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Energy Efficient Clustering in Multi-hop Wireless Sensor Networks using Minimum Distance and Maximum Energy Group Search

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Abstract

Energy Efficient Clustering became one of the most promising approaches for routing in Multi-hop Wireless Sensor Networks which has the challenge of Cluster Head (CH) selection. Even though there are several techniques to perform this, LEACH became the most popular one. But, it produces a random selection of CHs and does not consider distance as well as the residual energy. Good selection of CHs leads to stimulate energy efficient clustering results. We proposed an efficient heuristic approach known as Min-Max search which works in two phases. Our method differs with LEACH in setup phase where clusters will be selected based on the threshold computed by considering sensor nodes having Minimum Distance (from Base Station) and Maximum Energy. We compared this proposed method with LEACH and results proved that our method showing significant improvement than LEACH in terms of the network lifetime of the network.

Keywords: Wireless Sensor Networks, Multi-hop Networks, Energy Efficient Clustering, Life time of network.

INTRODUCTION

Wireless Sensor Network (WSN) [1] generally consist of hundreds or potentially even thousands of spatially distributed, low-cost, low-power, multifunctional, autonomous sensor nodes and communicate over short distances. WSN applications can be broadly classified into two types: Tracking application like Military information integration [2], Industry automation [3] etc. and Monitoring applications like Medical informatics services [4], environmental monitoring [5] etc. WSN application design always requires the construction of multi-objective functions because WSNs are influenced by a number of factors to be optimized known as Multi-Objective Optimization (MOO) metrics. Zesong [6] published the list of all MOO metrics along with types of algorithms useful for WSN application design. From this survey, it is clear that most of the researchers are attracted to address the problems of data aggregation and routing in WSN with optimization objectives as to minimize energy consumption, minimize latency and maximize lifetime. The lifetime of the sensor nodes can be increased by distributing energy dissipation over multiple nodes using multi-hop transmission instead of single-hop.

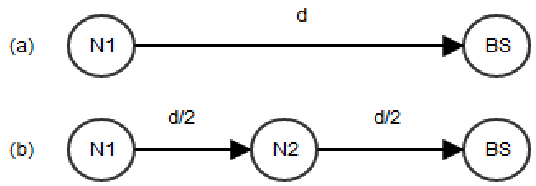

Figure 1: Transmission distance for

(a) Single-hop (b) Double-hop

Consider single-hop as shown in Fig. 1(a), if the distance between the source node (N1) and Base Station (BS) is *d*, then energy consumed to transmit data over this distance is E which will be dissipated by N1 only. But in case of double-hop as shown in Fig. 1(b), data will be transmitted through node N2. With this distance between N1-N2 and N2-BS is reduced to $\frac{d}{2}$ and energy dissipation is distributed among two nodes N1 and N2 with energy dissipation of approximately $\frac{E}{2}$ at each node. Energy efficient analysis published by Uros [7] concludes with all evidence that: Multi-hop transmission is more efficient than single-hop when receiver's power consumption is small enough in comparison to transmitters power consumption. This motivated several researchers to implement routing algorithms for multi-hop WSNs to achieve efficient utilization of energy. Even though there are several routing protocols, Energy Efficient Clustering protocols became most popular among them as energy efficiency is the most critical factor for wireless sensor nodes due to limited power sources.

All these clustering protocols start with the selection of Cluster Heads (CH) since cluster heads consume more energy than other nodes of the network. Since CH act as the intermediate node between source and base station (BS) and hence it needs to use both transmitter and receiver while source node uses transmitter only. Energy efficiency in the multi-hop network is mainly achieved by reducing power consumption due to receivers with the selection of a proper set of CHs for transmission. Improper selection of CHs causes an additional penalty of receiver's energy consumption that causes the death of nodes in short span of time.

