An Energy Efficient Hierarchical Clustering Algorithm for Wireless Sensor Networks

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About the paper

- Appeared in INFOCOM 2003
- 11 pages
- 30 references
- Cited by 673 papers
Topic classification

Network Type
- WSN

Issues
- Deployment
- Sensing
- Decision Making
- Routing

Algorithms
- Flat
- Location-based
- Hierarchical

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Paper Structure

- **Introduction**
- **Related Work**
- **Single-level Clustering Alg.**
- **Hierarchical clustering Alg.**
- **Optimal parameters**
- **Algorithm**
- **Simulation Results**
- **Numeric Results**
- **CH Probability**
- **Maximum hops**
- **Additional Consideration**
- **Conclusion & Future Work**
Related Work

- LCA
- LCA2
- WCA
- DCA
- DMAC
- LEACH
- non-purely hierarchical models
Assumptions (1/2)

a) The sensors are distributed as per a homogeneous spatial Poisson process of intensity $\lambda$ in 2-D space.

b) All sensors transmit at the same power level so have the same radio range.

c) Data exchanged between two communicating sensors not within each others’ radio range is forwarded by other sensors.
Assumptions (2/2)

d) A distance of $d$ between any sensor and its cluster head is equivalent to $d/r$ hops.
e) Each sensor uses one unit of energy to transmit or receive one unit of data.
f) A routing infrastructure is in place; so, only the sensors on the routing path forward the data.
g) The communication environment is contention- and error-free. (No retransmit)
Single-level Clustering Algorithm

1. Each sensor becomes a cluster-head (CH) with probability $p$ and advertises itself as a CH to the sensors within its radio range.

2. The advertisement is forwarded to all the sensors that are no more than $k$ hops away from CH. Any sensor that receives such advertisements and is not itself a CH joins the cluster of the closest CH.

3. Any sensor that is neither a CH nor has joined any cluster itself becomes a CH.
Optimal parameters

Probability of becoming a Clusterhead

\[ p = \left[ \frac{1}{3c} \left( \frac{3\sqrt{2}}{3c(2+27c^2 + 3\sqrt{3c\sqrt{27c^2 + 4}}/3} + \frac{(2+27c^2 + 3\sqrt{3c\sqrt{27c^2 + 4}}/3)}{3c} \cdot \frac{1}{\sqrt[3]{2}} \right) \right]^2 \]

where \( c = 3.06a\sqrt{\lambda} \).

Maximum number of hops allowed from a sensor to its clusterhead

\[ k_1 = \left[ \frac{1}{r} \sqrt{- \frac{0.917 \ln(\alpha/7)}{p_1\lambda}} \right]. \]
Results (1/4)
Results (2/4)
## Results (3/4)

<table>
<thead>
<tr>
<th>Number of Sensors ($n$)</th>
<th>Density ($d$)</th>
<th>Probability ($P_{opt}$)</th>
<th>Maximum Number of Hops ($k$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>5</td>
<td>0.1012</td>
<td>5</td>
</tr>
<tr>
<td>1000</td>
<td>10</td>
<td>0.0792</td>
<td>4</td>
</tr>
<tr>
<td>1500</td>
<td>15</td>
<td>0.0688</td>
<td>3</td>
</tr>
<tr>
<td>2000</td>
<td>20</td>
<td>0.0622</td>
<td>3</td>
</tr>
<tr>
<td>2500</td>
<td>25</td>
<td>0.0576</td>
<td>3</td>
</tr>
<tr>
<td>3000</td>
<td>30</td>
<td>0.0541</td>
<td>3</td>
</tr>
</tbody>
</table>
Results (4/4)

![Graph showing energy spent vs density of sensors](graph.png)
Hierarchical Clustering Algorithm (1/2)

- Each sensor decides to become a level-1 CH with $p_1$ and advertises itself as a CH to the sensors within its radio range.
- This advertisement is forwarded to all the sensors within $k_1$ hops of the advertising. Each sensor that receives an advertisement joins the cluster of the closest level-1 CH; the remaining sensors become forced level-1 CHs.
Hierarchical Clustering Alg. (2/2)

- Level-1 CHs then elect themselves as level-2 CHs with a certain probability $p_2$ and broadcast their decision of becoming a level-2 CH. This decision is forwarded to all the sensors within $k_2$ hops.
- The level-1 CHs that receive the advertisements from level-2 CHs joins the cluster of the closest level-2 CH. All other level-1 CHs become forced level-2 CHs.
- CH at level $3,4,\ldots,n$ are chosen in similar fashion, with probabilities $p_3, p_4,\ldots, p_n$ respectively.
Optimal parameters

Probability of becoming a Clusterhead

\[ E[C] = E[E[C \mid N = n]] = \lambda A \prod_{i=1}^{h} p_i \left( \frac{0.765a}{r} \right) + \lambda A \sum_{i=1}^{h} (1 - p_i) \prod_{j=1}^{i-1} (p_j) \left( \frac{1}{2r \sqrt{\lambda \prod_{j=1}^{i} p_j}} \right). \]

Maximum number of hops allowed from a sensor to its clusterhead

\[ k_i = \left[ \frac{1}{r} \sqrt{\frac{-0.917 \ln(\alpha / 7)}{\lambda \prod_{j=1}^{i} p_j}} \right]. \]
Results (1/4)
Results (2/4)
Results (3/4)

![Graph showing the relationship between the number of levels in the clustering hierarchy and the log of total energy spent. The graph includes lines for different values of r.]
Results (4/4)

The graph illustrates the logarithm of the total energy spent versus the number of levels in the clustering hierarchy for different values of \( \lambda \). The parameters are set as follows:

- \( n = 25,000 \)
- \( r = 2 \) units

The graph shows three curves for different \( \lambda \) values:

- \( \lambda = 1.5 \)
- \( \lambda = 5 \)
- \( \lambda = 10 \)

The energy spent decreases as the number of levels increases, with the rate of decrease being more pronounced for higher values of \( \lambda \).
Q&A
Conclusion (1/2)

- A distributed algorithm proposed for organizing sensors into a hierarchy of clusters.
- Objective is minimizing the total energy spent in the system to communicate the information gathered by these sensors to the information-processing center.
- The optimal parameter values found for these algorithms that minimize the energy spent in the network.
Conclusion (2/2)

- Assumed that the communication environment is contention and error free.
- In a contention-free environment, the algorithm has a time complexity of $O(k_1 + k_2 + \ldots + k_h)$, a significant improvement over the many $O(n)$ clustering algorithms in the literature.
- The algorithm is suitable for networks of large number of nodes.
Future Work

- Consider an underlying medium access protocol and investigate how that would affect the optimal probabilities of becoming a CH and the run-time of the algorithm.