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Stability Enhancement in LEACH (SE-LEACH) for Homogeneous WSN

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Abstract

In this paper, with an objective to increase stable region of WSN, stability enhancement for LEACH (SE-LEACH) protocol is propound which is capable of balancing the load ensuring all nodes dissipate power in similar fashion. Since best candidate selection is utmost requirement to play the role of cluster head, the selection criteria considers node density, residue energy, farness from base station & power dissipation if chosen as cluster head. Also, non-cluster head nodes elect their cluster head on the basis of residual energy, node density, the power it will dissipate during the round and distance to that cluster head. Simulation experiments are performed for two cases wherein a base station is kept at the center of the network in one hand and at far off distance on the other hand. Simulation results are compared with LEACH and MOD-LEACH which validate the extension of stability region and exhibit load balanced network for proposed protocol.

Keywords: Clustering, Energy Efficiency, LEACH, Cluster Head, WSN.

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1. Introduction

The advancement in microelectronics technology with low power consumption in electronic circuitry and communication has made it possible for expansion of Wireless Sensor Network (WSN) in almost every field. Some of the diverse applications of WSN are environmental monitoring, medical field, heath monitoring, object tracking, battle field surveillance etc. [1], [2] WSN is envisioned for gathering pertinent information from environment preferably for longer time duration. It has miniature electronic devices called sensor nodes (SN) which can sense, collect, compute and store data of interest from the surrounding. Huge collection of these micro-sensors gives exceptional prospects in varied diversified realms. There is a sensing, processing & communication unit driven by battery. With minute size, it is not possible to embed huge battery for power supply, large memory for data storage and powerful processors for computation in the SN. With these constraints, energy efficient utilisation of the SN is the key addressing issue globally for researchers in past decades expanding the system lifetime to most extreme conceivable degree. In WSN, maximum energy is drained in data transmission, therefore, design of an energy efficient protocol is needed[3].

WSN can be restricted to two categories: Homogeneous and Heterogeneous. In homogeneity based network, the characteristics of each SN is similar to one another in terms of power, hardware, processing etc. but it is not the case with heterogeneous network. In such network, the SN can be supplied with extraneous energy, additional computational capability with more storing capacity. It is cheaper to provide additional energy to SN at the time of deployment as compared to replacing a sensor [4].

Information gathering schemes in WSN can be categorized as Hierarchical & Non Hierarchical protocols. In Non-Hierarchy based protocols , SN forward the collected information in single or multi hop to base station(BS) expending more energy where as in Hierarchy based (Clustering) protocols SN forward data to respective cluster head(CH) which in turn can transmit it directly or hop by hop to BS conserving energy. As discussed in [5], communication dissipates most of the network's energy. Clustering is the grouping of nodes to form clusters[6]–[8]. Clustering has the capability to improve lifetime if good candidate is chosen as CH. It not only increases the robustness but also makes the network scalable. The task of cluster coordinator is not merely to accumulate data but also to meld or aggregate it. By reducing the number of bits for communication by applying aggregation or fusion, a good amount of energy can be conserved. The cluster coordinator may get exhausted prematurely than member nodes if the role is not rotated because CH role is very energy intensive task which can deplete battery level at faster rate[9]. Thus, for better lifetime, the CH role may be rotated on timely basis.

This literature focuses on increasing the stability of the LEACH [10] protocol by overcoming its limitations and improving the performance. The objective of LEACH is to prolong network lifetime by formation of clusters and rotating CH role. While designing the LEACH protocol, the author didn't consider some factors that affects the energy of the network like residual energy, density around node, farness from BS, tentative energy dissipation by CH node, average distance to nearby nodes. Also, the protocol is randomized which can lead to zero CH in some rounds. This papers covers all these limitations to enhance stability region for achieving more reliability in network.

Outline of this paper is as follows: Section 2 discusses literature survey. Section 3 describes proposed work. Section 4 presents the simulation experiments and performance evaluation. Concluding remarks with future directions are discussed in Section 5.

