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Energy Efficient Clustering Scheme (EECS) for Wireless Sensor Network with Mobile Sink

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Abstract The participants in the Wireless Sensor Network (WSN) are highly resource constraint in nature. The clustering approach in the WSN supports a large-scale monitoring with ease to the user. The node near the sink depletes the energy, forming energy holes in the network. The mobility of the sink creates a major challenge in reliable and energy efficient data communication towards the sink. Hence, a new energy efficient routing protocol is needed to serve the use of networks with a mobile sink. The primary objective of the proposed work is to enhance the lifetime of the network and to increase the packet delivered to mobile sink in the network. The residual energy of the node, distance, and the data overhead are taken into account for selection of cluster head in this proposed Energy Efficient Clustering Scheme (EECS). The waiting time of the mobile sink is estimated. Based on the mobility model, the role of the sensor node is realized as finite state machine and the state transition is realized through Markov model. The proposed EECS algorithm is also been compared with Modified-Low Energy Adaptive Clustering Hierarchy (MOD-LEACH) and Gateway-based Energy-Aware multi-hop Routing protocol algorithms (M-GEAR). The proposed EECS algorithm outperforms the MOD-LEACH algorithm by 1.78 times in terms of lifetime and 1.103 times in terms of throughput. The EECS algorithm promotes unequal clustering by avoiding the energy hole and the HOT SPOT issues.

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1 Introduction

The researchers and the scientists got attracted by the Wireless Sensor Network (WSN), due to its wide application in monitoring and surveillance. WSN is a tiny embedded processor which works on achieving a single goal. The wireless sensor node forms clusters and communicates the data to the sink through Cluster Head (CH) [1–4]. The clustered architecture serves the purpose of monitoring large Region of Interest (RoI). The wireless sensor nodes are battery operated and autonomous in nature, replacing the battery resource and seeking to harvest as a replacement is a major challenge. The mobile sink based WSN has got its application in industrial automation and agriculture [5–8]. The increase in the battery size could increase the lifespan of the network. However, the size of the node becomes bulky and unfit for monitoring applications. Increasing the lifetime and data reliability has become the top concern in WSN [9–14]. Optimal CH selection and reducing data load to network enhances the lifetime of the network. Figure 1 illustrates the typical clustered architecture of WSN. The sink is the data receiving centre of the network. The Cluster Member (CM) transmits its data to sink through CH. The sink in Internet of Things (IoT) based environment is mobile in nature [15–20]. Therefore, the clustering of the networks based on location of the sink becomes a more challenging issue. This paper deals with creating an energy efficient routing algorithm for WSN considering a total number of packets sent and residual energy of the node as factors.

The rest of the paper is organized with the related works discussing on the mobile sink and energy efficient routing algorithms in Sect. 2. Section 3 discusses the proposed Energy

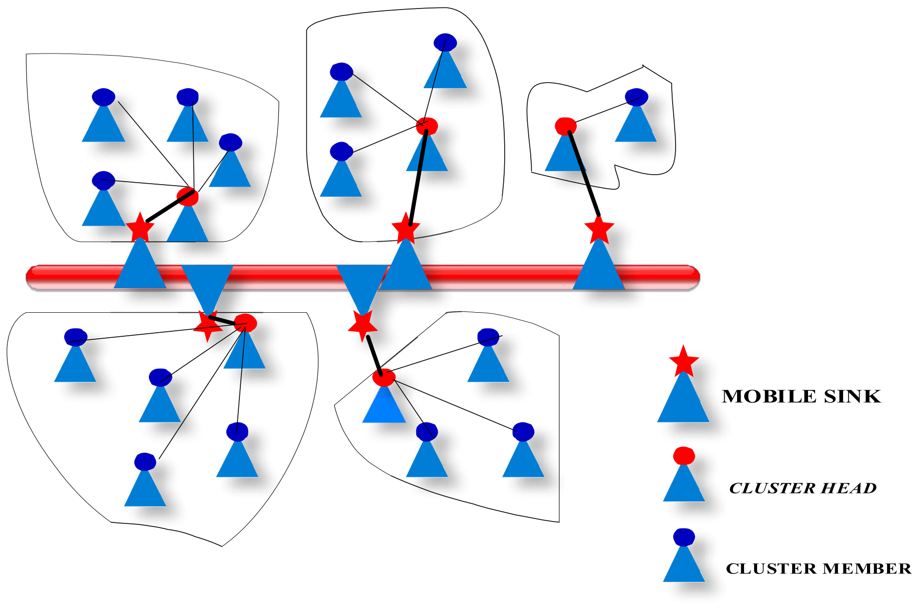


Fig. 1 Wireless Sensor Network architecture

Efficient Clustering Scheme, radio model, and mobility model. The results are briefly discussed in Sects. 4 and 5 concludes the paper.

