Analyzing And Modifying the performance of Hierachical Clustering Protocols with Optimizing Matrix of Network Evolution Model

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Abstract

In the distributed computing clustering of the nodes is generally used to make the communication process energy efficient. But in the mechanics of clustering the number of clusters increases as the energy of the nodes get depleted. This dispersive nature of clustering probability leads into quick death of the nodes. In this paper we have discussed the usage of optimization matrix from clustering probability as obtained from network evolution model to improve the data delivery and life time of the nodes in the network. The proposed framework showed considerable promise in boosting the efficiency of hierarchical clustering protocols in wireless sensor networks.

Keywords: optimization matrix, clustering probability, network evolution model

1. Introduction

Real large scale networks- biological , social or communication networks are complex dynamical systems. Studying the properties of these networks allow us to control and predict the behavior of such systems[8]. Roughly the above mentioned networks can be split into two types 1. small scale networks 2.large scale networks .while understanding the large scale the concepts like preferential attachment , anti preferential attachment etc. mainly probabilistic approach have been used to understand the network dynamics .But whereas in the understanding of small scale networks ,the graph theoretic approach is enriched with the concepts from soft computing and probability . [2] have reasonably succeeded in approximating the usage of large scale networks into small scale networks of the wireless sensor networks (WSN) domain.

Latest research [3] shows by combining the concept communication energy principles and geometry of the field conclusion like the clustering is independent of network size and the energy consumed by the of the transmitter circuitry has no impact on the optimal cluster size, and receiver circuitry can influence the clustering were made.

In the existing literature [14,15] there is evidence of designing newer protocols with the scale free concept but hardly any analysis on the improvement or analysis of the existing protocols with complex network theories[9].

Amongst WSN protocols LEACH protocol[1,5] is one of the hierarchical clustering routing protocols in wireless sensor networks which uses probability model in selection of the nodes to be cluster heads and common nodes.This makes LEACH attractive as a system to experiment using other probability based models.

Although there are many variants of LEACH protocols [4,10,11,12] , we found that LEACH which has a reputation of being versetile and used in numerous real life applications[17].This makes it suitable for our endeavour in experimenting Network Evolution Model with LEACH .

The subsequent sections of this paper are organized as follows: section 2 deals with the brief introduction of LEACH and network evolution model,section 3 discusses about the problem statement and the proposed framework ,section 4 details about the experimental setup section 5 is discussions and finally concludes the paper by conclusions and future work.

2. Review of Leach-c Protocol and Network Evolution Model

2.1. LEACH Protocol

The LEACH (Low Energy Adaptive Clustering Hierarchy)[1] is a protocol for micro wireless sensor networks that achieves low energy loss with high quality application specific delivery .In this architecture , the nodes collaborate locally to reduce the amount of data to be sent to the end user. It has been found that the proximity of the nodes strongly allows the data to be correlated. Hence the clustering architecture is used for data dissemination for LEACH protocol. This architecture uses a node designated as cluster head to receive data from the other sensor nodes .This cluster head takes the responsibility of reducing the received data signals into actual data while maintaining the effective information content. As there is no fixed infrastructure to receive the data , the cluster head has to be rotated among other members to increase the lifetime of the network. For rotation of cluster heads the cluster forming algorithm should ensure minimum overhead in terms of of energy and time.

Considering all the advantages of LEACH protocol ,yet it suffers from producing quality clusters by dispersing the cluster heads through out the network. Therefore LEACH-C (LEACH-Centralized) a protocol that uses the central base station for computing the best cluster heads with an expensive algorithm like simulated annealing , Self organizing maps coupled with K-means [16] etc are being used to determine optimum clusters as this problem is NP hard problem.

The fundamentals of getting good clusters is that the base station needs to ensure that the energy is evenly distributed among all the nodes .To achieve this the base station computes the average energy of all the nodes and segregate the nodes with low energy nodes than the average energy. These segregated nodes with energy higher than the average nodes runs the cluster selection algorithm thus reducing the computation overhead.

2.2. Network Evolution Model

Here the authors [2] have analytically used the theory of complex network to quantify some of the observed properties of topology control algorithms.

