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Energy Efficient Clustering for Network Stability and Longevity for Heterogeneous Wireless Sensor Network

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Abstract:
Wireless Sensor Network (WSN) suffers from the constraints of limited energy of sensor nodes while achieving the objectives of network longevity and stability period. The aforementioned objectives can be achieved only if the communication among the sensor nodes is made energy efficient. The various cluster-based routing protocols have been developed however, the research gap still lies in the Cluster Head (CH) selection as there are numerous parameters that are responsible for its selection. The appropriate CH selection ensures the energy conservation at the maximum level which ultimately makes the network running for longer duration. In this paper, the CH selection isproposed by incorporating residual energy, initial energy of node, distance to the sink, number of neighbor nodes and energy threshold factor to avoid penalization. It is observed that the proposed protocol improves the stability period and network lifetime by % and %, as compared to DRESEP and SEECP protocols respectively. Simulation analysis is done on the MATLAB Software and the performance evaluation is done against the protocols namely, DRESEP and SEECP.

I. INTRODUCTION

In recent years there have been large growth in wireless sensor networks (WSNs) because of the reduction in development costs and betterment in hardware manufacturing. Basically, WSN comprises of a large number of nodes deployed over a specific area where the environment or the surrounding has to be monitored[1]. A sensor node generally comprises of sensors, actuators, memory, a processor and communicating transceiver.

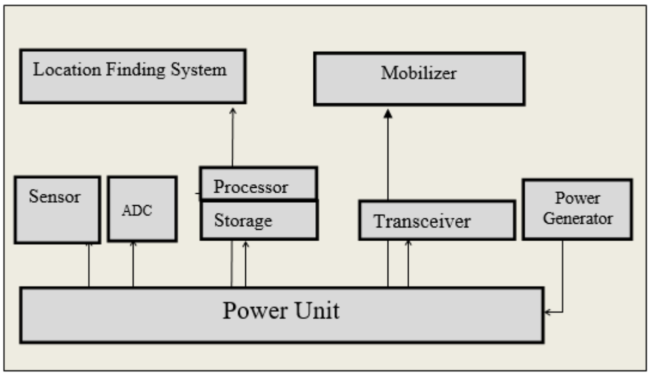

Fig. 1 Components of Wireless sensor node [1]

These wireless nodes follow communication through a wireless medium. This wireless medium can be of radio frequencies, infrared or any other medium, in fact even with no wired connection. The nodes are randomly deployed then after communicating each other to form an ad-hoc network.
When a node is located at far distance from the neighboring nodes then node follow the intermediate node to forward the data to the farthest node or to the sink.

WSN consists of various sensors such as seismic, humidity, temperature, infrared, magnetic, vibrational sensors. These sensors basically monitor various attributes like temperature, humidity, pressure, soil moisture and vibration etc. It is to be noted that WSN applications can be classified into two main genres[3].

a. Tracking: These applications include tracking different individuals like animals, any objects and they basically categorize the particular applications into different sectors of human life.

b. Continuous Monitoring: In this, the applications include health care monitoring, environmental monitoring that may focus on temperature, humidity, flood detection and seismic and structural monitoring etc.

Routing is very important for the battery preservation of sensor nodes. If the network is to be made energy efficient data aggregation, nodes are grouped together to form clusters [4][5].

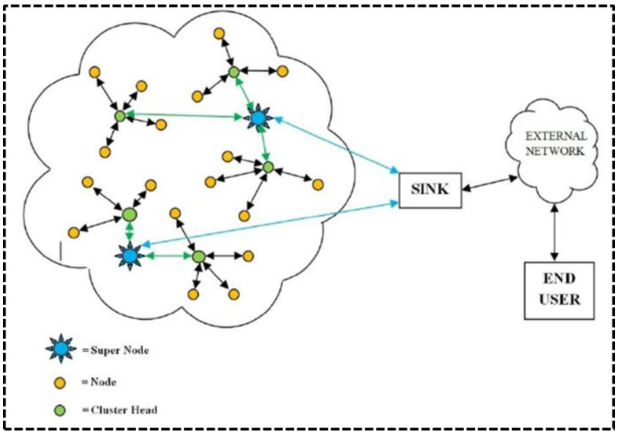

Fig. 2 Clustering in WSN [2]

The role of CH is to supervises the data collection task in each cluster as shown in Fig. 2. It then forwards the collected data to the Base Station. This clustering avoids unbalancing energy load in the whole network. LEACH [6], TEEN[7] DSEP[8]were the protocols which followed clustering approach for the data forwarding. PEGASIS [9]although worked in hierarchy manner, but it made the chain for the data forwarding.

