A hybrid BFO-FOA-based energy efficient cluster head selection in energy harvesting wireless sensor network

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Abstract: This paper proposed a hybrid bacterial foraging optimisation (BFO) and fruitfly optimisation algorithm (FOA) for energy efficient cluster head (CH) selection in wireless sensor network. The bacterial foraging optimisation algorithm is inspired by the group foraging behaviour of bacteria such as E. coli and M. xanthus realising chemistry in the environment and moving away from specific signals. The FOA is simple framework and easy to implement for solving an optimisation problem with different characteristics. It is robust and fast algorithm and used to solve discrete optimisation problems. The performance metrics of the proposed method is evaluated for end to end delay, packet delivery, drop ratio, energy consumption, network lifetime and throughput. The simulation results show that the proposed method achieves better energy efficiency and network lifetime of 35%, 58%, and 67% compared to existing methods like ant colony optimisation, particle swarm optimisation and genetic algorithm.

Keywords: energy harvesting; wireless sensor network; WSN; energy efficiency; bacterial foraging optimisation; BFO; fruitfly optimisation algorithm; FOA; packet delivery ratio.

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1 Introduction

Sensor has the ability to interface wirelessly and work together with each other wireless sensor network (WSN) (Ruan et al., 2017), for example, smart cities, environmental monitoring, military, and social insurance. A few challenges in ad hoc networks are routing, throughput, synchronisation, little memory, availability and security (Xiong et al., 2009), Heuristic sensor nodes have the capacity to harvest energy from environment and these procedures are utilised in WSN (He et al., 2013; Zhao et al., 2014; Guo et al., 2014). The accumulation of battery-powered sensor nodes in WSN is known as energy harvesting wireless sensor network (EH-WSN) (Lu et al., 2018). Energy harvesting is a key procedure to enhance the lifetime of network and to improve the energy of WSN (Dong et al., 2018; Kumar and Chaparala, 2017, 2019).

In Lu et al.'s (2018) framework, energy-efficient data sensing and routing scheme (EEDSRS) was endeavouring to take care of the energy issues. The plan is isolated into three stages for deciding the link quality, getting optimal data sensing rate and route all data to the destination. An energy efficient heterogeneous ring clustering routing protocol was presented for taking care of the energy balance issue in routing protocol for low power and loss networks (RPL). An occasion driven cluster head (CH) rotation component is utilised in this framework. Here the protocol is just used to expand the execution of unique RPL (Zhang et al., 2017).

To think about the offline and online power control policies energy harvesting is used to reduce the weighted whole contortion in the transmission of correlated sources. Be that as it may, in transmission, this investigation can't consider the little energy buffers (Dong et al., 2018). Energy harvesting routing and battery power routing-based methodologies balance the energy in two different ways, for example, single path and multipath methods. Since their energy harvesting gadget is extensive in size and surprising expense. For limiting the cost there should be decreased the harvested energy during the sensor nodes (Anisi et al., 2017; Mann and Singh, 2017). In WSN, genetic algorithms (GA) and evolutionary algorithms are looked into for routing protocol in CH selection. Wu and Liu (2013) exhibited an energy harvesting genetic-based unequal clustering algorithm for CH selection. The motivation of the work is to overcome the disadvantages of the existing methods, by using the proposed method.

In this paper, we proposed an energy harvesting-based hybrid bacterial foraging optimisation (BFO)-fruitfly optimisation algorithm (FOA) (named BFFOA) for energy efficient CH selection in WSN. In energy harvesting WSN the BFO has a tendency to get in local optimums. To overcome this issue the BFO is hybridised with FOA. The FOA is a popular strategy to take care of the optimisation issues of WSN because of its high solution, less computational burden simplicity, quality, and fast convergence. This optimisation cannot just boost the routing packets picked up incomes through the network effectively, yet in addition optimise the network energy management by making the cluster with little size nearer to the base station (BS). In this manner, the CH of these clusters will expend low energy. Whatever remains of this paper is sorted out as takes after: Section 2 shows a brief review of the related works. In Subsection 3.1, the network model, radio model, and energy harvesting model are introduced. Our proposed hybrid algorithm is discussed in Subsection 3.2. In Section 4; we provide the results and discussion. At long last, Section 5 concludes the paper.

2 Related works: a brief review

Various research works have already existed in the literature which depended on CH selection in WSN utilising different methods and different perspectives. A portion of the works is reviewed here.

