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ORIGINAL CONTRIBUTION

Optimal Energy-Efficient Cluster Head Selection (OEECHS) for Wireless Sensor Network

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Abstract Clustered architecture makes the large-scale monitoring ease to the user. Optimal cluster head (CH) selection is very much necessary for enhancing the network lifetime and data reliability. This paper concentrates on choosing an optimal CH selection based on the current consumed from the battery and as a factor of distance with other nodes. The current consumed by the node increases on decreased residual energy. Scheduling nodes as CH and cluster member (CM) based on current consumption and distance increases the network lifetime. Unequal clustering is observed distributing network load equally to all clusters. Probability for becoming a CH is given to the candidates with minimal distance with the sink, battery residual energy and current taken from the battery. The sensor node behaviour is modelled as finite state machine. The Markov model helps in predicting the next state of selection for the CH in the finite state machine for communicating data towards the sink. The proposed OEECHS is compared with LEACH, ALEACH and M-GEAR protocols. The algorithm outperforms LEACH by 1.35 times in terms of lifetime and 1.12 times in terms of throughput when compared to classic LEACH protocol.

Keywords Energy efficient · CH selection · Wireless sensor network (WSN) · Energy hole and hot spot problem

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Introduction

Wireless sensor network (WSN) is a collection of tiny embedded machines forming a network and sharing information. The sensing unit, processing unit and transceiving unit together constitute the wireless sensor node (SN). The major part of the energy dissipation in SN is done by transceiving unit. The sensor unit senses the information, and the information is processed by the processing unit and transceived to the nearby sink. The layered architecture is meant for small networks, which serves it purposes in monitoring, small area, underground or underwater sensor networks. The clustered architecture has the large scalable monitoring ability, which can deal with large amount of sensor nodes deployed in the region of interest (ROI). The SN forms clusters for monitoring operation, cluster constituting cluster member (CM) and cluster head (CH) [1–5]. The SNs are equipped with battery source for its working making it a power starving device. The distance with sink, residual energy of the node and intra-cluster distance are the major factors influencing the energy dissipation of the WSN [6–11]. Figure 1 illustrates the architecture of the SN constituting, sensing, processing, transceiving and power units. Figure 2 illustrates the typical architecture of WSN. The data sensed by the SN, i.e. CM, are sent to the CH, and the CH communicates the data to the near by CH and transmits the data to the sink. The

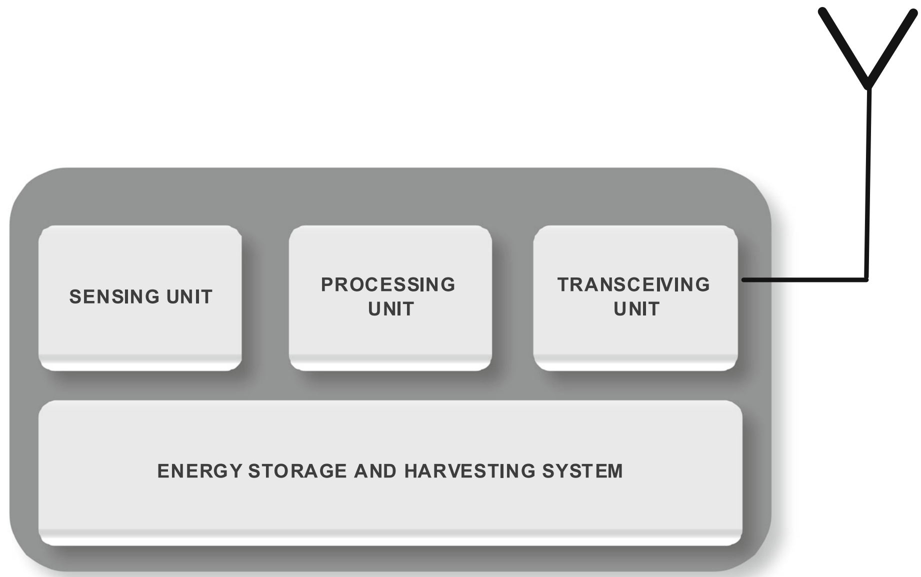


Fig. 1 Wireless sensor node

sink, a primary monitoring system, is integrated with IPV4 or IPV6 connection which is integrated with the external monitoring environment.