2. Related Work

In this section, we will discuss about some protocols which are based on or derived from LEACH[10] protocol. LEACH was proposed in the year 2000. It was pioneer in cluster formation in WSN. It is distributed protocol which needs global knowledge about the field. The protocol consists of rounds and operations in each round is distributed into two phases: Setup Phase & Steady phase. Setup phase is responsible for selecting CH, building clusters & providing TDMA schedule to member nodes whereas steady phase involves data gathering, fusion and transmission of fused information to BS. In CH selection, every node generates a random number and if it is less than a threshold *T(n)* which is calculated by eq. 1. then that node is elected as CH.

$$T(n) = \begin{Bmatrix} \dfrac{P}{1 - P * [r \bmod (1/P)]}, n \in G \\ 0, \qquad\qquad\qquad else \end{Bmatrix} \tag{1}$$

Where p is optimum percentage of CH and r is present round.

There are some limitations of this protocol which are discussed hereafter. Since selection of CH is based on randomization, there may be chance that no CH is selected, also a SN with low energy may be selected. Clusters in LEACH have unequal distribution which can overburden a weak CH. There is no restriction of count of CH.

In the year 2002, LEACH-C [11] protocol was proposed in which BS controls the decision of CH selection, formation of clusters and information distribution in network. There is no overhead on SN in setup phase. K-optimal clusters with uniformly distributed SN are created by BS and average energy of the network is computed and residue energy of SN is considered. It is presumed that each SN is GPS enabled for location determination. Since it is centralized approach, thus it is not scalable. Handy *et al.* propound LEACH-DCHS [12] by considering residue energy of nodes. LEACH-DCHS extended the network lifetime by 30% by multiplying remnant energy with Threshold T(n). In the year 2004, Voigt *et al.* propound sLEACH [13] where some SN transmit its solar and residual energy status to BS in order to be elected as CH. This protocol improved performance as compared to LEACH & LEACH-C. In 2005, Loscri *et al.* proposed TL-LEACH [14] with two level hierarchy of clusters. Upper level CH perform partial computation whereas lower level CH perform complete computation before transmitting data to BS. More SN uses shorter distance transmission in this protocol thereby conserving energy. In 2006, Oliveira *et al.* proposed SecLEACH [15] for secure WSN using random key pre-distribution. It is light weight approach for hierarchy based protocols.

In 2007, Chen and Shen proposed ME-LEACH[16] with homogenous static SN. It uses residual energy for CH selection and improved the performance by reducing average transmission distance among nearby nodes. This protocol is not suitable for large WSN. In the year 2008, Ali *et al.* proposed ALEACH [17] where two probabilities are used for CH selection; current state probability and general probability. It also considers residual energy while selection of CH. In the year 2009, Hong *et al.* proposed T-LEACH[18] in which the CH are fixed for certain round until their energy level falls below a calculated threshold thereby reducing communication cost and increasing lifetime. Wang *et al.* proposed LEACH-H[19] in which the CH are selected by BS using simulated annealing algorithm. Also, new CH is selected amongst the SN alive in the cluster conserving energy & extending lifetime.

In 2010, Tong and Tang proposed LEACH-B [20] for balanced cluster formation. Initially, the CH are chosen like LEACH and later residual energy is considered for CH selection. Only optimal number of CH are selected in each round but the message overhead is large in this protocol. Abdulsalam *et al.* proposed W-LEACH[21] in which a weight is assigned to each SN based on residue energy and node density. No two CH are elected which are close to each other. This is centralized protocol which substantially improves lifetime of network. Farooq *et al.* proposed MR-LEACH [22] in which SN with highest energy level is elected as CH. The target area is divided into different layers forming hierarchy. The number of hops for transmitting data to BS is equal for all clusters. Lower layer CH assist higher layer CH for data forwarding. In 2011, Liu and Ravishankar proposed LEACH-GA[23] which is based on genetic algorithm. SN participate in candidate cluster head (CCH) process. BS finds optimal CH percentage using evolutionary optimization process with crossover and mutation operators. In this, the value of p_{sat} =0.5. LEACH-GA depicts better performance than LEACH but message overhead is involved. In 2012, Feda' Al-Ma'aqbeh *et al.* propound FL-LEACH[24] which uses fuzzy logic to determine number of CH to be used in WSN. Two fuzzy variables: total nodes and their density is used in fuzzy inference system. Simulation results depict FL-LEACH outperforms LEACH & LEACH-GA.