In this paper, the reactive heterogeneous protocols are taken into consideration.

The organization of the remaining work is as follows. Section 2 represents the related work and section 3 represents the problem definition and characteristics comparison. Section 4 discusses the results and simulation. Thereafter, conclusion and future scope is presented. Then the reference listing is performed.

II. Related Work

This section describes the CH selection criteria defined under different protocols to enhanced stability period and network lifetime. The main focus in the energy heterogeneous network has been the Cluster Head selection[10]. There have been various strategies in the heterogeneous network which aim to improve the network lifetime and more importantly the stability period of network by exploiting various ways through which CH can be selected. The energy heterogeneity started from the two levels introduced by the SEP protocol[11]. It incorporated two types of sensor nodes; normal and advanced nodes, but working on only two energy level heterogeneous network. Gradually the research work was focused on the amendments in the probabilistic and threshold formulae for the CH selection.

Where SEP worked on only two energy level heterogeneity but it failed for multi-level. The CH selection was not efficient. The CH selection in DEEC[12] was incorporated with the residual energy factor introduced in the threshold formula. It faced the penalization effect for higher energy nodes for being selected as CH frequently.

In EEHC[13], the three level energy nodes were taken and it followed the energy factor based CH selection.

Thereafter the penalization at three energy levels was avoided by EDDEEC[14] protocol. However, the protocol was deprived of any distance factor that could have been incorporated to the energy effective CH selection.

BEENISH [15]worked at four level of energy heterogeneity but still faced the penalization for the frequent selection of high energy nodes as CH.

Paola G. et al.[16] presented a novel technique that organize the advanced nodes and helps in the selection of CHs in WSNs. The proposed protocol i.e. Prolong SEP (P-SEP) used two energy level nodes; normal and advanced nodes. It treats every node equally for the selection of CHs i.e. the probability of CH selection among all the nodes is same. It is observed that the proposed protocol outperforms the traditional schemes. The protocols[17] , DRESEP [18] and PROPOSED, SEECP[19] has outperformed various heterogeneous protocols these are discussed below.

III. Heterogeneous Protocols; DRESEP and SEECP

This section discusses about the reactive protocols, DRESEP and SEECP protocols.

A. DRESEP

Nitin Mittal et al. considered the residual energy and distance from BS for CH selection.

a) The protocol is distributed in nature and doesn't require global knowledge of network.
b) It is scalable due to multi hop communication as shown in Fig.3.
c) However, Stability period is reduced due to the fact that low energy node may become CH.

The CH selection of DRESEP follows following equations (1-8).

$$D(i) = \sqrt{(D_x(i) - Sink_x)^2 + (D_y(i) - Sink_y)^2} \quad (1)$$

$$Davg = \left(\frac{1}{n}\right) \times \left(\sqrt{(D_x(i) - D_x(j))^2 + (D_y(i) - D_y(j))^2}\right) (2)$$

