Energy-Efficient Algorithm for Cluster Formation and Cluster Head Selection for WSN

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Abstract— Advancements in sensors and actuator technology incorporated with data communication are enhancing the standards of control and automation areas for different applications. The Home area network (HAN) is based on IEEE 802.15.4 is considered for applications like Advanced metering infrastructure in Smart grid applications. In this paper, Wireless Sensor Network is considered for HAN. The sensor data is communicated to the sink via Cluster heads (CH). The work proposed in this paper is identifying a proper CH, among the available cluster nodes. Based on the above we are proposing a novel algorithm Energy-Efficient Algorithm for Cluster formation and Cluster Head selection (EEA-CFCHS) for heterogeneous WSN. The proposed methodology takes into account the energy degeneracy threshold value for all different kinds of nodes in a WSN network. Each CH and cluster nodes proceed to the following round based on the threshold value. Each round ends with a calculation of the CH residual energy. The network begins building a new cluster and electing a new CH, if the amount of energy left is less than the threshold value. The energy consumption is lowered as a result, and the stability period is greatly increased. In this algorithm, the simulation in MATLAB shows how to improve the network's lifetime. When compared to the ESRA and P-SEP protocols, the EEA-CFCHS for WSN improves the stability period by 42 %, 72% the network lifespan by 62%, and the network lifetime by 73.16%.

Keywords— Wireless sensor networks, EEA-CFCHS, Cluster Head, stability period, Network Lifetime.

I. INTRODUCTION

WSN has become a major resource due to the reference of better sensor capabilities in the advanced information conveyed. Smart cities, smart health monitors, and smart buildings are only a few examples of modern applications [1]. Sensing data from many kinds of heterogeneous sensors and converting it efficiently is attractive and increasingly important for current monitoring and control applications [2].

WSNs are becoming a valuable resource for advanced technologies such as cyber-physical systems and the Internet of Things (IoT) [3]. WSNs are made up of hundreds of sensors that are spatially spread over a large region to accomplish difficult tasks [4]. There is a need to improve the QoS (quality of service) parameter in WSNs to boost sensor potentiality [5]. In WSN, sensors organized will work with limited battery levels and communicate data within constraints [6].

The IEEE 802.15.4 standard governs the operation of WSN. Smart sensors in WSN are organized consistently based on application requirements [7]. The sensor node's communication range is 75m to 100 m and can be extendable upto approximately 1000m. Depending on the type of application, the sensor in WSN will work in the 868MHz, 915MHz, or 2.4GHz frequency bands [8]. The smart sensor's battery is depleted because of different type of operations, including data transmission and reception, data processing, and, most importantly, data retransmission due to collision [9]. The Direct Sequence Spread Spectrum [10] is used by WSN for secure data transfer. The architecture of heterogeneous WSN is presented in Figure 1. Our main goal is to improve the network's stability and lifespan of network.

Initially we have done the literature survey on the comparison of seven different energy efficient protocols for WSN by implementing them in Matlab, the performance parameters are evaluated in detail and the results are presented in [11]. In the present paper, EEA-CFCHS algorithm is proposed. Main aim of the proposed algorithm is to reduce node energy depletion and to increase the network's lifespan. This proposed algorithm is implemented in Matlab and the performance of algorithm is compared to similar existing protocols.

The remaining paper is structured as follows, Section II is a literature review related to this article. Section III defines the proposed algorithm's energy model. Section IV includes comprehensive details on the proposed algorithm ESEEA. Section V presents simulation and discussion. Finally, section VI presents the conclusion and followed references.

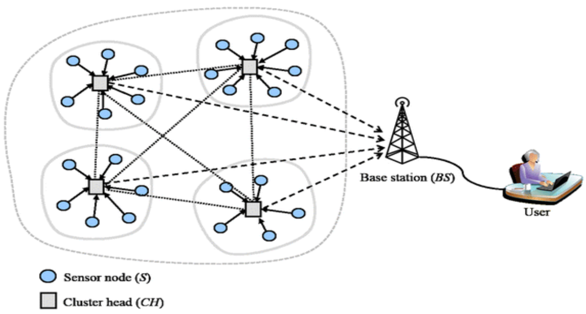

Fig. 1. Heterogeneous Wireless Sensor Network architecture.