The clustered architecture is more suitable for long region of coverage, communicating with more number of nodes.

Related Works

Many routing strategies have been discussed so far regarding energy efficiency, reliability, etc., [2]. LEACH protocol is the basic clustering protocol meant for monitoring large-scale monitoring operations. In LEACH protocol, the probability of becoming a CH is mainly depend on the residual energy of the battery. The LEACH protocol does not consider intra-cluster distance and battery parameters on selection of CH. LEACH does not provide solution for energy hole and hot spot issues. The CHs are the important members in the network acting as a full-functioned device (FFD), capable of acting as a transmitter and router. Election of CH influences the network lifetime and throughput of the network [12–17]. The energy dissipation due to distance and residual energy is discussed so far, which lags in intra-cluster distance and solution to energy hole problem. The energy dissipation of the CH is also influenced by the intra-cluster distance of the nodes inside the cluster [18–23]. The ALEACH algorithm discussed [8] provides a methodology in selecting CH based on residual energy and intra-cluster distance. However, the clustering of ALEACH protocol is irregular with respect to sink. Energy dissipation due to intra-cluster distance is not considered in many of the research works. Network should exhibit unequal clustering towards the location of the sink. The LEACH and ALEACH algorithms lack in addressing about the unequal clustering and clustering based on the location of the sink [1, 9]. The M-GEAR algorithm proposed [13] supports unequal clustering; however, it provides reduced throughput. The past scenario considers residual energy and intra-cluster distance for CH selection, and this paper serves as the better solution for the energy hole problem and increase in lifetime of the WSN. The power minimization should be mainly concentrated in the battery side. The battery characteristics are taken into account such as current characteristics which play a major role in making the network energy efficient in nature. The current drawn by the sensor nodes varies with respect to distance between the sender and receiver, voltage of the battery operation of the node and receiver signal strength of the node.

Optimal Energy-Efficient CH Selection (OEECHS)

The OEECHS algorithm mainly concentrates on reducing the energy consumed by the WSN. The power dissipation of SN is based on the distance between the transmitters, i.e. CM and CH. Since the battery powers the node, the current drawn from the battery is modelled as a piecewise linear equation and considered for choosing CH. The unequal clustering is exhibited by the OEECHS algorithm making it safe from energy hole problem. The clustering of OEECHS is based on the position of the sink. The CH is selected based on the residual energy of the node and distance. Higher the residual energy, higher the probability of being a CH. The SN is powered using the power starving

