The Research of Scale-free Sensor Network Topology Evolution Based on Cloud Computing

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ABSTRACT: *Cloud computing is fundamental for wireless sensor network. Firstly massive data is gathered by Wireless sensor. Then those data is sent to platform of cloud computing. In the platform data is shared and transferred. The whole System is controlled and managed. In the process reliable and integrity of data depends on performance of wireless sensor Networks Topology control is one of core key factors which can influence performance of wireless-sensor networks (WSN). So how to design topology structure with high reliable and survivability is becoming the important subject on wireless-sensor networks. For the issue, a topology evolution strategy based on scale-free network with energy efficient is proposed. First by clustering algorithm cluster nodes are distributed evenly. Then those nodes start evolving in accordance with random walk processes on scale-free network. Since some key factors such as residual energy of node and node degree are taken into account in evolving procedure, network topology obtains quality features such as load and energy balance. So the network is quite practical. Finally the simulation shows that network topology from the evolution algorithm have good robustness regardless of deliberate and random attack. Consequently robustness feature of wireless-sensor network under severe environment is satisfied.*

Subject Categories and Descriptors:
C.2.1 [Network Architecture and Design]: Network topology; **I.1.2 [Algorithms]:** Nonalgebraic algorithms; **C.2.1 [Network Architecture and Design]:** Wireless communication

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1. Introduction

In essence wireless sensor network is technology which can interconnect all types of sensors with Internet (Weiming Shi, Bo Hong, 2012). Its core is intelligent wireless sensor network. The network can be viewed as tentacle of human being's perception. Based on the tentacle, a variety of information in perception is gathered and sent to various Internets in physical world. Thereby various pictures in digital virtual world can be showed in human society and information can be perceived by human being. The process is generalized as "perception - transfer - Computing - Application". It is operation mode of wireless sensor network (Madoka Yuriyama, Takayuki Kushida, 2011). In the mode, nodes are required to be extensive distribution and massive number and can provide strong computing power. Node is the basic unit of wireless sensor network. It mainly completes IntelliSense, information gathering, data fusion, data transmission and builds the underlying physical network (P. Sasikala, 2013). Generally node is formed by sensor unit, processing unit, communication unit, power supply unit and other auxiliary components. Typically, the node is designed to satisfy several conditions:

(1) Universality, miniaturization, low power.

(2) Good interface strong perception.

(3) It can work in harsh environments and have strong anti-jamming capability.

(4) Data conversion capability (serial-to-parallel conversion data).

There are a large number of sensor nodes in a wireless sensor network. At each interval Massive data is collected. That data is operated at nodes. Those operations include aggregation, segmentation, statistics and backup. So computing power which node can provide is critical for wireless sensor network (Zheng Gengzhong, Liu Sanyang, Qi Xiaogang, 2012). Meanwhile, in the different time periods the resource load at node appear trend of fluctuation. Therefore, the self-adaptive wireless sensor network is better choice. On the one hand repetitive construction can be avoided; on the other hand existing theory and technology can be utilized well. In summary, cloud computing and wireless sensor network is a perfect combination because both have similar customer needs and physical device (Kasthurirathna Dharshana, Piraveenan Mahendra,Harre, Michael,2013). Based on the similarities, creating more dynamic operating platform will be available.

At wireless sensor network there generally are three characteristics:1) comprehensive perception 2) reliable delivery 3)intelligent processing. Intelligent processing adapts to current development of the cloud computing.

Cloud computing has become the latest computing model, following grid computing, Internet computing, software as a service, platform as a service. Cloud computing utilizes mainly virtual technology to integrity and abstract different kinds of resources from internet. In the process, reliable service - massive computing resources is provided to user. Thereby users can be free from the complexities of the underlying hardware logic, network protocols, and software architecture. The concept which has been advocated by cloud computing is “platform as a service” and “software as a service.”

Security in wireless sensor network must draw widespread attention. Nodes are generally likely to encounter following attack: information is intercepted, part of the network or nodes are controlled and other issues (Liu HaoRan , Yin WenXiao,Han Tao, Dong MingRu,2014). At present, the common solution is authentication and ZigBee technology.