To build this framework ,probabilistic approach of Li-Chen model[6] of Local world model is used to mimic the wireless sensor network .Ans the dynamics of clustering was addressed by the concept of preferential and anti preferential attachment. The anti preferential removal mechanism is more reasonable for deleting links that are anti parallel with the preferential connection[2,8]. It is also consistent with the functioning of clustering algorithms that runs in rounds in wireless sensor networks. The wireless nodes that do not have enough energy,that is, the dead nodes, are to be removed from the system. Thus, anti preferential [2] removal phenomenon is reasonable for clustering algorithms. Finally combining the mathematical realizations of the above mentioned facts in mean field theory , we obtain the distribution function as the degree distribution P(k) , where P(k)is the probability of the node has k edges. This distribution is further minimized with respect to the anti preferential attachment , which during the evolution process tends to zero as this phenomenon of non attachment to a preferential neighbor is absent for wireless sensor networks. This consideration reduces the distribution function to yield.

$$p = \frac{1}{2}\left[\sqrt{\frac{k+3}{k-1}} - 1\right] \tag{1}$$

the above expression is called the probability of clustering in the network. In order to draw a meaningful graph of the above equation to express the usefulness in wireless sensor network domain. We convert the P vs k to number of clusters Vs number of connections by multiplying the number of nodes in the network (ie 100 nodes in this case) to the probability obtained for different connections (k).Figure -I shows the nature of the graph.

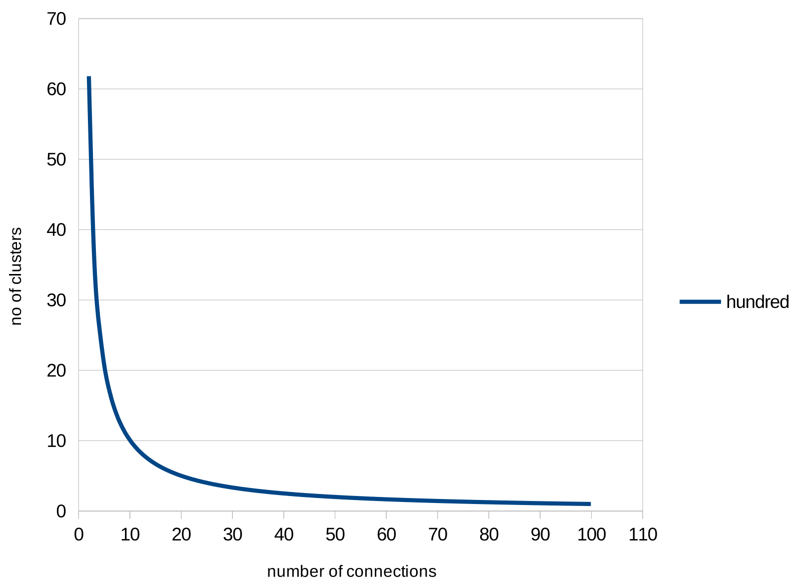


Figure 1: The plot between the number of clusters to number of connections. when N=100

Problem: Show the validity of random 100 node WSN network simulating 5 cluster head network.

Solution: the average number of connections in a cluster of 5 cluster 100 node network = (100/5) -1=19 connections.

To check the validity ,we therefore put the value of k in equation (1), and obtain the value of P as 0.0527707984 . Multiplying back with 100 we obtain 5.27 approximately 5 (considering the floor value w.r.t 5.5) which is the clusters that is possible with 100 node network.

Now for 6 cluster 100 node network we obtain the clustering probability value as 0.0627314339 .Similarly following the previous caveat the number of clusters will be 6. similarly for 4 cluster 100 node network we obtain the theoretical value of clusters as 4.15 which is round off to 4 , 3 cluster 100 node network to 3 cluster as theoretical value 3.03 which is round off to 3 and so it follows the same 2 and 1. Now for 7 cluster 100 node we obtain the clustering probability value as 0.0773502692 so the number of clusters will be 8. so the disparity among the desired number of cluster head to the calculated is observed .This indicates deviation from the optimized plane. So the good clusters can be between 1 to 6 percentage of the total nodes.

Hence this is the result in confirmatory with Heinzelman et al mathematical deduction of optimal clustering percentage (kopt) lies between 1 and 6 of the nodes to be cluster head for LEACH experiment [1].