In 2013, Chen *et al.* proposed LEACH-G [25] which adopts distributed as well as centralized approach for CH selection & cluster formation. It ensures certain count of CH with even distribution to ensure no premature death of SN. Mahmood *et al.* proposed MOD-LEACH[26] which conserves energy by signal amplification. Low amplified signals are used for intra communication and high amplified signals are used for inter communication. Rotation of CH takes place only if the residual energy of current CH falls below a defined threshold thereby conserving energy of network and improving lifetime. Sudhanshu *et al.* proposed EHE-LEACH [27] for extending network lifespan. A fixed threshold is calculated on the basis of distance. SN nearer to BS communicate directly where as distant SN used cluster based communication. Its performance is better than LEACH & SEP. In the year 2013, Gnanambigai *et al.* proposed Q-LEACH [28] in which the target area is divided into four quadrants and cluster formation takes place in each quadrant. It doesn't consider residual energy in clustering.

In 2014, Salim *et al.* proposed IBLEACH[29] with intent to minimize intra cluster communication & CH load. This protocol is sliced into three phases: Setup phase, pre-steady phase and Steady phase. The SN are classified in three categories in pre-steady phase: aggregators, CH, sensing SN. With balanced dissipation of energy, it significantly increases the performance of protocol. Eletreby proposed CogLEACH [30] which is spectrum aware protocol. It makes use of idle channels in a band as weight in CH probability. This protocol improves lifetime but suffers from unbalanced energy consumption. Cho *et al.* proposed P-LEACH[31] with mobile sinks. In this protocol, the network area is virtually divided and partition nodes and gate nodes are located for data collection and transmission. P-LEACH enhances the stability period but at the cost of system complexity and message overhead.

In 2016, Batra *et al.* proposed LEACH-MAC [32] which restricts the CH advertisements. A CHheard variable is used which counts the number of advertisements received by the SN. If the value of CHheard is less than p_{opt}, the SN declares itself as CH. This protocol does better than LEACH, ALEACH and LEACH-DCHS. Marappan and Paul proposed CL-LEACH [33] which exploits cross layer technique. During cluster formation, member nodes elect their CH on the basis of residual energy and farness from BS. There are relay nodes to transfer the collected data to BS. Jerbi *et al.* proposed O-LEACH[34] which takes care of orphan nodes which are not assigned any cluster. Two scenarios are considered for the solution. In first scenario, a gateway node is assigned to orphan node for collecting and transmitting data and in second scenario, all the orphan nodes form sub-clusters and choose CH having shortest distance to gateway node.

3. Proposed Protocol

SE-LEACH is proposed for homogeneous network where all the nodes have capabilities like sensing, processing, energy etc. at par. There are some limitations of LEACH protocol can be enumerated hereafter. LEACH is randomized in selection of CH which may result in No-CH selection in some rounds. Remnant energy which is a crucial parameter is not considered in LEACH. Density around node decides the burden in CH. Its inclusion may result in better cluster formation. LEACH is simulated for only one kind of environment where BS is located at centre. The energy which will be dissipated by node if selected as CH is not considered in LEACH. Distance from CH to BS is equally important as communication consumes large amount of energy. SE-LEACH attempts to overcome these limitations and improves the stability period with load balancing. Before we begin with the operation of proposed work, system model is discussed for better understanding of SE-LEACH.

3.1. Network Assumptions

Some of the assumptions which are made while designing SE-LEACH protocol are mentioned below:

1. The SN are deployed on the fly i.e. randomized.
2. All the SN are homogeneous having equivalent energy level.
3. Both BS and SN are immobile.
4. SN is powered by battery which is irreplaceable and non-rechargeable.
5. BS has continuous power supply.
6. Distance between two device is estimated by RSSI (received signal strength index)
7. Network has symmetric communication.
8. A node is presumed dead if it has zero battery level.

The area of interest (AOI) i.e. the target field is assumed be 100 m^2 with randomly scattered SN over AOI with BS located at the center in one scenario and aloof in another scenario as shown in Figure 1 & Figure 2 respectively.

