2012 International Conference on Information and Network Technology (ICINT 2012)
IPCSIT vol. 37 (2012) © (2012) IACSIT Press, Singapore

A New Approach for Interference Aware Cost Effective Routing Algorithm in Wireless Sensor Network

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Abstract. Due to energy and interference constraints of a sensor node in WSN, design of *interference* aware *energy-efficient* routing protocols is a crucial concern for WSN applications. Since in WSN data transmission is based on wave/signal transmission, efficient network communication requires the signal to be uncorrupted and the intermediate node should have the energy to send the signal to neighboring nodes. Corruption of data is mainly caused by signal interference. In this paper, we propose *interference aware energy balance* routing protocol for WSN that considers *interference* as well as *energy consumption of* nodes simultaneously for cost effective routing path determination. Thus, the quality of wireless communication is improved, because the effects of wireless *interference* and *energy consumption* are reduced.

Keywords: WSN, energy consumption, link interference, energy efficiency, energy sufficiency.

1. Introduction

WSN [8] is a specific class of wireless Ad-Hoc networks in which thousands of sensor nodes are participating together to accurately measure a physical phenomenon from the environment. The sensor nodes are battery-powered devices with limited energy. For increasing the longevity of such network, techniques to either increase the battery power or provide alternative source of energy is required. Thus the energy conservation is one of the most important issues in WSN. Again if *interference* around the node is very high, then nodes need more transmission energy for successful transfer of packet. It is evident that reduction of transmission power and interfering power for each node would greatly increase the life time of the network.

Many papers [1, 2] focus on minimization of energy consumption but *interference* is not taken into account, which is a major drawback. Whereas many works [4, 5] relate to the minimization of *interference* in the network, in those cases energy consumption for data transmission is not taken into account.

In this paper we describe a new approach for finding *interference* aware energy balance routing path from source to destinations. While selecting the routing path we need to choose those links that have high *energy* sufficiency and *efficiency*, lower *interference* etc. For selection of suitable routing path from a set of multiple paths for each source to destination pair is determined based on maximum priority.

In this paper Section 2 shows the related works in this approach and Section 3, 4 and 5 explains the definition of metrics used in algorithm and the proposed method respectively. In section 6 the complexity of our proposed scheme is given. Lastly in Section 7 we have simulation results and at the end the conclusion.

2. Related Works

WSN usually contains thousands or millions of sensors, which are randomly and densely deployed (typically 10 to 20 sensors per m^2) [1]. Due to high number of node count, it is not only impossible to keep track of each node but also not feasible to replace each node in case of their failure. This arouses the need for the sensor nodes with greater active lifetime to prevent the failure problem. The main goal is to prolong the

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lifetime of the network, defined in several ways: (1) the time when the first node depletes its battery, (2) the time till a given percentage of the sensors have enough energy to operate, and (3) the time till a given percentage of the region is covered by active sensors [2].Recently, much research has been done in the area of energy saving issues in WSN's. Many proposals are put forward to minimize energy consumption in sensor networks. In [2], a theory is proposed to save the energy by reducing the range of communication and the amount of data transmitted where as in [3] a model is proposed in which the sensor nodes are forwarded to sleep mode whenever the nodes are not sensing the environment. But as a single sensor node is prone to failure, there may be errors in the sensing. In [9], author proposed an interference aware minimum energy routing protocol considering both transmission and reception energy of nodes in wireless network.

3. Problem Definition and Network Model

Given a source and multiple destinations the routing protocol sends the data from source to multiple destinations using a suitable and robust routing path. Many routing metric like hop-count, minimum energy consumption and residual energy are currently available for designing such routing path. But existing routing metric are not sufficient to provide all properties of good quality that is, high throughput, less *interference* and energy efficient routing path. In this paper we propose *interference* aware energy balance routing protocol for Wireless Sensor Network to overcome the limitation of the existing routing metrics to some extent.

Here the Wireless Sensor Network is modelled as a directed graph $G= (V, E)$ where, V is set of static nodes and E is the set of wireless links between the nodes. Two nodes u and v is said to be within the transmission range of each other iff the Euclidian distance (d_{uv}) between the nodes is less than equal to transmission range of each node. Let R_u be the transmission range of each node u. Again, assume that $N(u)$ be the one hop neighbour set of node u. Any node $v \in V$ belongs to $N(u)$ iff v is within the transmission range of u. The interfering node set of node u is denoted by $IN(u)$.Therefore, the interfering region formed by link (u, v) denoted by $IN(u, v)$, is defined as the region centred at either u or v and radius R_u or R_v. So we can write,

$$IN(u, v) = IN(u) \cup IN(v)$$

In this proposed method we have made some assumptions:

- Each node has unique node id.
- Each node in assumed to have initial energy E_0.
- Each node has identical transmission range and *interference* range.

