may just communicate with nodes located in neighbor cells. There are two form of neighborhood for cell. In the first one, each cell may communicate with adjacent cells, horizontally and vertically. In second form, by communication of two cells we mean communication between nodes located in them. In continuation also, by communication of two cells, we mean communication between the nodes in them.

In the annex, lozenge, triangle, and hexagonal cell shapes also will be considered in addition to square shape; and, various neighborhoods will be defined for them. Each of these (according to their cell shapes) has some advantages and disadvantages, with direct effect on performance of the network. Shape of cells affects performance of the network in terms of energy consumption, lifespan, network topology, error tolerance, security, and scalability.

Different kinds of virtual grids in sensor networks

Most of protocols using virtual grid use them in square or triangle shape cells. These shapes have to be regular so that they may cover expansion surface of nodes in the network like mosaic, with no additional and redundant parts. Those regular shapes capable of being considered as shape of a grid cell are squares, lozenges, triangles, and hexagons (figure 3). As observed in figure 3, one type of grid may be considered for triangle cells. Again, bigger regular shapes may not be used because they are not capable of covering the network completely, due to empty spaces.

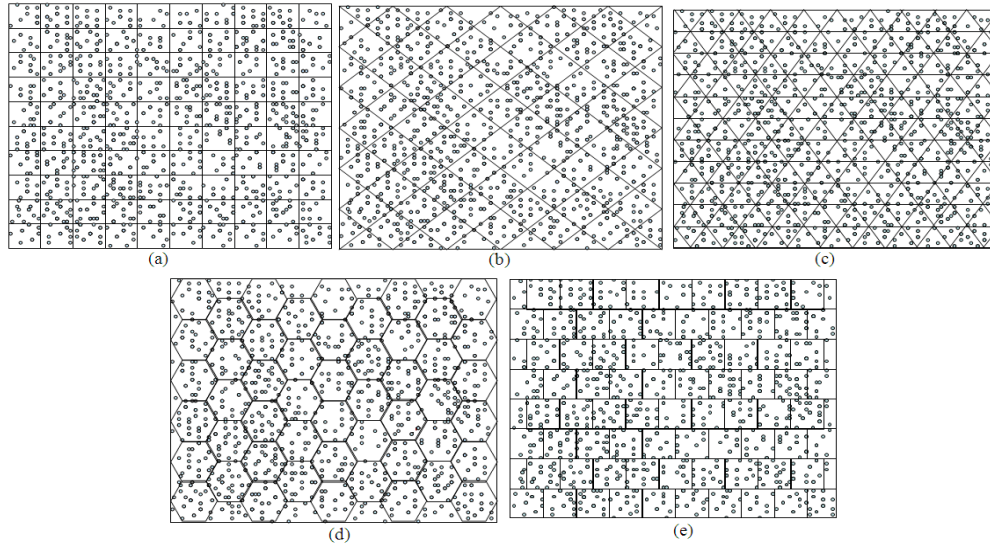[71] Coverage Protocol based on Learning Automata

Figure 3- Various cell shapes for virtual grid, supposed for nodes distribution domain in sensor network: a) grid with square shape cells type 1; b) grid with lozenge shape cells; c) grid with triangle shape cells; d) grid with hexagonal shape cells; and e) grid with square shape cells type 2.

Type of neighborhood defined for a cell directly affects network performance. Those two cells with nodes capable of communicating each other are considered as neighbor (considering transfer range of each node). For a grid with square shape cells (type 1), four types of neighborhood are defined which results in four types of grid. In triangle grid, each cell is capable of communicating with those cells sharing in one side.