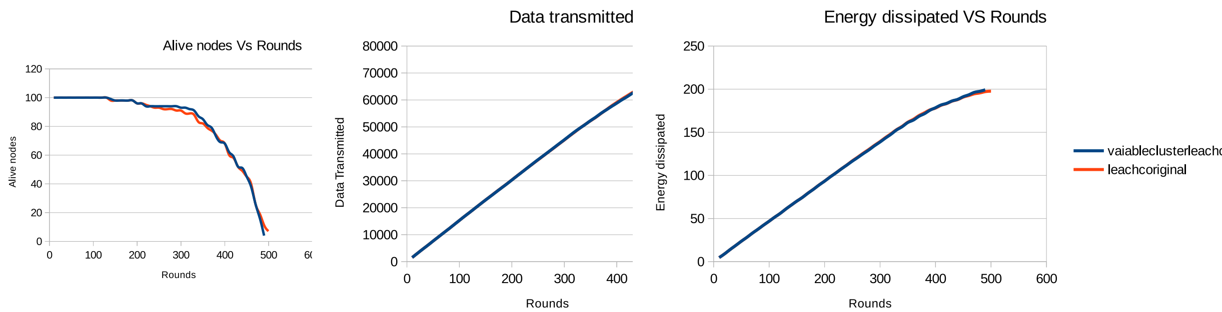
With this meaningful success we now proceed on the application of the equation in modifying the LEACH-C protocol for enhancing the energy efficiency , through put and alive nodes.

3. Problem Statement and Proposed Framework.

3.1. Problem Statement

Consider the simulations of LEACH-C in ns-2 of 5- cluster 100 node random network with intial simulations parameters as energy per node 2 Joules..The output of simulation is alive 4 ,data transmitted 67800, energy expense 198.160,number of rounds 510.These simulation has been done keeping the cluster heads fixed at 5by assumption [1,3].

On the contary ,we find that as the simulation proceeds the number of alive nodes decrease so the variation of cluster should be obvious to maintain the balance between cluster heads and non cluster heads. For implementation we take the reference of the equation (1) in terms of wireless sensor network and utilize it in determining the variable clustering throughout the rounds.The details of the implentation algorithm in Appendix B. The output of the performance is shown in Table 1. we can observe that there is almost no variation in the values when compared between the parameters. Instead , it is observed that varying the clusters lead in lowering the output characteristics values.The detailed table is depicted below. To look into the deteriorating performance closely we would use optimizing table to visualize original LEACH-C and the variable clustering LEACH-C.



(a) alive

(b) data

(c) energy

Figure 2: The plot of alive , data transmitted and energy spent versus rounds (200 nodes with 2J each node).[original Leach-C to Leach-C modified]

All Parameters	**Original Leach-C**	**Variable Clustering Leach-C**
Alive	4	4
Data transmitted	67800	67760
Energy Dissipated	198.160	199.3258
Number of Rounds	510	490

Table 1: Comparision between original LEACH-C and variable clustering LEACH-C

The optimizing table has alive nodes as column header and the probability due to number of connections available as row header . While the elements of this matrix constitute the cluster heads for any particular nodes.

Hence for the variable clustering LEACH-C. we plot the yellow boxes as the clusters that were made available at various times for the corresponding live nodes. Similarly for original LEACH-C where the cluster number was fixed(five in this case).we plot this number of cluster in the optimizing table as cyan . Clearly we can visualize that initially both the algorithms were performing the same but after 380 rounds the variable clustering LEACH-C suffered casualties which it could not recover and finally ended at 490 rounds ,whereas original LEACH-C carried the simulation upto 510 rounds.The construction and usage of optimizing matrix is discussed in Appendix A.

So far we have discussed the use of optimizing table. Now to the main question can we improve the output characteristic of LEACH-C. In the next section we discuss our improvement using optimization matrix.

3.2. Proposed Solution

The solution to this problem is more physical than algorithmic. Careful observation of the optimization table depicts that movement of the yellow boxes and the cyan boxes occurred along the diagonal direction .This implies the increase in the number of cluster heads for variable clustering LEACH-C and fixed in case of original leach. Another important aspect is that the cluster head either increased or remained fixed for decreasing number of live nodes which showed that the increase in the number of clusters heads leads in the dissipation of more energy.

