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Fault Tolerant Dynamic Multi Level Coverage for Clustered Three Dimensional Wireless Sensor Networks

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Abstract
An important issue in WSN is the regional covering. A coverage algorithm should solve this problem by considering the power consumption to improve the network lifetime. This requires employing the lowest number of sensors. This paper presents a novel approach to improve FEED algorithm for three dimensional clustering wireless sensor networks. This algorithm achieves full coverage in three dimensional wireless sensor networks. In this algorithm the area of a cluster which is a ball is to be divided into some small balls each one in charge of covering its corresponding 3D area by using lowest amount of nodes.

Keywords: **wireless sensor network, cluster head, supervisor node, energy reduction**

I. INTRODUCTION

Wireless Sensor Networks consist of a huge number of sensor nodes, with limitations like their energy resources, dispersed in a region. All network nodes have wireless communications and send information about their region to a base station either directly or via other nodes. Energy efficiency is one of the most important factors in wireless sensor networks. Routing plays a critical role in energy efficiency, so a suitable routing protocol should be selected for this purpose.

Clustering is an approach by which, all network nodes are organized into clusters and communicate with a cluster head which forwards received data to base station. Clustering aims at achieving an energy efficient routing protocol. In clustering, every cluster has a cluster head. In every round, some nodes are selected to act as cluster heads and regular nodes try to join to the nearest clusters.

In some clustering algorithms, cluster heads are selected randomly in every round (Heinzelman et al., 2000). Some others are sensitive to energy, distance, etc, like the algorithms mentioned in (Younis and Fahmy, 2004; Gupta, I., et al., 2005). Moreover, the algorithm mentioned in (Gupta, I., et al., (2005)) has tried to use other techniques including fuzzy logic to form clusters.

Selecting suitable cluster heads can lead to a decrease in overall energy consumption and also an increase in network lifetime. Also this can be affective for coverage problem as can be seen in (Shanbehzadeh,et al., 2011).

Some clustering algorithms like FEED (Mehrani,et al., 2010) pay attention to some very important factors like energy, density, centrality and distance between nodes to form clusters.

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FEED propose an energy efficient clustering method which selects suitable cluster heads by paying attention to energy, density, centrality and the distance between nodes for making clusters. Moreover, in this approach every cluster head has a supervisor node. This property leads to an increase in network life time and also a fault tolerant clustered network.

Denoting the turn on time slice for network nodes is very important to avoid of happening overlapping between covering areas of the nodes. Because each node just knows about sensing region of its own. The overlap areas will have negative impact on the energy factor. It is because of the possibility of repeating messages. To avoid overlap areas clustering technique can be utilized. In this paper first we introduce enhanced FEED algorithm which works in three dimensional regions, divide all the sensor nodes into some clusters by using this clustering algorithm and then we propose a very useful strategy to achieve at full coverage issue in an energy efficient manner.

In Section 2, we review related works. Then we describe our proposed algorithm in Section 3. Section 4 reveals the evaluation of the performance of the proposed algorithm. We conclude in Section 5, with a summary of the contributions of the proposed approach.

II. Related Works

A. *LEACH*

LEACH (Low Power Adaptive Clustering Hierarchy) is an algorithm used for clustering in WSN. In this algorithm there is a probability formula for every node to be a cluster head in every round. At the beginning of every round every node chooses a random number between 0 and 1. There is a threshold number T (n) which varies in every round. The node can be a cluster head in the current round if the random number chosen by it is less than T (n). If a node decides to be a cluster head in a certain round, it informs other nodes about this fact by broadcasting a message. Then every regular node joins the nearest cluster. The LEACH probability formula is:

$$T(n) = p(n)/(1 - p(n) * (r \bmod (1/p(n)))) \quad \forall \; n \in G \qquad (1)$$

Where *n* is the number of network nodes, *r* is the number of the round, *G* is the set of nodes that haven't been cluster head in the last *1/p* rounds and *p* is the desired percentage of cluster heads which equals to *0.05*. This formula lets every node to have the chance of being a cluster head once in every *1/p* rounds. LEACH enhances network lifetime and energy consumption compared with the Direct algorithm. One shortcoming of LEACH is that it doesn't consider the energy factor in selecting cluster heads. Thus chosen cluster heads aren't always suitable for the network.

