Reliable Transmission Method With Energy-awareness for Wireless Sensor Networks

Jian-ming ZHANG [1], Li-fang GU [1], Liang-min WANG [2]

Department of Computer Science, Jiangsu University, Zhengjiang, Jiangsu 212013 [1]
and
The Computer School of Xidian University, Xi'an, Shanxi 710071[2]

Summary

Reliability of data transmission is a key question in data-centric Wireless Sensor Networks (WSNs). A multi-path based transmission method is presented to solve this problem for hierarchical WSNs. The method can find all paths for any arbitrary given node to base station, and select the best way based on energy-awareness. By introducing transmit consumption power values, we can make this method more versatility. Finally, the experiment shows that the reliability of our algorithm is 10% higher than that of others.

Key words:
Multi-path; reliable route; hierarchical networks; Wireless Sensor Networks

1. Introduction

There existing several applications in Wireless Sensor Networks (WSNs) which require all gathered data to be successfully transmitted without loss. For example, in structure monitoring situation, data from all measuring points will finally build up a model in order to analyze the structure. Moreover, there lies three aspects of challenges in order to meet reliable transmission in WSNs, such as link asymmetry, mote function and energy constrains, as well as the network application [1] [2].

Ways used to improve the transmission reliability of the sensor networks mainly lies in link retransmission [3], erasure codes [3] and multi-path [4] approaches. Link retransmission can conquer the impact of increased number of hops on network link failure rates, but it will reduce the channel and memory utilization; erasure codes use information redundancy to rebuild original messages without link retransmission, however, the number of messages can not exceed the number of bits used to represent the message, the number of code words should be smaller than the size of extension field. Multi-path approach provides standby paths while risks take place in the main path, yet the disjoint multi-path would potentially be less desirable than the primary path, while link quantity and link quality of braided multi-path is closely related to the primary one, path constructed by this arithmetic could not suffer hard risks.

Multi-path approach can improve the reliability of data transmissions and balance the network load efficiently, however, there exists variety of limitations in current multi-path approaches, and a reliable retransmission method with energy-awareness in Wireless Sensor Networks is proposed to solve these challenges. The method includes building multi-paths between source nodes and destination nodes which are more balanced in energy consumption, optimizing and filtering these paths based on the whole path energy consumption, finally the base station feed back these forwarding tables to corresponding nodes. We use ACK affirm mechanism to check whether the packet is lost or not, thus we can judge the reliable transmission easier.

2. Hierarchical Topology Algorithm Based on LEACH

Compared to plan topology, hierarchical topology has more advantages. Hierarchical one conductive to save the energy spent in transmitting messages, to reduce the quantity of data transmission, to use communication bandwidth more efficiently, it also has agility in configuring network scales. So we propose our multi-path mechanism on the basis of hierarchical wireless sensor networks.

LEACH (Low Energy Adaptive Clustering Hierarchy) is designed by Heinzelman et al. of MIT [5].

LEACH includes a new, distributed cluster formation technique that enables self-organization of large numbers of nodes, algorithms for adapting clusters and rotating cluster head positions to evenly distribute the energy load among all the nodes, and techniques to enable distributed signal processing to save communication resources. It can

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improve 15% of life time compared to normal plan network.

At initialization phase, targeting cluster headers through the following mechanism. Sensor nodes generate random numbers between 0 and 1, if the number is more than the threshold T, the node becomes the cluster header. T calculated as follows:

$$T = \frac{p}{1 - p[r \bmod (1/p)]} \qquad (1)$$

Where *p* stands for the percentage of nodes to become a cluster leader, *r* is the current round number.

Once the nodes have elected themselves to be cluster heads, the cluster head nodes must let its neighbor nodes in the network know that they have chosen this role for the current round. Each non-cluster head node determines its cluster for this round based on the received signal strength of each cluster head, then these non-cluster head nodes inform the cluster head that it will be a member of the cluster by transmit a join-request message, the cluster head node sets up a Time Division Multiple Access (TDMA) schedule and transmits this schedule to the nodes in the cluster. After the TDMA schedule is known by all nodes in the cluster, the set-up phase is complete and steady-state operation can begin. In the steady-state operation, non-cluster head nodes continue to collect monitoring data and transmit them to cluster heads, after the heads made necessary integration, they transmit the result to sink nodes.

