Routing Model Based on Service Degree and Residual Energy in WSN

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Abstract. Energy constraint of sensor nodes is a key problem in WSN. Energy-based routing mechanism can significantly prolong the lifetime of sensor networks, but the current researches do not consider the number of service objects of a senor node. In this paper, we propose a routing model based on service degree and residual energy, named SERM. We put forward the node service degree to represent the service scale of some node, and the path service efficiency to show the path's service capability. Then, a multi-path transmission system of wireless sensor networks is designed based on the 2-dimension: the service degree and the residual energy of nodes. Finally, the simulation experiments using OPNET prove that SERM can prolong the network lifetime and collect more sensor data.

Keywords: Service degree · Service efficiency · Residual energy · Lifetime

1 Introduction

In high density deployment environment, sensor nodes are rather small and usually carry limited energy. Normally, the energy of wireless sensor nodes are provided by the battery, and the nodes need work for a few months or even one year without adding energy [1]. Energy constraint of sensor nodes affects the stability of the network and the lifetime of the network [2]. Therefore, energy awareness and efficient using of energy have become a hot issue in the research of wireless sensor routing protocol [3–6].

For any wireless node, its forwarding service scale is different. Therefore, the number of service objects should be considered in the process of routing. But the existing routing protocols mainly consider the number of hops, residual energy and the path of consumption.

In Fig. 1, a circle indicates a node, the number in circles represents a node identifiers. Then, the two tuples outside the circles are the node's residual energy and the number of service objects whose traffic may be forwarded by the node. The direction of the arrow indicates the direction of data transmission. In Fig. 1, N_4 communicates with N_0. First of all, we assume that the costs of 2 paths are

S. Wang and A. Zhou (Eds.): CollaborateCom 2016, LNICST 201, pp. 363–372, 2017.
DOI: 10.1007/978-3-319-59288-6_33

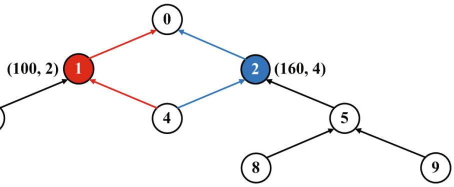

Fig. 1. Node service scale.

equal when data is forwarded from N_4 to N_1 or N_4 to N_2. If the path is selected only according to the residual energy, N_4 will select path: N_4-N_2-N_0. However, N_2 provides forwarding service for 4 nodes, and the average service capacity is 40. N_1 provides forwarding services for 2 nodes, and the average service capacity is 50. Obviously, it is reasonable that N_4 chooses N_1 as the next hop.

In this paper, we design a routing model based on service degree and residual energy (SERM). On account of the different service scale of some nodes, we put forward the node service degree, and path service efficiency which represents the path's service capability. Considering the residual energy and the service scale of the nodes, SERM chooses a optimal path to forward data.

SERM has the following characteristics: (1) SERM considers not only the node energy consumption but also the service capacity of nodes. (2) SERM chooses a different optimal path to forward data to sink node in different time. (3) SERM can prolong the network lifetime and the sink node can collect as many data as possible.

2 Related Work

As the main task of the WSN is to collect data from the sensor nodes to the observer, so the primary goal of the design of routing protocol is that sink node should collect the data information as much as possible in sensor network lifetime. Passive power supply environment has led to the energy of the sensor node is very limited [7], so another important goal of the routing protocol is to maximize the use of existing energy to improve the network's lifetime.

It is a focus of research that the shortest path routing design based on the minimum number of hops in recent years. Minimum hop routing protocol [8] is based on the flooding algorithm and directed diffusion algorithm, and adds the conception of hop count. But in the process of data transmission, nodes will send their packets to all the parent nodes, which results in the message redundancy and in the process of select the parent node only considers the nodes which close to sink one, but not considers the residual energy of nodes.

