WSN Lifetime Prolongation for Deterministic Distributions Using a Hierarchical Routing Protocol

Nora. A. Ali
Electronics and Communications Engineering Department
Cairo University
Giza, Egypt
engn_ahmed@yahoo.com

Omar. A. Nasr*
Electronics and Communications Engineering Department
Cairo University
Giza, Egypt
omaranasr@ieee.org

***Abstract*—Extending the lifetime of Wireless Sensor Networks is one important design goal when practically deploying them. The paper addresses the problem of choosing the optimum number of clusters in deterministically distributed nodes in a wireless sensor network in order to maximize its lifetime. Hierarchical routing protocol is used on some of the deterministic nodes distributions such as uniform, circular, hexagonal and star distribution, to show how to choose the optimal number of clusters. Compared to non-clustering case and arbitrary clustering, lifetime enhancement is noticed for all the examined distributions. The paper also shows that choosing the right cluster shape is one of the important factors that affect the network lifetime.**

Keywords— WSN; Clustering; Cluster Head

I. INTRODUCTION

Wireless Sensor Networks (WSN) has become an interesting field of research because of its wide range of applications such as environmental monitoring, military, electromagnetic pollution monitoring, medical applications and industrial applications [1-5]. A WSN consists of hundreds or thousands of multi-functioning sensor nodes with limited power capacity. Therefore, the main problem in WSN is the energy constrained sensors, and prolonging the lifetime is one of the important problems in wireless sensor networks [3, 6 and 7].

Different techniques were developed to overcome the problem of limited power capacity [5, 8, and 9]. In one of these techniques, energy efficient routing protocols are developed [3]. The most efficient routing protocol is the hierarchical routing protocol. In this protocol, the entire area is divided into clusters, and each cluster contains some nodes that can work as Cluster Heads (CH). A CH node is responsible for receiving data from all nodes in the cluster, aggregating it, and then sending the aggregated data to the final destination (sink).

One of the most popular routing protocols is Low Energy Adaptive Clustering Hierarchy (LEACH) [6]. LEACH technique is based on dividing the area of interest into clusters, where each cluster has some nodes working as CH nodes. CHs are responsible for collecting data from all nodes in the cluster, aggregating and sending a processed version of the data to the sink. The data sent from the sink may represent any statistical representation of the nodes data such as the minimum, the maximum or the average of the collected data. This strategy saves energy as transmissions will happen in two stages. The first stage is sending from the nodes to the CH that exists close to them, and the second stage; CH will send a compressed version of the data to the sink, rather than sending the data from each sensor node to the sink [9]. However, LEACH has some drawbacks as CHs are chosen randomly and cluster size will vary in size in a random manner [6]. Hence, LEACH is improved by the use of a central algorithm. The central version of LEACH is called LEACH-C. In LEACH-C, a central control algorithm that forms clusters such that CH nodes are distributed uniformly over the whole network [7].

In [10], LEACH-C results were improved by developing another algorithm that considers the network as a one cluster and uses round robin technique for choosing the Network Master (NM) nodes. The NM node plays the same role of CH node; it collects data from all nodes in the area, aggregates it and then sends the aggregated data to the sink. This technique allows each node inside the network to acts as a NM once and active node that senses the surroundings and sends data to the NM until the end of the lifetime. It was found that this technique in [10] results in 32% lifetime elongation compared to LEACH-C. However, this technique does not dictate predefined sensor locations as sensors are distributed randomly over the network area.

In this paper, we show that applying hierarchical routing in deterministic nodes distributions, such as uniform and star distributions, results in a prolongation of the network lifetime compared to no-clustering or a one cluster network. The distributions studied in this paper are among the most popular deterministic distributions [11]. The network is divided into clusters and the CHs collect the data and send them to the sink. The optimum number of clusters, the cluster shape and the effect of different location for the sink are investigated.

This paper is organized as follows. Section II describes the proposed algorithm. Section III describes the lifetime calculation and optimum number of clusters for the uniform distribution and section IV describes the effect of clustering for star distribution. Section V describes the effect of clustering on other distributions. Section VI shows the advantages of clustering, compared to the no-clustering case. Finally VII concludes the paper.

