SEEC- Structured Energy Efficient Clustering with Bi-fold Cluster Head Selection in WSN

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Abstract

In Wireless Sensor Networks (WSN), there is a greater research scope in energy efficient clustering for improving the life time of the network and also concerning about the load balancing among sensor nodes. Moreover, clustering is an effectual method for minimizing the energy consumption of the overall network. Since there are some energy limitations in battery depended sensor nodes and also some location based load balancing issues due to hot spotting, clustering has always been a crucial technique in WSN. The properties of energy heterogeneity of the network nature should be considered on designing a clustering model. With those concerns, a novel Structured Energy Efficient Clustering (SEEC) with uneven cluster size in the situation of producing diffusive energy on each sensor node has been proposed in this paper. For optimizing the energy consumption, the proposed model combines the multiple factors in the size of clusters and cluster numbers effectively. Moreover, the process of Cluster Head selection has been implemented through Bi-fold Cluster Head Selection (BCHS) model. In BCHS, the selection process works under two stages. First phase involves in selecting the temporary cluster head selection based on the sensor node's initial and lasting energy levels. Following that, in the second phase, the temporary cluster heads are replaced with an efficient CH among the defined cluster members and final list of cluster heads are formed. By employing this model, it is to be ensured that nodes having higher energy receive more chances for being CHs. Furthermore, the adduced model provides well distributed consumption of energy that obviously increases the longevity of network lifetime. Experiential results are analyzed with various factors such as throughput, packet delivery ratio, end-to-end delay and energy consumption. And, evaluated results re compared with the existing methodologies like LEACH, HEED and so on to provide the evidence for the efficiency of the proposed work.

Keywords: Wireless Sensor Networks (WSN), Structured Energy Efficient Clustering (SEEC), Bi-fold Cluster Head Selection (BCHS), Energy Consumption, Residual Energy.

1. INTRODUCTION

In general, WSN has been widely used in remote monitoring and tracking the environment to enhance the life style of people. WSN has attained a great scope of interest in the present scenario, because of its wide range of major applications like military and security oriented services, target tracking, environmental monitoring, etc [11]. The networks hold a significant role in analyzing and monitoring the active, unknown, dynamic and hostile environment [2]. Moreover, the sensor network comprises several tiny and smart sensor devices for performing various sensing tasks. Those devices have limited energy and battery lifetime. But, for making a large scale wireless sensor network with efficient energy consumption is a great deal and a difficult task to achieve. However, the energy consumption of sensing devices are mainly takes place during the data transmission, reception and the data allocation parts of the overall functions and it is also based on the distance between the sensing devices [4].

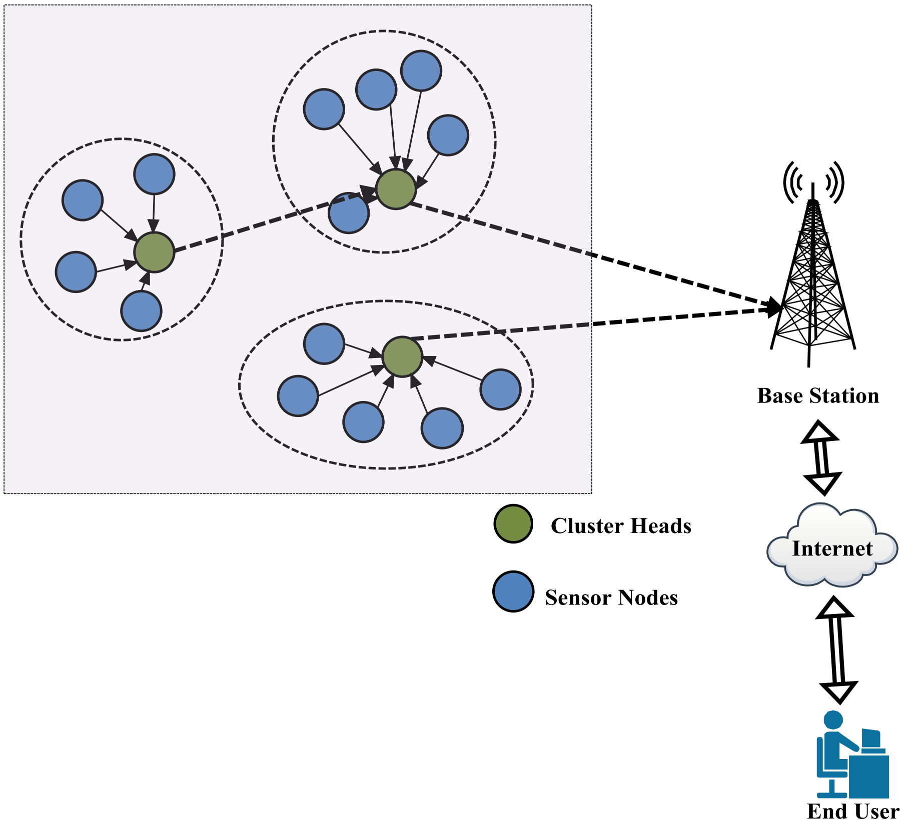

Figure 1: WSN Framework with Clusters

In order to address those challenges in WSN, network topology control provides some effective solution for enhancing the overall network performance and reducing cost complexities. While discussing about that, clustering is a predominant methodology to manage the topological functions in an effective manner. A typical wireless sensor network with clusters have illustrated in the following figure 1. It consists of some distributed wireless sensor nodes (termed as cluster members), Cluster Heads (CH) and Base Station (BS) for transmitting and receiving data. Since the connection between nodes is strong among the signals between sensing devices that are nearer among themselves, the data set can be minimized extremely through data aggregation and a high-level data function has been provided to the end user. Hence, the sensor network can perform efficiently without wasting the valuable resources by transmitting all the packets to the base station. It is obvious that clustering in wireless sensor medium provides some advantages like energy efficiency, high scalability and reduced delay in routing.

