PBR: Priority Based Routing in Multi-sink Sensor Networks

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Abstract − *Wireless sensor networks have been widely used in many fields with the developments of the related techniques. But there are many problems in traditional single sink sensor networks. The energy of the sensors near the sink or on the critical paths consumes too fast causing unbalanced energy consumption. The routing algorithms mainly focus on the nearest path or minimum hops. The invalidation of the single sink node causes the breakdown of the whole sensor network. In this paper, through the analysis of the disadvantages of single-sink sensor networks, we propose the system architecture of multi-sink sensor networks and a new routing algorithm Priority Based Routing (PBR) to balance the energy consumption of the sensor nodes in multi-sink sensor networks. Experiment results show PBR has better performances than traditional methods and prolongs the lifetime of the sensor networks.*

Keywords: Priority based, routing, multi-sink, sensor networks.

1. Introduction

Nowadays, the rapid developments of the techniques in such areas as wireless communications, computer science and micro electronics, promote the tremendous applications of sensor networks in various fields. Wireless sensor networks have been widely used in environment monitoring, habitat monitoring, military and industrial fields. The basic functions of sensor nodes are sensing, communicating and computing. These functions are affected by the limitations of the energy supply and memory capability of sensor nodes. Many researchers have been working on energy efficient routing and data management issues and gaining valuable improvements, while many issues still remain unsolved.

In single-sink sensor networks, the invalidation of the sink node will cause the breakdown of the whole sensor network. How to guarantee the smooth running of the network when the sink node fails needs further study.

The routing path is initiated by the single sink node. The data transmission goes along the routing path in the opposite direction. All the data will be transmitted to the single sink node eventually, so the sensor nodes near the sink have more workload than the other nodes. These nodes near the sink consume more energy and deplete quickly. How to prolong the lifetime of the network by balancing the energy consumption among the sensor nodes is a critical problem to be solved.

The data transmission in single-sink sensor networks usually only considers the number of hops and the total energy consumption from the source nodes to the sink. The routing path is the nearest path and may include nodes with less energy remaining and large energy consumption for data transmission. These routing paths can't guarantee the maximum lifetime of the networks.

The sink node has sustainable energy supply and is reusable. So recently many researchers are working on topics in multi-sink sensor networks, such as routing. In this paper, we propose the system architecture of multi-sink sensor networks and a new routing algorithm Priority Based Routing (PBR) to consider the balanced energy consumption of the sensor nodes.

The rest of the paper is organized as follows. In section 2, we discuss the related research. In section 3, we introduce the system architecture of the multiple sink sensor networks. In section 4, we propose the new routing algorithms ELBR and PBR. In section 5, we compare our new algorithms with the previous methods. In section 6, we conclude the paper and introduce future works.

2. Related works

Sensor networks formed by largely and densely deployed sensor nodes have been widely used for various fields [2], such as habitat monitoring [4], pollutant monitoring [6, 7], environment monitoring [3, 5]. To prolong the lifetime of networks, recent researches focus on multiple sink sensor networks, the research topics include routing [1, 9], location of sensor nodes [8], the lifetime issues [10]. The topology and data collection [11] depend on the system architecture of the sensor networks while few works have been done so that it is necessary to build up system architecture for data collection in multi-sink sensor networks. The energy model and Low Energy Adaptive Clustering Hierarchy (LEACH) proposed in [12] has been widely used in solving problems in wireless sensor networks.

3. System architecture of multi-sink sensor networks

We describe the system architecture and the topology construction in multi-sink sensor networks.

3.1 System architecture of multi-sink sensor networks

In multi-sink networks, we deploy multiple sink nodes as needed. Sensor nodes can connect with each other through a simple protocol like TCP/IP. We revise the system architecture of the single-sink sensor networks and propose the system architecture of multi-sink sensor networks. The components include task manager, proxy, sink nodes and sensor nodes. The architecture of multiple sink sensor networks is shown in Figure 1.

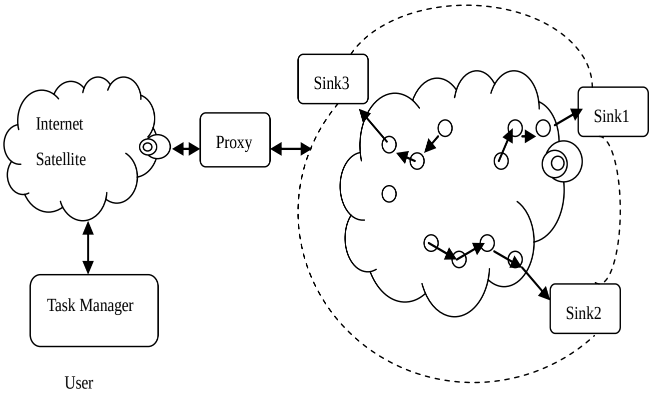


Figure 1 Architecture of multiple sink sensor networks

The users send queries through a task manager which are transmitted to a proxy by internet or satellite. The tasks of the proxy are dispatching and collecting data by broadcasting or P2P. The sensor nodes transmit the data to the optimized sink node.

