The Energy-Efficient Algorithm for a Sensor Network

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Abstract. We considered a network that consists of massively deployed tiny energy constrained sensors with one sink node to communicate with the outer world. The key challenge in design of wireless sensor networks is maximizing its lifetime. We explored this challenge and proposed our algorithm to increase a network lifetime. A node lifetime and numerical analysis show the comparison of the proposed algorithm with existing algorithm to increase a network lifetime. The proposed algorithm increases a critical node lifetime by 38% and hence a network lifetime.

1 Introduction

The rapid development in small, low-power, low-cost microelectronic and micro-electromechanical (MEMs) sensor technology along with the advances in wireless technology have enabled wireless sensor networks to be deployed in large quantities to form wireless sensor networks for a wide uses. There are multiple scenarios in which such networks find uses, such as environmental monitoring/controlling and interactive toys, etc.

In [1] authors describe about characteristics and challenges of WSN. Due to energy constrain, energy efficiency is a critical consideration for designing the sensor networks and its routing protocols. In [2] authors describe upper bound on the lifetime of sensor networks, while in [3] the lifetime of a cluster based sensor that provides periodic data is studied. In a large sensor network all the nodes send their data to sink node for the further processing as shown in figure 1, due to this fact the nodes near to sink node consumed their energy more rapidly compared to other sensor nodes. In [4] authors describe the problem of developing an energy efficient operation of a randomly deployed multi-hop sensor network by extending the lifetime of the critical nodes and as a result the overall network's operation lifetime, were considered and analyzed but they didn't propose any solution for the same. In this paper we are extending our work further from [4] and proposing algorithm to increase the critical node lifetime and hence a network lifetime. In [5–8] authors suggested power aware multiple paths algorithms to distribute the relay load equally among all the nodes.

In single path algorithm there is only one path available from source to sink and normally it is a minimum hop path. Due to single path there is always very

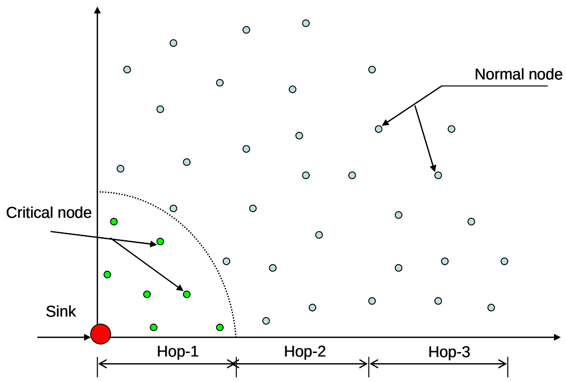


Fig. 1. Sensor networks

heavy traffic on the route and also its lifetime is short but we can overcome these disadvantages by implementing the proposed algorithm which distributes the load among the nodes. In multiple paths every node is connected to the number of paths and it is not practical to make them work in just one mode, such as sense or relay mode. Further we evaluated the efficiency of each algorithm from mathematical and numerical analysis.
Based on our study, all proposed solutions for the senor networks lifetime are categorized as follows [2, 3, 5–9, 11, 12, 15].

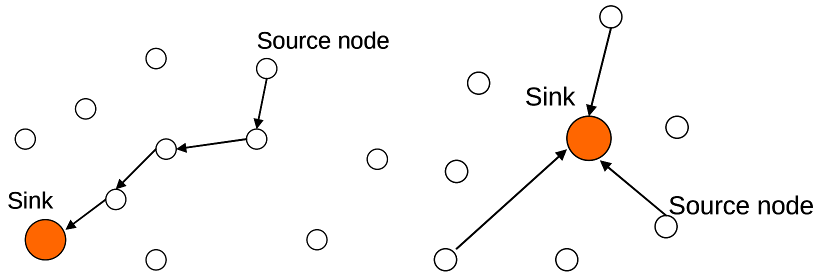
1. Using an energy efficient and multiple path routing algorithm.
2. Using higher battery capacity relay node or cluster based method.
3. Using the different working modes for a node.

