NETWORK LIFETIME MAXIMIZATION BASED ON ENERGY FORECAST AND COMPRESSION SENSING WITH INTEGRATED SINK MOBILITY FOR HETEROGENEOUS 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: \( E_0(1+a), m^n \text{ nodes} \)
Super Nodes: \( E_0 (1+b), m^m m^n \text{ nodes} \)
Super Ultra Nodes: \( E_0 (1+u), m^m m^m m^n \text{ nodes} \)

Where, \( a=2, b=2.5, u=3 \); advanced, super and super ultra-nodes are a fraction of normal nodes as \( m=0.6, m^m=0.5 \) and \( m^m=0.3 \) 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:

\[
p_{opt} = \frac{p_{opt}E_{r}}{(1 + m(a + m(-a + b + m(-b + u)))E(r)}
\]

Where \( p_{opt} \) = optimal CH selection probability of a node.

\( E(r) = \) average energy of network during round \( r \)
\( E_i(r) = \) 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 upon 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:

\[
F(i,j,r) = \frac{E_{res}(r)}{d^2(i,j)}
\]

Where \( F(i,j,r) \) is the calculated gravitation between a node and a cluster head \( s_j \) in the \( r \)th round;
\( E_{res}(r) \) is the residual energy of the cluster head for that round. [19][20].Cluster head that possesses 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.

\[ w = \frac{y}{E_{\text{res}}} + \frac{1 - y}{v} \sum_{i=1}^{v} (d_i - d_{\text{CH}})^2 \]  

(3)

Where

- \( v \): number of nodes in the sub-cluster,
- \( y \): weighted variable;
- \( E_{\text{res}} \): residual energy of cluster head associated with the parent cluster of the sub-cluster;
- \( d_i \): distance between nodes;
- \( d_{\text{CH}} \): 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 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 [2]. The optimal number of cluster head is given by equation (4) below as:

\[ k_{\text{opt}} = \sqrt{\frac{n}{2 \pi}} \times \frac{E_{fs}}{E_{mp}} \times \frac{x_m}{(d_{\text{toBS}})^2} \]  

(4)

Where,

- \( k_{\text{opt}} \) is the Optimum number of cluster head [3]
- \( N = \text{round}(n/k_{\text{opt}}) + 1 \)
- \( M = \text{round}(N/c) + 1 \)
- \( q = \text{mod}(r,M+2) \)

where \( n \): total number of nodes
- \( c \): compression ratio
- \( r \): number of round
- \( q \): reduced number of round
- \( \text{round}(a/b) \): rounding off the value ‘\( a/b \’

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:

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 \( k_{\text{opt}} \) as 23.91, and with compression ratio as 5, we reach the value
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.

3. SIMULATION PARAMETERS

The simulations were executed on the software MATLAB R2015a.

Table 1 below shows the values of various simulation parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Region Dimensions</td>
<td>100*100</td>
</tr>
<tr>
<td></td>
<td>200*200</td>
</tr>
<tr>
<td></td>
<td>500*500</td>
</tr>
<tr>
<td>Number of nodes</td>
<td>100, 200, 500</td>
</tr>
<tr>
<td>Initial Energy (E₀)</td>
<td>0.5 J</td>
</tr>
<tr>
<td>Energy consumed by radio electronics in transmit mode (Eₜₑₓ)</td>
<td>50 nJ/bit</td>
</tr>
<tr>
<td>Energy consumed by radio electronics in receiving mode (Eᵣₑₓ)</td>
<td>50 nJ/bit</td>
</tr>
<tr>
<td>Energy consumed by the Power amplifier on the free space model (Eₙₑ)</td>
<td>10 pJ/bit/m²</td>
</tr>
<tr>
<td>Energy consumed by the Power amplifier on the multi path model (Eₘₚ)</td>
<td>0.0013 pJ/bit/m²</td>
</tr>
<tr>
<td>Energy consumed for data aggregation</td>
<td>5 nJ/bit/signal</td>
</tr>
</tbody>
</table>

Normal nodes have E₀ 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 mobile 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

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.

<table>
<thead>
<tr>
<th>Protocol</th>
<th>100 nodes</th>
<th>200 nodes</th>
<th>500 nodes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100 x 100</td>
<td>200 x 200</td>
<td>500 x 500</td>
</tr>
<tr>
<td>BEENISH</td>
<td>56.67%</td>
<td>48.71%</td>
<td>78.1%</td>
</tr>
<tr>
<td>iBEENISH</td>
<td>73%</td>
<td>87.06%</td>
<td>122.14%</td>
</tr>
<tr>
<td>MBEENISH</td>
<td>102.8%</td>
<td>89.66%</td>
<td>73.60%</td>
</tr>
<tr>
<td>IMBEENISH</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Proposed without CS</td>
<td>53.22%</td>
<td>65.53%</td>
<td>72.39%</td>
</tr>
<tr>
<td>Proposed with CS</td>
<td>115%</td>
<td>137.6%</td>
<td>162.56%</td>
</tr>
</tbody>
</table>

F. Residual Energy

The following Fig 5 shows the Residual energy of nodes 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.

