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A Distributed Algorithm for Coverage Management in Wireless Sensor Networks

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ABSTRACT

Lifetime management of sensors is defined as one of the most critical and vital concepts of targets coverage in all kinds of wireless sensor networks. One of the most popular methods in order to increase a network's lifetime is dividing the sensors of that network into some temporary subsets in which each one could independently cover all the targets while they keep their connectivity with the sink node. Therefore a sensor network could easily use an activated subset of its sensors to cover its targets and let the other sensors sleep or stand by at the same time. Moreover, a network's lifetime could be efficiently managed by controlling of its coverage circumstances. In this paper, an improved distributed algorithm is proposed for the problem of connected partial targets coverage. Our experimental results demonstrate that the lifetime of a wireless sensor network is highly increased while it uses the proposed method in this paper.

KEYWORDS: Wireless sensor network- Energy optimization- connectivity- K coverage- Balanced energy consumption- Partial coverage

1. INTRODUCTION

During recent years, improvements in telecommunications technology and manufacturing developments of electric and electronic equipments have led to production of different kinds of tiny and cheap micro-sensors that could be connected to each other via the air interface and generated deferent kinds of Wireless sensor networks [1]. These networks are considered as an appropriate and flexible way in order to monitor and collect various types of environmental events and parameters.

In order to create an ideal and suitable wireless sensor network several concepts should be noticed such as its environmental coverage, number of required sensors and above all its lifetime that is considered as the most challenging point of the designing and implementation procedure. Up to now several approaches have been introduced to have a longer life for a wireless sensor network. In one way, it is capable to divide the time into some determined periods for a network, so that in each period a subset of sensors that could cover all the network's targets are activated while the others are deactivated or slept.

In most of applications it is needed to increase the targets coverage degree of a sensor network in order to increase its information accuracy. In other words, every target could be covered with K sensors. On the other hand, lifetime of every wireless sensor network could be maximized by the management of its targets coverage. In order to achieve this issue, in applications that the network's lifetime is more important than the amount of coverage degree, it is useful to assume that closed targets have similar information. Then we could just cover one of these closed targets with sensors and let the others uncovered so that as its consequence the number of sensors is reduced appropriately.

In this paper, the problem of partial targets coverage for covering sets that maintain their connectivity with their Base station is mentioned and analyzed. Moreover, In order to maximize the amount of a network's lifetime, a distributed algorithm that is able to determine some appropriate covering sets is introduced with the consideration of connectivity requirements and communication costs. In section II, some of major previous activities and their results are summarized. Section III is assigned to introduce a robust distributed algorithm that provides a significant K-coverage whereas it minimizes the number of activated sensors simultaneously. In section IV, at first some new metrics of Quality of Service (QoS) are introduced and then the capabilities of the proposed method are illustrated by the simulation results. Finally section V consists of conclusions that are related to the proposed method and its comparisons with some other similar algorithms.

2. Related works

While battery replacement is impossible in most of wireless sensor networks, the optimum use of power will be considered as one of the most essential and critical requirements in order to prolong the network lifetime. In [2] the MCS method that is based on maximizing the number of sensor sets is proposed. In this method it is permitted to every node to be placed in several groups that lets a network has a longer life. In this way, group selection is made by linear programs and

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calculated by a greedy method. A hierarchical clustering algorithm that is named DEEG is introduced in [3] to reduce the use of energy related to inter-network communications and load balancing.

In [4] another clustering method is introduced, that is based on maximum latency, wasted amount of energy in middle nodes and clusters' sizes. These parameters that have a significant influence on a network's lifetime are considered as some of the QoS parameters of that network. The proposed method that has a polynomial running time uses a recursive algorithm to select minimum weighted sets due to latency and energy usage limitations. In the EDTC method that is presented in [5] priorities are based on remaining energy and number of monitored targets. Two parameters of sensing coverage and network connections are concentrated more in [6] which is presented by Bai and his colleagues. In [7] another algorithm is presented in order to coverage independent targets and insures sensors' connectivity with their sink node. In this paper two different scenarios are presented so that at one of them each node is able to separate maximum number of L covered targets around its sensing area; while at the second one each node is only able to collect the information of it sensing radius without any capability for target separation. Another distributed algorithm whit the aims of coverage optimization and increasing the network lifetime is also proposed by Zhang et al in [8]. Cardei in [9] claimed that his proposed method that is able to cover some determined discrete targets and connects sensors to their sink node prolong the network lifetime. In order to achieve this issue, his proposed algorithm separates all the sensors of a network into sets so that the sensors of each set could cover all the targets individually while they keep their connectivity with the sink node. Finally, in [10] the problems of targets coverage and connectivity of sensors and sink node are mentioned. In this paper the additional parameter of minimum amount of desired coverage is joined to previous parameters to generate a centralized method that is also able to be implemented as a distributed algorithm; however there is not any explanation for that.