This paper is organized as follows. In section 2, we introduced our sensor networks model. Section 3 described our proposed algorithm. In section 4 we described a node lifetime analysis, followed by numerical analysis in section 5. Finally conclusion and future work are in section 6.

2 Sensor Network Model

All nodes in a sensor network are static, same in size, battery capacity, etc. Every node has a static ID (Not IP) and does the relying and sensing. A node in hop 2 will always find the critical path in hop 1. A network consists of randomly but uniformly deployed nodes. We make our further assumption from [4] as follows.

1. E_o = The energy of a node.
2. E_s = The energy needed to sense one bit. It depends on the power dissipation of the internal circuitry. It is denoted by ε_{si}. Where i represents i^{th} node (s_i).
3. $E_{b,rx}$ =The energy needed to receive a bit. It is denoted by ε_{rxi}.



(a) When sink is away from source (b) When sink is near to source

Fig. 2. Sink node at different positions

4. $E_{b,tx}$ = The energy required to transmit a bit. It is given by the $E_{b,tx} = \varepsilon_{tx} + \varepsilon_{rf}(d/d_0)^n$, where ε_{rf} is the energy consumed to transmit a bit to the reference distance d_0 and n is the path loss index.
5. $E_{b,process}$ = The energy consumed per bit for data processing, such as aggregation and special functions required to relay data. Let us denote by γ the data aggregation ratio. The energy per bit for aggregation is a function of γ that is given by $E_{b,process} = \varepsilon_p + \varepsilon_a f(\gamma)$, where $f(\gamma) = 0$ if $\gamma = 1$.
6. $\lambda_{org,i}$ = The number of packets generated per unit time by s_i. It is indicated by λ_{s_i}.
7. $\lambda_{re,i}$ = The number of packets relayed per unit time by s_i. It is indicated by λ_{ri}.
8. L = Length of a data packet.

Figure 1 shows a sensor network model's first quadrant, here we considered only one collector node which is placed at the center of a network. Now based on the above definitions and assumptions, the power dissipation of node s_i is given by

$$P_i = \varepsilon_{si}\lambda_{si}L + \varepsilon_{rxi}\lambda_{ri}L + [\lambda_{si} + \lambda_{ri}]\varepsilon_p L + [\lambda_{si} + \lambda_{ri}]\gamma\varepsilon_{tx}L \,. \quad (1)$$

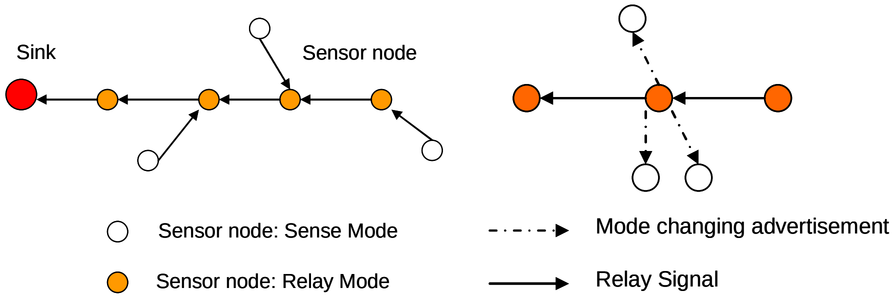
For simplicity we considered $\gamma = 1$ and $d = d_0$. Still we can simplify above terms by assuming that $\varepsilon_s = \varepsilon_p = \varepsilon/2$ and $\varepsilon_{rx} = \varepsilon_{tx} = \varepsilon$ [4]. From all above assumption we can rewrite (1) in the following way

$$P_i = [2\varepsilon + \varepsilon_{rf}]\lambda_{si}L + [2.5\varepsilon + \varepsilon_{rf}]\lambda_{ri}L \,. \quad (2)$$

And let $E(t_i)$ be i^{th} node life time that we have

$$E(t_i) = E_0/P_i \,. \quad (3)$$

From (2) we can observe that power consumed by a node is divided into two terms. First term is used only for sensing and transmitting its own data and second term used for the relaying purpose. Figure 2 (a) shows the above condition. From (2) we can conclude that 65% of its energy gets used only for the relaying data that is actually waste for a node [12]. If we can cut or make the second



(a) A sensor node working in two modes (b) A sensor node change its state

Fig. 3. A node's transition

term as low as possible, we can increase the node lifetime.
We can make second term equal to zero only if a node doesn't need to relay any external data packet. This can be possible only in one case when a sink node is in range of all sensors as shown in figure 2 (b). Here we proposed the algorithm which helps nodes to create an energy efficient routing backbone based on energy consumption metric.