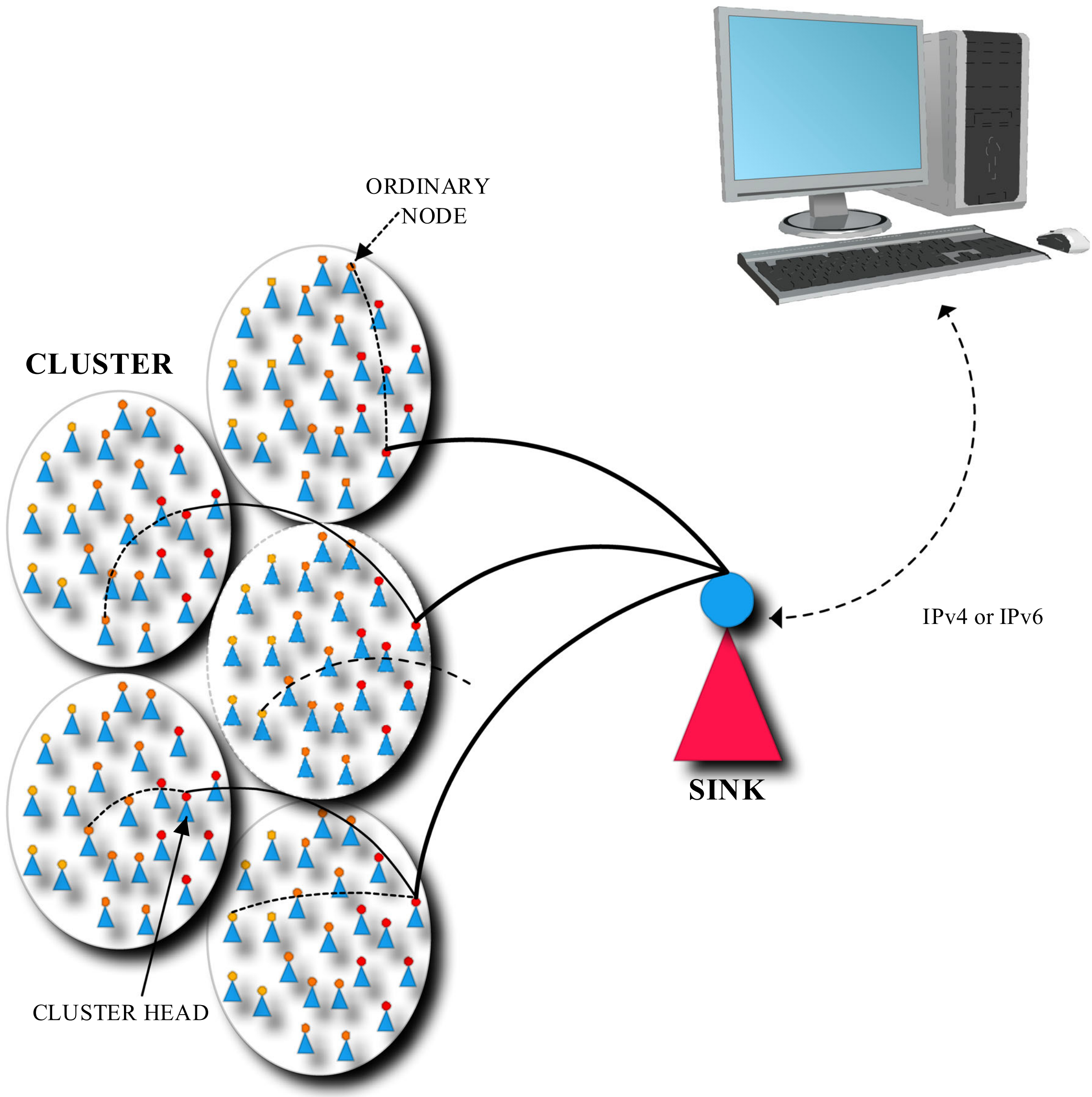


Fig. 2 Wireless sensor network scenarios

batteries causing reduced lifetime to the SN. The batteries are normally rated in ampere hour (Ah). The battery size is mainly determined by the Ah characteristics, and high Ah gives large lifetime making the node bulky sacrificing the size constraint. The SN is made to elect as the CH based on the current characteristic. The intra-cluster distances with all other nodes for the nodes having high battery strength are calculated for evaluation of β. The α and β values are evaluated by messaging hello packet with the neighbour nodes.

The probability of choosing the next step is determined by Markov model. The Markov model is a memoryless model which works based on the current input. The operation of SN is modelled as a finite state machine (FSM). Figure 3 represents the FSM realization of sensor node.

The operation of SN is modelled as FSM, and when the current drawn from the battery exceeds a limit, its working as a CH is resigned and re-election is claimed. When the battery energy is nil, the transceiver operation is made to sleep state in order to avoid unnecessary disturbance due to battery recovery state. The FSM is simulated using the Markov model. The Markov model is a memoryless model, in which the state transition is only based on the current input. Hence, the Markov model is taken for simulating the FSM.