B. *HEED*

In HEED (A Hybrid, Energy-Efficient, Distributed Clustering) several iterations are needed to choose a cluster head. The time slice for each iteration should be long enough for a node to receive all sent messages from its neighbor nodes. All nodes assume the initial probability to become a cluster head as follows:

$$CH_{prob} = C_{prob} \times \frac{E_{residual}}{E_{\max}} \qquad (2)$$

At the beginning of each round all uncovered nodes decide to be cluster heads with probability CH_{prob}. If a node decides to be a cluster head, it broadcasts a message to other nodes.

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ISSN1925-931X

In this message if CH_{prob} is less than 1, the node introduces itself as a tentative cluster head. If CH_{prob} is equal to or greater than 1, the node introduces itself as a final cluster head. At the end of each iteration all nodes double their CH_{prob}. A node assumes itself covered if it is covered by at least one tentative or final cluster head. If at the end of a round, a certain node isn't covered by any tentative or final cluster head, it reveals itself as a final cluster head. Then each node joins a cluster which generates the lowest cost for it.

C. *FEED*

FEED (Fault Tolerant, Energy Efficient Distributed Clustering for Wireless Sensor Network) selects the cluster heads based on factors such as: energy, density, centrality and distance between nodes. FEED algorithm executes in four phases. In the first phase each sensor node sends its *id* and coordinates to around neighbours and receives same messages from them. By doing such, each node can compute its density and centrality. A new method for computing centrality factor is also introduced in FEED algorithm. Each node calculates its first score by mixing energy, centrality and density factors and getting an average from them.

In the second phase, those of nodes that their energy and density factors are good introduce themselves as volunteers. Then in the third phase, each node gives second scores to its near volunteers by entering distance factor to first scores of the volunteers and reveals a volunteer with best second score as its deputy.

In the fourth phase volunteers calculates their final scores and according to that reveals themselves as CH, PCH or SN nodes. Then regular nodes join to nearer clusters.

This algorithm improves the network lifetime in a significant way in comparison with two well known clustering algorithms LEACH (Heinzelman et al.,2000) and HEED (Younis and Fahmy, 2004). Furthermore, FEED algorithm leads the network to be fault tolerant. "Fig. 1" shows the improvement of network life time by FEED in comparison to LEACH and HEED algorithms. In FEED when the remained energy of a cluster head falls under a threshold, its supervisor node will replace it and the cluster can continue its activity by the new cluster head. This property leads network to be fault tolerant. According to "Fig. 1", FEED algorithm improves network lifetime in comparison to two other algorithms. Supervisor node replacement can be a reason for this enhancement.

"Fig. 2" shows the percentage of total remaining energy of the network nodes after 1, 20 and 50 rounds. After one round, HEED algorithm outperforms the best, but in later rounds FEED algorithm performance is the best. After round 300 only FEED algorithm is still executing, but LEACH and HEED algorithms have terminated. "Fig. 2" shows that FEED significantly improves the network energy consumption.

Journal of Academic and Applied Studies
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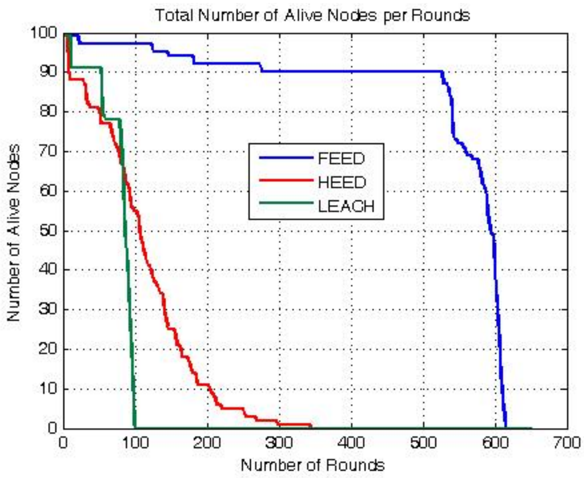

Figure 1. Total number of nodes per rounds

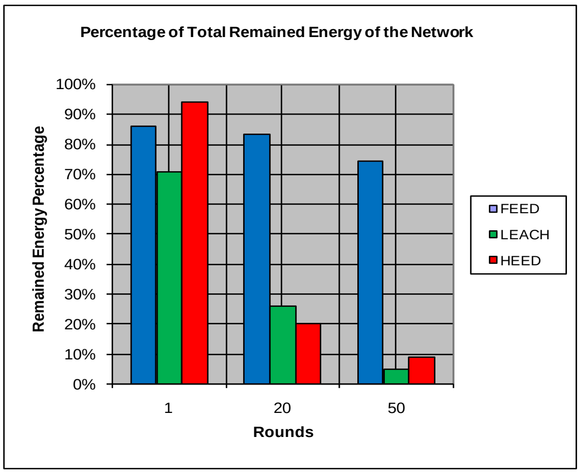

Figure 2. Percentage of total remained energy of the network nodes

D. Huang et al. (2004), consider a general geometric problem related to the coverage and deployment issues: Given a set of sensors in a 3D sensing field, they want to determine if this field is sufficiently α-covered, where α is a given integer, in the sense that every point in the field is covered by at least α sensors.