For triangle, hexagonal, and square cells, only one type of neighborhood is defined. In triangle grid, each cell may communicate with other cells having at least one point in common. In hexagonal grid, each cell may communicate with those cells having one side in common. In square grid (type 2), each cell may communicate those cells having one point in common. Those grids with triangle, hexagonal, and square cells are seen in figure 4, along with defined neighborhood for each.
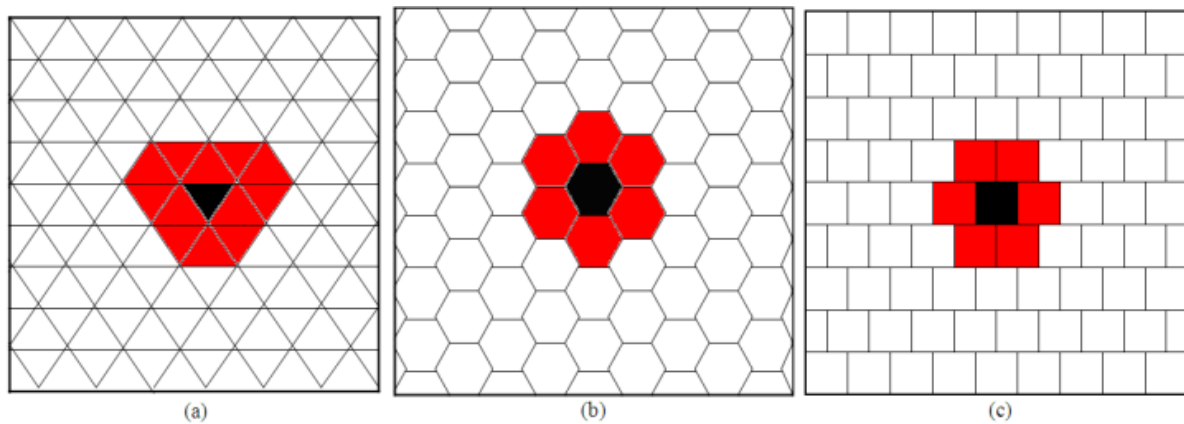

Figure 4- Grids with triangle, hexagonal, and square shape (type 2), along with their defined neighborhood: a) triangle grid; b) hexagonal grid; c) square grid (type 2)

Side length of each cell will be specified according to node transfer range. To calculate side length of each cell for various types of grids, maximum distance of two nodes in two neighbor cells has to be specified. The maximum distance shows that each node's transfer range has to be at least equal to this value to be capable of covering type of grid in mind, and its neighborhood. Maximum distance between two nodes in two neighbor cells for various grids is seen in figure 5. In figure 5, yellow dots show nodes, and x shows distance between two nodes or in another word, minimum range for transfer of nodes. Farthest distance of two nodes for hexagonal cells is equal to that of square shape cell (in equivalent grids).
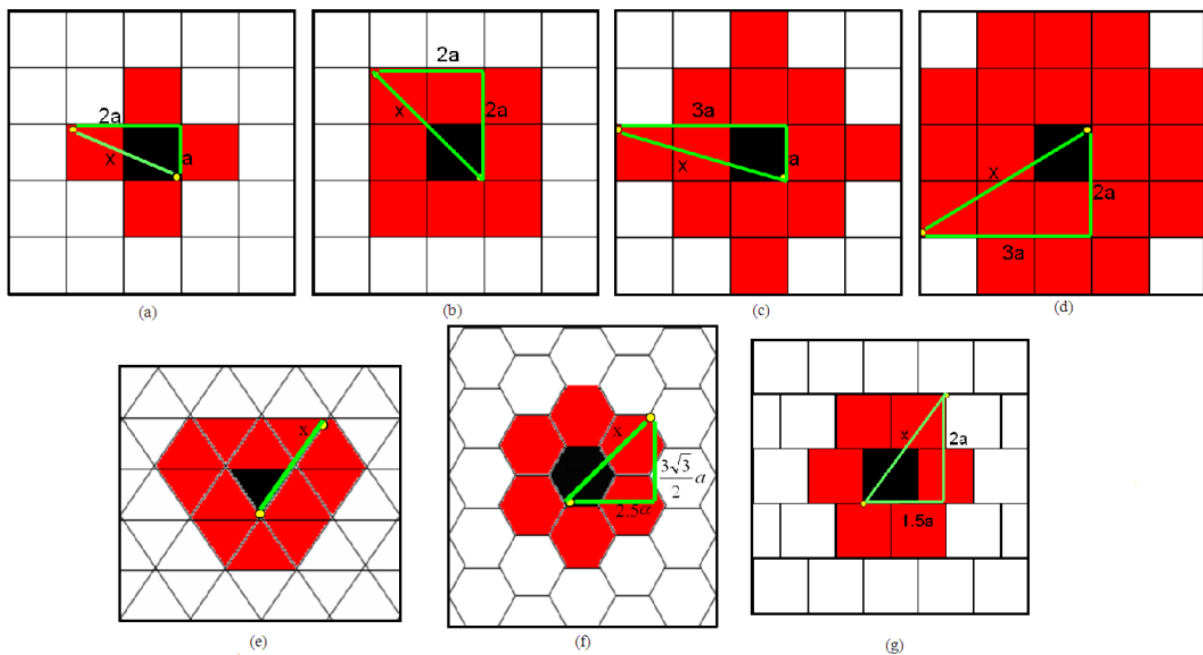
Figure 5- farthest distance of two nodes in two neighbor cells for various a, b, c, d, e, f, and g grids