Bahbahani and Alsusa (2018) presented a cooperative clustering protocol in light of low energy adaptive clustering hierarchy (LEACH) approach. Their approach was for the most part, exhibited for enhancing the lifetime of EH-WSN and it incorporates duty cycling and cooperative transmission. For enhancing energy neutral operation (ENO), the node grasps duty cycle of transmission of information and extra energy was put resources into exchanging another node packet. A cross-layer helpful time division multiple access (TDMA) was utilised to optimise the broadcasting performance. Sarang et al. (2018) presented an energy balanced routing algorithm in EH-sensor networks for balanced energy consumption and more network lifetime. Their approach achieves a better algorithm performance for transmission. In EH-SN the methodology of optimal power control was introduced to optimise the blackout probability in the bidirectional subchannel. For cooperative transmission, an optimal relay determination was used.

In 2018, Shafieirad et al. designed a maximum-signal to noise ratio (Max-SNR) opportunistic routing in EH-WSN for high scale reason. The striking interest presents their work was to allow the sensed data delivery to a fusion centre (FC). Their approach required a multi-hop communication and used for finding the relay node that comprises of best SNR. The benefit of their protocol was, it never needs appropriate network information and it expands the delivery ratio. Physarum-inspired routing protocol was executed by Tang et al. in 2018. In their approach, they presented EHWSN as the biological model and outlining a protocol for routing named as energy harvesting probability random process (EHPRP). In this strategy, every last information packets were exchanged one by one through the static sensor data and in conclusion, all are come to at sink. Their approach accomplishes unlimited network lifetime and limits the computational delay.

Bozorgi et al. (2017), Sharma and Sharma (2016), Kim and Kim (2019), Ray and De (2016), Datta and Nandakumar (2017), Chauhan and Kumar (2016) presented other clustering protocols for EH-WSN. Their approaches comprise of multi-hop routing, dynamic and static clustering operations and using a distributed centralised approach. In these strategies, CH was recognised in light of energy status and the harvested energy sum. Utilising energy aware multi-hop routing, each hub sends packets to CH and these packets are gotten by BS. Energy consumption was balanced by the aid of exhibited protocol. Yao et al. (2015) executed an enhanced energy aware cluster-based routing in

WSN in 2017. It actualised for taking care of the energy consumption issue. Their approach utilises the genetic algorithm (GA), for finding the optimal CH and clustering was done based on K-means calculation. For advantageous utilise the network was partitioned into GA cells. Their approach was additionally utilised for prolonging the network lifetime.

Zareei et al. (2018) displayed a protocol for EH-WSN that utilisations adaptive and distributed transmission power control. To expanding the end-to-end execution of the network, the transmission power was balanced by every node progressively as indicated by local data. They likewise gave a statistical portrayal to network availability it depicts the execution change of their convention. Sarkar and Murugan (2019), Dongare and Mangrulkar (2016), Almomani and Saadeh (2018), Yadav et al. (2018), Rehman et al. (2017), Mirzaie et al. (2018a) actualised a CH selection for energy efficient and delay-less routing in WSN. In their approaches, CH was selected in a way that was closer to the BS and in addition sensor nodes. To expanding the node lifetime and energy efficiency of the network by optimally picking the CH the Firefly algorithm was used.

Yuvaraj et al. (2018) present a time orient location energy availability data rate (LEAD)-based scheduling algorithm for the improvements of the performance of data collection in wireless sensor networks. The salient feature of this method is its scheduling the sensors for the polling point on the basis of energy and location of the sensor. Aslam et al. (2016) highlight three critical aspects of the internet of things (IoT), namely:

1 energy efficiency

2 energy balancing

3 quality of service (QoS)

And they present three novel schemes for addressing these aspects. In Shalini and Vasudevan (2017), entire network is separated as a set of clusters. Each cluster consists of one CH and non-cluster member nodes from each cluster will transfer the sensed data to the CH. This will take care of forwarding the information to the end user. In Sarkar and Murugan (2019), firefly with cyclic randomisation is proposed for selecting the best CH.

