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NETWORK LIFETIME MAXIMIZATION BASED ON ENERGY FORECAST AND COMPRESSIVE SENSING WITH INTEGRATED SINK MOBILITY FOR HETEROGENOUS WIRELESS SENSOR NETWORKS

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ABSTRACT

Optimum usage of battery resources and efficient consumption of energy are the primary concerns and design parameters for any WSN. Irregular energy consumption is the major problem in current WSNs. This paper focuses on efficiently using the energy resources and to maximize the network lifetime by the application of compressive sensing and optimum CH selection process coupled with sink mobility model. Compressive sensing allows us to reduce the number of transmissions taken for complete data transfer, while optimum CH election mechanism gives efficient energy consumption at the initial stages of transmissions and data transfer. The residual energy of the network is further optimized by using the sink mobility model, increasing the total lifetime of high energy nodes thereby leading to increased network lifetime. The algorithm was simulated in MATLAB and verified.

Keywords—*Wireless Sensor Network, Compressive Sensing, Sink Mobility*

1. INTRODUCTION

The new and recent advances in technology of microelectronic have made it possible to construct compact and inexpensive wireless sensors. Wireless Sensor networks [6,12,10,7] have been receiving significant attention due to its application in intelligent building, health care, military use etc. Improved technologies, enabling us to create massive sensor networks [14] call for the availability of efficient techniques for data aggregation and transmission, at reduced energy costs [15]. This paper deals with solving the issues of the main constraint of any WSN: The network lifetime. It's mainly due to finite battery energies, computational power and memory efficiency. Previous protocols that dealt with 4 level heterogeneity like BEENISH [7], iBEENISH, MBEENISH and iMBEENISH [3] did not consider the prospects offered by compressive sensing. This paper focuses on increasing the network lifetime by efficient cluster head election process [1] and by using compressive sensing [2] to efficiently transmit the data by reducing the total number of transmissions. The concept of sink mobility [3] is also incorporated to optimize the residual energy of high energy nodes and hence optimizing the energy depletion and thereby leading to network lifetime maximization. BEENISH and iBEENISH faces the issue of poor stability period [5], while MBEENISH and iMBEENISH is inefficient for large scale WSN. The proposed algorithm works with a higher efficiency for vast areas which are practically used.

2. OVERVIEW

A. Cluster Head Election

The proposed work overcomes the limitations of the previous algorithms associated with heterogeneous wireless sensor networks that led to inefficient CH election. The proposed algorithm follows a more efficient way to elect CH. The nodes are divided into four heterogeneity levels. Cluster head selection depends on the probability of a node to become a CH which varies with each node depending upon its residual energy and initial energy level. This ensures that the nodes which have higher energy have more probability of being assigned as a CH; which ensure a good stability period [5] for the network.The algorithm starts with the specification of the network simulation parameters and the creation of a random sensor network [3]; where nodes are scattered randomly over the network with four energy levels, which are:

Normal Nodes: E_0

Advanced Nodes: $E_0(1+a)$, m*n nodes

Super Nodes: E_0 (1+b), m*m_0*n nodes

Super Ultra Nodes: E_0 (1+u), m*m_0*m_1*n nodes

Where, a=2, b=2.5, u=3; advanced, super and super ultra-nodes are a fraction of normal nodes as m=0.6, m_0=0.5 and m_1=0.3 respectively, and n is the total number of nodes. The Cluster head selection follows a probabilistic approach (or probability model) [3] and is given by equation (1) below as:

Probabilistic Model:

$$p_i = \begin{cases} \dfrac{p_{opt}E_i(r)}{\left(1+m\left(a+m_0\left(-a+b+m_1(-b+u)\right)\right)\right)\bar{E}(r)} & \text{for normal node if } E_i(r) > T_{absolute} \\[2ex] \dfrac{p_{opt}(1+a)E_i(r)}{\left(1+m\left(a+m_0\left(-a+b+m_1(-b+u)\right)\right)\right)\bar{E}(r)} & \text{for advanced node if } E_i(r) > T_{absolute} \\[2ex] \dfrac{p_{opt}(1+b)E_i(r)}{\left(1+m\left(a+m_0\left(-a+b+m_1(-b+u)\right)\right)\right)\bar{E}(r)} & \text{for super node if if } E_i(r) > T_{absolute} \\[2ex] \dfrac{p_{opt}(1+u)E_i(r)}{\left(1+m\left(a+m_0\left(-a+b+m_1(-b+u)\right)\right)\right)\bar{E}(r)} & \text{for ultra-super node if } E_i(r) > T_{absolute} \\[2ex] \dfrac{c * p_{opt}(1+u)E_i(r)}{\left(1+m\left(a+m_0\left(-a+b+m_1(-b+u)\right)\right)\right)\bar{E}(r)} & \text{for all nodes if } E_i(r) \le T_{absolute} \end{cases} \quad \text{--(1)}$$

