Stable Heterogeneous Energy Efficient Protocol with Optimum Clustering (SHEEP-OC) in Wireless Sensor Network

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Abstract – Coverage holes and unbalanced energy consumption issues within the cluster and inter- cluster is caused by uneven clustering and uneven energy consumption in Wireless Sensor Networks (WSNs). We propose an optimized clustering and multi-hop cluster communication routing protocol SHEEP-OC, an improvement of SHEEP protocol. The optimized partitioning is done using RF communication based energy consumption model. Improved energy efficiency, coverage hole problem and balanced energy consumption of nodes in a cluster, can be achieved by using inter-cluster routing. It uses cluster head's energy and distance from the base station for selecting the minimum cost routing. The experimental simulation results show that the proposed algorithm effectively reduces the network energy consumption and prolong the life cycle of the network, it also increases the data throughput of the network.

Index Terms – Wireless Sensor Networks, Optimized Clustering, Coverage holes, Multi-hop routing, Energy Efficiency.

1. INTRODUCTION

In recent years, the wireless sensor networks (WSNs) are one of the significant technologies, it integrates the three technologies of computing, communication and sensing and has a wide range of potential applications[1]. Most of the applications of WSN are implemented and used in military, medical, environmental protection, Disaster monitoring and many other applications. Wireless sensor network WSN consists of various micro-sensor nodes, the objective is to real time monitoring and data acquisition over a distributed region. The main advantage being, it do not need to build a fixed infrastructure, it has flexibility of deployment, self-organizational ability and high reliability. Energy is scarce resource in WSNs. In the network, data transmission is controlled by the routing protocol. Therefore, to design a good network system cannot be separated from development of good routing protocol. Wireless sensor networks have the following characteristics:

- Nodes do not have a globally unique identifier, and traditional Internet routing protocols cannot be used in sensor networks.
- All nodes in the sensor network are source nodes and send data to the only destination Sink node.
- Since a large number of nodes are deployed inside or near the measured object, the data they collect is the same or similar. This requires a routing protocol with data fusion capabilities.
- Nodes have limited battery power, processing power and storage capacity.

Different hierarchical routing techniques have been proposed in WSNs, for efficient utilization of node energy. The primary aim is to achieve maximum lifetime of WSN by energy efficient algorithms. In order to form efficient clusters, selecting proper cluster head and reselection in each round better algorithms are used by the researchers. But optimized energy efficient techniques an load balancing techniques need further research.

The sensor nodes are organized in the form of clusters can effectively reduce the energy consumption of the network of many energy-efficient routing protocols. Hence the protocols are designed on the basis of the cluster structure [2,3]. Clustering techniques may also be used to perform data fusion, data fusion to combine a large amount of data sensed by the sensor into a small set of meaningful information [4,5].

Under some conditions it is sufficient to reach a predetermined data rate applications, The more the message transmissions less will be the energy savings. Meanwhile, clustering technology is also very effective for broadcast and data query message, the cluster head node can broadcast messages and help collect data of interest to the user within the cluster [6,7].

The sensor node sensing capability, computing power, communication capabilities, and energy may be different. Heterogeneous sensor networks refers to a variety of different types of network nodes constituting the sensor with different capability; conversely, the network consisting of the same type of sensor nodes is known as homogeneous sensor networks [9]. A heterogeneous network, characterized by heterogeneous energy is ubiquitous, since different types of sensor nodes need to optimally configure for different initial energy in order to prolong the lifetime of the network.

2. RELATED WORK

Many distributed clustering algorithm are proposed currently. The adaptive algorithm for sensor network is either for a homogeneous network or for a heterogeneous network, the clustering algorithm can be divided into two categories, i.e. clustering algorithm can be for the same energy level nodes or for different levels Energy-efficient clustering algorithm for heterogeneous networks is very difficult to design, because of the energy configuration and evolution of network complexity.