2 Related Works

Many mobile sink routing algorithm has been identified for prolonging network lifetime [2–4]. The residual leftover energy, distance and cost coefficient are taken as the parameters to increase the lifetime of the network. The Energy Efficient Routing Protocol with Static Clustering and Dynamic Structure (ERP-SCDS) [18] utilizes virtual points in a Corona-based WSN, static clusters with dynamic structures. A relay node selection mechanism is used instead of a complicated multi-hop route discovery algorithm. The Energy-Aware Data Aggregation scheme (EADA) [19] for grid-based WSNs with a mobile sink provides a solution to the data aggregation and energy dissemination problem. A theoretical model and a simple clustering algorithm called Location-based Unequal Clustering Algorithm (LUCA) [20] is suggested to enhance the lifetime and network throughput, where each cluster has a different cluster size based on its location information (which is the distance between a CH and a sink). In LUCA, in order to minimize the energy consumption of the entire network, a cluster has a larger cluster size as increasing distance from the sink. The maximizing data collection based frameworks suggested in [5] discusses on maximizing the throughput of the network. The distance between the node and velocity is taken as factors for CH selection. However, the residual energy and available time slot are not discussed. An Integer Linear Programming based solution is suggested in [13] in which residual energy of the node, average energy of the CH are taken as parameters. The problem is solved through linear programming approach. The approach to limit the control message is suggested in [10] and the next hop selection is done based on sink discovery, route planning and data transmission. The Fail Safe Fault Tolerant (FSFT) algorithm [14] discusses CH selection based on the battery voltage. However, this algorithm better suits the application with static CH. The Energy Efficient Balancing scheme discussed in [21] allocates the load proportionally according to the capacity of agents. This scheme uses a greedy algorithm and allocates the heaviest nodes to the most powerful agents. The maximization of data throughput is the major constraint for energy harvesting sensor network with mobile sink [17]. However, the above-discussed algorithms fail to discuss the waiting time, mobility and throughput maximization of the network. The energy efficient cluster-based dynamic routes adjustment approach addressed in [25] adjusts the mobile sink path based on the need of the network. Many WSN applications are event-driven, but the mobility of the sink cannot be adjusted. The event-driven inside the RoI is random in nature and many algorithms provides random mobility model as a mobility pattern followed by the sink [24]. The redundant data causes more energy consumption and data traffic in WSN. The aggregation protocol Mobility and Heterogeneity aware Cluster-based Data Aggregation for wireless sensor network (MHCDA) addressed in [22] promotes the lifetime enhancement by avoiding the redundant data and efficient data aggregation through intercluster and intracluster aggregations. However, the re-election of CH is not considered which may affect the energy of current CH. A fair CH selection process and unequal clustering scheme reduces the drop packets, establishing a healthy connection. The selection of CH based on the distance, provides high received signal strength by ensuring good communication and high network lifetime [23]. The speed of the sink influences the successful transmission of packets and limits the drop packet, thereby increasing the network lifetime. The lifetime of the network mainly depends on the transceiving unit. The major amount of energy dissipated in sensor node is through the transceiving unit. Scheduling the transceiving unit based on distance, residual energy and selection of CH prolongs the lifetime of the network. The proposed algorithm concentrates on distance and pause time of the sink. The sink mobility is predicted using random mobility model. The algorithm also concentrates on promoting the enhanced throughput. The CH, which can provide high throughput with limited energy cost, has been chosen.

The proposed EECS algorithm concentrates on the following (a) The proposed algorithm provides an enhanced lifetime to the network through novel CH selection approach. (b)The EECS algorithm selects CH based on the residual energy and distance with the sink that concentrates on unequal clustering which serves as a solution to the energy hole and the HOT SPOT issue. (c)The enhanced network lifetime provides extended working of nodes resulting in high throughput.