In some practical applications, the information transmission in sensor networks has a certain direction, so there is a directed diffusion routing protocol [9]. The routing protocol not only meets the feature of the direction of the information transmission in WSN, and still has potential advantage such as the shortest path, the minimal time delay, and the minimal energy consumption [10]. Through the simulated analysis of the directed routing network, the paper [11] gets the result that the gradient of the number of neighbor nodes and the nonuniformity of the distribution of data convergence flow can lead to the greater consumption of energy and delay.

Aiming at the problem of the excessive energy consumption of nodes caused by a single path, C. Shah Rahul proposed an energy multi-path routing mechanism [12]. The main principle of the routing mechanism design is to establish multiple paths between the source node and sink node, then according to the condition of residual energy and the path consumption, gives different paths a certain probability of selection. The model can balance the consumption of the whole network energy while forwarding data, and can prolong the lifetime of the network.

Multi-path routing strategy can not only balance the network traffic but also prolong the lifetime of the network. A routing mechanism for wireless sensor networks is proposed, which combines the residual energy of nodes and the maximum angle of nodes in [13]. Based on the residual energy and the node angle, the initial routing path of the network is established, and then the failure nodes in the network are replaced, and the path is selected again. In paper [14], the node degree, the residual energy and the transmission distance are regarded as the key factors in routing design. And the source node chooses the path to the sink node according to the forward cost which is calculated by the three factors.

Those related researches mentioned above have a good inspiration for this paper. But in this paper, the sensor nodes are distribution with a high density, so the path consume by the data transmission between nodes can be neglected. However, the scale of the service provided by the node is different, so the forward capability of the nodes is different. Therefore, the service scale of the nodes should be considered in the path selection.

3 Service Energy Efficiency Model

In general, there are multiple optional paths between the source nodes and sink node. In SERM, the source node chooses one path with the biggest service ability to forward data, based on the node residual energy and the service ability comprehensively. For instance, in Fig. 1, N_4 wants to send data to N_0. It has two optional paths, i.e. N_4-N_1-N_0 (the red path) and N_4-N_2-N_0 (the blue path). Since the former has a larger service capacity than the latter, the N_4-N_1-N_0 is selected to deliver data. Several important concepts in SERM are described below.

Note that the residual energy(RE) of a node changes with the network running. In this paper, we focus on the energy consumption of packets forwarding, so we compute the energy consumption by the unit of forwarding a packet. In Fig. 2, the residual energy of N_1 is 150, which indicates that N_1 has 150 units of energy. In other words, the residual energy of N_1 can still support the forwarding work for 150 packets.

Definition 1. Node Service Degree(SD): Node service degree represents the number of nodes that this node serve for. The service degree of the node N_k is m, which means there are m nodes which may deliver data to sink node through the node N_k. In the tree-like topology, it is apparent that node service degree is also the number of all descendants of this node.

In Fig. 2, only N_6 reaches N_0 via N_4, so the service degree of N_4 is 1.

Definition 2. Node Service Efficiency(*NSE*): Node service efficiency represents the node's service capability for its SD. It is computed as:

$$NSE(N_i) = RE(N_i)/SD(N_i) \tag{1}$$

In Fig. 2, the $SD(N_8)$ is 2, and the $RE(N_8)$ is 60, so the $NSE(N_8)$ is 30.

Definition 3. Path Service Efficiency(*PSE*): Path service efficiency can reflex the optimal path from the node to sink node. That is:

$$PSE(N_i) = min\{max\{PSE(N_{f_1}), \cdots, PSE(N_{f_n})\}, NSE(N_i)\} \tag{2}$$

In Fig. 2, there are two paths from N_4 to N_0. Hence N_4 selects the maximum value of PSE_s of N_4's parent N_1 and parent N_2, which is 50. Then it selects the minimum value compared with $NSE(N_4)$. Eventually $PSE(N_4)$ is 50.

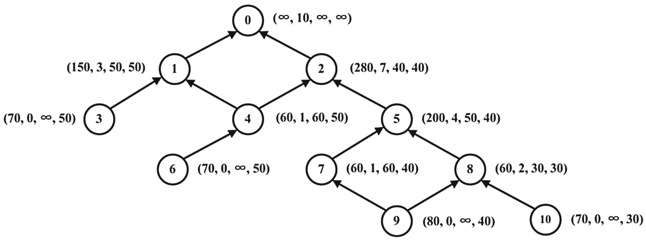

Fig. 2. The diagram of SERM.