Supposing transfer range of each node (R) as fixed, side length of cell for various grids will be obtained through equations 1 to 7. Side length for hexagonal cells equals that of square cells (in equivalent grids).

$$R^2 = (2a)^2 + a^2 \Rightarrow a_{SC_{n4}} = a_{LC_{n4}} = \frac{R}{\sqrt{5}} \tag{1}$$

$$R^2 = (2a)^2 + (2a)^2 \Rightarrow a_{SC_{n8}} = a_{LC_{n8}} = \frac{R}{\sqrt{8}} \tag{2}$$

$$R^2 = (3a)^2 + a^2 \Rightarrow a_{SC_{n12}} = a_{LC_{n12}} = \frac{R}{\sqrt{10}} \tag{3}$$

$$R^2 = (9a)^2 + (2a)^2 \Rightarrow a_{SC_{n20}} = a_{LC_{n20}} = \frac{R}{\sqrt{13}} \tag{4}$$

$$R = 2a \Rightarrow a_{TC_{n12}} = \frac{R}{2} \tag{5}$$

$$R^2 = (\frac{5}{2}a)^2 + (\frac{3\sqrt{3}}{2}a)^2 \Rightarrow a_{HC_{n6}} = \frac{R}{\sqrt{13}} \tag{6}$$

$$R^2 = (2a)^2 + (1.5a)^2 \Rightarrow a_{SC_{n6}} = \frac{2R}{5} \tag{7}$$

Proposed Method

In this section, proposed method of creating coverage in wireless sensor networks will be discussed. This is a probabilistic covering model based on learning automata which will be studied, in details.

Proposed probabilistic covering protocol

The protocol has been introduced for complete monitoring of environment. The requirement is evident in many wireless sensor networks' applications. Proposed protocol typically assures that all points located in θ range have been covered by a set of sensors. However, probabilistic covering protocol does not suit

those applications in need of coverage degree of more than 1, or coverage with variable roles of events; but, they may have any type of distribution. In simulations, uniform random distribution will be used. Considering aforementioned, probabilistic protocol begins activity, after an appropriate value of s is proved. The process does not consider type of sensing model.

Proposed protocol takes place in several rounds, during R seconds. R value is commonly less than that of lifespan of the network. At the beginning of each round, all of the network nodes begin activation with no consideration of neighbors. A number of messages are exchanged for distance between the nodes, to be estimated. It is called work cycle in each round. Protocol time is divided to estimating active and inactive modes at convergence time. This division may be transform to smallest time. After convergence time, convergence message will not be exchanged by protocol procedure or any of nodes, till the next round.
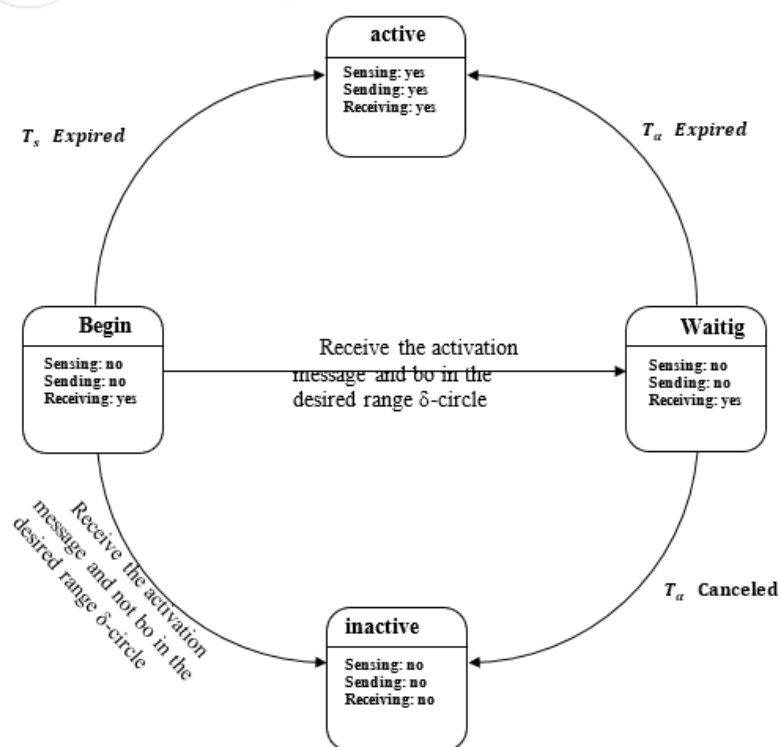
Figure 6- Probabilistic covering protocol diagram