Most of the current clustering algorithms are the same type of structure, which comprises LEACH [10], PEGASIS [11], HEED. LEACH Using all nodes periodically alternating in cluster heads so that all nodes in a way to achieve a uniform energy consumption purposes. LEACH Is a distributed protocol, each node is determined by a probability of whether they become cluster head. Nodes are organized in chain in PEGASIS, chain formation is calculated by each node or base station, it is necessary to know global knowledge of the network topology. HEED It is also a fully distributed clustering algorithm, which randomly selects cluster head node election probability is directly related to the residual energy of the node. However, HEED Only for homogeneous network environment. In heterogeneous networks, HEED May cause low energy nodes may have the probability to become cluster head than high energy nodes. But in a heterogeneous network, the above algorithm is difficult to take full advantage of the characteristics of heterogeneous energy, low energy nodes die earlier than the high energy nodes. Unlike the above-described clustering algorithm, the proposed DEEC Algorithm is designed for heterogeneous networks. It draws LEACH The cluster head rotation idea, while allowing the cluster head node election directly related to the residual energy, avoiding problems with clustering homogeneous algorithms encountered. DEEC Also retains the advantage of the distributed algorithm does not need to provide global information center mechanism during network operation.

Therefore, some of the problems faced in LEACH have been overcome in SEP protocol, basically designed of heterogeneous network, heterogeneity in terms of the energy attached to the nodes. SEP assumes two types of nodes with different energy, called advanced and normal nodes, advanced nodes have more energy than normal nodes. SEP protocol resolves the issue of unbalanced energy dissipation in the clusters by introducing well balanced energy consumption constraint in the stable period. SEP is designed for two-layer heterogeneous networks, but SEP is not suitable for multi-layer heterogeneous networks.

SHEEP protocol [12] is another enhancement of SEP protocol, which introduces multi-level heterogeneity in this protocol stability period is increased by efficient use of energy heterogeneity of sensor nodes, it elects the higher energy nodes as a CHs and reducing the setup time.

Cluster Formation In SHEEP protocol:

In the SHEEP algorithm for the energy level determination of sensor nodes, it is assumed that the sensor nodes know their maximum energy E_{max}, residual energy E_r, and threshold energy E_{th}. While forming the clusters the nodes with the highest energy level are given an opportunity to become the CHs, to ensure stability and longer lifetime of the network.

The basic functioning of the protocol SHEEP starts from network formation, each round consists of setup phase an steady state phase, in the setup phase nodes are grouped according to different energy levels, then the cluster head selection process starts as shown in the fig. 1, nodes starts associating with their respective CHs, by considering their distance and the transmission power. In the steady state phase sensor nodes send the sensed data to their respective cluster head, data collected by the Cluster Head will be aggregated and transferred the to the Sink node (Base Station).

3. PROPOSED WORK

The common problems exist in the above algorithms are the presence of "coverage holes" and "energy holes" effecting the reliability and energy efficiency of the network. To overcome the above problems, an improved algorithm is developed based on radio communication network size, energy consumption model and clustering, by optimizing the position and the energy of the nodes.

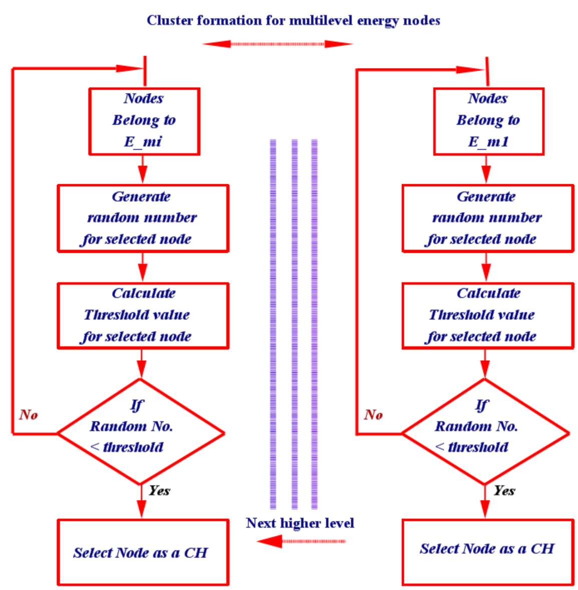


Fig: 1 Flowchart for cluster head selection for SHEEP protocol

Cluster heads (CHs) are selected based on energy and space distribution. In order to minimize communication cost of routing, multi-hop communication is done, between the cluster head to cluster head and the base station BS.