* Dr.Omar A. Nasr is also affiliated with the Egyptian National Telecomm. Regulatory Authority (NTRA). This work was partially funded by the NTRA.

II. THE PROPOSED ALGORITHM

Different energy efficient techniques are used to overcome the problem of extending the network lifetime. The most efficient protocol is the hierarchical routing protocols such as LEACH, LEACH-C, and others [6, 7, and 12]. These techniques have some drawbacks, which were overcome using the proposed algorithm in [10]. In this algorithm, the network is considered as one cluster; therefore, the CH will be called Network Master (NM). It is assumed that GPS sensor locations are known to all sensors [7]. Therefore, the sink is responsible for choosing which sensor will be the NM for a certain number of cycles. The sink chooses the NMs using round robin technique, each sensor in the network acts as a NM once and as an active node until the end of the network lifetime. This technique resulted in a longer network lifetime as the energy of all sensors in the network is better exploited, unlike in the case of LEACH-C [7].

In this paper, we apply a hierarchical routing protocol on the technique used in [10].The network will be divided into a number of clusters, and each node inside any cluster will act as a CH once for a certain number of cycles and active node until the end of the lifetime. This algorithm will be applied on the deterministic distributions such as star, uniform, circular and hexagonal distribution. Consequently, the cluster shape will not be random as done in LEACH and LEACH-C, but it will take deterministic shape based on the used distribution. Fig. 1 describes the algorithm inside a cluster for one "cycle". The algorithm is repeated each cycle inside all network clusters.

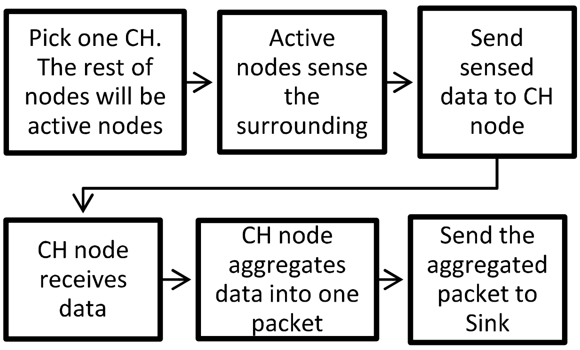

Fig. 1. Description for the Proposed Algorithm.

III. LIFETIME CALCULTION AND OPTIMUM NUMBER OF CLUSTERS FOR UNIFORM DISTRIBUTION

Many applications, such as environmental monitoring and military applications use random distributions because the network locations are inaccessible [8, 12]. On the other hand, geometric distributions are more adequate for urban applications [13]. Uniform distribution is one of the most common distributions that are more adequate for a lot of applications such as chemical and nuclear sensing systems [11, 14]. Hence, this section focuses on the effect of using clustering technique on the lifetime of the uniform distribution using the same network parameters in [10- 11] as shown in Table I.

TABLE I. NETWORK PARAMETERS

Parameter	Value
Network Size (A×A)	100×100m^2
Number of Sensors (N)	100
Transmitter /Receiver Electronics Energy(E_{elec})	50 nJ/bit
Transmitter Amplifier (E_{amp}) for short distance for long distance	 10pJ/bit/ m^2 0.0013 pJ/bit/ m^4
Aggergation Energy (E_{DA})	5 nJ/bit/signal
Path Loss Factor (n) for short distance for long distance	 2 4
Sink Location	(0, −125)
Transmitted Frame Length (L)	2048 bits
Initial Energy of sensor node (E_i)	2J

It is assumed that the network consists of N uniformly distributed nodes over the network area and the network is divided into K clusters. Due to the symmetry of the deterministic distribution, each cluster will have the same number of nodes (N/K).