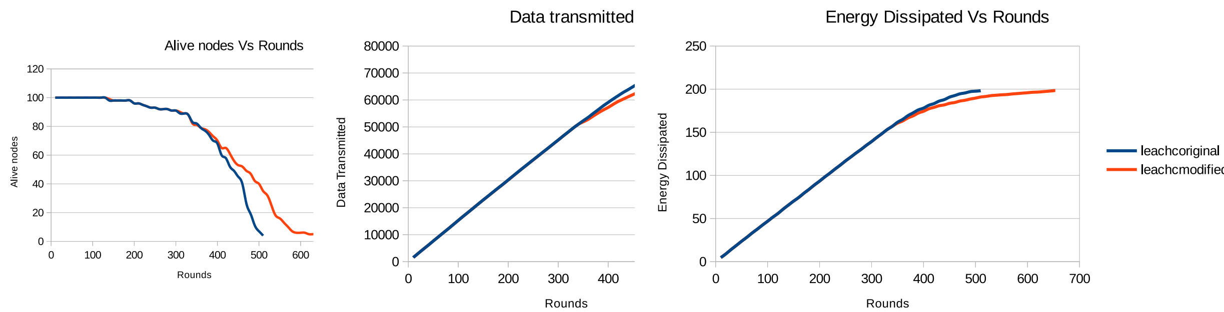
Leading by the above observation we logically vary our cluster row wise as shown by green boxes starting from the point where variable clustering LEACH-C , original LEACH-C have started. From the optimization table we can observe that as the alive nodes reduce , the number of cluster heads also reduce.

As the optimization table does not say anything about energy of the system under consideration . It is hard to say whether in the green path will be energy efficient or not , but at least the shortest path in alive nodes connection space.

4. Expermental Details

The simulation of original LEACH-C , Variable clustering LEACH-C and modified variable clustering LEACH-C were simulated in NS-2.34 . We have installed NS-2.34 in intel P-IV , 512 MB RAM 32 bit machine using ubuntu-14.01 .This simulator is chosen because it has a proper radio model ,a mac protocol and complex scenarios can be easily tested . For our experiments, we used a 100-node network where nodes were randomly distributed with the BS at location at origin. The bandwidth of the channel was set to 1 Mb/s, each data message was 500 bytes long, and the packet header for each type of packet was 25 bytes long. The following figures describe the output of the experiment

We assume a simple model for the radio hardware energy dissipation where the transmitter dissipates energy to run the radio electronics and the power amplifier, and the receiver dissipates energy to run the radio electronics. For the experiments described here,both the free space (power loss) and the multipath fading (power loss) channel models were used, depending on the distance between the transmitter and receiver. For the experiments described in this paper, the communication energy Eelec =50 nJ /bit,ef=10

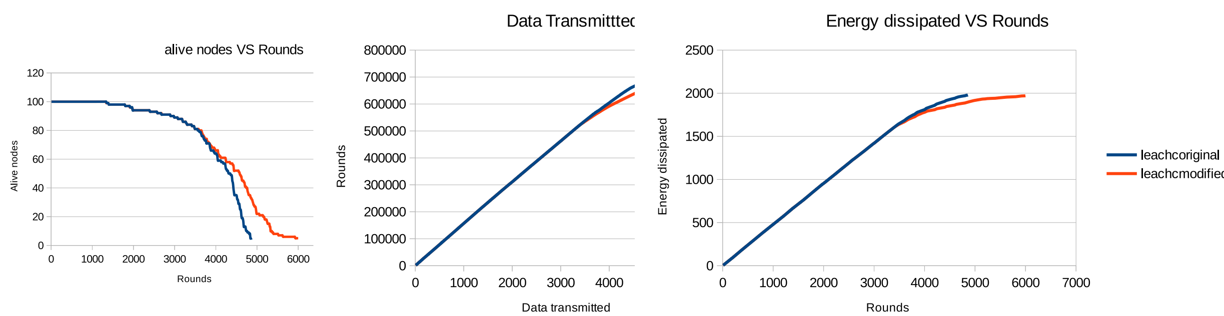


(a) alive

(b) data

(c) energy

Figure 3: The plot of alive , data transmitted and energy spent versus rounds (200 nodes with 2J each node).[original LEACH-C to LEACH-C modified]



