A New Design Scheme for a Disperse Two Tiered Wireless Sensor Network

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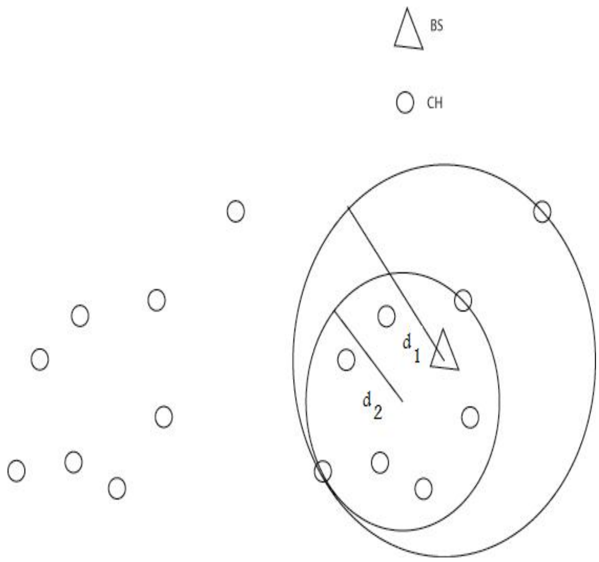
***Abstract*— In energy constrained Wireless Sensor Networks (WSN), network lifetime is considered as one of the most important metrics from the design point of view. In our paper, we have addressed the impact of a disperse node on network lifetime and have proposed a new design approach, Lifetime Enhancement for Disperse Networks (LEDN) to reduce its effect on a two tiered WSN. A mathematical analysis has also been presented in our paper to discuss the impact of a disperse node on network lifetime. Simulation studies confirm the significant improvement in network lifetime using our proposed design scheme.**

***Index Terms*— Wireless sensor network, disperse node, lifetime, minimum enclosing circle.**

I. INTRODUCTION

A WSN is a resource constrained communication network. Sensors are driven by batteries and recharging the batteries is not a good option in WSNs. As a result, a great deal of efforts is made in each layer so that the network can run for the maximum time. In the physical layer, a significant amount of energy is spent in the process of transmission and reception of signals which demands for optimal Base Station (BS) locations. For a sensor node (SN), most of the energies are spent in the transmission and reception process [1-2]. A small amount of energy is spent for sensing and processing comparing to the energy required for transmission and reception purpose. Thus energy consumption of a sensor node is distance dominated [3] i.e. the farthest node will consume more power comparing to the nearest one. Consequently, some nodes will die much earlier than other nodes due to the non-uniform distance from the BS. As a result, connectivity with some parts of the network is lost. This scenario is undesired in some applications where connectivity throughout the network is of maximum priority. Therefore, a careful planning on BS locations can lengthen network lifetime. Pan *et. al* [3-4] found that the best location for single BS is the center of the minimum enclosing circle, that encloses all the nodes. They worked on constant data rate and different types of definitions of network lifetime. Hong *et. al* [5] worked on variable data rate using Particle Swarm Optimization (PSO) to identify the best locations for multiple BSs. Hou *et.al* [6] provided a solution for multiple BSs locations where aggregation and forwarding nodes (AFNs) can communicate with the BS in multi-hop. Hu *et.al* [7] worked on anycast routing based on a source based tree. Algorithm for optimum BS location was also proposed in [8].



(a) (b)

Figure1. Impact of a disperse node on network lifetime

Unfortunately, nothing is mentioned about disperse network in their papers. A disperse network is a network that contains geographically disperse nodes located far away from the majority of the nodes. In case of a disperse network, the traditional approaches [3-12], are not suitable as network lifetime is drastically reduced due to the presence of a disperse node(s). Therefore, we come

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up with a new design scheme called LEDN. In this paper, we propose LEDN for a two tiered heterogeneous WSN, where inter cluster routing is performed in multi hop, intra cluster routing is performed in single hop and the death of first Cluster head (CH) defines the end of network lifetime.

The remainder of this paper is organized as follows. In section II, a detailed mathematical analysis is performed to show the impact of a disperse node(s) on network lifetime. In section III, we provide a mechanism for identifying the disperse nodes and specify the network design scheme followed by an algorithm to calculate lifetime for the scheme. In section IV, we provide simulation results. We conclude the paper in section V.