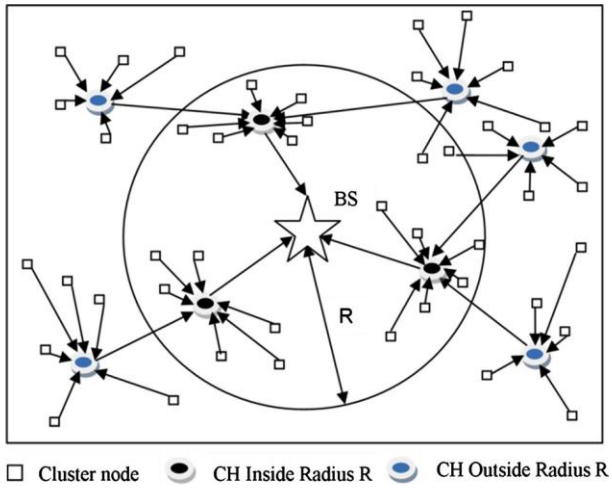

Fig. 3 Scenario for dual hop communication

$$P_N = \frac{P}{(1+m\alpha+m0\beta)} \quad (3)$$

$$P_{IN} = \frac{P(1+\beta)}{(1+m\alpha+m0\beta)} \quad (4)$$

$$P_{AN} = \frac{P(1+\alpha)}{(1+m\alpha+m0\beta)} \quad (5)$$

$$T(n_N) = \left\{\frac{P_N}{1-P_N\left(r \bmod \frac{1}{P_N}\right)} \frac{D_{avg}}{D_{BS}} \times \left[\frac{E_{CNT}}{E_{MAX}} + \left(r_s \operatorname{div} \frac{1}{P_N}\right)\left(1 - \frac{E_{CNT}}{E_{MAX}}\right]\right\} \quad (6)$$

$$T(I_N) = \left\{\frac{P_{IN}}{1-P_{IN}\left(r \bmod \frac{1}{P_{IN}}\right)} \frac{D_{avg}}{D_{BS}} \times \left[\frac{E_{CNT}}{E_{MAX}} + \left(r_s \operatorname{div} \frac{1}{P_N}\right)\left(1 - \frac{E_{CNT}}{E_{MAX}}\right]\right\} \quad (7)$$

$$T(A_N) = \left\{\frac{P_{AN}}{1-P_{AN}\left(r \bmod \frac{1}{P_{AN}}\right)} \frac{D_{avg}}{D_{BS}} \times \left[\frac{E_{CNT}}{E_{MAX}} + \left(r_s \operatorname{div} \frac{1}{P_N}\right)\left(1 - \frac{E_{CNT}}{E_{MAX}}\right]\right\} \quad (8)$$

In equations (1-8) the probabilities for normal node, intermediate node and advanced node is shown by P_N, P_{IN}, P_{AN} respectively. The threshold formula for normal node, intermediate node and advanced node is shown by$T(n_N)$,$T(I_N)$, $T(A_N)$ respectively.

These threshold values are compared with the random number, if for a node random number is less than threshold value generated, a node is selected as Cluster Head otherwise node is a normal node.

B. SEEECP

Nitin Mittal et al.[20]explored deterministic model for CH selection as compared to threshold based selection in other protocols thereby reducing the uncertainties in CH selection. It focused onfollowing factors.

a) It uses multi hop communication by determining radius R for the region by using geometric theory.
b) No. of CHs are already predefined with 5% of the total nodes.
c) CH selection is entirely based on the residual energy, which is inefficient approach. The other factors like Distance and Node Density are not considered.
d) There is no such mechanism being considered to determine whether the CH located outside R should calculate its distance first from the relay CH and BS before sending data to anyone of them. Rather, it is being made to send data to relay CH irrespective of its distance.
e) The radius R is calculated based on geometric theory and it doesn't consider the random deployment of nodes making it energy efficient.

The protocols follow the two phases operation. These include setup phase and steady state phase as shown in Fig. 3. Set up phase includes deployment of nodes and cluster formation. Steady state phase includes data transmission for inter cluster and intra cluster communication. Energy of node is checked after each round; the network is said to be dead when all the nodes are dead.

C. PROPOSED PROTOCOL

The three energy level nodes are deployed namely, normal; intermediate and advanced nodes.

a) Working process

The implementing scenario ofproposed protocol follows the following steps.

a. The proposed network scenario starts with the deployment of heterogeneous network including heterogeneous nodes and BS in the middle of the network. The fundamental radio parameters are identical to ones which are used in the other routing protocols. In this phase, the energy values are defined to the nodes.
b. To make the network functioning, energy of nodes is checked if it is not zero, otherwise node is said to be a dead node. Thereafter the dead nodes are checked, if the dead node number is equal to the total number of nodes taken initially, if it happens, then the whole network is said to be dead. Henceforth, the network stops functioning.
c. If the energy of a node is not zero, it goes through the set up and steady state phase. These phases are presented in Fig. 3 and explained as following.

