Energy Minimization of Sensor Nodes by Placing the Base station in Optimal Location

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Abstract - The Base station placement plays a major role in the wireless sensor network to minimize the energy consumption. A new optimal method (orthocenter-based approach) has been proposed for the two-tier architecture of sensor nodes which may face a problem of path loss. The path loss varies from the node based on their distance to the base station. In this paper, the optimal location for the base station is selected so as to minimize the path loss and increase in the energy utilization. The result shows that new method gives a better solution than the previous method (Centroid-based approach).

Keyword: Energy Utilization, path loss, Orthocenter, centroid

Introduction

A sensor node consumes energy for the following: events sensing, data aggregation, data transmission, modulation and the reception. The sensor network is densely deployed with the limited energy resource and a single base station to collect and process the data. The transmission power for data is proportional to the square of the distance between the sender and the receiver. The data aggregation will be done locally and also by the anchor (base station), so the energy will be more consumed for the data aggregation.

Dorottya et al.\([4]\) discussed about the movement of the base station of a sensor network for the energy conservation for the communication to increase the life time of the network. They followed the three different strategies to reduce the energy Minavg, minimizes the average energy required for the communication. Minmax, minimizes the maximum energy consumption among the active sensor nodes. minrel, minimizes the maximum relative energy consumption of the nodes by considering their remaining battery power. They proved Minavg to be the better among the three.

R.K.Tripathi et al.\([21]\) has proposed an algorithm for the base station placement by considering the distance between the nodes to the base station (placing base station as centroid) using the path loss models.

Kemal Akkaya et al.\([2]\) discussed about dynamic positioning of base station in dealing with dynamic variations in the network resources and surrounding environment. The dynamic positioning of the base station proves the increase in network life time, data delivery and protecting the network efficiency.

System Model

Transceiver Model

The transceiver model is to estimate the energy consumption in the process of base station location optimization. The transmitter utilizes the energy to run the components of transmitter and the power amplifier, and the receiver utilizes the energy to run the components of the receiver. The distance between the transmitter and the receiver determines the usage of energy. If it is greater than threshold \((d_0)\) then the multipath loss model is used otherwise the free space model is used.

In the transceiver, for transmission amplifier the path loss exponent \(n=2\) for free space model and \(n=4\) for multipath loss model. In previous works related to the radio communication for free space the same exponent were used in their model for analyzing optimal base station positioning. The energy used by the amplifier to transmit \(NB\) bits at distance \(d\) is \(E_{\text{amp}}(NB\ , \ d)\).

\[
E_{\text{TX}} = (E_{\text{elec}} \times NB) + (e_{\text{amp}} \times NB \times (\frac{d}{2})^2) \quad (1)
\]

\[
E_{\text{RX}}=E_{\text{elec}} \times NB \quad (2)
\]

\(E_{\text{TX}}\) is the energy of the transmitter. \(E_{\text{RX}}\) is the energy of the receiver and \(E_{\text{amp}}\) is the energy of the amplifier.

\(NB\) is the number of bits

\[
E_{\text{amp}} = \begin{cases} E_{\text{fl}} \times d^2 & \text{if } d < d_0 \\ E_{\text{ml}} \times d^2 & \text{if } d \geq d_0 \end{cases} \quad (3)
\]
Here $\varepsilon_R$ is the free space loss constant measured in J/bit/m$^2$ and $\varepsilon_{ml}$ is the multipath loss constant measured in J/bit/m$^2$.

The redundant data transmission can be eliminated by forming the cluster and by electing a node among the cluster to be a cluster head. Here we have considered the energy model which was used in LEACH (Low Energy Adaptive Clustering Hierarchy). Here the cluster heads are selected among all nodes in each round of data transmission. Each node chooses the nearest node for the data forwarding packets to the base station. In each round of data transmission one cluster head will be selected among all the nodes. The nodes will forward the data packet to the base station by choosing the shortest path (ie) (less hopping between the nodes).

Let $n$ be the nodes distributed in xxx area and $C$ be the cluster in the sector. By an average there will be $\frac{n}{c}$ nodes per cluster. $\frac{n}{c} - 1$ is a non cluster head and $\frac{n}{c}$ is a cluster head in a sector.

