On Scale-Free Routing Algorithm In Wireless Sensor Networks

XU Ye, WANG Zhuo
College of Information Science and Engineering, Shenyang Ligong University, Shenyang, China
xuy.mail@gmail.com

Abstract

A scale-free routing protocol and algorithm in wireless sensor networks are studied in this paper. The algorithm could be used to form a WSN with a scale-free-network-like topology which helps shorten the length of the routing path. Together with the information fusion function involved in the scale-free routing protocol, the algorithm could dramatically reduce the redundancies of the datagram transferred in the WSN and thus improve the life cycle of WSN.

Keywords: *Scale-free routing protocol, WSN*

1. Introduction

Wireless Sensor Networks (WSN) is a kind of wireless networks usually composed of a large quantity of sensors (nodes) [1][2][3]. The topology structure of a WSN is dynamic due to the emerging invalid sensors and new added sensors. Besides, any motions of the sensors, the target object or the sink nodes in a WSN would lead to reconstruction of the whole networks, so an effective WSN is supposed to be easily re-constructed, auto-adjustable and self-configurable[4][5][6].

A routing protocol based on a notion of scale-free and its algorithm is studied in this paper. It can create a WSN with a topology structure of scale-free networks, and can also implement auto-adjustment if the topology structure changes.

2. Scale-free routing algorithm

2.1. Properties of scale-free networks

The scale-free networks, having connectivity distribution of $P(k) \sim k^{-\alpha}$ (where k is the connectivity degree of node), is a kind of networks in power-law distribution[6]. So in scale-free networks, a few nodes have most links with most other nodes have very few links. Fig. 1 gives an example.

Scale-free networks have relatively the shortest average path[7][8] and this key property of scale-free networks could be effectively used in a routing algorithm of WSN to shorten the length of routing path.

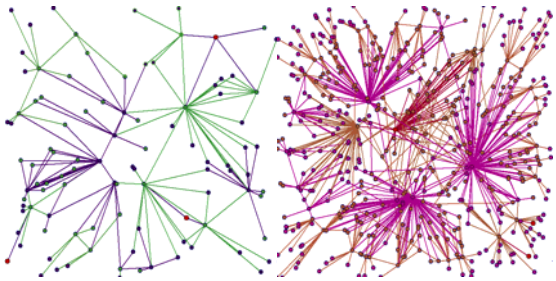


Figure 1. Examples of scale-free networks.

2.2. Routing selection in WSN

Routing selection in WSN is a rule trying to transfer a datagram by a shortest path optimized according to some certain rules[9]. So, studies of routing selection in WSN could be transformed into studies of path optimization under an energy-limited WSN[9]: assume $G=(V,E)$ is a WSN, where $V(G)$ comprises M nodes in the network. Of all M nodes, $S(S=M-1)$ of them belongs to source node, and the target node set comprises only one node. E is a link set of the network. With $G=(V,E)$, a cost function is defined as $F=f(N,B,T)$, where N is energy cost for transferring a single unit data, B is the channel capacity remained in the network and T is the average delay time. Then, routing selection in WSN is equivalent to solve the following equation, i.e., to minimize the following equation.

$$\min\{\sum_{j}[F(k)+p(k)]\} \qquad (1)$$

where $F(k)$ is cost function of transferring datagram, $p(k)$ is the cost of processing datagram, k is path's hops and j is the order of the nodes in WSN.

2.3. Scale-free routing properties

(1) The topology of the WSN generated by the scale-free routing rules is the kind of scale-free networks. The most-important nodes in it could be used as routers to transmit datagram.

(2) If the topology of WSN varies due to the movement of nodes in the network, a method of preferential attachment, i.e., nodes with larger degree are more likely to be attached, is applied. And this helps to set up a new scale-free network in the quickest way.

(3) Nodes in WSN have capabilities of information fusion[11][12], which would help to reduce the redundant information of datagram transferred by the node after fusion process.

2.4. Alogrithms and protocols

Scale-free routing algorithm is composed of four parts: (1) cluster generation protocol by scale-free rule, (2) cluster maintenance protocol, (3) intra-cluster routing protocol[10] and (4) inter-cluster routing protocol.