With those descriptions, the main motive of this paper is to propose a structured clustering model with the randomly distributed sensor nodes. Moreover, converging based clustering methodology has been induced for effectively overcoming the drawbacks present in hierarchical based clustering. The clustering model concentrates on the distance between the nodes, the nodes to the BS and the parameters of residual energy evaluation. The proposed Structured Energy Efficient Clustering (SEEC) model is based on the distance and the energy factors, in which the constraints are easily applicable during convergence. It is obvious that the clusters that are farther from the BS and having lower residual energy will be in smaller sizes.

In general, the functions of clustering are divided into number of rounds and each round involves in Cluster Head (CH) selection. For maintaining a well-distributed network with efficient energy consumption and network longevity, it is very important to select proper cluster head. For that, Bi-fold Cluster Head Selection (BCHS) model is incorporated in this paper that comprises two stages of CH selection. The first stage involves in selecting a temporary CH based on the comparative levels of initial and the remaining energy of sensors. In second stage, the temporary cluster head is replaced by a cluster member that contains high range of energy and forms the final CH list. The parameters of heterogeneity and adaptability have been considered in the whole working process. And, the proposed model actively involves in selecting high energy sensor nodes as CHs, hence attain better energy resource utilization.

The remainder of this paper is organized as follows: Section 2 deliberates the related literature, section 3 describes about the proposed SEEC model with Bi-fold CH selection procedures, and section 4 gives the results and evaluations under simulation. Finally, section 5 concludes the paper with some points to the future enhancements.

2. RELATED WORKS

In last two decades, there are many clustering approaches have been developed in terms of proving that, in WSN, consuming energy is a very important thing. Low Energy Adaptive Clustering Hierarchy (LEACH) has been the first clustering algorithm designed for WSN [12]. There, clustering functions are done with two states: set-up and the steady-state. In set-up state, in each round, some distributed sensor nodes are randomly chosen as cluster heads. In steady state, data transmission is made between the CHs and nodes, the cluster heads are responsible for the sensed data aggregation and that is forwarded to its base station respectively. Power Efficient Gathering in Sensor Information System (PEGASIS) [1] is another algorithm, which is termed as the extended LEACH. In PEGASIS, all sensor nodes are formed as chains and each node forwards the sensor data to the adjacent ones and one node is requested from that chain to aggregate all information and forward to the BS. When compared to LEACH, the algorithm is energy efficient, but results in extensive delay. Hence, it is not efficiently applicable for large scale WSNs.

There are also some other approaches have been developed for balancing the various factors of WSN for energy consumption and network longevity. In [7], the distributed network region is divided into a set of equivalent area and a GPS independent algorithm is utilized for deployed data from the nodes. In that, nodes in a particular closed area are requested to form clusters and the cluster head is elected among them in each round. Hybrid Energy Efficient Distributed (HEED) [3] clustering protocol concentrates on two parameters in cluster head selection. First one is node's closeness to its adjacent sensor nodes and its residual energy. It also ensures for matching cluster head circulation throughout the network. The Inter and intra cluster data transmission and communication have also been taken into account on the protocol design process.

In [9], UHEED algorithm has been proposed by Ever et al. for mainly avoiding the inactive CHs neared to the BS by modifying the radius attained by the HEED algorithm by using the EEUC algorithm referred below.

Probably, the first algorithm based on balancing energy consumption is USC [13]. In that, the senor nodes are formed into unequal clusters. However, the results are stated that the algorithm is not feasible to practice in WSNs. A high degree based clustering approach has been proposed in [5]. The CH is selected on the basis of nodes having maximum neighbours among all cluster members. But, results produced show lower throughput than other models. Energy Efficient Unequal Clustering (EEUC) has been developed and described in [8]. According to the distance between distributed nodes and the base station and the remaining energy among nodes, unequal clusters are formed. As mentioned in the paper, the drawback is the algorithm's efficiency is completely dependent on the node's initial distribution of the node and the cluster heads. Further, the algorithm considered the distance as the major designing factor rather than the node density and this would cause some complexity in whole network coverage.

FLOC is a clustering technique described in [6], minimizes the overriding between clusters using the property called solid disc. A reliable communication between nodes is made within their unit distance determined as its inner band range and the nodes within the outer band range, defined as $m \leq 2$. Furthermore, Energy-Aware Distributed Unequal Clustering (EADUC) [10] protocol deals with both the homogeneous as well as heterogeneous sensor networks. The phases involved in cluster formation have been divided into three phases, namely: 1. collecting the information of neighbour nodes, 2. CH election phase and 3. Cluster creation phase. CHs having more residual energy and farer from the BS always would be larger in cluster size.