(a) alive

(b) data

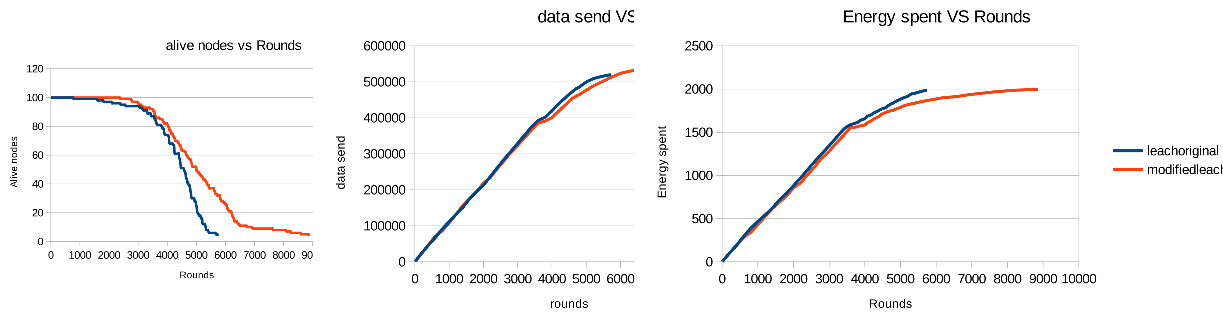
(c) energy

Figure 4: The plot of alive , data transmitted and energy spent versus rounds (100 nodes with 20J each node).[original LEACH-C to LEACH-C modified]

pJ bit m ,parameters are set as: emp=0.0013pJ bit m the energy for data aggregation is set as 5 nJ bit signal [1]. The algorithm of Variable clustering LEACH-C and original LEACH-C details in explained in Appendix B.

From the observation of output characteristics we find there is some improvement in the performance in terms of alive nodes , data transmitted and energy dissipated. The Table 1 below depicts the visa vis performance.

Graphically and numerically examining the data we found that the work of the optimization matrix was effective after the death of some nodes(73 rd node in case of LEACH-C Modified). Instead of stretching the reduced number of nodes(alive nodes) to more clusters we have reduced the number

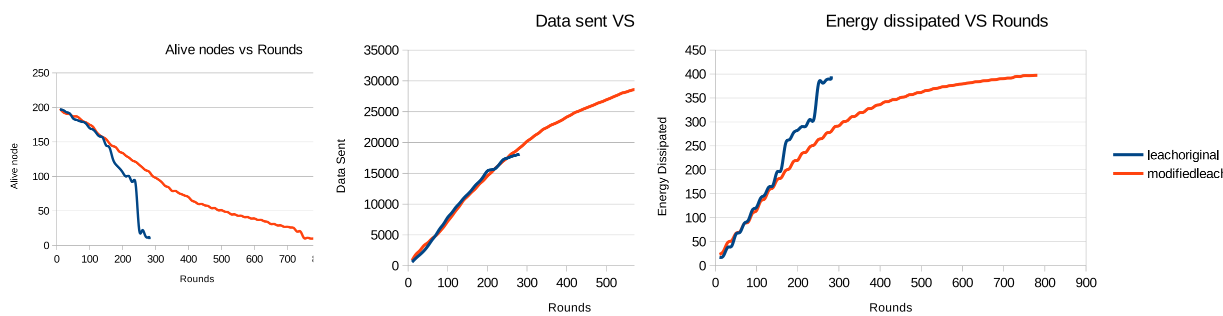


(a) alive

(b) data

(c) energy

Figure 5: The plot of alive , data transmitted and energy spent versus rounds (100 nodes with 20J each node).[original LEACH to LEACH modified]



(a) alive

(b) data

(c) energy

Figure 6: The plot of alive , data transmitted and energy spent versus rounds (200 nodes with 2J each node).[original LEACH to LEACH modified]

of clusters.

Roughly we can say that this procedure is effective with 27 percent of the nodes at the last cycle. So we ran the experiments with the nodes with higher energy so that we can capture the manifestations at the last of the cycle.

Keeping the above observation in mind we design another two experiments . The first experiment with 100 nodes , 20 joules energy for each nodes and the second experiment with 200 node with 2 joules for each node.This essence of these experiments are to capture the management of clustering at the end of the cycle.

All Parameters	Original Leach-C	Leach-C Modified
Alive	9	10
Data transmitted	56886	61190
Energy Dissipated	396.613	393.6059
Number of Rounds	444	720

Table 2: A comparison of performance between original Leach-C and Leach-C Modified for 200nodes, 2J each node

All Parameters	Original LEACH-C	LEACH-C Modified
Alive	4	5
Data transmitted	679709	693918
Energy Dissipated	1978.506	1970.248
Number of Rounds	4850	6000

Table 3: A comparison of performance between original Leach-C and Leach-C Modified for 100 nodes 20J each node

The Figure-3,4 and Table-2,3 describe the output graphs of the above mentioned experiment The analysis of the experiment with 200nodes ,2J per node is worth noting , which describes the effect of modified LEACH-C protocol on the clustering at the end cycle of the experiment.The effect is more pronouced in the case of large number of nodes than fewer nodes with higher energy.

In the similar lines of experiments LEACH was also considered for simulation purpose.The outcome the experiments are depicted in Figure 5,6 and Table 4,5 respectively for two different cases.