In the application, Survivability is one of the most primary indexes which estimate reliability of network (Mohammad Al-Rousan, Taha Landolsi, Wafa M. Kanakri, 2010). Due to some negative circumstances such as severe environment, constrained energy and deliberate attack, some nodes lose efficacy in the network. So survivability is referred as most of the nodes in the network are still connected when some nodes become ineffective (TheinLai Wong, Tatsuhiro Tsuchiya, Tohru Kikuno, 2008). In other words, network has the ability to maintain network performance when some sensor nodes fail. Currently research on survivability has become a key issue to improve the robustness of the wireless sensor network topology (Xinrong Li, 2010), relay node is introduced to change scope of node communication in order to improve survivability of network (Kalvinder Singh, Vallipuram Muthukkumarasamy, 2010), and an integrated coverage and connectivity configuration in wireless sensor network is proposed. When nodes become disconnected in some regions, connection can be recovered by covering primary nodes in adjacent areas (K Lin, M Chen, S Zeadally, JJPC Rodrigues, 2012). A strategy which uses a minimum of relay nodes can ensure full connectivity between node and station in order to improve network survivability (Hai Van Luu, Xueyan Tang ,2012). For the deployment of sensor nodes in harsh environment, an energy efficient fault-tolerant topology is constructed. By building k-connectivity network, network connectivity can be still maintained under k-coverage strategy even if some nodes fail (N. Jiang, S. Jin, Y. Guo, Y. He, 2013). From the perspective of software rejuvenation methodology, a practical survivability model of wireless sensor network is designed. So To satisfy network survivability, most research focus on redundancy mechanism. Although the network survivability is improved, the network topology becomes more complex. The reason is that scale of hardware and software is increased (V.H. Dang, V.D. Le, Y.K. Lee, 2010). To some extent, not only the operating costs of the network are increased, but also the network performance is reduced. Finally, the network lifetime is impacted. Combined with complex networks theory and traditional BA scale-free network model, a scale-free network topology evolution model with energy efficient (TEMEE, Topology Evolution Model with Energy Efficiency) is proposed. The model is suitable for practical application because some key factors such as residual energy, node degree are included in proposed evolution strategy. The simulation results show that network topology which is generated by TEMEE model can well improve network survivability without extra facilities. So on the premise of reliable data transmission, the robustness of the network can be improved.

2. The Network Structure to Describe

The wireless sensor network is a special kind of complex network. In order to make evolution of wireless sensor network topology satisfy features of scale-free network and avoid mutual interference among nodes that is caused by communication radius of nodes, network structure is assumed as:

(1) The power of sensor nodes have adjustable. According to node’s residual energy, node can adjust transmit power and determine communication radius.

(2) Two different transmissions frequency are used in node communication. Low frequency is suitable for node communication within communication radius. The high frequency is suitable for node communication outside communication radius.

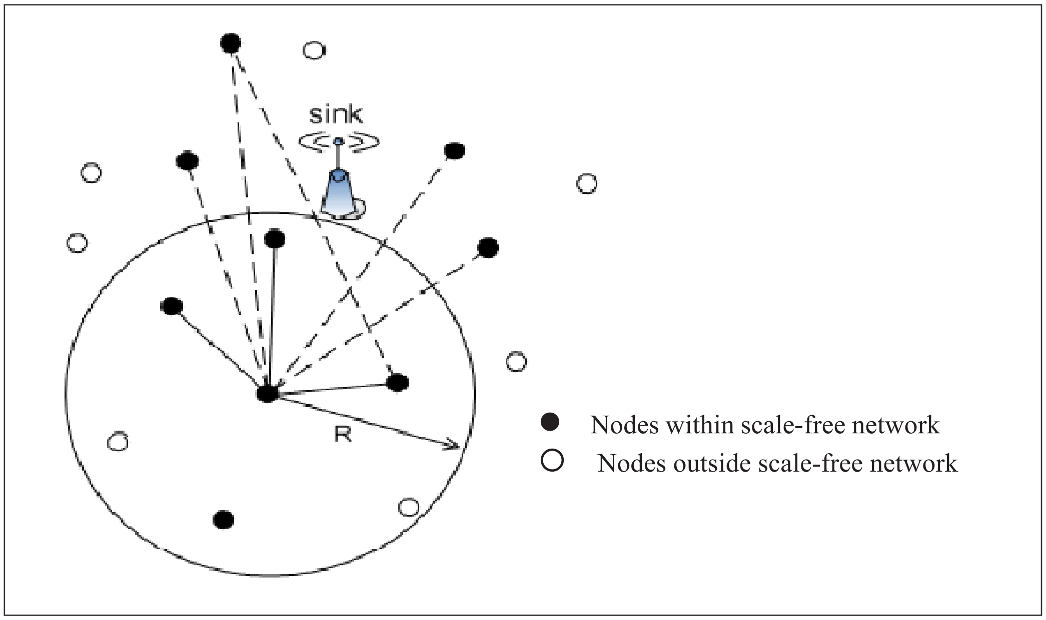


Figure 1. Network Topology

(3) Distribution of nodes approximates to uniform distribution at entire circular area.

(4) Sink node is placed at the centre of the network;

(5) Clustering mechanism is adopted in network topology management.

Based on the assumption, network structure is shown in Figure 1.