II. RELATED WORK

The WSN is considered as the technological revolution in the automation world. In the field of WSN applications, clustering, and energy efficiency have been considered as important research concentration. The routing and area coverage are also important concerns in the field of WSN. The performances of above parameters have a direct impact on network application performance. In WSNs, a set of sensors forms a cluster and elects a cluster head

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(CH). The cluster member node communicates with the CH, and the CH aggregates data. CH transfers aggregated and processed information to the base station. As a result, the amount of energy wasted in CH node is quite large.

O. Abasikeles et al. in 2020 [12] proposed spread clustering, with reduced uncovered nodes for WSN, to solve the uncovered network (UN) problem. A. Debark et al in 2019 [13] proposed two CH selection algorithms based on energy and distance-based CH selection and proposed EDBCHS with balanced object function. The proposed methodology aims to balance energy ingesting across all nodes in WSN. The EDBCHS protocol creates a new cluster contour. K. N. Dattatraya et al. [14] presented research aiming to increase network lifespan and energy efficiency. A novel CH selection model is developed. M. R. Feylizadeh et al. in 2022 [15] proposed an approach for cluster elections by using the fuzzy logic The proposed method considers amount of residual energy of nodes and number of active nodes and is assessed based on the LEACH algorithm and FCA approach.

A. Garcia-Najera et al. 2021 [16] applied three multi-objective evolutionary algorithms by considering WSN parameters like distance, delay, and remaining energy. A. Hossan et al. 2022 [17] proposed DE_SEP algorithm considering distance and energy aware active routing protocol that enables the best possible energy saving. P. Kathiroli et al. 2021 [18] proposed a hybrid Sparrow exploration method with a differential evolution algorithm to explain the energy efficiency problem in WSN through CH selection. The suggested technique makes use of the Sparrow Search Algorithm's high-level search efficiency and the vivid possibility of differential evolution, which increases node lifetime.

W. Osamy et al. (2018) [19] proposed two layers of routing, aggregation, and reconstruction in the Cluster Tree Scheme for Data Gathering (CTRSDG) algorithm. Also, proposed a self-organizing, active clustering method based on entropy for CH selection and cluster formation. A straightforward and effective clustering technique called EESC algorithm was presented for the field of environmental monitoring by Y. Padmanaban et al. in 2018 [20].The proposed research considers the average transmission distance and residual energy for CH selection. A novelty proposed in [20] is considering the parameters known as the CH to the normal ratio that is useful in selection of CH duty among the nodes. Performance is measured by the first node die, simulation duration, scalability, load balancing, and a brand-new metric called complete useful data percentage.

Y. Padmanaban et al. 2020 [21] proposed the EESC-with relay is a grid-based data collection algorithm. The grid in this methodology has a single grid leader and several grid relays (GR). Depending on the grid's location of the destination sink, the number of GR's in the grid could change. This can be based on multi-hop reduced-distance data transmission that results in reduced power consumption. R. K. Poluru et al. 2020 [22], proposed a model Cyclic Rider Optimization Algorithm and a modified Rider Optimization Algorithm. In terms of latency, standardized energy, living nodes, and cost function metrics, the proposed algorithm outperforms several conventional algorithms like the firefly, grey wolf optimization, the whale optimization algorithm. A. S. M. S. Sanwar Hosen et al. [23] proposed a QoS-aware clustering-based routing algorithm that integrates cluster formation, CH selection, and the best routing path selection approach for low power and lossy networks in fog-enabled IoT.

A. Seyyedabbasi et al. 2020 [24] considered four characteristics to choose the CH there are node energy, neighboring node energy, hops, and connections to neighboring nodes. A distributed cluster formation strategy using fuzzy algorithms, as proposed by N. Shivappa et al. in 2019 [25], has centrally elected CH. In this research, the sink is located at cluster centers and the member nodes that belong to them using the fuzzy c-means technique. By using hierarchical routing in WSN and a hybrid optimization method is proposed in [26]. This method considers an effective sustainable CH selection framework. This framework is known as Particle Distance Updated Sea Lion Optimization, combines with the concepts of Particle Swarm Optimization and Sea Lion Optimization. In this research, the authors has considered energy, distance, delay, and Quality of Service in selecting a CH.