3 The Proposed Energy-Efficient Algorithm

Here we considered a large area network for a monitoring application which contains the number of sensor nodes with one sink. All nodes have to transfer their data to sink that means a common destination address for all the nodes. As we mentioned above to maximize networks lifetime, load distribution of a relay packet is very important. In [6–8, 11] authors follow multiple route paths algorithm. The basic idea of the proposed algorithm and detailed procedure can easily be understood from the following steps.

1. All nodes are working under two mode, relay and sense and keep changing their modes as per the algorithm's set condition. Figure 3 gives clear idea about these two modes and their transition.
2. At first, sink node will broadcast an advertisement for hop count information and after some delay all nodes will know its hop position.
3. After the hop information, sink node will run 3 color's algorithm [14] to choose random nodes which are one hop apart from each other for carrying relay loads.
4. Let us denote all randomly chosen nodes as Cluster Node (CN). All CN nodes advertise about their status and thus inform its cluster members to send all their data.
5. All CN nodes will establish connection with just one node which is only one hop apart and has lower hop count than CN and it will be also consider as CN.

6. Whenever any sensor node wants to send data, it will send to its reachable CN and from CN to lower hop CN and thus to sink.
7. All CN will operate in relay mode and the rest of the nodes are in sense mode.
8. CN will operate in relay mode until the remaining energy reach to its set energy threshold. Then it will broadcast an advertisement for a mode change. This advertisement contents its ID, upper and lower hop CN ID and its energy level.
9. CN will wait for some random delay. During this delay time some response will come from the near by node and CN will change its mode from relay to sense furthermore it will choose new CN for the relay.
10. Now old CN will work in sense mode till predetermined energy threshold. If any advertisement comes for relay and if that advertisement satisfied all decision condition then it will again enter into the relay mode otherwise remain in a same mode.

3.1 Proposed Algorithm Pseudo Code

Here we specified the algorithm in pseudo code for a single path energy-efficient scheme.

```
Begin
    If (mode==sense) sense_mode ();
    else relay_mode ();
End
    sense_mode ();
Begin
    If (senser_pkt_int==arrived)
       ++ sense;
       energy;
       create_data_tx ();
    Begin
       If (energy>adv_energy)
       change_mode ();
       else cont_sense_mode ();
    End
End
    relay_mode ();
Begin
    If (relay_pkt_int==arrived)
       ++ relay;
       energy;
       next_hop_tx ();
    Begin
       If (enrgy<limit)
       energy_adv_tx ();
```

```
        else cont_relay_mode ();
    End
End
```

where,

1. $create\_data\_tx()$ = Procedure for creating data frame and transmitting to near by CN.
2. $change\_mode()$ = Procedure for changing the operation mode.
3. $cont\_sensing\_mode()$ = Procedure for continuing the operation in sensing mode.
4. $next\_hop\_tx()$ = Procedure for transmitting packet to next hop.
5. $energy\_adv\_tx()$ = Procedure for transmitting an advertisement for changing the mode and change the mode on receiving acknowledgement.