b) Set up Phase

CH is selected in this phase. The parameters of residual energy and initial energy is considered in a ratio ($\frac{E_{RESD}}{E_{inital}}$) in the threshold formula. Distance factor is also included in a similar fashion by using the ratio ($\frac{D(i)}{D_{avg}}$) of distance of a node from the sink and the average distance of all nodes from the sink. N_M represents the number of neighbor nodes.

i. The use of three parameters the probabilities are calculated for each type of nodes. Normal nodes, intermediate nodes and advanced nodes will have different probabilities due to their different energy resources. Thereafter, the threshold is calculated for each type of nodes.

ii. In parallel, a random number (Rn) is generated. Then Rn value is compared with the threshold value computed for each node. If Rn<threshold calculated, then a node becomes CH otherwise it's a cluster member.

a. Selection of Cluster Head

The selection of CH is done by using the following mathematical model. D(i)is the distance of a node from the BS. Davgis the average distance of all the nodes from the BS. The CH selection of the proposed protocol follows following equations (1-8).

$$D(i) = \sqrt{(D_x(i) - Sink_x)^2 + (D_y(i) - Sink_y)^2} \quad (1)$$

$$Davg = \left(\frac{1}{n}\right) \times \left(\sqrt{(D_x(i) - D_x(j))^2 + (D_y(i) - D_y(j))^2}\right) \quad (2)$$

$$P_N = \frac{P}{(1+m\alpha+m0\beta)} \quad (3)$$

If $E_{(i)} > E_0$

$$P_{IN} = \frac{P(1+\beta)}{(1+m\alpha+m0\beta)} \quad (4)$$

$$P_{AN} = \frac{P(1+\alpha)}{(1+m\alpha+m0\beta)} \quad (5)$$

If $E_{(i)} \leq E_0$

$$P_{IN} = k * \frac{P(1+\beta)}{(1+m\alpha+m0\beta)} \quad (6)$$

$$P_{AN} = k * \frac{P(1+\alpha)}{(1+m\alpha+m0\beta)} \quad (7)$$

$$T(n_N) = \left\{ \frac{P_N}{1-P_N\,(r \bmod \frac{1}{P_N})} \frac{D(i)}{D_{avg}} \times \left[\frac{E_{RESD}}{E_{inital}} + (r_s \operatorname{div} \frac{1}{P_N})(1 - \right.\right.$$
$$ERESDEinital \times NM \quad (8)$$

$$T(I_N) = \left\{ \frac{P_{IN}}{1-P_{IN}\,(r \bmod \frac{1}{P_{IN}})} \frac{D(i)}{D_{avg}} \times \left[\frac{E_{RESD}}{E_{inital}} + (r_s \operatorname{div} \frac{1}{P_N})(1 - \right.\right.$$
$$ERESDEinital \times NM \quad (9)$$

$$T(A_N) = \left\{ \frac{P_{AN}}{1-P_{AN}\,(r \bmod \frac{1}{P_{AN}})} \frac{D(i)}{D_{avg}} \times \left[\frac{E_{RESD}}{E_{inital}} + (r_s \operatorname{div} \frac{1}{P_N})(1 - \right.\right.$$
$$ERESDEinital \times NM \quad (10)$$

In equations (3-5) the probabilities for normal node, intermediate node and advanced node is shown by P_N, P_{IN}, P_{AN} respectively. The threshold formula for normal node, intermediate node and advanced node is shown by $T(n_N)$, $T(I_N)$, $T(A_N)$ respectively shown in equations (6-8). These threshold values are compared with the random number, if for a node random number is less than threshold value generated, a node is selected as Cluster Head otherwise node is a normal node.

c) Steady State Phase

The data transmission is processed in this phase. The following steps are taken into consideration.

i. After when CH is selected, the average distance of all the nodes from the BS is computed. On this average distance which is termed as Radius (R), the communication is decided to be a single hop or dual hop communication.
ii. Thereafter, the distance of CH is computed from the BS. If it is more than R, then the CH forwards the data to the nearest CH that lies within R otherwise it sends data directly to the BS.

