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Energy Efficient Energy Hole Repelling (EEEHR) Algorithm for Delay Tolerant Wireless Sensor Network

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Abstract Reducing energy consumption and increasing network lifetime are the major concerns in Wireless Sensor Network (WSN). Increase in network lifetime reduces the frequency of recharging and replacing batteries of the sensor node. The key factors influencing energy consumption are distance and number of bits transmitted inside the network. The problem of energy hole and hotspot inside the network make neighbouring nodes unusable even if the node is efficient for data transmission. Energy Efficient Energy Hole Repelling (EEEHR) routing algorithm is developed to solve the problem. Smaller clusters are formed near the sink and clusters of larger size are made with nodes far from the sink. This methodology promotes equal sharing of load repelling energy hole and hotspot issues. The opportunity of being a Cluster Head (CH) is given to a node with high residual energy, very low intra cluster distance in case of nodes far away from the sink and very low CH to sink distance for the nodes one hop from the sink. The proposed algorithm is compared with LEACH, LEACH-C and SEP routing protocol to prove its novel working. The proposed EEEHR routing algorithm provides improved lifetime, throughput and less packet drop. The proposed algorithm also reduces energy hole and hotspot problem in the network.

Keywords Wireless Sensor Network (WSN) · Sensor Node (SN) · Energy efficient · Hotspot · Energy hole

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1 Introduction

Need of Wireless Sensor Network (WSN) is increasing day by day due to its exponential applications in unmanned monitoring situations. The sensor nodes are battery powered and energy starving in nature; this requires frequent recharging of batteries and loss of nodes in some cases [1–4]. Improving network lifetime increases the monitoring duration and reduces the human intervention often. Typical sensor node consists of sensing unit, processing unit, transceiving unit and power unit [3–7]. In some cases power unit will be having energy harvesting device which makes the network lifetime infinity based on the availability of resource to harvest energy. The transceiving unit acts as a Full Function Device (FFD) (i.e.) router and Reduced Function Device (RFD) (i.e.) end device. The increase in network lifetime can only be done either by limiting the data or the distance between the sender and receiver [8–13]. The clustered architecture in WSN favours very large region to be monitored and also provides increased lifetime when compared to the layered architecture. The layered architecture suits small Region of Interest (RoI) in which all nodes are nearly one hop to the sink. The clustered architecture consists of nodes working either as participant or head [14–18]. The duty assigned to the head is to collect data from all the members and send to the sink (i.e.) it acts as a router to the network [19–23]. The other participant simply forwards the data to the CH to pass the same to the sink via other CH. Figure 1 illustrates the typical Clustering architecture of WSN.

The data from the sensor device is aggregated in the CH and the same is transmitted to the sink via the nearby CHs. The CH near the sink is overloaded transmitting its own cluster data and the data from the far away cluster. So number of clusters near the sink is increased, thereby load is shared among more number of CHs resulting in reduction of energy holes.

2 Related Works

Many of the routing protocols in WSN concentrate on increasing the lifetime and throughput of the network [2, 3, 13, 14]. The algorithm increases the lifetime by scheduling the communication module and limiting the number of bits sent through the communication module. The CH selection in the WSN mainly influences the network lifetime and throughput. The energy hole problem in WSN disables the communication to the sink, though the nodes far away from the sink are capable to do the same. The solution to the energy hole problem is given through multiple sink and mobile sink approach [15, 16]. However tracing the sink mobility and channel contention problem is an unsolved issue in the WSN. The Low Energy Adaptive Clustering Hierarchical routing protocol [12] provides better lifetime and throughput when compared with layered architecture. The CH selection is based on the random number in case of the LEACH algorithm, availing chance of energy holes and hotspot issue inside the network. The Battery recovery based lifetime enhancement algorithm addressed [15] provides solution to energy hole and hotspot problem by modelling the recovery effect of the battery. The Fail Safe Fault Tolerant algorithm addresses the fair CH selection based on the voltage level of the battery. The voltage level of the battery is a clear indicator to get knowledge on the residual energy of the node. The energy spent by the node is a factor of distance and number of bits sent by the sender to the receiver [13, 24, 25]. Proper clustering method reduces the distance between sender and receiver thereby reducing distance between the sender and receiver