A new distributed energy-efficient clustering scheme for heterogeneous Wireless Sensor Networks is proposed and evaluated. This cluster based routing protocol (SHEEP-OC Stable heterogeneous energy efficient protocol with optimal number of clusters) is an extension to the SHEEP protocol. By obtaining optimal number of clusters and determining optimal number of hops for inter-cluster routing, energy efficiency has been improved as well as coverage hole problem has been resolved.

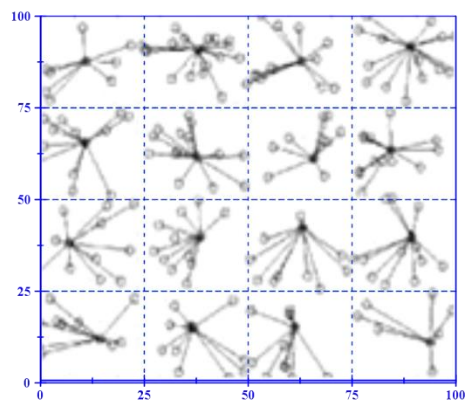


Fig.2 Clustering structure in SHEEP-OC protocol

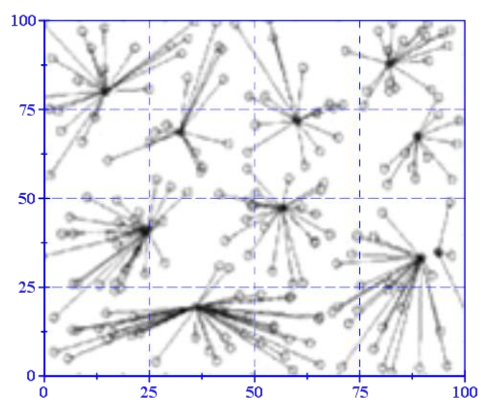


Fig.3 Clustering structure in SHEEP protocol

3.1. Clustering and network optimization mechanism

In the process of clustering of WSN, it has to be ensured the total coverage and the intra-cluster connectivity among the clusters. If the cluster coverage is inadequate or too large, the problem of "coverage hole" or "cover overlapping" will occur. Similarly if inter-cluster connectivity is insufficient or too large, will lead to energy hole or energy wastage problem. Thus by clustering reasonable and balanced energy routing in the network is one of the way to solve the problem.

RF energy consumption given by:

$$E_{Tx} = \begin{cases} K \times E_{elec} + K \times \mathcal{E}_{fs} \times d^2 & d < d_0 \\ K \times E_{elec} + K \times \mathcal{E}_{mp} \times d^4 & d \geq d_0 \end{cases} \quad \text{-(1)}$$

$$E_{Rx} = K \times E_{elec} \quad \text{-----(2)}$$

In the formula, E_{Tx} is the energy consumed in transmission, E_{Rx} energy consumed in receiving the data bits, $'K'$ is the number of bits transmitted in a data packet, E_{elec} is the energy consumed in sending or receiving 1 bit of data, $\mathcal{E}_{fs}$ is the amplifier parameter, $\mathcal{E}_{mp}$ is a remote transmitter amplifier parameter, 'd' is a radio frequency signal transmission distance between the transmitter and the receiver, 'd_0' is the critical distance between the sending and receiving end of the transmitted RF signal. By formula (1) analysis is not difficult to see that the communication includes a RF transceiver energy consumption and energy consumed in data communication.

Cluster coverage depends on the location of the nodes and a Radio radius 'R_c' . according to SHEEP-OC partitioning rule algorithm, during the clustering the network is divided into several sub-regions. Assuming a side length of the sub-region 'R', as shown in the Fig 4.

In the best case of clustering the cluster head is centrally located sub-region, the $R_c = \sqrt{2}\,R/2$, and the sub-region will completely cover the space as shown in Fig. $5(a)$. In the worst case of the cluster head node is located vertex sub-regions when the communication distance $R_c = \sqrt{2}\,R$. In order to fully cover the sub-region of

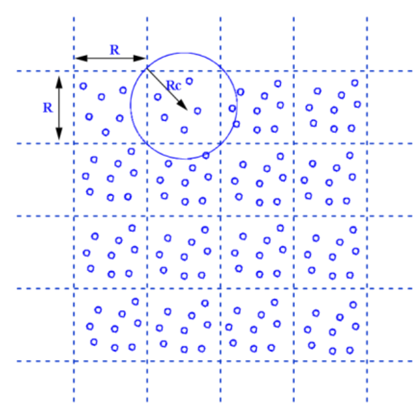
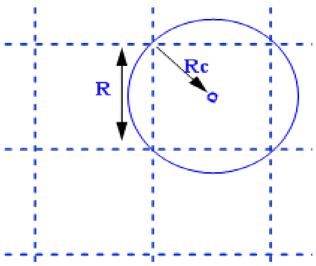