A circle in Fig. 2 indicates a node, the numbers in circles are node identifiers, the four tuples outside the circles are: node residual energy, node service degree, node service efficiency, and path service efficiency. The arrows indicate the direction of data transfer.

4 SERM Implementation

SERM includes three parts: topology construction, routing, topology maintenance, etc.

4.1 Topology Construction

When sink node powers on, it means the beginning of the topology construction. The topology is a tree-like structure. In the topology construction process, each node has a "layer" attribute which is the hops from the node to sink node. Let sink node is layer 0, and the direct children nodes of sink node are layer 1.

Algorithm 1. the joining procedure of N_i

Input: The timer is T_1; the max number of child node is max_child;
Output: The parent of the node N_i;
while T_1 **do**
  N_i receives the service message from the nodes;
  if the number of it's child <= max_child;
  then put the nodes into a set S_1;
  if T_1 *is expires and* S_1 *is NULL* **then**
    reset the T_1;
select the nodes whose layer is minimum in S_1, put into a set S_2;
return the nodes in the set S_2;

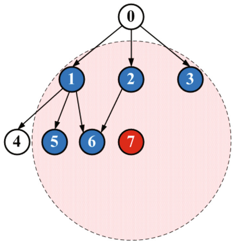

Fig. 3. Topology construction.

Let N_i is a node who has not connected the topology, then Algorithm 1 describes the joining procedure of N_i.

Suppose that the maximum of node connection number is 3. In Fig. 3, the dotted line circle represents the communication range of N_7. After N_7 starts to search parent nodes, it can receive the messages from N_1, N_2, N_3, N_5 and N_6. And then it will compare their connection numbers, so S_1=$\{N_2, N_3, N_5, N_6\}$. After that, N_7 selects the nodes whose layer are minimum, so S_2=$\{N_2, N_3\}$. It means N_7 joins the tree-like topology through N_2 and N_3.

4.2 Routing

After the topology construction, there may be multiple paths from a source node to sink node. In SERM, a node selects the transmission path based on the RE and SD. At any moment, the node always chooses the path whose PSE is maximum to forwarding packets.

In order to choose an optimal path, we need to get the RE and SD of nodes. We suppose nodes in WSN have self awareness of their energy, so we still need to get the SD of each node and PSE of each path.

We first define an array of the SD (referred to as SA), which contains the number of all nodes that reach the node. The SD is the size of the SA. Then Algorithm 2 describes the obtaining procedure of SD.

Algorithm 2. the obtaining procedure of $SD(N_i)$

Input: The number of the child node of N_i is Num_child
Output: The service degree of N_i as $SD(N_i)$

SA_i = NULL;
for *m = 1; m <= Num_child; m++* **do**
    N_i receives the connect message from it's child N_m;
    $SA_i = SA_i + N_m$;
$SA_i = SA_i + N_i$;
the number of the SA_i is $SD(N_i)$;
return $SD(N_i)$;

In Fig. 2, N_9 and N_{10} send the connection messages in which the SA is empty to the parent N_8. After receiving the connection messages, N_8 counts its SA, $SA_8 = \{N_9, N_{10}\}$, the SD of N_8 is 2.

At present, the RE and SD of a node are already known, so the NSE of the node can be calculated according to expression (1). Then Algorithm 3 describes the obtaining procedure of PSE.

Algorithm 3. The obtaining procedure of $PSE(N_j)$

Input: The number of the parent node of N_j is Num_parent; the $RE(N_j)$; and the $SD(N_j)$;
Output: The path service efficiency of N_j as $PSE(N_j)$

$NSE(N_j) = RE(N_j)/SD(N_j)$;
$PSE(N_j) = NSE(N_j)$;
for *n = 1; n <= Num_parent; n++* **do**
    N_j receives the price message from it's parent N_n;
    $PSE(N_j) = \min\{PSE(N_j), PSE(N_n)\}$;
return $PSE(N_j)$;

4.3 Topology Maintenance

During the operation of WSN, the RE of some nodes will decrease gradually, and there may be some failure nodes whose electricity drain out. These changes directly affect the selection of the transmission path.