One node in proposed protocol may stay on four active, inactive, waiting, and starting modes. At the beginning of a round, all nodes are in starting mode. A T_s work starting scheduler appropriate for remaining energy of nodes will be considered. A node with smaller T_s time becomes active and informs its neighbors of its status through a message. Sender of activation message is called activator. Activation messages try to make active those nodes located on central vertexes of hexagons; while, the remaining nodes in hexagons go to inactive mode. When a node receives activation message, it may specify if it is located on vertex of hexagon or not, after computing the distance. In case the angle between nodes is equal to $\frac{\pi}{3}$ and their distance is s, node will be activated and turned to an active node. Otherwise, it goes to inactive mode. In real distribution of network, these types of triangulation arrangement and certain vertexes may not be implemented 100%; because, in proposed scenario, nodes are randomly dispersed in the environment. Proposed model tries to activate the nearest nodes to hexagon vertexes, as observed in figure 7.
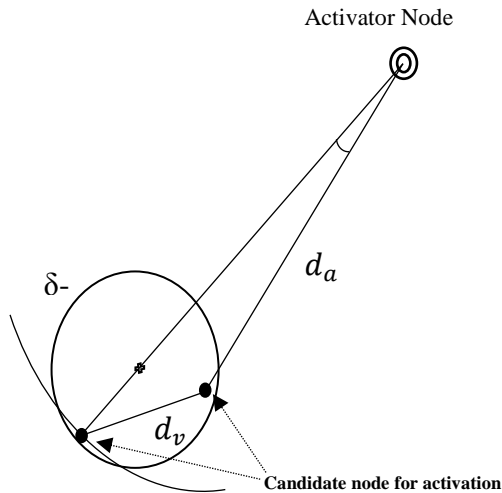
Activator Node

δ-

d_a

d_v

Candidate node for activation

Figure 7- The way nearest sensor node to triangle side is selected

Each node receives an activation message so that it computes a T_a scheduler according to a function of the nearest nodes to vertex of hexagon nodes through following equation:

$$T_a = \tau_a(d_v^2 + d_a^2\gamma^2) \qquad (1)$$

Values of d_v and d_a are equal to Euclidean distance between the node and vertex of hexagon, and the node and activator, respectively. γ is equal to the angle between node and activator line; and, the angle between triangle vertex and activator T_a is also a constant. Please note that, the node nearer to the vertex has smaller T_a. After computing the T_a, a node becomes inactive and remains so, as far as its T_a is not expired or cancelled upon activation request. When smallest T_a is expired, node will be activated. More optimization lies in the way network activators are distributed. To understand better, δ-circle concept will be first defined as follows:

