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Energy Efficient Clustering Protocol for Minimizing Cluster Size and Inter Cluster Communication in Heterogeneous Wireless Sensor Network

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Abstract: There are many applications like battle field monitoring, habitat monitoring, disaster relief operations, hostile areas, object tracking, remote harsh fields, and contaminated urban regions etc. which need random deployment of sensor nodes. In random deployment the sensor nodes may be grouped or sparse in the sensing field. Some of the existing clustering protocols used probabilistic threshold and random number for cluster head selection process. In these protocols cluster heads can be overlapped or grouped in small region. Due to randomness property in cluster head selection, any sensor node can become cluster head and also form uneven sized cluster. In large size cluster, member nodes need more energy for data transmission. More number of clusters in sensing field reduces the cluster size as well as energy consumption of cluster members. It can increase data transmission from cluster head to base station (Inter cluster communication) that consumes lot of energy in the larger area network. The proper coordination among grouped cluster head can increase the stability period and network lifespan. In this paper a new Energy Efficient Cluster Protocol (EECP) has been proposed for cluster head selection and coordination among grouped or nearby cluster heads.

Keywords: Cluster head selection, cluster size, inter cluster communication, stability period.

I. INTRODUCTION

Sensor networks are needed to restructure dynamically their network and data paths in response to changing network conditions. This is particularly important for energy efficiency because nodes have limited energy source. Nodes are generally unattended in many applications, therefore energy supply is irreplaceable. Because of this reason, nodes organization technique should aim to increase nodes lifetime. If a battery of a node is depleted, it shall affect its neighbour's node who rely on it for connection to the rest of the network. Nodes organization techniques (clustering) should consider overall network energy consumption and node should not die early. Ideally all nodes should die at the same time. However, in reality, this is impossible due to the different node position and uneven traffic in the network. We need energy efficient clustering so all the nodes have same lifetime [1].

LEACH protocol was the first homogeneous clustering protocol proposed by Wendi Rabiner Heinzelman et. al. LEACH significantly reduces the energy consumption for data transmission than direct communication [2]. LEACH protocol does not energy aware and number of clusters in each round is not equal. After that many researchers hang around to the LEACH protocol.

The first heterogeneous clustering protocol developed by Georgios Smaragdakis et. al called SEP protocol. They introduced the energy heterogeneity in clustering protocol and significantly improved the network lifetime than homogeneous clustering protocols [3]. SEP protocol is similar to the LEACH protocol except energy heterogeneity and energy awareness in cluster head selection process.

Dilip Kumar et. al extended the SEP protocol to the three level of energy heterogeneity in EEHC [10]. In last few years many clustering protocols have been proposed by many authors for energy minimization, but there are two protocols: two levels LEACH and three layered LEACH for inter cluster communication.

In two levels LEACH, clustering procedure accomplish in two phases [7]. First phase describe the selection of cluster head for first level and second phase to reselect the some of the cluster head as a second level cluster heads. All the sensor nodes in the field send sensed data to its respective first level clusters.

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Second level cluster heads receive the aggregated data from first level cluster heads and send to base station. It require more time for clustering and cannot be assure for energy minimization because of random cluster head selection at both level.

In three layered LEACH, cluster-heads elected at set-up phase [8]. TL-LEACH does not communicate directly with base station. Authors reselect another *N'* p (N'* stands for the number of the level 1 cluster-heads and *N'=N*p,* while *p* is the percentage of level 2 cluster-heads) nodes as the cluster-heads to send data to the base station. Information from other cluster heads will be fused in these N'*p nodes and then be transmitted to the base station. When the level1 cluster-heads selection finished, level 2 cluster-heads which communicate with base station will be selected among these level l cluster-heads based on the left power of them. The TL-LEACH is not suitable for large area sensor network. It also requires more energy at the level 2 communications and fails when base station is positioned within the sensing field. We require an efficient approach which reduces energy consumption for performing network operations.

The rest of the contents are as follows. In section II we described existing problem for inter cluster communication. In section III we explained the proposed clustering technique, In section IV the results of proposed approach are given and section V contains the conclusion.

II. PROBLEM STATEMENT

In wireless sensor network due to randomness property [14], clustering protocols form clusters that can be small or large in their size. Large sized cluster consumes more energy than small sized cluster because it has long intra cluster distance (total distance from cluster members to cluster head). The above stated problem can be optimized by increasing cluster count. On increasing the number of clusters in sensing field inter cluster communication also increases. Inter cluster communication is the biggest challenge in wireless sensor network for energy conservation because huge amount of energy is consumed in each round. In inter cluster communication energy consumption can be reduced by reducing its distance, which is the distance from cluster head to base station. Total inter cluster distance (T_{icd}) is the sum of the distances of all cluster heads to base station, defined as:

$$T_{icd} = \sum_{i=1}^{N_{CH}} d(i, BS) \qquad 1$$

Here N_{CH} is the total number of cluster heads in the field and $d(i, BS)$ is the distance of a cluster head to base station. Energy consumption for inter cluster communication depends on the inter cluster distance. Total energy consumption for inter cluster communication E_{T-ICC} is defined as:

$$E_{T-ICC} = \sum_{i=1}^{N} E_{ICC}(i, BS) \qquad 2$$

Where $E_{ICC}(i, BS)$ is the energy required for inter cluster communication between cluster head i and base station BS.