3. THE PRESENTED METHOD

3.1. Definitions and assumptions of the proposed method

In distributed methods each node runs its own algorithm individually, collects some slight and limited information from its adjacent nodes, and decides to send its information locally. Therefore, in comparison with the centralized methods, these methods have more advantages because they distribute their processing duties among their sensors. As a consequence, these methods are able to extend their coverage areas and support massive amounts of sensors.

In this paper based on the optimization of introduced methods in [9] and [10] a new partial targets coverage algorithm is presented. In this way, it is tried to overcome disadvantages of previous algorithms and add some useful capabilities to them.

It is assumed that all the scattered sensors in a field have the same ranges of sensing ($\boldsymbol{R_s}$) and communicating ($\boldsymbol{R_c}$) so that $\boldsymbol{R_s < R_c}$. Moreover, with the consideration of this claim that adjacent targets have same information; network coverage degree (K) and uncovered region radius (M) are defined so that each target could be covered by the maximum number of K different sensors while M is the radius of a circle around a covered target in which its adjacent targets that are located on that circle are not covered by the network. After this, this circle is called uncovered region. The amount of M equals to either zero in which in this case all the targets are covered or a quantity grater than $\boldsymbol{R_s}$ so that covered targets are decreased while M is increased. Therefore, in the second case, fewer numbers of sensors are needed for targets coverage and information communication at the expense of lower amounts of network's accuracy. The number of sensors and targets are also considered to be N and C respectively, so that each node has the initial and temporary energy amounts of E and $\boldsymbol{e_i}$ for a determined period of T. Moreover, it is assumed that all the sensors are synchronized and they are aware of coordination of themselves, their targets and sink node.

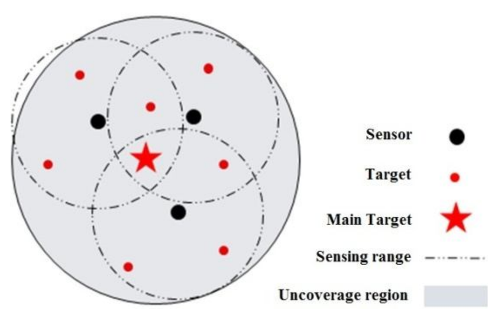

Figure 1: a sample of uncovered region's influence on targets coverage degree

3.2. Proposed Method's Stages

The proposed method is divided into three practical sections below.

3.3.1. First Phase: Data Collection

In this phase each node starts to collect its needed information in order to run its own local algorithm. Thus, each node sends a hello packet to its neighbors. Then the neighbor nodes generate and send the transmitter node their reply packets that include their IDs and coordination. As a consequence at the end of this phase each node knows its neighbors and their coordination in order to calculate a minimum spanning tree (MST) that its vertex and nodes are the sink and targets respectively, , as demonstrated in figure 2.