II. IMPACT OF A DISPERSE NODE(S) ON NETWORK LIFETIME

In a two tiered WSN, two types of nodes are deployed and the communication responsibility is divided among those nodes which can be identified using [13]. The whole network is divided into clusters [1-2]. The low capable nodes perform sensing and relaying information to the Cluster-Head (CH). The CH, which has a higher capability than other nodes, aggregates the received information and transmits the information to the BS. The CHs consume more power comparing to the macro sensor nodes. The death of a CH can define the end of network operation where connectivity is of primary concern [3]. That is why, surveillance of CHs is very important in a two tiered WSN. Let n is the number of cluster heads (CHs) inside the network which represent n distinct regions of interest. According to the chosen definition for network lifetime, the furthest CH from the BS will define network lifetime [3],[5]. A CH's lifetime can be calculated as:

$$l\,(i) = \frac{e(0)}{r \times (a_1 + a_2 \times d_i'^b)} \qquad (1)$$

Where, i is the CH identity, r is the data rate, a_1 is a distance independent parameter, a_2 is a distance dependent parameter, d_i' is the distance from the CH to a destination CH or BS , b is the path loss exponent, typically ranges between 2 and 4 based on the type of environment and $e(0)$ is the initial energy of the CH. The lifetime of the network is defined as $L = \min_{i=1}^{n} l(i)$,

If we consider $a_1 = 0$ and $a_2 = 1$, then expression (1) becomes $l(i) = \frac{e(0)}{r \times d_i'^b}$. If $e(0)$ and r are treated as constants, we can write

$$l(i) = \frac{k}{d_i'^b} \qquad (2)$$

Where, $k = \frac{e(0)}{r}$ is a constant. For a given number of CHs, we can figure out the optimal BS location through a minimum enclosing circle. If the maximum distance among the CHs is D, then we can find a minimum enclosing circle with radius d which varies in the range $D/2 \le d \le \sqrt{3} \times D/2$ (Details can be found in [3]) and the center of the circle is the best position for locating a BS. A minimum enclosing circle can be found by a set of 2 or 3 critical CHs. At least 2 or 3 CHs will reside on the perimeter of the minimum enclosing circle. Therefore, the maximum distance between a CH and the BS is *d*. Expression (2) tells us that the furthest CH from the BS will place the constraint on network lifetime. Since *d* is the maximum distance between a CH and the BS for a minimum enclosing circle, the CH(s) that are at distance d will define network lifetime.

A disperse CH in a topology for a particular network refers to a CH which is located away from the region where CHs density is high. Let p be the disperse CH for a topology T_1. A minimum enclosing circle C_1 can be found for T_1, where the limit of radius d_1 of the circle is $D_1/2 \le d_1 \le \sqrt{3} \times D_1/2$ and network lifetime can be obtained by the following expression.

$$L(T_1) = \frac{k}{d_1^{\,2}} \qquad (3)$$

Here D_1 is the maximum distance between any two CHs in T_1. If we ignore the disperse CH (p) from T_1 , all the CHs can be enclosed by a minimum enclosing circle C_2 for the virtual topology T_2; where C_2 is less than C_1. If D_2 is the maximum distance between any two CHs in T_2 then radius d_2 of the circle C_2 is defined as $D_2/2 \le d_2 \le \sqrt{3} \times D_2/2$ and network lifetime can be determined by expression (4).

$$L(T_2) = \frac{k}{d_2^{\,2}} \qquad (4)$$

Let d_3 is the difference between d_1 and d_2.

$$d_3 = d_1 - d_2 \qquad (5)$$

Expressions (3) and (5) are combined together to find expression (6)

$$L(T_1) = \frac{k}{(d_2 + d_3)^2} \qquad (6)$$

The reduction of lifetime is given as

$$L(T_2) - L(T_1) = \frac{2kd_2d_3 + kd_3^{\,2}}{d_2^{\,4} + 2d_2^{\,3}d_3 + d_2^{\,2}d_3^{\,2}} \qquad (7)$$