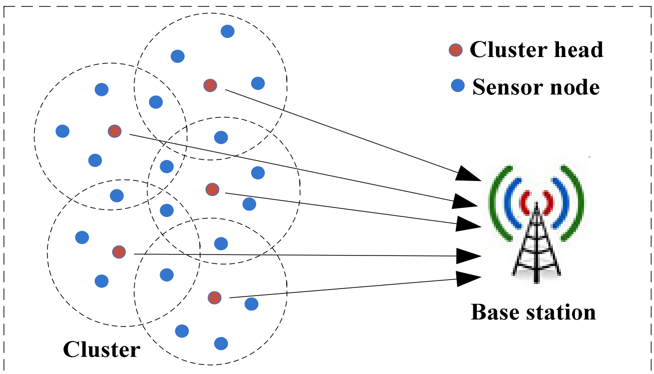
Mirzaie and Mazinani (2018b) proposed algorithm (MACHFL-FT) clusters heterogeneous nodes by using three different algorithms. The holding CH has been avoided by saving more energy in some rounds by using a fixed threshold value. In Mothku and Rout (2019), a fuzzy-based delay and energy-aware intelligent routing mechanism has been proposed to select efficient routes. Nunoo-Mensah et al. (2018) discuss existing bio- and socio-inspired-based trust schemes implemented for wireless sensor networks, viz. quality-based distance vector protocol, enhanced bio-inspired trust and reputation model for wireless sensor network, bio-inspired trust routing protocol, machine learning-based bio-inspired trust and reputation model, socio-psychological trust and reputation model, and finally reputation framework for sensor network. In Zhang et al. (2016), an improved DV-Hop localisation algorithm called least squares DV-Hop (LSDV-Hop), is proposed based on the theory of least squares. LSDV-Hop aims to improve the localisation accuracy by extracting a least squares transformation vector between the true and estimated location data of anchor nodes which are randomly chosen. Mahima and Chitra (2019) proposed energy harvesting-cluster head rotation scheme (EH-CHRS) algorithm. It minimises the energy overflow and energy outage in the network by optimal CH selection and CH rotation method.

3 Proposed methodology

3.1 System model

The EH-WSN is made out of energy harvesting sensor nodes and single base station, which comprises of vast power supply and availability of network. By sensor nodes the information are sampled and routed to BS, for different nodes every sensor node could likewise go about as routers and each can be either node (ordinary) or CH. So to diminish the aggregate sent information message, here the information fusion is utilised.

Figure 1 The proposed network model for cluster head selection (see online version for colours)



As indicated by the distance the nodes could alter its transmission power, i.e., alter the transmission power of node. The EH-WSN is considered with N_{SN} static sensor nodes with one base station. The sensor nodes freely gather data and as per a given routing protocol it sends to the sink. With an EH unit every sensor node prepared. So it can gather energy, for example, the solar energy and the wind energy from surrounding environments. Just radio frequency (RF) unit the harvested energy is thought to be utilised.

As a coordinated graph $g = (v, e)$ the EH-WSN can be represented. A vertex $V \in v$ represents the sensor nodes and base station. Figure 1 demonstrates the proposed system model. Let the position of arbitrary and the sink node is represented as (x_{AN}, y_{AN}) and (x_{SN}, y_{SN}) separately. The distance D between the nodes is denoted as

$$D_n = \sqrt{(x_{AN} - x_{SN})^2 + (y_{AN} - y_{SN})^2} \tag{1}$$

From the two nodes with position the pair wise distance is assessed as

$$D_{n_1 n_2} = \sqrt{(x_{AN_1} - x_{AN_2})^2 + (y_{AN_1} - y_{AN_2})^2} \tag{2}$$

The cluster-based head selection is considered in this paper for an energy needed EH-WSN, from Figure 1 the sensor nodes are arranged into CH and non-CH nodes categories. The CH node gathers data from the closest non-CH node and forwards it to the base station. The cluster head node together with its sensor nodes frames a cluster.

3.1.1 Radio model

The proposed strategy utilises the radio model with some radio constants in Heinzelman et al. (2000). For transmitting data the energy consumed within the clusters are relative to distance between nodes (d_n^2). However, the long range transmission from CH to the base station, the consumed energy is proportional to d_n^4. To accomplish a satisfactory SNR the transmitter energy consumption (E_{tx}) (Heinzelman et al., 2000) is given by

$$E_{tx}\left(N_b, d_n\right) = \begin{cases} E_{ed}n + E_f N_b d_n^2; & \text{if } d_n < d_{t_0} \\ E_{ed}n + E_m N_b d_n^4; & \text{if } d_n \geq d_{t_0} \end{cases} \tag{3}$$