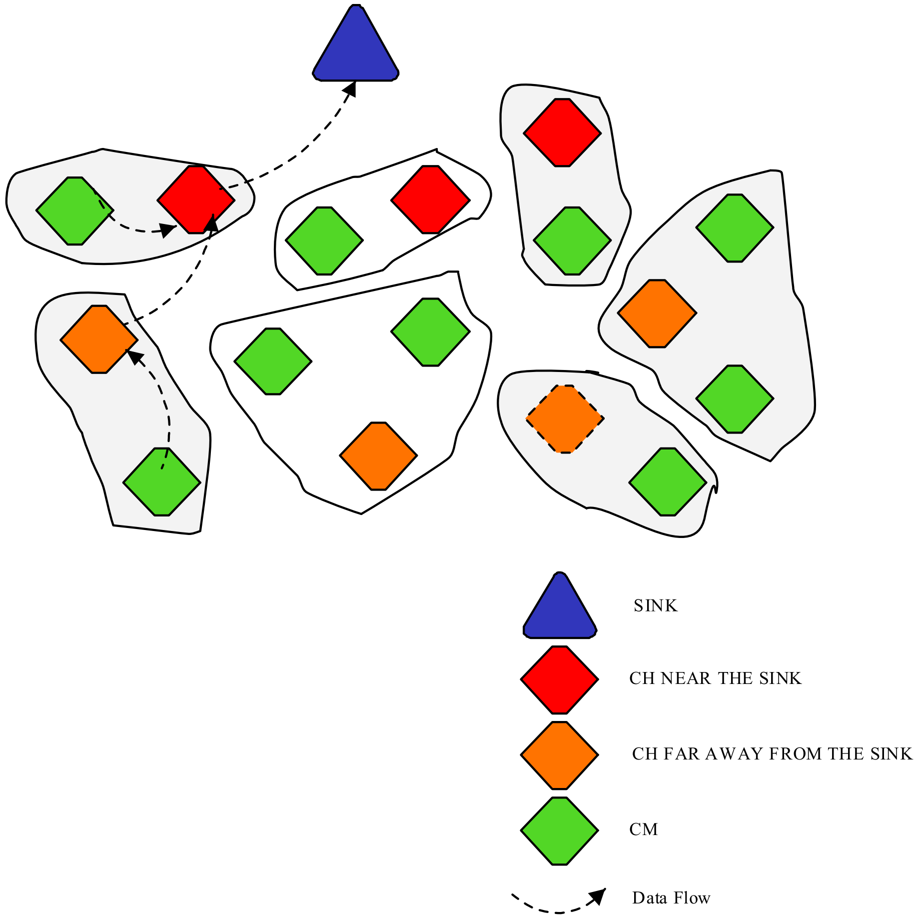

Fig. 1 Clustering architecture in Wireless Sensor Network (WSN)

[14]. Delay Tolerant Networking architecture [15] describes delay and disruption- tolerant network (DTN). In this network, nodes undergo frequent partitioning and are governed by divergent set of protocols. Optimal probabilistic forwarding (OPF) protocol [18] maximizes the delivery probability based on knowledge about the network. The optimality of OPF is based on the assumption that mobility of nodes show long term regularity and intermeeting time can be estimated from history. The optimal CH rotation in [13, 14] is done based on residual energy level; however the threshold level to rotate the CH is unfair and unclear. The proposed Energy Efficient Energy Hole Repelling (EEEHR) algorithm provides solution to these problems by optimal CH rotation and fair CH election methodology. The voltage curve model provides knowledge on the CH selection, the current drain characteristics guides in rotation of CH after particular time. The energy hole issue is addressed by limiting the number of Cluster Members (CMs) near the sink. The number of CMs is chosen based on the distance and radio energy model. The energy dissipated by the node increases in the power of four, when the distance is above d_0 (threshold) [15, 16]. Increasing the number of clusters near the sink (i.e.) increasing the number of CH reduces the cluster size thereby equally distributing the network load. The

rotation of the CH near the sink becomes frequent than the clusters far away from the sink. The data communication near the sink is frequent, making CH rotation frequency high.

3 Energy Efficient Energy Hole Repelling (EEEHR) Algorithm

The proposed Energy Efficient Energy Hole Repelling (EEEHR) algorithm promotes lifetime by reducing the distance with the sink in case of the clusters near the sink. The Intra cluster distance is taken care with the clusters far away from the sink. The nodes near the sink are overloaded due to its easy access to sink. The node near the sink drains its major energy because of routing the data from the far away clusters. The proposed clustering approach takes distance to sink also as a factor for forming clusters. The nodes near the sink are loaded with its own cluster load and routing load, hence the clusters near the sink are provided with less number of CMs and cluster far away from the sink are having more CMs. The proposed algorithm increases the number of clusters near the sink, thereby equally sharing the load to all nodes near the cluster extending its lifetime.