The main objective of this part is to determine the optimum number of clusters (K) for the uniform distribution that maximizes the network lifetime. The lifetime of the network is defined as the time until the first node fails due to its battery outage. The total energy consumed in the network is related to the initial energy of nodes (E_i) as shown in the following equation:

$$E_i = \sum_{j=1}^{K} \left(E_{C_j} + E_{R_j} \right) \quad (1)$$

where E_{R_j} is the remaining energy of the nodes in the cluster j after network failure and E_{C_j} is the energy consumption for the cluster j in the network. E_{C_j} is calculated according to the following equation:

$$E_{C_j} = \sum_{i=1}^{\frac{N}{K}} C_{i,j} E_{Cycle_{i,j}} \quad (2)$$

where $C_{i,j}$ is the number of cycles when node i in the cluster j is working as a CH. $E_{Cycle_{i,j}}$ is the total energy consumed per cycle in a cluster j when the node i acts as a CH. This energy includes the energy consumed by the CH node and the active nodes; which can be calculated according to the following equation:

$$E_{Cycle_{i,j}} = E_{CH_{i,j}} + \sum_{\substack{l=1 \\ l \neq i}}^{\frac{N}{K}} E_{active_{l,i}} \tag{3}$$

where $E_{CH_{i,j}}$ is the energy consumed by the CH i in cluster j and $E_{active_{l,i}}$ is the energy consumed by the node l to send to the cluster head i in the same cluster j. These energies are calculated by the following equations [6, 7]:

$$E_{CH_{i,j}} = L\left(E_{elec} + E_{DA}\right)\left(\frac{N}{K} - 1\right) + L\left(E_{elec} + E_{amp} d_{Sink_i}^{n}\right) \tag{4}$$

$$E_{active_{l,i}} = L\left(E_{elec} + E_{amp} d_{CH_{l,i}}^{n}\right) \tag{5}$$

where d_{Sink_i} is the distance from CH i to the sink and $d_{CH_{l,i}}$ is the distance from node l to CH i.

The above two equations describe the functions of a node when it acts as CH or an active node. Equation (4) shows the energy consumed by a node when it acts as a CH. It receives the data from all the nodes in the cluster and then processes it to remove any redundancy. This redundancy occurs due to the high correlation between the data produced by the nodes residing in the same cluster. Therefore, data aggregation is an effective process to save node energy. The aggregated data will be represented by only one packet, and then the CH sends this packet to the sink. Equation (5), describes the function of the node when it acts as an active node, which sends the measured data to the CH.

To increase the network lifetime, all nodes in a cluster will work as a cluster head for a certain number of cycles, and as an active node for the rest of the network lifetime. The number of cycles allocated to each node to work as a CH for a certain cluster j will be calculated using the following equation:

$$\begin{bmatrix} E_{CH1,j} & \cdots & E_{active\ 1,\frac{N}{K}} \\ \vdots & \ddots & \vdots \\ E_{active\ \frac{N}{K},1} & \cdots & E_{CH\ \frac{N}{K},j} \end{bmatrix} \begin{bmatrix} C_{1,j} \\ \vdots \\ C_{\frac{N}{K},j} \end{bmatrix} = \begin{bmatrix} E_1 \\ \vdots \\ E_{\frac{N}{K}} \end{bmatrix} \tag{6}$$

In the above equation, the column on the right hand side contains the initial energies of the N/K nodes (all the nodes have the same initial energy); each row on the matrix on the left hand side contains the total energy consumed by the node during the whole lifetime. It includes the energy of the node when it acts as a CH and as an active node. This way, the number of cycles when a node works as a CH will be proportional to its initial energy, and inversely proportional to the distance between the node and the sink. The network lifetime will be the minimum lifetime of all clusters as described in (7):

$$Lifetime = \min_{j} \sum_{i=1}^{\frac{N}{K}} C_{i,j} \tag{7}$$

From the previous analysis, it is clear that both the total energy consumed in the network and network lifetime are functions of the number of clusters. By simulation using MATLAB [15] when the sink is located at (0,-125), the proposed algorithm is applied to the uniform distribution shown in Fig. 2. Table II shows that dividing this distribution into two clusters as shown in the figure is more efficient, and results in a lifetime increase by approximately 7% compared to the lifetime in case of only one cluster. The lifetime when using two clusters is approximately three times better than the lifetime of the network without clustering, which equals to 2783 cycles. Also the table shows that the lifetime is decreased with increasing number of clusters.

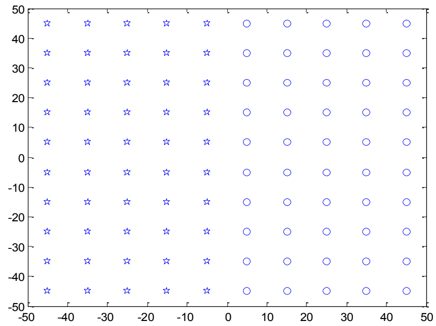

Fig. 2. Uniform distribution with two clusters.