The advantages of multi-sink sensor networks compared with single-sink sensor networks are as follows.

The existences of multiple sink nodes avoid the breakdown of the whole sensor networks due to the invalidation of the single sink node in single-sink sensor networks. When one sink node fails, the data can be transmitted through other sink nodes.

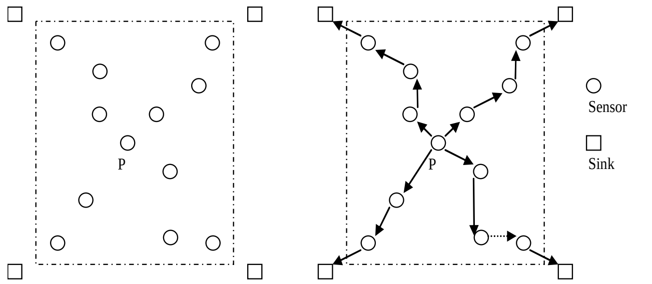
The existences of multiple sink nodes relieve the unbalanced energy consumption among sensor nodes. In single-sink sensor networks, almost all the data should pass the sensor nodes near the sink. So the energy consumes fast among these nodes. While in multi-sink sensor networks, the data transmission burden is shared among all the sinks so as to balance the energy consumption and prolong the lifetime of the networks.

We can develop different routing algorithms for multi-sink sensor networks. In single-sink sensor networks, the routing path is initiated by the single sink node and in fixed direction. In multi-sink sensor networks, the routing paths can be initiated by different sink nodes and data can be transmitted along different routing paths.

3.2 Topology construction in multi-sink sensor networks

Multi-sink sensor networks should first construct the topologies before dispatching queries and collecting data.

There are several steps in topology construction. First, the proxy sends topology construction messages to sink nodes. Second, the sensor nodes nearest to the sink broadcast message to find neighbor nodes. The neighbor nodes receive the message and wait for a while which is proportional to the distance between the neighbor nodes and the sender. Finally the sensor network is divided into many clusters, and every cluster has a cluster head. The cluster head is in charge of collecting data from the nodes in this cluster. The topology construction is shown in Figure 2.



(a) Sink and sensor nodes **(b) Paths from P to sinks**

Figure 2 Topology discovery of multi-sink sensor networks

The layout of the sensor nodes and sink nodes is shown in figure 2 (a). The sensor nodes are deployed in an inspection area and the sink nodes are deployed in the margin of the area. The topology of the multi-sink sensor network is shown in figure 2 (b). Paths are created from sensor node P to every sink node.

The amount of transmitted data and the transmission distances are different among the sensor nodes. The energy consumption will be unbalanced after running the sensor network for a period of time.

In section 4, we will discuss in detail the routing algorithm based on energy level of the sensor nodes how to balance the energy consumption among the sensor nodes.

4. Routing algorithm: PBR

We first clarify some definitions then introduce our algorithm in detail.

4.1 Term definitions

Definition 1 Sensor networks

A sensor network can be described by an undirected graph G (V, E). V means the set of all the nodes, E means the routing set.

$$V = V_{sensor} \bigcup V_{\sin k} \quad (1)$$

$$E = \{(u,v) | u,v \in V_{sensor}\} \bigcup \{(u,v) | u \in V_{sensor}, v \in V_{\sin k}\} \quad (2)$$

Definition 2 Path

Path is defined as the ordered set of all the nodes starting from the sensor node through one hop or multi hop to the sink nodes.

$$P = (V_{sensor\_1}, V_{sensor\_2}, ..., V_{\sin k\_i}) \quad (3)$$

Definition 3 Cost of communication

Cost of data transmission is defined as the energy cost of direct communication between two sensor nodes.

$$Cost(d_{(i,j)}) = kd_{(i,j)}{}^{a} + \tau \quad (4)$$

Here $d_{(i,j)}$ is the distance between two sensor nodes v_i, v_j, k is power dissipation parameter of transmission circuit, τ is the total energy consumption for sampling, computation and receiving of sensor nodes. α is a power dissipation exponent, its value varies according to the environment.