Consider the problem we studied has similar background, we made some assumptions according to literature [5] about the sensor nodes and the underlying network model.

(1) For the sensor nodes, we assume that all nodes are quasi-stationary. This is typical for sensor network applications.

(2) For the network, we use a model where nodes always have data to send to the end user (Base Station, BS) and nodes located to each other have correlated data.

(3) Communication available between neighbor cluster heads. Communication diameter of cluster head $d_{cluster\_head}$ is two times longer than the diameter of cluster communication scope $d_{cluster}$ to ensure that the distances between adjacent cluster heads also came to mutual communication.

3 Multi-path Mechanism

Because the data collected from sensor nodes have high redundancy, so it has little impact on cluster member nodes to use one hop direct path to communicate with cluster heads. In general hierarchical networks, cluster heads transmit amalgamation data to BS through only one available transportation path. When in large-scale sensor networks situations, heads far from BS will quickly run out of battery in order to transmit data to BS, this will affect the network coverage and life time. So change the communication mechanism between source nodes and BS becomes very important in improving the transmission reliability in WSNs.

We present arithmetic of building multi-paths between source nodes and BS, the use of multi-paths can add more insurance to reliable data transmission. Multi-hops between source nodes and end nodes can save much transmission energy so as to prolong the network lifetime of WSNs. Figure 1 shows the data packets format in our experiment. We define the packet format as follows:

Figure 1(a) shows the definition of path request information,

```
typedef struct Path_ask_Msg {
  uint8_t type;
    //Message type , we divide the message type into
      three categories: Path_ask_Msg、Path_rep_Msg
      and Path_update_Msg  unit8_t ows;
    // One-Way Sequence (OWS) number value used
      for authentication in reliable transmission, avoid
      intervene from neighbor clusters.
  unit16_t source_node;
    // source node of this message, i.e. cluster head Na
      or Nb so.
  unit32_t path_info;
    //path_info, records the nodes information
      particular about the nodes which forward
      the message at one time.
  unit32_t sig_info;
    //sig_info, stands for the signal strength parameter.
      It is the ratio of signal incept and signal emit of
      source node a and end node b.
  unit16_t destination_node;
    //The destination of this message. The end of this
      Path_ask_Msg is the base station.
} Path_ask_Msg;
```

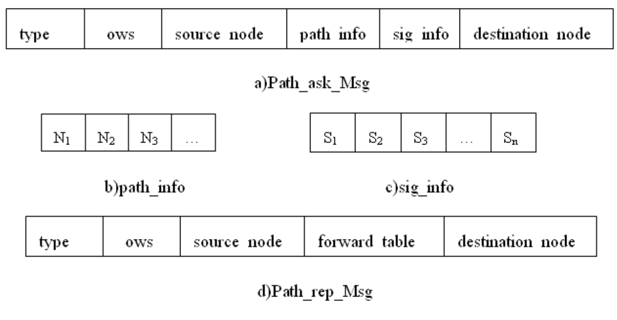

Figure 1 packet format

Figure 1(d) shows the definition of the feed back packet,

```
typedef struct Path_rep_Msg {
  uint8_t type;            // Message type.
 unit8_t ows;
  // One-Way Sequence (OWS) number value used for
     authentication in reliable transmission, avoid
     intervene from neighbor clusters.
 unit16_t source_node;
  // source node of this message. The source node of
     Path_rep_Msg is base station.
 array forward_table;
  // forwarding table computed by base station
     recording the multi-path for each head.
 unit16_t destination_node;
  //The destination of this message. The end of this
     Path_ rep _Msg is each cluster head.

  } Path_ask_Msg;
```

After cluster heads have established, they send path request messages to BS. Because of the limited communication range of cluster heads, they must forward the request messages to BS through neighbor cluster heads. The data packets record all the nodes information as well as the signal strength parameters it had past. Nodes information includes the nodes who have ever forwarded the message, the signal strength parameters mean the corresponding S_s in each node which will particular described below. After the packet arrives at the BS, information recorded in the packet will be analysis and computed. Then the BS would set up a TDMA schedule, assign a corresponding time slot for each cluster head, only in their own time slots, cluster heads can transmit data to BS.