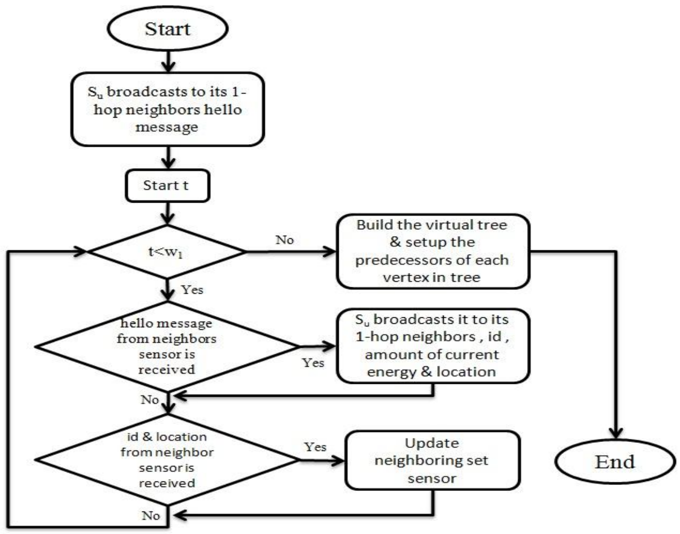

Figure 2: The process of data collection in phase one

3.2.2**. Second Phase: Selection of Sensing Nodes**

In this phase appropriate covering sensors that should remain activated are determined. In this procedure the energy amount of each selected node should be greater than a threshold amount that is needed for a node to be alive in a period of T seconds. The selected nodes should also cover designated targets so that K coverage degree is retained and targets within a radius of M meter of covered targets are uncovered. Before any explanation about this phase it is needed to represent some definitions.

In the proposed method, all the targets are divided into three groups:

1. First group that includes the nodes that are not covered by even a sensor or the nodes that are not stood in an uncovered region of a covered target and are covered less than K-coverage. After this, these targets are shown as $\boldsymbol{T_{uc}}$.
2. Second group pertains to the targets that are covered by K sensors and there is not any need for them to be covered by another sensor. They are referred to as $\boldsymbol{T_c}$.
3. And finally third group is assigned to uncovered targets that are placed within a circle less than M meter radius of covered targets so that there is not any need for them to be covered. These are called $\boldsymbol{T_{nc}}$.

In this method the first sensor that covers a target is named supervisor node and as is shown in figure 3 other remaining K-1 nodes have to send their information to their supervisor in order to be transferred to the sink node.

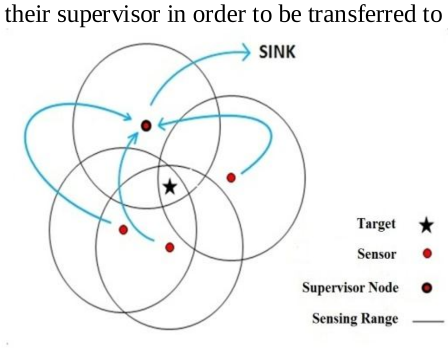

Figure 3: A schematic display of data transferring procedure for K=4.

In this phase an uncovered region is considered to be a circle around the closest target to an arbitrary sensor. This phase itself is divided into two sub-phases that are run in parallel.

3.2.2.1: first duty

In this stage sensors through relation (1) try to compete against each other to be selected as sensing nodes. Therefore, each sensor waits for a computed backoff time based on its residual energy amount and number of under-covered targets. When the backoff time of a node expires if there would not be another recognized node as a winner that node is selected as the winner of competition [9].

$$\boldsymbol{Delay_i = \left(1 - \alpha\frac{|Targets_i|}{|T|} - \beta\frac{e_i}{E}\right) Delay_{max} + Rnd(d)} \quad \textbf{(1)}$$

Where $\boldsymbol{Delay_{\ i}}$ is the calculated amount of backoff time for $\boldsymbol{i}$th node, α and β are constant coefficients that determine the amounts of influence and priority of coverage and energy levels. $\boldsymbol{e_i/E}$ is the proportion of $\boldsymbol{i}$th residual energy to its initial value. $\boldsymbol{|Targets_i|}$ is number of targets around the sensing range of the $\boldsymbol{i}$th sensor. $\boldsymbol{|T|}$ is the number of all targets in the field.

$\boldsymbol{Delay_{max}}$ is the maximum amount of waiting at the process of coverage. Finally $\boldsymbol{Rnd(d)}$ is an integer number which is randomly selected from the interval [0,d].

When a node wins the above competition it starts to send two messages around its communicating area. The first one that is called (A) is sent to inform other adjacent nodes about the supervision or targets coverage situation. And the second one that is called (B) is sent to inform other sensors about the determination of M as the radius of uncovered area around the covered target. The second is sent if and only if the transmitter node was the first node that covers a $\boldsymbol{T_{uc}}$ target.