Cluster formation and CH selection are essential for improving the performance of the cluster routing protocol, according to [27]. To improve the logic of cluster formation and CH selection, an energy-efficient routing protocol based on multi-threshold segmentation was proposed. During the cluster formation process, a novel node clustering technique was developed that was inspired by multi-threshold visual segmentation. During the process of CH selection, a calculation theory of the optimal number and location of CH was proposed to minimize network energy consumption. For mobile nodes, J. Zhang et al. 2019 [28] proposed the centralized energy-efficient clustering routing protocol to minimize network energy loss and enhance the packet delivery ratio.

III. ENERGY MODEL FOR THE PROPOSED NETWORK

While considering the routing parameter in a WSN, energy balancing and energy management are very critical to consider. In this paper, we will focus on the implementation of a routing algorithm for reducing the network's energy usage. As a result, the node's life improves in WSN. To minimize energy loss, three rankings of a network's heterogeneity were considered. First-level nodes with the least energy are considered as normal nodes, second-level nodes with a medium degree of energy are intermediate nodes, and finally, nodes with the most energy are advanced nodes.

Let the preliminary energy of normal nodes be E_o , and the total energy of normal (ENN), intermediate (E_{IN}), and advanced nodes (E_{ADN}) are represented by equations (1), (2), and (3).

$$E_{NN} = s * E_o(1 - x - y) \quad (1)$$

$$E_{IN} = s * y * E_o(1 + Y) \quad (2)$$

$$E_{ADN} = s * x * E_o(1 + X) \quad (3)$$

In the WSN, the advanced node is represented by the letter x, and their energy level is X. The Intermediate nodes are represented by y, and their energy level is considered as half of the normal node. In each category, the 's' denotes the size of the node. eq. (4) shows the overall energy usage.

$$E_{total} = s * E_o(1 - x - y) + s * y * E_o(1 + Y) + s * x * E_o(1 + X)$$
$$= s * E_o(1 + xX + yY) \quad (4)$$

The threshold value of energy of a node in WSN is determined for selecting CH. Let G_1, G_2 and G_3 be the set of normal, intermediate and advanced nodes. The average probability of selecting the CH in every iteration can be done using eq. (5), eq. (7), and eq. (9) as follows. The calculation of threshold value for selecting CH in every iteration is proposed in eq. (6), eq. (8) and eq. (10). Where P_{NN} represents the probability of a normal node, P_{IN} shows the probability of an intermediate node and P_{AdN} is indicate the probability of an advanced node.

For normal node:

$$P_{NN} = \frac{P}{1+xX+yY} \quad (5)$$

$$T_{SNN} = \begin{cases} \frac{P_{NN}}{1-P_{NN}\left(r \bmod \frac{1}{P_{NN}}\right)} & ; if\ s_{NN} \in G_1 \\ 0 & ;\ other\ wise \end{cases} \quad (6)$$

For intermediate node:

$$P_{IN} = \frac{P(1+Y)}{1+xX+yY} \quad (7)$$

$$T_{SIN} = \begin{cases} \frac{P_{IN}}{1-P_{IN}\left(r \bmod \frac{1}{P_{IN}}\right)} & ; if\ s_{IN} \in G_2 \\ 0 & ;\ other\ wise \end{cases} \quad (8)$$

For advance node:

$$P_{AdN} = \frac{P(1+X)}{1+xX+yY} \quad (9)$$

$$T_{SAdN} = \begin{cases} \frac{P_{AdN}}{1-P_{AdN}\left(r \bmod \frac{1}{P_{AdN}}\right)} & ; if\ s_{AdN} \in G_3 \\ 0 & ;\ other\ wise \end{cases} \quad (10)$$

Where T_{SNN} is shown as the threshold value of the normal or standard node, T_{SIN} is indicated as the threshold value of the intermediate node and T_{SAdN} is represent the threshold value of the advanced node. To calculate the average probability for selecting the CH per one iteration is given as eq. (11).

