Efficient Energy Modeling in Wireless Sensor Networks

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Abstract
WSN consists of a number of sensor nodes, each node assigned with the task of sending the sensed information from surroundings to a central base station. In this type of network setup, sensor nodes are generally energy deficient when compared to the base station which is all powerful. Hence it is essential to look into the pattern of energy consumption and protocols adopted by various nodes, so as to increase the lifetime of the network. In this paper, we present a multi-hop ad hoc routing protocol which is all energy aware, hence it reduces the overall energy consumption in the network, thus increasing the life time of nodes in network. This protocol is an event-driven and location based and designed by assuming a stationary configuration of nodes. In this setup we assume that the sensor nodes are distributed uniformly in a rectangular grid, with base station at one of the corners of grid. Then we give a modeling for energy consumed by each node, assuming that an event happens at one node in the grid. By taking into consideration, a uniform distribution of events all across the grid, we give a formulation for expected energy consumed by a node. Based on the formulation, we realized that there was uneven distribution in the pattern of energy consumed by the nodes that are present at boundaries of the grid, and hence we give a small modification to the proposed protocol which makes the energy consumption pattern uniform, across all the nodes in network.

Keywords: WSN, Routing, Energy-aware routing, Energy Modeling, Event driven protocol.

1. Introduction
A wireless sensor network consists of a number of sensor nodes cooperatively monitoring some conditions of the surroundings. It is an ad hoc network typically consisting of a base station, sensor nodes and events taking place in the area of network. Sensor nodes are equipped with a receiver, transmitter and a battery which is the power source for nodes. The sensor nodes usually have a large scale deployment and are generally energy constrained where as the base station is assumed to be all powerful. On occurrence of an event, sensor nodes sense the data and cooperatively work together to transmit the data to base station. The energy constraints necessitate energy-awareness at all the layers of network protocol stack. In this paper, we address the problem of designing an energy-aware routing protocol.

1.1 Challenges of routing in WSN
Routing in a sensor network is challenging and some of the characteristic features which distinguish it from contemporary networks are:

- Due to the existence of large number of nodes there is no global-addressing scheme.
- Sensor network involves transfer of data from multiple regions to a sink (base station).
- Multiple sensors might generate same data and hence there might be a lot of redundancy in data transmitted across the nodes.
- The sensor nodes are highly energy constrained.

All these require us to carefully design the routing protocols for sensor networks so as to increase the lifetime of network.

The rest of the paper is organized as follows: In section 2 we describe the existing system and flaws associated with it. Section 3 gives the idea of the protocol. Section 4 gives analysis and energy modeling of the protocol and its results. Section 5 gives the changes made to the protocol to make it more uniform. We finally conclude in section 7 and give hints for future work.

2. Existing System
The nodes in WSN are subjected to various resource constraints. Among them, energy is of prime concern, since it is severely constrained at sensor nodes and it is not feasible to either replace or recharge the batteries of sensor nodes.
nodes that are often deployed in hostile environment. As the sensor nodes are typically very small and powered by irreplaceable battery, energy control becomes primary and also the most challenging problem in designing sensor networks [2]. In WSNs, each sensor node has different energy consumption rate due to inequality in event sensing and distance from Base Station. This leads to energy disparity among sensor nodes in the network which in turn shortens the lifetime of the network.

Keeping in view about the life time and energy associated with each node in the network we present a multi-hop ad hoc routing protocol which is energy aware. The protocol is designed to be event-driven, location-based assuming a stationary configuration of nodes. Also all the nodes are assumed to be homogeneous and symmetric (that is if a node is within the transmission range of the other, the vice versa is also true).

3. Proposed System

3.1 Network Setup

To setup a WSN, we assume a rectangular grid of nodes with base station at one of the corners of the grid and sensor nodes located at each of the grid points. Suppose that an event takes place in the network and data ‘d’ is sensed by nodes in the grid. Now a node at one of the grid points need to send data ‘d’ sensed by it to the base station. Assume that each node is in the transmission range of ‘r’ such that \( \sqrt{2} \leq r \leq 2d \) i.e., data transmitted by a node can be sensed/received by 8 of its immediate neighbors as shown in Figure 1.

![Network Setup Diagram](image)

Fig. 1 Network Setup.

3.2 Routing Technique

In figure 1, node M wants to transmit ‘d’ amount of data to the base station which is located at the bottom left corner of the grid. As mentioned earlier, the data transmitted by it is sensed by 8 of its neighbors - G, H, I, L, N, Q, S and T. The nodes L, Q, S are closer to the base station with respect to node M whereas the other 5 nodes are farther from the base station compared to M. Hence once the data has been received by these nodes, only the nodes L, Q and S are involved in further transmission of the data to the base station.