In case of Markovian model, the probability of selection of r steps from one state to another is given by conditional approach.

Probability of choosing x state to y state for n steps is given by Eq. (1)

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

Equations (1) and (2) denote the next state transition in Markov chain.

The probability of single-step transition from x to k is given by Eq. (2)

$$P_{xk} = P_r(P_1 = q | P_0 = x) \quad (2)$$

Equations (3) and (4) represent the time homogenous transition from one state to other. The r step transition is chosen based on Eq. (3).

For a time-homogeneous Markov chain

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

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

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

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

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

Figure 4 represents the typical current characteristics of the SN where the increase in current intake is observed on decrease in residual energy.

The capacity of the battery is termed in ampere hour, and increased intake of current from battery reduces the lifetime of the battery, thereby making the node die soon. Making the SN as CH causes increased intake of the current from the battery making it drain its energy causing a energy hole in the network. The CH is chosen as per the battery current characteristics graph as shown in Fig. 4.

Figure 5 illustrates the OEECHS algorithm, and when a CH looses the energy below a certain limit, it claims for a re-election and all the other nodes send its energy level and intra-cluster distance with other member inside the cluster. The current CH decides the participant and optimally selects the CH based on the OEECHS algorithm.

Mathematical Proof

The α value in the algorithm is set based on the current characteristic curve shown in Fig. 4. Equation (6) illustrates the current voltage energy relation at time t.

$$E = V \times I \times t \quad (6)$$

Here, E is the rnergy consumed by the SN, V is the voltage of the battery, I is the current drawn from the battery, and t is the number of bits transmitted $\times$ transceiver operating speed.

The energy consumed by the SN is directly related to the current drawn from the battery. Equation (7) represents the summation of all distance with respect to eligible candidates. The nodes communicate hello packet with other nodes and receive the α value.

$$\beta = \sum_{i=1}^{N} d(i, i+1) \quad (7)$$

Evaluate the intra-cluster distance β for all nodes. The energy dissipated is a factor of distance and number of bits sent to the sink. Equations (8), (9) and (10) illustrate the

