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Research Paper

Optimum Number of Clusters in Randomly Distributed Wireless Sensor Networks

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Abstract

The wireless sensor networks (WSN) are energy constraint because of finite batteries used as energy resources. The efficient utilization of these energy resources and prolonging lifetime are the most crucial research challenges in WSN. Clustering is considered one of the best suitable technique that carries out efficient resource allocation and higher scalability for sensor networks. The clustered networks have a big concern on the optimum number of clusters in a network. In a WSN, such a number of clusters significantly contribute in the betterment of network life time, energy resource utilization, system scalability and efficient data routing. In the proposed work, an analytical approach has been explored that provides optimum number of cluster in a WSN for various topologies. The proposed method takes both free space and multipath losses into consideration by assuming that the base station is located at the boundary of the sensing field.

Keywords: *Wireless Sensor Networks; Cluster; Cluster Head; Optimal Number; Energy Efficient Network.*

1. Introduction

As the technology is growing, there are many changes in WSN. Due to the technology changes the sensors used in WSN becomes micro in nature, and they have a finite battery and small memory on chip. The sensors work as a transducer they sense the physical phenomenon and convert them into an electrical signal. These electrical signals contain the information happens around the sensors. The receiver/transmitter section of WSN transmits this information to the desired location. The sensors used in the network, have the finite energy resources, so it is the main constraints which affect the life and the nature of the network. A most popular way to minimize power expenditure and enhance the lifespan of a WSN is clustering. In the clustering technique, the nodes are partitioned into groups basis on some phenomenon. In Clustering the clusters are formed in ordered manner, these Clusters efficiently used the energy and hence increase the life of sensor network. Clustering is used in WSN because it provides many benefits. The overall communication is reduced due to the different number of clusters, so it minimizes the energy expenditure. The WSN split into several clusters. In the every cluster a cluster head node and other member nodes are presents, the CH guided to all other node works as a member node. The CH node performs the most important function it receives all the information from member nodes of a group after that aggregate this information and sends this information to the sink by single hope or multi-hope communication. The CH node spends much higher energy compare to members nodes because the CH nodes collect information from all member nodes and transfer it to sink. For getting equilibrium in the power expenditure for a network or in a cluster, the all other nodes also have an opportunity to play the role of a CH. [1, 2]

The optimal performance of a wireless sensor network mainly depends on network lifetime, scalability and efficient load balancing. To establish a energy efficient cluster based sensor network some issues, such as optimum number of clusters, number of nodes in an individual cluster and optimal location of cluster head (CH) in the appropriate cluster, should be handled. Several parameters influence the optimal values of clusters in sensor network at network level, clustering level and radio model level. In this work, network level parameters as base station positioning, node density and size of sensing fields have been addressed. [3]

2. Related Work

A Low Energy Adaptive Clustering Hierarchy (LEACH) protocol has been proposed by the Heinzelman et al. [4]. In this protocol, an analytical method has been suggested to find the optimal count of clusters. They used the computation and communication energy models and considered that the sink is located at long distance from the sensor nodes.

$$K_{opt} = \frac{\sqrt{N}}{\sqrt{2\pi}} \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \frac{M}{d^2_{CHtoBS}} \tag{1}$$

Kim et al. [5] analytically derived the optimal digit of cluster heads for randomly deployed, surrounded field with side 2a. This method reduces the overall energy expenditure for the sensor network, during the communication when all the sensor nodes transmit their data to the sink through the CH nodes.

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$$K_{opt} = \left\{ \frac{0.5855.N.\varepsilon_{fs}.a^2}{\varepsilon_{mp}.d^4{}_{CHtoBS} - E_{elec}} \right\}^{1/2} \quad (2)$$

Chan et al. [6] presented fixed optimal cluster (FOC) numbers that provides even energy consumption for two distinct instances.

Case 1: In this case, the sink is placed at the midpoint of the network and considered only free space loss.

$$k_{opt} = \sqrt{N} \quad (3)$$

Case 2: At this time the base station is placed outside from the network and only multipath loss is considered.
Then K_{opt} is given by

$$K_{opt} = \sqrt{N}\sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}\frac{M}{M^2+6B^2} \quad (4)$$

Here

$$B \geq \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}} - \frac{M^2}{6}} \quad (5)$$

Gupta and Kumar [7] gives a analysis for finding the optimal number of cluster in WSN with a mobile base station, and it is given as:

$$k_{opt} = \sqrt{\frac{n \text{ A } \varepsilon_{fs}}{2 \pi \text{ E}_{elec}}} \quad (6)$$

Tripathi et al.[8] established an expression for non-uniformly deployed sensor nodes in the circular field with radius R. They consider that the sink is nearer to the nodes, so only free space loss is taken.

$$K_{opt} = \frac{N.\sqrt{N} \text{ R}}{\sqrt{2}\sum_{i=1}^{j}\lambda_i \text{ A}_i \text{ R}_i} \quad (7)$$

Above methods have certain restrictions for finding the optimal number of clusters. None of them considers the situation where the free-space as well as the multipath losses occur. In this situation, some nodes are closer and all the leftover nodes at long distance from the sink. So, in this work an analytical approach has been proposed that considers the base station at the boundary of the sensing field where both types of losses are taken.