δ-circle define: Smallest circle which may be considered would be called δ-circle, on condition that at least one node exists in it. δ is considered as diameter of aforementioned circle. Diameter δ will be computed from the way nodes are distributed and deployed. In the next section, method of calculating δ for various deployment distributions has been introduced. The network will be optimized when waiting time of network nodes becomes minimized and nodes immediately decide upon becoming active or inactive. The procedure results in efficient energy consumption in the network; because, as presented in the proposed protocol diagram, node receiving module is turned on in waiting mode. However, in inactive mode all modules will become inactive. Proposed protocol performs this optimization just through those nodes inside δ-circle and near to hexagon's vertex, which are in waiting mode. Then all neighbor nodes will become inactive (those outside δ-circle). Center of δ-circle is located in $\left(s - \frac{\delta}{2}\right)$ distance from activator node, and an angle being a multiple of $\frac{\pi}{3}$. Finally, it has to be mentioned that at the end of rounds changing process, active nodes remain active after current round is finished, and at the beginning of the new round. Duration of the process equals duration of protocol convergence. After this time interval, status of nodes will be changed. The reason for such time interval is keeping active the active nodes so that no interruption occurs in coverage.

Method of Computing δ-circle for Various Distributions in development

As mentioned in previous section, the way nodes are distributed and developed makes clear the value of δ. The circle is the smallest on in the environment having at least one node, with diameter of δ. In this section method of calculating δ for grid and uniform distribution will be dealt with. Calculation of δ for other distributions will be also derived from the same calculations. Suppose that n nodes are located in a $l \times l$ square. For distribution of grid, nodes are distributed in a way that they are located in a $\sqrt{n} \times \sqrt{n}$ virtual network. The distance between each two adjacent point in the grid is equal to $\frac{l}{\sqrt{n}}$. To calculate δ , each grid network cell has to be composed of some squares in form of $\frac{l}{\sqrt{n}} \times \frac{l}{\sqrt{n}}$. It is obvious that, δ ebing bigger than square diameter may guarantee that each area of the network with δ-circle has covered at least on node. So, for a network with grid distribution δ is equal to:

$$\delta = l\sqrt{\frac{2}{n}} \qquad (2)$$

However, when nodes are uniformly distributed in $[0,2\lambda]$ range, the distance limit between adjacent nodes is equal to λ. This is when maximum permitted range between neighbor active nodes is equal to 2λ. Similar

to method of calculating δ in the network with grid distribution, δ value is equal to $2\sqrt{2}\,\lambda$. In uniform distribution of n nodes over a $l \times l$ square, λ value should be equal to $\frac{l}{\sqrt{n}}$, and δ would be computable via:

$$\delta = 2l\sqrt{\frac{2}{n}} \qquad\qquad (3)$$

It has to be noted that in real world, random deployment distributions of δ values will be more. Proposed protocol does not require δ with a fixed threshold during network lifespan. Instead, δ could be made variable for failed nodes or those nodes located in those areas with less density. For example, δ may be doubled after several rounds of network. For this, the node is required to have a numerator for number of rounds passed.

Synchronization Interval

Proposed protocol has to make some nodes active within the intended time, for each round to be started. The most important point in the protocol is time synchronization of processes. Any synchronization pattern in proposed protocol may be used. First activator node puts remaining time of current round in activation message. When nodes receive activation message, they may calculate ending time of the round after deduction of delay and release levels. The process is performed for sequential activations.

Method of implementing active and inactive mechanisms in adjacent nodes through learning automata

Considering the point that sensing radius of the sensor existing in proposed protocol is mostly higher than s, in this triangulation structure all nodes on vertexes or inside each triangle have not to remain on. Therefore, through an adaptation mechanism, in each round only 3 nodes from among those located on vertexes or inside triangles will be on. So, three types of nodes will exist in each round, respectively as listed below:

- Active node (type 1);
- Node Adjacent to active node (type2); and
- Nodes far from active node (type 3).

In order to be active in future round and after the time for current activity is expired, each of nodes has following automata probability.

Table 1- Current and future probabilities table considered for various types of nodes

Type of node	Type 1(%)	Type 2 (%)	Type 3 (%)
Current round probability	100	0	0
Future round probability	25	50	25
Future round penalty	50	10	40
First energy threshold 75% (current round probability)	25	50	25
Second energy threshold 50% (future round probability)	20	60	20

Active current node has low probability of being active in next round; because, continuous activity results in high energy consumption. Nodes close to active node are best alternatives for activity in future round; so, they have higher probability percentage for next round. However, nodes farther are those alternatives with low percentage of probability; because, in adjacent node they are considered as close neighbors. Penalty percentage after being active in current round would be 25, along with supplementary reward percentage. The reason is that, programming has been made just for future round; and, in case member nodes are not available, the process will be compensated via farther nodes and probabilistic approach of coverage. In continuation of work procedure of the protocol and after first round, energy levels of network nodes are not similar. So, energy levels are supposed to be considered in selection of nodes for activity in future round (s).