The first message that is sent up to two hops includes the covering sensor's ID and coordination, and also its covered targets' IDs and coordination. The second message that is simultaneously sent with the first one includes the main target's coordination and a time stamp which could show the winning time of the transmitter sensor. This message is also broadcast through the air interface for a radius of r that is calculated from the relation (2)

$$\boldsymbol{r = m + R_s} \qquad \textbf{(2)}$$

While a sensor received a type (A) massage for the first time, that node starts to check whether there were any similar target or targets between the received message and its own list or not. If there is a similar target, the receiver node does the following procedure. As long as the amount of its targets counter was less than K the receiver node adds one unit to that as a $\boldsymbol{T_{uc}}$ target. While its targets counter was equal to K its type is changed to $\boldsymbol{T_c}$ and that target is eliminated from the receiver node's covering list. Moreover if the targets counter of a message is equal to one, the receiver node finds out that its transmitter is the supervisor node of that target. On the other hand, if that similar target is a $\boldsymbol{T_{nc}}$ one, the receiver node only changes its type from $\boldsymbol{T_{nc}}$ to $\boldsymbol{T_c}$ and eliminates that target from its covering list. It is also important to say that if a node has more than one $\boldsymbol{T_{uc}}$ target, it selects its closest target as its main target.

While a sensor received a type (B) message it changes its determined targets from $\boldsymbol{T_{uc}}$ to $\boldsymbol{T_{nc}}$ in its list of under-covered targets if those targets were placed around the main target with distances less than the amount of M. Moreover, if the receiver distance with its transmitter is less than r, the receiver relays that message to its next hop, otherwise nothing will be happened.

As it is indicated in figure 4 those targets that are located in the shaded area will be uncovered by sensors. On the other hand, K sensors cover the main target while its nearest sensor is its supervisor.

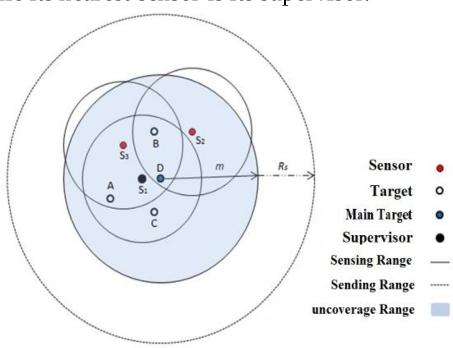

Figure 4: A view of main target coverage and uncovered region

3.2.2.2**: second duty**

The aims of this stage are to restrict the amount of information transmission at proceeding stage, and select appropriate nodes that are responsible for information relaying from K-1 sensors to their supervisor node. The second aim is proposed only because of the assumption $\boldsymbol{R_c \geq R_s}$ that prevents us being sure about direct communications between K sensing nodes of a target.

Therefore, each node prepares a table that includes coordination of its all adjacent nodes and targets for itself. Moreover, in this table all of the adjacent nodes' targets that are located in their sensing radiuses are determined and it is calculated that which adjacent nodes could cover a similar target or targets while their communication ranges are not overlapped each other. If there were such neighbors, they would be specified and their related covering messages will be only relayed to them for the second hop in order to prevent extra relay messages.

In order to specify intra-cluster relaying nodes, all sensors that relay covering messages from the first hop to the second one, extract and save some information from the above messages, such as transmitters' locations, their situation of being supervisor or not for each target, and their lists of covered targets. Afterwards, using this information each node could easily select itself as an intra-cluster relay if its two neighbors cover a same target while one of them is its supervisor and also the neighbor nodes could not directly communicate with each other. All of this procedure is completely illustrated in figure 5.