A cluster is defined as small unit in a scale-free networks, it usually comprises several nodes tightly connected to each other by scale-free rule. A few nodes in a cluster are of much greater degrees than other nodes, and are generally named as cluster heads or semi-cluster-heads of the cluster.

2.4.1. Cluster generation protocol: *Cluster generation protocol by scale-free rule is the key part in scale-free routing algorithm since it starts to produce a WSN with scale-free clusters*

from scratch. The protocol labels the originally equivalent nodes into different levels by conditions of each node's position and energy in WSN. And the key output of the protocol is the selection of cluster head. By linking nodes to this very cluster head, the backbone network structure could be set up.

2.4.2. Cluster maintenance protocol: *Cluster maintenance protocol functions when the topology of clusters changes due to death of nodes, new-added nodes and so on, and it helps to maintain the scale-free properties of the network's topology. And the protocol is listed in Table 1.*

Table 1. Cluster generation protocol

Steps	Contents
(1)	If a certain node is going to be dead, i.e., out of energy, it informs the cluster head. And the cluster head would send information to the Sink node.
(2)	If a certain node fails temperorily or permanently, the head would consider it to be dead after waiting for a certain period of time. And the head would send the information to the Sink node.
(3)	Cluster head, or the semi-cluster head would send a CLE datagram to its cluster members once it is going to be dead. And a new head would be selected among the nodes in the same cluster.
(4)	If a certain head or semi-head fails, the nodes would consider it to be dead after waiting for a certain period of time. And selection of new head or semi-head would be started.

2.4.3. Intra-cluster routing protocol: *Intra-cluster routing protocol is responsible for transferring data between the heads and the common nodes in the same cluster[10]. And information fusion procedure is processed by the heads and semi-heads.*

The information fusion procedure[11][12] is as follows.

$$y = F(S_i(n), w_i(n)) \quad (2)$$

where $S_i(n)$ is the data collected by the ith node, and $w_i(n)$ is the weight coefficient of the ith node. The intra-cluster routing protocol is listed in Table 2.

Table 2. Intra-cluster routing protocol

Steps	Contents
(1)	For each node in a cluster, the collected data are supposed to be processed by certain fusion algorithms.
(2)	If the data are completely identical to that of the last time, the fusion results would be zero, and nothing would be ransferred.
(3)	Or else, the only fusion results, not the whole data, would be transferred.

2.4.4. Inter-cluster routing protocol: *Inter-cluster routing protocol handles communications among clusters. And its algorithm is listed in Table 3.*

Table 3. Inter-cluster routing protocol

Steps	Contents
(1)	The cluster head and semi-cluster head only connect the head nodes of the upper-level cluster.
(2)	The cluster head and semi-cluster head give priority to connecting the upper-level head which is close in distance.
(3)	The cluster head and semi-head do not connect the same upper-level heads.

2.4.5. Scale-free routing algorithm: *With all the four parts of the protocol, we could implement the scale-free routing protocol, and the scale-free routing algorithm is listed in table 4.*

Table 4. Scale-free routing algorithm of WSN

Steps	Contents
(1)	The sink node acquires the information about the positions and energy conditions of all nodes in WSN, and break them into several layers.
(2)	/* Call: Cluster Generation Protocol */
(2.1)	For the nodes in each layer, scale-free clustering algorithm is performed to form clusters.
(2.2)	Cluster heads, semi-cluster-heads are selected by competition algorithm in each cluster.
(2.3)	Each node in a cluster is connected to the cluster head and semi-cluster head according to the "preferential attachment rule". The semi-cluster heads are so called intra-routers, and the cluster head are inter-routers in WSN.
(2.4)	Information fusion by intra-routers. Data is processed by information fusion operations in cluster heads, and then transferred to other cluster heads by inter-routers.
(2.5)	Repeat step (2.4), till data is tranferred to the sink node.
(3)	If (error occurs in WSN) {