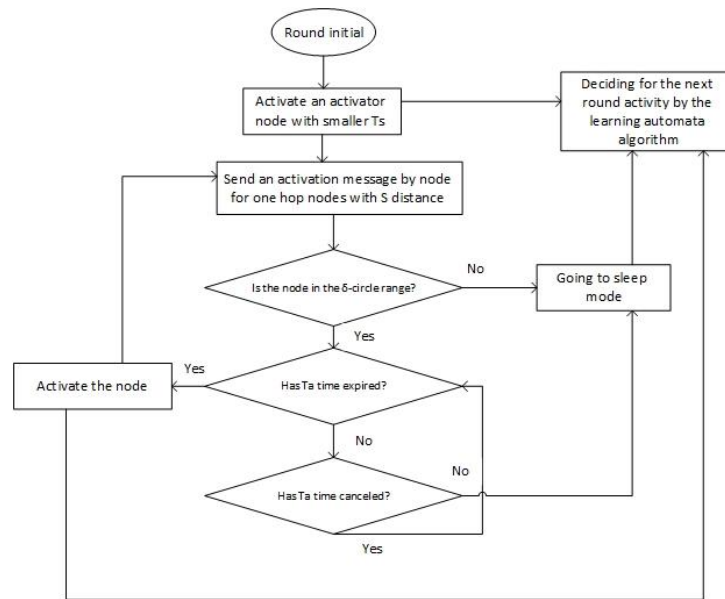Conceptual and overall diagram of proposed method is presented in figure 7:

Figure 7- Conceptual diagram of proposed model

Simulation, Evaluation and Conclusions

In previous section, CPLA proposed protocol has been explained in details. Here, we are aiming at review of effects of active and inactive mechanisms with learning automata, along with aggregated algorithm, and proposed routing through some tests. So, according to the table 2, required parameters have been implemented in NS2 simulator. The simulator is used because of its popularity and strength. Effort has been made to evaluate proposed algorithm through three different scenarios with 600, 800, and 1000 nodes so that optimized status of protocol would be specified; and, to see if it is of more efficiency in busy environments or those with less density.

Simulation objectives

As far as the protocol under comparison also has probabilistic model, effort has been made for evaluation to be made under equal and similar conditions. Compared protocols have been equipped with prevailing mechanisms including active and inactive in which random arrangement structure, disk cover, and approximation structures have been used. In this type of network, to compare efficiency, several basic parameters of the network have to be calculated. These parameters will be explained in details in chapter 5, and the results will be compared. In terms of coverage and as far as wireless sensor networks coverage is visually supported by NS, pursuant to aforementioned mathematical models in previous chapter and observable results it could be proved that network coverage is optimized. Meanwhile, least number of active sensor nodes and minimum full coverage of points have been used.

Introducing simulation parameters

Table 2- Simulation parameters of proposed protocol

Effective parameters	First scenario	Second scenario	Third scenario
Physical layer	Phywireless-Mica2	Phywireless-Mica2	Phywireless-Mica2
Type of antenna	OmniAntenna	OmniAntenna	OmniAntenna
Queue type	DropTail/preQ	DropTail/preQ	DropTail/preQ
Queue length	50	50	50
Energy resource	Battery model	Battery model	Battery model
Network size	250x250m	250x250m	250x250m
Number of AP (access points)	1	1	1
Network distribution	Random	Random	Random

Simulation duration	1000s	1000s	1000s
AP location	Center of network	Center of network	Center of network
AP initial energy	100j	100j	100j
AP range of communications	1200m	1200m	1200m
Number of network nodes	1000	800	600
Communication range of nodes	200m	200m	200m
Sensing time interval	0.5s	0.5s	0.5s
Initial energy of nodes	10j	10j	10j