Definition 4 Cost of path

Cost of path is defined as the total energy consumption of one communication between sensor nodes and a sink.

$$Cost_P = \sum Cost(d_{(i,j)}) \quad (5)$$

We should consider not only the energy consumption but also the balance of the energy consumption in order to prolong the lifetime of the network as much as possible. We propose a new concept called energy level to represent the communication capacity of the sensor nodes.

Definition 5 Energy level

Energy level is defined as the number of times a sensor node can transmit data to its neighbors under the current remaining energy.

$$L_{i,m} = \lfloor E_{\mathrm{Re}sidual} / Cost(d_{(i,j)}) \rfloor \quad (6)$$

Here m represents the sink node, i.e., the direction of data transmission.

Definition 6 Energy level of the path

Energy level of the path is defined as the minimum value of the energy levels along the path from a sensor node to the sink. The minimum value of the energy level reduces to 0 means this path is broken.

$$S_P = \min_{i \in P}(L_{i,m}) \quad (7)$$

When we choose routing path, we can base on cost of communication or energy level. We describe the two routing algorithms.

4.2 Minimum energy cost routing algorithm

Suppose the data source is the sensor node v_i. There are n sink nodes deployed in the sensor networks. The total energy consumption from v_i to sink v_k is cost(v_i, v_k). So the minimum communication cost routing algorithm is described as $\min_k (Cost(V_i, V_k))$.

The following is the pseudo-code of energy cost based routing algorithm.

```
Algorithm 1 Energy cost based routing
Input: source node p and RT (routing table) on this node
Output: the label of the sink node
  Begin
  MinCost=Cost(Vp,V1); SinkNodeID=V1;
  for Cost(Vp,Vi) of every path in RT do
     if Cost(Vp,Vi) < MinCost then
        MinCost= Cost(Vp,Vi);
        SinkNodeID= Vi;
  Return SinkNodeID;
  End
```

4.3 ELBR: Energy level based routing algorithm

ELBR is a routing algorithm based on energy levels of the sensor nodes. We first calculate the energy level of the path, and then choose the path with the maximum energy level to transmit data.

$$\max_n(S_{i,k}) = \max_n(\min_j(L_{j,k})) \quad (8)$$

```
Algorithm 2 ELBR: Energy level based routing
Input: source node p and RT (routing table) on this node
Output: the label of the sink node
  Begin
  for every path Pk from p to sink do
     MinEnergyLevel=Lp,k
     for enery sensor node Vi in Pk do
        If  Li,k < MinEnergyLevel then
           MinEnergyLevel= Li,k
       PathEnergyLevelList[k]=MinEnergyLevel;
  SinkNodeID=V1;
  MaxPathEnergyLevel= PathEnergyLevelList[1];
  for every value in PathEnergyLevelList then
     if PathEnergyLevelList[i] > MaxPathEnergyLevel then
       MaxPathEnergyLevel= PathEnergyLevelList[i];
       SinkNodeID= Vi;
```

Return SinkNodeID;
End

4.4 PBR: Priority based routing algorithm

This method takes both the energy level and the energy cost of the routing path so the energy consumption is more balanced and the network lifetime is more prolonged.

Assume the data source is node i, and there are k sink nodes in the sensor network. The energy consumption of data transmission from i to sink j is $Cost(v_i, v_j)$, the energy level of the path is $S_{(i,j)}$. The maximum energy consumption from node i to all the sink nodes is $\max_n(Cost(v_i, v_k))$. After generalization, we get $Cost(v_i, v_j) / \max_n(Cost(v_i, v_k))$.

The PBR can be presented as

$$\max_n(p_{i,k}) \quad (9)$$

$$p_{i,j} = (\max_n(Cost(v_i, v_k)) / Cost(v_i, v_j))^{\alpha} * (s_{i,j})^{\beta}$$

(10)

$j \in v_{\sin k}$, which means j is a sink node; α, β are influential exponents.

When $\alpha = 1, \beta = 0$

$$p_{i,j} = \max_k(Cost(v_i, v_k)) / Cost(v_i, v_j) \quad (11)$$

and the value of $\max_k(Cost(v_i, v_k))$ is invariant in the same sensor network, so PBR is actually the minimum energy cost routing algorithm.

When $\alpha = 0, \beta = 1$,

$$P_{i,j} = s_{i,j} \quad (12)$$

so PBR is energy level based routing algorithm.

The effects of energy cost and energy level are greater than 1, so $\lg(p_{i,j})$ is an increasing function. For simplicity, the algorithm is calculated by $\lg(p_{i,j})$.