To perform these operations we have considered the following data structures: *distance matrix*, *adjacency matrix*, *interference matrix, cost matrix* and *power matrix*.

4. Proposed Path Selection Technique

As the routing path for a specific source destination pair consists of a set of links, we identify the link cost function composed of three terms, link *interference* level, *energy efficiency* of the link and *energy sufficiency* of the link, which will be extensively explained in following sub-sections 4.1, 4.2 and 4.3 respectively.

4.1. Link interference level

For any node $r \in V$ and $r \in IN(u, v)$ and $r \neq u, r \neq v$, the amount of *interference* produced by link (u, v) on node r is given as follows:

When u sends data to v and distance between them is d_{uv}, then amount of transmission power required by u is

$$P_{uv} = P_{rev} . d_{uv}^{\alpha} \tag{1}$$

Where α is a path loss constant [7] and $\alpha = [2, 4]$

If r is situated in the *interference* range of u, then d_{ru} distance from node u. Therefore the amount of *interference* received by $r \in V$ is given by,

$$P_{r,uv} = \frac{P_{rev}.d_{uv}^{\alpha}}{d_{ur}^{\alpha}} \quad (2)$$

P_{rev} is received power and it is assumed to be same for all the nodes and without loss of generality, P_{rev} is negligible. Therefore, for relative *interference* on *r* produced by link (*u, v*) is given by,

$$P_{r,uv} = \frac{d_{uv}^{\alpha}}{d_{ur}^{\alpha}} \quad (3)$$

Again, for relative interference on *r* produced by link (*v, u*) is given by,

$$P_{r,vu} = \frac{d_{vu}^{\alpha}}{d_{vr}^{\alpha}} \quad (4)$$

As $d_{uv}^{\alpha} = d_{vu}^{\alpha}$, the total interference level produced by the link (*u, v*) is calculated as,

$$IL(u,v) = \sum_{\substack{u,v,r\in V \\ r\neq u,r\neq v \\ r\in IN(u,v)}} \frac{d_{uv}^{\alpha}}{d_{ur}^{\alpha}} + \frac{d_{vu}^{\alpha}}{d_{vr}^{\alpha}} = \sum_{\substack{u,v,r\in V \\ r\neq u,r\neq v \\ r\in IN(u,v)}} \frac{d_{uv}^{\alpha}}{d_{ur}^{\alpha}} + \frac{d_{uv}^{\alpha}}{d_{vr}^{\alpha}} \quad (5)$$

Definition 1: The total *interference* level of the path P_i for any given source – destination pair (s-d pair) is the summation of *interference* level of each link along the path P_i.

$$IL(P_i) = \prod_{(u,v)\in P_i} IL(u,v) \quad (6)$$

It is quite obvious that $P_i \in P(s,d)$ where $P(s,d)$ is the set of all possible paths from be given source(*s*) to destination (*d*).

4.2. Energy sufficiency of the link

The purpose of *energy sufficiency* is to keep the nodes of the network alive as long as possible. *Energy sufficiency* of any path P_i is symbolized by $ES(P_i)$. The residual energy of any node $u \in V$ is denoted by *RE (u)* and is defined as the amount of energy left at a particular node after transmission of data. From equation (1) we see the transmission power required to send data from *u* to *v* is P_{uv}. Therefore the residual energy at *u* is given by:

$$\begin{aligned} RE(u) &= RE(u) - P_{uv} \\ &= RE(u) - P_{rev}.d_{uv}^{\alpha} \end{aligned} \quad (7)$$

Definition 2: The *energy sufficiency* (*ES*) of the link (*u, v*) is calculated as:

$$ES(u,v) = RE(u) - P_{rev}.d_{uv}^{\alpha} \quad (8)$$

Definition 3: The *energy sufficiency* of path P_i is the minimum *energy sufficiency* of all the links along the path. Therefore the *energy sufficiency* of the path P_i is described by,

$$ES(P_i) = \min_{(u,v)\in Pi} ES(u,v) \quad (9)$$

4.3. Energy efficiency of the link

It takes account how much energy is needed for transmitting a packet from one node to another node. It is quite desirable to keep the value of this metric as much as low.