Testing number of active nodes in each round

In the test that is dependent on our virtual grid calculations, number of active nodes in each round of protocol has been compared to number of 600, 800, and 1000 nodes. The more the area under coverage of network is covered with minimum number of nodes; it could be recognized that the protocol has achieved its coverage objective.
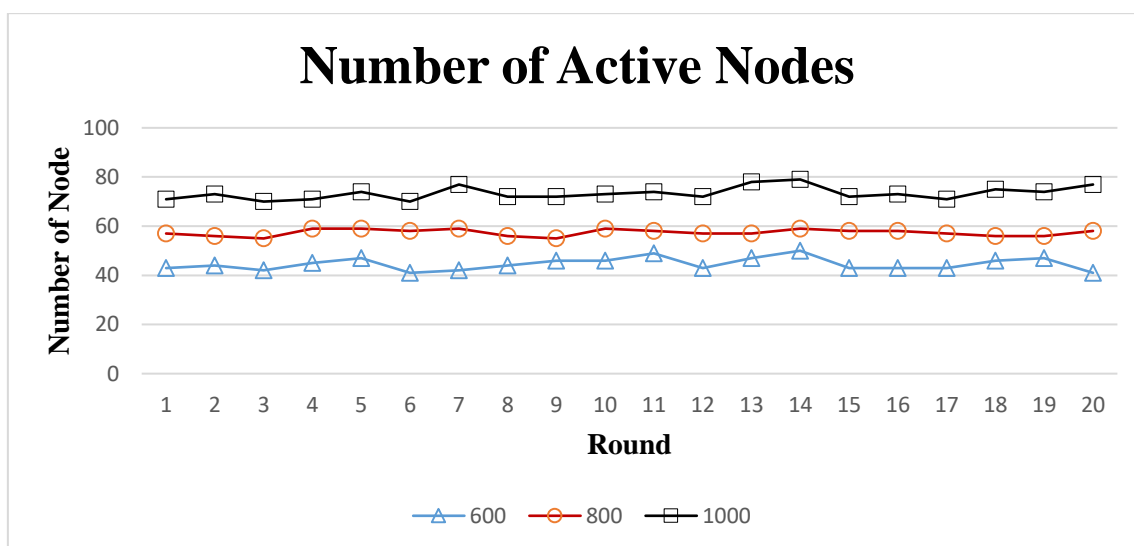

Figure 8- Testing number of active network nodes with 600, 800, and 1000 sensor nodes in 20 rounds of virtual grid implementation
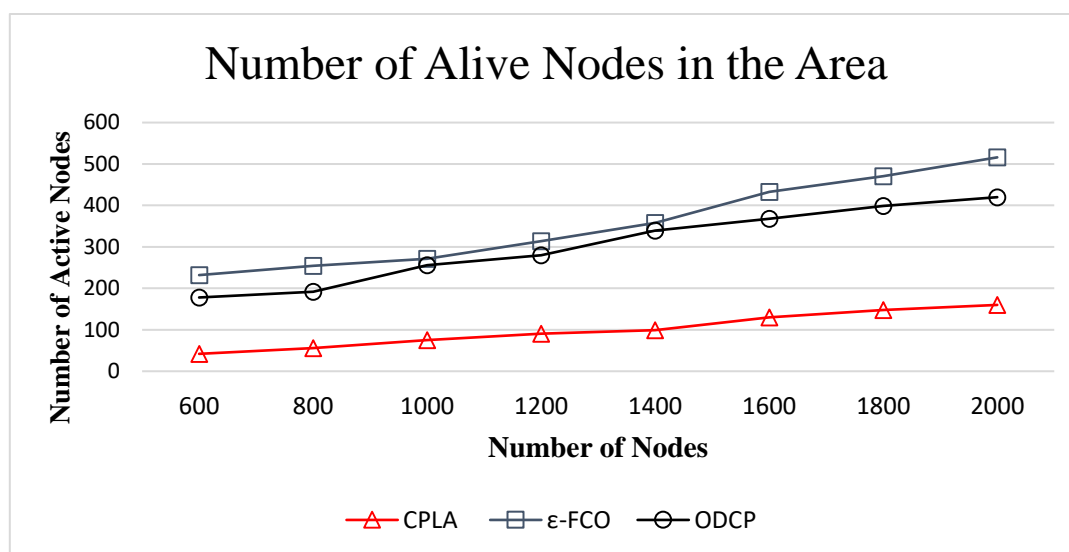
Figure 9- Testing number of active network nodes with various numbers of nodes, comparing to ODCP and ε-FCO protocols