3. Topology Evolutions

In a real network, procedure of selecting a new connection generally prefers random walk [6] method rather than global BA scale-free network model. For example, In World Wide Web, starting link node can be selected randomly. Pages are browsed by hyperlink. If new node is expected to be my neighbours, hyperlink is used to bridge the two nodes. In personal network, fresh person meet new friend by old friend. So the new relationship is established. In academe, references on published papers can be chosen to be own paper's references. Thus, random walk method has more realistic than global optimum model.

So with random walk model, novel topology evolution algorithm is proposed. In evolution procedure, firstly clustering Algorithm Based on Bayesian Game (CABG) is applied to distribution of cluster headers nodes. Then based on random walk method and evolutionary mechanism of BA scale-free network, connectivity among cluster headers nodes is established selectively. According to practical application of wireless sensor network, connectivity optimization strategy includes mainly the following two key factors:

(1) **Residual energy:** Residual energy of cluster-header node influences its life-span directly. So less than residual energy node has, less connection probability is.

(2) **Node Degree:** Cluster-header node with higher residual energy has more chance to connect more edges. But due to excessive connection, energy of node is consumed in advance. Under these circumstances, energy hole is generated. So "node degree" is introduced to limit maximum number of connections for cluster-header nodes.

Evolution mechanism of TEMEE model has four features:

(1) **Cluster Distribution:** CABG clustering algorithm is used to achieve distribution of cluster

(2) **Growth:** Similar to the scale-free network model, the scale of the network is expanding.

(3) **Random Walk:** Based on random walk, new cluster-header nodes are added to network structure

(4) According to certain probability (residual energy, node degree), new added cluster-header nodes choose cluster header nodes to establish connection.

4. Topology Evolution Model

Based on BA Growth Network Model and Preferential Attachment, with Random Walk Method, Topology Evolution Model is Described as Follows:

(1) Clusters are formed reasonably and steadily by using CABG clustering algorithm.

(2) There is initial network $V_{init-network}$ with m_0 nodes and e_0 edges .those nodes are composed of sink node and its neighbours cluster header nodes.

(3) In initial network, a cluster head node is selected randomly as starting node of random walk. The length of the random walk is $l(0 < l < m_0)$. So local network $V_{init-network}$ is form by nodes which are located at random walk path.

(4) By certain probability $\prod_i$, $m(0 < m < l)$ different cluster header nodes are selected randomly from local

network $V_{local\text{-}network}$. Then those m cluster header nodes are waiting for connecting new cluster header nodes. probability Π_i is referred as (1) :

$$\Pi_i = \alpha_1 \frac{E_i}{\Sigma E_j} + \alpha_2 \frac{k_i}{\Sigma k_j} \quad (1)$$

In equation (1), α_1 is defined as regulation parameter for node energy. α_2 is defined as regulation parameter for node degree, and $0 < \alpha_1 < 1$ $0 < \alpha_2 < 1$ $\alpha_1 + \alpha_2 = 1$.

(5) Go back step (3) until all cluster header nodes are connected in the network.

To demonstrate evolution process of TEMEE model, the corresponding topology evolution algorithm is shown in Figure 2.