Where

m = fraction of normal nodes for advanced nodes.

m0 = fraction of normal nodes for super nodes.

m_1 = fraction of normal nodes for ultra-super nodes.

a = fraction of additional energy for the advanced nodes.

b = fraction of additional energy for the super nodes.

u = fraction of additional energy for the ultra-super nodes

p_{opt} = optimal CH selection probability of a node.

$\bar{E}(r)$ = average energy of network during round r

$\bar{E}_i(r)$ = average energy of node I during round r

$T_{absolute}$ = absolute residual energy of the network.

The optimum probability of cluster head selection p_{opt} is set as 0.1, and the average energy of the network is calculated the same way as explained in iMBEENISH. The above mentioned probability calculation ensures higher energy nodes are selected more frequently as well as u pon reaching homogeneity in the network, the probabilities follow one equation to ensure fair selection of cluster heads in the heterogeneous phase of the network.

B. Quadrant Formation

After the cluster head election, clusters are formed and the area is divided into 4 quadrants [1], which are decided by the location of the CH.

Prior to the division of clusters, selection of the cluster head is done via analogous universal gravitation [16]. This is done so as to ensure that the nodes select their cluster heads, and subsequently their clusters not only on the basis of distance but also residual energy of the cluster heads.[17][18]. The calculated gravitation between a node and a cluster head s_j in the r^{th} round is given by equation (2) below as:

$$F(i,j,r) = \frac{E^j_{res}(r)}{d^2(i,j)} \qquad (2)$$

Where $F(i,j,r)$ is the calculated gravitation between a node and a cluster head s_j in the r^{th} round; $E^j_{res}(r)$ is the residual energy of the cluster head for that round. [19][20].Cluster head that posesses a greater value of gravitation is selected as the cluster head for that node.

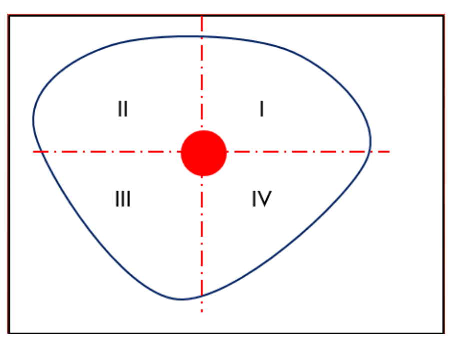

Fig 1: Quadrant Division After CH Election

For each of these quadrants [shown in Fig 1], a relay node is selected, which acts as an intermediary node for all the nodes that may reside in that specific quadrant. A relay node is chosen as to aggregate all the data from its quadrant and forward it to the CH. The selection of relay node [1] is designed to reduce the overall distance cost to each of the nodes.

$$w = \frac{\gamma}{E_{res}} + \frac{1-\gamma}{v}\sum_{i=1}^{v}(d_i - d_{iCH})^2 \qquad (3)$$

Where

v: number of nodes in the sub-cluster,

γ : weighted variable;

E_{res} : residual energy of cluster head associated with the parent cluster of the subcluster;

d_i : distance between nodes;

d_{iCH} : distance between the node and the cluster head.

This function allows for the minimization of the variance of the distance of the nodes from the relay node; this is done to achieve a more uniform distribution around the relay node, a requirement of any node that may act as an intermediary between the cluster head and a non-cluster member node.

The node with the minimum calculated *w* possesses on an overall greater energy and minimum distance variance as compared to other nodes.

The node with the minimum value of w is used as a relay node. This ensures a relay node with overall higher energy as compared to the other nodes as well as lower distance variance of the rest of the nodes around it, resulting in an even spread of nodes around the relay node. This reduced distance as well as energy costs.

The data is aggregated at the level of the relay nodes and the pushed forward to the cluster head, where it is aggregated and compressed with a specific compression ratio [as shown in Fig 2]. The cluster heads are then visited by a mobile sink which optimizes the path along the cluster heads and collects the data.