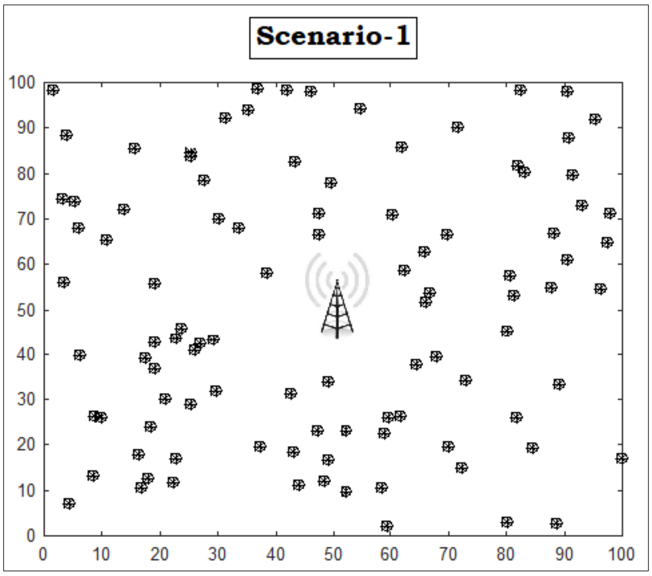

Figure 1. Network Layout-Scenario-1

3.2. Energy Radio Model

In this proposed work, the radio model used in LEACH [10] is adapted. It is lightweight model with free space and multipath fading relying on separation between transmitter and receiver.

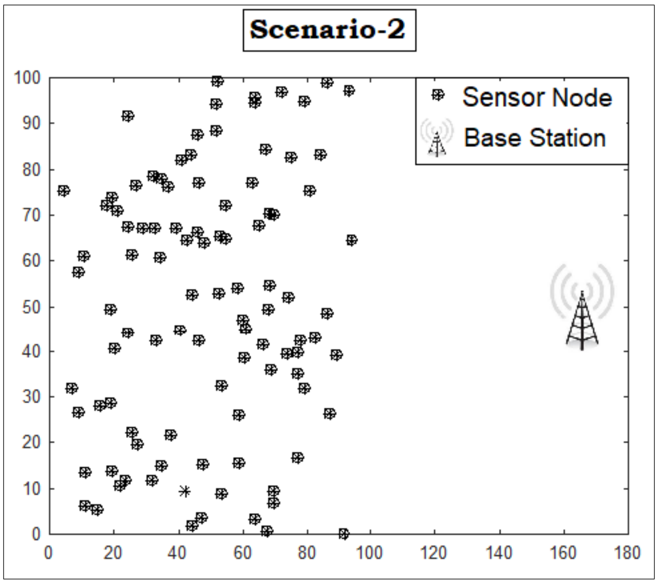

Figure 2. Network Layout-Scenario-2

To transmit s bits packet, energy utilized by transmitter & receiver is denoted by E_{Tx} & E_{Rx} respectively as shown in Eqs. (2) and (3).

$$E_{Tx}(s,d)=\begin{cases} sE_{elec}+s\varepsilon_{fs}d^2, & d<d_o \\ sE_{elec}+s\varepsilon_{mp}d^4, & d\geq d_o \end{cases} \quad (2)$$

Where $d_0=\sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}$

$$E_{Rx}(s)=E_{Rx-elec}(s)=s.E_{elec} \quad (3)$$

The total energy exhausted by a CH in one round is calculated by Eq. (4)

$$E_{CH}=(n/p)s(E_{elec}+\varepsilon_{fs}d_{BS}+E_{DA}) \quad (4)$$

Where the distance to BS is represented by d_{BS} and n/p is cluster members. Similarly, the amount of energy dissipated by a cluster member is computed by Eq. (5) in which d_{CH} is the distance to its CH.

$$E_{CM}=(sE_{elec}+s\varepsilon_{fs}d_{CM}) \quad (5)$$

Where $d_{CM}=\sqrt{\frac{M^2}{2\prod p}}$

3.3. Clustering Process

The operation of this proposed work is classified into three phases: CH selection phase, Cluster formation phase and data dissemination phase.