The energy used by the amplifier to transmit NB bits to the cluster head distance = Total no. of transmitted bits *(Total. no. of nodes in WSN – No. of. cluster in WSN Topology * Free space loss constant *$l$)

$$l = \frac{(\text{Length of the side of square WSN topology})^2}{2 \pi \cdot \text{Number of cluster in WSN}}$$

Whereas $E_{CH}$ be the Energy of cluster head , $E_{N,CH}$ be the energy of Non cluster head nodes and $E_{CL}$ be the energy of the cluster

$$E_{N,CH} = NB \cdot E_{elec} + NB \cdot E_{fl} \cdot d_{CH}^2$$

$$E_{CL} = E_{CH} + (\frac{n}{c} - 1) \cdot E_{N,CH}$$

The energy dissipated in one round in the network is the sum of energy spent by all the clusters in the network is represented as $E_R$.

$$E_R = \sum_{i=1}^{n} E_{CL}(i)$$

### Energy consumption Model

Case 1:
If the nodes nearer to the base station experience the free space loss when the data transmission is between the nodes to the base station. The $E_R$ can be given as

$$E_R = NB[(2 \cdot n - c) \cdot E_{TX-TR} + n \cdot NB \cdot E_{Ag} + E_{amp} ((NB \cdot d_{bs}(i)) + \sum_{i=1}^{n} E_{amp} ((NB, d_{CH}(i)))$$

$$NB(n - c) \cdot E_{fl} \cdot \frac{x^2}{2nc} = \sum_{i=1}^{n} E_{amp} (NB, d_{CH}(i))$$

The energy consumed in one round is given as

$$E_R = NB[(2n - c) \cdot E_{TX-TR} + n \cdot E_{Ag} + (n-c) \cdot E_{fl} \cdot \frac{x^2}{2nc} + E_{fl} \cdot \sum_{j=1}^{c} d_j^2]$$

Where $d_i$ is the distance between the cluster head to the base station and vice versa, $E_{Ag}$ is the energy used by the data aggregation in the cluster head. After the $\frac{n}{c}$ rounds, once all the nodes became cluster head then the total energy spent is given as,

$$E_T = NB \cdot E_{TX-TR}^2 + n \cdot E_{Ag} + (n-c) \cdot E_{fl} \cdot \frac{x^2}{2nc} + NB \cdot E_{fl} \cdot \sum_{j=1}^{c} d_j^2$$

Case 2:
If the distance between the nodes and the base station is longer during transmission the nodes exhibit the multipath loss. Then $E_T$ is given as

$$E_T = E_1 + NB \cdot E_{fl} \cdot \sum_{j=1}^{c} d_j^4$$

$$E_T \text{ Spent during } \frac{n}{c} \text{ round is}$$

$$E_1 = NB \cdot \frac{n}{c} [(2n - c) \cdot E_{TX-TR} + n \cdot E_{Ag} + (n-c) \cdot E_{fl} \cdot \frac{x^2}{2nc}]$$

Case 3:
When some nodes are near and some nodes are far away from BS then $E_T$ is given as

$$E_T = E_1 + NB \cdot E_{fl} \cdot \sum_{i=1}^{a} d_i^4 + NB \cdot E_{ml} \cdot \sum_{j=1}^{b} d_j^4$$

Where $i$ is the set of nodes in a, nearer to the base station and the $j$ is the set of nodes far away the base station. For the case 1: To the shorter distance the energy for the transmitting data to base station $E_{bs}$ in each $\frac{n}{c}$ round.

$$E_{bs} = NB \cdot E_{fl} \cdot \sum_{j=1}^{n} d_j^2$$

For Case 2:
For the longer distance the energy for the transmitting data to base station $E_{bs}$ is
\[ E_{bs} = NB * \epsilon_{m} * \sum_{j=1}^{n} d_{j}^{4} \]  

**Problem Formulation:**

Here n be the nodes distributed uniformly in the square field at \((a_{1}, b_{1}), (a_{2}, b_{2})\) and \((a_{n}, b_{n})\) respectively and the base station is deployed at \((a, b)\) as shown in the Fig.

The Euclidean distance between the base station and nodes are \(d_{1}, d_{2}, d_{3}, ..., d_{n}\)

\[ d_{i} = \sqrt{(a - a_{i})^{2} + (b - b_{i})^{2}} \]  

Where \(\Delta a = a - a_{i}\) and \(\Delta b = b - b_{i}\)

\(a_{i} \in X, b_{i} \in X\)

\(d_{0}\) is the constant threshold distance for this Model.