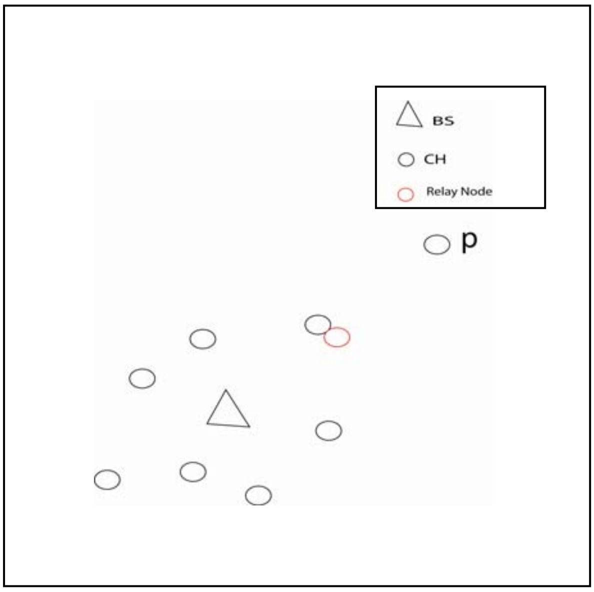

Figure 2. LEDN architecture

All the terms in the numerator and denominator are positive which ensures the reduction of network lifetime. The amount of lifetime reduction can be calculated using expression (7). The d_3 terms in the numerator and the denominator gives us an idea about the impact of a disperse CHs on network lifetime. If d_3 is large, the impact on network lifetime will be significant since *k>>d*, and the change of BS location due to the presence of a disperse CH is indicated in Fig.1 (b).If we stick to the existing approaches to locate the BS, the presence of a disperse CH will also accelerate the energy consumption of other CHs and this can be ensured using the residual energy (R.E) calculation of a network.

$$R.E = \sum_{i=1}^{n} R.E(i) = \sum_{i=1}^{n} \left[e(0) - (r \times d_i'^2) \times t \right] \tag{8}$$

III. Proposed design scheme 'LEDN' for a disperse network

Our proposed algorithm "**DisperseNodesAlgo"** analyzes the data to determine the presence of a disperse CH(s). If there is no disperse CH, our proposed approach will find out optimal BS location. In case of a disperse CH, our proposed scheme initially discards the disperse CH(s) from the original topology (T_1) and find out the optimal location of the BS for the virtual topology (T_2). We then return to the original topology and replace the network lifetime of the virtual topology for the original topology to determine the number of relay nodes required using the ratio of d_1 (The maximum distant CH from the BS in T_1) and d_2 (The maximum distant CH from the BS in T_2) . If the ratio is fractional, we will take the ceiling value. The relay nodes are used to relay the information of the disperse CH(s) to the BS and this ensures the network lifetime is not limited by the disperse CH(s). Our LEDN architecture is presented in Fig.2.

Algorithm for the proposed scheme
LEDN

1. Get the locations of the CHs
2. $T_1 \leftarrow$ Topology of n CHs
3. $T_2 \leftarrow$ Topology of CHs discarding the disperse CH(s)
4. Run Disperse Nodes
5. Discard the disperse CHs from T_1
6. Find BS location for T_2
7. $d_2 \leftarrow$ The maximum distance between a CH and the BS in T_2
8. $d_1 \leftarrow$ The maximum distance between a CH and the BS in T_1
9. Set the transmission range to floor of d_1 / d_2 for the disperse CH(s)
10. Calculate network lifetime

Proposed Algorithm for finding a disperse CH(s)

For a dynamic network, it is possible to obtain the co-ordinates of the CHs using GPS tracking device and for a fixed network the co-ordinates of the CHs are determined by network designers in accordance with the application requirements. A detailed discussion on this issue can be obtained from [13]. Following Fig.1 (a), we observe the mean average distance of the disperse CH from other CHs in the network will deviate from the remaining $(n-1)$ CHs. Using this observation, we can find out the disperse CHs. The distance between any two CHs can be calculated using the Euclidian formulae, $d = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$.