3 Energy Efficient Clustering Scheme (EECS)

The EECS algorithm proposes a novel clustering technique that the lifetime of the network mainly depends on the total number of bits sent and the CH selection. The CH selection is done based on the waiting time of the mobile sink and the maximum number of packets that can be sent to the sink within the waiting time of the mobile sink in a particular location. The role of a node is realized as Finite State Machine (FSM) having CH, CM, and IDLE states. The node having high residual energy and capable of transmitting a maximum number of packets is been chosen as CH. The transition from one state to other state is estimated using Markov model. The operation of the node and transition in Markov model are mainly based on the present state and not on the past history. The Markov model helps in realizing the role of the node. Since the location of the sink is mobile in nature, clustering with respect to the sink location is very much necessary. The mobility of the sink is realized using a mobility model. Random mobility model is used for predicting the mobility pattern of the sink inside the RoI.

3.1 Finite State Machine (FSM)

The role of the sensor node is modeled as FSM with IDLE, CM & CH states. Figure 2 illustrates the FSM model of the EECS algorithm. The node which has a minimum energy cost among the participants is chosen as CH. The CH works for a period up to the waiting time of the sink. Once the CH transmits the data, then it claims the re-election and new CH will be selected. When the CM loses energy below the minimum value, then it goes into the sleep mode without disturbing the network operation. When the number of participants is less, the node which is in IDLE condition participates as CM.

The entire node in the cluster gets equal opportunity and equal load condition based on this modeling. The CH rotation reduces the loading effect, HOT SPOT issue and energy hole problem in the network.

The FSM is realized using the Markov model. The node operation status is purely based on the current input energy level and cost. Hence the FSM is realized as Markov model.

The probability of choosing x state to y state for n steps is given in Eq. 1.

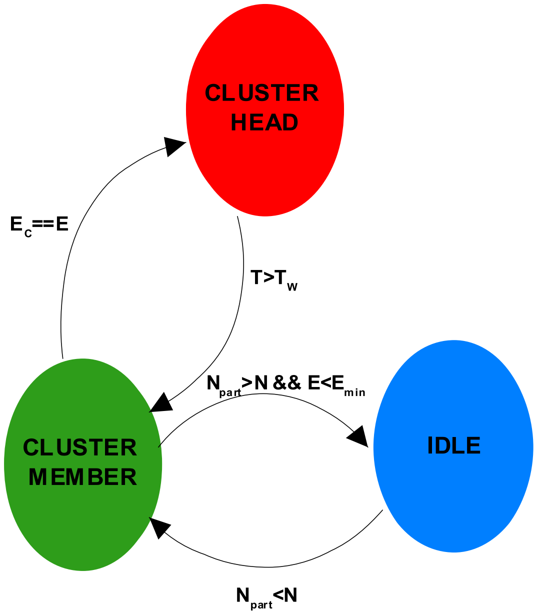


Fig. 2 FSM realization of sensor node

$$P_{xy} = P_r(P_n = y|P_0 = x) \tag{1}$$

Equation 2 denotes the next state transition in Markov chain.

The probability of single-step transition from x to k is given by

$$P_{xk} = P_r(P_1 = k|P_0 = x) \tag{2}$$

Equation 3 represents the time homogenous transition from one state to other. The r step transitions are chosen based on Eq. 3.

For a time-homogeneous Markov chain

$$P_r(P_n = y) = \sum_{r \in s} P_{ry}\, P_r(P_{n-1} = r) \tag{3}$$

Generalized probability of choosing r steps is given in Eq. 4.

$$P_r(P_n = y) = \sum_{r \in s} P_{ry} P_r(P_0 = r) \tag{4}$$

The probability P of transition from one state to other is represented by the matrix given in Eq. 5.

$$P = \begin{array}{c c} & \begin{array}{ccc} S1 & S2 & S3 \end{array} \\ \begin{array}{c} S1 \\ S2 \\ S3 \end{array} & \begin{bmatrix} P_{r11} & P_{r12} & P_{r13} \\ P_{r21} & P_{r22} & P_{r23} \\ P_{r31} & P_{r32} & P_{r33} \end{bmatrix} \end{array} \tag{5}$$

Figure 3 illustrates the proposed EECS algorithm, where the CH is chosen based on the speed of the sink with the consideration of the data packets sent. The state transition of FSM is based on the input from mobility and radio model.