Close examination of the data revels that after the death of 50 percent of nodes ,the modifiedleach performs very well in terms of energy and life expectancy of the nodes. But this is more evident in case with 200 nodes.

It is worth noticing the fact that the energy expense graph of originalleach as described in figure 6 states how abruptly the energy is used up by the remaining 50 percent nodes.This abrupt energy expense is due to the presence of unstable clustering of the nodes which can be seen as mitigated by the smooth graph of the modifiedleach in figure 6.Thus we can infer the proper management of clustering is done at the end of the cycle which is reflected by increased lifetime of the nodes.

All Parameters	Original LEACH	LEACH Modified
Alive	4	4
Data transmitted	519831	543903
Energy Dissipated	1985.088	1997.186
Number of Rounds	5740	8870

Table 4: A comparison of performance between original LEACH and LEACH Modified 100 nodes 20J per node

All Parameters	Original LEACH	LEACH Modified
Alive	9	9
Data transmitted	18130	31274
Energy Dissipated	395.136	397.397
Number of Rounds	280	780

Table 5: A comparison of performance between original LEACH and LEACH Modified 200 nodes 2J per node

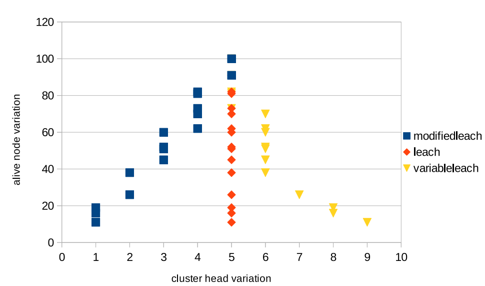


Figure 7: The Cluster Head Vs Alive Nodes

5. Discussions

The above experiments suggests that the network evolution model provides another way of optimizing the performance of the system.It can can be easily concluded from the section 2.2 that the number of optimum clusters can also be obtained from this evolution model without the use of communication energy principles.

Another important aspect of the Network Evolution Model is the optimizing matrix which seeks the global optimization rather than local.This matrix which forms the basis of energy efficient cluster variation lays the possiblity of other possible variations. The main contibution of this framework is all about the management of the clusters after the death of fifty percent nodes.The effectiveness of this framework is strongly confirmed in case of large number of nodes as compared with small number.Thus this framework can serve as a effective tool in driving the efficiency of the protocol without much change in the algorithm.

From Figure 7 describes the plot between the number of (cluster-Alive) nodes space the expression of LEACH-C , variable clustering LEACH-C and modified LEACH-C.

6. Conclusions and Future Work

This experimental simulations described in this paper clearly indicates that fixed clustering throughout the LEACH , LEACH-C and like protocols forbids the performance in system level. This framework is succesful in understanding the clustering dynamics of the system , it predicts the efficent scheme of clustering,which is dependent on total number of nodes into consideration rather than the geometry of the field or the electronics used in sensor nodes.

The electronics of the sensor node and the geomerty of the test field is intresting to find out how efficiently the perfect clustering schema may be implemented.

The future work can be in the direction of the system with soft computing based cluster forming protocols.

7. Acknowledgements

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9. Appendix A

The Optimization Matrix is a spreadsheet based numerical analysis for the changing of the alive nodes in the experiment. We would discuss the matrix with reference to the figure. The columns B and C represent the number of connections per cluster and the corresponding probability as calculated by equation 1. And rest of the columns are the multiplication of the corresponding probability (due to connections) to the number of nodes.In this way the