Yang and Zhang have developed Energy- Balancing Unequal Clustering Protocol (EB-UCP) in [14], in which the authors have stated that the sensor nodes closer to the BS are having more probability for chosen as the cluster heads. Moreover, in this algorithm, the network is partitioned into layers and the nodes present in each cluster contain their own probability to be elected as CHs. Efficient Hierarchical Distributed Clustering Algorithm (EHDCA) has been proposed in [16], where the clustering done with two phases like setup phase and steady phase as traditional methods of clustering. The CHs are elected on the basis of communication cost, remaining energy of nodes and the distance between the nodes.

In a different way, fuzzy based clustering algorithms have been proposed in [15, 17], where the model used unsupervised learning methodologies for sensing distinctive images when there is a change is detected. Group redundancy has not been handles with WSN. Multi objective fuzzy clustering has been developed in [18], but, the disadvantage is the process uses more energy while using mobile sensors. Moreover, in [19], artificial neural networks are used in WSN for detecting the energy drain attacks. But, the approach is not feasible when the sensor nodes are mobile.

3. PROPOSED WORK

In general, the functions of a clustering algorithm are divided into round. A particular round starts with the set-up state that involves in cluster head selection and cluster formation. Following that, steady state is taken place for handing with data transmissions. In order to attain optimal consumption of energy and WSN lifetime longevity, electing appropriate CHs in each round is important. Hence, heterogeneity of energy among nodes, choosing optimal CH and scalability are considered while designing the SEEC algorithm.

3.1 Network Model and Initial Considerations

While deigning the network model, several assumptions have been made. In the proposed work, the WSN contains 'n' number of sensor nodes and the sensor sets are given as SN_i (i=1, 2, 3... n) which are evenly distributed in the target region of size R×R for sensing the environment in a continuous manner. It is hard to perform the evaluative deployment is sensing perilous or large areas, in which the nodes are fixed at some superlative locations manually. Hence, the node placements are assumed to be randomly deployed and can be utilized for the common network topology for modelling.

Due to the heterogeneous energy levels of sensor nodes, it is to be assumed that, the sensor nodes contains the initial or start-up energy level ranges between {EY_0 and (1+a(max) EY_0)}, where EY_0 is the lower level of energy and a (max) defines the diverse factor that provides the maximum attainable extra energy from battery. Additionally, it is to be considered that each node has the knowledge about the overall network that can be made possible by receiving a message that is broadcasted from the respective base station. The total energy of the overall network is evaluated as follows.

$$Total\ Energy\ (TE) = \sum_{i=1}^{n}(1 + a(i))\, EY_0 = EY_0(n + \sum_{i}^{n} a(i)) = EY_0(n + A) \quad (1)$$

In the proposed approach, clustering is formed in a structured manner and the selected cluster heads are responsible for data aggregation and correlation. Additionally, it is also assumed that the data are subjective to the fixed packet length. Every cluster members forwards M_D bits of data to its corresponding CH in each round and the consumed energy rate is given as, EY_{DA}(nJ/bit/signal). According to the distance between the nodes, the transmitter and receiver, the amount of energy required for transmitting M-bits is determined from the following equation (2).

$$EY_T = \begin{cases} M\ EY_{el} + M\ \varepsilon_f dt^2 & dt \le T(d) \\ M\ EY_{el} + M\ \varepsilon_m dt^4 & dt > T(d) \end{cases} \quad (2)$$

Where EY_{el} , ε_f and ε_m are the basic parameters involved in circuit transmissions and receptions. 'dt' be the distance between the nodes and T(d) is denoted for the threshold distance value referred to the network model. And, the energy consumed for receiving the M-bits is given as,

$$EY_R = M\ EY_{el} \quad (3)$$

Following that, the cluster heads are required to perform data aggregation to form M_D bit packet. Hence, the total energy consumed by the network in single round is derived from the following formula.

$$EY_{round} = M_D(2n\ EY_{el} + \ n\ EY_{DA} + \left(dist(H,B)\right)^4 + (dist(M,H))^2) \quad (4)$$

Where $dist(H,B)$ represents the average distance between the cluster heads and the BS,$dist(M,H)$ point the mean distance between the cluster members and the cluster heads.

3.2 Bi-fold Cluster Head Selection

Different from traditional clustering methods, the set-up phase in clustering is divided into three stages. As given in figure 2, the phases are cluster formation, temporary CH selection and CH replacement.