Transmitting data, nodes select the path according to the PSE. When the RE of a node is changed, the PSEs of descendant nodes are updated according to the Algorithm 3. Once a node is failure, its child nodes first judge whether the node to the sink node still exist path, if there is no path, re-select the parent node according to Algorithm 1. Then the parent node first updates its own SD, and then the SDs of their ancestors are updated according to Algorithm 2, finally the PSEs of entire network are updated according to Algorithm 3.

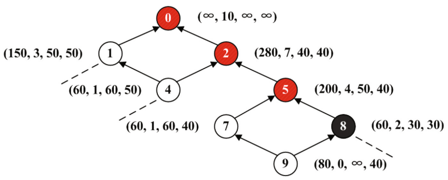

Fig. 4. Before the topology maintenance.

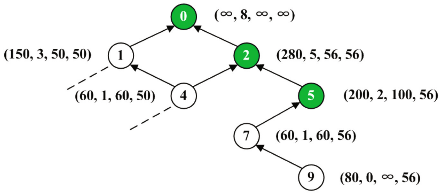

Fig. 5. After the topology maintenance.

Figures 4 and 5 show the topologies before and after N_8 failure respectively. The two figures are both a partially views of Fig. 2. N_8 is a failure node, and N_0, N_2 and N_5 are the nodes affected. N_8 fault, N_5 updates its SA, namely SA_5=$\{N_7, N_9\}$, and the $SD(N_5)$ is 2. According to the Algorithm 2, N_5 sends connection message to its ancestor node, and then the $SD(N_0)$ is 8. At last, the topology and related parameters are updated according to Algorithm 3, which are shown in Fig. 5.

5 Performance Analysis and Experimental Simulation

Compared with the shortest path model (Min Path) and the maximum energy model (Max RE), SERM can prolong the network lifetime, but it needs some cost for SD and PSE. In SERM, we do not care about the energy consumption of sink node. Except sink node, every node needs to store the RE (2 bytes), SD (1 bytes) and the PSE (1 bytes). Let M be the size of memory cost for SERM, the formula is:

$$M = \begin{cases} 0, & if \ sink \ node \\ 4, & else \end{cases} \tag{3}$$

Except the leaf node, each node needs to send packets to convey energy efficiency of paths downwards. Let BW_1 is the bandwidth cost of it. The packet contains 8 bits of the PSE, and 224 bits of packet encapsulation. For any node N_i, assuming the number of its direct son nodes is m, and a message be sent every t time, then BW_1=m*(224+8) /t. Take m=2, t=100s, then BW_1 = 4.64 bit/s. In addition to sink node, each node needs to send packets to convey service information upwards. Let BW_2 is the bandwidth cost of it. The packet contains all of the descendants of the node, and 224 bits of packet encapsulation. Suppose the node N_i has the number of the parent node is n, the number of the descendant node is k, then BW_2=n*(224+k*8)/t. Assuming the topology is the 5 layer of the binary tree-like, we take the second layer node as an example, n=2, k=9, t=100s, then BW_2 = 5.92 bit/s. So the cost of memory and bandwidth are both small in SERM.

To verify the performance of SERM, we use the OPNET to simulation experiments. The parameters used in the simulation are shown in Table 1. In order

Table 1. Table of simulation parameters

Parameters	Value
The regional scale (m)	1000*1000
The communication radius (m)	100
The number of nodes	60, 100
The packet delivery (pkts/min)	0.5, 1, 1.5, 2

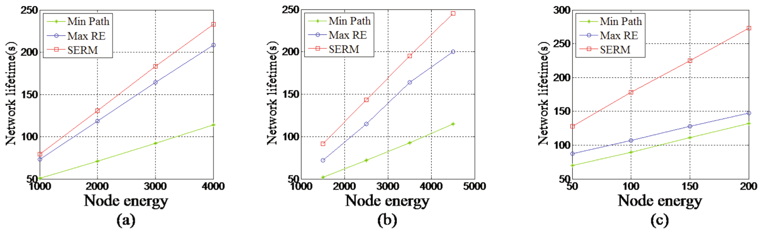

Fig. 6. The lifetime of 60 nodes.