Energy efficient clustering became popular from 2000 onwards by Wendi [8] through energy efficient communication for Wireless Micro-sensor Network using Low Energy Adaptive Clustering Hierarchy (LEACH) protocol which proved to be a good clustering protocol. LEACH is a self-organizing, hierarchical and clustering based protocol for multi-hop networks. This protocol became popular as it utilizes randomized rotation of local cluster base stations (cluster-heads) to evenly distribute the energy load among the sensors in the network dynamically. Initially, when the cluster is created, each node decides whether or not to become a cluster-head for the current round. Using threshold, each node will be a cluster-head at some point within $\frac{1}{P}$ rounds. Distributing the energy among the nodes in the network is effective in reducing energy dissipation from a global perspective and enhancing system lifetime. But, it produces a random selection of cluster heads which means for each round new cluster head will be selected based on random probability which may die first. Moreover, it is suitable for static and small-scale networks only. Later, several clustering proposals can be observed form the history and remaining paper is organized as follows. The Literature review was discussed in section 2 and our proposed method was presented in section 3. Finally, section 4 explains comparison of results in terms of energy efficiency and the lifetime of the proposed method.

LITERATURE REVIEW

The primary and critical step of any Energy Efficient Clustering technique is Selection of Cluster Heads which mainly influences the energy consumption. Variety of proposals for large-scale networks can be observed from the literature after LEACH protocol. Most of them are multi-objective functions to address optimization of the lifetime, energy consumption and transmission delay. First of all, Minhas [9] constructed multi-objective cost function using Fuzzy membership functions and rules. An advanced ant colony algorithm based on cloud model (AACOCM) proposed by Wei[10] to adapt different services requirements, alternatively Carlos[11] implemented Strength Pareto Evolutionary Algorithm (SPEA2) to make an efficient use of the energy in the network and decrease the possibility of packet loss and Cheng [12] designed a multi-objective optimization (MOO) framework for cluster-based WSNs. In the same way, several clustering based algorithms for multi-hop networks can be observed as follows: Seema [13] proposed a distributed, randomized clustering algorithm to organize the sensors in WSNs, Trong [14] proposed an energy and delay efficient multi-hop scheme called Cluster and Chain based Energy*Delay Efficient Routing Scheme (C2E2S) to extend network life time, similarly K-means-midpoint algorithm based energy efficient clustering protocol was implemented by Anindita [15], another clustering algorithm using Type-2 fuzzy logic (FL) was introduced by Padmalaya[16] for decision making in WSNs.

Along with them some other diverse methods can be identified including wakeup scheme for sensor networks to achieve balance between energy saving and end-to-end delay by turning off sensors radio when communication is not great potential by Xue [17], Zhu [18] implemented network utility maximization (NUM) framework to formulate the network lifetime maximization and fair rate allocation, Lu [19] introduced fuzzy random variables to describe both fuzziness and randomness of link delay, link reliability and nodes residual energy. From this literature, it is evident that most of the researchers are attracted to implement clustering based algorithms to address energy efficiency, the lifetime in multi-hop WSNs. This motivated us to implement energy efficient clustering technique using Minimum Distance and Maximum Energy node search method to select a proper set of CHs for transmission.

MINIMUM DISTANCE AND MAXIMUM ENERGY (MDME) NODE SEARCH

Distance from BS is one of the key factors that influence the energy consumption of sensor node. If the distance between the source and destination is large then more power dissipation occurs. Energy dissipated by Transmitter (E_{Tx}) mainly depends on both distance (d) and amount of data (k). It can be considered from Radio Channel Model [7, 20] of WSNs which requires some standard electronic parameters with fixed values listed in Table I including the transmitter or receiver electronic energy (E_{elec}) and Amplification factors (E_{fs} and E_{mp}).

Table I. Standard values of electronic parameters

Parameter	**Values**
Transmitter or Receiver Electronics (E_{elec})	50 nJ/bit
Free-space energy amplification factor (E_{fs})	100 pJ/bit/m^2
Multi-path fading amplification factor (E_{mp})	0.0013 pJ/bit/m^4
Data aggregation energy (E_{DA})	5 nJ/bit

The amount of energy required to transmit k bits over a distance d can be represented as Equation (1) where threshold distance d_0 can be computed from Equation (2) which depends on amplification factors. Similarly, the energy dissipated by receiver depends only on the amount of data (k) and can be calculated by Equation (3). In multi-hop WSNs, normal nodes dissipate only transmission energy E_{Tx} as they need to switch off receivers. But, CH causes more power dissipation due to use of both Transmitter and Receivers. If there are t members in a cluster then energy dissipated by CH will be the sum of energies for relieving data from (t-1) nodes, data aggregation energy for all t nodes and transmission energy to BS which can be computed using Equation (4).