Figure 4 illustrates the architecture of EECS algorithm. The pause time of the sink is estimated, and the cost function is calculated for each node. The node which is capable of transmitting a maximum number of data packets within the waiting time is chosen as the CH. Thereby, the algorithm supports high data throughput in an energy efficient manner.

3.2 Radio Energy Model

The Eqs. 6, 7 denotes the energy consumed by the model on transmitting a bit of data and receiving a bit of data. The energy consumption increases on increase in distance between the sender and receiver. The energy cost is calculated based on Eqs. 6 , 7. More than 95% of energy spent in the node are through the transceiving unit. Energy cost is calculated with the radio model provided in Eqs. 6, 7. The energy cost of each elected participant is calculated among which, the node having minimum E_C and can send the maximum amount of data is selected as CH.

INPUT : $\boldsymbol{S_S}$ *→ Speed of the sink,* $\boldsymbol{E_c}$ *→ Current energy,* ***d*** *→ Distance,* ***t*** *→ Mobile sink waiting time,* ***D*** *→ Data overhead,* $\boldsymbol{C_f}$ *→ Cost function,* $\boldsymbol{t_s}$ *→Time n → Number of cluster nodes in a corresponding cluster,* ***E[C]*** *→ Energy cost.*

OUTPUT ***:*** ***CH*** *→ Optimal Cluster Head*

BEGIN PROCESS:

While

Echo location (t,t+1)

Calc $S_s(RSSI_t, RSSI_{t+1})$;

t= mobility$f\left(P_xP_y(x,y)\right)$

announce n;

echo$E_{i \in n}$

if $E_i > E_{mean \in n}$

i== $C_{h \rightarrow participant}$

Compute(C_f(D,E_c,d));

announce CH;

Communicate data to sink € t_s=t;

CH = = min(E[C]);

else

i==CM

end if

end while

END PROCESS

Fig. 3 Energy Efficient Clustering Scheme algorithm

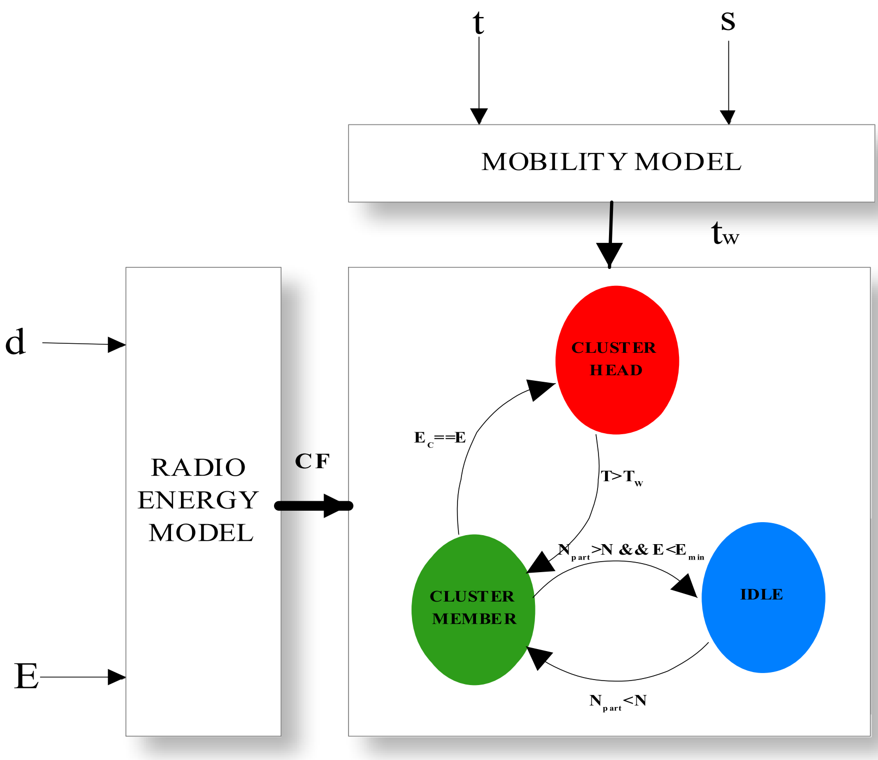


Fig. 4 EECS architecture

$$\begin{aligned} E_{tx}(k,d) &= E_{elec}k + E_{fs}kd^2; \quad d < d_0 \\ &= E_{elec}k + E_{mp}kd^4; \quad d < d_0 \end{aligned} \tag{6}$$