Let there be an area A where n sensor nodes are randomly distributed. The distance of any node from the base station or its cluster head may be $> d_{reference}$ or $< d_{reference}$, where $d_{reference}$ is the reference distance to decide which model has to be followed free space model ($< d_{reference}$) or multipath model ($> d_{reference}$) [2]. Thus, the energy dissipation in the cluster head (E_{CH}) during a round is given by the following formula:

$$E_{CH} = lE_{RX}C_m + lE_{DA}(C_m + 1) + lE_{TX} + l \in_{mp} d^4_{CHtoBS} \qquad 3$$

Where C_m is the number of members in a cluster, $lE_{RX}C_m$ is the power required by cluster head to receive l length of data from cluster members (C_m). $lE_{DA}(C_m + 1)$ is the power consumed by cluster head to aggregate l length of data sensed by cluster head and received through cluster members (C_m), lE_{TX} is the power consumed to transmit l length of data, ϵ_{mp} is the energy dissipated by transmitter amplifier in multipath model, d_{CHtoBS} is the distance between the cluster head (CH) and base station (BS). From eq. 3, the amount of energy consumed by cluster head CH_i and CH_j for l bit data transfer is:

$$E_{CH_i} = lE_{RX}C_m(i) + lE_{DA}\{C_m(i) + 1\} + lE_{TX} + l\epsilon_{mp}d^4_{CH_i\,to\,BS} \qquad 4$$

$$E_{CH_j} = lE_{RX}C_m(j) + lE_{DA}\{C_m(j) + 1\} + lE_{TX} + l\epsilon_{mp}d^4_{CH_j\,to\,BS} \qquad 5$$

Where $C_m(i)$ and $C_m(j)$ is the number of cluster members in cluster heads CH_i and CH_j respectively, d_{CH_itoBS} and d_{CH_jtoBS} is the distance between the cluster heads CH_i and CH_j to base station. The total energy consumed by the two cluster heads is:

$$E_{CH_i} + E_{CH_j} = lE_{RX}\{C_m(i) + C_m(j)\} + lE_{DA}\{C_m(i) + C_m(j) + 2\} + 2lE_{TX} + l\epsilon_{mp}\left(d^4_{CH_i\,to\,BS} + d^4_{CH_j\,to\,BS}\right) \qquad 6$$

If cluster heads CH_i and CH_j are very near in the sensing field then

$$d_{CH_i\,toBS} \cong d_{CH_j\,toBS} \qquad 7$$

Putting the value of eq. 7 into eq. 6

$$E_{CHi} + E_{CH_j} = lE_{RX}\{C_m(i) + C_m(j)\} + lE_{DA}\{C_m(i) + C_m(j) + 2\} + 2lE_{TX} + 2l\,\epsilon_{mp}\left(d^4_{CH_j\,to\,Bs}\right) \qquad 8$$

In this eq. 8 the total energy consumption is two times more than the energy consumed by one cluster head. The inter cluster distance affects the total energy consumption drastically. Some authors proposed various approaches to minimize the inter cluster distance problem using a second level clustering. In the second level clustering [5] the cluster head selection process is also random, which is not suitable for energy conservation.

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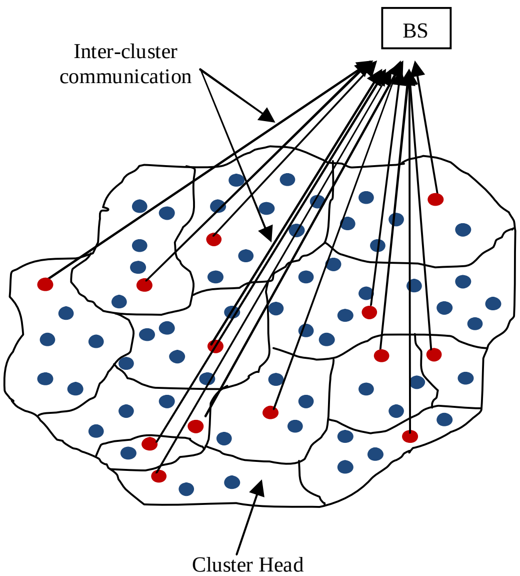
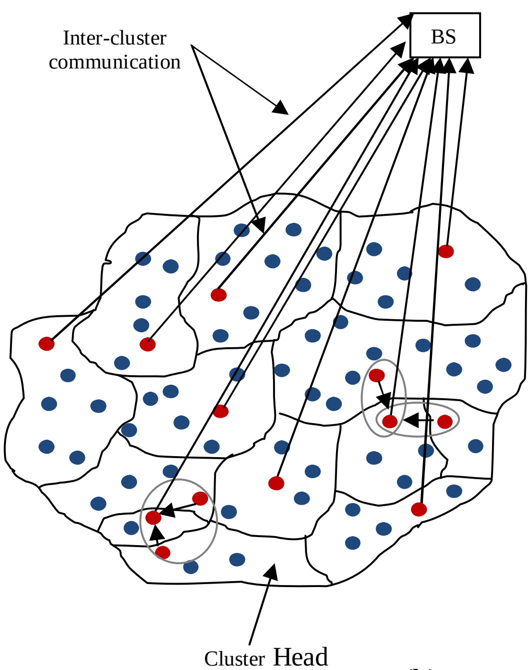
Their approaches failed for large areas and also were not suitable for many applications where base station is positioned at the centre of sensing field [5, 7, 8, 9, 11, and 12].



(a)



(b)

Fig. 1. Inter cluster communication.

The random selection of cluster heads leads to grouping of cluster heads in small region as has been shown in fig. 1 (a). Each cluster head sends aggregated data to base station which is not energy efficient because E_{T-ICC} is larger than fixed clustered wireless sensor network E_{T-ICC}. The observation made in above figures show that many protocols like LEACH, SEP, EEHC [2,3,10] have used random selection of cluster heads and suffered the above problem, therefore, an approach to reconfigure the topological arrangement of cluster heads is needed. The topological arrangement of the cluster heads is reconfigured in such a way, that whole network energy can be minimized and also does not affect the data reliability as shown in fig. 1 (b).