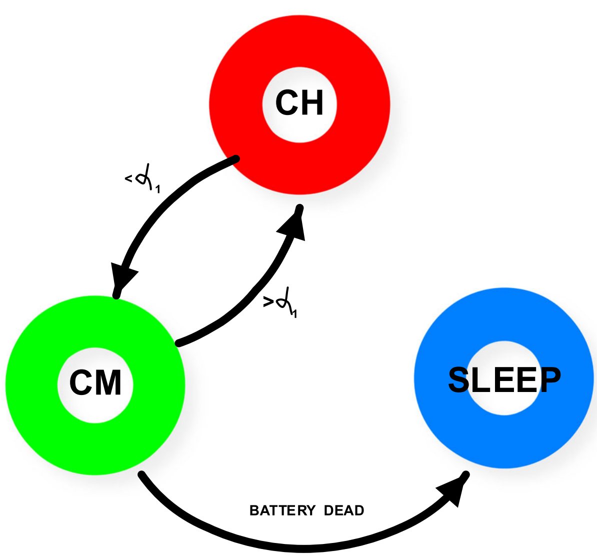


Fig. 3 Finite state machine representation

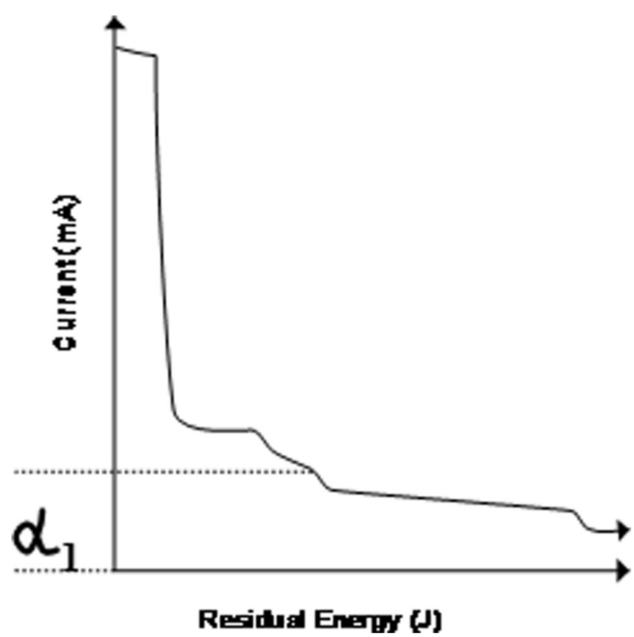


Fig. 4 Battery current characteristics of SN

Fig. 5 OEECHS algorithm

DATA : **α_1 Current consumption limit for being a CH** ,N number of nodes in a corresponding cluster

INPUT : **α current taken by the node at time (t)**, Intra cluster Distance **β_i**

OUTPUT : Optimal CH;

Begin

```
    if(α1>α)
        deny CH;
        declare re election;
    for(i€N)
        get α, β value from all nodes within corresponding cluster;
      if1(α>α1)
            evaluate β for all nodes, select the minimum;
      else
        decline election;
      end if1
    end if
end Begin
```

Table 1 Simulation prelims

Parameters	Value
Prelims-simulation results and network parameters	
Network size	500 × 500 m^2
Number of nodes	200
Base station location	(250,750)
E_{elec}	50nJ/bit
Efs	10pJ/bit-m^2
Initial energy	2 Joule
Probability of becoming a CH	0.1
Data message size	2000 bytes
Header bytes	50 bytes

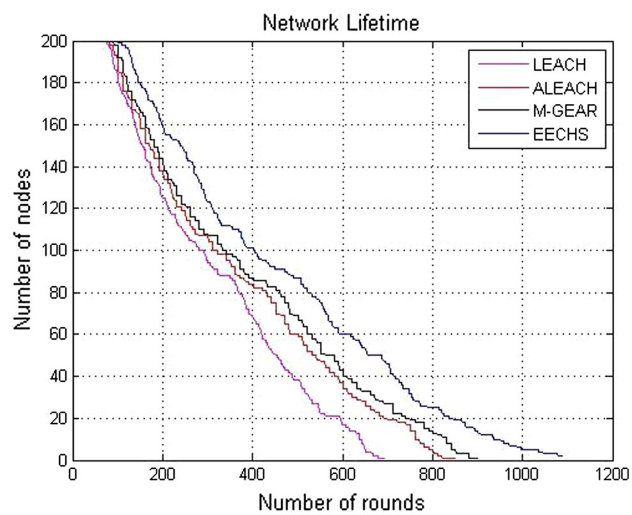


Fig. 6 Node survivability

energy drawn by the transceiver, since the energy consumed by the sensing and processing part is negligible comparing to the transceiving part.

$$E_{tx}(k,d) = E_{elec}k + E_{fs}kd^2; d < d_0 \quad (8)$$

$$E_{tx}(k,d) = E_{elec}k + E_{mp}kd^4; d > d_0 \quad (9)$$

$$E_{rx}(k) = E_{elec}k \quad (10)$$

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

The energy consumed by the battery directly relates the number of bits transmitted, distance.