Since we want uniform consumption of energy by various nodes (to maximize the lifetime of the setup), we assume that in the next level, each of the nodes transmits 1/3\(^{rd}\) of the data that it senses. Hence it can be assumed that node L transmits the first 1/3\(^{rd}\), node Q the next 1/3\(^{rd}\) and node S the final 1/3\(^{rd}\) of the data that it receives. The other nodes just ignore the data. Each data packet received has the location of origin of data and also its immediate predecessor from where the data has been received. This helps the nodes in determining the data that it has to send in a particular level. The nodes on the boundary of the setup do not have 3 neighbors towards the base station, hence they just transmit the entire data sensed rather than sending only 1/3\(^{rd}\) of data that they sense. Thus, the node X transmits the entire data sensed which is further transmitted by node W and so on till the data reaches the base station.

Thus by using this protocol each node transmits the data sensed by it in various levels, each level involving various nodes hence there will be a uniform transmission of data by each node.

4. Energy Modeling

The energy consumed in transmission of data and amount of data are directly proportional to each other since it is assumed that all the nodes have same transmission range. Also the energy consumed in sensing is far less compared to the transmission energy. Hence the amount of data sent by each node is analyzed to get the energy consumption pattern of various nodes.

Consider a rectangular grid of size \( h \times k \). Suppose that a node M at \((i, j)\) wants to transmit data of size 1 to the base station. The node transmits the data and it is sensed by 8 of its neighbors. We name this as Level 0. In the next level, we have the 3 neighbors of the node M towards the base station each transmitting 1/3\(^{rd}\) of the data sensed by them. We call this as Level 1. In this Level, the nodes involved in transmission are \((i - 1, j), (i - 1, j - 1)\) and \((i, j - 1)\). The data transmitted by these 3 nodes is transmitted by 6 nodes in the next level. Some of the nodes received data from 2 nodes in the previous level and while some only from 1 node. In a general case, we will have a node receiving data from 3, 2 or 1 of the nodes of the previous level. Note that in Level 1, the data sent by each node is 1/3\(^{rd}\). Assuming
that we do not reach the boundary, we have $1 + 2 + 3 + \ldots + n$ nodes involved in transmission in a level. Also nodes involved in a level from an annulus of the shape as shown in Figure 2. Figure 3 shows the data sent by each node up to 3 levels (Level 0, 1 and 2) when the node $M(i, j)$ is the origin of data that needs to be sent to the base station.

Inductively it can be shown that the data sent by nodes in an annulus at an $a$th level is:

\[
\frac{x^a}{3^a}, \frac{y^a}{3^a}, \frac{(x+y)^a}{3^a}, \ldots, \frac{(x+y)^a}{3^a}
\]

Now suppose that a node at $(i, j)$ needs to transmit data of amount 1 to the base station. Then a node at $(x, y)$ gets involved in transmission at a level when it is on one of the two straight edges of the borders of the annulus and it is involved in transmission up to a level till it reaches the border of the annulus which is diagonal (shown in Figure 2 as $x + y = i + j - a$). Hence the node gets involved in transmission at the level $s = \max (i - x, j - y)$ and is involved in transmission up to the level $e = (i + j) - (x + y)$.

If a node $(x, y)$ is involved in transmission of data in an $a$th level, then the data sent by it in that level $= \left(\frac{x}{3^a}, \frac{y}{3^a}\right)$ where $k = j - y$ and $l = x - (i - a)$.

Hence the total data transmitted by a non-boundary node of the grid for the occurrence of an event at $(i, j)$ is given as:

\[
d(x, y) = \sum_{a=s}^{e} \left(\frac{x}{3^a}, \frac{y}{3^a}\right)
\]

Where $k = j - y$ and $l = x - (i - a)$ and $s = \max (i - x; j - y), e = (i + j) - (x + y)$

For a border node on the X-axis, it is given as:

\[
d(x, 0) = d(x, y) + \frac{\sqrt{3}}{4} d(r, 0)
\]

Similar formula for a border node on the Y-axis would be:

\[
d(0, y) = d(x, y) + \frac{\sqrt{3}}{4} d(0, r)
\]

4.1 Results

Now suppose that events take place at grid points and the node at the place of the event generates data which is to be sent to the base station. The analysis of the data sent by each node has been done on Matlab and the plots below show the data transmitted.
Figure 4 and 5 shows the data sent by each node assuming individual events in a grid of size 10x10. The base station is at the bottom left corner and is shown as black as it does not transmit any data. The events are assumed to be occurring at 2 places - one at (6, 6) and other at (7, 3). In case of the first event, the pattern of data sent by each node is symmetric whereas for the second event, it can be seen that most of the data is sent through the border nodes hence leading to over use of a particular region of the network - the boundary nodes.

Now assume that events take place uniformly all over grid, i.e., each node in the grid senses an unique event. In other words, we have events taking place at all the grid points. Figure 6 shows the data sent by each node assuming this uniform distribution of occurrence of events. It can be clearly seen from the plot that the boundary nodes are over-used. This can be attributed to the asymmetry seen in the case when events take place at nodes \((i, j)\) where \(i \neq j\) as in Figure 5. These events cause the over use of boundary nodes hence resulting in non uniformity in data sent by nodes around the base station and not utilizing the network to its capacity. So we propose a modified protocol as defined explained below.