$$s\ (1 - x - y)\ P_{NN} + s\ x\ P_{IN} + s\ y\ P_{AdN} = s\ P \quad (11)$$

The formula is as follows: (12) as well as eq. (13) depicts a communication architecture in which the sensor node uses energy to send k bits to each packet.

$$E_{Tr}(k, d) = E_{Tr\_ele}(k) + E_{Tr\_amp}(k, d) \quad (12)$$

Where is 'k' represents the packet size, 'd' indicates the distance between nodes, E_{Tr} represents the energy for data transmission, E_{Tr_ele} indicates transmission electrical energy and E_{Tr_amp} shows the amplification energy,

$$E_{Tr}(k, d) = \begin{cases} \in_{ele} * k + \in_{fs} * k * d^2; if\ d \le d_0 \\ \in_{ele} * k + \in_{amp} * k * d^4; if\ d > d_0 \end{cases} \quad (13)$$

$\in_{fs}$ And $\in_{amp}$ represents the amplifier's characteristics for sending packets over free and multi-path fading channels. The volume of energy used by the sensor node to transmit the packet is indicated as $\in_{ele}$. The amount of energy required to receive the packet is known at eq. (14).

$$E_{Rc}(k) = E_{Rc\_ele}(k) + k * \in_{ele} \quad (14)$$

For CH selection, the energy threshold value is calculated by measuring the energy usage in each round.

IV. ENERGY-EFFICIENT ALGORITHM FOR CLUSTER FORMATION AND CLUSTER HEAD SELECTION FOR WSN (EEA-CFCHS)

Three levels of probability are discussed for the heterogeneity network proposed in this work. The proposed algorithm constricts with the value of the energy dissipation threshold for all nodes in a WSN network. Depending on the threshold value, each cluster's CH and member nodes will either move on to the following round or not. CH residual energy is calculated after each round. If the residual energy is less than the threshold value, the network begins forming a new cluster and selecting a new CH. The proposed method decreases the amount of energy used to advertise routing information as well as the development of a new CH.

The CH and the sensor node will never consume the same amount of energy. Data collection, consolidation, and forwarding are some of the additional responsibilities of the CH node. As a result, CH consumes more energy than the other normal sensor nodes of WSN. As a result, if the CH is degraded to a normal node in the following round, the proposed EEA-CFCHS for WSN distributes the high amplification energy to the CH. The Energy-Efficient Algorithm for Cluster formation and Cluster Head selection for WSN assigns a low amplification energy value to the node.

A. *Energy consumed for new cluster and cluster head formation.*

Let μ represent the percentage of clusters in the WSN and also shows the number of times CH has been replaced and N be the total number of nodes in the network. E_{kTr} Reflects the size of the packet to send, as well as E_{kRc} reflects the size of the receiving packet.

The energy expended on cluster formation and CH replacement is given as E_c shown in eq. (15).

$$E_c = \{E_{kTr}E_{Tr} + E_{kRc}E_{Rc}(Q\complement - 1)\}\ \complement * q \quad (15)$$

The energy spent for transmitting bits of data (8-bits) is represented by E_{Tr} where the cluster size is denoted $q = Q * \complement$. Where 'Q' represents the total number of node networks and $\complement$ indicates cluster count. The energy expended for receiving bits of data is represented by E_{Rc}.

B. *Energy consumption of sensor nodes.*

The cluster energy usage is computed by multiplying the preliminary energy supplied to all kinds of nodes in the cluster. There are standard nodes, intermediate nodes, and advanced nodes inside the cluster. E_z Represents the cluster's energy consumption, which is expressed in eq. (16), eq. (17) as well as eq. (18).