4 A Node Lifetime Analysis

As we proposed in the algorithm all nodes will work in two modes and their energy consumption will change according to their operating mode. Energy consumed in relay mode is given by

$$P_{ri} = [2.5\varepsilon + \varepsilon_{rf}]\lambda_{ri}L\,. \tag{4}$$

Energy consumed in sense mode is given by

$$P_{si} = [2\varepsilon + \varepsilon_{rf}]\lambda_{si}L\,, \tag{5}$$

but in our proposed algorithm sensor node also need to transmit and receive some overhead signals. We added 0.5ε in the above term. So modified equation is as follows.

$$P_{si} = [2.5\varepsilon + \varepsilon_{rf}]\lambda_{si}L\,. \tag{6}$$

In multiple paths a node has to consider some overhead energy consumption and is given by

$$P_i = [\lambda_{si} + \lambda_{ri}][2.5\varepsilon + \varepsilon_{rf}]L\,. \tag{7}$$

In the proposed algorithm nodes change its state according to energy threshold set, so to find life time of a node we need to find average power consumption at node during all modes and it is given by

$$P_i = \sum_{i}^{n/2} \left\{ \sum_{H_{i+1}}^{H_t} \lambda_{rhti}(2.5\varepsilon + \varepsilon_{rf})L + (2.5\varepsilon + \varepsilon_{rf})\lambda_{si}L \right\} / n, \tag{8}$$

where n is threshold interval.
To know networks lifetime we need to calculate average lifetime of critical node. Here critical node means a node which connects sink with other sensor nodes. To calculate average lifetime of a node we need to calculate maximum traffic rate arriving at critical node in multiple paths as well as single path case.

4.1 Multiple Paths Analysis

Maximum traffic that can arrive at critical node is given by

$$\mathit{Relay\,packets} + \mathit{Own\,generated\,packets} = \left[\sum_{i}^{n_p} \lambda_{ri} f(e) + \sum_{i}^{n_{cp}} \lambda_{ri} + \lambda_{si}\right] . \quad (9)$$

Where, n_p is the number of path connected to critical node and n_{cp} means the number of critical paths connected to critical node. If we consider that multiple paths algorithm is energy aware, n_p is depends on a function of energy and its value varies from 1 to 0. Here critical path means, a path don't have any other routing path except one connected to critical node. Now from (1), (7) and (9), power consumed at multiple paths node is given by

$$P_i = \left[\sum_{i}^{n_p} \lambda_{ri} f(e) + \sum_{i}^{n_{cp}} \lambda_{ri} + \lambda_{si}\right] \times [2.5\varepsilon + \varepsilon_{rf}]L \,, \quad (10)$$

from (4) and (10) node lifetime is given by

$$E(t_i) = E_0 / \left\{\sum_{i}^{n_p} \lambda_{ri} f(e) + \sum_{i}^{n_{cp}} \lambda_{ri} + \lambda_{si}\right\} (2.5\varepsilon + \varepsilon_{rf})L. \quad (11)$$

4.2 Single Path Analysis

Maximum traffic that can arrive at node when it is in relay mode is given by

$$\lambda_{ri} = \sum_{H_{i+1}}^{H_t} \lambda_{rhti} \,. \quad (12)$$

Where, H_t means total number of hop count and H_i is individual node hop count. Maximum traffic at node when it is in sense mode is given by λ_{si}. If we set energy threshold to E_0/n, average P_i is given from (8).From (4) and (8) node lifetime is given by

$$E(t_i) = E_o n / \left[\sum_{i}^{n/2} \left\{\sum_{H_{i+1}}^{H_t} \lambda_{rhti}(2.5\varepsilon + \varepsilon_{rf})L + (2.5\varepsilon + \varepsilon_{rf})\lambda_{si} L\right\}\right] , \quad (13)$$

from (11) and (13) we can compare a critical node lifetime for single and multiple path algorithms.

5 Numerical Analysis

All nodes have 6 joule battery capacity which can support 9000 packets of 32 byte long. In sensor networks relay rate is always higher than the packet generating

Table 1. Parameter's Value

Parameters	Assumed value
E_0	6J
ε	$50n$J
λ_s	$5pkt/hr$
L	$32byte$
ϵ_{rf}	2.5μJ

rate. From [4,12,15] we assumed some parameter's values and summarized them in table 1.