For any CH in T_1, we obtain a set of $(n-1)$ members ; each member representing the distance between the CHs and some other CHs in the network, n CHs give n sets each having $(n-1)$ members. The mean value of a set can be found using the following expression.

$$Mean\ m = The\ sum\ of\ the\ (n-1)\ values / (n-1).$$

As n sets give n mean values, we define a set S of n mean values,

$$Set\ S = \{m_1, m_2, m_3 .... m_{n-2}, m_{n-1}, m_n\}.$$

Let M be the mean of the set S. We find the variance (*V*) of the data set by expression (9):

$$V = \frac{\Sigma (X - M)^2}{N - 1} \tag{9}$$

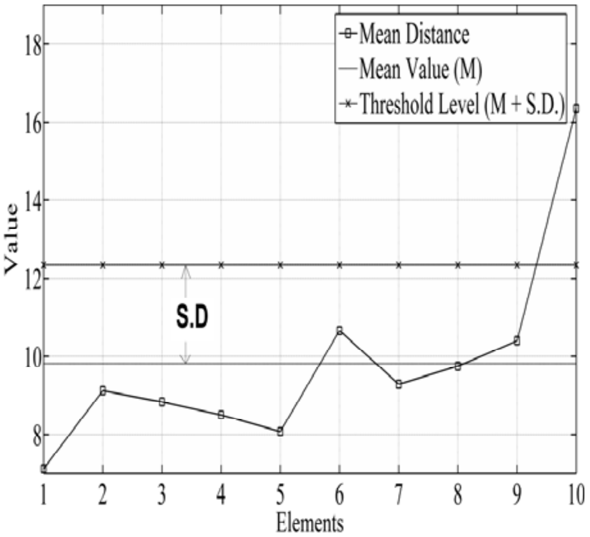

Figure 3. Finding a disperse CH in a network

Where X represents the members of set S and n represents the total number of members. The standard deviation (S.D) of the set S can be found by the square root of variance $S.D = \sqrt{V}$ which gives us the spread out of data from mean. We add up the mean M of set S with the standard deviation S.D to set that value as the threshold level. The disperse node(s) has (have) a mean average distance greater than the threshold level which is shown in Fig. 3. For verification of our hypothesis in this subsection, we take an example- let a network contains CHs having co-ordinates {(0,0), (0,5), (0,10), (5,0), (5,5), (5,10), (10,0), (10, 5), (10,10), (20,10)}. Fig. 3 shows that the CH having co-ordinate (20, 10) is the disperse CH which is the obvious case. However, it would be a nice idea to set up different threshold levels aiming to get different numbers of disperse CH(s). We leave this issue as a future research topic for interested readers. In this paper, we have set up the example case with a single disperse CH.

Algorithm for disperse CH(s)

DisperseNodesAlgo

1. Declare an array of n sets
2. Start Loop (1:n)
3. For each CH
4. Find the distance from (n-1) CHs and store the values inside a set.
5. End Loop
6. Start Loop (1:n)
7. For each set find find the mean value and store value inside a set S.
8. End Loop
9. M ←Find the mean value from the set
10. S.D ←Find standard deviation from the mean
11. Set threshold level equal to (M+S.D).
12. Find out the CHs that have a mean value greater then the threshold level
13. Return CHs

Power savings for a disperse CH(s)

Energy dissipation for a disperse CH becomes critical as the BS location is moved in our scheme LEDN. Therefore, we must have a power saving scheme for the disperse CH(s) and the scheme is to reduce the transmission range for the disperse CH and using some redundant nodes for relaying the information.

Let consider a linear network where the nodes are equally spaced (r) and path loss exponent is 2., If the source node uses h hops to transmit data to the destination node, the transmit power of that node is to communicate with the neighbor node is given by expression (10).

$$P_{Tx} = P_{Rx}(r) \times r^2 \qquad (10)$$

Here, P_{Tx} is the transmit power and P_{Rx} is the receiving power. On the other hand, the transmission power required for the node to directly communicate with the destination node is given by expression (11)

$$P_{Tx} = P_{Rx}(hr) \times (hr)^2 \qquad (11)$$

The power savings achieved for multi-hop is given by expression (12).

$$P(savings) = \frac{P_{Rx}(hr) \times (hr)^2}{h \times P_{Rx}(r) \times r^2} = h \qquad (12)$$