5. Topology dynamic analysis

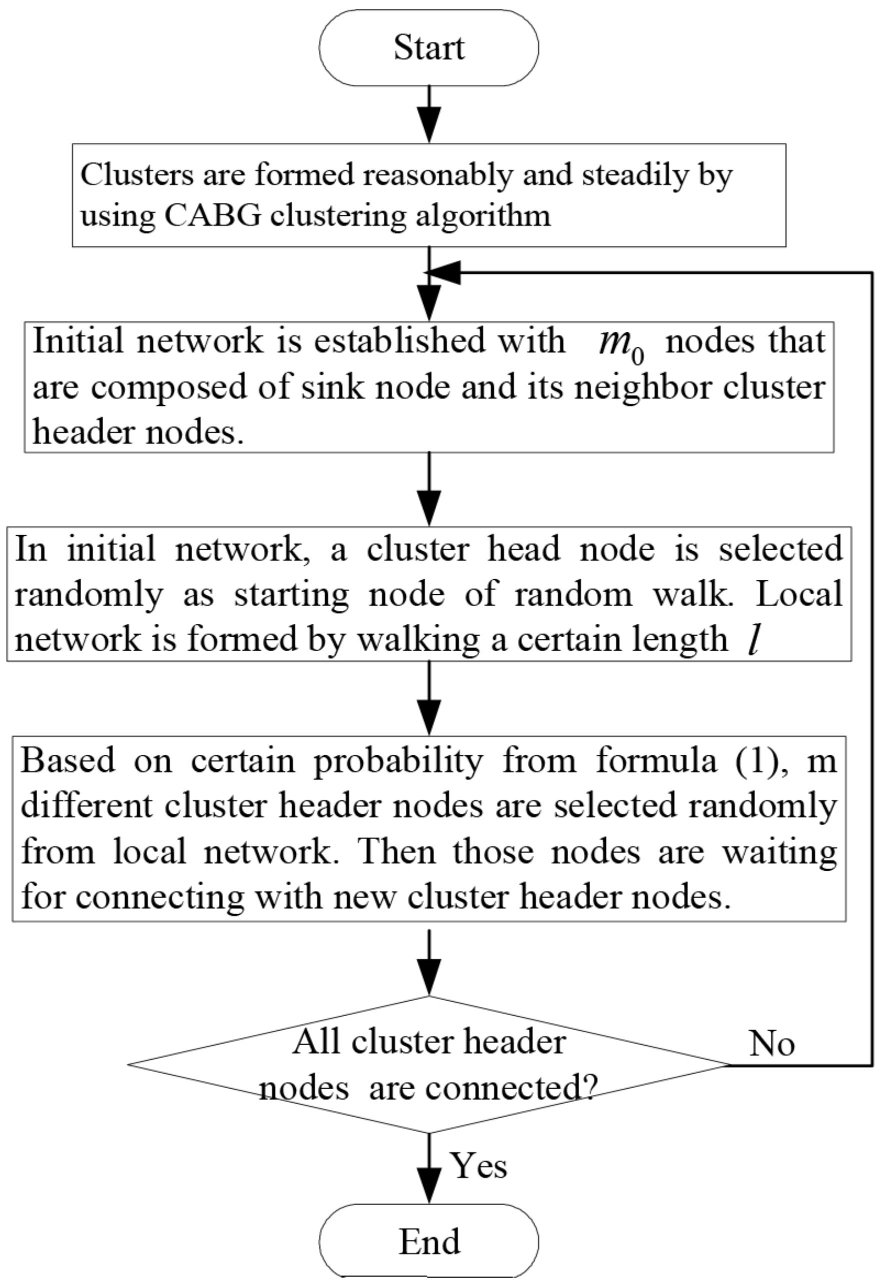
In TEMEE model, probability of preferential attachment of cluster header nodes is referred as

$$\Pi_i = \alpha_1 \frac{E_i}{\Sigma E_j} + \alpha_2 \frac{k_i}{\Sigma k_j}.$$

With the mean-field theory, the distribution of node degree in evolution model is analyzed as follow:

Assume random variable is defined as continuous. The mean-field equation (Barabási and Albert) of scale-free network evolution model are defined as:

$$\frac{\partial (k_i)}{\partial (t)} \approx m\Pi_i = m\left(\alpha_1 \frac{E_i}{\Sigma E_j} + \alpha_2 \frac{k_i}{\Sigma k_j}\right) \quad (2)$$



Figur 2. TEMEE model topology evolution algorithm process

In (2) equation: $\Sigma E_j \approx t<E_t>, <E_{t>}$, is defined as the average energy of the cluster header node at time t.

$\Sigma k_j = 2mt$, So equation (3) is deduced:

$$\frac{\partial(k_i)}{\partial(t)} \approx m\prod_i = m\left(\alpha_1 \frac{E_i}{t<E_j>} + \alpha_2 \frac{k_i}{2mt}\right) \quad (3)$$

Adjust equation (3):

$$\frac{\partial(k_i)}{\partial(t)} = m \frac{2ma_1 \frac{E_i}{<E_t>} + \alpha_2 k_i}{2mt} \quad (4)$$

In equation (4), set $f(E) = \frac{E_i}{<E_t>}$, $f(E)$ is relevant function of energy of cluster header nodes. So:

$$\frac{\partial(k_i)}{\partial(t)} = \frac{2ma_1 f(E) + \alpha_2 k_i}{2t} \quad (5)$$

Solve differential equation (5). The result is:

$$k_i(t) = Ct^{\frac{\alpha_2}{2}} - 2m\frac{\alpha_1}{\alpha_2} f(E) \quad (6)$$

According to initial condition $k_i(t) = m$, the result is:

$$k_i(t) = (m + 2m\frac{\alpha_1}{\alpha_2} f(E))\left(\frac{t_1}{t_2}\right)^{-\frac{\alpha_1}{\alpha_2}} - 2m\frac{\alpha_1}{\alpha_2} f(E) \quad (7)$$

The probability of degree of a cluster header node being less than k is defined as:

$$p(k_i(t)<k) = p((m+2mf(E))(\frac{t_1}{t_2})^{-\frac{\alpha_1}{\alpha_2}} - 2m\frac{\alpha_1}{\alpha_2} f(E) < k)$$
$$= p((\frac{m(1+2f(\alpha)f(E))}{k+2mf(\alpha)f(E)})^{\frac{2}{\alpha_2}} t < t_i) \quad (8)$$