Figure 4 shows the average number of packet processed by a node in the proposed algorithm. From figure 4 we can observe that the number of packet processed by a critical node changes according to the operating mode. Normally packet arrival rate is very high compared to packet generating rate. We divided the total energy into the number of threshold level, as we proposed in the algorithm node will change its state on every threshold level. As we can see it from figure 4, the number of packet arrival rate will also change accordingly. When a node is in a relay mode it has to process on a larger number of packets than in sense mode. This is the key factor of the proposed algorithm. Because of two operating modes average arrival rate of packets is low compared to energy aware multiple paths algorithm.

Figure 5 and 6 show some important numerical results which are based on a node lifetime analysis and assumptions. Figure 5 shows the critical node lifetime. From figure 5 we can observe that the proposed algorithm increases the critical node lifetime and hence a networks lifetime. From figure 5 we can observe that the arrival rate of packets in multiple paths algorithm is depends on a function of energy. As the energy level decreases the number of packet process by a node decreases but the average arrival rate of packet is higher than a single path algorithm. This is the main difference between the two algorithms. Figure 6 shows the energy consumed by 1 packet to reach destination from source. The proposed algorithm always creates a minimum hop path from source to

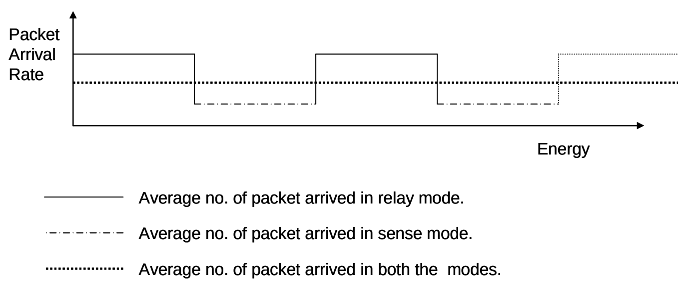


Fig. 4. Average number of packets process by a node

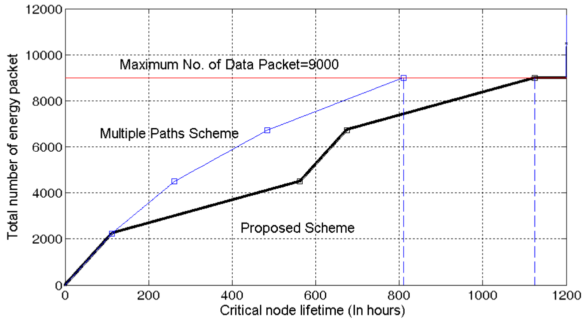


Fig. 5. Critical node lifetime

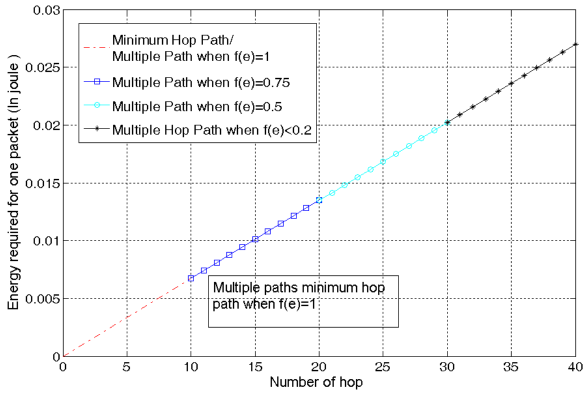


Fig. 6. Hop path for a node

destination. But in multiple paths algorithm it is a function of energy.For real time application the number of hop required to transmit the data from source to destination is very important because it involves the delay factor in transmission.

6 Conclusion and Future Work

In this paper we proposed the algorithm to increase a network lifetime and we compared it with multiple energy aware paths algorithm. The proposed algorithm increases a network lifetime by fairly distributing the relay load among the nodes with the help of two different operating modes. So our approach is suitable for a large number of sensor network. Numerical result shows the good improvement in a critical node lifetime. The proposed algorithm increase the lifetime by around 38% which looks quite promising and the proposed algorithm generate a minimum hop path which is very important result for the real time data applications.
In future work we want to explore the possibility of several sink nodes located

in different places and also want to consider the heterogeneous nodes in the networks.

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