$$E_{ZNN} = E_0 * Q * \complement \quad (16)$$

$$E_{ZIN} = E_0(1 - Y) * Q * \complement \quad (17)$$

$$E_{ZAdN} = E_0(1 - X) * Q * C \quad (18)$$

C. Energy utilization of each cluster per round

For a single round, the energy consumption of each cluster 'α' is determined based on the node energy that is equal in both cases, one as the sensor node, and the other as the CH, as shown in the equation below (19),

$$E_c(\alpha) = \{(q_\alpha - 1) * E_{kTr} * E_{Tr} * E_{kRc} * E_{Rc}\} +$$

$$\{(q_\alpha - 1) * E_{kTr} * E_{Tr} + (q_\alpha - 1) * E_{kRc} * E_{Rc}\} \quad (19)$$

The energy used by the sensor node to transfer packets to the CH is denoted by $Q * E_{Tr}$. Whereas the energy used by the CH for data aggregation is denoted by $Q(q - 1) * E_{Rc}$. The amount of power utilized by the CH to transmit data to the base station node is provided as $Q * (q - 1) * E_{Tr}$. The node enters a state of sleep when no data packets are being sent or received.

D. The threshold cost for replacement of CH

Calculating the CH's energy threshold value requires taking into account the number of rounds. The following equations, .eq. (20), (21), and (22), are used to determine the total number of rounds 'R' for the standard, intermediate, and advanced nodes.

$$R_{NN} = \frac{E_C}{E_Z(N_n)} * 100 \quad (20)$$

$$R_{IN} = \frac{E_C}{E_Z(I_n)} * 100 \quad (21)$$

$$R_{AdN} = \frac{E_C}{E_Z(Ad_n)} * 100 \quad (22)$$

The estimated amount of energy needed to select CH is produced by the eq. (19), (20), (21), and (22), and is then given in eq. (23), (24), and (25),

$$T_{NN} = R_{NN} * (E_{KTr} + E_{kRc})E_{Tr} \quad (23)$$

$$T_{IN} = R_{IN} * (E_{KTr} + E_{kRc})E_{Tr} \quad (24)$$

$$T_{AdN} = R_{AdN} * (E_{KTr} + E_{kRc})E_{Tr} \quad (25)$$

T_{NN}, T_{IN} and T_{AdN} Show the estimated threshold value for the standard, intermediate, and advanced nodes, respectively. The proposed energy threshold model is intended to replace the CH by minimizing energy use while maximizing node lifetime.

E. Latency of Network.

We modify the generic analytical model for calculating the network latency of the IEEE 802.15.4 beacon-enabled mode. We assume a star topology in which all nodes in the network compete for channel acquisition and data transmission to the network coordinator. To arrive at the following formula, we use a combination of mathematical and algebraic procedures. We discovered that correct analysis is computationally intensive and therefore unsuitable for sensor devices with limited resources.

The network's latency or delay quantifies how long it takes for all of the data to reach the sink node starting from the moment the first bit is delivered from the source node. The various parts of latency are called Transmission delay (T_d), propagation delay (P_d), queuing delay (Q_d), and processing delay (Pr_d). In eq. (16), the network's latency is shown.

$$L_N = T_d + P_d + Q_d + Pr_d \quad (26)$$

The transmission delay T_d is defined as the time it takes to place the entire data packet on the transmission medium. The transmission delay is calculated using eq. (27).

$$T_d = \frac{s}{BW} \quad (27)$$

Where the data size is marked by 's', and the network bandwidth is represented by'BW'. The propagation delay, or the time it takes for a bit of data to be transportable from the source to the sink node, has been represented by P_d is given in eq. (28).

$$P_d = \frac{d}{p_s} \quad (28)$$

Where d has denotes the space between the source node and sink node. p_s is represented as the propagation speed. Q_d In eq. (26) has denoted the queuing delay i.e. the time required for individually in-between or BS to hold the data be for it can be administered. The queuing time is not a fixed factor it deviations with load imposed network. When heavy traffic is on the routing path the queuing time is increased. The Pr_d represented in eq. (26) is processing delay i.e. how much time the node of the network takes to process the sensed data.

F. Simulation parameters and Network Area

The simulated network field is (100 m x 100 m) in size, with 100 nodes placed. Inside the network field, the sink is placed.