	B	C	D	E	F	G	H	I	J	K	L	M	N
1	k	p	Np (100)	91	82	81	73	70	62	60	52	51	45
2	2	0.618033989	61.80339887	56.24109298	50.67878708	50.06075309	45.11648118	43.26237921	38.3181073	37.08203932	32.13776741	31.51973343	27.81152949
3	3	0.366025404	36.60254038	33.30831174	30.01408311	29.64805771	26.71985448	25.62177826	22.69357503	21.96152423	19.033321	18.66729559	16.47114317
4	4	0.263762616	26.37626158	24.00239804	21.6285345	21.36477188	19.25467096	18.46338311	16.35328218	15.82575695	13.71565602	13.45189341	11.86931771
5	5	0.207106781	20.71067812	18.84671709	16.98275606	16.77564928	15.11879503	14.49747468	12.84062043	12.42640687	10.76955262	10.56244584	9.319805153
6	6	0.170820393	17.08203932	15.54465579	14.00727225	13.83645185	12.46988871	11.95742753	10.59086438	10.24922359	8.882660449	8.711840056	7.686917696
7	7	0.145497224	14.54972244	13.24024742	11.9307724	11.78527517	10.62129738	10.18480571	9.020827911	8.729833462	7.565855667	7.420358443	6.547375097
8	8	0.126783171	12.67831705	11.53726852	10.39621998	10.26943681	9.255171449	8.874821937	7.860556573	7.606990232	6.592724867	6.465941697	5.705242674
9	9	0.112372436	11.23724357	10.22589165	9.214539727	9.102167291	8.203187806	7.866070499	6.967091013	6.742346142	5.843366656	5.73099422	5.056759606
10	10	0.100925213	10.09252126	9.184194345	8.275867431	8.174942219	7.367540518	7.06476488	6.25736318	6.055512755	5.248111054	5.147185841	4.541634566
11	11	0.091607978	9.160797831	8.336326026	7.511854221	7.420246243	6.687382417	6.412558482	5.679694655	5.496478699	4.763614872	4.672006894	4.122359024
12	12	0.083874208	8.387420812	7.632552939	6.877685066	6.793810858	6.122817193	5.871194568	5.200200904	5.032452487	4.361458822	4.277584614	3.774339365
13	13	0.077350269	7.735026919	7.038874496	6.342722074	6.265371804	5.646569651	5.414518843	4.79571669	4.641016151	4.022213998	3.944863729	3.480762114
14	14	0.071771875	7.17718749	6.531240616	5.885293742	5.813521867	5.239346867	5.024031243	4.449856244	4.306312494	3.732137495	3.66036562	3.22973437
15	15	0.06694671	6.694670951	6.092150566	5.48963018	5.422683471	4.887109795	4.686269666	4.15069599	4.016802571	3.481228895	3.414282185	3.012601928
16	16	0.062731434	6.273143387	5.708560482	5.143977577	5.081246144	4.579394673	4.391200371	3.8893489	3.763886032	3.262034561	3.199303127	2.822914524
17	17	0.059016994	5.901699437	5.370546488	4.839393539	4.780376544	4.308240589	4.131189606	3.659053651	3.541019662	3.068883707	3.009866713	2.655764747
18	18	0.05571893	5.571893023	5.070422651	4.568952279	4.513233348	4.067481907	3.900325116	3.454573674	3.343135814	2.897384372	2.841665442	2.50735186
19	19	0.052770798	5.277079839	4.802142654	4.327205468	4.27443467	3.852268283	3.693955887	3.2717895	3.166247904	2.744081516	2.691310718	2.374685928
20	20	0.050119604	5.011960422	4.560883984	4.109807546	4.059687942	3.658731108	3.508372295	3.107415462	3.007176253	2.606219419	2.556099815	2.25538219
21	21	0.047722558	4.772255751	4.342752733	3.913249715	3.865527158	3.483746698	3.340579025	2.958798565	2.86335345	2.48157299	2.433850433	2.147515088
22	22	0.045544726	4.554472559	4.144570029	3.734667498	3.689122773	3.324764968	3.188130791	2.823772987	2.732683535	2.368325731	2.322781005	2.049512652
23	23	0.043557307	4.35573065	3.963714892	3.571699133	3.528141827	3.179683375	3.049011455	2.700553003	2.61343839	2.264979938	2.221422632	1.960078793
24	24	0.041736339	4.173633889	3.798006839	3.422379789	3.38064345	3.046752739	2.921543722	2.587653011	2.504180333	2.170289622	2.128553283	1.87813525
25	25	0.040061725	4.006172487	3.645616963	3.285061439	3.244999714	2.924505915	2.804320741	2.483826942	2.403703492	2.083209693	2.043147968	1.802777619
26	26	0.038516481	3.851648071	3.504999745	3.158351419	3.119834938	2.811703092	2.69615365	2.388021804	2.310988843	2.002856997	1.964340516	1.733241632
27	27	0.037086156	3.708615553	3.374840153	3.041064753	3.003978598	2.707289354	2.596030887	2.299341643	2.225169332	1.928480088	1.891393932	1.668876999
28	28	0.035758376	3.575837561	3.254012181	2.9321868	2.896428424	2.61036142	2.503086293	2.217019288	2.145502537	1.859435532	1.823677156	1.609126902
29	29	0.034522484	3.452248382	3.141546028	2.830843674	2.79632119	2.520141319	2.416573868	2.140393997	2.071349029	1.795169159	1.760646675	1.553511772
30													

Figure 8: The optimizing matrix

cells are populated and the matrix is created. We can see that the plot is along the diagonal lines , these lines implies that the system is taking the longest performable path . Due to rapidly changing cluster heads the setup phase of LEACH-C do not perform if the schema of changing cluster heads are done above the yellow line as seen in the optimizing matrix.