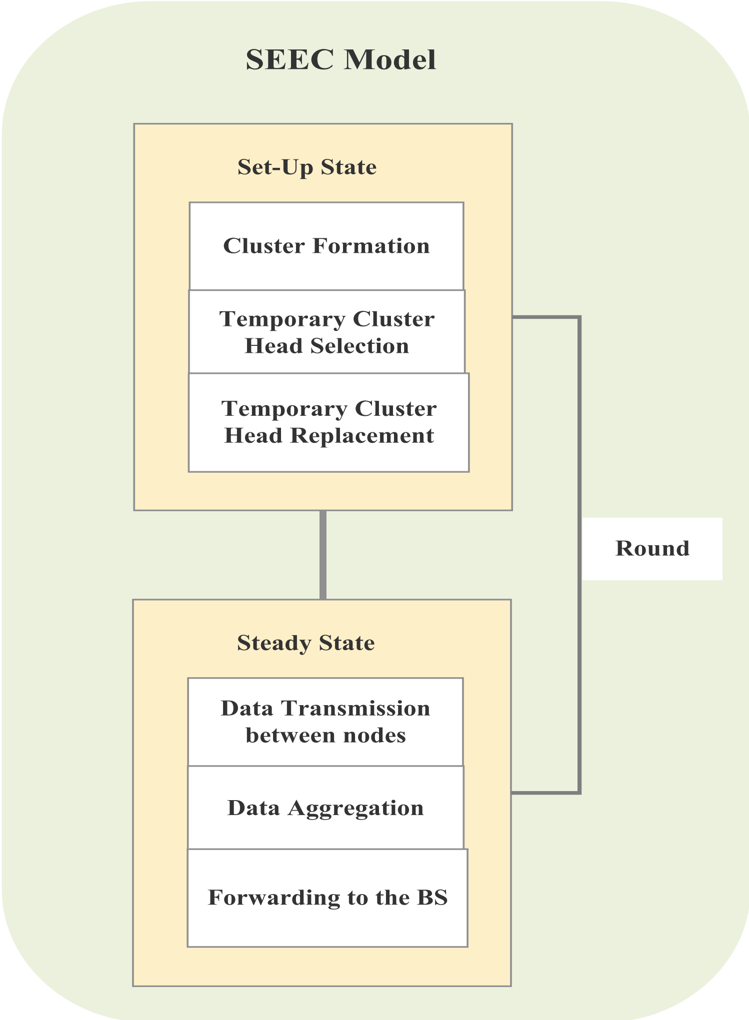

Figure 2: Operations in SEEC

The temporary CHs are selected on the basis of the comparison on the initial and the remaining energy of sensor nodes. Following that, the low energy temporary CHs are replaced with efficient cluster heads. In general, clusters are formed in the cluster formation phase. The rest involves in electing CHs with more energy.

3.2.1 Temporary CH Selection

In the working phase of temporary CH selection, it is important for each sensor node to fix its own selection probability range, termed as $prob_i$ in dynamical manner, based on the primary and residual levels of energy. In SEEC model, the selection probability of the sensor node SN_i is derived as follows.

$$prob_i = prob_{opt} \times \frac{1+a(i)}{\frac{n+A}{n}} \times \frac{RE_i(r)}{AE(r)} \quad (5)$$

Where $prob_{opt}$ points the optimal percentage of CH in a network, $RE_i(r)$ denotes the residual energy of the sensor node 'i' in each node and $AE(r)$ presents the average energy consumed in every round of operations. Moreover, the average energy $AE(r)$ is calculated from the following equation (6).

$$AE(r) = \frac{1}{n}\sum_{i=1}^{n} RE_i(r) \qquad (6)$$

In every rounds of temporary CH selection process, each sensor node evaluates its threshold probability value that would be a random number that lies between 0 and 1 and nominates or selects itself for being as CH; when the random number drops lower than the predefined threshold. Further, the probability threshold for each sensor SN_i correspond with the $Prob_i$ is equated as follows,

$$Td\ (SN_i) = \begin{cases} \frac{prob_i}{1-prob_i(r \bmod \left[\frac{1}{prob_i}\right])} & , if\ SN_i \in CL \\ 0 & , if\ SN_i \notin CL \end{cases} \qquad (7)$$

From the above equation, CL denotes the candidate list, that is, set of nodes that are appropriate for the CH election in a particular round. From the above derivation, it is very obvious that the proposed model is very robust to the changes of energy levels in the network.

3.2.2 Average Residual Energy Calculation

The evaluation of average energy *EY(r)*, which contains the overall information about the whole energy level of the network, is an important function. It is analyzed by evaluating the average energy consumed by the network. Generally, EY*(r)* is the principle energy in each sensor that should retain a better energy distribution throughout the network. In that way, the AE(r) is evaluated as follows,

$$RE(r) = \frac{1}{n} EY_{tot}\left(1 - \frac{r}{r_{opt}}\right) \qquad (8)$$

Where, r_{opt} denotes the optimal round of the whole network and it is defined as the ratio between the EY_{tot} and EY_{round}. And, it is stated in the expression as,

$$r_{opt} = \frac{EY_{tot}}{EY_{round}} \qquad (9)$$

Using the above estimations and the probability threshold rate, each sensor independently fixes its range of election with respect to its local computations and makes itself visible to the network as temporary CH if it is selected. Former, the process is attained by broadcasting a message through MAC protocol that comprises the identity of the sensor, state of residual energy and a header denoting the declaration of being a temporary CH. When it reaches the target time of the temporary election phase, the methodology looks into the next function to check if any temporary CHs having lower energy are to be replaces with the members with higher energy. The following figure 3 provides the flow of Bi-fold CH Selection (BCHS) process.