5. Modified Protocol

The above protocol has a small performance glitch that the boundary nodes on an average are over-used compared to non-boundary ones and this can be attributed to the way data transfer is handled for an event occurring at a node \((i, j)\) with \(i \neq j\). In order to overcome this problem, we modify the protocol to certain extent in the case when events take place at these kinds of nodes.

The modified protocol is as follows:-

For events taking place at nodes \((i, i)\), the protocol remains unchanged.

For events taking place at nodes \((i, j)\) with \(i \neq j\) - it can be clearly seen in the previous protocol that the total number of levels involved by the time the data reaches the base station is \((i + j)\). Without loss of generality let \(i > j\) (the other case can be handled similarly). In this case after \(j\) levels, the annulus touches the X-axis. Once the annulus touches the X-axis, each node, rather than sending the 1/3\(^{rd}\) data, it sends the entire data sensed to the left node i.e., towards the base station. Note that this was the idea which was used only for the boundary nodes in the earlier protocol but here it has been extended to the non-boundary nodes too. This process continues for the next \(i - j\) levels till the annulus touches the other axis too. Once the annulus touches the other axis, we shift back to following the old protocol where a non-boundary node is involved in sending only 1/3\(^{rd}\) of data whereas a boundary sends the entire data along the boundary to the base station.

5.1 Results

For the new protocol, the plots obtained are as shown in Figures 7 and 8 for the events taking place at nodes (6, 6) and (7, 3) for a 10X10 grid.
For the event taking place at (6, 6), the plot remains the same but for the second event, it can be clearly seen that the data sent has been more distributed compared to earlier protocol thus reducing the over use of the boundary nodes. Now by assuming events all across the grid to be uniform, we have the plot shown in Figure 9. Now it can be seen that the protocol is more uniform as the data sent by nodes around the base station is almost same. The values for various nodes around the base station are as shown in the table below.

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<th>32.6811</th>
<th>27.9266</th>
<th>17.9937</th>
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<td>26.8288</td>
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<td>16.6986</td>
<td>13.3507</td>
</tr>
</tbody>
</table>

Table 1: Values around the base station for uniform distribution of events. The base station is at the top left corner.

5.1 The Parameter ‘p’

The values obtained previously are more or less uniform. But we had arbitrarily chosen the fraction as 1/3 in the protocol. Changing the value of p could be a possible source of improvement and in order to test this possibility we decided to make this fraction ‘p’ as the parameter in our simulations.

Hence it has been assumed that p fraction of the data will be sent to the node along the diagonal and (1 - p)⁄2 will be sent to the other 2 nodes. Varying p changes the distribution of data sent by various nodes. As the value of p decreases, data sent by border nodes decreases and as p increases, the data sent by the border nodes increases. Figures 10 and 11 shows the distribution of data sent by various nodes for p = 0 and p = 0.9. Hence, it can be said that there is a value of p for which the protocol gives the best (most balanced) performance. It was found that this ideal value of p is a function of grid size. For instance for grid of size 5X5, it has been observed, we have uniform distribution around the base station at p = 0.6515.

6. Related Works

Threshold sensitive Energy Efficient sensor Network (TEEN) [1] conveys two attributes to the nodes from the cluster heads, namely, (i) Hard Threshold and (ii) Soft Threshold. Hard threshold was the absolute value of the sensed parameter beyond which the value must be transmitted to the cluster head. Soft threshold was the value of the sensed parameter beyond which the node must activate its transmitter.
But there are drawbacks were if the threshold is not reached then data is not communicated to the base station. There were no messages to inform the base station that whether the node has gone dead or the data is not crucial enough to be reported. Thus, the reliability of data reportage becomes an important drawback.

**Adaptive Periodic Threshold sensitive Energy Efficient sensor Network** APTEEN [3] was designed to remove the drawbacks of TEEN. APTEEN adds an extra attribute to the packet sent by the cluster heads to the cluster members. It not only includes the thresholds but also includes the maximum interval between two packets. This modification makes the protocol usable even by time driven networks. As the data get sent periodically, it is easy for base station to know that the node is dead or has failed to send data. Some of the protocols [8], [9], [10], [11], [12] are based on energy efficiency routing in WSN’s. Most of the above protocols are either based on flooding, clustering, gradient or geographic based approach. The geographical approach will increase the cost of the network. In clustering approach inappropriate load balancing will consume the energy and there is also a overhead of selecting the new cluster head when the old cluster heads threshold will reach a particular level. The flooding based mechanism will achieve reliability of transmission at the cost of duplicate packets in to the network As a result the cost associated with the network is more or energy of network is over utilized at certain circumstances.

7. Conclusion and Future Work

We have presented a routing protocol which is energy aware and have given energy modeling for the same. The protocol is successful in balancing the energy spent by nodes which are nearest to the base station but the bottleneck problem is still prevalent in the protocol. Later modifications have been proposed which make the protocol more uniform. In future, the protocol might be made asymmetric to remove the bottleneck problem. Also modifications can be made to the protocol so as to further increase the lifetime of the network. Another modification can be to change the value of 'p' based on the distance from the event origin and hence choose different 'p' values for different levels.

8. References