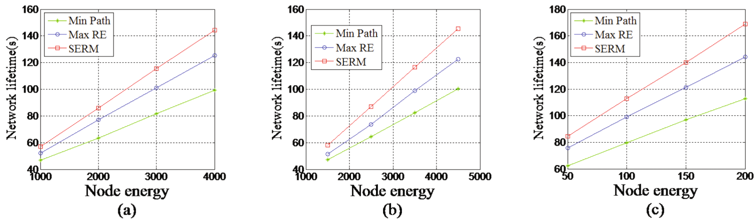

Fig. 7. The lifetime of 100 nodes.

to reflect the reliability of the experimental data, we compare SERM with Min Path and Max RE in same topology.

In this paper, the lifetime of network is defined as the time from beginning of the network to energy exhaustion of any node [15]. Figure 6 shows the lifetime of 60 nodes in different energy distribution. The abscissa represents the energy value of the node, the ordinate indicates the time when the first node failure. In Fig. 6.a, all of the node energy are same. In Fig. 6.b, the energy is a random value in range. In Fig. 6.c, the energy of leaf nodes is 1000, each reducing one layer, the energy is increased by 50, 100, 150 and 200.

No matter what kind of energy distribution, the lifetime of SERM is always longer than Min Path and Max RE. And the slope of SERM is the largest, which reflects the greater the energy, the advantage of SERM is more obvious. Figure 7 shows the lifetime of 100 nodes in different energy distribution.

We define the network throughput as the number of packets that sink node is collected in the lifetime of the network. Figure 8 shows the throughput of 60 nodes in different energy distribution, and the frequency of the packet delivery is

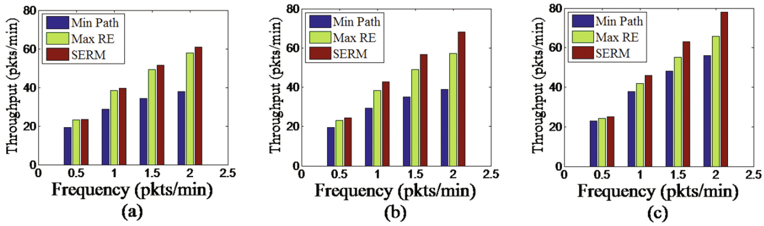

Fig. 8. The throughput of 60 nodes.

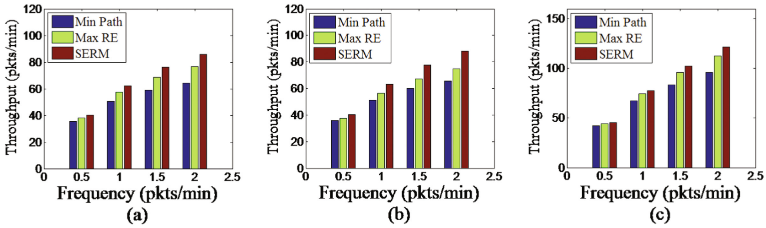

Fig. 9. The throughput of 100 nodes.

0.5, 1, 1.5 and 2 per minute respectively. In Fig. 8.a, all the node energy is same, which is 1000. In Fig. 8.b, the energy of nodes is different, which is a random value in [1000,2000]. In Fig. 8.c, the energy of nodes is increased layer by layer. The energy of leaf nodes is 1000, and each reducing one layer, the energy is increased by 50. The simulation results show that SERM in different contract frequency, different node energy distributions, the throughput of the network are better than Min Path and Max RE. So during the lifetime, sink node can collect more packets with SERM. Figure 9 shows the throughput of 100 nodes in different energy distribution.