III. Proposed Approach

There are many energy efficient approaches proposed for cluster formation and cluster head selection to reduce the inter cluster communication. But most of the approaches cannot be implemented because of complex and intelligent computing in distributed clustering algorithms. Sensor nodes have low storage capacity and the computing is extremely energy consuming, therefore, a distributed approach is required for cluster formation that should be simple for implementation and energy efficient. In this paper a new cluster head selection method has been proposed to increase the number of clusters in each round and reconfiguration approach to optimize the energy consumption in inter cluster communication.

A. *The Energy Efficient Clustering Protocol*

The clustering process in EECP is accomplished in two phases: setup phase and steady state phase. In the setup phase, cluster head selection and clusters formation process is completed. In the steady state phase, twin cluster head or group of cluster heads selected in small region is identified. These cluster heads are reconfigured to reduce the inter cluster communication. The aggregated data is sent to base station. There are some assumptions for our protocol as given below:

- Base station should not be limited to the energy resources and the position of base station should be known.
- The sensor nodes are deployed randomly over sensing field.
- Sensor nodes are not mobile.
- Location of sensor nodes are not known.

i. *Cluster Head Selection*

At the beginning of network operation, the base station broadcasts a signal at a certain power level. Each sensor node computes its approximate distance from the base station according to the strength of receiving signals. The sensor nodes elect themselves as cluster head according to their threshold. Each sensor node chooses a random number between 0 and 1 separately [4]. If this is lower than the calculated threshold $T(i)$ for node i, then it becomes a cluster head. Each node becomes a cluster head in one epoch [11, 12]. An epoch is defined as:

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$$epoch = \frac{1}{P_{opt}} \qquad 9$$

A threshold has been formulated for cluster head selection, therefore more number of cluster heads should be selected in sensing field. In the two-level heterogeneous network (normal nodes and heterogeneous nodes), a reference value P_{opt} has been replaced by weighted probabilities as given in eq. 10 for normal nodes and as in eq. 11 for heterogeneous nodes. The heterogeneous node (m) has α amount of more energy than normal node.

$$P_{norm} = \frac{P_{opt}}{1+\alpha m} \qquad 10$$

$$P_{hetro} = \frac{P_{opt}}{1+\alpha m}(1+\alpha) \qquad 11$$

$$P_i = \begin{cases} \frac{P_{opt}}{(1+\alpha m)} \frac{\varepsilon_{cu}(i)}{E\,(i)} \times \frac{\#Sub}{\#Main} & if\ i\ is\ the\ normal\ sensor\ node \\ \frac{P_{opt}\,(1+\alpha)}{\left(1+\frac{a}{\alpha m}\right)} \frac{\varepsilon_{cu}(i)}{E\,(i)} \times \frac{\#Sub}{\#Main} & if\ i\ is\ the\ \text{heterogeneous}\ sensor\ node \end{cases} \qquad 12$$

Where P_{opt} is the reference value of an average probability P_i , #main and #sub is the value that represents how many times a sensor node is selected as main and sub cluster head respectively, $\varepsilon_{cu}(i)$ is the current energy and $E\,(i)$ is the initial energy of sensor node i. These parameters determine the rotating epoch and threshold $T(i)$ of node i.

The threshold $T\,(i)$ is given by

$$T\,(i) = \begin{cases} \frac{P_i}{1-P_i \times \left(r \times mod \frac{1}{P_i}\right)} & if\ i \in G \\ 0 & otherwise \end{cases} \qquad 13$$

Where r is the current round, G is the set of sensor nodes consisting of heterogeneous nodes and normal nodes and still have not become cluster heads within the last $1/P_{hetro}$ rounds of the epoch for heterogeneous nodes, and $1/P_{norm}$ rounds of the epoch for normal nodes. $T\,(i)$ is the threshold applied to a population of n nodes. This guarantees that each heterogeneous node will become a cluster head exactly once every $1+\alpha \times m / P_{opt} \times (1+\alpha)$ rounds per epoch, and normal node will become a cluster head exactly once every $1+\alpha \times m / P_{opt}$ rounds per epoch. This period is defined for heterogeneous nodes as the sub-epoch. It is clear that each epoch (heterogeneous epoch) has $(1+\alpha)$ sub-epochs and as a result, each heterogeneous node becomes a cluster head exactly $(1+\alpha)$ times within a heterogeneous epoch. The average number of cluster heads that normal nodes and heterogeneous nodes have per round per epoch is equal to $n \times (1-m) \times P_{norm}$ and $n \times m \times P_{hetro}$ respectively.

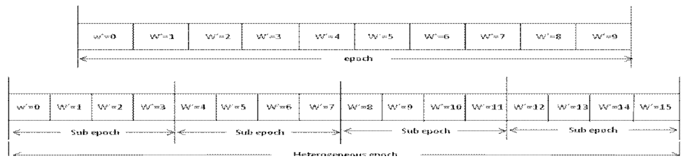

Fig. 2. The epoch and sub epoch for cluster head selection.

Thus the average number of cluster heads per round per epoch is equal to $n \times P_{opt}$ which is the desired number of cluster heads per round per epoch as shown in fig 2. With the help of $\#main$ and $\#sub$, the probability of sensor nodes becoming the cluster heads has increased and it results in more number of sensor nodes selected as cluster head in each round.

ii. Cluster formation

After the cluster heads have been selected, they broadcast an advertisement message to the non cluster head nodes in the network as they are the new cluster heads. Upon receiving this advertisement message, all the non cluster head nodes decide the cluster which they want to belong. Cluster head nodes record the distance of other's cluster head nodes, based on the received signal strength of the advertisement message. The non cluster head nodes inform the appropriate cluster heads (which is nearest) that they will be the members of the cluster. After receiving all the messages from the nodes that would like to be included in the cluster, based on the number of nodes in the cluster, the cluster head node creates a TDMA schedule and assigns each node a time slot when it can transmit. This schedule is broadcasted to all the nodes in the cluster. It allows the radio components of each non-cluster head node to be turned off all the times except during their transmit time.