The energy consumed by the CH is given in Eqs. (11) and (12).

$$E_{CH} = Et_x + E_{rx} \quad (11)$$

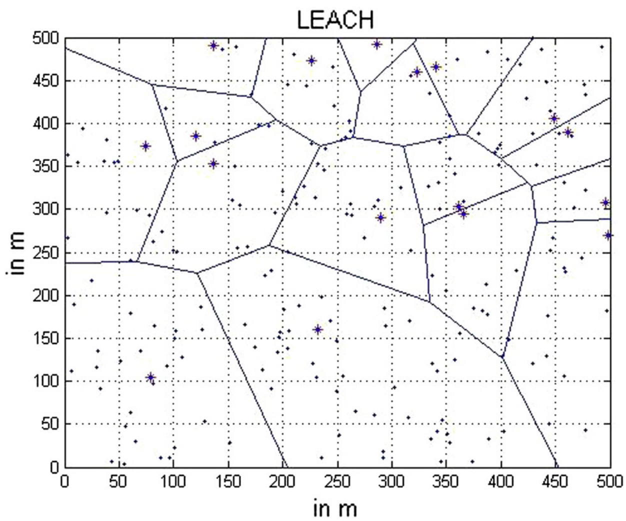


Fig. 7 Voronoi LEACH

$$E_{CH} = E_{elec}k + E_{mp}kd^4 + E_{elec}k \quad (12)$$

Equation (12) illustrates that the loading node as CH increases the energy dissipation.

$$V \times I \times t = E_{elec}k + E_{mp}kd^4 + E_{elec}k \quad (13)$$

$$I = \frac{E_{elec}k + E_{mp}kd^4 + E_{elec}k}{V \times t} \quad (14)$$

Equation (14) supports that the increase in load increases the current taken from the node, thereby decreasing the lifetime. Increased usage of battery decreases the voltage and in turn increases the current making a chain effect.

Results and Discussions

The proposed scenario is simulated in MATLAB 7.0. The nodes are deployed in 500 × 500 m area, and the sink is located in 250, 750 for evaluating its better performance. Simulation prelims are listed in Table 1.

Table 1 represents the simulation parameters taken to support the proposed work. Table 1 discusses the network size, number of nodes, base station location, E_{elec}, E_{fs}, initial energy, probability of becoming of CH, data message size and header bytes.

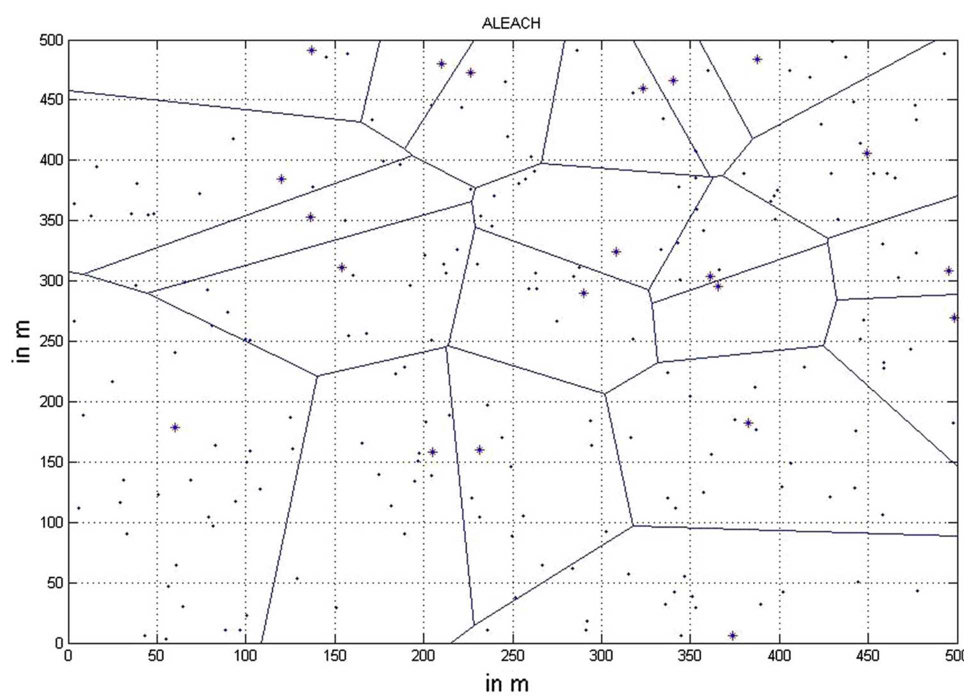
Following assumptions are made in the simulation

- All sensors are deployed in the ROI and are homogeneous in nature.
- All nodes are energy constrained.
- The nodes are either a CH or CM.
- All nodes are static in nature.