6 Conclusion

In wireless sensor networks, nodes resources are limited. Thus for a routing model, one of the most significant tasks is to maximize the energy utilization of nodes. In dense networks, there usually exist multiple paths for a node to send data to sink node. Therefore, in SERM, the path selection considers not only the remaining energy of nodes, but also their service degree. Simulation experiments prove that SERM has certain advantages in terms of network throughput and network lifetime, in spite of some additional cost for the storage and transmission of SD and PSE.

Acknowledgment. This research is supported by the National Natural Science Foundation of China (Nos.61373161, 61502320, 61300171), Youth Backbone of Beijing Outstanding Talent Training Project (No. 2014000020124G133), and the Fundamental Research Project of Shenzhen Municipality (No.JCYJ20160228172531429).

References

1. Liu, M., Cao, J.N., Zheng, Y., Chen, L.J., Xie, L.: Analysis for multi-coverage problem in wireless sensor networks. J. Softw. **18**(1), 127–136 (2007)
2. Kaur, R., et al.: Optimized cluster based deployment of sensor nodes to enhance the network lifetime in wireless sensor network. In: Fifth International Conference on Advanced Computing & Communication Technologies (ACCT), pp. 658–665. IEEE Computer Society (2015)
3. Yao, Y., Cao, Q., Vasilakos, A.V.: EDAL: An energy-efficient, delay-aware, and lifetime-balancing data collection protocol for heterogeneous wireless sensor networks. IEEE/ACM Trans. Netw. **23**(6), 810–823 (2015)
4. Lee, A., Ra, I.: Adaptive-gossiping for an energy-aware routing protocol in wireless sensor networks. In: International Conference on Wireless Communications & Mobile Computing, pp. 1131–1135. ACM (2010)
5. Rachamalla, S., Kancharla, A.S.: Power-control delay-aware routing and MAC protocol for wireless sensor networks. In: IEEE International Conference on Networking, Sensing & Control, pp. 527–532 (2015)
6. Zaman, N., Low, T.J., Alghamdi, T.: Enhancing routing energy efficiency of wireless sensor networks. In: International Conference on Advanced Communication Technology (ICACT), pp. 587–595. IEEE (2015)
7. Chang, J.H., Tassiulas, L.: Maximum lifetime routing in wireless sensor networks. IEEE/ACM Trans. Netw. **12**(4), 609–619 (2004)
8. Han, K.H., Ko, Y.B., Kim, J.H.: A novel gradient approach for efficient data dissemination in wireless sensor networks. In: IEEE Vehicular Technology Conference, pp. 2979–2983 (2004)
9. Chiang, S.S., Huang, C.H., Chang, K.C.: A minimum hop routing protocol for home security systems using wireless sensor networks. IEEE Trans. Consum. Electron. **53**(4), 1483–1489 (2007)
10. Akyildiz, I.F., Su, W., Sankarasubramaniam, Y., et al.: Wireless sensor networks: A survey. Comput. Netw. **38**(4), 393–422 (2002)
11. Wang, W., Li, Y., Li, H.S., et al.: The analysis of link availability for directional routing in mobile ad hoc network. In: International Conference on Computer Application and System Modeling (ICCASM), pp. 353–356. IEEE (2010)
12. Shah, R.C., Rabaey, J.M.: Energy aware routing for low energy ad hoc sensor networks.In: Wireless Communications and Networking Conference, pp. 350–355. IEEE (2002)
13. Wei, M., Huang, X., Wu, C., et al.: Network coding based energy-efficient multipath routing for wireless sensor network. In: International Conference on Advances in Mobile Computing & Multimedia, pp. 240–244. ACM (2012)
14. Qi, X.G., Wang, H.F., Zheng, G.Z., Xie, M.D., Duan, L.: Analysis on resilience of wireless sensor networks growth model. J. Softw. **25**(1), 131–138 (2014). (in Chinese)
15. Mak, N.H., Seah, W.K.G.: How long is the lifetime of a wireless sensor network? In: International Conference on Advanced Information Networking & Applications, pp. 763–770. IEEE (2009)