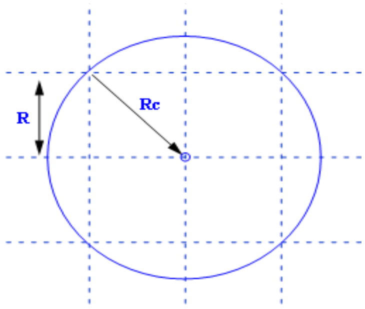
Fig. 4 Network optimization partition

space as Fig. $5(b)$. i.e., in this case the following rules should be followed for $'R_c'$ selection. it can be draw coverage radius of cluster head node 'R_c' satisfy the following condition (*Rule i)*:

$$\sqrt{2}\frac{R}{2} \leq R_c \leq \sqrt{2}\,R \quad < d_0 \;--\; (3)$$



$(a)\ R_c = \frac{\sqrt{2}}{2}\ R$



$(b)\ R_c = \sqrt{2}\ R$

Fig.5 Coverage radius of the schematic node in the cluster

It depends on the inter-cluster connectivity, distribution of clusters, location of cluster head and the communication distance 'R_t'. from the hypothesis $CH_2, CH_3, ..., CH_i$ ($i = 2, 3, \ldots, D_N$). The cluster head CH_1 with the neighborhood cluster head CH_i, as shown in the Fig. 7 wherein, 'D_N' the number of sub-clusters. The critical distance between the cluster heads can be given by

$$R_{tr}^{\ 2} = (2 \times R)^2 + (2 \times R)^2 = 8 \times R^2 \quad \text{-- (4)}$$

In order to ensure a stable connection between the cluster head with its neighbor cluster head, while avoiding the wastage of energy, 'R_{tr}' set the rule to be followed.

Rule ii: Ensure that the cluster head 'CH_i' versus 'CH_j' (i ≠ j) is connected between the neighboring clusters which cover the minimum communication area.

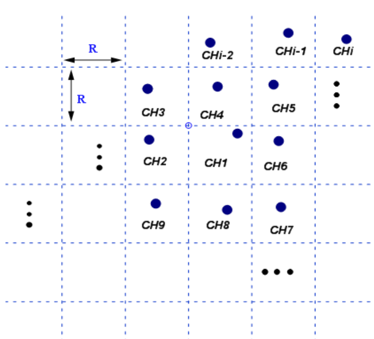


Fig. 6 Cluster distribution of network.

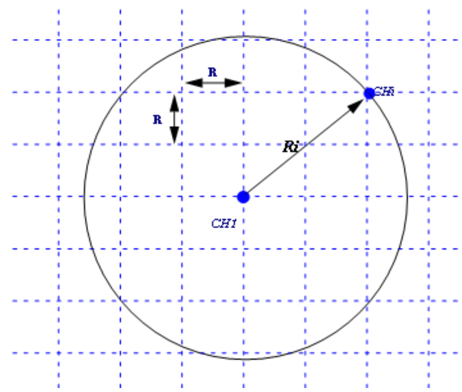


Fig. 7 CH_1 the first cluster with its neighbor cluster head CH_i calculation of critical distance

Thus the radial connection between the cluster head R_{tr} can be obtained as

$$R_{tr} \leq 2\sqrt{2} \times R \quad \text{------------------ (5)}$$

3.2. Cluster optimization calculations

For the number of clusters optimization calculation, assuming a ($M \times M$) random network uniformly distributed in the region with 'N' Nodes, wherein the base station is located at the top region. To put it into 'D_N' clusters, number of nodes in each cluster is given as {(N / D_N) − 1}. For the member nodes, in each round of energy performance data sensing and sending the data to the cluster head are two parts.