$$E_{rx}(k) = E_{elec}k \tag{7}$$

where k: no. of bits, d: distance, E_{elec}: energy dissipated per bit to run the transmitter or the receiver circuit, E_{fs}, E_{mp}: energy dissipated per bit [pJ/(bit)] to run the transmit amplifier based on the distance between the transmitter and receiver.

3.3 Mobility Model

The mobility patterns of the sink in IoT based application are mostly random in nature. The sink mobility is realized using random mobility model approach. Equation 8 elucidates the distance transition of the sink from position x to y inside the RoI.

$$f_{P_x P_y}(x,y) = \begin{cases} {}^{1}/_{ab} & \text{for } 0<x<a \text{ and } 0<y<b. \\ 0 & \text{else.} \end{cases} \tag{8}$$

a, b Signifies the length and breadth of the RoI. The sink waits for a time t in position $f_{P_x P_y(x,y)}$. The energy cost, E_C is calculated with the help of radio model and mobility model. Equation 9 illustrates the energy cost among which node exhibiting minimum energy cost is considered.

$$E[C_i] = \sum_{i=1}^{N=n} E_{tx}(k_i, d_i) + E_{rx}(k_i) \quad (9)$$

Min $\{E[C_i]\}$ is selected as a CH for a duration t. The value t is predicted by the mobility model.

4 Results and Discussion

The proposed EECS algorithm is evaluated with the mobile sink, with 500 m × 500 m square region. Table 1 illustrates the simulation prelims. The EECS algorithm is compared with MOD-LEACH and M-GEAR algorithms. The nodes are deployed randomly inside the RoI. Figure 5 illustrates the sensor deployment inside the RoI. The list of assumptions considered for evaluating this simulation is as follows,

1. The sink is non-power starving in nature.
2. All nodes are homogenous in nature.
3. All nodes are having 2J initially.
4. All nodes can act as CH and CM.
5. All nodes are equipped with the Omni-directional antenna.

Table 1 illustrates the simulation prelims considered for the simulation.

Figure 6 illustrates that the proposed algorithm outperforms the MOD-LEACH and M-GEAR algorithms in terms of lifetime. The algorithm outperforms MOD-LEACH algorithm by 1.78 times. The first node dies after 956 rounds and 1063 rounds in the MOD-LEACH algorithm and M-GEAR algorithms. Whereas, the first node dies at 1156 rounds in case of the proposed EECS algorithm. As a result, the EECS algorithm outperforms the MOD-LEACH and M-GEAR algorithms.

Figure 7 illustrates the total amount of packets sent to sink by MOD-LEACH, M-GEAR, and EECS algorithms. The proposed EECS algorithm outperforms the MOD-LEACH algorithm by 1.10 times. An average of 50 simulations is done to validate the EECS algorithm with MOD-LEACH and M-GEAR algorithms.

Table 1 Simulation prelims

Parameter	Value
Network size	500 m × 500 m
Number of nodes	100
Initial energy of sensor nodes	2 J
Propagation model	Two ray ground
Packet size	4000
E_{elec}	50 nJ/bit
E_{mp}	50 pJ/bit
Simulation time	500 s
Packet generation rate	0.02–0.2 Kb
Sink mobility	10 m/s