$$E_{Tx}(k,d) = \begin{cases} k * E_{elec} + k * E_{fs} * d^2 \ if\ d < d_0 \\ k * E_{elec} + k * E_{mp} * d^4 \ if\ d \geq d_0 \end{cases} \quad (1)$$

$$d_0 = \sqrt{\frac{E_{fs}}{E_{mp}}} \quad (2)$$

$$E_{Rx}(k) = k * E_{elec} \quad (3)$$

$$E_{CH} = k * E_{elec} * (t-1) + k * E_{DA} * t + E_{Tx}(k,d) \quad (4)$$

These are the standard equations used for the any multi-hop WSN simulation or implementation. Come to the proposed method which functionally works similar to Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol with two phases: setup and advertisement phases. In case of LEACH, for each round setup phase involves clustering starts by generating a random number for each node which will be compared with the threshold value *T(n)* to advertise itself as CH. If the value of random number (between 0 to 1) is less than threshold values *T(n)*, then the node has a chance to become CH where the threshold is set as:

$$T(n) = \begin{cases} \frac{P}{1 - P * (r \ mod\ \frac{1}{P})} & if\ n \epsilon G \\ 0 & otherwise \end{cases}$$

Here *r* is round number, *G* is set of nodes which are not selected as CH and *P* is desired percentage of cluster heads for example if P = 0.1 means each CH can get the chance of getting CH after $\frac{1}{P}$ rounds i.e. $\frac{1}{0.1}$ = 10 rounds. Now, each node having a chance of getting CH will advertise itself in the second phase known as advertisement phase. In this phase after the announcement of CHs by broadcasting, all other nodes will be assigned by joining message to nearest CH node for transferring data. Even though it is dynamic clustering protocol, it suffers from few defects as follows: random selection of CHs may cause possibility for selection of low residual energy nodes as CHs and more over distance is not at all considered for CH selection. These drawbacks motivated us to work on distance and residual energy of nodes for the selection of CH which was ignored by LEACH.

Our method differs with LEACH in setup phase while CH selection, however, advertisement phase is same. In this proposed method, in each round for each node *chance* value is calculated by considering the distance from BS and the residual energy of the node into account. The value of *chance* is computed by average of two probabilities: Distance probability (D_P) is the ratio of the node distance from BS to X_{max} is the maximum distance of the network i.e. diagonal distance and Energy probability (E_P) is the ratio of the current energy of node (E_{Cur}) to the initial energy of node ($E_{initial}$) as shown in Equation (5) and D_P and E_P can be computed using Equation (6) and (7).

$$Chance = \frac{(1 - D_P) + E_P}{2} \quad (5)$$

$$D_P = \frac{Distance\ from\ BS}{X_{max}} \quad (6)$$

$$E_P = \frac{E_{Cur}}{E_{Initial}} \quad (7)$$

$$Th = Chance_{Min} + \frac{Chance_{Max} - Chance_{Min}}{2} \quad (8)$$

After computation of *chance* value for each node, CH will be selected by comparing the node *chance* value with threshold value *Th* computed at each round using Equation (8). Here, $Chance_{Min}$ and $Chance_{Max}$ are the minimum and maximum chance value of the nodes computed in each round. These equations mainly used to search sensor node with Minimum Distance from BS (D_P) and Maximum Energy remaining (E_P) and hence this method named as Minimum Distance and Maximum Energy (MDME) node search. The value of *chance* will be high if the node is near to BS and having more residual energy.