Due to the communication distance in the cluster is short, by using free-space channel model, the energy consumption of each member node is 'E_{non-CH}' given by

$$E_{non-CH} = K . E_{elec} + K . \mathcal{E}_{fs} . d_{to\ CH}^{\ \ 2} \quad \text{--- (6)}$$

In the formula, '$d_{to\ CH}$' is the distance between the node to its cluster head. If the cluster nodes are randomly distributed, then the node distribution density $\rho = 1 / (M^2/D_N)$

According to the (*rule i*), if the cluster head is located in the sub-regional center, from the definition distance of the member node from the cluster head is:

$$d_{to\ CH}^{\ \ 2} = \rho . \iint (x^2 + y^2)\, dx\, dy$$

$$= \rho . \int_{\theta=0}^{2\pi} \int_{r=0}^{R_c} r^3 dr\ d\theta = \frac{M^2}{2\pi D_N} \quad \text{------ (7)}$$

In the formula above the first cluster is centered radius $R_c = M \Big/ \sqrt{\pi D_N}$ covers round area, (x , y) is the position of member nodes within a cluster. In each round the cluster heads receives the data from the member nodes, performs data fusion, and transmits the data to a base station or neighboring cluster heads. If the distance from the cluster head to first base station or between neighboring clusters is less than d_0, Then using free-space model, or the use of multipath fading model, wherein the ratio of free space model is employed $m = \pi d^2/M^2$, and multipath fading ratio model is $(1-m)$ therefore energy consumption of the cluster head is given by:

$$E_{CH} = K.E_{elec}.\left(\frac{N}{D_N}-1\right)K.E_{DA}\left(\frac{N}{D_N}-1\right)+K.E_{elec}+K.\mathcal{E}_{mp}.(1-m).d_M^4+K.\mathcal{E}_{fs}.m.d_F^2$$

------------------ (8)

In the formula, 'E_{DA}' is the data fusion energy, 'd_F' , 'd_M' is the distance between the cluster head of first field to base station or neighboring cluster in free space model & multipath fading model. According to the *rules ii*, d_F^2 with d_M^4 the formulae are as follows:

$$d_F^4 = \frac{1}{\pi.d_0^2}\iint_c (x^2+y^2)\,dx\,dy = \frac{d_0^2}{2} \quad \text{----- (9)}$$

$$d_M^4 = \frac{1}{M^2-\pi.d_0^2}\iint_{s-c}(x^2+y^2)^2\,dx\,dy$$

$$= \frac{1}{M^2-\pi.d_0^2}\left(\frac{7M^6}{180}-\frac{\pi.d_0^6}{3}\right) \quad \text{-------- (10)}$$

In the formula, C is the center of the base station or neighborhood cluster head circle, d_0 domain circle radius, S is the entire area covered by the network, (x , y) is a cluster head position in the network. In each round energy consumption of in a cluster '$E_{cluster}$' is given by

$$E_{cluster} = E_{CH} + \left(\frac{N}{D_{N-1}}\right).E_{non-CH} \quad \text{------ (11)}$$

So, the total energy consumption of the network E_{Total} is:

$$E_{Total} = D_N.\ E_{cluster} \quad \text{------------------ (12)}$$

substituting equation (7), (9), (10) and (11) into (12), and taking partial derivative of E_{Total} with variables D_N. and equate to zero we obtain the optimal value.

The optimum number of clusters is given by

$$D_{Nopt} = \left[\frac{3m.d_0^2}{M^2.N}-\frac{6(E_{elec}+E_{DA})}{\mathcal{E}_{fs}.M^2.N}+\frac{\mathcal{E}_{mp}.(1-m).(7M^6-60\pi.d_0^2)}{30\mathcal{E}_{fs}M^2.N.(M^2-\pi.d_0^2)}\right]^{-1/2}$$

------- (13)

by observation of the equation (13), analysis is not difficult to see that the best number of clusters points D_{Nopt} mainly related to network size M, the number of nodes N. Hence the D_{Nopt} is uniquely determined by network area and number of nodes.

In order to allow the partition-shaped structure, to cover the whole network area by partitioning an aliquot of rows and columns, the partition of the square sub-region, so the final number of clusters be D_{Nopt}, value of the number of squares in the region.

3.3. SHEEP- OC algorithm sequence

In SHEEP-OC algorithm three steps has to be built:

- The network initialization,
- cluster head election and
- inter-cluster routing.