TABLE I: SIMULATION PARAMETER

S.No	Considered Parameters	
	Parameters	***Value***
1	Area of network	(100,100)m
2	Energy consumed by a node to transmit packet ($\in_{ele}$)	50nj/bit
3	Energy consumption of amplifer($\in_{amp}$)	0.0013pj/bits/m^2
4	Energy consumed for freespace model ($\in_{fs}$)	10pj/bit/m^2
5	Distance between node (d_0)	87m
6	Energy consumption for data aggregation (E_{DA})	5nj/bit/signal
7	Packet size(K)	4000 bits
8	Total energy consumption for the network (E_o)	In joules
9	Number of Nodes	100

The proposed method takes into account the energy depletion and threshold value for every type of node in a WSN network. Each cluster's CH and member nodes proceed to the upcoming round based on threshold value. Each round ends with a calculation of the CH residual energy. As a result, the energy consumption is reduced and the stability time is significantly extended. Algorithm 1 presents the steps of the proposed algorithm.

Algorithm: EEA-CFCHS

Input:

G represents the sensor nodes

S_i Signify the set of cluster member nodes

T Indicate the energy threshold for CH selection.

C Represent the CH counters

E_{res} Identifies the current CH residual energy.

Begin:

1. ***For*** *μ in 1 to max do*
   C=0;
2. *Utilizing equations (5), (7), and (9) to calculate the probabilities for NN, IN, and AdN.*

3. *Compute the Threshold value for NN, IN, and AdN using the eq.(6), eq.(8), and eq.(10);*
4. *C=C+1;*
5. ***if** G= =C **then***
6. *High amplifying energy is allocated to component C;*
7. ***else***
8. *Low amplification energy is allocated to component G;*
9. ***end if***
10. ***For** α in 1to n **do***
11. *Use **eq.(13) and eq.(14)** to change the node's residual energy, E_{res} **;***
12. *Calculate the threshold value for NN, IN, and AdN. using eq. (23) and eq.(25);*
13. ***if** $(E_{res} < T(NN) \&\& E_{res} < T(IN) \&\& E_{res} < T(AdN))$ then*
14. *The new CH is selected from S_i*
15. ***else***
16. *Repeat the same CH for the following round;*
17. ***end if***
18. ***end for***
19. ***end for***
20. ***end***

V. SIMULATION AND DISCUSSION

In MATLAB software version 2021a, the proposed protocol is simulated. Out of 100 total nodes, 10% are advanced nodes, 30% are intermediate nodes, and the remaining nodes are normal. Figure (2) depicts the node's placement in the network field. Figure (3) illustrates how clusters originate in a network field. Nodes are split into clusters, each of which has a cluster head. The remaining nodes became members of the cluster.

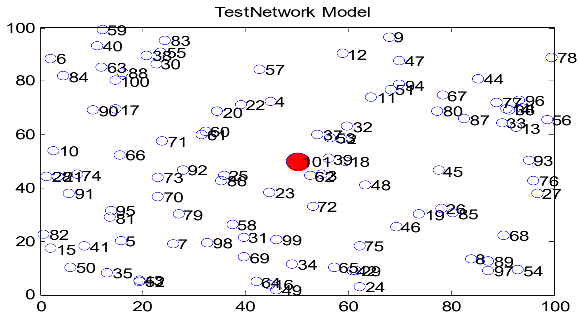

Fig. 2. Deployment of nodes in the field

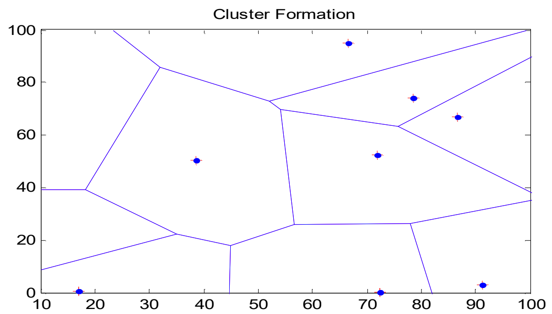

Fig. 3. Cluster formation in the Network field

A. Stability period

The stability period is the number of rounds covered after the first node has died. The simulation was run in MATLAB, and the stability period was extended. By 42 % compared to ESRA and 70.29% compared to P-SEP in ESEEA. Because of the CH, a longer period of stability is attained, and the regular node consumes less energy. ESRA has 434 rounds in its arsenal. ESEEA covers 700 rounds till the first node is dead, whereas D-SEP and P-SEP cover 390 and 400 rounds, respectively.