The whole working process is shown in flow chart in Fig. 4. and Fig. 5 that explains the CH selection in proposed work.

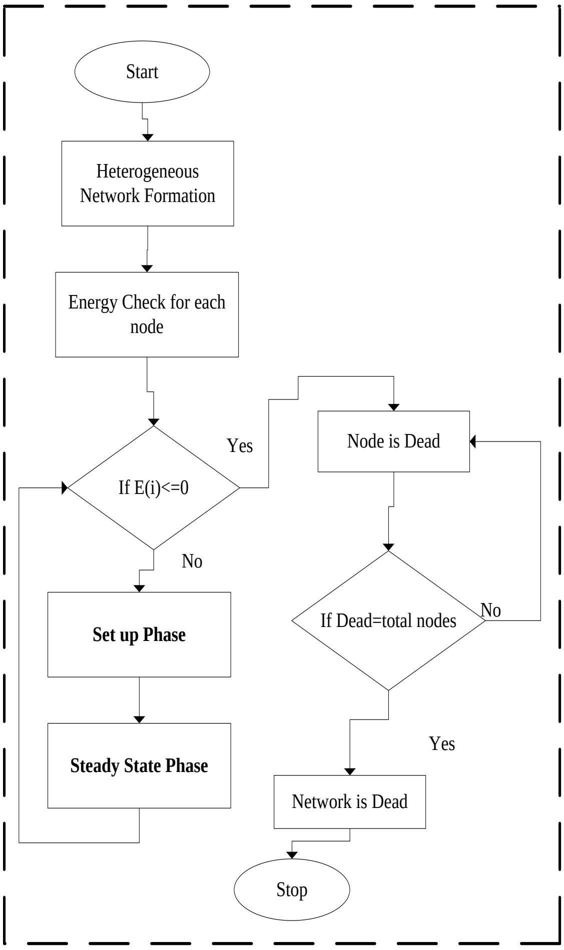

Fig. 4. Flow chart for the network scenarios in heterogeneous protocols

a. Network Assumptions

There are some network assumptions which are taken into consideration while implementing the proposed protocol in real.

i. The nodes in the network are stationary. The batteries of nodes are irreplaceable.
ii. Nodes are said to be dead when the whole battery is drained. At that moment it gets disconnected from the network.
iii. The energy consumption takes place according to the radio energy model which is used fundamentally in all the routing process of WSN.
iv. The security aspects are not taken into consideration.

IV. Simulation Results

The network is simulated in MATLAB Software version 2016. There are different performance metrics on which the performance of protocols is evaluated. These include stability period, network lifetime and networks remaining energy. Stability period of PROPOSED, SEECP and DRESEP is found to be 1004, 685, and 337 rounds respectively as shown in Fig.4.

The stability period of Proposed protocol is higher than SEEP and DRESEPdue to the inclusion of various parameters that stables the network. Moreover, the dual hop communication involved is made efficient by defining circular radius on some particular parameters.

The stability period of PROPOSED, 46.5% higher than the SEECP protocol.