In equation (8) $f(\alpha) = \frac{\alpha_1}{\alpha_2}$

Assume new cluster header nodes are added into network at the same interval: time of each cluster header node joining the network is completely random. Therefore, random variables obey uniform distribution at the interval. Probability Density Function:

$$p(t_i) = \frac{1}{m_0 + 1} \quad (9)$$

Equation (9) merges with equation (8)

$$p(k_i(t)<k) = 1 - p(t_i < (\frac{m(1+2f(\alpha)f(E))}{k+2mf(\alpha)f(E)})^{\frac{2}{\alpha_2}} t)$$
$$= 1 - \frac{t}{m_0+t}(\frac{m(1+2f(\alpha)f(E))}{k+2mf(\alpha)f(E)})^{\frac{2}{\alpha_2}} \quad (10)$$

Therefore, Degree distribution of TEMEE model network topology is defined as:

$$p(k) = \frac{\partial p(k_i(t)<k)}{\partial k}$$
$$= \frac{t}{m_0+t}\left(\frac{(\frac{2}{\alpha_2}-1)(m+2mf(\alpha)f(E))^{\frac{2}{\alpha_2}}}{(k+2mf(\alpha)f(E))^{\frac{2}{\alpha_2}+1}}\right) \quad (11)$$

In equation (11), when $t \to \infty$

$$p(k) = \frac{\partial p(k_i(t)<k)}{\partial k}$$
$$= \frac{(\frac{2}{\alpha_2}-1)(m+2mf(\alpha)f(E))^{\frac{2}{\alpha_2}}}{(k+2mf(\alpha)f(E))^{\frac{2}{\alpha_2}+1}}) \propto k^{-(1+\frac{2}{\alpha_2})} \quad (12)$$

From equation (12), Degree distribution of TEMEE model network topology obeys power law probability distribution. Power-Law Index: $\gamma = 1 + \frac{2}{\alpha_2}$. Network have scale-free feature. When $\alpha_2 = 1$, the degree distribution of network topology is the same with that of BA model.

6. Simulation Experiment

The degree distribution is an important feature of the network topology. It has an important influence on network reliability and behaviour of transmission dynamics. So the degree distribution of TEMEE model is simulated and Survivability of model is verified. All simulation results are average values of repeated at least 20 times random simulation.

Parameter	Description	Value
m_0	The number of the initial cluster header nodes in the network	1
m	In local network, the number of the random selection cluster header nodes which are waiting for connecting new cluster header nodes	1-3
t	Evaluating time of network model	2000s
t_1	Time for new cluster header node joining network	$t_i > 0$
E_{max}	The maximum energy of cluster header node	1J
R	Communication radius of cluster header node	60m-100m

Table 1. Gives the related simulation parameter

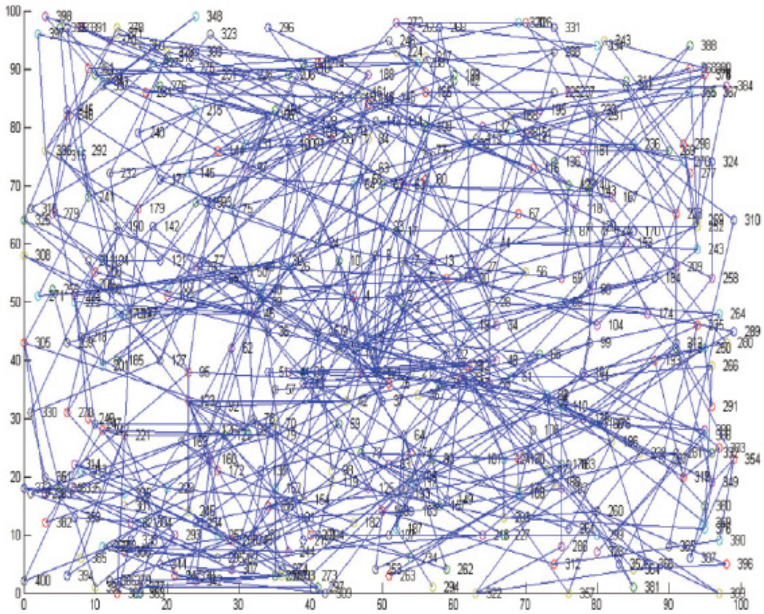
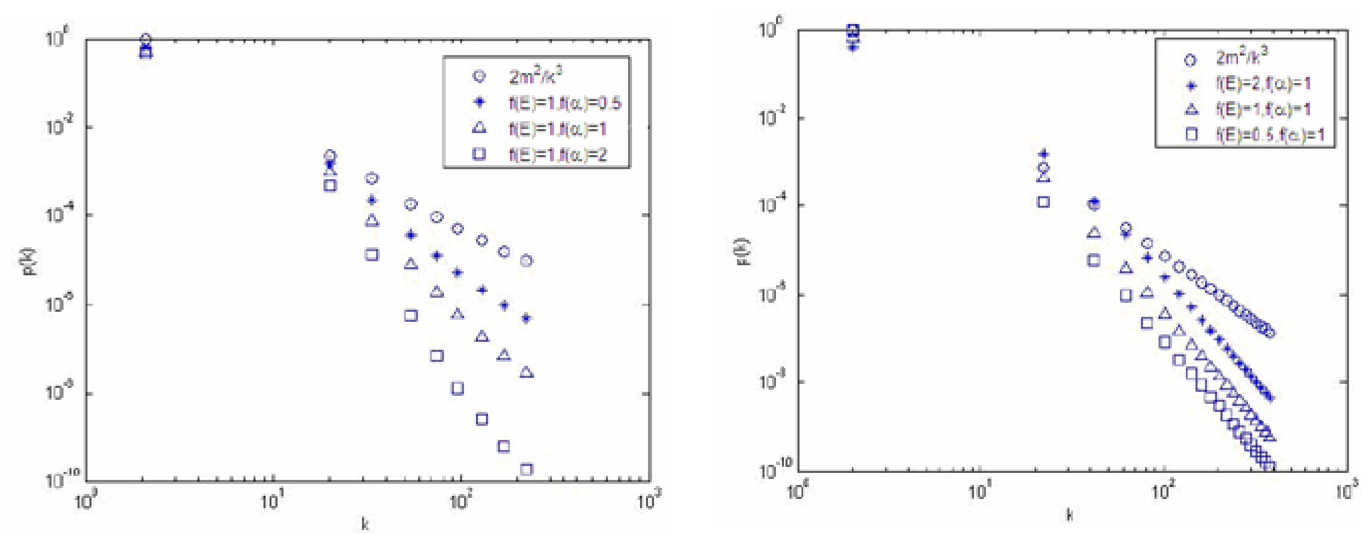