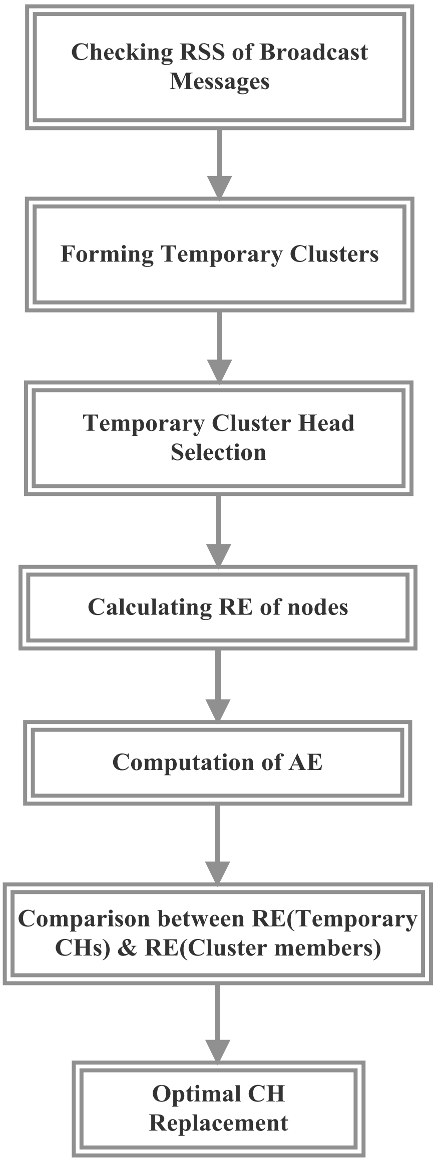

Figure 3: Flow of Bi-fold Cluster Head Selection

3.2.3 Temporary CH Replacement

Because of the network adaptability and distributed framework, there always exist some defects on CH selection. That is efficiently handled by the proposed mechanism by replacing the low energy CHs with a list of CHs having optimal energy range. At this stage, based on the Received Signal Strength (RSS) of the broadcasted message, the non-elected nodes frames a temporary cluster with minimized communicational energy and have some temporary CHs. The cluster members compare its residual energy with the temporary CH and if the members contain more energy, the temporary CH will be replaced by the particular member by broadcasting a message to the whole network.

Particularly, the replacement operation takes place between the process of temporary CH election and the establishment of new clusters. This process tends to enhance the probability of selecting nodes with high energy for being the CHs. Following that, the cluster establishment has been made but sending a request message from all the member nodes to the adjacent clusters to combine. The steady state process has taken place for further efficient network communication. In each round, the operations on Bi-fold CH selection is processed for obtaining effective results on energy efficiency and prolonged network lifetime in WSN.

4 RESULTS AND DISCUSSIONS

In this section, the performance of the proposed SEEC protocol is analyzed using Network Simulator tool (NS2) with the assumption of the initial parameter values as mentioned in Table 1. The initial energy of each distributed sensor node is assumed to be 5 joules in the distributed area as 100m× 100m. For proving the efficiency of the proposed model, the obtained results are compared with the existing mechanisms such as LEACH, HEED and EHDCA. Moreover, the comparison has been done on the basis of factors like packet delivery ratio, energy consumption, throughput, end to end delay, packet drop and residual energy of nodes in each round.

SIMULATION PARAMETERS	VALUES
Network Simulator	NS-2.34
Sensing area	100m x 100m
Simulation Time	800 s
No. of nodes	Varies from 1-100
Mobility Model	Random Waypoint
MAC type	IEEE 802.11
Traffic type	CBR
Mobility speed	5 m/s
EY_{el}	5 nJ per bit
ε_f	10 pJ/bit/m^2
ε_m	0.0013 pJ/bit/m^4
Payload Size	512 bytes
Wireless Transmission Range	250 m
Initial Energy	5Joules per Node

Frequency	9 Mhz
Threshold Energy	0.02 J

Table 1: Parameters for Simulation

The graph presented in figure 4 portrays the Packet Delivery Ratio (PDR) comparison among models such as LEACH, HEED, EHDCA and SEEC. It is considered to be a significant parameter for evaluating the efficiency of the proposed SEEC. In general, the PDR is defined as the ratio between the actual data packets received at the destination to the total data packets sent from the source. The PDR rate is increased by time respectively and from the comparison, it is to be stated that the SEEC model achieves higher PDR than the rest. Following that, the next figure 5 depicts the end-to-end delay comparison. Usually, end-to-end delay evaluated as the mean time acquired by the data packet to be came out from the source to the respective target over the network. Initially, the SEEC model produces 6.2 mSec of delay, which is comparably lower than the compared methodologies. As there is an increase in time, the approach stably balancing the delay and it is obvious that the model achieves minimum delay on data transmission.