Definition 4: The *energy efficiency* (*EE*) of the path P_i is defined as the summation required transmission energy of all the links along the path P_i. Therefore, we can write,

$$EE(P_i) = \sum_{(u,v)\in P_i} P_{uv} \quad (10)$$

Using the equation (6), (9) and (10), the *interference* aware energy balance path for a given *s-d* pair can be calculated. This path selection algorithm compositely uses metrics defined in (6), (9), and (10) to pursue the energy balance for the sensor network. Therefore, the priority of each *interference* aware and energy balance path is given by equation (11).

$$PT(P_i) = W_1.ES(P_i) + W_2.EE(P_i) - W_3.IL(P_i) \quad (11)$$

Where, W_1, W_2 and W_3 are constants such that $W_1 + W_2 + W_3 = 1$ and $W_1 > W_2 > W_3$

Definition 5: The optimal *interference* aware and energy balance path for data transmission for an *s-d* pair is obtained by

$$TP(s, d) = Max_{P_i \in P(s,d)} PT(P_i) \quad (12)$$

Where $i=1, 2, ...n$ and n be the number of routing paths for (*s, d*) pair.

5. Algorithmic Description of Proposed Method

In our algorithm we have search the minimum transmission cost paths for each source destination pair using Dijkstra`s algorithm [6]. For each such path we calculate the *interference* level, *energy sufficiency* and *energy efficiency* for selecting best priority path for data transmission. If the residual energy of any node in the chosen path falls below the threshold value, we choose the next best priority path for transmission. The algorithm for Interference Aware Energy Balance Routing Path Generation is given below.

Interference Aware Energy Balance Routing Path Generation

Input:

G (V, E) ←Directed graph; *s* ← Source node; *adj[ ][ ]* ←Adjacency matrix

powr[ ][ ] ← Initial power at each node

dist[ ][ ] ← Distance between any two nodes that has link between them

int[ ][ ] ← Interference matrix

cost[ ][ ] ← Transmission cost of sending data from one node to another

dstn[ ] ← Destination matrix (all destination nodes are stored)

Output: Max priority paths for each source to destination pairs.

1. Let k be the number of destinations, where $k \in V$, is stored in *dstn[ ]*
2. For each destination $d \in [1, k]$
   i) $P_{i,d}$ ← minimum cost path from s to dstn[i]
   ii) $P(s, d) \leftarrow P(s, d) \cup \{P_{i,d}\}$
   iii) Call Path_Generator ( )
   iv) For each $P_{i,d}$, using equation (6), (9) and (10) ,Calculate $PT (P_i)$
   $PT(P_i) \leftarrow W_1.ES(P_i) + W_2.EE(P_i) - W_3.IL(P_i)$
   v) Call Path_Selection ( )

Function Path_Generator ( )

Input:

adj[ ][ ] ← Adjacency matrix

cost[ ][ ] ← transmission cost of sending data from one node to another

Output: All possible alternate paths for each s-d pairs.

1. Do{
2. Consult the *temp [ ][ ]* for ith destination.
3. Find the 1st row of the unmarked vertices that has more than one smallest equal key value.
4. Store the row in *R* and the position of smallest key value in *P*
5. Choose another position with the smallest key value, except *P*
6. Update the *temp[ ][ ]* with position *P*
7. Let *temp1[ ][ ]* ←*temp[ ][ ]*
8. *R*` is set as the row where destination is reached.
9. From *R*` traverse the upper rows and perform the same operations
   } while (*destn value*! = ∞)
10. Return

Function Path_Selection ( )

Input:

P(s, d) ← A set of paths found using Path _Generator ( )

PT $(P_{i,d})$ ← Priority value of path P_i from *s* to *d* where *i*=1,2,….n

Output: *PT* ($P_{i,d}$), $P_{i,d}$

1. For each path $P_{i,d} \in [P_{(s,d)}]$
2. If $PT(P_{i,d}) > PT(P_{i+1,d})$

   $temp \leftarrow PT(P_{i,d})$

   $PT(P_{i,d}) \leftarrow PT(P_{i+1,d})$

   $PT(P_{i+1,d}) \leftarrow temp$
3. Return ($PT(P_{i,d})$)
4. Return ($P_{i,d}$)

6. Computational Complexity Analysis

The complexity of Path_Generator in worse case is $O(V^3)$. The complexity of the Path_Selection is $O(V^2)$. So the overall complexity of routing path generation algorithm for a source destination pair is $O(V^3)$. If k is the number of destinations, then the total complexity of the proposed scheme is $O(kV^3)$.