IV. SIMULATION RESULTS

The simulation has been carried out using MATLAB to show the performance of the proposed LEDN scheme. The initial energy of the CH’s is 10000 nJ and the data rate is 5bps and has been performed on varying number of CHs and the positions of CHs are randomly generated. Note that the data rate and the initial energy of real-life sensors may not fall in the above range. We conducted simulation for 10 different topologies with CHs ranging from 5 to 50 and data were generated randomly for the CHs. For routing of information we used LEACH protocol [14]. Fig.4 shows the remarkable improvement in network lifetime for LEDN. It is also confirmed that the network lifetime depends on the dispersive nature of the network, not the number of CHs. For example, while 10 CHs is considered of which one CH (disperse) is too far from the dense region, the network lifetime is improved in order of several times on average using our proposed approach. The graph suggests that a modest modification using relay node in the network architecture can reduce the impact of a disperse CH on network lifetime. The simulation result vindicates our prediction in derived expression (7). If the network is left unmodified and only the optimal position of BS is taken into consideration, network lifetime can be significantly reduced due to the presence of a disperse CH. Fig. 5 indicates that the energy consumption of the CHs is accelerated due to the presence of the disperse CH . In existing approaches (such as Pan et. al, Hong et. al, Paul et. al, Showkat et. al), a position for BS is identified in such a way that a balance is created for non-uniform distances from CHs to BS. Still the average distance from the CHs to the BS is increased due to the presence of a disperse CH as observed in Fig.1 (b). As a result energy consumption rate for those CHs increases which in turn, diminishes the battery lifetime. The fact that we add up the residual energy of all the CHs gives rise to the total residual energy as we increase the number of CHs in Fig.5. On the other hand, the average distance from CHs to the BS is minimized in LEDN with the help of a relay node for the disperse CH. Since the average distance from CHs to BS is reduced because of the modification in the network before deciding the best location for BS, a better response (for example: 0.1 to 0.23 mj for 25 CHs) is obtained in our scheme.

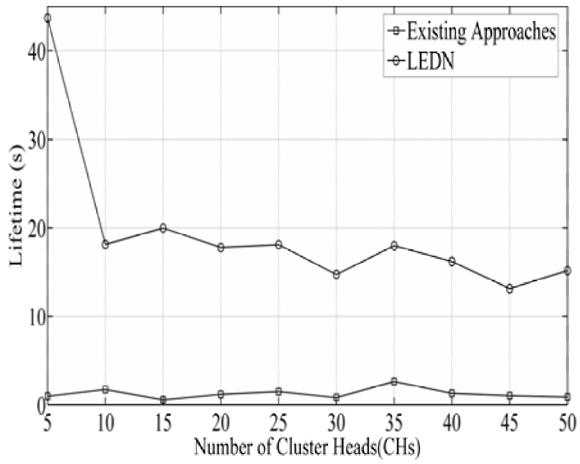

Figure 4 Network lifetime comparison graph

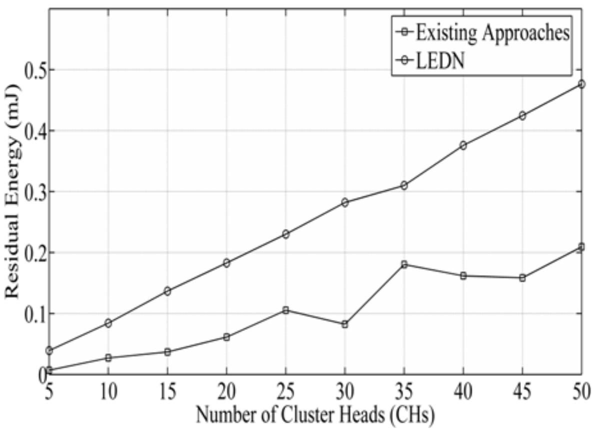

Figure 5. Residual energy comparison graph

V. CONCLUSION

In this paper, we have investigated a two tiered disperse WSN and observed a better response using our proposed design scheme in compare to other schemes. We have also presented an algorithm to figure out the existence of disperse CHs in the network. The position of a disperse CH(s) is a major limiting factor for network lifetime and our proposed scheme LEDN overcomes this limitation and increases network lifetime.

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