Algorithm 3 PBR: Priority based routing
Input: source node p and RT (routing table) on this node
Output: the label of the sink node

```
Begin
  MaxCost=Cost(Vp,V1);
  for every path Cost(Vp,Vi) do
    if Cost(Vp,Vi) > MaxCost then
      MaxCost= Cost(Vp,Vi);
  for every path Pk from p to sink do
          MinEnergyLevel=Lp,k
    for every node Vi in path Pk do
      If  Li,k < MinEnergyLevel then
        MinEnergyLevel= Li,k
    PathEnergyLevelList[k]=MinEnergyLevel;
  SinkNodeID=V1;MaxPriority=alpa*(lg(MaxCost)-
  lg(Cost(Vp,V1))+beta*lg(PathEnergyLevelList[1]);
  for every path Pk in RT then
  temp=alpa*(lg(MaxCost)-lg(Cost(Vp,Vk))+beta*lg(
  PathEnergyLevelList[k]);
    if temp > MaxPriority then
      MaxPriority=temp
      SinkNodeID=k;
  Return SinkNodeID;
End
```

PBR considers the energy consumption and the number of communication, so it can balance the energy consumption among the sensor nodes and prolong the lifetime of the whole multi-sink sensor network.

5. Experiment

We make an example to show the two routing algorithms. Assume we have a sensor network topology as shown in figure 3. The initial energy of every sensor node is 20, and the value between two sensor nodes is the energy consumption of data transmission. For example, the energy consumption of data transmission between v_6 and v_5 is 2.

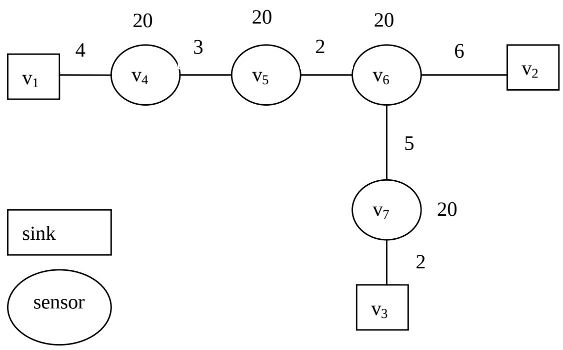


Figure 3 the initial state of sensor network

Energy cost based routing algorithm:
$Cost(V_6,V_1) = Cost(V_6,V_5)+(V_5,V_4)+Cost(V_4,V_1)=2+3+4=9$
$Cost(V_6, V_2) = 6$
$Cost(V_6, V_3) = Cost(V_6, V_7) = Cost(V_7, V_3) = 5+2=7$

According to this algorithm, we choose V_6-V_2 to transmit data. The number of data transmission is 20/6=3.

ELBR: Energy level based routing algorithm:
The energy level of every sensor node:

$$L_{6,1} = 20/2 = 10, L_{5,1} = 6, L_{4,1} = 5$$

$$L_{6,2} = 20/6 = 3$$

$$L_{6,3} = 20/5 = 4, L_{7,3} = 20/2 = 10$$

The energy levels of paths from source to every sink node:

$$S_{6,1} = \min_j(L_{j,1}) = 5$$

$$S_{6,2} = \min_j(L_{j,2}) = 3$$

$$S_{6,3} = \min_j (L_{j,3}) = 4$$

According to this algorithm, we choose the path with the maximum energy level, so v_6-v_1. We can transmit 5 times. Compared to energy cost based routing algorithm, the lifetime of the network is extended.

PBR: Priority based routing algorithm:

According to energy cost based routing algorithm, we get

$$\max_n(Cost(v_i, v_k)) = Cost(v_6, v_1) = 9$$

And from ELBR, we get $s_{i,j}$. Put these in formula (11), we get the priorities of every path.

Assume $\alpha = 1, \beta = 1$,

$$p_{6,1} = (9/9) * 5 = 5$$

$$p_{6,2} = (9/6) * 3 = 4.5$$

$$p_{6,3} = (9/7) * 4 = 5.1$$

According to PBR, we should send data to sink node 3. PBR combines the advantages of energy cost based routing algorithm, which chooses the path with the minimum energy cost to transmit data, and ELBR, which chooses the path with the maximum number of transmitting times, so PBR balances the energy consumption of the sensor nodes and prolongs the network lifetime.

6. Conclusions and Future Works

There are many disadvantages in single-sink sensor networks, such as the unbalanced energy consumption of the sensor nodes, invalidation of the sink, routing algorithm is single. We propose multi-sink sensor networks and a new routing algorithm called PBR priority based routing algorithm to avoid these problems and prolong the lifetime of the network.

Our future works is testing our algorithms and query processing in multi-sink sensor networks.

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