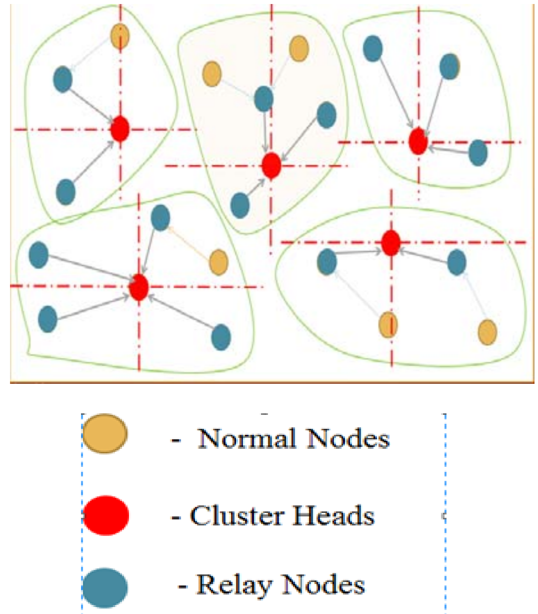

Fig 2: Sensor Network

C. Compressive Sensing

Once the data is aggregated at the level of relay nodes, it is pushed forward to the cluster head, where it is aggregated and compressed with a specific compression ratio [2]. The optimal number of cluster head is given by equation (4) below as:

$$k_{opt} = \sqrt{\frac{n}{2*\pi}} * \sqrt{\frac{E_{fs}}{E_{mp}}} * \frac{x_m}{(d_{toBS})^2} \qquad (4)$$

Where,

k_{opt} is the Optimum number of cluster head [3]

N = round(n/k_{opt}) + 1;

M = round(N/c_r) + 1

q = mod(r,M+2)

where n: total number of nodes

c_r: compression ratio

r: number of round

q: reduced number of round

round(a/b): rounding off the value ‘a/b’

Based on various scenarios, the value of q varies for each round. In the proposed algorithm, for q = 1, CH election is performed and for every other value of q, data transmission takes place [21][22].

Taking these formulae into consideration, for the 1st simulation scenario, we obtain k_{opt} as 23.91, and with compression ratio as 5, we reach the value

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of M+2 as 4, which means that after every 3rd round, we need to appoint new cluster heads.The previous 4 level heterogeneity based WSN algorithms like the variants of BEENISH appoint a new CH every round. The proposed algorithm nullifies the need to appoint a new cluster head every round and hence reduces the overall number of transmissions [23][24].

D. Mobile Sink

The aggregated data is then held at the cluster head after compression takes place. These cluster heads are then visited by a mobile sink [3] which optimizes the path along the cluster heads and collects the data [25][26].The transmission of data follows the first order radio model, as described in numerous papers [3][10][6][7]. The following Fig 3 shows the flowchart of the proposed algorithm

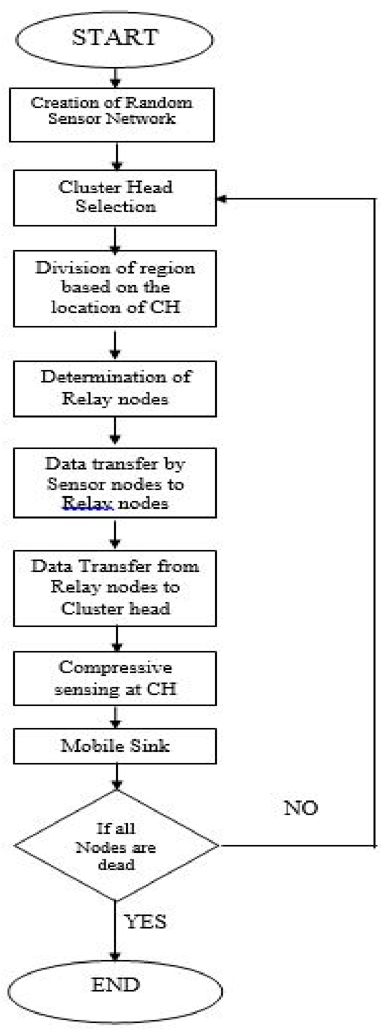


Fig 3: Flowchart Of The Proposed Algorithm.

3. SIMULATION PARAMETERS

The simulations were executed on the software MATLAB R2015a.

Table 1 below shows the values of various simulation parameters.