B. Network Lifetime

While data transmission is taking place, the cluster's member nodes are delivering data to BS via CH while using energy. As a result of this technique, the sensor nodes die because they are exhausted. Known as network lifespan or last node death (LND), this movement means the death of every node. The LND of ESEEA is 2250, whereas the LNDs of ESRA and P-SEP are 1450 and 1069, respectively, indicating a 62% and 73.16 % improvement over the ESRA and P-SEP protocols.

C. Number of dead V/S Rounds

To determine the number of alive nodes as the number of rounds increases. Figure (4) reveals that ESEEA outperformed ESRA and P-SEP in terms of the number of dead nods V/S rounds. The content of the dead node is analysed in this graph while data transmission is in progress.

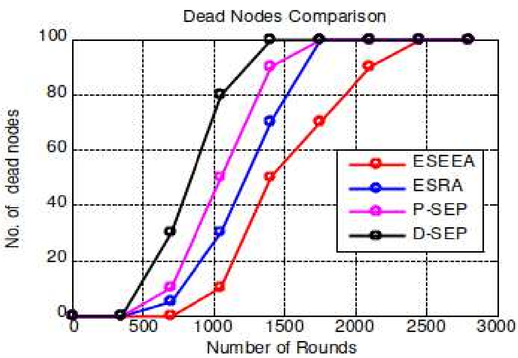

Fig. 4. Dead nodes Comparison

D. Remaining Energy of Network

Figure (5) demonstrates that the ESEEA's leftover energy outperforms the ESRA and P-SEP in comparison to other rounds.

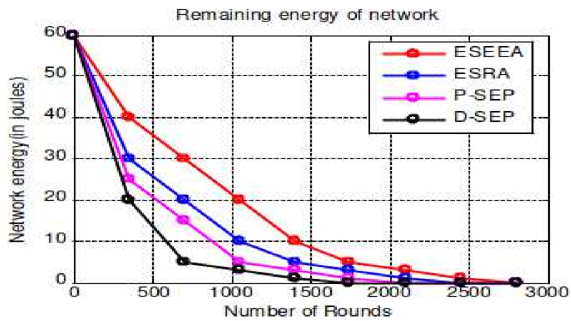

Fig. 5. Remaining energy of network

E. Number of alive nodes

When it comes to network load balancing, this measure is quite essential. As seen in figure (6), the protocol ESEEA has a higher number of rounds than other protocols. As a result of the network's load balancing, this is the case.

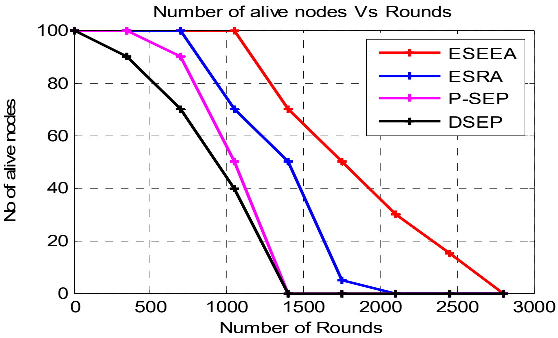

Fig. 6. Number of alive nodes Vs Rounds

VI. CONCLUSION

The standards of control and automation domains are improving for many applications due to developments in sensor and actuator technology combined with data connectivity. In advanced applications like smart grid, advanced metering infrastructure takes into account the networks based on IEEE 802.15.4. In the proposed algorithm EEA-CFCHS, the CH and associated nodes in each cluster progress to the following round based on threshold value. After each round, the CH's energy is calculated, based on this value, a new cluster and electing a new CH can be happened. In this article, EEA-CFCHS based WSN improves the stability period by 42 %, 72% when compared to the ESRA and P-SEP protocols. The EEA-CFCHS also improves the network lifespan by 62% and 73.16% when compared to the ESRA and P-SEP protocols.

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