$$d_{t_0} = \sqrt{\frac{E_f}{E_m}} \tag{4}$$

where d_n is distance between nodes, N_b is the message number bit, E_{ed} (nJ/bit) the energy dissipated per bit for transmitter run is or the circuit of receiver, the threshold transmission distance is represented as d_{t_0}, depending on the transmitter and receiver distance the energy dissipated per bit to run the transmit amplifier is E_f (pJ/(bit/m^2)) and E_m (pJ/(bit/m^2)).The energy consumption of the receiver (E_{rx}) is characterised as

$$E_{rx}\left(N_b\right) = E_{ed}n \tag{5}$$

For amplification the required energy is represented as

$$E_{AM}\left(N_b, d_n\right) = E_f d_n^2 \tag{6}$$

The total energy cost associated with a network is expressed as

$$E_T = E_{tx} + E_{rx} + E_i + E_{sen} \tag{7}$$

where the energy cost during the idle state is denoted as E_i and the energy cost while sensing is E_{sen}.

The electronic energy E_{EE} is expressed as

$$E_{EE} = E_{tx} + E_{D_{ae}} \tag{8}$$

where in equation (8) the data aggregation energy is $E_{D_{ae}}$.

3.1.2 Energy model of EH-WSN

All the wireless sensor nodes are furnished with EH devices; this subsection portrays the energy model of how sensor nodes harvest, utilise and store energy. At a single node the energy accessible in environment may change transiently. In the meantime for various nodes there might be spatial variations of the harvested energy. In this way, we assume that every N node has an individual rate of harvesting power is $P_{R(EH)_N} > 0$. Then in storage device the harvested energy is stored, for instance, battery. In most sensor networks the principle energy consumer is radio communication, accept the base station which has an unlimited power source and without generality loss the information detecting and production of packet consumes insignificant energy.

Thus the EHWSN energy model discrete time system at N node is given by

$$P_{R_N}(t) = \min\left(P_{R_N}(t-1) + P_{R(EH)_N}(t-1), E_{MBC,N}\right) - I_f\left(A_N(j)\right)\left(E_{tx} + E_{rx}\right) \quad (9)$$

where, $E_{MBC,N}$ is denoted as maximum battery capacity, the residual energy at N node is $P_{R_N}(t)$ at each time slot end t. Node N receives the energy replenishment at each t time slot beginning which is accumulated in previous slot of time, denoted as $P_{R(EH)_N}(t-1)$. Node N is not allowed to exceed $E_{MBC,N}$ the maximum energy in all times, the indicator function is I_f and the event that node N transmits and receives packets is expressed as $A_N(j)$. $P_{R_N}(t)$ should keep each node, until to start up again it has enough harvested energy to shut down.

3.2 Proposed method for cluster head selection

This section portrays the proposed hybrid BFFOA algorithm for CH selection in EH-WSN. A hybrid algorithm is the joined execution of both BFO (Gazi and Passino, 2011) and FOA. Initially the objective function definition for clustering is discussed which is utilised for choosing the optimal CH position, i.e., selecting the best solution.

3.2.1 Definition of fitness function for clustering

In order to maximise the network lifetime and minimise the energy consumption, a set of optimal CH position should be selected for EH-WSN. Here, the objective fitness function is formulated to fulfil this objective containing four parameters like degree of node, residual form node energy, and coverage ratio intra-cluster distance. The derivations of these parameters are given as follows.

3.2.1.1 Degree of node

The degree of node ($N_{SN(\deg)}$) is defined as number of sensor node reachable from a CH. At the CH it is used to balance the load.

$$N_{SN(\deg)}(Minimise) = \sum_{a=1}^{M} \left|C_{m_a}\right| \quad (10)$$

where the number of cluster members of a^{th} CH is $|C_{m_a}|$ and the number of CHs is M.

3.2.1.2 Residual node energy

For the CH selection, the proposed method uses maximum energy node as better candidate. In order to facilitate balanced network energy consumption it should have better energy budget. It is defined as sensor node residual energy ($N_{SN(RE)}$) in condition (11).

$$N_{SN(RE)}(Minimise) = \sum_{a=1}^{M} \frac{1}{RE_{CH_a}} \quad (11)$$

where the residual energy of a^{th} CH is RE_{CH_a}.

3.2.1.3 Coverage ratio

To eliminate the un-clustered sensor nodes $CH_{(\text{cov})}$ parameter is used. The number of left-out nodes is minimised using this parameter and enhances the selected CHs coverage, which is evaluated as follows:

$$CH_{(\text{cov})}(Minimise) = \frac{(N_{SN} - M)\sum_{b=1}^{M} |CM_b|}{\sum_{b=1}^{M} |CM_b|} \tag{12}$$

where the total number of sensor nodes is indicated as $N_{(SN)}$, the number of cluster members in the b^{th} the cluster is represented as $|CM_b|$.