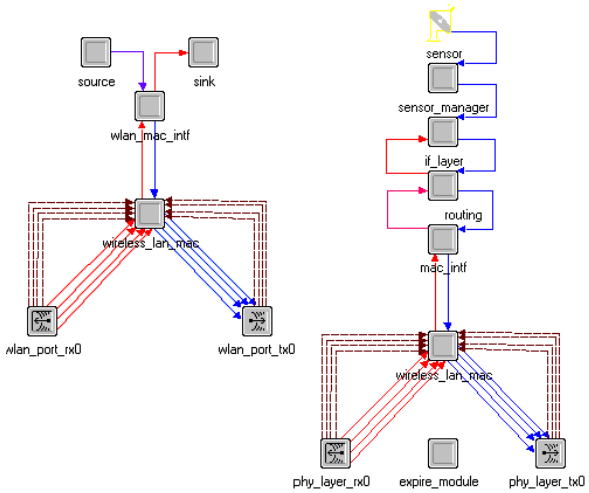
(4)	If (cluster head or semi-cluster head fails) {
	Call "Cluster maintenance protocol"
	//Re-select the cluster head, semi-cluster head dead
	//and reconstruct the cluster;
	If (cluster maintenance fails) {
	Set the cluster dead;
	If (all cluster are dead)
	Goto step (5);
	Else
	Go to step (2): Call "Cluster generation protocol";
	//Re-construct the cluster;
	}
	Else if (common nodes fail) {
	Notify the heads or semi-heads;
	Heads notify the sink nodes;
	}
	}

(5)	WSN is out of energy, and fails.

3. Simulation Test

3.1. Test Platform and Simulation Models

WLAN models in OPNET 8.0[13] are selected to be the basic simulation platform in this paper. And the model is illustrated in Figure 2.



(a) wlan_station **(b) wsn node**

Figure 2. Models of the wlan_station and wsn node.

3.2. Evaluation of the Simulation Results

Some other WSN routing protocols such as flooding, gossip, and NBEERP[14] are involved to evaluate the performance of the scale-free routing protocol in this paper. And the evaluations comprise four main parts.

(1) Evaluations of the overall performances are listed in table 5.

Table 5. Evaluation results of the overall performances of different routing protocols

Algorithms	Scale-free	Flooding	Gossip	NBEERP
Computation complexity	High	Low	Low	High
Network bandwidth usage	Low	Highest	High	Medium
Implementation complexity	High	Low	Low	High
Node ratio	Lowest	Highest	High	Low
Life cycle	Long	Short	Short	Medium

(2) Evaluations of the routing cost are in table 6.

Table 6. Evaluations results of the routing cost of different routing protocols

Algorithms	Gossip	Flooding	NBEERP	Scale-free
Number of the effective datagram	1,133,563	1,181,245	1,435,263	628,020
Average routing time (ms)	187.2	151.2	97.8	80.4
Average hops	19.7	15.5	10.1	8.3
Routing cost ratio per datagram	1	0.86	0.62	0.56
Routing cost ratio per data unit	1	0.86	0.62	0.28

(3) Evaluations of the routing reliability are in table 7.

Table 7. Evaluations results of the routing reliability of different routing protocols

Simulation times(ms)	Routing Reliability (%)			
	Flooding	Gossip	NBEERP	Scale-free
20	80.01	70.21	83.22	88.30
40	88.23	67.77	93.22	92.11
60	85.75	69.38	89.40	95.43
80	67.71	64.82	85.80	95.84
100	58.13	56.68	71.76	92.40
Average	77.45	65.77	84.68	92.8

(4) Evaluations of the ratio of the successful routing are listed in table 8.

Table 8. Evaluations Results of the Ratio of the Successful Routing of Different Routing Protocols

Simulation times(ms)	Number of datagram received successfully by the sink node			
	Flooding	Gossip	NBEERP	Scale-free
20	376,068	280,834	332,884	143,213
40	763,426	542,136	745,768	312,854
60	1,052,990	832,532	1,072,852	493,342
80	1,115,343	1,037,123	1,372,852	573,390
100	1,181,245	1,133,563	1,435,263	628,020
Average	897,814	765,238	991,924	430,163

We could see from table 8, that scale-free routing protocol uses the least network bandwidth and cost the least energy.

4. Conclusions

In conclusion, scale-free routing protocol is superior in aspects including routing reliability, network bandwidth usage, energy reserving and life cycle. So the scale-free routing protocol of WSN discussed in this paper is deemed effective.

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Authors

Xu Ye, Ph.D, associate professor. His current research interests include complex network modeling, adaptive signal processing and pattern recognition.