3.1 Battery Characteristics Model

The residual energy is known by the difference between voltage of the node and initial voltage level. Figure 2 illustrates the voltage curve of the lithium battery; here V_1 and V_2 are mentioned based on its current drain characteristics.

The energy dissipated by the node for transmitting and receiving bit in terms of voltage and current is given in Eq. 1.

$$E = V_b \times I_b \times t_d \tag{1}$$

where V_b Battery end Voltage, I_b battery output current, t_d time required to transmit N_{frames}.

The battery voltage level is taken as the metric to select the CH in the cluster. The node having high voltage has the high probability to become a CH. The battery decaying

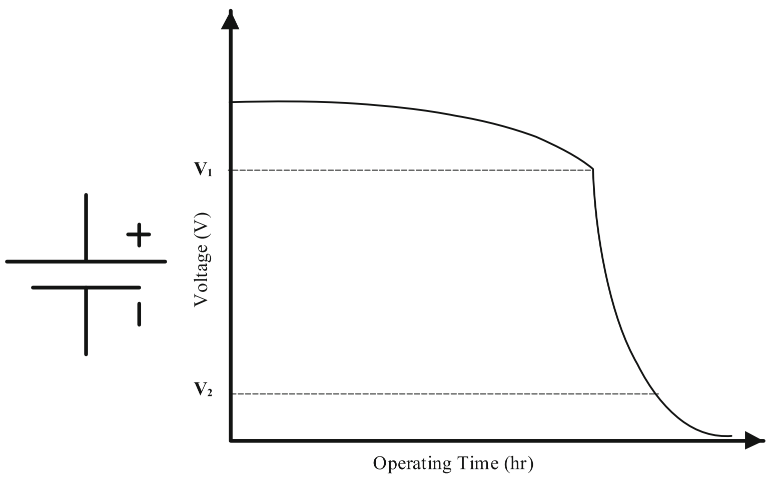

Fig. 2 Battery characteristics modelling

Table 1 Voltage and current specifications of WASPMOTE

S. no	Mode	Distance (m)	Voltage (V)	Current (mA)
1.	CH	5	4.3	15
2.	CM	5	4.3	14
3.	CH	12	4.3	17
4.	CM	12	4.3	16.2
5.	CH	5	3.0	17
6.	CM	5	3.0	16
7.	CH	12	3.0	19.3
8.	CM	12	3.0	17.5
9.	CH	5	2.8	19
10.	CM	5	2.8	18.2
11.	CH	12	2.8	21.7
12.	CM	12	2.8	20.8

Voltage and current value of the WASPMOTE (GE1653450-IS2P) – 2300 mAh

parameters with respect to battery curve parameters is illustrated in Eq. 2 in whicha_1, b_1, c_1, a_2, b_2 and c_2 are curve constants of the battery.

$$f(x) = a_1 \sin(b_1 x + c_1) + a_2 \sin(b_2 x + c_2) \tag{2}$$

Additional load as CH in the region V_1 to V_2 increases the current intake from the battery to compensate the lack of voltage supply by the battery. The diffusion of electrons slows down in the V_1 to V_2 region making decrease in voltage a drastic effect. Load scheduling of nodes based on the voltage level decreases the current intake from the battery making the drastic effect to be moderate. Table 1 illustrates the current drawn from the battery for node acting as a CH and CM. The current drawn from the battery increases as distance between cluster and sink increases.

3.2 Radio Energy Model

The transceiver module in the sensor node is realized as a second order radio model. The radio model is considered to transmit data in omni direction. The cluster size is determined by the radio model equation and distance with the sink. The nodes within one hop from the sink follow first radio model Eq. 3, whereas the node far away from the sink follows Eq. 4 in the radio model. The cluster size is determined only based on the transmission range of CH. The energy consumed by the node on transmitting data is given in Eqs. 3 and 4. The energy consumed on receiving a bit of data is given in Eq. 5. When the distance between the transmitter and receiver is higher than value d_0, the energy consumed on transmitting a data becomes very high. Equations 3, 4 and 5 denotes the energy dissipated on transmitting and receiving a bit of data.