Step 1: Initialization of the network, by partitioning of the complete network area to form the clusters, and each cluster is given a unique identification ID. Each node of the cluster will be given their association to their cluster:

Based on RF energy consumption model of a communication protocol, calculate the minimum number of optimal energy clusters "D_{Nopt}" will be done.

According to the determined D_{Nopt}, optimization of the entire Sensor network area by clusters will be done, each child nodes will be associated with corresponding formed cluster region. For each cluster i (i = 1 , 2 , ..., D_{Nopt}) will be given a unique identification number ID_0 .

The Center position (x_{ic}, y_{ic}) and radius of coverage R_c. will be calculated for each cluster i.

The average energy of node E_{ai}, and average distance D_{ai} from the cluster center (x_{ic}, y_{ic}) will be calculated.

To construct an array of structures, partition information comprising ID , center (x_{ic}, y_{ic}) with radius R_c, for each cluster structure area is obtained, this information is broadcast over the area.

Step 2: is to elect cluster head:

Cluster head election done for each cluster by same procedure followed in SHEEP protocol.

Step 3: Construction of inter-cluster routing

Within a cluster, Cluster Head CH is responsible for the data fusion and transmission of the information to Base Station by data forwarding through inter-cluster routing.

To perform multi-hop routing, cluster head node identifies CH_i (i = 1 , 2 , ..., D_{Nopt}) their corresponding position (x_{ic}, y_{ic}) and compute the distance to cluster head node CH_i (i = 1 , 2 , ..., D_{Nopt}) to a base station through its neighboring cluster head CH_n (n = 1 , 2 , ..., M) , M being number of neighboring cluster heads.

Using the formula (4) calculate distance for CH_i to its neighboring cluster head CH_n and construction of the route between the cluster head to base station using cost function $cost(i,n)$

$$cost(i,n) = \begin{cases} \frac{d^2_{CH_i toCH_n} + d^2_{CH_n toBS}}{E_{CH_N}} & i \neq n \\ \frac{d^2_{CH_n toBS}}{E_{CH_N}} & i = n \,\&\, d^2_{CH_i toBS} \leq d_0 \\ \infty & i = n \,\&\, d^2_{CH_i toBS} > d_0 \end{cases}$$

----------(14)

Among them, $d_{CH_i toBS}$ with $d_{CH_i toCH_n}$ represent the distance from cluster head CH_i to the base station BS, through CH_iCluster heads to the neighborhood CH_n. $d_{CH_i toBS}$ represents the distance between the neighborhood cluster head CH_i to the base station BS. E_{CH_n} represents the remaining energy of neighborhood cluster head CH_n. When $i = n$ means that cluster head select itself as a relay node.

In case CH_i neighbor-hood cluster head CH_p satisfies the formula (15) conditions, then select CH_p as a CH_i relay routing node.

$cost(i,p)$ = min { $cost(i,n)$} $n = 1, 2, \ldots, M$ -------------(15)

During the data transfer phase, the main cluster head uses TDMA mechanism, collects the data from the nodes in the cluster using CSMA (inter-cluster routing mechanism to complete and forward the data to a base station). Then enters into the next round.

3.4. Results and analysis:

In order to verify the effectiveness of the algorithm SHEEP-OC, simulation results of proposed algorithm is compared with LEACH, SEP & SHEEP algorithm.

It assumed that the network has the following attributes:

1) Base station BS is deployed at the top of the network, and it has enough energy;
2) All sensor nodes are randomly distributed in a uniform edge length in (100 X 100) Square area, sensor nodes are stationary;
3) Except BS, all the sensor normal nodes having a unique identifier, and has the same computing and communications capabilities and the initial energy, but the energy is limited. The remaining advanced nodes are having additional energy;
4) All sensor nodes have the ability to power control, may change their transmission power.
5) Simulations are conducted by using Matlab simulation parameters as shown in Table 1.