3.2.2 Working procedure of BFFOA algorithm

In this section, the hybrid algorithm is described for optimal CH selection process. Assume that in the network M_{SN} number of sensor nodes is selected as CH among N_{SN} sensor nodes. The hybrid algorithm is the join execution of both BFO and FOA. The BFO was proposed by Passino which is an evolutionary-based algorithm and used to increase energy efficiency of every sensor node. The FOA is a new approach for finding global optimisation, based on the food finding behaviour of the fruit fly. The output obtained from the BFO is updated using the FOA. The operation of hybrid algorithm has following steps:

Algorithm 1: BFFOA-based CH selection algorithm

Input: The set of sensor nodes $SN = \{sn_1, sn_2, \ldots, sn_{N_{SN}}\}$ and N_{SN} be the total number of sensor nodes

Output: Optimal position of CH

Initialise the number of sensor nodes $SN = \{sn_1, sn_2, \ldots, sn_{N_{SN}}\}$

Randomly generate the initialised parameters

Evaluate the fitness by equation (14).

Initialise the chemotaxis, reproduction, elimination and dispersal loop

While terminal condition is not met **do**

  For each node, update the position using FOA

    If $i_c = i_c + 1$ then

      CH is selected

    elseIf

      distance and direction for search is randomly generate by equations (17) and (18)

      calculate the smell concentration judgment value SC_i by equation (20)

      update the best configuration by fitness using equation (14)

    end if

  end for

  Repeat the process from the whole node and selects optimal CH with energy efficient and maximum network life time.

end while

3.2.2.1 Steps of the BFO algorithm

BFO model is the behaviour of E. coli bacteria consist of two types of movements like tumbling and swimming. A bacterium moves in a straight line in a given direction of swimming movement but the movement of tumbling changes its direction randomly.

Step 1 Initialisation

In this step, it initialises the number of sensor nodes that are act as the input to BFO.

Step 2 Random generation

This step randomly generates the initialised input parameters as

$$IP_{rg}(N_{SN}) = \begin{bmatrix} IP_{11}(N_{SN}) & IP_{12}(N_{SN}) & \cdots & IP_{1n}(N_{SN}) \\ IP_{21}(N_{SN}) & IP_{22}(N_{SN}) & \cdots & IP_{2n}(N_{SN}) \\ \vdots & \vdots & \ddots & \vdots \\ IP_{m1}(N_{SN}) & IP_{m2}(N_{SN}) & \cdots & Ip_{mn}(N_{SN}) \end{bmatrix} \tag{13}$$

where $IP_{rg}(N_{SN})$ represents the random generation of the input parameters, during the occurrence of error.

Step 3 Evaluation

The BFO position evaluates the fitness (objective function) of the population. In the following equation, the required objective function is given

$$fitness(f) = \min\{N_{SN}(\text{deg}), N_{SN}(RE), CH_{SN}(\text{cov}), P_{DR}\} \tag{14}$$

where P_{DR} is the packet delivery ratio.

Step 4 Chemotaxis loop

To maximise the energy level (swimming) and tumbling movement for bacterium life time and to perform nutrient search is denoted in equation (15).

$$\phi^{i}_{(j+1,k,l)} = \phi^{i}_{(j,k,l)} + C_1(i) \cdot \left(\delta(i) \Big/ \sqrt{\delta^{t}(i)\delta(i)} \right) \tag{15}$$

where the chemotactic movement of the bacteria is represented as $\phi^{i}_{(j+1,k,l)}$, i^{th} bacterium at j^{th} chemotactic, k^{th} reproduction and elimination-dispersal l^{th} is denoted as $\phi^{i}_{(j,k,l)}$, the size of the steps taken at random direction is $C_1(i)$, and a vector in the arbitrary direction is indicated as $\left(\delta(i) \Big/ \sqrt{\delta^{t}(i)\delta(i)} \right)$ whose element lies between [–1, 1].

Step 5 Reproduction loop

The first half of bacteria population is used to survive where the remaining bacteria split into two in the same position which are placed as their parent.