E. The work presented in (Shanbehzadeh et al., 2011) proposed an energy efficient coverage algorithm. This coverage algorithm starts after clustering the network by FEED algorithm. Every cluster head divides its neighboring area into four parts each one as a quarter of circle1 and its radius would be equal to the distance between cluster head and its hindmost member (r). Also circle2 is inside the circle1 and its radius is r/2. Each circle has four parts each one should be covered completely.

The coverage radius considered by cluster head for each node is based on its remained energy. There is a maximum sensing range which depends on *0.33r*, and also there is a minimum sensing range which depends on *0.25r*. *MaxSensingR* changes in different rounds.

Cluster head selects covering range of every one of its member based on (3):

Journal of Academic and Applied Studies
Vol. 3(6) June 2013, pp. 18-30
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Journal of Academic and Applied Studies

ISSN1925-931X

$$sr = \begin{cases} 0 \quad , \quad node.energy < threshold \\ \text{Max}[node.energy * MaxSensingR , (0.25r)] , \text{otherwise} \end{cases} \qquad (3)$$

In (3), *sr, node.energy*, *r* and *MaxSensingR* are the sensing range of a node, the percentage of the remained energy of a node, the distance between cluster head and its hindmost member and the maximum sensing range of the node respectively. The sensing range of each node that the cluster head denotes is between *0.25r* and *0.33r*.

"Fig. 3" shows part of the region covered by a cluster which has eight covering active nodes. There are four active nodes in circle1 (red circles) and four active nodes in circle2 (black circles).

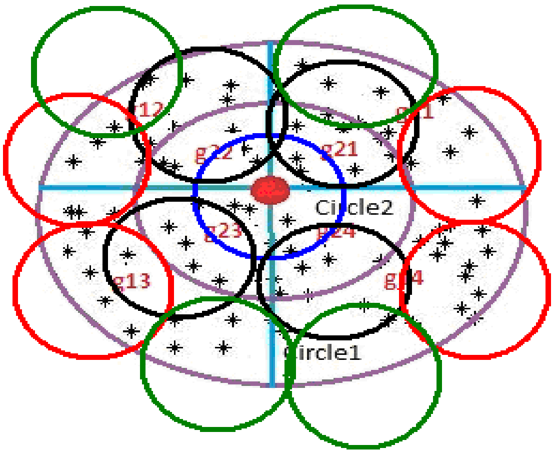

Figure 3. A part of region covered by a cluster

By changing the percentage of clusters, percentage of minimum and maximum number of the slept nodes per round will change and consequently sensing range will change. Let *a* to be the usual sensing range of a node which is equal to 8 meters, but it changes when the percent of clusters changes. *MaxSensingR* , *a* and *r are* related together as follows:

$$MaxSensingR = \begin{cases} max(0.25r , 1.2a) , & a < 0.25r \\ max (0.29r , a) , & 0.25r < a < 0.33r \\ 0.33r , & a > 0.33r \end{cases} \qquad (4)$$

As mentioned *a* is equal to 8 meters that is something used in FEED clustering method. In equation (4) three ranges for *MaxSensingR* can be seen. The size of the cluster is the basic factor for denoting these amounts. When *a* is less than *0.25r* then the amount 8 as the amount of *a* is not suitable because assuming this amount won't lead to full coverage in the part that an active node is functioning. So, this formula attempts to increase it to be close to *0.25r*. Thus

Journal of Academic and Applied Studies
Vol. 3(6) June 2013, pp. 18-30
Available online @ www.academians.org

ISSN1925-931X

max(0.25r , 1.2a) as the *MaxSensingR* for active node will lead to full coverage in the corresponding area. When *a* < *0.25r* then *1.2a* will be closer to *0.25r* but for making sure about best amount, this formula selects the maximum amount from *0.25r* and *1.2a*. By doing such, the different between *0.25r* and *1.2a* will be very low. Also this strategy guarantees best amount for *MaxSensingR* leading to full coverage of the corresponding area.