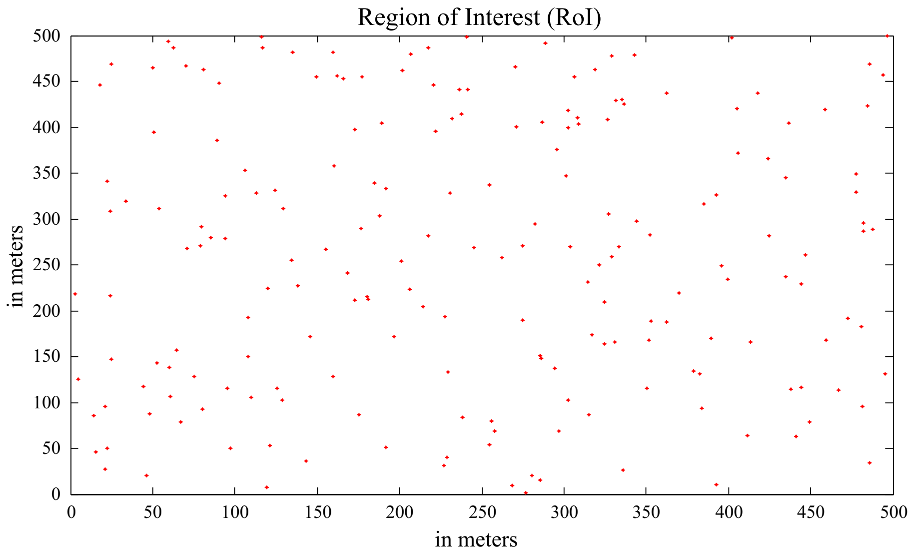


Fig. 5 Sensor node deployment inside RoI

Figure 8 illustrates the residual energy of the nodes after 500, 1000 and 2000 rounds at sink location (250, 250). It illustrates that the energy status of the nodes near the sink is healthy providing resistance to energy hole problem. The proposed EECS algorithm also avoids HOT SPOT problem and uneven loading of nodes.

Figure 9 illustrates the Voronoi diagram of EECS algorithm for sink location (50, 450), (250, 250) & (450, 50). The proposed EECS algorithm provides unequal clustering, forms smaller clusters.

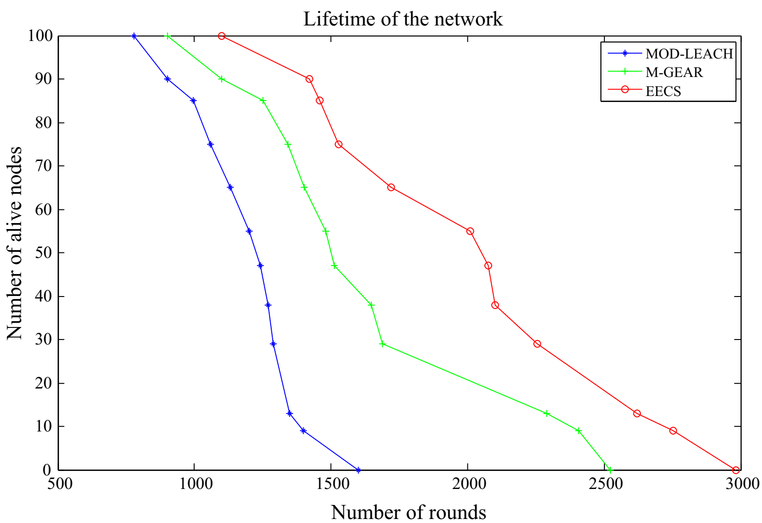


Fig. 6 Lifetime comparison

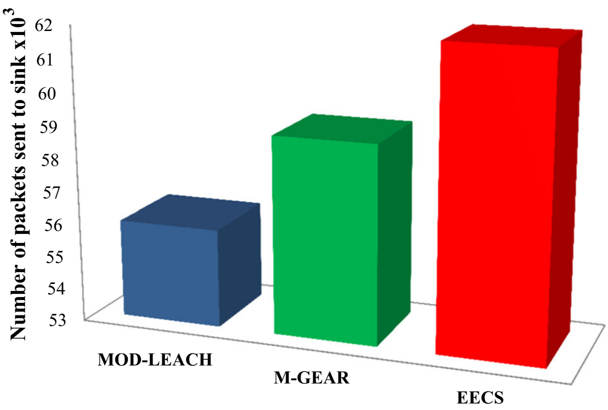


Fig. 7 Throughput of the network

The size of clusters near the sink is small when compared to the size of the clusters away from the sink. Figure 9 justifies the unequal clustering of the proposed EECS algorithm. The concentration of the cluster is with respect to the location and movement of the sink. The unequal clustering of EECS algorithm serves to be the solution for HOT SPOT issue and energy hole problem in the network. Figure 10 illustrates the First Dead Node (FDN) and Half-Life Period (HLP) of the three algorithms. The EECS algorithm outperforms the MOD-LEACH and M-GEAR algorithms in both the cases.