During its life after $N_{SN}(c)$ steps fitness value for the i^{th} bacterium can be representing in equation (16)

$$Rj^{i}_{health} = \sum_{j=1}^{(N_{SN}(c)+1)} Rj(j,k,l) \quad (16)$$

where, the bacteria health is Rj^{i}_{health}, ascending values bacteria are sort. So the bacteria x^{th} with highest values Rj^{i}_{health} die and with best values other bacteria x^{th} is split into two. Therefore the ratio of bacteria is keeps constant in reproduction step.

Step 6 Elimination and dispersal loop

With the probability the BFO algorithm makes some bacteria to get eliminated and dispersed after the $N_{SN}(re)$ number of reproductive events. To increase the bacteria ability for global searching and to prevent them from becoming involved in local optimums, the BFO position is updated using FOA.

Step 7 Updating the position using FOA

By updating solution, the CH is selected according to the optimal parameter, if there is better solution is found ($i_c = i_c + 1$). If the parameter has not achieved better solution, the FOA is used for optimal CH selection. The steps for FOA are: initially, the fruit fly swarm location is randomly initialised. For the search of food using osphresis the random direction and distance by an individual fruit fly is given by equation (17) for better solution.

$$x_i = x_{axis} + Random_{value} \quad (17)$$

$$y_i = y_{axis} + Random_{value} \quad (18)$$

where the population size of fruit flies is i.

Step 8 The distance to the origin is estimated first if the food location cannot be known, and then, which the reciprocal of distance is dis_i.

$$dis_i = \left(x_i^2 + y_i^2\right)^{1/2} \quad (19)$$

$$SC_i = 1/dis_i \quad (20)$$

Step 9 Find the fitness using SC_i value, where the best solution can be determined by the equation (14).

Step 10 Memorise the best solution achieved so far.

Step 11 Iteration range

To check the iteration range the below conditions are utilised

- If the iteration does not reach the maximum value increase the iteration count as $i_c = i_c + 1$.

- When the iteration reaches the maximum value the process has been terminated.

Once the process is completed, the proposed method selects optimal cluster head with efficient energy and maximum network life time in EH-WSN. The pseudo code for CH selection is shown in Algorithm1.

4 Results and discussions

In this section, to enhance the network lifetime the energy efficient cluster head is selected in EH-WSN. Using NS2 the performance of the proposed method is analysed with varying number of nodes. The performance metrics used in the paper include the end to end delay, packet delivery ratio, packet drop ratio, energy consumption, network lifetime and throughput.

4.1 Performance metrics

4.1.1 Packet delivery ratio

The ratio of number of packets successfully delivered to a destination to the number of data packets sent by the source node is called packet delivery ratio (*PDR*). It is calculated by equation (21).

$$PDR = \frac{\sum_{0}^{n} Packets_{Received}}{\sum_{0}^{n} Packets_{Sent}} \quad (21)$$

4.1.2 Packet drop ratio

The rate of the number of packets dropped to the number of data packets sent is called packet drop ratio (P_{DR}). P_{DR} is calculated by condition (22).

$$P_{DR} = \frac{\sum_{0}^{n} Packets_{Dropped}}{\sum_{0}^{n} Packets_{Sent}} \quad (22)$$

4.1.3 End-to-end delay

The end-to-end delay is defined as the time difference between the previous received packet and the current sent packet. The formula used to calculate the delay is calculated in equation (23).

$$Delay = \sum_{0}^{n} \left(Packets_{Received\ time} - Packets_{Sent\ time} \right) \quad (23)$$

4.1.4 Throughput

The average of successful messages delivered to the destination or communication links (present in the network) is throughput. Using equation (24) the average throughput is estimated.

$$Throughput = \frac{\sum_{0}^{n} \left(Packets_{Received}(n) * Packets_{Size} \right)}{1,000} \tag{24}$$

4.1.5 Energy consumption

The total energy consumed for transmitting the packet is expressed as

$$Energy_{total} = transmitted_{energy} + N_{avg} received_{energy} \tag{25}$$

The average number of neighbours of the transmitting node is represented as N_{avg}.