Table 1: Technical Specifications And Simulation Parameters

Parameter	Value
Region Dimensions	100*100 200*200 500*500
Number of nodes	100,200,500
Initial Energy (E_0)	0.5 J
Energy consumed by radio electronics in transmit mode (E_{Tx})	50 nJ/bit
Energy consumed by radio electronics in receiving mode (E_{Rx})	50 nJ/bit
Energy consumed by the Power amplifier on the free space model (E_{fs})	10 pJ/bit/m^2
Energy consumed by the Power amplifier on the multi path model (E_{amp})	0.0013 pJ/bit/m^2
Energy consumed for data aggregation	5 nJ/bit/signal

Normal nodes have E_0 intital energy, advanced nodes have 2 times, super nodes have 2.5 times and ultra-super nodes have 3 times the energy of normal nodes.

For simulation in first scenario:
- Normal nodes: 40
- Advanced nodes: 30
- Super nodes: 21
- Ultra-super nodes: 9

For simulation in second scenario:
- Normal nodes: 80
- Advanced nodes: 60
- Super nodes: 42
- Ultra-super nodes: 18

For simulation in third scenario:
- Normal nodes: 200
- Advanced nodes: 150

Super nodes: 105
Ultra-super nodes: 45

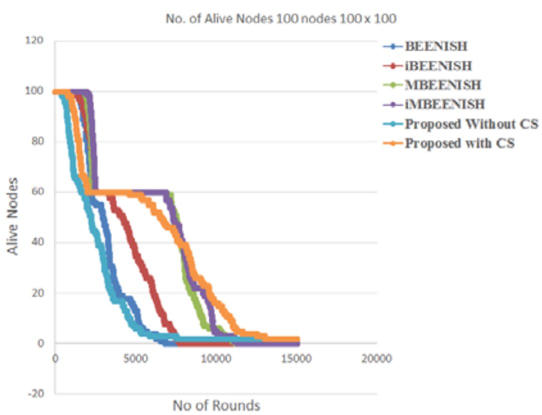
The optimal election probability is 0.1, the energy of the mobiles sink is assumed to be infinite and the packet length is taken to be 4000 bits, along with compression ratio of 5.

4. RESULTS

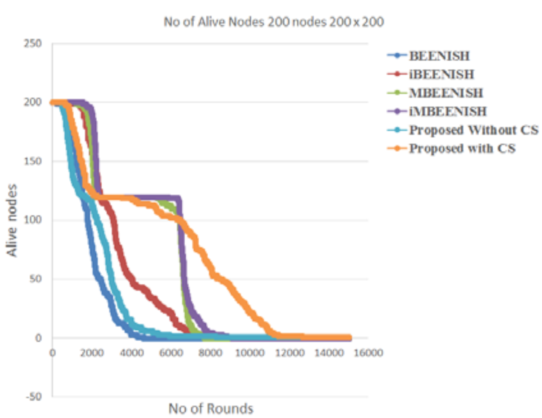
Three scenarios are taken into consideration, 100 nodes in a sensor field of 100 * 100 dimension, 200 nodes in a sensor field of 200 * 200 dimension and 500 nodes in a sensor field of 500 * 500. The parameters of comparison are: Number of Alive nodes, Throughput, Residual Energy and CH count. The algorithm defined in this paper is compared with the protocols – BEENISH, iBEENISH, MBEENISH and iMBEENISH.

The following Fig 4 shows the alive nodes during the network lifetime.

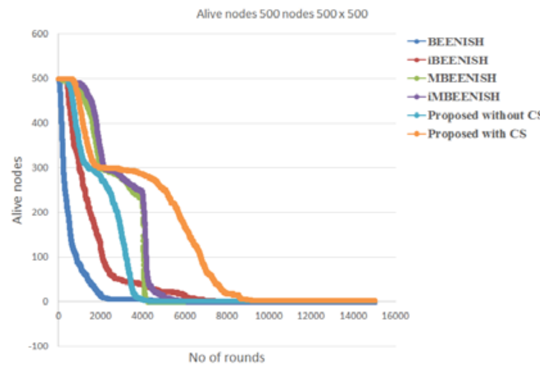
E. *Alive Nodes*



*(A) Alive Nodes For Dimension 100m*100m With 100 Nodes.*



*(B) Alive Nodes For Dimension 200m*200m With 200 Nodes.*



*(C) Alive Nodes For Dimension 500m*500m With 500 Nodes.*

Fig 4:(a-c) Alive Nodes During The Network Lifetime.