CH selection phase

In this phase, the proposed protocol attempts to select the best candidates for CH role. After the SN deployment, a packet (LOC_BS) is broadcast by BS which contains the coordinates of BS and TDMA schedule. All the SN need to collect local information from the surrounding and thus broadcast (INFOR_PKT) within its radio range according to schedule received from BS. Once all broadcasts gets completed, SN calculate local information like farness from BS, density, energy level, average distance from each nodes and average power required to communicate to each node within radio range. After calculating the CH rank from equation (6)

$$Rank(i)=\frac{SN(i).E*SN(i).N\_Density}{SN(i).AD\_MN*SN(i).DBS*SN(i).AVG\_PWR} \quad (6)$$

each node broadcast their candidature within radio range as per schedule. After receiving all ranks, if the rank of node is highest, then it will proclaim its candidature and broadcast (HEAD_NODE) which has its density, battery level and average distance to nearby nodes or else it will wait to join optimal cluster. The CH selection algorithm is discussed in Algorithm 1.

Algorithm1: CH selection phase in SE-LEACH

Begin:

1 : TN ← total nodes in network

```
i ← Identity of nodes
TN(i).Energy← current battery level
TN(i).Type ← member
TN(i).Rank ← 0 // initially rank set to 0
TN(i). AD_MN  //Average distance to member
    nodes
TN(i). AVG_PWR  // Average power required if
    chosen as CH
Count_of_CH ← 0
TN(i).N_Density ← Nodes within radio range
TN(i).D_BS ← Distance of SN to BS
Each node compute its rank
Each node broadcast its rank to pronounce its CH
    candidature
For (i=1 to p% )
{
   If TN(i).Rank > Received_TN(j).Rank then
      TN(i).Type ← CH
      Count_of_CH ++
      Add TN(i) to List_of_CH
      Broadcast (HEAD_NODE) packet
   end If
 }
End For
End
```

Cluster formation phase

Once the CH are decided, cluster formation phase comes into execution. The NON-CH nodes now need to take the decision of joining the clusters. NON-CH nodes have information like density around CH, its residue energy, distance to the CH node and average distance to member nodes from CH. With all these crucial information, it will calculate their chance using equation (7).

$$Chance(i) = \frac{CHNode(i).E * CHNode(i).N\_Density}{Dist\_to\_CHNode(i) * CHNode(i).AD\_MN}$$

(7)

After computation of the chances of each CH node, NON-CH node will choose a CH node with highest chance and send a packet (JOIN_CL). The CH node will accept the request and send acknowledgement (ACK_ACCEPT_JOIN) to the requesting node with a TDMA schedule. In this manner, all the clusters are formed.

Data dissemination phase

After completing the cluster formation, with an objective to collect information from the field, member nodes communicate sensed data to their respective CH according to TDMA slot to evade collision. To limit the repetitive information, CH aggregates the received information from SN and communicate it to BS adhering to the TDMA schedules. In this manner, a round is completed by SE-LEACH.

4. Simulation & Performance Evaluation

The simulation of the proposed protocol is performed in matrix laboratory (MATLAB). The area of interest is considered to be $100m^2$ with static nodes deployed around the area. Extensive experiments are performed for normalized results. The optimum percentage (p %) of CH is kept 10%. Two scenarios are considered in which the position of BS is varied. In first scenario, BS is located at the center i.e. (50, 50) & in scenario 2, the BS is positioned at distant place (175, 50). SE-LEACH is compared with LEACH & MOD-LEACH. The simulation parameters are shown in Table 1.

Table 1. Configuration of Simulation parameters

Parameter	Value
Total Nodes, N	200
Free Space model	$10pJ/bit/m^2$
Multipath Model	$0.0013pJ/bit/m^4$
Initial battery level(E_o)	0.5J
Packet size (s)	4000bits
Data aggregation(E_{DA})	5nJ/bit/report
Electronic Circuitry (E_{elec})	50nJ/bit

The performance of the proposed protocol is measured by following metrics

- ✓ *Dead Nodes per round*: It is the count of total nodes died till current round.
- ✓ *Throughput*: It estimates the successfully transmitted packet to BS.
- ✓ *Stability period*: It is a reliable period which guarantees complete coverage of area of interest as all nodes are alive.
- ✓ *Half Node Death*: It is the round where only half of the deployed SN are alive.