Distill the nodes information as well as S_s from the path request packets, we can turn the information data into the graphics storage form as follows:

$$G = \langle V_i, E_{kj}, S_s, d^m_{uv} \rangle \quad i,k,j,s,u,v,m \in N \tag{2}$$

Where V_i is a set of cluster heads and BS point. E_{kj} is two bunch of correspondence link set of node V(k) and V(j) which belong to set V. Ss is the set of signal strength parameters, we define $S_s = S_{Rec(v_i)} / S_{Tran(v_j)}$ here, where $S_{Rec(v_i)}$ means the signal strength when destination node V(i) receive the message , $S_{Tran(v_j)}$ means the signal strength when father node V(j) forwarded it, this value is relevant to transmission power and communication distance. d^m_{uv} means the link charge between node V(u) and V(v). The whole process divides into two phases, the first phase is the creation of the multi-paths based on tree-like topology, and the other is the energy-awareness optimization.

3.1 Multi-path Algorithm

Assuming there are cluster heads *a, b, c, d* and a base station *Base* shown in figure 2. The algorithm seek all the available paths starting from node a. We hypothesis in this case the reliability of link transmission is 100%, no exterior distribution.

Way production algorithm realization steps are as follows:

Step 0:
Initialization, all nodes including cluster head and sink nodes input to set node_V.

Step 1:
Get one node from node_V and go to step 2;

Step 2:
Compute all neighbor nodes of the input node, for example in figure2, there are two neighbor nodes for node *a*.

Step 3:
If there is no neighbor nodes in this set, go to step 1, otherwise turn to step 4;

Step 4:
All neighbor nodes input to neigh_V, then checking with following three constraints:

(1) If there exists a node V*i*, which is same to father nodes, delete it . See fig 3, delete the path *a-b-a*.
(2) If there exists a node V*i*, whose residual energy is low, delete it.
(3) If there exists a node V*i*, which is the base node, output the path, then delete the base node from neigh_V.

Step 5:
if neigh_V≠0, turn to step 2.
if neigh_V=0&&&node_V=0, end the search.
if neigh_V=0&& node_V≠0, turn to step 1.

Figure 3 shows all the available paths for cluster head *a* according to the algorithm above.

3.2 Optimization Mechanism

The purpose of the optimization mechanism is to filter and order the paths in the forwarding table of corresponding cluster heads, as well as to delete the paths containing the slightest closure. Without taking into account the natural factors, path *a->c->Base* is the slightest closure for path *a->c->d->Base* contains the slightest closure, as the longer the path is, the more energy it charges, so we would delete the path *a->c->d->Base* from the link assembly.

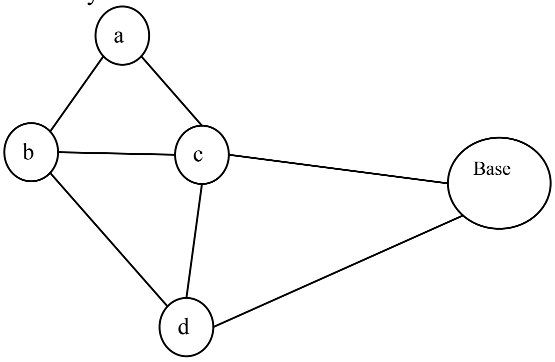

Figure 2 topology of cluster heads and base station

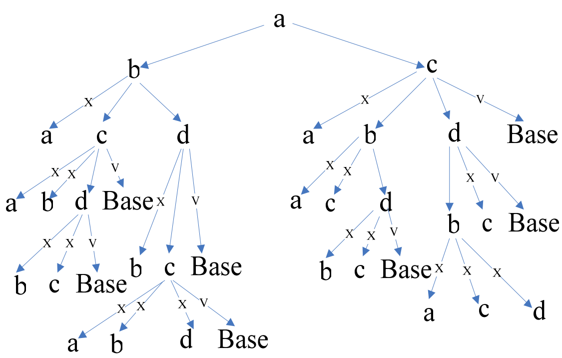

Figure 3 path searching

Actually, the energy consumption of any two nodes with same distance would be different in case of the impersonality factors, so we propose an energy-awareness method by supplying transmit consumption power to each link to simulate the environment of the sensor network. This will finally make the transmission reliability much better.