The analysis of the network for these different areas shows that the proposed algorithm performs best for larger networks, i.e. 500×500 $m2$ with 500 nodes. Increasing the area of region decreases the stability period for the variants of BEENISH protocols; while it increases in the proposed algorithm. This is due to the presence of relay nodes that reduce the distance needed to transmit by a particular node, thereby saving up on energy. Here the multi-hop transmission helps in conserving energy. The tabular analysis and graphical representation of the network lifetime (indicated by the death of last node) for different scenarios are given below in Table 2:

Table 2: Last Dead Nodes Of Protocols.

Protocol/ Area of region, Nodes	**100×100 $m2$, 100 nodes**	**200×200 $m2$, 200 nodes**	**500×500 $m2$, 500 nodes**
BEENISH	5690	4751	4394
iBEENISH	7336	7061	6872
MBEENISH	10324	7272	4141
iMBEENISH	10039	8110	5626
PROPOSED WITHOUT CS	5343	5315	4073
PROPOSED WITH CS	11612	11162	9146

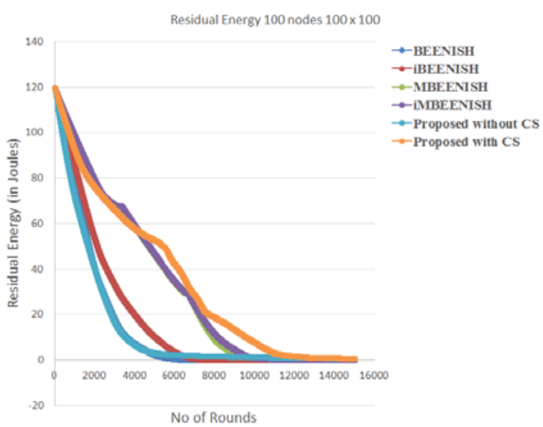
Assuming iMBEENISH to be the benchmark, the comparison all the rest of the protocols and their lifetimes as compared to iMBEENISH is shown in the following Table 3:

Table 3: Percentage Comparison Of Last Dead Nodes Of Protocols.

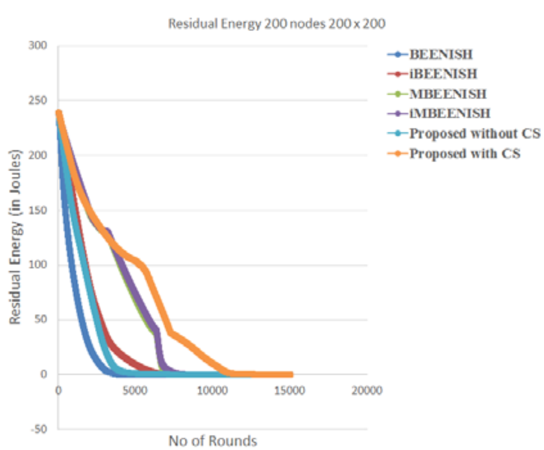
Protocol	100 nodes 100 x100	200 nodes 200 x 200	500 nodes 500 x 500
BEENISH	56.67%	48.71%	78.1%
iBEENISH	73%	87.06%	122.14%
MBEENISH	102.8%	89.66%	73.60%
iMBEENISH	100%	100%	100%
Proposed without CS	53.22%	65.53%	72.39%
Proposed with CS	115%	137.6%	162.56%

F. Residual Energy

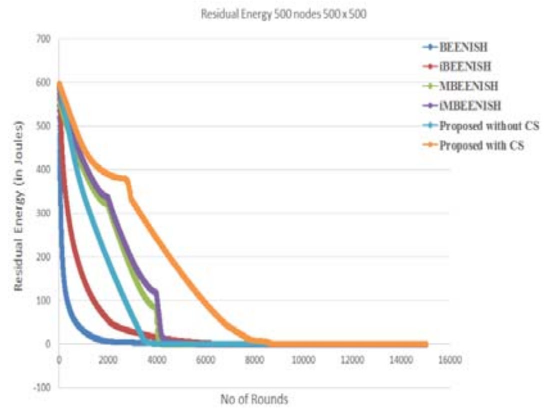
The following Fig 5 shows the Residual energy of nodes during the entire network.



*(A) Residual Energy For Dimension 100m*100m With 100 Nodes.*



*(B) Residual Energy For Dimension 200m*200m With 200 Nodes.*



*(C) Residual Energy For Dimension 500m*500m With 500 Nodes.*

Fig 5: (A-C) Residual Energy During The Entire Network.