$$E_{tx}(k,d) = E_{elec}k + E_{fs}kd^2; \quad d < d_0 \tag{3}$$

$$= E_{elec}k + E_{mp}kd^4; \quad d > d_0 \tag{4}$$

$$E_{rx}(k) = E_{elec}k \tag{5}$$

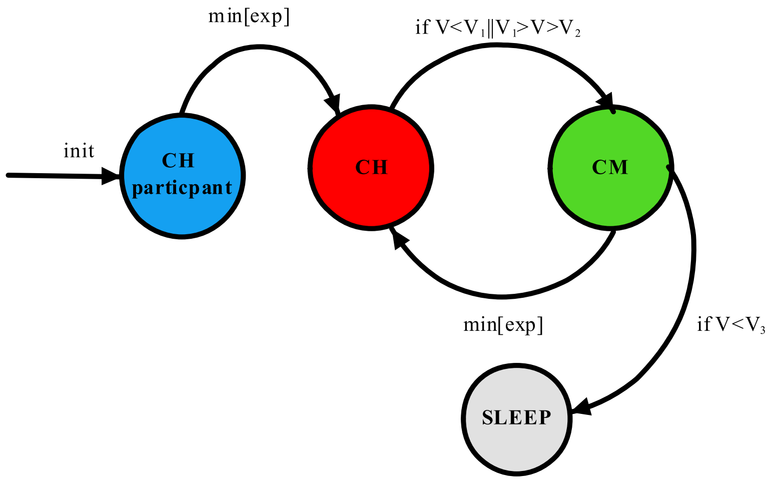

Fig. 3 Finite State Machine (FSM) representation of the proposed algorithm

where k is the number of bits, d is Distance, E_{elec} is energy dissipated per bit to run the transmitter or the receiver circuit, E_{fs}, E_{mp} are energy dissipated per bit (pJ/(bit m^{-2})) to run the transmit amplifier based on the distance between the transmitter and receiver.

The role of transceiving unit is modelled as a Finite State Machine (FSM) with its role as its state (Cluster Head, Cluster Member, and Sleep). The Cluster Head mode is nothing but Full Function Device (FFD) and node acting as a Cluster Member is called as Reduced Function Device (RFD). The CM forwards information to the CH and the CH forwards to sink through nearby CH in a multihop fashion as in Fig. 3. Figure 3 illustrates the Finite State Machine approach of the proposed algorithm. The node with minimum energy dissipation and minimum distance with sink is elected as a CH in clusters one hop to the sink. Once the node reaches a voltage limit V_1, re-election is claimed to the corresponding cluster. In case of the cluster far from the sink, the node having minimum intra cluster distance and high voltage level is considered as the CH. Once the CH reaches voltage V_2, re-election is claimed. When the CH is rotated, the information on new CH is forwarded through *I am alive* packet. The next hop CH revises its routing table based on the acknowledgement packet. Here the load to the cluster is less, hence frequent re-election for CH selection is avoided in the corresponding cluster.

The distance between the sender and receiver is calculated using Eqs. 6 and 7. The d_0 threshold range is calculated by transceiver parameters.

$$\mathrm{d_{ij}} = \sqrt{\left(x_j - x_i\right)^2 - \left(y_j - y_i\right)^2} \tag{6}$$

$$\mathrm{d_0} = \sqrt{\frac{E_{fs}}{E_{pw}}} \tag{7}$$

The node far away from the cluster sends the data to the sink in a multihop fashion. The CH forwards the data to next hop whichever is in idle state and having high residual energy i.e. high battery voltage.

The clusters near the sink have to forward its own cluster data and data from the faraway cluster. Hence the load to these clusters is reduced by limiting the number of CMs.

CH of clusters far away from the sink sends data of its own cluster only. Hence the clusters far away are with high number of CMs. By limiting the number of participants in the cluster with respect to distance with the sink, the load is equally distributed.

3.3 Mathematical Proof

From the Eq. 1, the energy dissipated is proportional to current drawn from the battery. Data transmission to the increased distance extracts high energy. Solving Eqs. 1, 3, 4 and 5.

$$\mathrm{Itx_1} = \mathrm{q} \times \mathrm{E_{elec}k} + \mathrm{E_{fs}kd^2}; \quad \mathrm{d} < \mathrm{d_0} \tag{8}$$

$$\mathrm{Itx_2} = \mathrm{q} \times \mathrm{E_{elec}k} + \mathrm{E_{mp}kd^4}; \quad \mathrm{d} > \mathrm{d_0} \tag{9}$$

From Eqs. 8 and 9 $\mathrm{Itx_1} \ll \mathrm{Itx_2}$ and increase in number of bits also increases the energy dissipation. From Eq. 2, it is understood that decrease in voltage increases the current consumption making it a chain effect. Hence Current I at Voltage greater than V_1 is less when compared to I at Voltage less than V_1.