During the steady state phase, the sensor nodes begin sensing and transmitting data to the cluster heads. After receiving all the data, cluster head nodes aggregate the data. Before sending data to the base station, a group of cluster heads detects and manages the topology arrangement of these cluster heads. After determining time the network goes back into the setup phase.

iii. Twin or group of cluster detection

At the end of steady state phase a small period of time is allotted before data transfer from cluster heads to base station. This time is used to detect the twin or multiple cluster heads grouped in a small region. During this procedure each cluster head finds a group of neighbour cluster heads called a sub-neighbour. The sub-neighbours of cluster head are calculated by their distances. Each cluster head broadcasts their energy level to sub-neighbour cluster heads if they exist. Sensor node within the limited range can receive the packet. If the node is a cluster head then it sends back a confirm packet, with its own current energy status.

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iv. Sub cluster head assignment

After a constant time interval t_{wt1} each cluster head knows their neighboring cluster head's energy. Each cluster head compares their energy level to neighbor's cluster head energy. If it is greater, cluster head declares itself as a main cluster head and informs its entire neighboring cluster heads. If a tie happens, then based on the distance to base station main cluster head is selected. The nearest cluster head is preferable to become the main cluster head, otherwise cluster head joins the nearest neighbour cluster head and become sub cluster head. Each main cluster head creates a TDMA schedule for their sub cluster head, if it is more than one as shown in fig. 3. Using EECP protocol total energy required by two cluster head is shown in eq.15

Energy required for transmitting data from cluster head CH_j to cluster head CH_i

$$E_{CH_j to CH_i} = lE_{RX}\, C_m(j) + lE_{DA}\{C_m(j) + 1\} + lE_{TX} + l \in_{fs} d^2_{CH_j to\, CH_i} \qquad 14$$

Where ϵ_{fs} is the energy dissipated by transmitter amplifier in free space model.The total energy required to transmit data from cluster head CH_i and CH_j to base station.

$$E_{CH_i and\, CH_j} = lE_{RX}\{ C_m(i) + C_m(j)\} + lE_{DA}\{C_m(i) + C_m(j) + 2\} + lE_{TX} + l\epsilon_{fs} d^2_{CH_i to CH_j} + l\epsilon_{mp} d^4_{CH_i to BS} + lE_{RX} \qquad 15$$

Through this approach distance from cluster head to base station ($d_{CH\ to\ BS}$) has been reduces because only one cluster head send data to base station but it require data transmission among cluster heads ($d_{CH_i to CH_j}$) which is very less than $d_{CH\ to\ BS}$. The equations 8 and 15 show that total energy consumption in this approach is less than existing approaches. The algorithm for clustering process in shown in algorithm1.

v. Data aggregation and transmission

After sub cluster head assignment each sub-cluster head sends aggregated data to their main cluster head. Main cluster head receives data from its sub cluster heads and then sends aggregated data to base station. The algorithm of clustering process and time line of this protocol is shown below.

Algorithm 1

Notation:

n=Total number of nodes, S=set of nodes
P_{Hetro} = Probability threshold for heterogeneous nodes
P_{nrm} = Probability threshold for normal nodes
//**Initialization**

Each node generates a random number.

Start
Phase -I
Set: CH = 0,i=1;Count=1
While i! = n
Repeat
If ($S(i)$ is heterogeneous node)
If (S(i)$_{\text{random number}}$ <= P_i)
Then CH (count) =i; count=count+1;
Else If (S(i)$_{\text{random number}}$ <= P_i)
Then CH (count) =i; count=count+1;
End

Phase -II

While (CH! = ∅)

Repeat

If (($d(CH_i\ ,\ CH_j)$ < $R\,m$) and($i \neq j$))
If
(energy)>energy(
CH_j)) *and* ($d(CH_j\ ,\ BS)$ > $d_{reference}$)
Then $CH_j$is added in the sub-cluster head list of CH_i and CH_i is added in the
main-cluster head field of CH_j
else If (energy(CH_j)>
energy(CH_i))*and* ($d(CH_i\ ,\ BS)$ > $d_{reference}$)
Then CH_i is added in the sub-cluster head list of CH_j and CH_j is added in the
main-cluster head field of CH_i
else If ($d(CH_i\ ,\ BS)$< $d(CH_j\ ,\ BS)$)
Then CH_j is added in the sub-cluster head list of CH_i and CH_i is added in the
main-cluster head field of CH_j
else If ($d(CH_i\ ,\ BS)$> $d(CH_j\ ,\ BS)$)
Then CH_i is added in the sub-cluster head list of CH_j and CH_j is added in the
main-cluster head field of CH_i
End

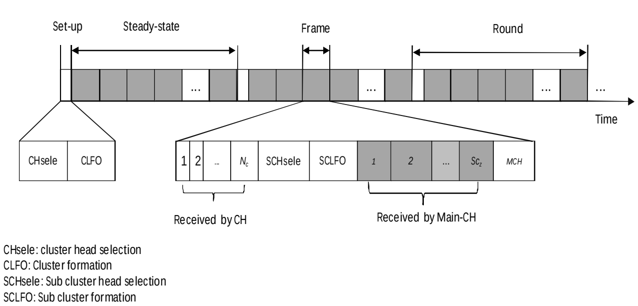

Fig. 3. Time line showing the operation of EECP protocol.