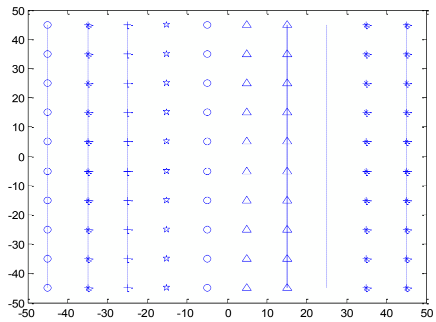

Fig. 3. Uniform distribution with 10 clusters.

TABLE II. LIFETIME IN CYCLES FOR THE UNIFORM DISTRIBUTION AT DIFFERENT NUMBER OF CLUSTERS

No of clusters (K)	1	2	3	4	5	6	10
Lifetime (cycles)	7380	7887	7747	7503	7496	7127	6756

Furthermore, the proposed algorithm is examined at different sink locations. It is found that if the sink is located at the center of the area (0, 0), the lifetime will increase, and the optimum number of clusters will be changed. It is found that dividing the network into 10 clusters as shown in Fig. 3

increases the network lifetime by approximately 16% compared to the lifetime in case of only one cluster.

These results indicate that the number of clusters that maximizes the lifetime is related to the sink location. Small number of clusters is more suitable if the sink is located far away from the area because the transmitted energy is the dominant factor compared to the aggregated energy. In contrast, large number of clusters is more suitable if the sink is located in the center of the area because the aggregation energy is the dominant factor compared to the transmission energy, which makes clustering more efficient because it reduces the energy consumed for aggregation. Also the cluster shape is related to the sink location and affects the network lifetime. The cluster was chosen to have vertical rectangular shape as shown in Fig. 2 and Fig.3. This choice maximizes the lifetime because it provides symmetry that makes the clusters approximately look the same. Therefore, after the network failure, the remaining energy in all clusters will be very small.

IV. Optimum Number of Clusters for the Star Distribution

Star topology is one of the most popular geometric distributions used in networks [11, 14, 16]. It was found in [11] that star distribution is the most efficient distribution that gives the highest lifetime compared to the other distributions. The proposed algorithm with clustering technique is applied to the 10×10 star shown in Fig. 4. The main characteristics of the star distribution as shown in the figure are equal angles between branches, equal distances between sensors in each branch and each branch has an equal number of sensors.

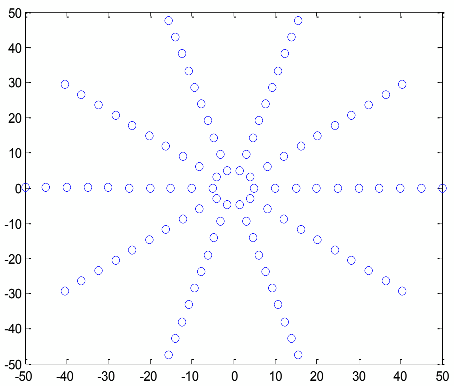

Fig. 4. 10x10 Star Distributions.

We apply the clustering technique on 10×10 star distribution that shown in Fig. 4 with the sink located outside the area at (0, -125), lifetime is increased by about 3% and the optimum number of clusters equals 2 if the cluster is chosen to have rectangular shape as done in the uniform distribution. Also, by simulating the same distribution for the sink located at center of the area at (0, 0), it is found that dividing the network into 10 clusters and considering each branch as a cluster is more efficient than any other clustering. The lifetime with ten clusters equals to 10071 cycles, while it equals 8460 cycles in case of one cluster. This means that the lifetime increased by 1611 cycles (approximately by 20%) compared to the case of one cluster. From these results, it can be concluded that for any star distribution deployed with the previous characteristics and with the sink located at the center of the area; clustering will be more efficient if each branch is considered as a cluster. Consequently, the optimum number of clusters in case of the star distribution equals to the number of branches.

V. Effect of Clustering on the other Deterministic Distribution

There are many deterministic distributions that depend on the geographical area and the used application. The hexagonal distribution was chosen to be examined in this paper due to its wide and comprehensive coverage [16, 17] as shown in Fig. 5.