The analysis of the network for these different areas shows that the proposed algorithm performs best among all the other protocols. Increasing the area of region, which for the previous protocols causes an increase in the rate of residual energy dissipation, has little to no effect on the proposed algorithm. This is due to the improved clustering structure as well as the application of compressive sensing that helps extend the lifetime of the system.

The tabular analysis and graphical representation of the residual energy (in joules) in after 4500 rounds for different scenarios are given below:

Table 4: Residual Energy After 4500 Rounds.

Protocol/ Area of region, Nodes	100×100 m2, 100 nodes	200×200 m2, 200 nodes	500×500 m2, 500 nodes
BEENISH	4.5136	0.0277	1.477
iBEENISH	14.4940	13.7589	10.7852
MBEENISH	52.3786	83.9829	0
iMBEENISH	52.7226	87.9359	6.1484
PROPOSED WITHOUT CS	4.3608	2.1086	0.8049
PROPOSED WITH CS	54.8613	107.4880 9	201.5039

For the first scenario, the above analysis shows that in terms of stability, the proposed algorithm is 12.15 times better than BEENISH, 3.7 times better than iBEENISH, 1.03 times better than

MBEENISH and 1.04 times better than iMBEENISH.

For the second scenario, the above analysis shows that in terms of stability, the proposed algorithm is 378.6 times better than BEENISH, 7.8 times better than iBEENISH, 1.28 times better than MBEENISH and 1.22 times better than iMBEENISH.

For the third scenario, the above analysis shows that in terms of stability, the proposed algorithm is 136 times better than BEENISH, 18.7 times better than iBEENISH and 32.7 times better than iMBEENISH.

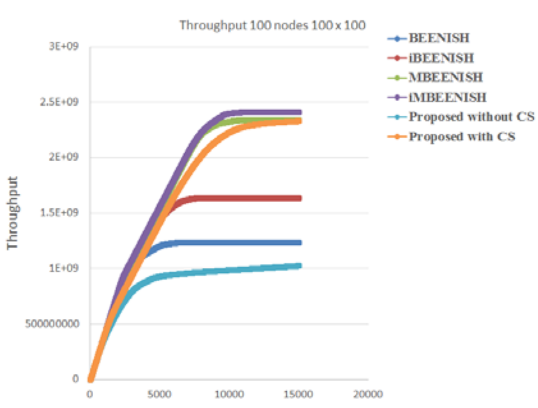
The percentage comparison of the residual energies is given in Table 5 below:

Table 5: Percentage Comparison Of Residual Energy After 4500 Rounds

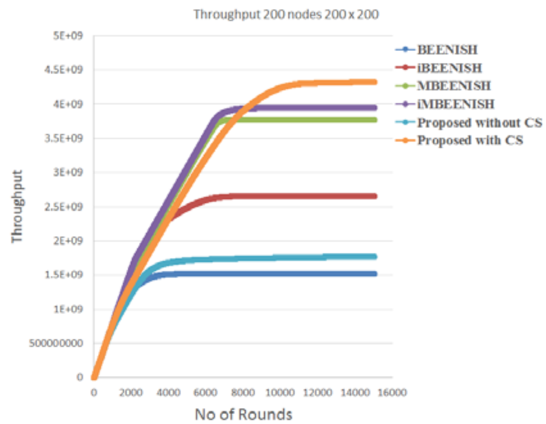
Protocol	**100 nodes 100 x100**	**200 nodes 200 x 200**	**500 nodes 500 x 500**
BEENISH	8.5%	0.000315%	24.02%
iBEENISH	27.49%	15.6%	175.41%
MBEENISH	99.34%	95.5%	0%
iMBEENISH	100%	100%	100%
Proposed without CS	8.27%	0.023%	13.09%
Proposed	104.05%	122.2%	3889.12%

G. Throughput

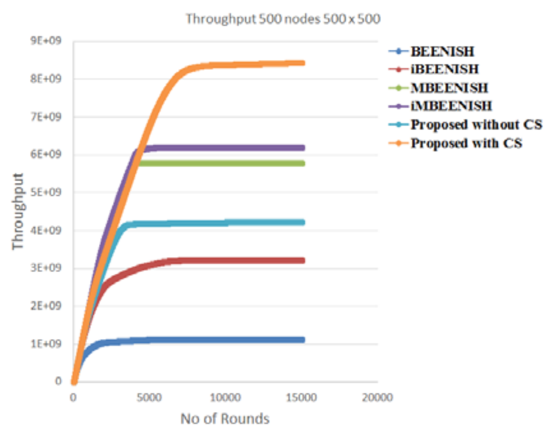
The following Fig 6 shows the throughput during the entire network.