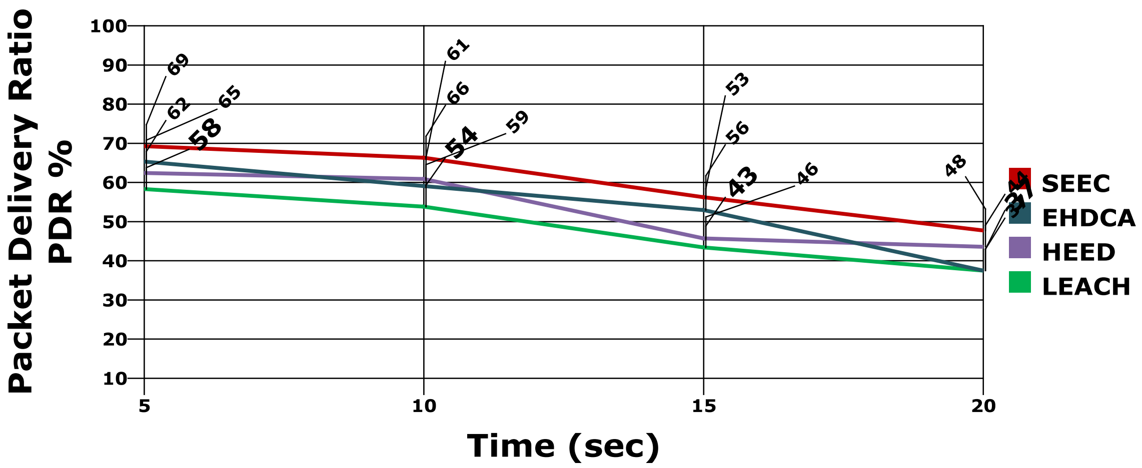

Figure 4: Packet Delivery Ratio Comparison

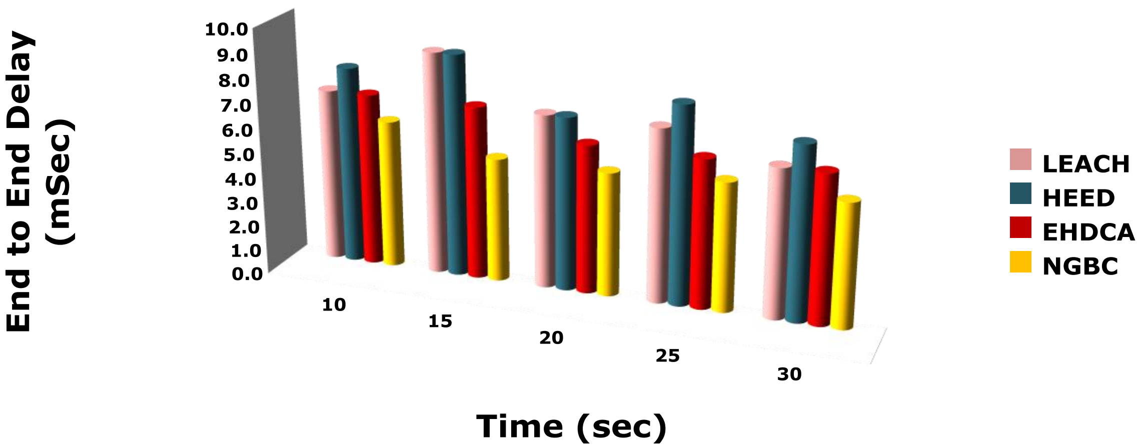

Figure 5: Evaluation of End to End Delay reg. Time

Figure 6 shows the comparison of Packet Drop between LEACH, HEED, EHDCA and SEEC on the basis of time. Packet dropping happens when the packets are roaming over the network but refused to reach the destination. Possibly, it is caused because of network congestion. Moreover, it is defined as the rate of dropped data packets in accordance with the packets sent. Also, the graph shows that the proposed model attains lesser packet drop rate than others. On the other hand, the figure 7 presents the number of data packets received at the base station. The packet reception is completely based on the sending rate and time. In this, it is shown that the proposed model outperforms the rest.