The proposed EECS algorithm provides a novel solution to the lifetime problem in WSN by providing a novel CH selection approach which increases 1.78 times enhanced lifetime when compared to MOD-LEACH. The CH selection in the proposed scheme is based on the distance and residual energy promoting unequal clustering with respect to sink location. The clusters near the sink are smaller, and a number of nodes in the nearby cluster are also less in case of the proposed EECS algorithm. The EECS algorithm works for a longer duration serving monitoring purpose as a goal and in turn, provides high throughput when compared to the MOD-LEACH and M-GEAR algorithms.

5 Conclusion

The proposed algorithm serves to be the better solution of mobile sink based WSN. The EECS algorithm outperforms the MOD-LEACH algorithm in terms of a lifetime by 1.78 times and throughput by 1.103 times. The EECS algorithm outperforms the M-GEAR and MOD-LEACH in terms of lifetime and throughput. Moreover, the scheme also resists the energy hole problem and HOT SPOT issue. The proposed algorithm supports unequal clustering towards the sink. The future work of this paper includes investigating EECS with multiple sink WSN monitoring for large RoI.

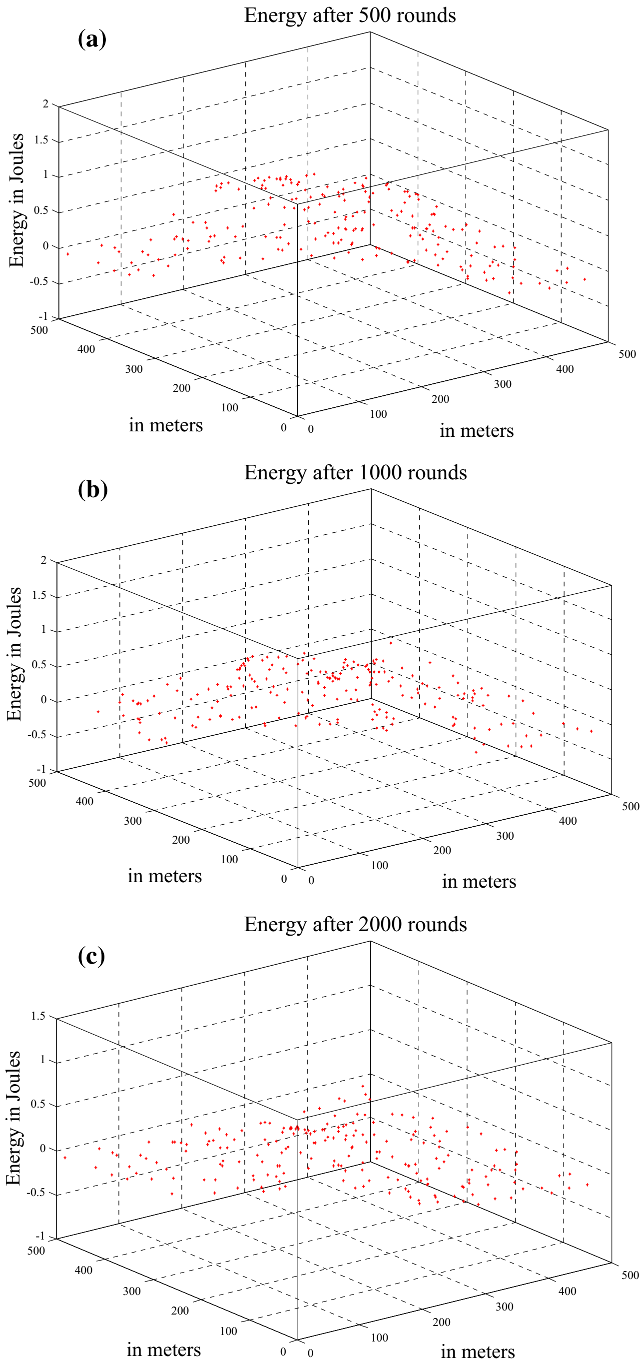


Fig. 8 Residual Energy of the network. **a** Energy after 500 rounds, **b** energy after 1000 rounds, **c** energy after 2000 rounds