This is like something done in the second part of this formula. When *0.25r* < *a* < *0.33r* the average amount for *a* is *0.29r* but sometimes it maybe *0.26r* and even *0.32r*. In this case, if the formula selects *0.29r* then we can be sure the minimum permitted amount for *MaxSensingR* is selected and if the formula selects *a* we can make sure the area is covered without having over coverage. Totally, selecting maximum amount from *0.29r* and *a* will guarantee full coverage without over energy consumption made because of over coverage.

In the third part *a* is greater than *0.33r*. Any amount greater than *0.33r* will guarantee full coverage but unfortunately over coverage may happen which leads to over energy consumption. In fact the best amount in this case is *0.33r* such that full coverage will be performed without any over coverage and consequently without any over energy consumption.

The results of this method are shown in "Fig. 4". According to this chart, this method can save energy from %28 to %67 during coverage.

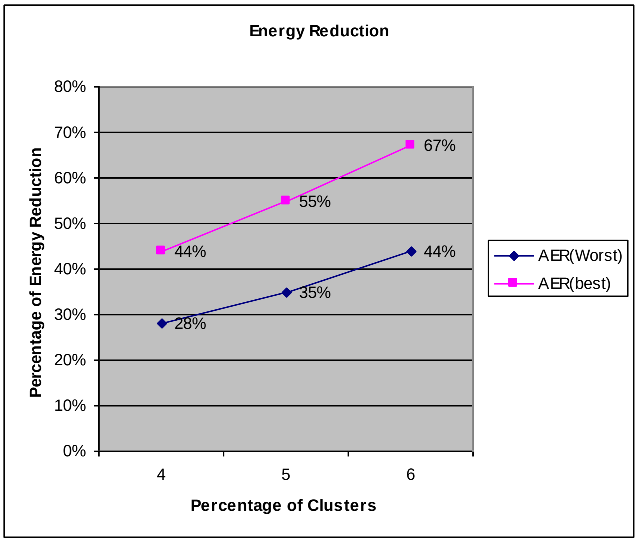

Figure 4. The results of the persented coverage algorithm

III.THE PROPOSED ALGORITHM

The proposed algorithm presents a new method for coverage all the parts of the three dimensional area via clustering the area by using a three dimensional clustering algorithm. So, at first the region should be clustered. We extend our previous work [FEED] to three dimensional form and use it for clustering.

The first change in FEED is to consider *z* axis (height) of all the sensor nodes in all the calculations rather than *x* and *y* axis. Sensor nodes are equipped with GPS and are aware about their exact positions. So they know about their height and assume it as another factor of their coordinates. The height of a node will be used wherever needed, for examples in calculating the density in the first phase, in giving scores to volunteers and also themselves during algorithm execution, etc.

We have other extensions that we want to apply on FEED and improve it to three dimensional form. In FEED all the volunteers are aware about their score and can distinguish their priority in comparison with other volunteers of the same cluster. In the proposed method there are four supervisor nodes (SN) in each cluster rather than cluster head. Thus, there are SN_1, SN_2, SN_3 and SN_4. "Fig. 5" and "Fig. 6" show a cluster of the clustered network which has been clustered by 3DFEED algorithm. As can be seen in this figure cluster head (red node) is at the center of the cluster while there is a supervisor node (SN) in each quarter of the sphere (blue nodes).