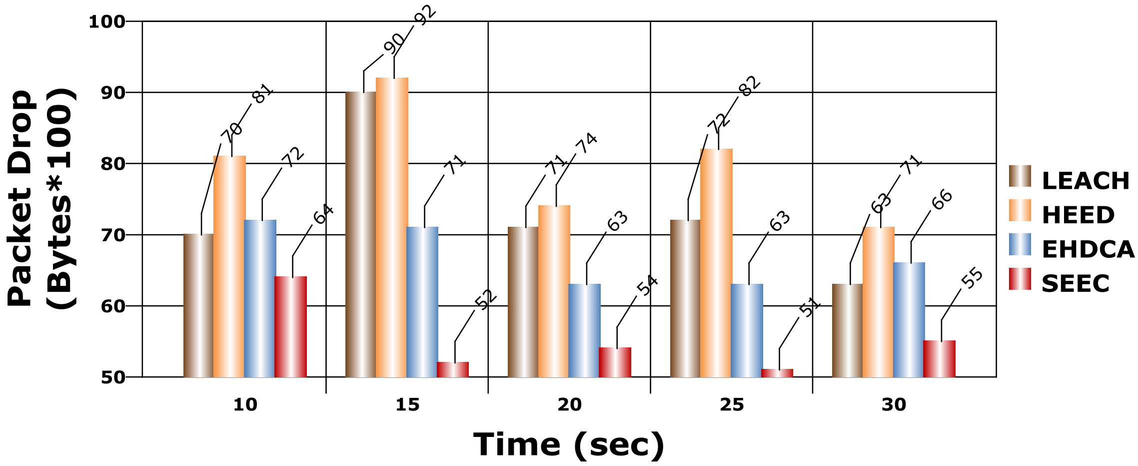

Figure 6: Comparison on Packet Drop among Models

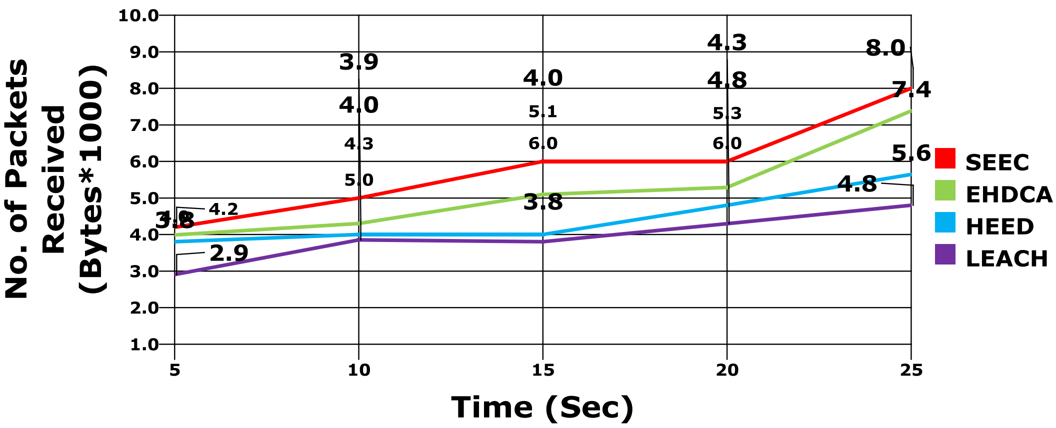

Figure 7: Graph for Number of Packets Received

Throughput is the next important parameter to be considered while designing a clustering protocol in WSN. Typically, throughput is defined as the rate of the total packets received at the destination from the source node at a moment the latest data received is computed as bytes per second. It is proved from the graph that the SEEC model increases the results with higher throughput rate than remaining approaches.

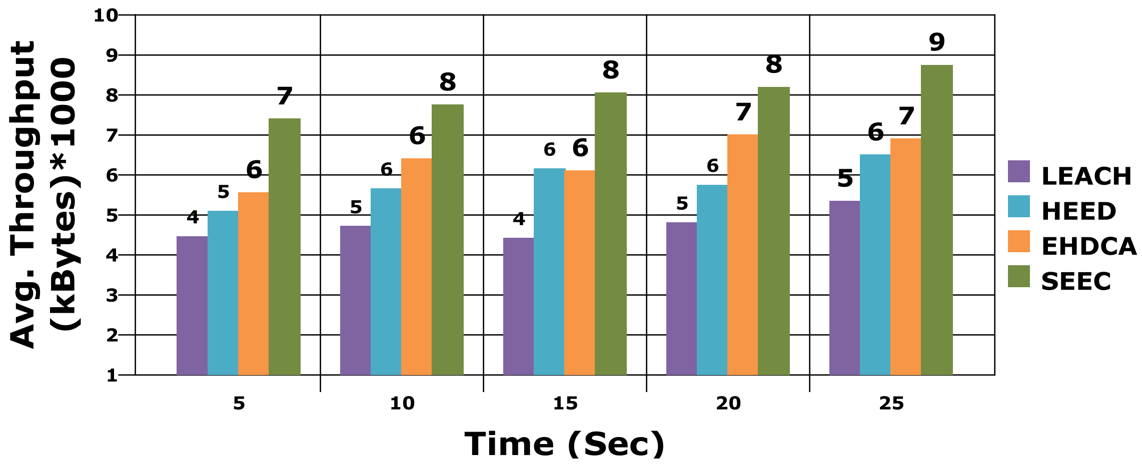

Figure 8: Average Throughput among Models

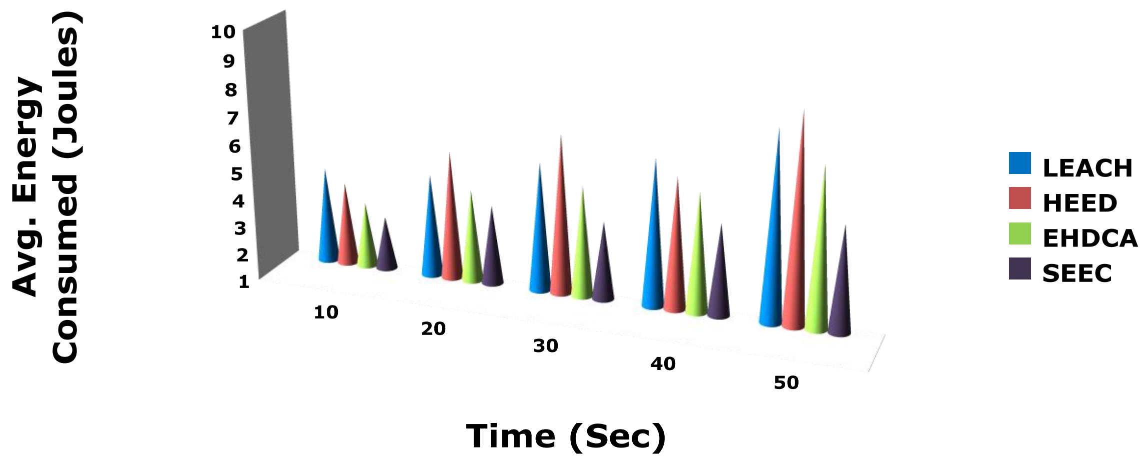

Figure 9: Average Energy Consumption Vs Time

Then, the most important factor of this work, energy consumption is discussed here, based on time and rounds involved in efficient CH selection. Because of BCHS, energy consumption is considerably optimized in the proposed model. The computations are given in the section 3. The energy consumption results are given in the figure 9 and figure 10. After 50 sec of processing, the overall energy consumption by the nodes are relatively low than others. And, from the figure 10, the energy consumption is calculated for 5, 10, 15, 20 and 25 rounds. At last, the consumed energy of the proposed model is minimized when compared with energy consumed by LEACH, HEED, EHDCA and SEEC.