*(A) Throughput For Dimension 100m*100m With 100 Nodes.*



*(B) Throughput For Dimension 200m*200m With 200 Nodes.*



*(C) Throughput For Dimension 500m*500m With 500 Nodes.*

Fig 6: (a-c) Throughput During The Entire Network.

The analysis of the network for these different areas shows that the proposed algorithm performs best in the last region, i.e. 500×500 m^2 with 500 nodes. The increased number of nodes as well as area poses several drawbacks for the discussed protocols, such as BEENISH, MBEENISH and iMBEENISH. These problems are less effective when it comes to the proposed algorithm, as demonstrated by the increased lifetime. The tabular analysis and graphical representation of throughput of the network (indicated by the throughput at last round) for different scenarios are given below.

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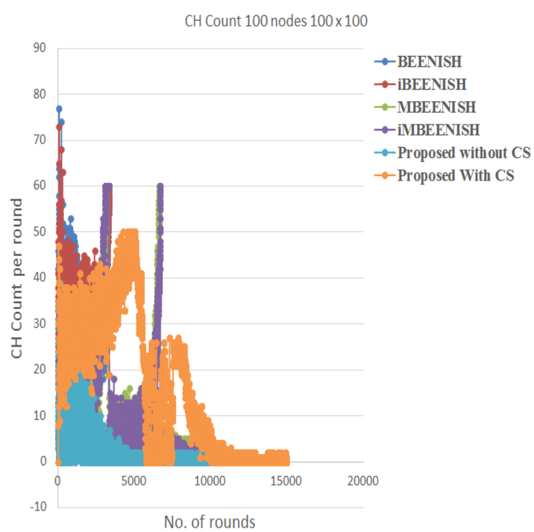
Table 6: Throughput Of The Protocols After 15000 Rounds

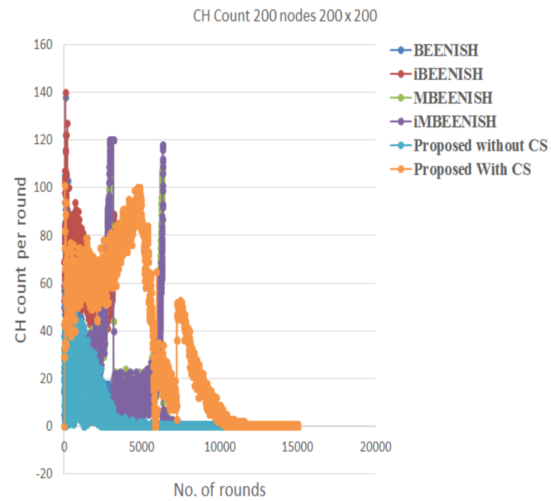
Protocol/ Area of region, Nodes	100×100 m^2, 100 nodes	200×200 m^2, 200 nodes	500×500 m^2, 500 nodes
BEENISH	1239344000	1520424000	1133212000
iBEENISH	1637060000	2660504000	3223060000
MBEENISH	2343744000	3782680000	5788096000
iMBEENISH	2416980000	3948564000	6201576000
PROPSED WITHOUT CS	1027544000	1778112000	4236748000
PROPOSED WITH CS	2333260000	4328056000	8441644000

H. CH Count

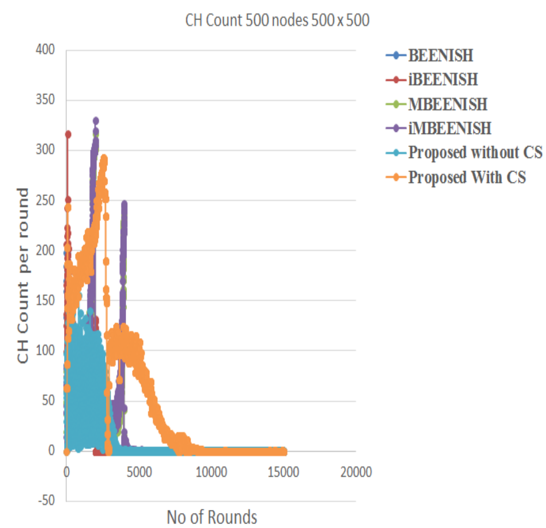
The following Fig 7 shows the Cluster Head count during the network lifetime.