Radio energy Model

The energy model for the sensors is based on the radio model. The transceiver model equation is given in Eqs. (8)–(10). Equation (4) depicts the energy consumed during receiving a packet from an another node. The simulation started with nodes carrying an initial energy of

Fig. 8 Voronoi ALEACH



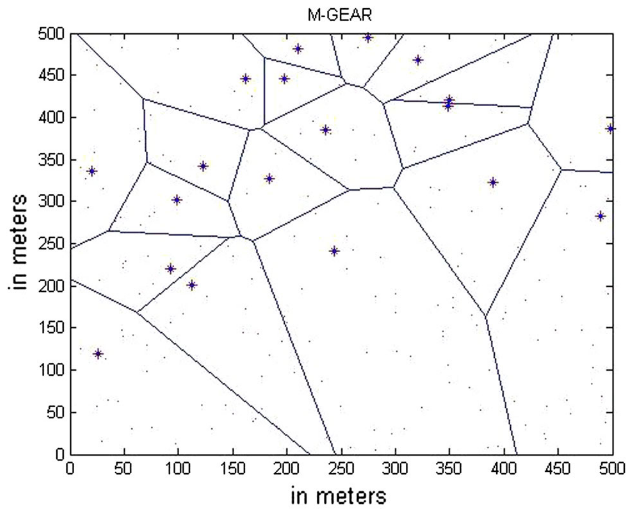


Fig. 9 Voronoi M-GEAR

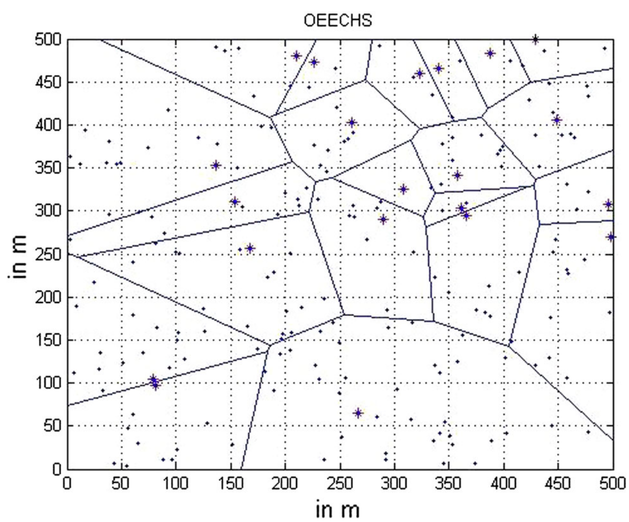


Fig. 10 Voronoi OEECHS

2 J. The data to the next hop are selected based on Markov model. The first node death in case of LEACH, ALEACH and M-GEAR protocols is early when compared with OEECHS. Figure 5 represents the node survivability of the OEECHS, and the OEECHS outperforms the LEACH, ALEACH and M-GEAR protocols surviving more rounds. OEECHS outperforms with 1.35 times increased lifetime when compared to LEACH. The CH selection is based on α value from the current curve (Fig. 6).

Figure 7 represents Voronoi diagram of the LEACH, and the cluster formation of the LEACH is irrespective to the sink location exhibiting equal clustering. The nodes near the sink die creating an energy hole problem, making the network unusable even the nodes away from the sink are equipped with good energy.

Figure 8 represents the Voronoi diagram of the ALEACH protocol, and unequal clustering is partially exhibited towards sink in case of ALEACH protocol.

Figure 9 represents the Voronoi diagram of M-GEAR protocol. The protocol supports unequal clustering; however, the nodes near the sink die soon due to improper loading of CH.