7. Result and Analysis

We have compared our proposed scheme with the minimum distance routing and minimum hop count routing. The total *interference*, life time of the network, total energy consumption and the hop-count are chosen as the performance metrics for the simulation purpose. The environment chosen for simulation is Netbeans IDE. We have run our method for 50 numbers of nodes; the energy at each node is taken as 0.5 Joule, except the source and destinations where energy is taken as 1 Joule.

In fig.1 it is shown that the *interference* is lesser in the proposed scheme than the other two methods. This is due to the fact that with the increase in number of nodes, the *interference* among the participating nodes increases as number of contenders becomes dense in the network. In fig.2 we can see that with the increase in the number of nodes the lifetime of the network decreases in all cases. In our proposed algorithm the lifetime is improved in dense network than the minimum hop-count routing and minimum distance routing.

Fig.3 shows that how total energy consumption is subjected to increment with the increase in number of nodes in the network, since the data needs to travel long distances to reach the destinations. In the proposed scheme energy consumption is lightly higher than distance based routing and hop-count routing.Fig.4 shows that the average hop count is minimised in our proposed algorithm.

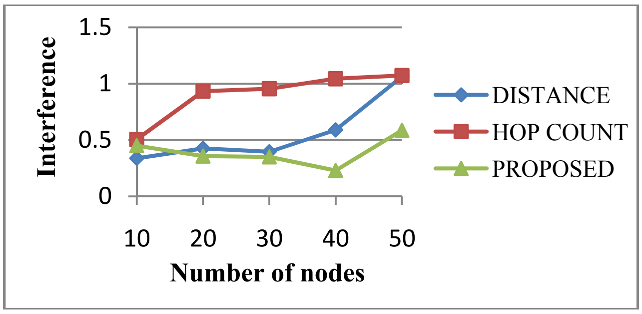

Fig. 1: Interference Vs Number of nodes.

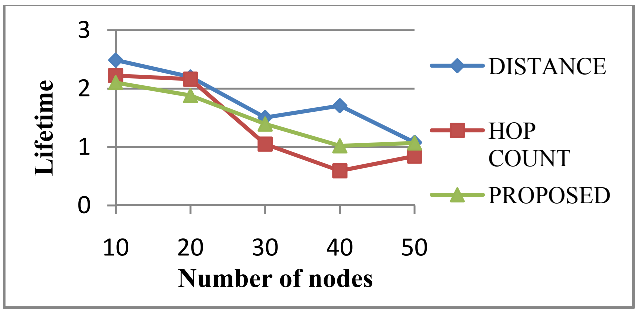

Fig. 2: Lifetime Vs Number of nodes.

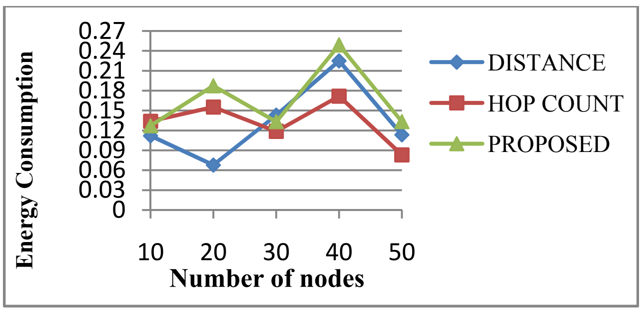

Fig.3: Energy consumption Vs Number of nodes.

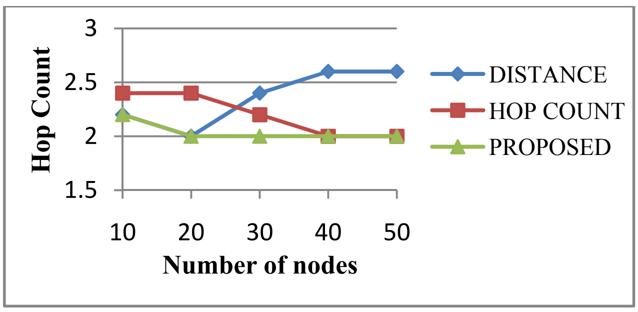

Fig.4: Hop-count Vs Number of nodes.

8. Conclusion

In the proposed scheme, for a given source destination pairs we are trying to find a cost effective routing path that minimizes path *interference* level and maximizes the residual energy of the node, thus enhance the network lifetime. In order to increase the network lifetime the proposed method takes *interference* as a major parameter for estimating a robust and suitable routing path while minimizing total network energy consumption. In future, the scheduling of this routing tree is under progress.

9. Acknowledgement

The first author gratefully acknowledges the facilities and support provided by the Director and Department of Computer Science and Engineering, National Institute of Technology, Durgapur, India.

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