<table>
<thead>
<tr>
<th>Protocol/ Area of region, Nodes</th>
<th>100×100 m², 100 nodes</th>
<th>200×200 m², 200 nodes</th>
<th>500×500 m², 500 nodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>BEENISH</td>
<td>4.5136</td>
<td>0.0277</td>
<td>1.477</td>
</tr>
<tr>
<td>iBEENISH</td>
<td>14.4940</td>
<td>13.7589</td>
<td>10.7852</td>
</tr>
<tr>
<td>MBEENISH</td>
<td>52.3786</td>
<td>83.9829</td>
<td>0</td>
</tr>
<tr>
<td>IMBEENISH</td>
<td>52.7226</td>
<td>87.9359</td>
<td>6.1484</td>
</tr>
<tr>
<td>PROPOSED WITHOUT CS</td>
<td>4.3608</td>
<td>2.1086</td>
<td>0.8049</td>
</tr>
<tr>
<td>PROPOSED WITH CS</td>
<td>54.8613</td>
<td>107.4880</td>
<td>201.5039</td>
</tr>
</tbody>
</table>

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>
<thead>
<tr>
<th>Protocol</th>
<th>100 nodes</th>
<th>200 nodes</th>
<th>500 nodes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100 x 100</td>
<td>200 x 200</td>
<td>500 x 500</td>
</tr>
<tr>
<td>BEENISH</td>
<td>8.5%</td>
<td>0.000315%</td>
<td>24.02%</td>
</tr>
<tr>
<td>iBEENISH</td>
<td>27.49%</td>
<td>15.6%</td>
<td>175.41%</td>
</tr>
<tr>
<td>MBEENISH</td>
<td>99.34%</td>
<td>95.5%</td>
<td>0%</td>
</tr>
<tr>
<td>iMBEENISH</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Proposed</td>
<td>8.27%</td>
<td>0.023%</td>
<td>13.09%</td>
</tr>
<tr>
<td>Proposed (w/o CS)</td>
<td>104.05%</td>
<td>122.2%</td>
<td>3889.12%</td>
</tr>
</tbody>
</table>

G. Throughput

The following Fig 6 shows the 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 m² 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.
### Table 6: Throughput Of The Protocols After 15000 Rounds

<table>
<thead>
<tr>
<th>Protocol/Area of region, Nodes</th>
<th>100×100 m², 100 nodes</th>
<th>200×200 m², 200 nodes</th>
<th>500×500 m², 500 nodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>BEENISH</td>
<td>1239344000</td>
<td>1520424000</td>
<td>1133212000</td>
</tr>
<tr>
<td>iBEENISH</td>
<td>1637060000</td>
<td>2660504000</td>
<td>5223060000</td>
</tr>
<tr>
<td>MBEENISH</td>
<td>2343744000</td>
<td>3782680000</td>
<td>5788096000</td>
</tr>
<tr>
<td>iMBEENISH</td>
<td>2416980000</td>
<td>3948564000</td>
<td>6201576000</td>
</tr>
<tr>
<td>PROPOSED WITHOUT CS</td>
<td>1027544000</td>
<td>1778112000</td>
<td>4236748000</td>
</tr>
<tr>
<td>PROPOSED WITH CS</td>
<td>2333260000</td>
<td>4328056000</td>
<td>8441644000</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>100 nodes 100 x 100</th>
<th>200 nodes 200 x 200</th>
<th>500 nodes 500 x 500</th>
</tr>
</thead>
<tbody>
<tr>
<td>BEENISH</td>
<td>31.79</td>
<td>28.79</td>
<td>28.138</td>
</tr>
<tr>
<td>iBEENISH</td>
<td>35.41</td>
<td>58.848</td>
<td>83.59</td>
</tr>
<tr>
<td>MBEENISH</td>
<td>10.44</td>
<td>27.74</td>
<td>63.2</td>
</tr>
<tr>
<td>iMBEENISH</td>
<td>10.169</td>
<td>26.36</td>
<td>58.27</td>
</tr>
<tr>
<td>Proposed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>without CS</td>
<td>4.23</td>
<td>13.18</td>
<td>33.74</td>
</tr>
<tr>
<td>Proposed with CS</td>
<td>20.58</td>
<td>42.92</td>
<td>94.74</td>
</tr>
</tbody>
</table>

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 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.

REFERENCES