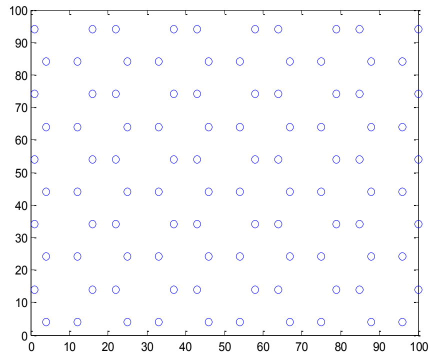

Fig. 5. Hexagonal Distribution.

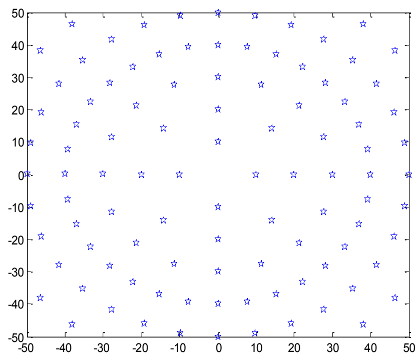

Fig. 6. Circular Distribution.

It was derived from the typical cellular communication topology. By applying the clustering technique on this distribution, it is noticed that the lifetime is increased by approximately 11% compared to the lifetime in case of only one cluster if the sink located outside the area and by 17% if the sink is located at the center of the area. Also, Circular distribution with uniform density is one of the most popular deterministic distributions [11]. It differs from the star topology by increasing the number of sensors per circle as they move away from the center, as shown in Fig. 6. Applying clustering technique, with the cluster shape as the same as cluster shape of the Uniform distribution, on this distribution results on lifetime increase by about 16% compared to the lifetime with only one cluster for the sink located at the center. The optimum number of clusters that resulted in this increase is ten. Also the lifetime is increased by about 8% for the sink located outside the area. The optimum number of clusters that resulted in this increase is two.

VI. LIFETIME IN NO CLUSTERING CASE FOR SINK LOCATION OUTSIDE THE AREA

We study the advantages of clustering technique, compared to no clustering, if the sink is located outside the area, which is more suitable case for many applications. Fig. 7 summarizes the results of the lifetime in case of no clustering for all the examined distributions in this paper and in case of clustering. It is noticed from the figure that the lifetime values in case of no clustering for all the examined distributions is approximately the same, with less than 5% variance between them. This can be explained by examining the definition of lifetime of the network. The lifetime in case of no clustering will be the number of cycles of the node that has the minimum number of cycles. This node will be the farthest node which is approximately located in the same location for all the examined distributions.

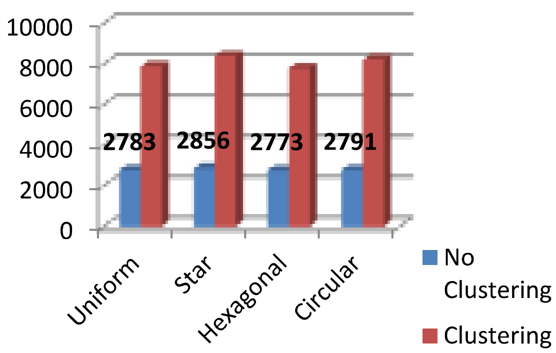

Fig. 7. Lifetime (Cycles) in case of no Clustering and with Clustering.

VII. CONCLUSION

A major challenge in deploying Wireless Sensor Networks is the prolonging of the network lifetime. This paper focuses on using the hierarchical clustering routing protocol on some of the deterministic distributions such as uniform, star, hexagonal and circular distribution. It was found that the network lifetime is enhanced by using clustering for all the examined distributions. Also, it is found that using clustering for the star distribution is more efficient and results in a large increase in the network lifetime if each branch is chosen as a cluster and the sink located at the center of the area. We found that the optimum number of clusters that maximizes the network lifetime is a function of the sink location for all the examined distributions. Cluster shape has also large impact on network lifetime and the optimum number of clusters.

REFERENCES

[1] I.F. Akyildiz, W. Su, Y. Sankarasubramaniam and E. Cayirci, "Wireless Sensor Networks: A Survey," *Computer Networks Magazine*, 2002.