3.4 Markov Model

The state transition of the Finite State Machine (FSM) is purely based on present state and not on the historic past inputs. Hence Markov model is used to evaluate the state transition of the FSM.

Probability of opting x state to y state for n steps is given in Eq. 10.

$$P_{xy} = P_r(P_n = y | P_0 = x) \tag{10}$$

The probability of single transition from x to k is given in 11

$$P_{xk} = P_r(P_1 = q | P_0 = x) \tag{11}$$

Equation 12 illustrates the time-homogeneous Markov chain:

$$P_r(P_n = y) = \sum_{r \in s} P_{ry} P_r(P_{n-1} = r) \tag{12}$$

Generalized probability of choosing r steps is given in Eq. 13.

$$P_r(P_n = y) = \sum_{r \in s} P_{ry} P_r(P_0 = r) \tag{13}$$

Equations 11, 12 and 13 represent the probability of choosing the next state by the node in the system model. Equation 14 represents the state transition matrix with state transition probabilities.

$$P = \begin{array}{c} \\ S_1 \\ S_2 \\ S_3 \end{array} \begin{array}{c} \begin{array}{ccc} S_1 & S_2 & S_3 \end{array} \\ \left\{ \begin{array}{ccc} P_{r11} & P_{r12} & P_{r13} \\ P_{r21} & P_{r22} & P_{r23} \\ P_{r31} & P_{r32} & P_{r33} \end{array} \right\} \end{array} \tag{14}$$

Algorithm 1 illustrates the Energy Efficient Energy Hole Repelling (EEEHR) algorithm.

Input: Residual Energy(E), Voltage(V), Intra cluster Distance(d), Distance with sink(D).

Output: Optimal Cluster Head (CH).

Begin process:

While (1)

  if$_1$ *cluster one hop to the sink*

    if$_2$**(d < d0)**

      compute the expected energy expenditure with distance to sink

      elect node with low Energy expenditure

    be as a CH till the node reaches voltage level V_1

    end if$_2$

    go to if$_1$

  else$_1$

    compute expected energy expenditure with intra cluster distance

    elect node with low Energy expenditure

    be a CH till node reaches level V_2

  end$_1$

end While

End Process

4 Results and Discussion

The proposed Energy Efficient Energy Hole Repelling (EEEHR) algorithm is compared with SEP, LEACH and LEACH-C algorithms. The proposed algorithm is implemented with 200 nodes with simulation prelims as given in Table 2.

Table 2 Simulation prelims

Parameters	Value
Network size	500×500 m^2
Number of nodes	200
Base station location	(250, 750)
E_{elec}	50 nJ/bit
Efs	10 pJ/bit m^2
Initial energy	2 J
Probability of becoming a cluster head	0.1
Data message size	4000 bytes
Header bytes	150 bytes