4.1.6 Network lifetime

In the network the time to drain out the first battery which is equal to that of the minimum life time of all nodes. It is defined as following condition in equation (26).

$$Network_{lifetime} = \min\left(lifetime_u \right) \tag{26}$$

where $Network_{lifetime}$ denotes the network life time and $lifetime_u$ indicate the node life time, which is expressed as,

$$lifetime_u = \frac{e_u}{\sum_{v \in n_{HN}} E_{uv} \sum Q_{uv}} \tag{27}$$

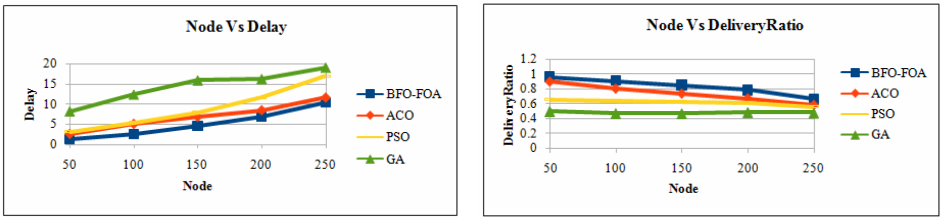
where the initial battery power of node u is e_u and the requirement transmission energy to attain from node u to v is indicated as E_{uv}, Q_{uv} represents the transmitted message rate and n_{HN} be the one hop neighbour list of node u.

4.2 Comparison results for performance measures

In the simulation environment the nodes are distributed in the ranges from 50 to 250. The performance measures of the proposed method are compared with the early works like ant colony optimisation (ACO), particle swarm optimisation (PSO) and GA.

Figure 2(a) shows the comparison in terms of delay with number of nodes. While comparing delay the proposed method is 11.23% lower than ACO, 39.41% lower than PSO and 46.06% lower than GA. The comparison in terms of delivery ratio with number of nodes is shown in Figure 2(b). From the figure, it is noticed that the packet delivery ratio of the proposed method increased by12.12%, 16.67% and 28.79% when compared to existing methods. This is because of the energy parameters in the cluster head selection process of the proposed method.

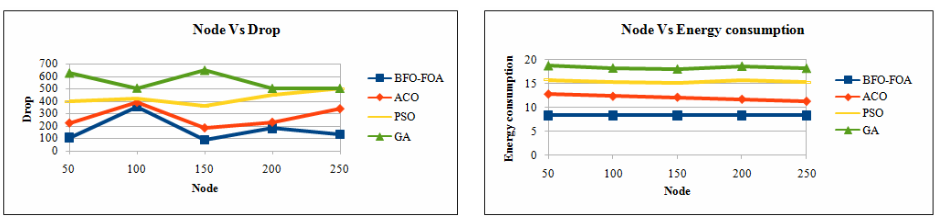
Figure 2 Comparison in terms of (a) delay and (b) delivery ratio with number of nodes (see online version for colours)



(a) (b)

Figure 3(a) shows the comparison in terms of drop ratio with number of nodes. The packet drop ratio of the proposed method is lower by more than 60%, 68.8% and 72.9% compared to the existing methods in Figure 3(a).The comparison in terms of energy consumption with number of nodes is shown in Figure 3(b). From the figure, it is noticed that the energy consumption of the proposed method is lower by 25%, 45% and 54% when compared to existing methods. Thus, lower the energy consumption, higher the performance of the network.

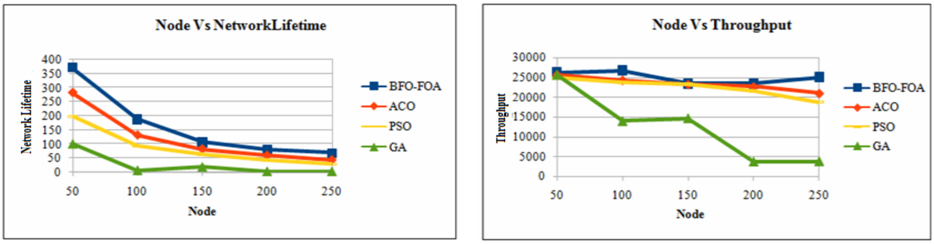
Figure 3 Comparison in terms of (a) drop ratio and (b) energy consumption with number of nodes (see online version for colours)



(a) (b)