[2] X.Wang, X. Zhang, G. Chen and Sh. Tian, "An Adaptive and Distributed Clustering Scheme for Wireless Sensor Networks," *Convergence Information Technology*, 2007.

[3] A. Martirosyan, A. Boukerche and R. Pazzi, "A Taxonomy of Cluster-Based Routing Protocols for Wireless Sensor Networks," *Proceedings of the International Symposium on Parallel Architectures, Algorithms, and Networks (i-span 2008)*, Sydney, Australia, May 2008.

[4] O. Moussaoui and M. Naimi, "A distributed energy aware routing protocol for wireless sensor networks," *Proceedings of the 2nd ACM International Workshop on Performance Evaluation of Wireless Ad-Hoc, Sensor and Ubiquitous Networks,* Montreal, Quebec, Canada, October 2005.

[5] G.F. Zaki, H.M. ElSayed, H.H. Amer and M.S. El-Soudani, "Energy Efficient Hybrid Wireless Sensor Networks in Urban Areas," *International Journal of Factory Automation, Robotics and Soft Computing*, April 2008.

[6] W. Heinzelman, A. Chandrakasan and H. Balakrishnan, "Energy-Efficient Routing Protocols for Wireless Microsensor Networks," *Proceedings of the 33rd Hawaii International Conference on System Sciences (HICSS),* Maui, Hawaii, USA, January 2000.

[7] W. Heinzelman, A. Chandrakasan and H. Balakrishnan, "An Application Specific Protocol Architecture for Wireless Micro sensor Networks," *IEEE Transactions on Wireless Communications*, vol. 1, no.4, October 2002.

[8] P. Minet and S. Mahfoudh, "Survey of Energy Efficient Strategies in Wireless Adhoc and Sensor Networks," *Proceedings of the 2009 International Conference on Wireless Communications and Mobile Computing: Connecting the World Wirelessly,* Leipzig, Germany, June 2009.

[9] K. Akkaya and M. Younis, "A survey on Routing Protocols for Wireless Sensor Networks," *Journal of Ad Hoc Networks,* vol. 3, no.3, May 2005.

[10] S. Botros, H. ElSayed, H.H. Amer and M.S. El-Soudani, "Lifetime Optimization in Hierarchical Wireless Sensor Networks," *Proceedings of the 14th International Conference on Emerging Technologies and Factory Automation*, ETFA, Mallorca-Spain, September 2009.

[11] S. Nouh, R.A. Abbas, D. Abou El Seoud, N.A. Ali, R.M. Daoud, H.H. Amer and H.M. ElSayed, "Effect of Node Distributions on Lifetime of Wireless Sensor Networks", *Proceedings of the IEEE International Symposium on Industrial Electronics ISIE*, Bari, Italy, July 2010.

[12] C. Nam, H. Jeong and D. Shin, "The Adaptive Cluster Head Selection in Wireless Sensor Networks," *Proceedings of the IEEE International Workshop on Semantic Computing and Applications,* Incheon, Korea, July 2008.

[13] A. Bestavros, I. Matta and N. Riga. "DIP: Density Inference Protocol for wireless sensor networks and its application to density-unbiased statistics," *Proceedings of the Second International Workshop on Sensor and Actor Network Protocols and Applications (SANPA),* Boston, Massachusetts, USA, August 2004.

[14] C. Cheng and X. Liu, "Energy Node Placement in Wireless Sensor Networks," *Proceedings of the Global Telecommunications Conference*, Dallas, Texas, USA, December 2004.

[15] Official Site of MatLab: www.mathworks.com.

[16] V. Rosello, J. Portilla, Y. E. Krasteva and T. Riesgo, "Wireless Sensor Neywork Modular Node Modeling and Simulation with VisualSense," *Proceedings of the 35th Annual Conference of the IEEE Industrial Electronics Society, IECON,* Porto, Portugal, November 2009.

[17] Sh. Prabh, Ch. Deshmukh and Sh. Sachan, "A Distributed Algorithm for Hexagon Topology Formation in Wireless Sensor Networks," *Proceedings of the 14th International Conference on Emerging Technologies and Factory Automation*, ETFA, Mallorca, Spain, September 2009.