The figure 11 depicts the average residual energy of nodes with respect to the rounds taken place. The RE is computed by the equation (8), given in the section 3.2.2. The SEEC model contains higher residual value than the other compared models, since the energy consumption is low than others. This provides a satisfying evaluation about the proposed model.

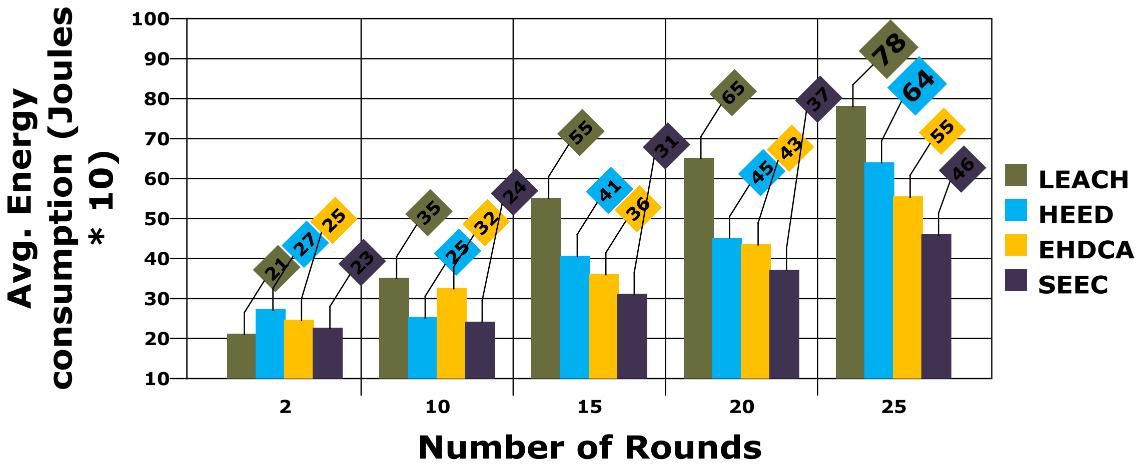

Figure 10: Energy Consumption in each Round

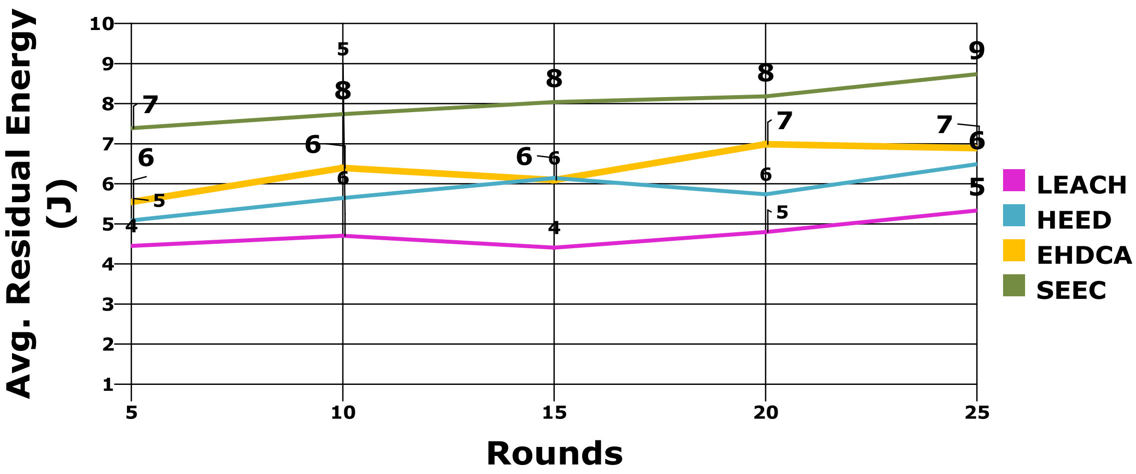

Figure 11: Average Residual Energy Vs Rounds

5. CONCLUSION AND FUTURE WORK

In this paper, a novel clustering approach called Structured Energy Efficient Clustering (SEEC) has been proposed and equations are derived for efficient energy consumption in WSN. For achieving that, Bi-fold Cluster Head Selection (BCHS) model is designed and incorporated in SEEC. In BCHS, an additional phase is introduced for prolonging the network's stability and thereby, increasing the network lifetime. In the proposed model, initially, the distributed sensor nodes select temporary cluster heads using some probability functions based on the initial and the remaining energy of the sensor nodes. Following that, the additional phase called CH replacement phase has been executed for replacing the CHs with the cluster members having higher residual energy than the current cluster heads. This phase balances the load and the energy levels of the overall network. The efficiency of the proposed model is evidenced from the experimental results and comparisons, in which the energy consumption is efficiently optimized and hence, the network lifetime is increased.

The work can be extended by applying in distinctive sensor network domains with various challenges. In another extend, the implementation could be made with neural or fuzzy logics and the results can be analyzed.

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