Figure 3. TMEEE Evolution Topology



(a) Distribution of TEMEE model:$(f(E) = 1, f(\alpha) = 0.5,1,2)$ (b) Distribution of TEMEE model: $(f(E) = 2,1,0, f(\alpha) = 1)$

Figure 4. Distribution of TEMEE model

Figure 3 shows the deployment of 400 cluster header nodes in 100×100m2. It is evolved to base on TEMEE model. According to Figure 3, degree of most cluster header nodes is low while degree of less cluster header nodes is high. This phenomenon is consistent with the features of scale-free network. In addition, evenly distributions of cluster head nodes with lager degree make whole network obtain good robustness regardless of random attack or deliberate attack. Why? The reason is that node energy and node degree as important factors are added into connection strategy. So network load and energy consumption can be more balanced.

Figure 4 shows degree distribution of node of TEMEE model. This picture indicates that degree distribution have scale-free feature.

To analyze dynamic feature of TEMEE model, difference parameters for $f(E)$ and $f(\alpha)$ are selected so as to analyze degree distribution of node. Figure 4(a) and 4(b) show the whole trend. For one thing, degree distribution decreases with increasing $f(\alpha)$.this benefits balance communication load among nodes. For another, degree distribution increases with increasing $f(E)$. This indicates that based on energy equation (1) nodes with higher residual energy have larger load. It is conducive to the balance of energy consumption.

Figure 4(a) and 4(b) show that influence of $f(\alpha)$ for degree distribution is greater than that of. Increasing $f(\alpha)$ can balance communication load of network while increasing $f(E)$ can make node with higher residual energy obtain larger load. So, balancing the value of α_1 and α_2 need to consider those key factors such as node distribution and communication characteristic of sensor node. Probability formula of preferential attachment is formed by adjusting the value of α_1 and α_2. In this way, optimal distribution of node degree and balance of energy and load can be achieved at the same time. Finally network survivability is improved.

Figure 5 shows distribution of power law index γ of TEMRM model under adjusting α_1, α_2, n. From figure, with change of accelerative growth parameter θ, the whole network shows different degree distribution by adjusting parameter α_1, α_2, n. So TEMRM model has a wide range of adjustability. It is suitable for wireless sensor application.