*(A) CH Count For Dimension 100m*100m With 100 Nodes.*



*(B) CH Count For Dimension 200m*200m With 200 Nodes.*



*(C) CH Count For Dimension 500m*500m With 500 Nodes.*

Fig 7:(a-c) CH Count During The Network Lifetime.

The average cluster heads elected during lifetime of various protocols for different nodes is given in Table 7 below:

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Table 7: Average Cluster Heads Elected During Lifetime Of The Protocols.

Algorithm	100 nodes 100 x 100	200 nodes 200 x 200	500 nodes 500 x 500
BEENISH	31.79	28.79	28.138
iBEENISH	35.41	58.848	83.59
MBEENISH	10.44	27.74	63.2
iMBEENISH	10.169	26.36	58.27
Proposed without CS	4.23	13.18	33.74
Proposed with CS	20.58	42.92	94.74

5. PERFORMANCE EVALUATION

We evaluate our algorithm by comparing it with the variants of BEENISH in terms of: network lifetime, residual energy and throughput.

I. Network Lifetime

1. *100 nodes in 100 x 100 dimension WSN field*
   Proposed algorithm performs nearly 12% times better than iMBEENISH and MBEENISH.
2. *200 nodes in 200 x 200 dimension WSN field*
   Proposed algorithm is 35% times better than iMBEENISH.
3. *500 nodes in 500 x 500 dimension WSN field*
   The proposed algorithm gives 33% better results than iBEENISH and higher for all the other algorithms.

J. Residual Energy

1. *100 nodes in 100 x 100 dimension WSN field after 5000 rounds*
   The network is left with 13% more energy in the proposed algorithm as compared to iMBEENISH.
2. *200 nodes in 200 x 200 dimension WSN field after 5000 rounds*
   The network has 41% more residual energy in proposed algorithm when compared with iMBEENISH.
3. *500 nodes in 500 x 500 dimension WSN filed after 5000 rounds*
   The residual energy of the network is manifolds high in proposed algorithm than any variant of BEENISH.

K. Throughput

1. *100 nodes in 100 x 100 dimension WSN field*
   The proposed algorithm is 3% weaker than iMBEENISH but performs better than the other variants of BEENISH.
2. *200 nodes in 500 x 500 dimension WSN field*
   The proposed algorithm is nearly 9% more efficient than iMBEENISH.
3. *500 nodes in 500 x 500 dimension WSN field*
   The proposed algorithm is 36% better than iMBEENISH.

Based on this analysis, it can be clearly observed that the proposed algorithm overcomes the drawbacks of BEENISH[8] and iBEENISH, by being highly efficient in CH election and with higher stability period as well. Also, it solves the problem of MBEENISH and iMBEENISH as it performs more efficiently when the area and the number of nodes increase.

6. CONCLUSION

The proposed algorithm is defined for a 4 level heterogeneous WSN with nodes categorized into 4 different energy levels. The algorithm focuses on CH selection based on the initial and residual energy of the nodes. This allows the nodes with higher energy (ultra-super or super) to be elected as CH more often than the low energy nodes (advanced or normal). The quadrant division takes place after CH election and relay nodes are selected for each quadrant. The selection of relay nodes reduces the load on the CH. Compressive sensing plays a crucial role in the efficiency of the algorithm as it focuses on reducing the number of transmissions and hence reduce a lot of unnecessary transmissions and subsequently any form of unnecessary consumption of energy. The data is aggregated and compressed at the CH which is then collected by a mobile sink which follows the sink mobility model. Incorporating sink mobility reduces the energy consumption furthermore and hence maximizes the network lifetime.

The proposed algorithm performs better in terms of both throughput and network lifetime when compared with previous 4 level heterogeneity protocols. The addition of compressive sensing significantly improves the performance of the proposed algorithm and hence is better than all 4 variants of BEENISH, i.e. BEENISH, iBEENISH, MBEENISH and iMBEENISH. However when the number of nodes is less (100) then the throughput of the proposed algorithm is 3% weaker than iMBEENISH.(but performs better than the other variants of BEENISH). Any future advancements in the algorithm can include the use of computational intelligence techniques, such as metaheuristic algorithms [4][9][11][17] and other techniques to improve clustering as well as data routing techniques.

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