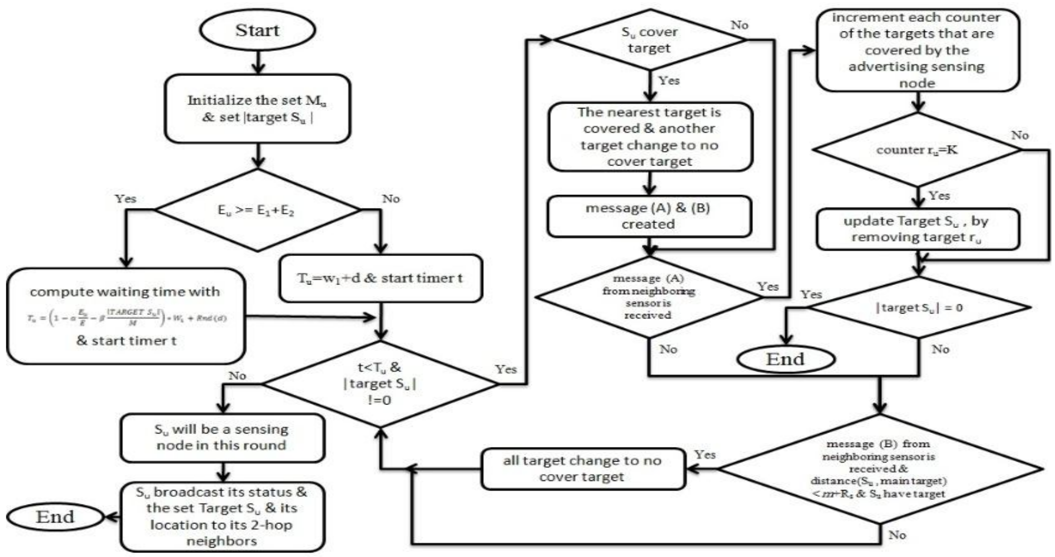

Figure 5: A flowchart for Selection of Sensing Nodes in phase two

3.2.3: **Third Phase, Determination of Relay Nodes**

In this phase a series of nodes are selected to relay the collected information from a network's supervisor nodes to its sink node. Based on the parameter of distance MST that was calculated in phase one is the best path of connecting all supervisors to the sink node. Although it should be mentioned that all targets are not covered by the tree in our proposed method and the targets that are located in uncovered regions have to be uncovered.

In the proposed method each supervisor node based on its under-covered target's position on MST, has to send a message that is named Path Finding Message (PFM) to its next node on the tree. This message includes information such as IDs of transmitter supervisor and its target, supervisor's coordination, and the maximum considered distance that the message must traversed. While a sensor receives a message, it relays that massage to its next hop if and only if that node is not the target covering node that is determined and its distance was less than the specified amount in that message, and it is also save its transmitter's ID. Otherwise nothing specific is happened and that message is eliminated by its receiver. On the other hand, if a supervisor or a temporary covering node of a desired target receives a message that is about that target, one two cases below will be happened based on the target's type:

3.2.3.1: Case one: out of uncovered region targets

If the desired target is a main target while is covered simultaneously with K sensors, it is clear that the receiver sensor is a supervisor one. Thus, a unicast Path Acknowledgement Message (PAM) is sent to the transmitter back through the same path and its intermediate nodes are selected as relay nodes. Figure 6 demonstrates a procedure for the selection of relay nodes between two covering nodes that have connected targets on the MST. In this figure the nodes (A) and (B) transmit PFM and PAM messages to each other respectively.

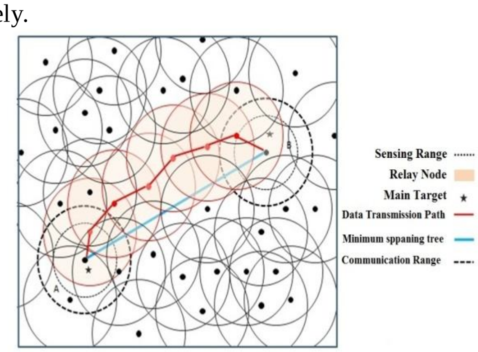

Figure 6. Formation of a connection path and selection of relay nodes

3.2**.3.2: Case two: intra-uncovered region targets**

A destination target will be eliminated at the end of this phase if its type is $\boldsymbol{T_{nc}}$, or in other words if it is located in one of uncovered areas. Therefore, this node relays its PFM message for the next node on the MST that is calculated at the first phase. A massage that only mentions it is a relay message. This procedure is continued until a supervisor node that covers a main target receives it.