Figure 10 represents the Voronoi diagram of the OEECHS algorithm, exhibiting unequal clustering with respect to sink. The Voronoi diagram of the OEECHS concludes the avoidance of energy hole problem of the OEECHS algorithm. Creation of shorter clusters is noticed in OEECHS algorithm making the network survivable for longer duration. The unequal clustering is exhibited by the OEECHS algorithm on varying sink positions.

Figure 11 represents the nodes energy status after 750 rounds, and OEECHs appear to have more number of nodes when compared to LEACH, ALEACH and M-GEAR algorithms. The nodes are equally distributed avoiding energy hole problem to the network.

Figure 12 represents the throughput comparison of the OEECHS with respect to other protocols. OEECHS outperforms LEACH, ALEACH and M-GEAR algorithms with 1.12 times leading throughput when compared to LEACH protocol. The drop packets in case of OEECHS are less avoiding resending of data causing additional energy loss and burden to the CHs.

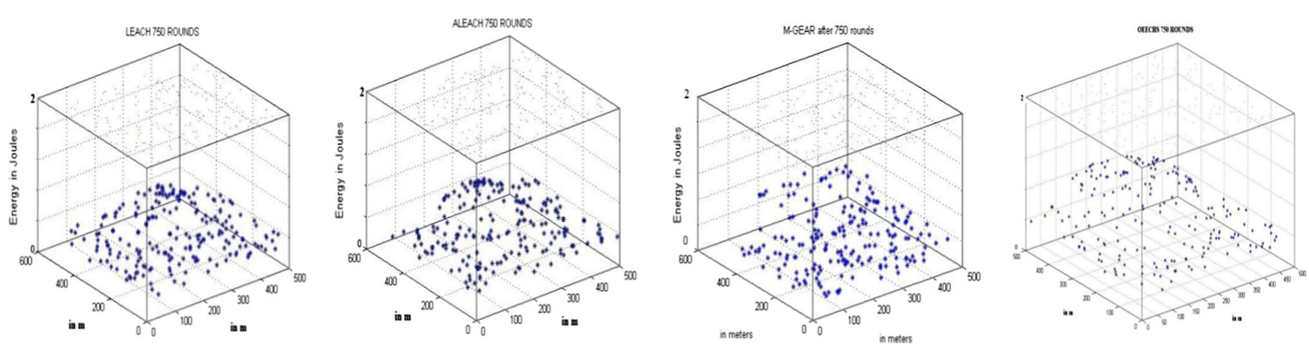


Fig. 11 Network lifetime after 750 rounds for LEACH, ALEACH, M-GEAR and OEECHS algorithms

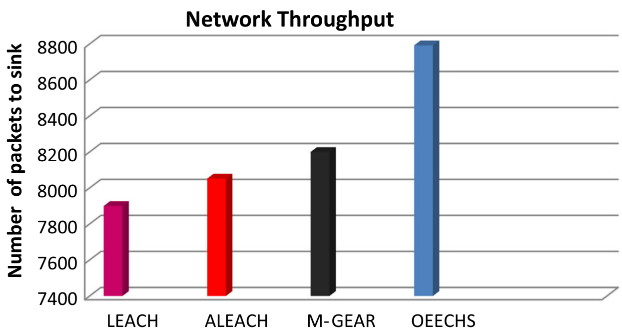


Fig. 12 Throughput comparison

Conclusion

The OEECHS proves its efficiency of improving lifetime of the network with increased throughput. The lifetime is increased by 1.35 times, and throughput is increased by 1.15 times when compared to classical LEACH protocol. Energy hole problem of the network is solved by exhibiting unequal clustering mechanism. The clusters near the sink are small when compared to the cluster far away. The load to the nodes near the sink is reduced because of the unequal clustering mechanism. The OEECHS serves to be the better key for cluster-based routing protocols for enhanced lifetime in WSN. The future work of this paper includes analysis of other metrics of the network with increased nodes and network size.

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