Due to the influence of impersonality factors such as high mountains, structures, remoras as well as the elements of wind, rain or thunder, the communication in wireless network might change frequently or even intermit. All these factors decide the value of the transmit consumption power *w*, smaller *w* is, more ideal the transmission conditions are, which means higher successful transmission rate. We define the matrix of *w* like formula (3):

$$W = (w_{ij})_{n\times n} \tag{3}$$

where

$$w_{ij} = \begin{cases} w^*_{ij} & e_{ij} \in E \\ 0 & e_{ij} \notin E \end{cases} \tag{4}$$

Where e_{ij} is the link between node V(*i*) and node V(*j*), w^*_{ij} is the transmit consumption power of the two nodes V(*i*) and node V(*j*), and $0 \le w^*_{ij} \le 1$, E is the set of links defined in G above, n represents the number of nodes in V.

As we know, the information transmit consumption P defines as formula (5):

$$P = kd_{ij}^2 \tag{5}$$

In which k is the energy parameter, d_{ij} stands for the distance between node V (*i*) and node V (*j*). We can see that the energy consumption and the distance square have the direct ratio. Along with increment of distance, the consumption would leap quickly, so it is necessary to decrease the single hop communication distance in the premise of high communication connection.

Moreover, when the message arrives at the destination node, the signal intensity is reliance to the distance between the source node and the destination node, thus we have equation (6),

$$d_{ij} = q(S_{Tran(v_j)} - S_{Rec(v_i)}) \tag{6}$$

Where q is a parameter of signal strength and distance, $S_{Rec(v_i)}$ represents the signal intensity when it arrives at the destination node V(*i*), while $S_{Tran(v_j)}$ when it begin to transmit in source node V(*j*), i, j∈V.

Synthesize equation (5) and (6), we get formula (6) as follows,

$$P = k \times d_{ij}^2 = kq^2 \times (S_{Tran(v_j)} - S_{Rec(v_i)})^2 \tag{7}$$

We can see from equation (6) that transmit consumption *P* is associate with signal strength parameter *S*, along with the transmit consumption power in each link, we can get matrix P,

$$P = (p_{ij})_{n\times n} \tag{8}$$

where

$$p_{ij} = \begin{cases} P^*_{ij} & e_{ij} \in E \\ 0 & e_{ij} \notin E \end{cases} \quad (9)$$

In equation (9), E is the set of links defined in G, n represents the number of nodes in V. P^*_{ij} is the transmit consumption power of the link between node V(i) and node V(j). We also define the P^*_{ij} as follows,

$$p^*_{ij} = (1 + w_{ij})kq^2 \times (S_{Tran(v_j)} - S_{\mathrm{Rec}(v_i)})_{ij}^{2} \quad (10)$$

According to equation (3) and (8), we can optimize the multi-path created in phase one, transmit consumption power of each path is equal to the summation of the corresponding P^*_{ij} in matrix P , larger P_{path} is, larger the transmit consumption for the link。

$$P_{path} = \sum_{i,j \in path} p_{ij} \quad (11)$$

We compute all the available paths' total consumption and order them by the consumption results, path cost least consumption is the most excellent, and others take secondary place. If there exist paths which have the same value of p, then order them by W_{path} defined in equation (12), the smaller the W_{path} is, the more ideal transmit conditions are, the higher transmit reliability is, the higher of the path PRI is.

$$W_{path} = \sum_{i,j \in path} w_{ij} \quad (12)$$

4. Performance Analysis

Wireless sensor networks reliable transmission has its special application domains. When the network suffered from unforeseen catastrophe, we must ensure that the data collected could still be able to be sent to the observation point, the design of effective strategies to improve the reliability of the transmission network is to the main issues in studying reliable transmission in wireless sensor networks.