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IV. RESULTS

A heterogeneous clustered wireless sensor network has been simulated with 100,200,300 sensor nodes. The normal and heterogeneous nodes are randomly distributed over the sensing field. This means that the horizontal and vertical coordinates of each sensor node (normal and heterogeneous) is randomly selected between 0 and maximum value of the dimension. The base station is in the center of the sensing field. The simulation parameters are summarized in table 1

TABLE 1
SIMULATION PARAMETERS

Parameter		Value
Network size		(100 m x100 m)
Node number (n)		100
Base station position		(50 m, 50 m)
Initial energy	Normal node	2 J
	Heterogeneous node	4 J
Transmitter/Receiver electronics E_{elec}		50 nj/bit
Data aggregation (E_{DA})		5 nj/bit/report
Reference distance ($d_{reference}$)		87 m
Transmit amplifier ϵ_{fs}		10 pJ/bit/m^2
Transmit amplifier ϵ_{mp}		0.0013 pJ/bit/m^4
Message size (l)		4000 bits

A. Performance measures

To evaluate the performance of the proposed protocol EECP, some of the performance measures are listed below.

A. Sub cluster Size: The number of cluster heads selected in a group (having less distance to each other), reconfigured as a sub cluster. The number of cluster heads in a sub cluster is defined as sub cluster size.

B. Cluster Density: The number of sensor nodes in a cluster is called cluster density.

C. Stability Period (First Node Dies): This is the period, when a network operation starts until first sensor node dies. This is appropriate in situations where death of a single node deteriorates the quality of the network.

D. Network Lifespan (Last Node Dies): This is the period from when the network operation starts until last sensor node dies. This parameter can be considered as a way to measure the lifespan of a sensor network.

E. Sensitivity Analysis: In this analysis the uncertainty in the output of a mathematical model or system can be apportioned to different sources of uncertainty in its inputs. To perform the sensitivity analysis in this work network energy and network area are considered[13].

B. Simulation Results

Under similar conditions, simulations are performed in MATLAB 8.0 for the comparison of existing protocols LEACH, SEP, Two levels LEACH, Three Layered LEACH and EEHC, [2,3,7,8,10] with our proposed EECP protocol.

i. Analysis of size of sub cluster

The size of sub cluster is proportional to energy conservation.

$$Energy\ Conservation \propto Size\ of\ subcluster\ (Sc_z)$$

Three values have been taken for the size of sub clusters (Sc_z=2, 3, 4). For each value of Sc_z performed an analysis as shown below.

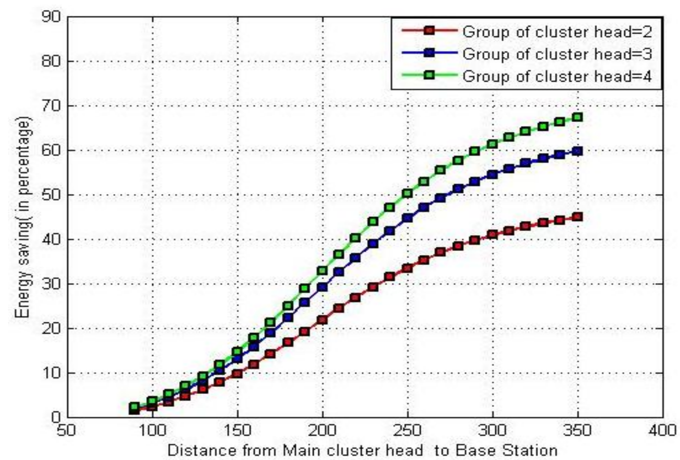

Fig.4. Analysis on the group of cluster heads vs. energy saving.

Fig. 4 indicates that as on increasing the distance from main cluster head to base station EECP performs well. Energy saving also increases when sub cluster size increase.

ii. Analysis of Cluster Density

Cluster members participate to sense the object or parameters and send the sensed data to cluster head. Cluster heads also deplete their energy for receiving data from cluster members (cluster density), therefore the density of the cluster is inversely proportional to energy conservation.

$$Energy\ conservation \propto \frac{1}{total\ numberof\ cluster\ members\ (C_m)}$$

Five values have been taken for the density of the cluster (C_m=10, 20, 30, 40, 50) with three values of sub cluster size (Sc_z= 2, 3, 4) at an *average* distance (cluster head to base station) d = 220. An energy consumption analysis has been performed for inter cluster communication in all cases as shown below.

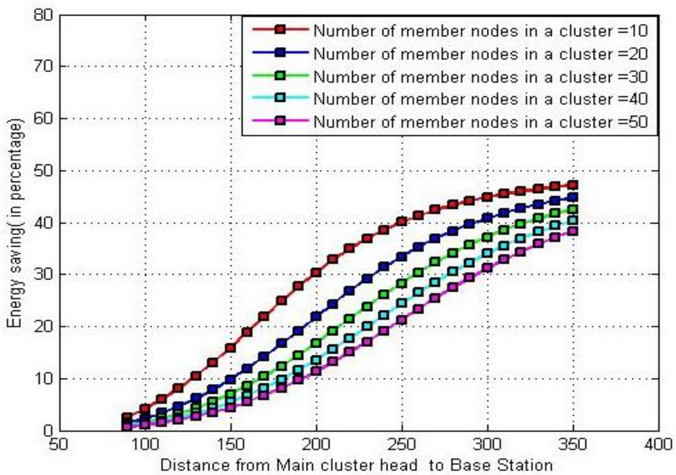

Fig. 5 Analysis of average saved energy based on variable sub cluster size (Sc_z= 2).