Consider five nodes randomly located over an area of 100 x 100 m^2 along with initial and current energies as shown in Table II. If the BS is located at (50, 50) then the distance from BS can be computed using fundamental geometric equation. The distance between two nodes with location coordinates as (x1, y1) and (x2, y2) can be computed using Equation (9).

$$distance = \sqrt{(x1 - x2)^2 + (y1 - y2)^2} \quad (9)$$

Table II: Sample network with five nodes

Node	Location	Initial Energy	Current Energy	E_P	Distance from BS	1-D_P	Chance
N1	15, 20	0.5 J	0.23 J	0.46	46.10	0.67	0.57
N2	20, 20	0.5 J	0.32 J	0.64	42.43	0.70	0.67
N3	10, 30	0.5 J	0.34 J	0.68	44.72	0.68	**0.68**
N4	30, 30	0.5 J	0.22 J	0.44	**28.28**	**0.80**	0.62
N5	20, 30	0.5 J	**0.41 J**	**0.82**	36.06	0.75	**0.78**

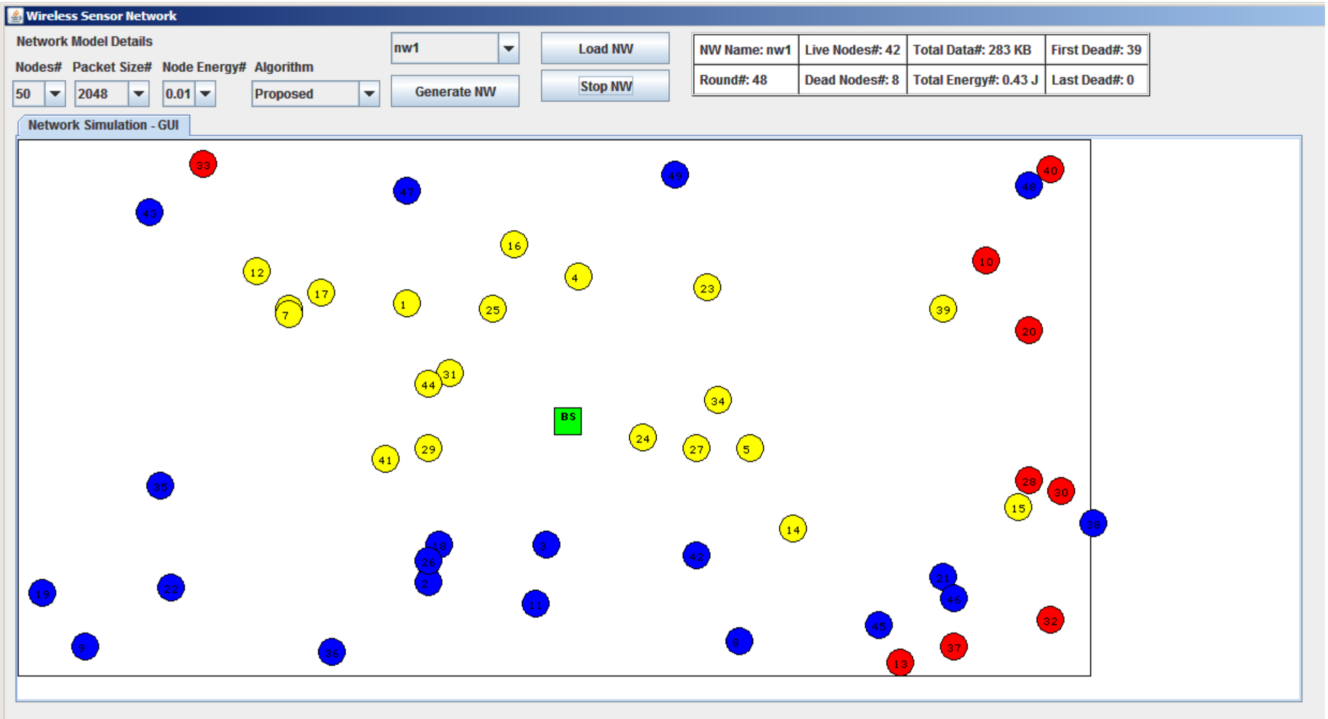

Figure 2: Running instance of network simulation

Table III: Comparison of network life time

Nodes#	Packet Size (in bits)	Energy Dissipated (in J)		First Dead		Network Life Time increase (in rounds)
		LEACH	MDME	LEACH	MDME	
50	1024	0.53	0.53	62	78	16
	2048	0.53	0.53	28	39	11
100	1024	1.03	1.04	52	59	7
	2048	1.05	1.07	15	30	15
150	1024	1.54	1.55	59	65	6
	2048	1.57	1.57	22	31	9
200	1024	2.05	2.05	58	65	7
	2048	2.07	2.11	27	31	4