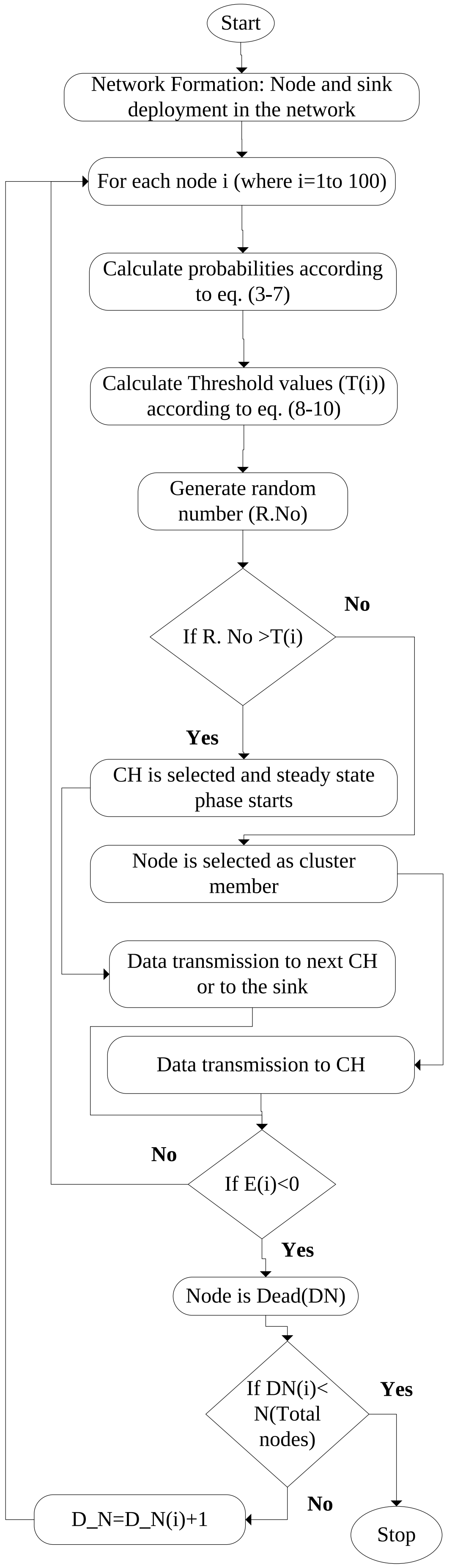

Fig. 5 Flow chart for CH selection in proposed work

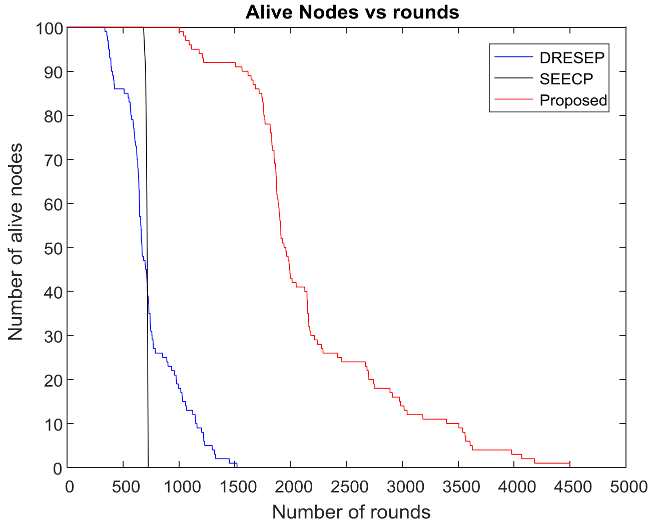

Fig. 6. Alive Nodes vs rounds

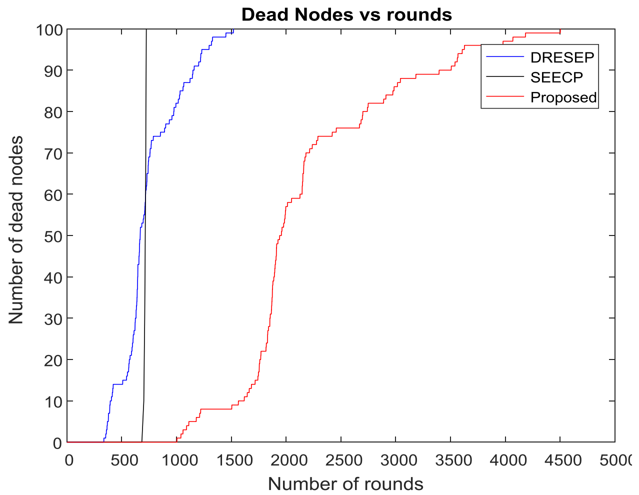

Fig. 7. Dead Nodes vs rounds

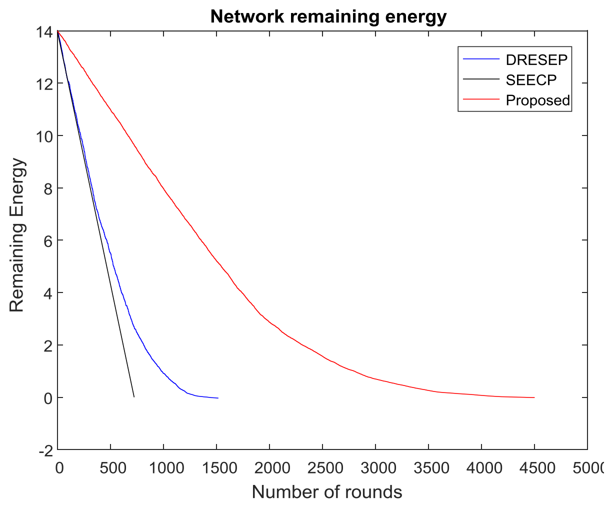

Fig. 8. Network's remaining energy vs rounds

The graph of dead nodes vs rounds is shown in Fig. 7, and it is observed that network lifetime for PROPOSED, SEECP, DRESEP is 4502, 725, and 1519 rounds respectively.

It can be observed from the Fig. 8 that more number of rounds are covered as the network operates. In case of PROPOSED, SEECP, all nodes are dead at one particular value of round that indicates the load balancing by PROPOSED, SEECP protocol.

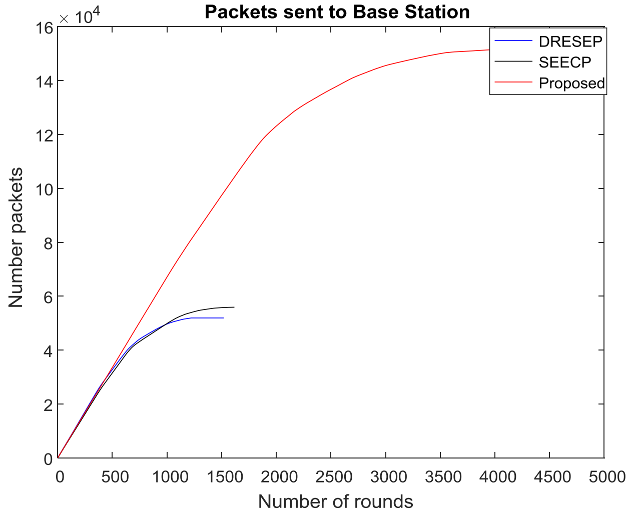

Fig. 9. Throughput vs rounds

The networks remaining energy as shown in Fig. 8, is observed to cover more number of rounds in PROPOSEDas comparison to the DRESEP and SEECP protocols. It is due to the energy efficient CH selection that includes the initial energy and residual energy into consideration.
The throughput is also enhanced comprehensively as shown in Fig. 9 as compared to SEECP and DRESEP protocols.

Table 1 Summarized analysis of Proposed, DRESEP and SEECP protocols

Protocols	Proposed (Rounds)	SEECP (Rounds)	DRESEP (Rounds)
Stability Period	**1004**	685	337
Half Node Dead	**1941**	715	669
Network Lifetime	**4502**	725	1519

Table 2 Percentage improvement by Proposed as compared to other protocols

Protocols	SEECP (%)	DRESEP (%)
Stability Period	46.5	197.9
Half Node Dead	171.4	190.13
Network Lifetime	520.96	196.37

In Table 1 and Table 2, the summarized analysis is given about the number of rounds and percentage improvement covered by the Proposed as compared to DRESEP and SEECP protocols. It is basically due to the enhanced CH selection and defining the average distance of nodes from the CH as a deciding element for dual hop communication.

V. Conclusion and future scope

WSN has tremendous applications worldwide in different sectors of human life. The energy constraints on sensor nodes make them limited for various applications. Clustering not only improves the scalability factor for WSN but also improves the network performance in terms of load balancing. Various heterogeneous routing protocols have been developed so far that presents different methods of CH selection. In this paper, the CH selection is improved by incorporating residual energy, distance to the sink, initial energy, number of neighboring nodes and threshold factor for avoiding penalization of high energy nodes. The proposed protocol is compared with DRESEP and SEECP which are also discussed. Simulations are performed in MATLAB and it shows that the proposed protocol improves stability period by 46.5% and 197.9 % as compared to SEECP and DRESEP protocols. Furthermore, the network lifetime is enhanced comprehensively i.e., by 520.96 % and 196.37 % as compared to SEECP and DRESEP respectively. In future the work can be extended to use of mobile sink in the network.

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