Fig. 5 shows the analysis of energy conservation in inter cluster communication. In the average distance (d = 220) the energy saving is up to 30% with average number of cluster member (C_m = 10) when subcluster constructed by two cluster heads. The energy conservation decreases as cluster density increases. As the cluster members are increased from 10 to 50 the energy saving decreases from 35% to 17%.

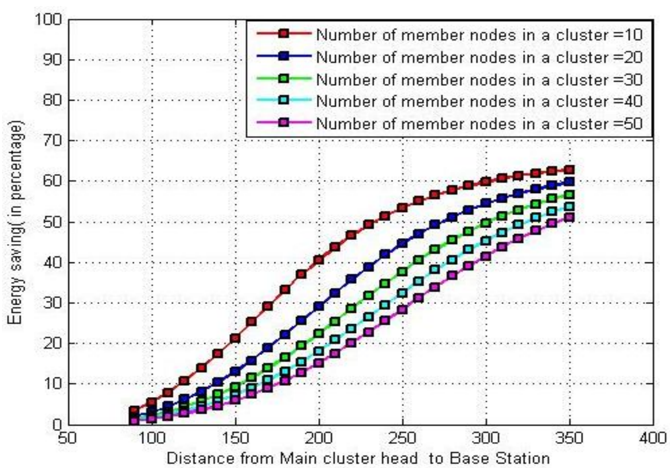

Fig. 6. Analysis of average saved energy based on variable sub cluster size (Sc_z= 3).

Fig. 6 shows the analysis of energy conservation in inter cluster communication. In the average distance (d = 220) the energy saving is up to 40% with number of cluster members (C_m = 10) when subcluster constructed by two cluster heads. The energy conservation decreases as cluster density increases. As the cluster members are increased from 10 to 50 the energy saving decreases from 40% to 23%

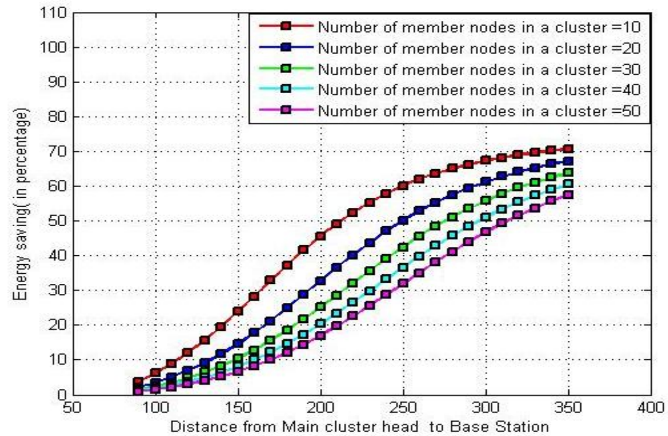

Fig. 7. Analysis of energy conservation in inter cluster communication based on variable sub cluster size (Sc_z=4).

Fig. 7 shows the analysis of energy conservation in inter cluster communication. In the average distance (d = 220) the energy saving is up to 45% with number of cluster members (C_m = 10) when subcluster constructed by two cluster heads. The energy conservation decreases as cluster density increases. As the cluster members are increased from 10 to 50 the energy saving decreases from 45% to 25%.

iii. Stability Period and Network Life Time

The network lifetime and stability are used as key indicators to evaluate performance of the proposed protocol. The data transmissions from sensor nodes were simulated until all the sensor nodes died. Here the performance of the EECP protocols is compared with LEACH, SEP and EEHC in the same heterogeneous setting, but with different values of heterogeneity.

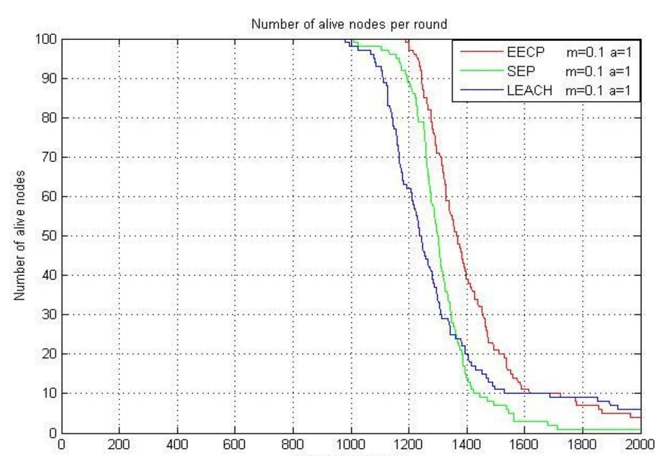

Fig. 8. Comparison between LEACH, SEP and EECP protocols in presence of heterogeneity.

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Fig. 8 shows the results for LEACH, SEP and EECP using 10% heterogeneous nodes and two times more energy. It is obvious that the stable region of SEP extended 5% as compared to the LEACH. It also shows that the stable region of EECP protocol extended as compared to the LEACH by 22% and SEP by 10% .Moreover, the unstable region of EECP protocol is shorter than LEACH but larger than SEP.

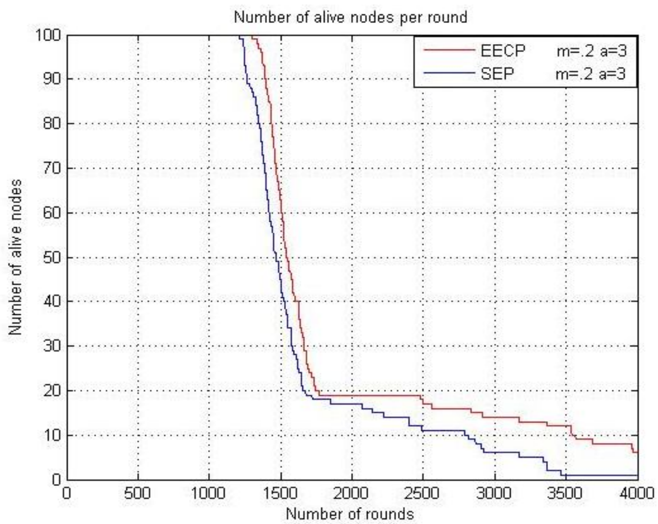

Fig. 9: Comparison between SEP and EECP protocol in the presence of heterogeneity.