4.1. Dead nodes per round

A graph is plot for dead nodes per round for both the scenarios as shown in Figure 3. Premature death of SN makes the network unstable and unreliable. It exhibits the network lifespan after the network gets operational (i.e. beginning of clustering process). We can observe from Figure 3 that SE-LEACH successfully balances the energy depletion of the network for both the scenarios.

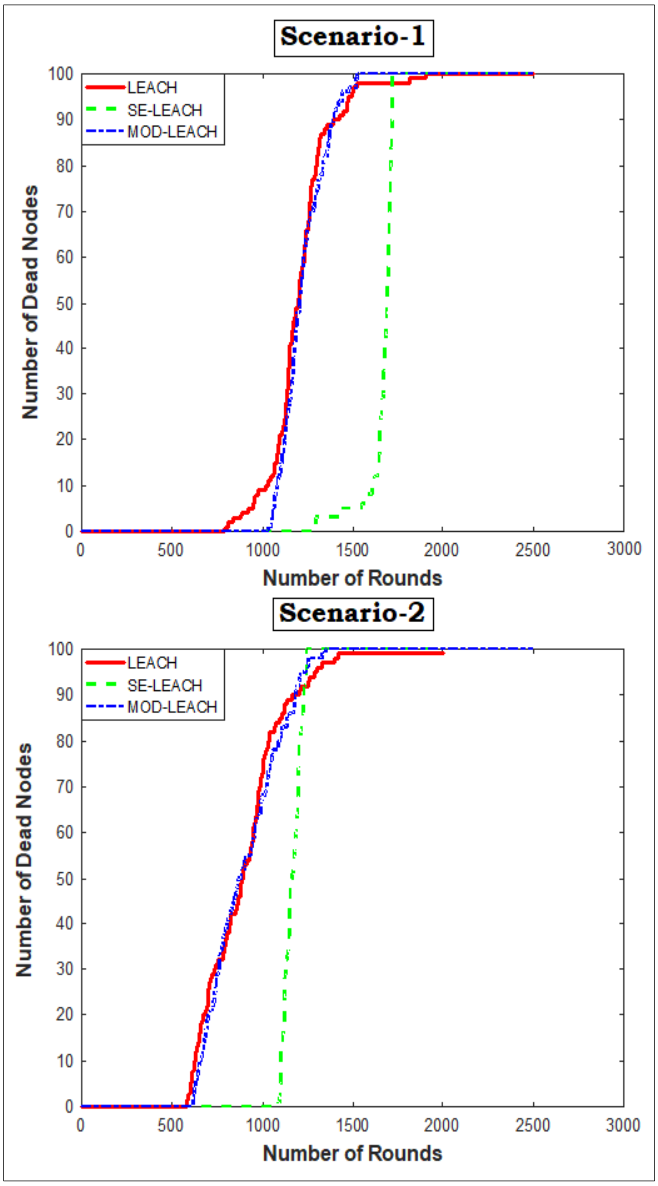

Figure 3. Dead Nodes per round

4.2. Average Energy per round

The energy of the network is expended mainly in sensing processing and communication. If the network is consuming more energy per round and depleting its average energy then its lifetime will get affected and that protocol will have poor stability region. We can see in Figure 4 that the average energy level of SE-LEACH is always greater and much more than LEACH & MOD-LEACH in both the scenarios making the protocol more reliable. This improvement is achieved by selecting the best candidate for CH by considering the parameters which affects energy more.