Notice: In order to decrease the number of redundant messages and amount of consumed energy in a network, if a supervisor node knows that its next target on MST is a $\boldsymbol{T_{nc}}$ one, it could directly choose its next target and put that in its PFM message. The whole of this process is shown in the figure 7.

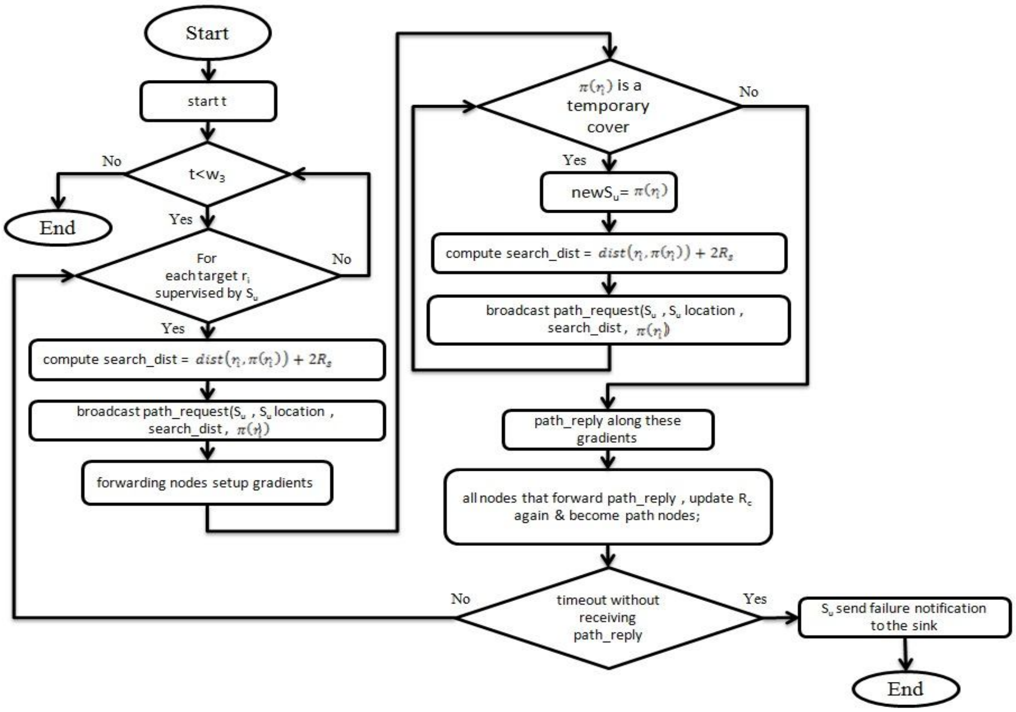

Figure 7: A flowchart for Determination of Relay Nodes in phase third

After the end of this phase all the covering and relay nodes that are determined in both phases two and three will remain alive in this period, and the other nodes will change their mode into the sleep.

4. SIMULATIONS AND RESULTS

4.1. Evaluation and Simulation

Using C++ an appropriate experimental environment is generated for our proposed method. This simulation environment have some inputs such as communication range, sensing range, number of scattered sensors in the field and their initial amount of energy, number of targets and their coverage degree, maximum needed amount of energy that used to transferring data, uncovered region radius (M), time of the simulation and etc. A 400*400 field is considered for our simulation.

4.2. Simulation assumptions

It is assumed that 800 sensors were scattered in our field while the sink node is located at its center. Communications and sensing ranges are considered to be 40 and 30 respectively. The initial energy amount of each node is assumed to be 10000 mw/h, while the needed energy amount for information communicating and sensing operations are considered to be 10 and 5 mw/h respectively. Finally it is assumed that $\alpha=\beta=0.5$ and each simulation runs for 300 iterations.

4.3. Active sensors in Cardei and proposed Methods

This section is assigned to compare our proposed method with the Cardei method from the point of average number of needed sensors for target coverage in each period. So it is assumed that M=0 and K=1 cause in Cardei Method M>0 and K>1 could not be considerable. Moreover, the number of scattered sensors is 400 while the number of targets will be varied between 1 and 30.