Network lifetime test

Based on methods and strategies already presented, we may find that adaptive active and inactive scheduling mechanism will have direct and close relationship with energy consumption rate in the network. Using minimum active nodes in each time interval may result in appropriate procedure of energy consumption.
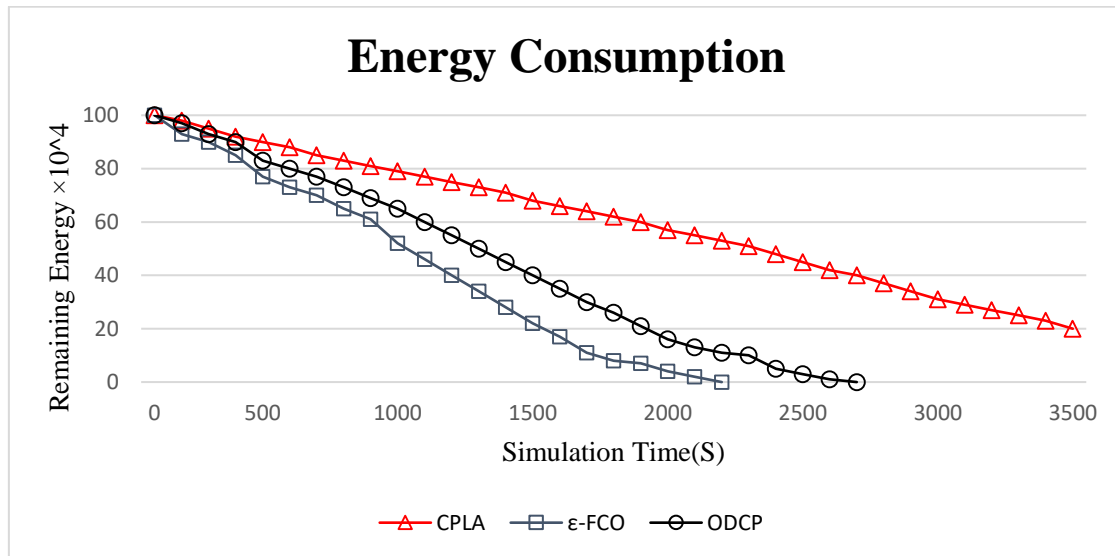

Figure 10- Testing energy consumption rate in CPLA network during activity, comparing to ODCP and ε-FCO protocols

Conclusions and Future Works

In the research, a method based on learning automata has been presented and evaluated for implementing coverage in directional wireless sensor networks. The method performance was very desirable, comparing to other methods. Proposed method uses four statuses for network nodes, each becoming active according to schedulers and messages sent from nodes, in various times. Considering markings and discussions, the followings will be resulted.

Number of starting nodes in each round may be controlled and programmed through T_s active time range. Value of T_s is randomly selected between zero and τ_s constant. Suppose that we are going to obtain τ_s value for each round in the proposed protocol with average number of K nodes. To do so, it is supposed that convergence time average in the proposed protocol is equal to T_c. Please note that, if T_s starting time of a node is less than T_c, the node will be transformed to starting node before the time of network convergence. Number of expected nodes is equal to $k = (\frac{T_c}{\tau_s})n$ when T_s is smaller than T_c. Where, τ_s is equal to $\tau_s = n(\frac{T_c}{K})$. Finally, is equal to reverse of remaining normal energy level $E_r : (0 < E_r \le 1)$ and shows that with higher level of remaining energy, the node has more chance to be transformed to a starting node. So, this is τ_s that through computing $\frac{nT_c}{KE_r}$ permits K transformation of K to a starting node with the highest level of remaining energy, in average. This keeps more nodes alive for longer time, and eventually network lifespan would be increased.

In continuation, the research may be expanded and strengthened in theoretical and practical terms including usage of more comprehensive analysis, more parameters, and other types of automata. For other scenarios also the method could be applied for more complete analysis to be performed. Researching usage of proposed method on various sensor networks is considered as an item for future expansion of research.

Considering efficiency and quality parameters as well as quality of service will be from among other items for development in future.

Acknowledgment

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