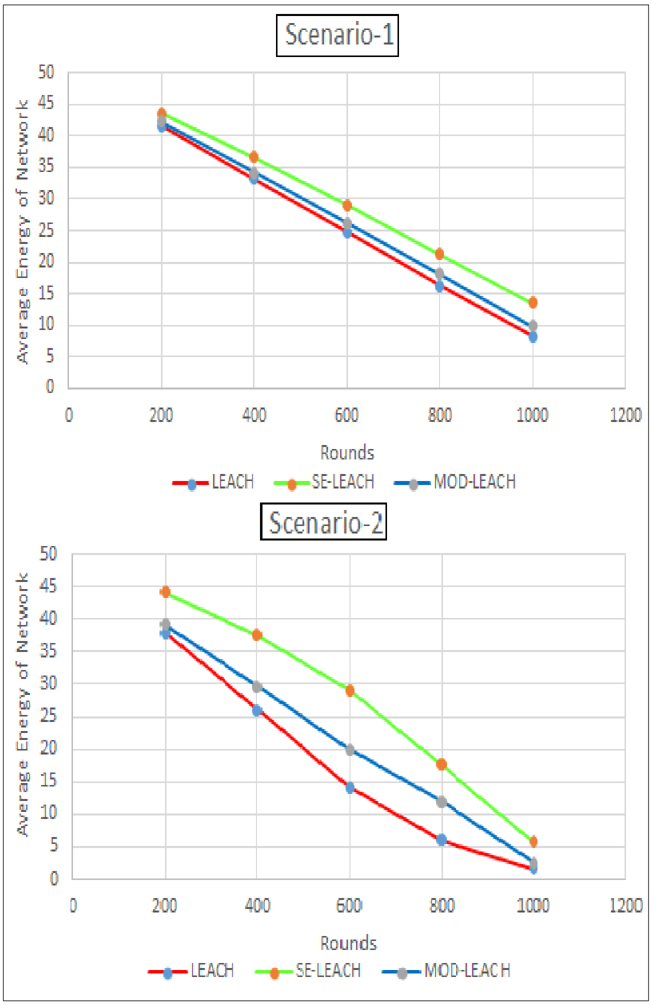

Figure 4. Network's Average Energy

4.3. Throughput

If more number of packets are delivered to BS then more information is collected fulfilling the objective of WSN. Figure 5 depicts the total packets delivered to the BS per round. From the plot, we can figure out that SE-LEACH delivers more packet as compared to LEACH & MOD-LEACH protocol in both the scenarios. The packet delivery is somewhat proportional to the energy consumption by the network. If more energy is there in the network, then more packet delivery will be there to BS.