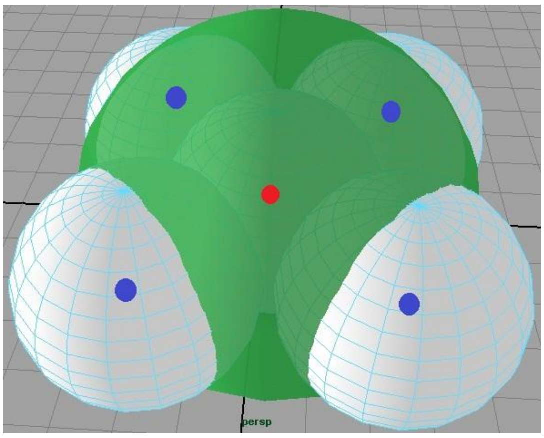

Figure 5. A three dimensional cluster with its CH and SNs

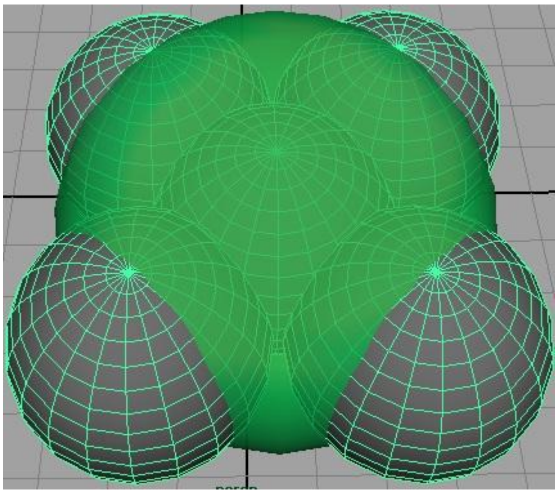

Figure 6. A three dimensional cluster in different view

Now, in the presented algorithm we extend the mentioned coverage algorithm into three dimensional form and also will apply some changes and improvements in its overall functionality.

Every cluster head divides its neighboring area into five parts each one as a quarter of an assumed sphere that we name it big sphere. The radius of the big sphere would be equal to the distance between cluster head and its hindmost member. We assume this amount as *r*. So *r* is the radius of the big sphere. We name each one of these quarters of the big sphere a small sphere.

To achieve at full coverage all over the region looked by all five small spheres of the big sphere should be completely covered. The radius of each small sphere is equal to *r/2* and the distance between the center of the big sphere and the center of each small sphere is equal to *0.7r*.

Cluster head denotes those of nodes that should be active and those that can go to sleep mode. If percentage of the remaining energy of a node is more than a threshold amount then it can be contributed in coverage else it won't contribute in coverage and its sensing range will be equal to zero.

There are five small spheres and there will be just two active nodes in each. The sensing range of each active node is equal to *0.33r*. By doing such we can make sure about full coverage in each small sphere and consequently in all over the sphere. "Fig. 7" shows a small sphere which contains its SN with blue color at the center and two active nodes with white color at around the SN.

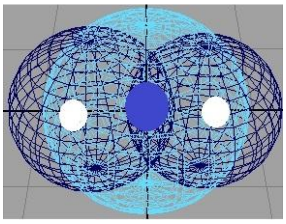

Figure 7. A small sphere with its SN (blue) and active nodes (white)

As we mentioned there are just two active nodes in each small sphere while other nodes are slept. Thus, there are an amount of energy reduction in each small sphere and also in the big sphere and consequently in all over the network. Furthermore, the communication range of active nodes will be less than or more than usual communication range, because active nodes send sensed information from the region to their SN with different distances depending on network implementation. Then SNs will compress and send received information to cluster head and cluster head aggregates information and sends them to base station.

Suppose *n* is the number of the nodes in the network. Usually, the percentage of clusters is equal to *0.05n* but it may change to other amounts, too. Table I mentions the affect of the percentage of clusters on the size of the clusters. By changing this amount, *r* also changes which leads to have different amounts for MinSensingR and MaxSensingR and therefore the percent of active and slept nodes per a cluster will change. According to Table I whatever the percent of clusters is bigger then *r* will be smaller and there would be a decrease in both of minimum and maximum sensing ranges. It is clear that having bigger sensing range will lead to achieve at full coverage more and more but energy consumption for active nodes will increase and this verity reduced network lifetime. So, a compromise should be considered between these factors.

ISSN1925-931X

Table I. Average percent of active and slept nodes

Percentage of clusters	r	MinSensingR = 0.25r	MaxSensingR= 0.33r
1	100	25	33
2	50	12.5	17
3	33	8	11
4	25	6	8.5
5	20	4	6.5
6	17	4.25	6
7	14	3.5	4.5
8	12.5	3.25	4.25
9	11	3	4
10	10	2.5	3

Percent of clusters has also direct affect on the number of nodes that are in charge of covering the region and number of other nodes that can sleep. Table2 shows the percentage of active and slept nodes. It is clear that active nodes are covering the region while slept nodes don't do anything in region covering. So, slept nodes are saving energy. This technique leads to have decrease in overall energy consumption of the network in coverage issue and consequently network lifetime increases in a significant way.