Table II listed other computational values like distance from BS, Distance probability, Energy probability and *chance* values. From this table we can find that node N4 is located very near to BS with a distance of 28.28 m and its D_P value can be calculated as: $D_P = \frac{28.28}{141.42} = 0.20$, where X_{max} = Diagonal distance from (0, 0) to (100,100) $= \sqrt{(100-0)^2 + (100-0)^2} = 141.42$ m. But according to the proposed method Minimum distance node will have the higher *chance* and Maximum distance node will have the lower *chance*. Hence, we must consider $(1\text{-}D_P) = 1 - 0.20 = 0.80$ while computing *chance* value.

But, Energy probability (E_P) can be considered directly, because node with high energy will lead to a higher probability for *chance*. From the Table II, as $Chance_{Min}=0.57$ and $Chance_{Max}=0.78$, the threshold (*Th*) for this round can be calculated as $Th = 0.57 + \frac{0.78-0.57}{2} = 0.57 + \frac{0.21}{2} = 0.675$. From the above table it is clear that N2 and N5 have higher *chance* value than *Th (0.675)* value and hence these two nodes can be selected as cluster heads. Even though N4 has minimum distance it is not selected because of low residual energy which may die early if it is selected as CH. This motivated to use the distance and energy probabilities for computing *chance* value. Finally, this proposed MDME algorithm works completely with following four steps:

Step 1: Initialization

- Calculate D_P, E_P and *Chance* for each node using Equations (5), (6) and (7)
- Compute minimum chance value $Chance_{Min}$ and maximum chance value $Change_{Max}$

Step 2: Cluster Head (CH) Selection

- Node having *Chance* > *Th* will be announce itself as CH

Step 3: Cluster Formation

- Assign remaining nodes to nearest CH based on distance

Step 4: Transfer data

- Finally transmits data through CHs to BS

RESULTS AND COMPARISONS

Experimental setup plays a vital role in comparison of results. Wireless Sensor Networks are generally simulated using MATLAB, but in order to take advantage of flexible customization of the configuration of network simulation, we implemented our method using JAVA. We converted MATLAB code [21] of the LEACH to JAVA for experimental comparisons and considered some assumptions for computation of proposed method such that sensor nodes are stationary and homogeneous. Similarly, Base Station (BS) located at the center of the 100 x 100 square meter network area. Running of simulated results of the network with 50 nodes, packet size of 2048 bits and 0.01 J as initial energy at round 48 for the proposed algorithm can be seen from Figure 2. This will represent BS node as green color rectangle, CH as blue color circle, Normal node as yellow color circle and Dead node as red color circle. This interface also provides flexibility to change various network parameters including the number of nodes of the network, the packet size of the network and initial energy of the node for customization of the network. However, the area of the network was fixed to 100 x 100 square meters and the maximum number of rounds as 1000 but can be changed from code. Similarly, we experimented with various possible network parameters with initial energy of each sensor node as 0.01J and results are tabulated as shown in Table III. This table shows the comparison of network life time between proposed MDME with LEACH. It is clearly evidenced that our method performed well consistently in terms of sustaining network life time of network by postponing the first death of node with almost equal energy dissipation as LEACH method. For example in case of network with 50 nodes to send packet of size 1024, LEACH causes death of first node in round 62, while our proposed MDME method causes death of first node in round 78 with an increased life time of 78-62=16 more rounds. Form this we can say our method increasing network life time on an average of 9 more rounds to sustain the death of nodes.

CONCLUSIONS

LEACH has shown itself as one of the energy efficient clustering techniques for routing of WSNs. However, it suffers from the random selection of the cluster heads which leads to more energy dissipation of network which can be optimized by the proper selection of CHs at each round. In general, CH selection will be affected by considering distance and residual energy into account. Our method considered these two factors as Energy probability (E_P) and Distance probability (D_P) to compute change value for each node. This method produces the highest chance for the node which has Minimum Distance from BS and Maximum Residual Energy. Nodes with higher chance than the threshold (Th) will be selected as CH for the round. Results section proved our method performed well when compared with LEACH in terms of network lifetime of the network by sustaining the death of nodes around an average of 9 more rounds.

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