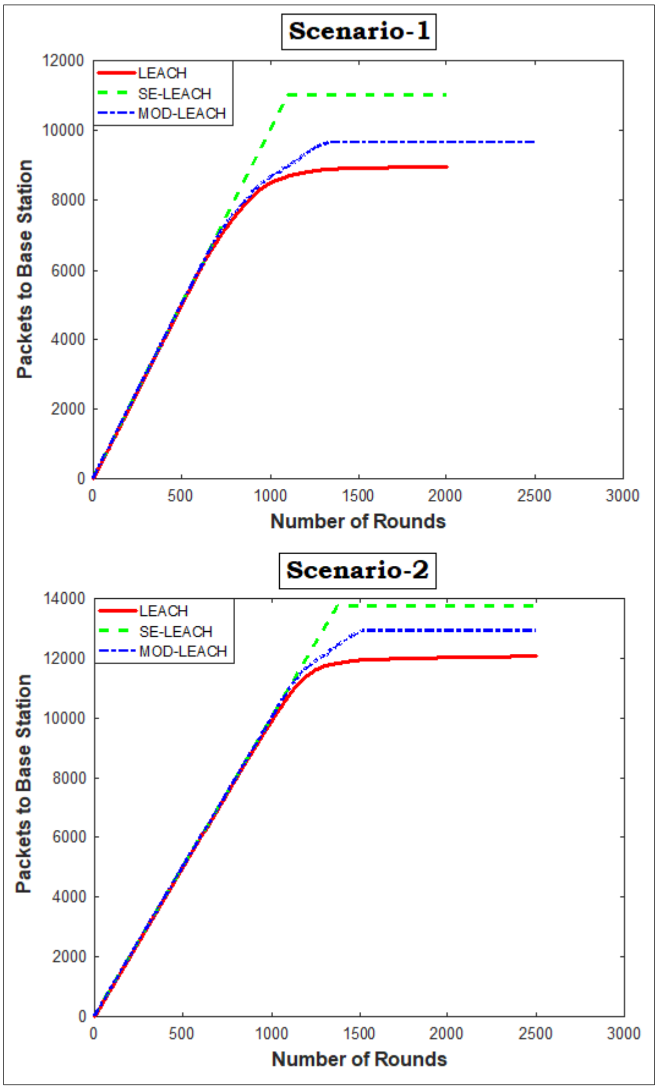

Figure 5. Network throughput

4.3. Stability Period & Half Node Death (HND)

The objective of proposing SE-LEACH is the enhancement of stability period of LEACH. Figure 6 depicts the stability period as well as half node death plot for both the scenarios. Longer stable regions establishes reliability in protocol[35], [36]. In scenario 1, stable region for SE-LEACH is 1293 which is around 38.74% & 21.88 % more than LEACH & MOD-LEACH protocol. Similarly for scenario 2, stability period is attained till round number 1090 round where as in LEACH & MOD-LEACH, it is only 579 & 617 rounds which means that SE-LEACH overpowers LEACH by 46.88% & MOD-LEACH by 43.39%. For scenario 1 , the rounds up to which half of the nodes are available in the network for SE-LEACH is 1180 where as it is 860 for LEACH & 867 for MOD-LEACH which is around 27.11% & 26.52% more respectively. Correspondingly for scenario 2, SE-LEACH shows better performance in HND by 30% & 29.10 % as compared to LEACH & MOD-LEACH respectively.

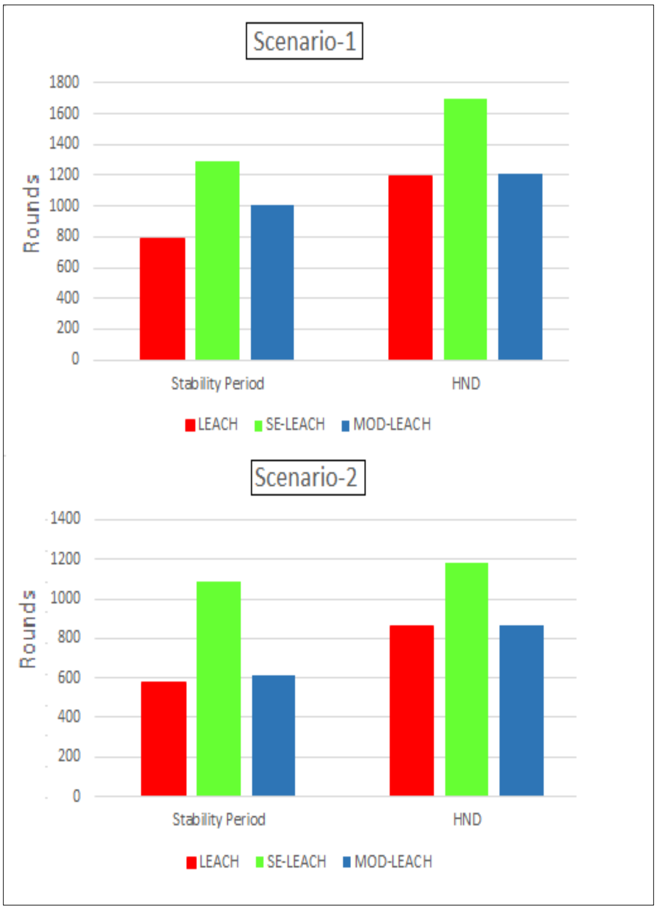

Figure 6. Stability period & Half Node Death (HND)

5. Conclusion

With an objective to overcome the limitations and enhancing the stability of LEACH protocol, SE-LEACH is proposed in this paper. In SE-LEACH, the operation of a round is divided into three phases: CH selection phase, cluster formation phase and data dissemination phase. While selection of CH candidates, key parameters like remnant energy, density around node, average distance to other nodes, average power consumption on election of CH and distance to BS which affects energy are taken into consideration. While forming clusters, all non-CH nodes intelligently choose their CH by calculating chance of each CH nodes. Simulation experiments are performed for two scenarios by changing the position of BS making the protocol suitable for any application type in WSN. Simulation results show the extended stability period along with balanced energy consumption with better throughput. In future work, we will apply fuzzy logic for selection of CH & Cluster formation to achieve more prolonged stability period.

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