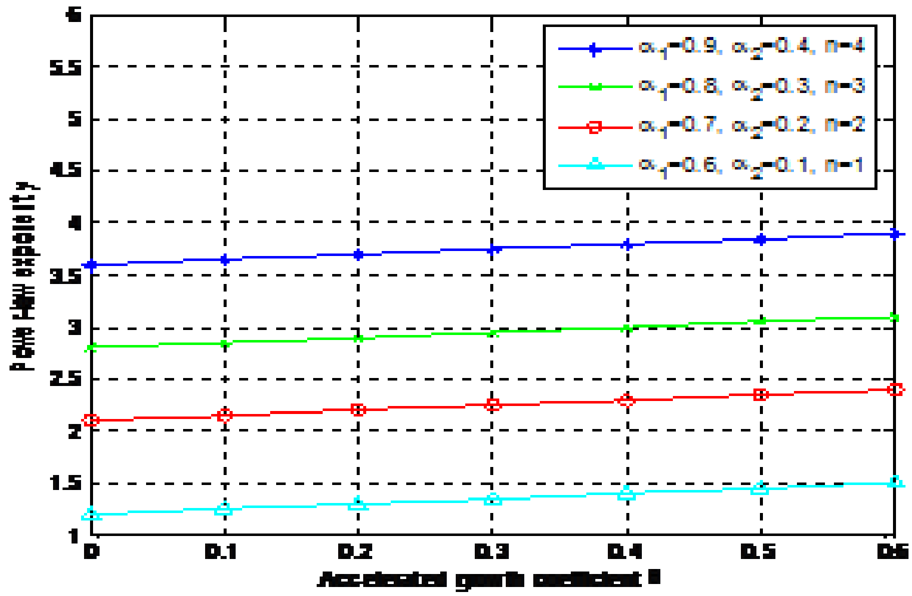


Figure 5. Trend of distribution of power law index of TEMRM model with accelerative growth coefficient θ

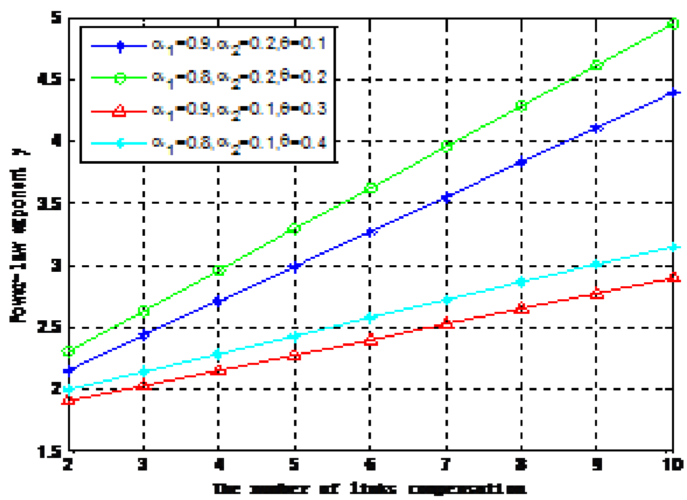


Figure 6. Trend of distribution of power law index of TEMRM model with number of compensated links

In order to guarantee self-recover and reconstruction, reconnection mechanism is introduced into TEMRM model. Figure 6 shows the change of power law index ã with compensated the number of links n.

In reality, value range of distribution of power law index of scale-free network is from 2 to 4[10]. From figure 5.10, in order to gain good degree distribution, the value range of optimal number of compensated links is from 3 to 7 when network fails. Simulation results show that when network fails, the appropriate compensation of link can ensure network connectivity while excessive compensation can result in an unstable network.

Figure 7 shows the trend of the power law index of network with the deletion probability α_2. From figure, when deletion probability is from 0.1 to 0.2, the power law index is from 2 to 4.So a good degree distribution can be obtained at the deletion probability interval. But when probability exceeds the interval, the result is not ideal. Network connectivity is poor.

In order to further analyze survivability of the TEMEE model, survivability measure from literature [8] is introduced to compare survivability among different models such as TEMEE model, BA model and Topology Evolution among Cluster Heads by random walker, TECHRW. In TECHRW model, Connection probability of preferential attachment is defined as:

$$\Pi_i = \frac{E_i}{\sum E_j}$$

In literature [8], Survivability is measured by coverage rate of network after attack. Survivability measure is defined as:

$$C(T) = \frac{\sum_{i=1}^{n} k_i(T)}{N(N-1)} \qquad (T \geq 1) \qquad (13)$$

In equation (13), T is max hop count allowed by data fusion among nodes. N is the number of the initial nodes. N is the maximum number of connected cluster header nodes after attack. $k_i(T)$ is the number of nodes, distance of which to node i is less than T.

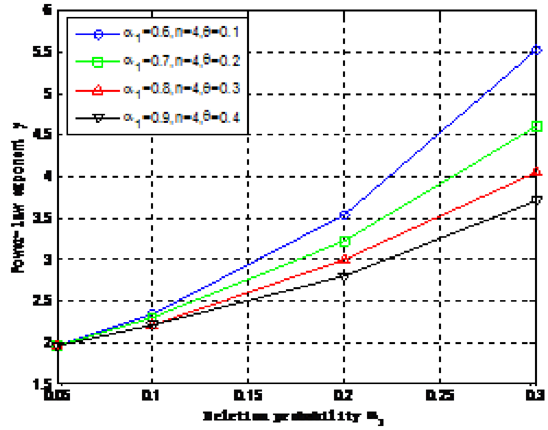


Figure 7. Trend of distribution of power law index of TEMRM model with deletion probability α_2