Literature [7] increased transmission reliability through *disjoint* multi-path and *braided* multi-path, we compare relative performance to the braided multi-path in our experiment.

4.1 Performance Analysis Comparison

In this section, we evaluate the performance of our mechanism via simulations. Working with the failure model, we use one important metric in judging the performance of these competing approaches, the *resilience* of a scheme measures the likelihood that, when the shortest path has fails, an alternate path is available between source and sink,

We make up the failure model of *isolated failures*, each node in the multi-path has a probability of failure P_i during some small interval T. Then, for each of our multi-path schemes, we define resilience to isolated failure to mean the probability of at least one alternate path being available within the interval T, given that at least one node on the primary path has failed. This latter constraint captures our use of multi-path routing for recovery from shortest path failure.

To compute a multi-path's resilience to isolated failures, we present the following set of steps a large number of times:

- Fail each node on the primary with probability Pi;
- If a node on the primary path has failed, then, the assign a value of one to this set if at least one alternate path is available, add zero otherwise.

4.2 Performance Comparison

We made the experiment in TOSSIM, an operating system for sensor networks. Assuming that there are 10 cluster heads uniformly dispersed into a field with dimensions 70m×30m. Figure 4 shows the cluster heads position information and the corresponding link transmit consumption power values (per energy unit).

We change the node failure rates in primary path, then compute the resilience of network in the case of the two different multi-path algorithms. The result shows as figure 5.

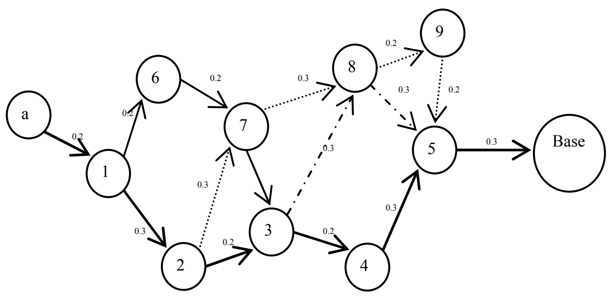

Figure 4 heads position and link power values

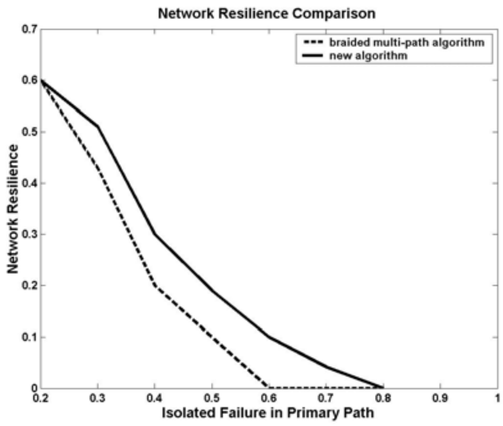

Figure 5 comparison result

According to figure 5, when the same failure rate of the nodes in primary path happens, path created using the new arithmetic can increase 10% of the network resilience.

Moreover, the number of paths created by *braided* multi-path is four, so the average energy consumption of each path is about $(E_{min}+E_{max})/2=1.475$ per energy unit, while the number of paths created by our new algorithm is thirteen, the average energy consumption of each path is $(E_{min}+E_{max})/2=1.585$ per energy unit. So we can get the conclusion that, each path in new algorithm charge more energy than *braided* multi-path, that is (1.585-1.475)=0.11 per energy unit, so the new algorithm consumed additional $0.11\times13=1.43$ per energy unit in all, but it can improve $9/(4+9)\times100\%=69.2\%$ of the transmit reliability.

So we said, in the need of high transmission reliability, such a new algorithm has its practical application value, though it cost a little more energy.

5. Conclusions

This article proposed an algorithm to establish multi-paths, as well as carry on the optimization mechanism to filter and order the path in forwarding table according to the link energy consumption. The mechanism is adaptive to environment influence, and has strong adaptability. When unexpected situation happened, our mechanism has higher reliability than traditional *braided* multi-path mechanism, in can also satisfy the requirements of reliable transmission very well.

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