According to formula (13), D_N is calculated, the optimal value D_{Nopt} is 19.92 , Its nearest square number is 16 . In order to test D_{Nopt}

Table 1: Simulation Parameters

Description	Value
N, Number of sensor nodes	100
Area (meter square)	100 x 100
E_0 , Initial energy	0.5 J
E_{elec} , Electronics energy	50 nJ/bit
E_{DA} , Energy of data aggregation	5 nJ/bit
K, Data packet size	512 bytes
k_{broad} , Broadcast packet size	25 bytes

In the Fig.2 shows clustering structure of the proposed algorithm SHEEP-OC and the Fig.3 shows the structure of SHEEP algorithm. We can notice that with respect to SHEEP algorithm, SHEEP-OC cluster structure is more uniformly distributed, nodes in each cluster density difference is very small, this is because SHEEP-OC algorithm is divided into clusters based on network size and structure of the distribution nodes.

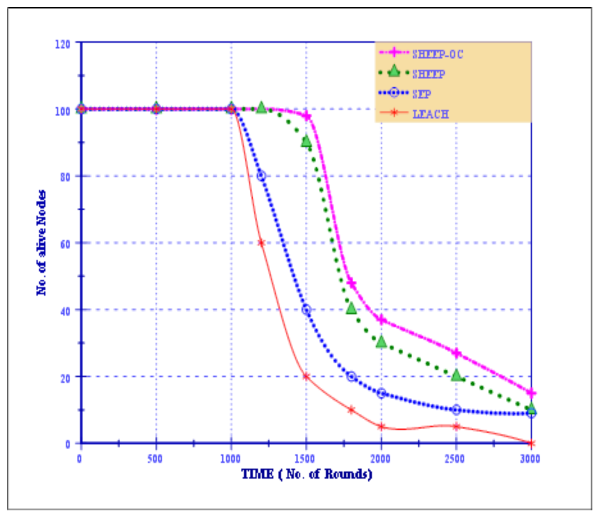


Fig.8 Life time analysis for proposed cluster protocol SHEEP-OC with LEACH, SEP and SHEEP.

Fig. 8 shows the number of alive nodes with respect to simulation time, it can be noticed that proposed protocol SHEEP-OC is better compared to LEACH, SEP & SHEEP. This is because SHEEP-OC algorithm combines energy consumption of global and local nodes in the cluster distribution and load balancing between intra-node cluster, and between the cluster to the cluster, it overcomes network "coverage holes" and "energy hole" problems.

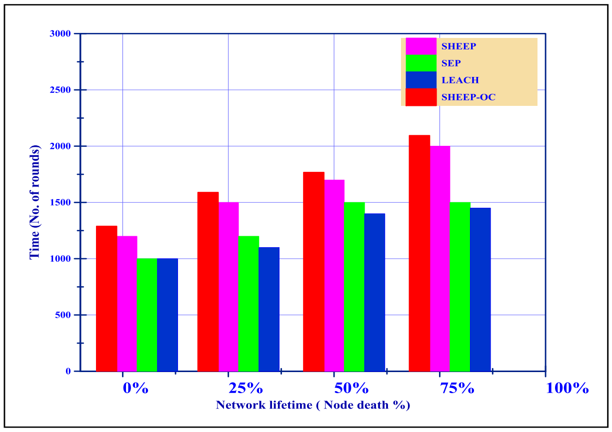


Fig.9 Comparison of Node death percentage per number of Rounds of proposed SHEEP-OC with LEACH, SEP & SHEEP protocols.

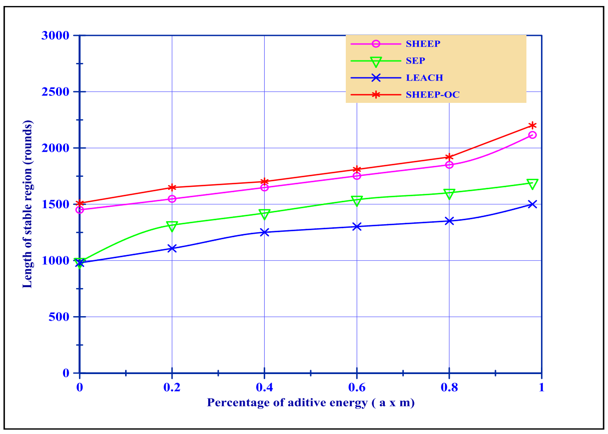


Fig.10 Effect of heterogeneity on stable region comparison LEACH, SEP & SHEEP with SHEEP-OC.