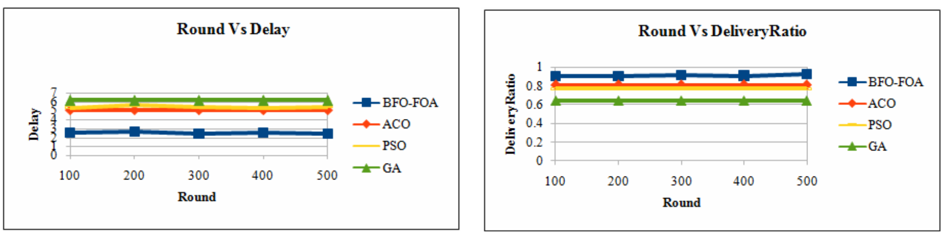
Figure 4(a) shows the comparison of network lifetime with number of nodes. The proposed method has maximum network lifetime of 371 for 50 range node and higher than 35%, 58% and 67% of ACO, PSO and GA. The comparison in terms of throughput with number of nodes is shown in Figure 4(b). From the figure, it is noticed that the throughput of the proposed method is 9%, 11% and 13% higher when compared to existing methods. Hence increase in packet delivery ratio automatically increased the throughput. The comparison of delay and delivery ratio with number of rounds is shown in Figure 5. While comparing delay the proposed method is 45% lower than ACO, 47% of PSO and 52% of GA seen from Figure 5(a). Figure 5(b) shows with each number of round the packet delivery ratio is increased.

Figure 4 Comparison in terms of (a) network lifetime and (b) throughput with number of nodes (see online version for colours)



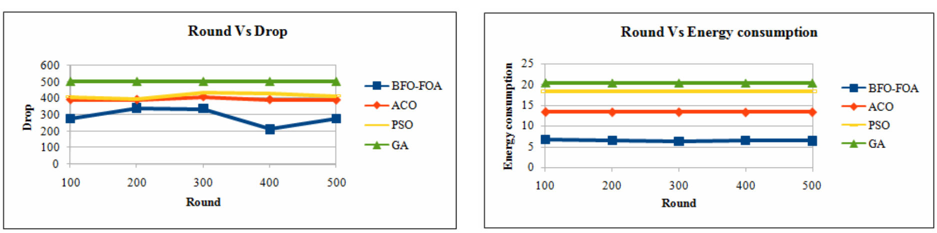
(a) (b)

Figure 5 Comparison in terms of (a) delay and (b) delivery ratio with number of rounds (see online version for colours)



(a) (b)

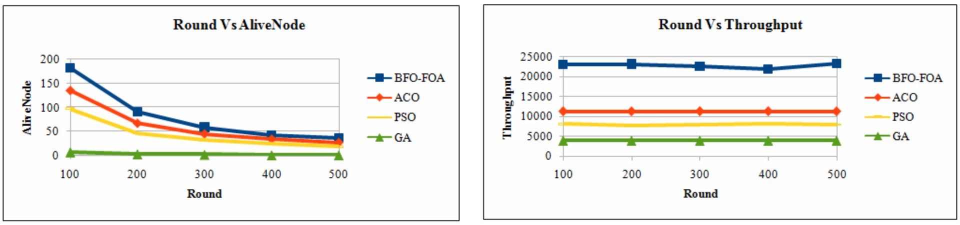
Figure 6 Comparison in terms of (a) drop and (b) energy consumption with number of rounds (see online version for colours)



(a) (b)

Figure 6(a) shows the comparison in terms of drop ratio with number of rounds. The packet drop ratio of the proposed method is lower by more than 28%, 33% and 44% compared to the existing methods in Figure 6(a).The comparison in terms of energy consumption with number of rounds is shown in Figure 6(b). From the figure, it is noticed that the energy consumption of the proposed method is lower by 52%, 65% and 70% when compared to existing methods. Lower the energy consumption, higher the performance of the network. Figure 7(a) shows the comparison of network lifetime with number of rounds. The proposed method has maximum network lifetime of 183 for 100 round and higher than 27%, 48% of ACO and PSO. The comparison in terms of throughput with number of rounds is shown in Figure 7(b). From the figure, it is noticed that the throughput of the proposed method is 51%, 64% and 82% higher when compared to existing methods. Hence increase in packet delivery ratio automatically increased the throughput.

Figure 7 Comparison in terms of (a) alive node and (b) throughput with number of rounds (see online version for colours)



(a) (b)

5 Conclusions

In this paper, hybrid BFFOA-based cluster head selection for EHWSN is performed and measured the end to end delay, packet delivery ratio, packet drop ratio, energy consumption, the network lifetime and throughput. The cluster head selection is based on degree of node, residual form node energy, and the coverage ratio intra-cluster distance. The comparison of proposed hybrid method with ACO, PSO and GA are listed for all performance measured in detail with graphically. The simulation results show that the proposed optimisation algorithm gives the maximum life time and hence increases the battery life. While comparing the end to end delay, the proposed method is 11.23% lower than ACO, 39.41% of PSO and 46.06% of GA. The energy efficiency of proposed method is lower by 25%, 45% and 54% in comparison.

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