3. Proposed Analytical Method

In this work, an analytical method has been suggested to determine the optimal clusters number for the sensor network configuration where the base station is at the boundary of the sensing field. Consider a network with N number of nodes is randomly deployed in an M X M m^2 field and it is divided into K_{opt} (optimal value of clusters) clusters. In this network, every individual cluster carries N/K_{opt} nodes, out of which one node act as a cluster head (CH) and remaining (N/K_{opt} - 1) nodes are members of that cluster. The CH node dissipates the energy in three tasks as, collection, aggregation and transmitting the data. As the base station is at the boundary therefore, free spaces as well as multipath losses are considered.
Thus, the energy consumption for the CH node in a single round is given as:

$$E_{CH} = \left(\frac{N}{K_{opt}} - 1\right) l.\ \text{E}_{elec} + \frac{N}{K_{opt}}.\ l.\ \text{E}_{DA} + l.\ \text{E}_{elec} + l_{\varepsilon_{fs}}.\text{d}^2{}_{toBS} + l_{\varepsilon_{mp}}.\text{d}^4{}_{toBS} \quad (8)$$

Where, l and d_{toBS} represents the message bits and the length from the CH to the BS respectively

On the other hand, every member node sends its data to CH node ones in a round. Without loss of generality, assume that, in a cluster the length among the member nodes and CH is smaller than the threshold, so only the free-space model is pursued. Hence, the member nodes energy consumption is given by:

$$E_{non-CH} = l.\text{E}_{elec} + l_{\varepsilon_{fs}}.d^2{}_{toCH} \quad (9)$$

Where d_{toCH} represents the distance between the CH to the member nodes. In general, each cluster take the area equal to N/K_{opt} and it is in random pattern with a node distribution ρ (x ,y). Now, develop an expression for the expected squared distance between the CH and member nodes in a cluster. Assuming that the CH locates at the midway of the cluster, this expected squared distance is given by:

$$E[d^2{}_{toCH}] = \int_{x=0}^{x_{max}}\int_{y=0}^{y_{max}} (x^2+y^2)\rho(x,y)\ dxdy = \int_{\theta=0}^{2\pi}\int_{r=0}^{r_{max}} r^2\rho(r,\theta)r\ \text{d}r\text{d}\theta \quad (10)$$

Let's consider that the each cluster is a circle and its radius is $R = \frac{M}{\sqrt{\pi K_{opt}}}$ and ρ (x ,y) is constant for r and θ, so equation (10) to reduce as:

$$E[d^2{}_{toCH}] = \rho\int_{\theta=0}^{2\pi}\int_{r=0}^{\frac{M}{\sqrt{\pi K_{opt}}}} r^3 dr d\theta = \frac{\rho}{2\pi}.\frac{M^4}{K^2{}_{opt}} \quad (11)$$

With the assumption of uniform node density across all clusters, one can verify that $\rho = \frac{K_{opt}}{M^2}$ and replacing in equation (11) gives:

$$E[d^2{}_{toCH}] = \frac{1}{2\pi}.\frac{M^2}{K_{opt}} \quad (12)$$

Combining energy and distance expressions for non-cluster heads (equations (12) and (9)) will end up with a closed-form formulation for the E_{non-CH}.

$$E_{non-CH} = l.\text{E}_{elec} + l_{\varepsilon_{fs}}.\frac{1}{2\pi}\frac{M^2}{k_{opt}} \quad (13)$$

So, the energy consumption in a complete cluster during a single round is:

$$E_{Cluster} = E_{CH} + \left(\frac{N}{K_{opt}} - 1\right)\text{E}_{non-CH} \approx E_{CH} + \left(\frac{N}{K_{opt}}\right)\text{E}_{non-CH} \quad (14)$$

The overall energy consumed in the network is given as:

$$E_{Total} = K_{opt}.\text{E}_{cluster} = l(\ \text{E}_{elec}\text{N} + \text{E}_{DA}\text{N} + K_{opt}\varepsilon_{fs}.\text{d}^2{}_{toBS} + K_{opt}\varepsilon_{mp}.\text{d}^4{}_{toBS} + \text{E}_{elec}\text{N} + \varepsilon_{fs}\frac{1}{2\pi}\frac{M^2}{K_{opt}}N) \quad (15)$$

The optimum count for the clusters can be obtained, by differentiating equation (15) with respect to K_{opt} and setting it zero.

$$\varepsilon_{mp}.d^4_{toBS} + \varepsilon_{fs}.d^2_{toBS} - \varepsilon_{fs}\frac{1}{2\pi}\frac{M^2}{K_{opt}}N = 0 \quad (16)$$

$$K^2_{opt} = (\ \varepsilon_{fs}.\frac{1}{2\pi}.\frac{M^2}{\varepsilon_{mp}.d^4_{toBS} + \varepsilon_{fs}.d^2_{toBS}}N) \quad (17)$$

$$K_{opt} = \frac{\sqrt{N}}{\sqrt{2\pi}}\sqrt{\varepsilon_{fs}}\frac{M}{d_{toBS}(\sqrt{\varepsilon_{mp}d^2_{toBS} + \varepsilon_{fs}})} \quad (18)$$

This K_{opt} provides the optimal number of cluster for the WSN.