Table2- Percent of active and slept nodes

Percentage of clusters	Number of nodes in each cluster	Percent of active nodes in each cluster	Percent of slept nodes in each cluster
1	100	10/100=%10	90/100=%90
2	50	10/50=%20	40/50=%80
3	33	10/33=%30	23/33=%70
4	25	10/25 = %40	15/25 = %60
5	20	10/20 = %50	10/20 = %50
6	17	10/17 = %59	7/17 = %41
7	14	10/14=%71	4/14=%29
8	12	10/12=%83	2/12=%17
9	11	10/11=%90	1/10=%10
10	10	10/10=%100	%0

Rather than facts that have been alluded to, changing in sensing ranges because of using proposed algorithm should also be considered. Assume *a* as the usual sensing range for sensor nodes. By using the proposed algorithm the MaxSensingR will have different amount by changing the percent of clusters, so the sensing range of active nodes will change. Thus, the sensing ranges of active nodes maybe more than or even less than the usual sensing range. By changing the usual sensing range, active nodes may have over energy consumption (OEC) that can be positive or negative. Table III shows these facts. If the sensing range that cluster head or supervisor node assumes for a node is more than the usual sensing range there will be over energy consumption for active nodes in covering process, meanwhile assuming a

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sensing range less than usual sensing range for active nodes will decrease consumption of energy for them.

The words must be said are the proposed coverage algorithm always almost achieve at full coverage but sometimes this operation will lead to over energy consumption for active nodes while sometimes the amount of over energy consumption is negative which means having less energy consumption for active nodes. Table3 mentions over energy consumption of active nodes depending on percent of clusters.

Table3- Percent of over energy consumption for active nodes

Percentage of clusters	R	MinSensingR = 0.25r	MaxSensingR=0.33r	OEC
1	100	25	33	300%
2	50	12.5	17	100%
3	33	8	11	37%
4	25	6	8.5	6%
5	20	4	6.5	-20%
6	17	4.25	6	-25%
7	14	3.5	4.5	-44%
8	12.5	3.25	4.25	-47%
9	11	3	4	-50%
10	10	2.5	3	-63%

IV. PERFORMANCE EVALUATION

Now, in this section we evaluate the functionality of the proposed coverage algorithm. Percent of energy reduction can be calculated by applying (5).

$$PER = PSN - (OEC * PAN) \qquad (5)$$

In (5), PER is the percent of energy reduction after putting the proposed algorithm into effect, PSN is percent of slept nodes, PAN mentions the percent of active nodes and OEC reveals over energy consumption for active nodes. “Fig. 8” shows the results of the algorithm. In this figure the results are shown by using (5), considering the usual sensing range (*a*) and also percent of clusters.

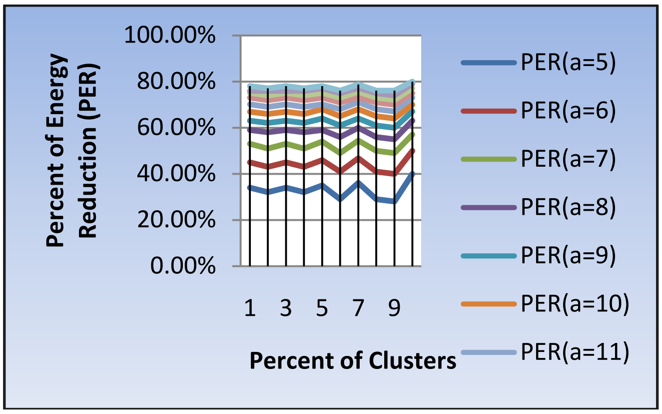

Figure 8. Percent of energy reduction in different network implementations

As can be seen in the text, all the assumptions are evaluated by mathematical formulas and equations. All the situations are considered and based on the so-called equations the results are achieved and shown in a chart. According to "Fig. 8" using proposed algorithm leads network to have between 28% to 80% energy reduction during coverage the region which is a very good outcome.

V. Conclusion

In this paper we presented an extension and significant improvements in FEED algorithm -our last work- for clustering three dimensional wireless sensor networks. Then, our new method in coverage issue has been applied on clustered network. This idea had been used in 2D apace successfully and could be used in 3D area by adding some necessary changes and improvements to it. We proposed a novel method to achieve at full coverage in three dimensional wireless sensor networks. In this algorithm the area of a cluster which is a ball has been divided into some small balls each one in charge of covering its corresponding 3D area by using lowest amount of nodes. Using the proposed algorithm can lead to decreasing overall energy consumption of the network during covering in a significant way.

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