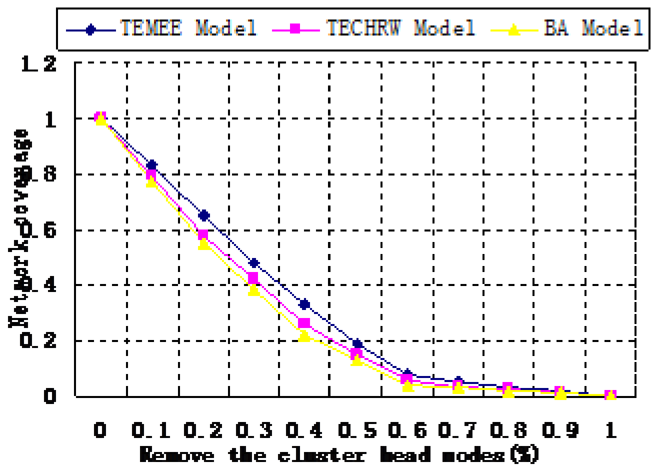


Figure 8. Comparison of Survivability Under Random Attack

Figure 8 shows comparison of survivability among TEMEE model, BA model and TECHARW model under random attack. Coverage rate of TEMEE model is highest. Coverage rate of TECHRW model is middle. Coverage rate of BA model is lowest. But the three have little difference. The main reason is scale-free network has better robustness under random attack. So under random attack network is impacted weakly. Furthermore, design of the TECHRW model considers only the node residual energy while the design of TEMEE model not only considers the node energy, but also considers the node saturation. In TECHRW model, excessive connection of several nodes can lead to the energy hole. So with evolution of network topology, coverage of TEMEE model is higher than that of TECHRW.

Figure 9 shows comparison of survivability among TEMEE model, BA model and TECHARW model under deliberate attack. Coverage rate of TEMEE model is highest. Coverage rate of TECHRW model is middle. Coverage rate of BA model is lowest. Coverage rate of TECHRW and BA model starts to decline sharply when about 5% of cluster header nodes are removed. When about 20% of cluster header nodes are removed, coverage rate of both models approximates to zero. But when about 10% of cluster header nodes are removed in TEMEE model, coverage rate starts to fall. When about 25% of cluster header nodes are removed, TEMEE model still maintain certain coverage rate. The main reason is that TEMEE model takes node energy and saturation into consideration. So the network load and energy consumption are relatively balanced. Especially the distribution of nodes with higher degree is more even than that of TECHRW model and BA model. So the network has higher survivability under deliberate attack.

7. Conclusions

Scale-free network provides research model for survivability of wireless sensor network. In this paper, complex network theory is introduced into topology evolution of the wireless sensor network. According to the actual application of the wireless sensor network, those important parameters such as node residual energy and node degree are introduced. By adjusting probability of node's preferential attachment, based on BA scale-free network, novel topology evolution model is proposed. The new model is analyzed dynamically by mean field theory. The simulation results show that degree distribution of evolution model obeys to power-law distribution. The model has also feature of scale-

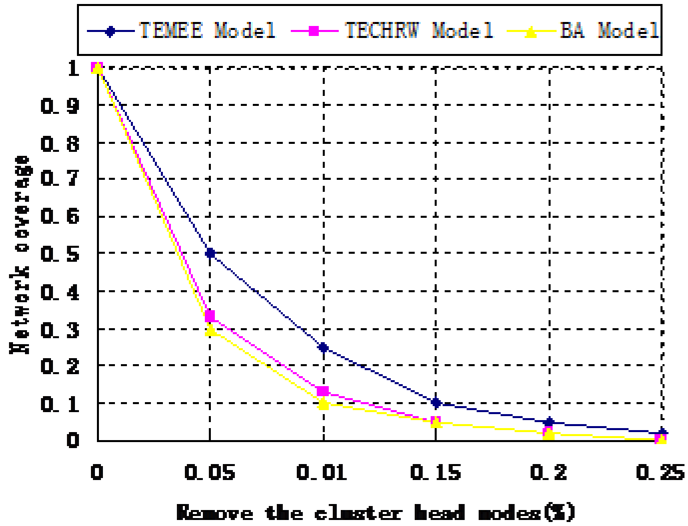


Figure 9. Comparison of Survivability Under Deliberate Attack

free network. Since evolved network topology has quality load and energy balance, When the network failure, through the reconnection mechanism can make the network topology self-healing and refactoring, network topology has good survivability regardless of random and deliberate attack and can provide quality service for upper communication protocol, Can meet in harsh environments such as natural disasters, military applications of wireless sensor network robustness requirement.

8. Acknowledgment

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