4. Simulation and Results

In the simulation, nodes are randomly deployed in a square field. To evaluate the performance of the proposed method two strategies are considered. In first one, the area is fixed and nodes density is variable and in the second nodes density is constant and varies the deployed field. At these conditions the numbers of rounds after the first node dead are calculated for the network. The simulation has been carried out in the MATLAB environment by taking all parameters as in [9] except BS location. Since LEACH provides a base for many of the hierarchical wireless sensor network research, the performance of proposed scheme has been analyzed and compared with LEACH protocol by varying the node density and area of the network.

Table-1 shows the variation of optimum number of clusters with number of data rounds keeping deployed network area fixed. It can be observed from this table that the proposed method always performs better than the conventional LEACH protocol and increases number of rounds with lesser number of clusters. However, a trend of increase in number of optimum clusters has been also found as the number of cluster nodes increases.

Table 1. Variation of optimum no. of clusters with number of rounds for different nodes density and M=500*500

Node density	Optimal numbers of Clusters		Number of Rounds	
	LEACH	Proposed Method	LEACH	Proposed Method
50	8	3	113	170
100	11	4	167	243
150	13	5	188	323
200	15	6	239	377
250	17	7	285	400
300	18	7	313	432
350	20	8	352	483
400	21	9	375	529
450	22	9	394	580
500	24	10	416	622

Table-2 includes the variation of optimum number of clusters with data rounds for fixed number of nodes and different network areas. The content of this table concludes that there is a trend of decrement in the number of rounds as well as optimal clusters with increment in the network area. This trend is found significant for both LEACH and proposed method. However, proposed scheme again performs better than the LEACH protocol and provides higher number of data rounds with lesser number of clusters.

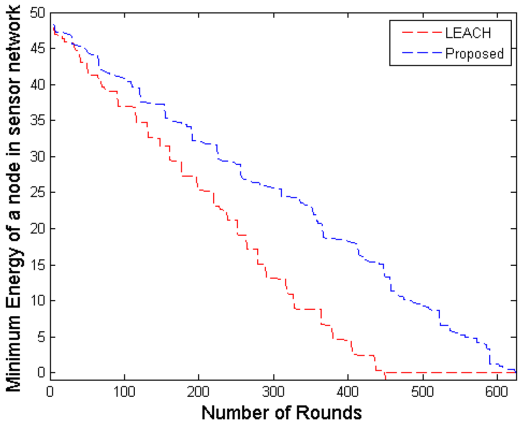

Fig. 1 Comparison of lifetime for M =N = 500

The performance analysis of the presented work has been also carried out in terms of variation of minimum node energy with data rounds (life time) for fixed number of nodes and different network areas. Figure 1 and 2 illustrate the variation of life time for the network of 500 nodes with 500 X 500 m^2 and 800 X 800 m^2 areas respectively. It can be easily observed from both the figures that proposed method provides better network life time than LEACH protocol. Figure 1, shows that nodes energy continuously decreases as number of rounds increases. From Figure 2, it can also be concluded that number of data rounds i.e. network life time gets decreased as the area of the network increases.

Table 2. Variation of optimum number of clusters with no. of rounds for different Area and N=500 nodes

Node density	Optimal numbers of Clusters		Number of Rounds	
	LEACH	Proposed Method	LEACH	Proposed Method
300	18	10	2980	3977
400	16	8	972	1422
500	14	7	450	625
600	12	6	179	272
700	10	5	65	118
800	8	4	48	70

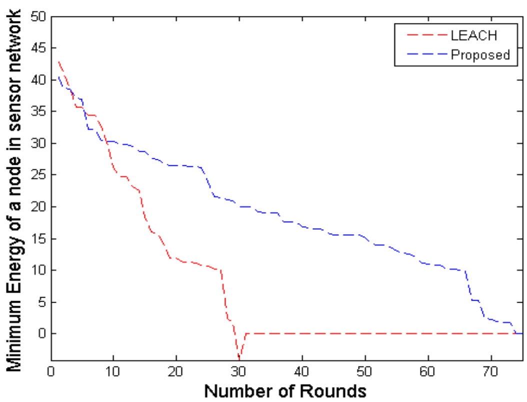

Fig. 2. Comparison of lifetime for M =800, N =500

5. Conclusion

In this work, an analytical approach has been proposed that finds the optimum count of the clusters, which leads to increase the lifetime in terms of rounds in the sensor network for various topologies. The result shows that the optimal parameter values for these scenarios and complex model will not only depend on N (number of nodes) but also depends on the network area, distance between the nodes and BS, amplification energy parameters etc. The analogy among the network nodes density with optimal count of clusters percentage has been also checked and it has been found that the percentage of optimal count of cluster is not global for all the topologies in fact it depends on the nodes density.

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