**Case 1:**

If \(d_{i} < d_{0}\) : Let the \(d_{i}^{2}\) be the sum of the square of the all Euclidean distance

If the base station is placed in the centroid of the plane X If \(d_{i} < d_{0}\) the nodes will only experience the free space loss as it is nearer to the BS (One hop from the node to the BS)

\[ E_{d} = NB * \epsilon_{m} * (d_{1}^{2} + d_{2}^{2} + ... + d_{n}^{2}) \]  

Where the \(d^{2}\) is minimum at the centroid of the nodes. Thus the energy consumed by the amplifier will also minimum at this place. The energy consumed for a distance is measured as where \(E_{TX-TR}\) is a transceiver.

\[ E_{d} = NB * (2 * n - c) * E_{TX-TR} + \epsilon_{f} \]  

**Case 2:**

If \(d_{i} \geq d_{0}\) means the nodes experience the multipath loss or more than one hop communication to the BS (Base station), so the energy has to be minimized by placing the BS to an optimal place

\[ E_{d} = NB * \epsilon_{m} * (d_{1}^{4} + d_{2}^{4} + ... + d_{n}^{4}) \]  

\(E_{d}^{4}\) is the minimum at a point , say G. This point will be the optimal place to place the base station.

We can determine the optimal place for the base station by the heuristic search method.

\[ x_{i} \& y_{i} \in p, q \]

Where the Total Energy \(E = E_{d}^{4} + E_{d}^{4}\)

The \(x\) and \(y\) are the elements in the set of \(p\) and \(q\).

**Algorithm for the Base station Location**

To find the location of base station \(E_{d}\) is minimum

**Step 1:**

Find the centroid of the nodes in the field. The centroid for the set of \(p\) element is

\[ c_{p} = \frac{\sum_{i=1}^{n} x_{i}}{n}, c_{q} = \frac{\sum_{i=1}^{n} x_{i}}{n}, c_{p} = \frac{\sum_{i=1}^{n} y_{i}}{n}, c_{q} = \sum_{i=1}^{n} \frac{y_{i}}{n} \]  

**Step 2:** Find the nodes that are less distance from the centroid.

**Step3:** Consider the Centroid as one of the three vertex in a plane and find the orthocenter place for the nodes in the field. This is the place where the energy \(E_{d}\) is minimum and it is given as:

For the orthocenter the slope of the side \(AB\) is calculated as

\[ Slope\ of\ AB = \frac{y_{2} - y_{1}}{x_{2} - x_{1}} \]  

The perpendicular slope of the side gives the slope of the altitude and it can be given as

Then the slope of CF is \(m = -\frac{1}{2}\)

The Equation of the CF is given as

\[ y - y_{1} = m(x - x_{1}) \]
Step 4: The Proposed base station distance is estimated as

$$BS_p = d_{1cen} + d_{1o}$$

$d_{1cen}$ is the distance from a vertex of a plane to the centroid.

$d_{1o}$ is the distance from the centroid of a plane to the orthocenter.

$BS_p$ is the proposed base station position.

**Energy Estimation calculation for the Base station at centroid and the orthocenter**

Let us consider three points in a 300 * 300 rectangular area plane, at positions (0,300),(0,0) and (300,300). The centroid for these points is to be (100,200). The distance from the centroid to points 1, 2 and 3 are $d_{1cen}$, $d_{2cen}$ & $d_{3cen}$ respectively.

Here $d_{1cen} = 141.42$ and $d_{2cen} = d_{3cen} = 223.6$. Here the assumption value for the multipath loss constant ($\varepsilon_{ml} = 1.3 \times 10^{-15}$ J/bit/m$^4$) and the free space loss constant($\varepsilon_{fl} = 10^{-11}$ J/bit/m$^2$).

Thus the energy for the nodes at the centroid is J/bit-node for three nodes at the centroid is

$$E_{cen} = (\varepsilon_{fl} \cdot d_{1cen}^2 + \varepsilon_{ml} \cdot d_{2cen}^2 + \varepsilon_{ml} \cdot d_{3cen}^2) / 3 = 2.23 \times 10^{-6}$$ J/bit-node

If BS in optimal place ($d_0 = 87.7$ J/bit-node) so at the position (0,0) (62.01, 237.9) and (300,300) the distance from the optimal place to the points 1,2 and 3 are $d_{1opt}$, $d_{2opt}$ & $d_{3opt}$ respectively. Here $d_{1opt} = 87.7$ and the $d_{2opt}$ and the $d_{3opt} = 245.8$. so the energy for the nodes at the optimal place is $2.00 \times 10^{-4}$ J/bit-node
The slope of AB = \( \frac{y_2-y_1}{x_2-x_1} \)
so the slope of AB = 2
Slope of CF = \(-1/-2 = -0.5\)
The equation of CF is given as \( y-y_1=m(x-x_1) \). By solving the equation is \( 0.5x + y = 450 \) ….. (1)
Similarly the slope of BC and AD is to be computed with the equation of AD is given as \( X+Y=300 \)….. (2)
By solving these two equations (1) and (2) \( x = -300 \) and \( y=600 \).