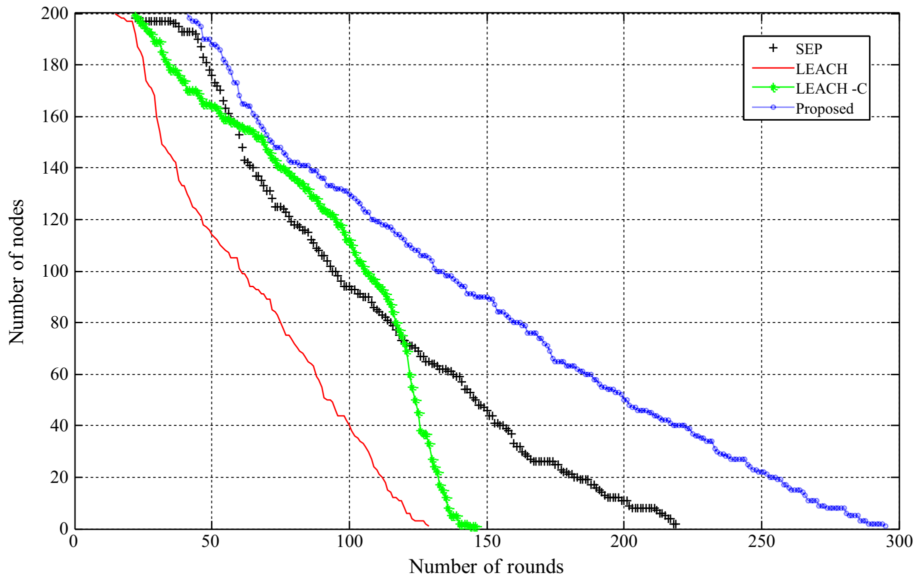

Fig. 4 Lifetime comparison

Fig. 5 Lifetime metrics comparison

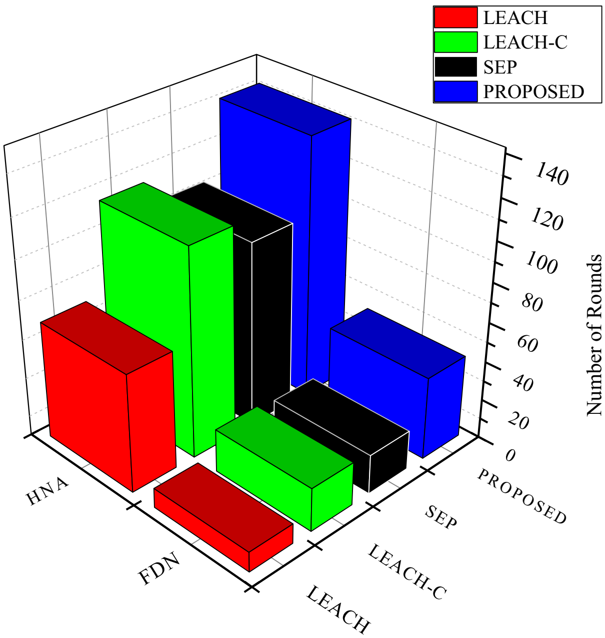

Figure 4 illustrates the Network lifetime comparison graph with other protocols. The proposed algorithm outperforms the existing SEP, LEACH, LEACH-C algorithms by surviving more number of rounds.

Figure 5 illustrates the Half Node Alive (HNA) and First Dead Node (FDN) of the proposed, LEACH, LEACH-C and SEP algorithms. The proposed EEEHR algorithm outperforms the compared algorithms providing good survivability.

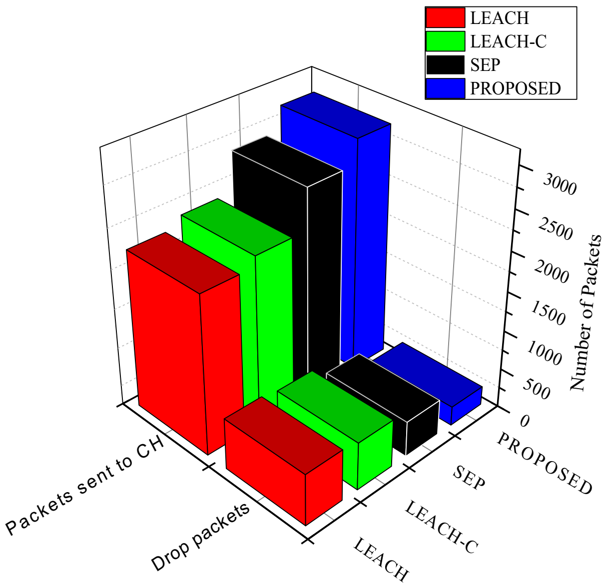

Fig. 6 Data transmission metrics comparison

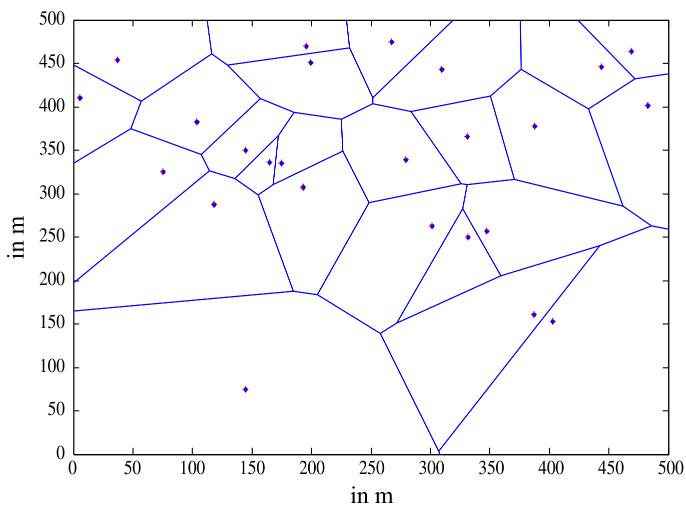

Fig. 7 VORONOI LEACH

Figure 6 illustrates the packets sent to sink and the amount of drop packets by LEACH, LEACH-C, SEP and EEEHR algorithms. The proposed EEEHR algorithm shows better results on existing compared algorithms.