Fig.9. shows the results of SEP and EECP using 20% heterogeneous node and four times more energy. Now EECP protocol takes the advantage of small sized clusters (more cluster head selected in sensing field), therefore the stable region is increased by 12% as compared to SEP.

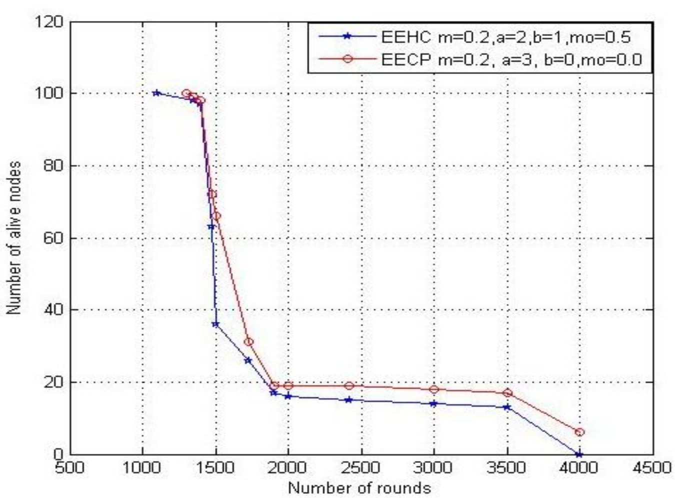

Fig. 10. Comparison between EEHC and EECP protocol in the presence of heterogeneity.

Fig. 10 shows the results of EEHC and EECP using three level of heterogeneity. First level of heterogeneous nodes is equipped with three times more energy than normal nodes and 20% nodes are in first level heterogeneous nodes. Second level heterogeneous nodes are equipped with two times more energy and 50% nodes are in second level heterogeneous nodes. Now EECP protocol simulated with 20 % of heterogeneous nodes are equipped with four times more energy. The stable region of EECP is about 1300 rounds which are larger than EEHC stable region (1100 rounds).

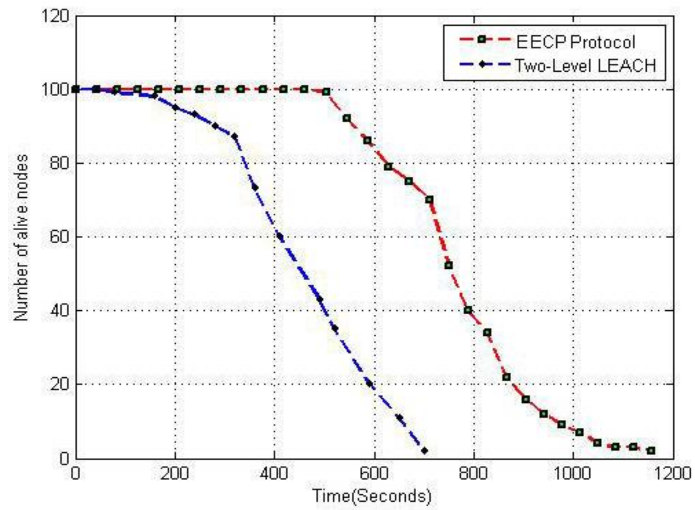

Fig. 11 Comparison between Two level LEACH and EECP protocol.

Fig. 11 shows the comparative results of Two Level LEACH and EECP for network stability period and lifetime [7]. The stable region of EECP is about 500 seconds which is larger than Two Level LEACH stable region (170 seconds). The network lifespan also increased from about 700 rounds to 1160 seconds.

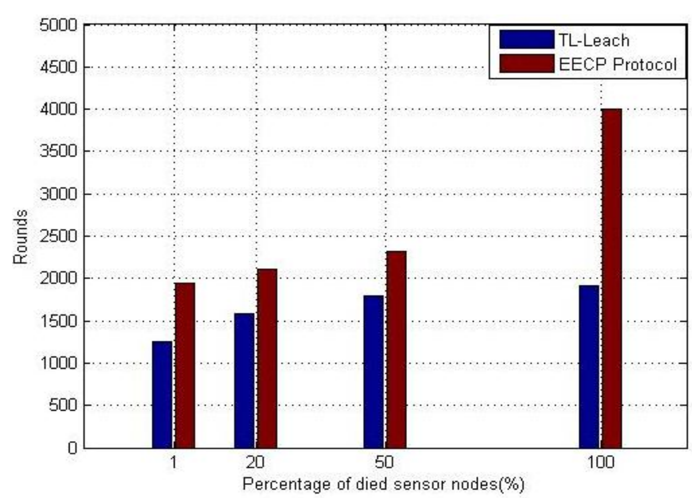

Fig. 12. Comparison between TL (Three layers) LEACH and EECP protocol.

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Fig.12 shows the comparative results of Three layered LEACH and EECP protocol for network stability period and lifespan. The stable region of EECP is about 1920 rounds which is larger than Two Level LEACH stable region (1250 rounds). The network life time also increased from about 1970 rounds to 4000 rounds.