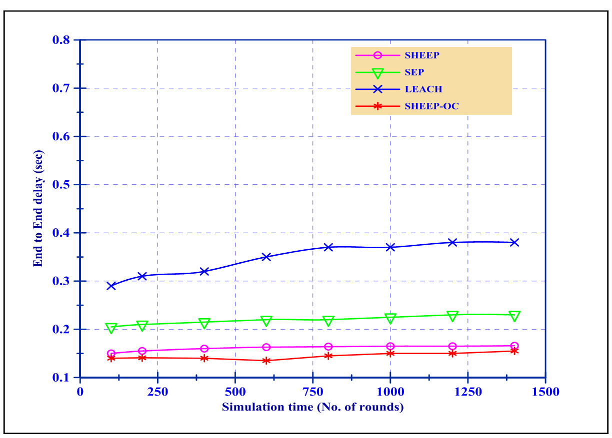


Fig.11 End to End delay comparison for the proposed with LEACH,SEP & SHEEP.

In the Fig.9 length of stable region for different values of energy heterogeneity is simulated, we observed that stable period is extended of approximately 48% more than LEACH protocol. In heterogeneous WSNs, SHEEP-OC has longer stable region than LEACH, SEP & SHEEP for different values of energy heterogeneity.

Fig. 11 & 12 shows the end-to-end delay & throughput between the SHEEP-OC with LEACH, SEP & SHEEP Protocols. It shows that the proposed protocol takes lesser time to aggregate and forward the data to BS than the exiting with LEACH, SEP & SHEEP Protocols.

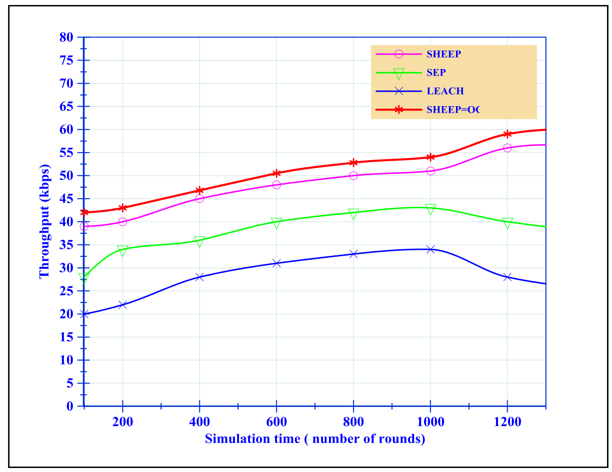


Fig. 12 Throughput analysis by varying simulation time for proposed SHEEP-OC with the existing LEACH, SEP & SHEEP Protocols.

Fig.13 shows the packet delivery ratio of the proposed SHEEP-OC with the existing LEACH, SEP & SHEEP Protocols. The proposed system results in a greater packet delivery ratio than the existing protocols.

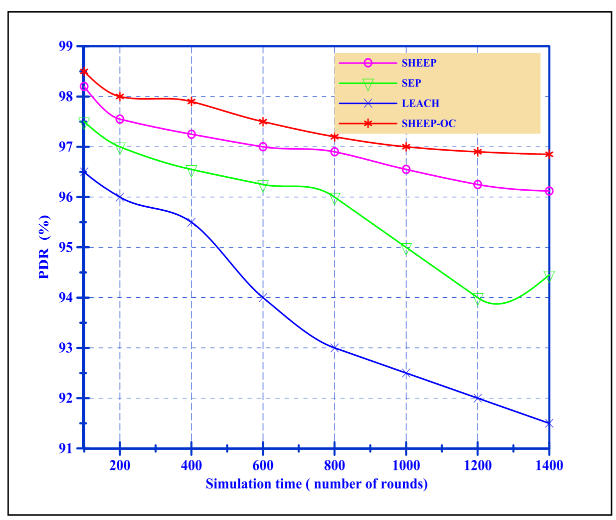


Fig. 13 Packet delivery ratio of SHEEP-OC with the existing LEACH, SEP and SHEEP Protocols.

4. CONCLUSION

In Wireless Sensor Networks, cluster based routing algorithm has a wide range of applications, however efficient use of energy, and prolonging the life cycle of the network has been one of the challenging task . SHEEP-OC algorithm has been proposed base on the optimized clustering and multi-hop routing. Coverage hole, energy hole issues have been resolved and load balancing in the network has been achieved with improved throughput and end-to-end delay.

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