The proposed algorithm also resists hotspot and energy hole problem in the network. The EEEHR algorithm promotes unequal clustering sharing equal load across the networks. The sink is placed in 250, 750 outside the RoI to view the clustering nature of the proposed algorithm. Figures 7, 8, 9 and 10 provides the clustering nature of LEACH, LEACH-C, SEP and EEEHR routing protocols.

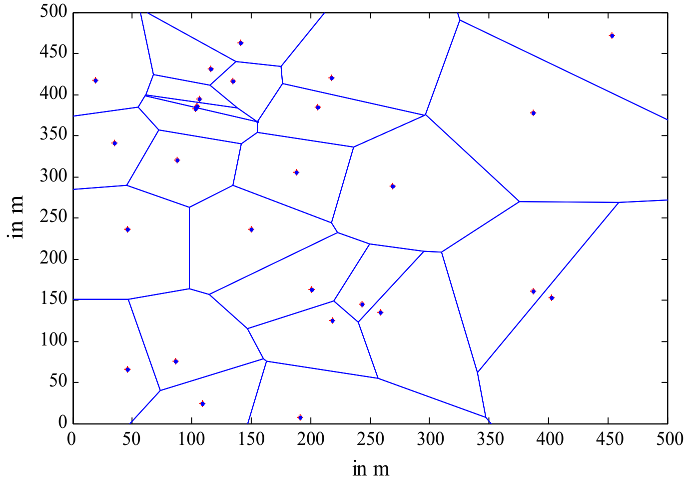

Fig. 8 VORONOI LEACH-C

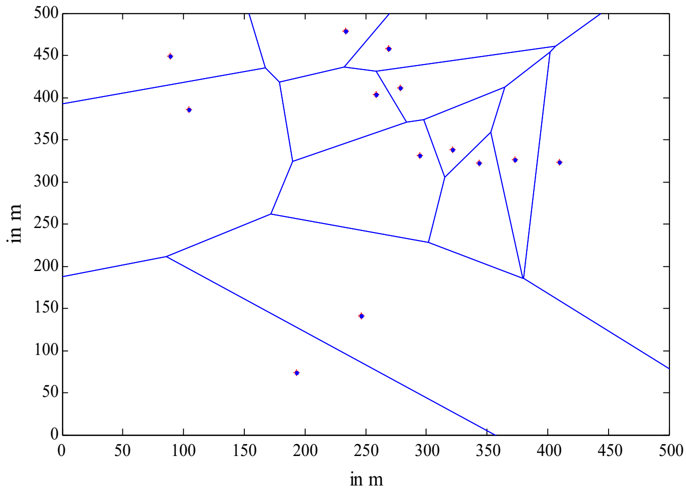

Fig. 9 VORONOI SEP

Figure 11 shows the unequal clustering of nodes inside the network with different sink location. The sink is placed in (0, 0) in case of Fig. 11a, and it is placed in (0, 400) in case of Fig. 11b. The network provides unequal clustering in both cases, the clusters near the sink are smaller and the clusters far away from the sink are larger in nature.

The energy status of the nodes inside the network is given in Fig. 12. The nodes near the sink are with high energy state compared to the node, far away from the sink.

The number of clusters near the sink is high in case of the proposed EEEHR routing algorithm. The increase in the CH increases the routing path, thereby reducing the delay in the network. Considering the network to be a M/M/c queuing model with ρ, λ, μ as waiting time, arrival rate and Service time. Table 3 illustrates the increase in number of cluster near the sink in case of the LEACH, LEACH-C, SEP and EEEHR algorithms