C. Sensitivity of EECP Protocol

The analysis of sensitivity in EECP protocol in terms of length of the stability period of two parameters: network energy and network area [13]. Comparisons made between SEP and EECP protocols.

i. Network Energy

The effect of total network energy for the stability period for two different models (sensing field $100\times100\ m^2$ with 100 sensor nodes and sensing field $300\times300\ m^2$ with 900 sensor nodes) was analysed.

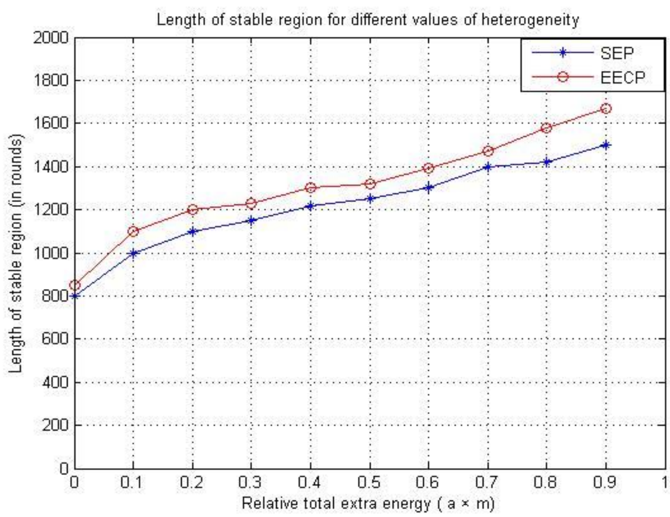

Fig. 13. Sensitivity of SEP and EECP protocol based on the degree of heterogeneity in small-scale networks.

Fig. 13 shows the length of the stability region versus degree of heterogeneity ($m \times a$). As the graph shows the performance does not depend on the individual values of m and a, but on their product, which represents the total amount of extra initial energy brought by heterogeneous nodes. The observation also shows that, as expected stability period of EECP protocol increases faster than SEP.

Fig. 14 shows that the stability period of EECP protocol is better than SEP in the large scale area $(300\times300\ m^2)$. By increasing the extra energy $(0.1\ to\ 0.9)$ stability period also increased (600 rounds to 1090 rounds) respectively.

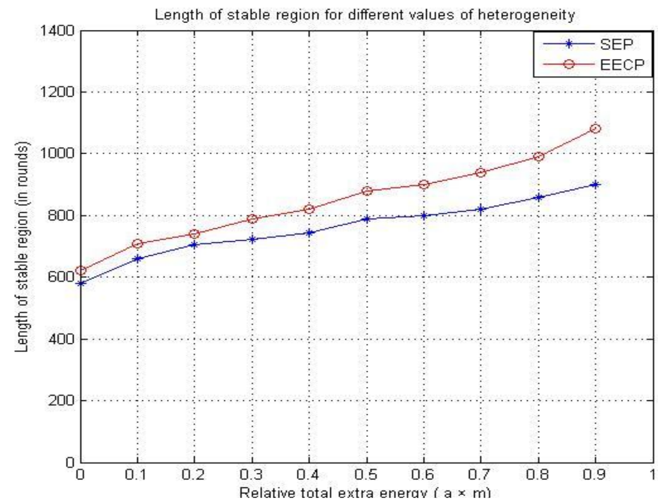

Fig. 14 Sensitivity of SEP and EECP Protocols based on the degree of heterogeneity in large-scale networks.

ii. Network Area

The effect of network area on the stability period has been analysed when number of sensor nodes (500) and network energy are fixed ($m = 0.2, a = 3$).

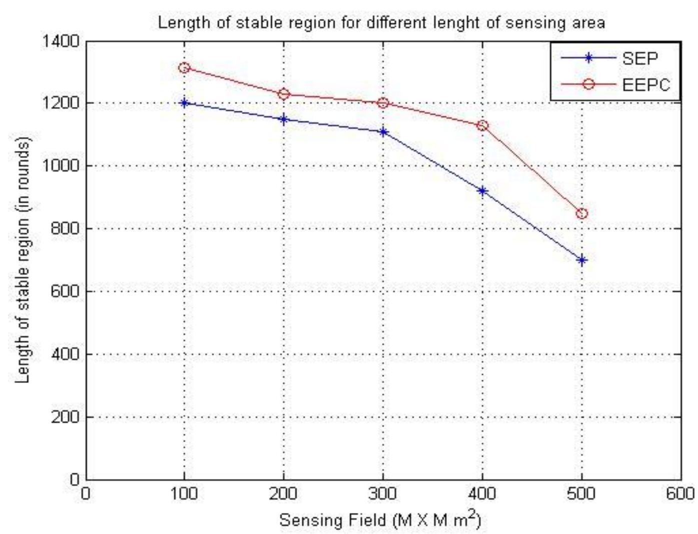

Fig. 15. Sensitivity of SEP and EECP Protocol to length of sensing area.

Fig. 15 shows the stability period of EECP and SEP protocol in terms of varying sensing area. 500 sensor nodes are spread in sensing field and 20 % heterogeneous nodes (with 3 times more energy) are taken in the network. With the increases in size of the sensing area (from $100\times100\ m^2$ to $500\times500\ m^2$) stability period decreased from 1300 rounds to 850 rounds in EECP, where as it decreased d from 1200 rounds to 700 rounds in SEP protocol, still the stability period remained larger in EECP compared with that in SEP.

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V. Conclusion

An attempt has been made through this paper, to suggest a new protocol which avoids the drawbacks of existing clustering protocols based on random selection of cluster head, while combining its advantages. A new method is designed to find out the group of cluster heads at the end of steady state phase in each round. The conception of sub-cluster head is provided, which is used to reduce the transmission distance of cluster heads to base station, thus energy can be save more efficiently. Results from our simulation shows that the EEPC protocol provides better performance for stability period and network lifespan.

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