Fig 3: Energy estimation at the orthocenter of the plane
By considering the orthocenter point as \((-300,600)\), distance from point centroid \((100,200)\) to orthocenter \((-300,600)\) is 447.21. \( d_{\text{ortho}} = 447.21 + d_{\text{cen}} \) (447.21+141.42 =588.63). similarly the \( d_{\text{ortho}} = \) 670.82.

Thus the energy for the nodes at the orthocenter is J/bit-node for three nodes at the ortho is
\[
E_{\text{ortho}} = \left( \varepsilon_{m1} \times d_{1\text{ortho}}^4 + \varepsilon_{m2} \times d_{2\text{ortho}}^4 + \varepsilon_{f1} \times d_{3\text{ortho}}^4 \right) / 3 = 1.76 \times 10^{-4} \ \text{J/bit-node}
\]
The \( d_{1\text{ortho}} \) is computed by \( d_{\text{cen}} \) in addition to the distance between the point of centroid and the orthocenter .
Thus the energy for the nodes in the optimal position is J/bit – node for three nodes at this position is
\[
E_{\text{opti}} = \left( \varepsilon_{m1} \times d_{1\text{opti}}^4 + \varepsilon_{m2} \times d_{2\text{opti}}^4 + \varepsilon_{m3} \times d_{3\text{opti}}^4 \right) / 3 = 2.00 \times 10^{-4} \ \text{J/bit – node}
\]
So by comparing the energy consumption of the positions in the optimal place , centroid , the orthocenter (proposed point) is efficient, so the base station placement in the orthocenter point is better.
The weighted average for the proposed station proposed pr is
\[
A_p = \frac{0.0+d_{3\text{opti}}^2+300}{1+d_{3\text{opti}}^2+300} = 141.02
\]
\[
A_p = \frac{300+0+d_{3\text{opti}}^2}{1+d_{3\text{opti}}^2} = 158.98
\]
The proposed point is \((141.02, 158.98)\)
\[
E_{pr} = \left( \varepsilon_{f1} \times d_{1\text{pr}}^4 + \varepsilon_{m1} \times d_{2\text{pr}}^4 + \varepsilon_{m1} \times d_{3\text{pr}}^4 \right) / 3 = 1.899 \times 10^{-6} \ \text{J/bit - node}
\]
By placing the Base station in the Mid of the line \((150, 150)\)
\[
E_{MP} = \left( \varepsilon_{m1} \times d_{1\text{MP}}^4 + \varepsilon_{m1} \times d_{2\text{MP}}^4 + \varepsilon_{m1} \times d_{3\text{MP}}^4 \right) / 3 = 2.6 \times 10^{-6} \ \text{J/bit – node}
\]
\[
E_{pr} - E_{opti} = \frac{1.88 \%}{E_{opti}}
\]
\[
E_{cen} - E_{opti} = \frac{2.2 \%}{E_{opti}}
\]
\[
E_{MP} - E_{opti} = \frac{2.5 \%}{E_{opti}}
\]
The table 1 shows the energy consumption of the nodes when base station is placed in the centroid of a plane. The Table 2 shows the Energy consumption of the nodes when it is placed in the optimal place (orthocenter of the plane). As there is an increase in the number of nodes, the nodes experiences more multipath loss than the free space loss if the base station is positioned at the centroid of the plane. So the Energy consumption is more, but in this optimal location the energy consumption is less due to the experience of nodes with equal multipath loss and the free space loss. The Energy efficiency is better in the proposed point than the centroid.

Table I: The Energy Efficiency of the nodes at the Centroid

| Length of the side, x | Number of nodes |
|----------------------|-----------------|
| 200                  | 4.21            |
| 220                  | 3.61            |
| 240                  | 2.41            |
| 260                  | 1.73            |
| 280                  | 0.53            |

Table II: The Energy Efficiency of the nodes at the proposed point

| Length of the side, x | Number of nodes |
|----------------------|-----------------|
| 200                  | 4.51            |
| 220                  | 3.82            |
| 240                  | 2.61            |
| 260                  | 1.83            |
| 280                  | 0.92            |

Conclusion

In this paper the energy minimization of the nodes is taken as a key aspect. The energy minimization was experienced in this two tire architecture, if the node is closer to the base station it experience the free space loss and if it far way it experiences the multipath loss. In this we have experimented the efficient positioning of the base station for the energy minimization. Our proposed point shows the better performance when compared with the centroid of the plane.
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