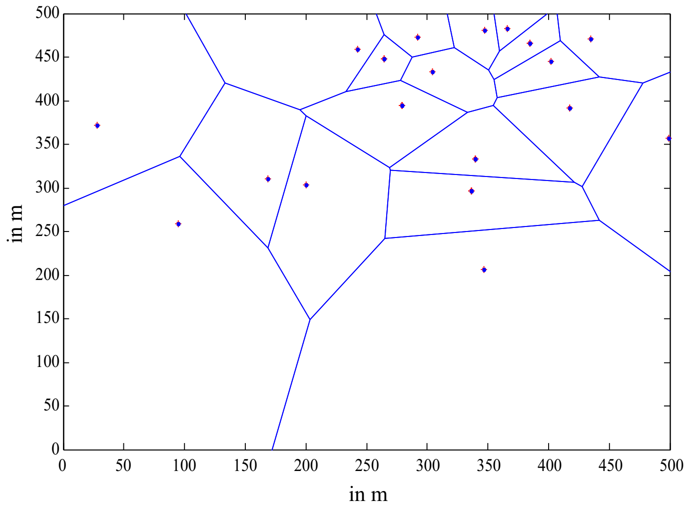

Fig. 10 VORONOI EEEHR

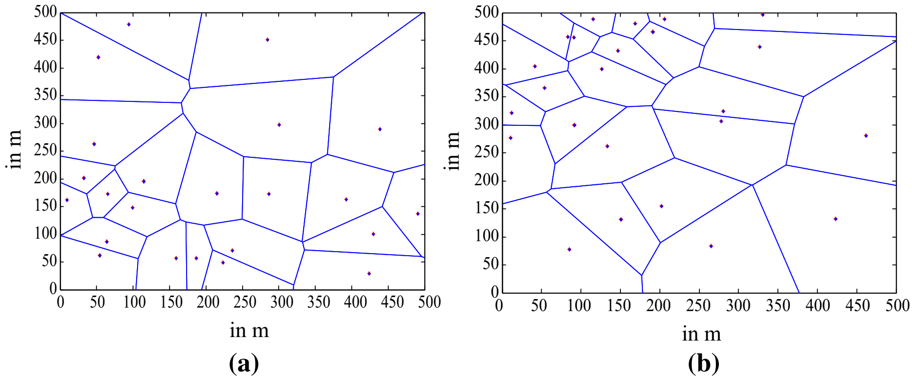

Fig. 11 VORONOI EEEHR at different sink location. **a** VORONOI EEEHR (0, 0), **b** VORONOI EEEHR (0, 400)

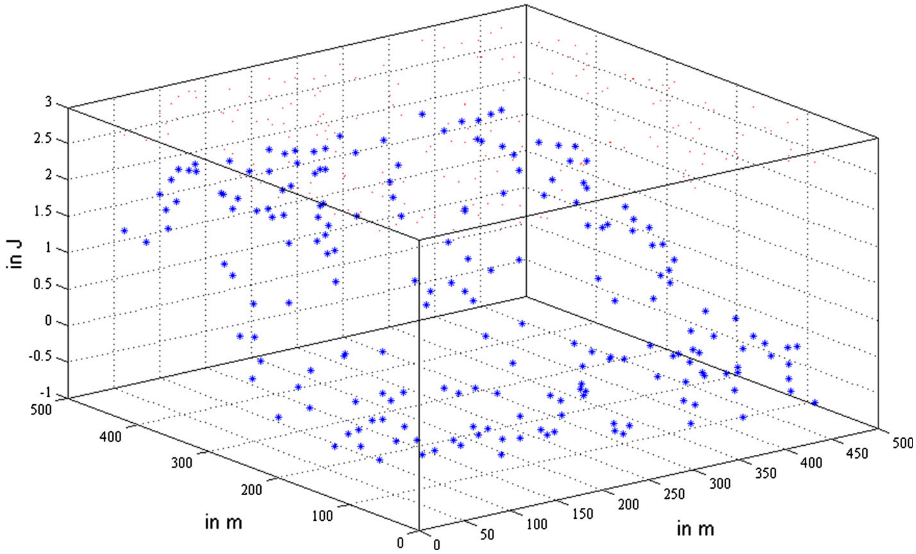

Fig. 12 Energy status after 150 rounds

Table 3 Number of clusters near the sink

Algorithm	LEACH	LEACH-C	SEP	EEEHR
Number of clusters	6	6	4	9

Since $\rho = \lambda/\mu c$, increase in number of c would effectively reduce the waiting time of the data inside the network. The proposed algorithm also provides reduced delay and serves as a solution to delay intolerant applications.

5 Conclusion

Energy hole and hotspot inside the network creates additional load to the nodes making the hole larger. The problem is solved through proper clustering mechanism in the network. The proposed algorithm provides better clustering and repels the energy hole when compared to other LEACH, LEACH-C and SEP algorithm. The clustering mechanism is also with respect to the location of the sink. The proposed algorithm provides better lifetime and throughput to the network. The increase in the number of cluster near the sink also promotes reduced time delay making effective solution to the delay problem. The EEEHR algorithm serves to be a novel solution for the energy problem currently faced by the network.

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Publisher's Note

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