Figure 8 indicates the effect of targets' number on the number of active nodes that are used to cover them. Various amounts of coverage degree are used to evaluate our proposed method and compare that with Cardei algorithm. Assuming M=0 and K=1 both methods have similar results. But it is obvious that when the above condition changes significant and dramatic improvements are obtained from the proposed method. It is also could be derived from figure 8 that both the algorithms are closed to each other because of their closed output averages for their large numbers of iterations.

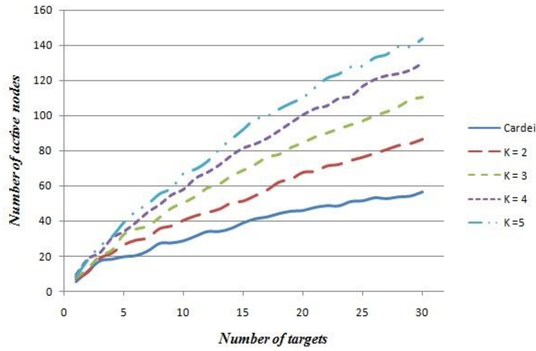

Figure 8: the number of activated nodes with consideration of various numbers of targets in a distributed case

Finally based on our obtained results it is clear that the number of activated nodes increased when K increases. Moreover, it could be also seen slopes of activated nodes' numbers that have direct relations with targets' number are not linear. For example in case K=1 (Cardei), only an average number of one sensor is added in proportion with the increase of each target. Whereas, in case K=5, that average number of added sensors would not be necessary increased to 5 for each target. That is because of that some sensors could cover several targets simultaneously. In addition they could also participate in data communication to the sink node.

4.4. Effect of uncovered region (M) on the lifetime

As it was mentioned before, every network's lifetime is one of its most important parameters. So in this section it is tried to evaluate the lifetime of a network based on different uncovered region radiuses.

During the simulations it is assumed that 20 targets are scattered through our field and also the amount of coverage degree for all targets is considered to be one. In each period while a sensor covers a target, it determines an event and sends a data packet to the sink node with the energy of 30mw/h.

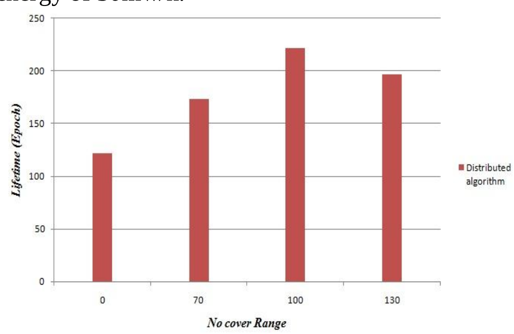

Figure 9: the effect of uncovered region radius on a network's lifetime

As it could be easily seen from the figure 9 the lifetime of a network could be rise while M is increased. However, if the amount of M exceeds a particular number as it is illustrated below the lifetime parameter reduces On the contrary.

In the proposed method, while the uncovered region radius is determined, each covering node must send other nodes a packet and inform them not to cover those targets that are inside its related uncovered region. In addition, some energy consuming messages are sent in the phase of path determination. While the amounts of these messages reduce considerably, lower amounts of events should be processed and as its consequence fewer numbers of messages have to be sent to the sink node. So energy saving would be inevitable. In fewer amounts of M, the proportion of saved energy to the consumed energy increased interestingly. On the other hand, while M exceeded a significant amount reversed results are seen, because of that in this algorithm larger amounts of M involve more numbers of nodes that should be aware of M and as its consequence larger amounts of energy should be used in order to inform other nodes.

5. **Conclusion**

In this paper the problem of partial target coverage is questioned at first and then a distributed energy efficient algorithm that has similar results with Cardei algorithm is proposed. In order to have an improved algorithm it is assumed that adjacent targets have similar probable information. Thus, in order to decrease total amount of consumed energy while a target is covered, its adjacent targets that are placed in a radius of M around that are avoided to be covered by the proposed algorithm. Simulation results indicate that this method could significantly reduce energy consumption. Moreover, in order to increase the accuracy of proposed method K-coverage and connectivity are considered in that. Finally simulation our results demonstrated that most of a network's critical parameters such as energy usage, number of active nodes and lifetime is improved dramatically.

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