If we attempt to move below the green line ,it is against the system under consideration because the LEACH-C protocol operates with decreasing number of alive nodes. It also is seen that the sum of all the cluster heads produced along the green line is lowest as compared with the previous sums obtained at the preceding rows.Thus in the number of (alive node - cluster) space this green line is the optimised cluster head varying scheme.

10. Appendix B

Below we describe the C style algorithm representation of equation 1. In the diagram below we see the step called control the number of Chs in Figure 8 .This process is responsible for the execution of the cluster head controlling algorithm generated due to equation 1 Figure 9 and Figure 10.

In order to plot the cluster heads for example in case of variable clustering LEACH-C we get the following results from Table 5 which is plotted in optimization matrix as yellow.Similarly we plot the original LEACH-C with the following results from the Table 6 and the plot is shown in cyan.

No. of alive nodes	**No. of clusters**
100	5
91	5
81	5
73	5
70	6
60	6
51	6

Table 6: Variable clustering LEACH-C alive nodes and number of clusters

No. of alive nodes	**No. of clusters**
100	5
82	5
73	5
70	5
60	5
52	5

Table 7: LEACH-C original alive nodes and number of clusters

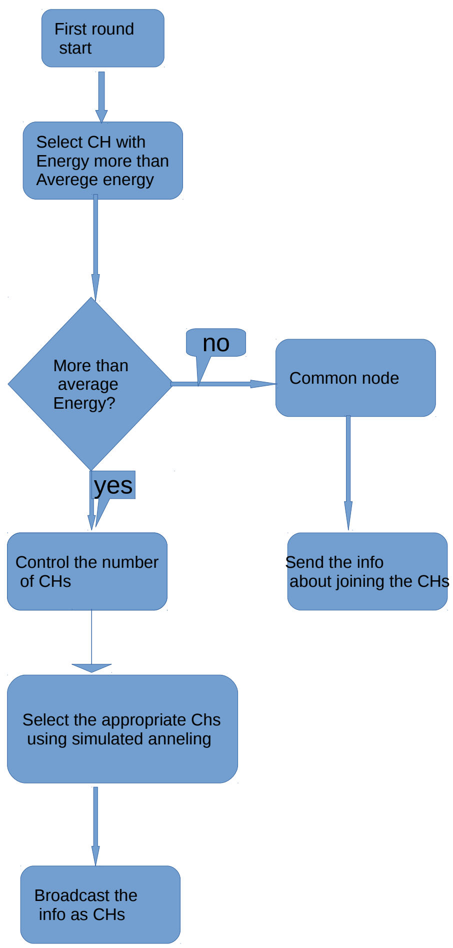

Figure 9: The Flow Chart for LEACH-C Protocol

```
//nn_ the total number of nodes
//w the number of alive nodes
//p_the number of clusters
num_conn=((double)(w)/(double)(p_))-0.5;
 t=int (num_conn);
 num_conn=(double)t;
 if((num_conn - 1)<= 0)
          {
     z=p_;
          }
 else
 {
 printf("%f the connection\n",num_conn);
  proba=0.5*(pow((num_conn + 3)/(num_conn - 1) , 0.5) - 1);
  printf("%f the probability\n",proba);
//w is the alive nodes
 z=(int)((w*proba)+ 0.5);
  }
```

Figure 10: Algorithm for variable LEACH-C

```
//nn_ the total number of nodes
//w the number of alive nodes
//p_the number of clusters
num_conn=((double)(w)/(double)(p_))-0.5;
 t=int (num_conn);
 num_conn=(double)t;
 if((num_conn - 1)<= 0)
          {
     z=1;
          }
 else
 {
 printf("%f the connection\n",num_conn);
  proba=0.5*(pow((num_conn + 3)/(num_conn - 1) , 0.5) - 1);
  printf("%f the probability\n",proba);
//w is the alive nodes
 z=(int)((w*proba)+ 0.5);
if(z==0){z=1;}else {z=z;}
  }
```

Figure 11: Algorithm for modified LEACH/LEACH-C