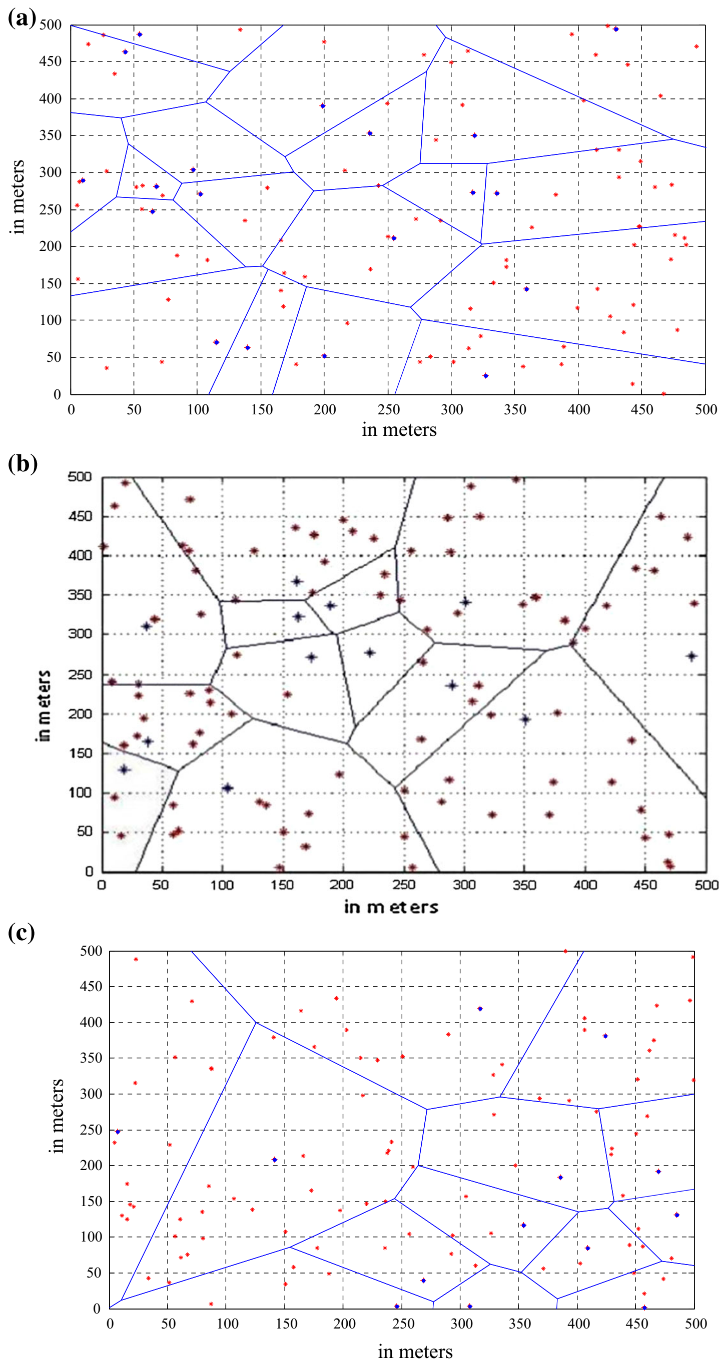
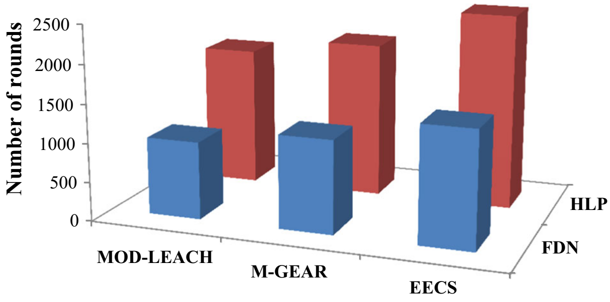


Fig. 9 Voronoi diagram of EECS for sink location. **a** Sink location (50, 450), **b** sink location (250, 250), **c** sink location (450, 50)

Fig. 10 FDN and HLP of MOD-LEACH, M-GEAR, and EECS algorithms



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