Wireless Sensor Network Model Based on Non Uniform Clustering Mechanism

Deng-Chao Huang1,a, Jing FAN2,b,*, BI-JIAN Jian3,c, Hui ZHANG4

1-4Laboratory of Wireless Sensor Network in Yunnan Mingzu University Kunming China

aHuangdengchao19@163.com, b FanJing9476@sina.com, cjianbijian@163.com

*Corresponding author

Keywords: Complex networks, Non uniform clustering, Competitive radius, Network coverage, Optimal hop count.

Abstract. This paper constructed a wireless sensor network model which includes multi hop mechanism based on the theory of complex network. In the non uniform clustering algorithm, the selection of the competitive radius affects the lifetime of the whole network. The optimal hop mechanism is added into the growth phase of the scale free network model, which makes the probability of the link between the nodes relate to the actual distance between nodes. This paper also discusses how parameters C and parameters Rmax affect the degree distribution, network coverage, and the number of cluster heads in the entire network model. We use the theory to analyze the degree distribution of the network along with the growth of network. And we also use the software to simulate the network performance parameters. We find that with the increase of parameters C, the network of competitive radius is more heterogeneous, the number of cluster heads are lager, and the proportion of the value between (2,10) of nodes degree in the network are large, but the coverage rate of the network are low. We also found that with the increasing of the parameters Rmax, the number of cluster heads in the network are smaller, and the proportion of the value between (2, 10) of nodes degree in the network, and the coverage rate of the network would increase.

Introduction

In recent years, the complex network theory is applied to many fields of science, such as, the Internet, neural networks, social networks, electricity networks, network traffic, and so on. in 1999, Barabasi and Albert[1] proposed a scale-free network model. But in reality, the formation of network needs to go through much more complex steps. And if we want to simulate network, a variety of mechanisms is needed. Therefore, to ensure the ability to simulate a network with better effect, we need to consider much more practical factors, as well as detailed steps and methods.

At present, many researchers have proposed many topology models for wireless sensor network based on the theory of the complex network model. Andras Farago [2] are reviewed many topology models, including all kinds of scale-free network model, and a lot of wireless sensor network model. Mahesar A.W., Malik M etc. in [3] proposed application of calculus in the wireless sensor network model. Chen et al. [4] proposed an evolution local area world model for wireless sensor network based on classical BA scale-free model, which is robustness for random failure of the node. And this model provides a reference for constructing a

In wireless sensor networks, data transmission communication mode is by many to one. Thus when a node is close to the sink node, the node would dead early, because it have overburdened forward task information, the data which come from distant node can’t transmit to sink node. The life cycle of the whole network will be too short. Most of the remaining energy in the node would be wasted, that is "energy hole" phenomenon. Wireless sensor networks with clustering routing mechanism and multi hop forwarding mechanism can significantly reduce the energy consumption, so many energy efficient clustering routing protocols have been proposed. An energy efficient non uniform clustering routing mechanism is proposed in the literature [8].

The problem of non uniform clustering network modeling is rarely involved based on the complex network theory of wireless sensor networks. In the non uniform clustering routing mechanism, the size of the competition radius affects feasibility of the whole routing protocol. This paper is to establish a non uniform clustering network model based on complex network theory, so as to analyze what is the size of the competition radius can make the whole network topology performance is the best. In this paper, (1) using WUCA non uniform clustering algorithm to cluster nodes in the region. (2) This model take full account of the nodes through the optimal multi hop mechanism so that the nodes have the minimum energy consumption when its transfer data. (3) We use matlab to simulate those three parameters which are the network degree distribution $P(k)$, the number of cluster heads and the network coverage.

### Construction of the Network

This paper is divided into the following parts: in the second part, we put forward a new model of wireless sensor networks. In the third part, we will analyze network degree distribution based on the mean field theory. In the fourth part, we use matlab to simulate those three parameters which are the network degree distribution $P(k)$, the number of cluster heads and the network coverage.

In this part, we propose a non uniform clustering network model. In the initial stage of the model, the network has $m_0$ nodes, and $e_0$ links. The network growth as follow,

1. A network which has $m_0$ nodes, each step adds a new node and connect to $m$ existing node. ($m \leq m_0$).

2. In this paper, the optimal hop count mechanism is introduced in this paper. In the actual environment, the cluster head transmit data to the gateway through multi hop, first we define a threshold distance, if the distance is less than the threshold distance, the node sends data to the gateway directly; otherwise, according to the route finding the next hop forwarded cluster head. The conditions of sending data package and having the minimum energy consumption as blow:

   Lemma 1[1] a given distance $D$ and hop count $k$, when all hops $(d_1,d_2,...,d_k)$ are equal to $D/k$, the total energy consumption are the minimum.
Lemma 2[1] Optimal hop count $k_{opt} = \left\lfloor \frac{D}{d_{opt1hop}} \right\rfloor$ or $k_{opt} = \left\lceil \frac{D}{d_{opt1hop}} \right\rceil$, $d_{opt1hop}$ is the Characteristic distance.

$$d_{opt1hop} = a \sqrt{e_{le} + e_{rx}} \sqrt{(\alpha - 1)e_{ta}}$$

(1)

By Eq.1, we can see that the characteristic transmission of the distance $d_{opt1hop}$ and distance $D$ has nothing to do, it simply depends on transceiver circuit characteristics and channel loss, when $k_{opt} - 1$ forwarded nodes locate right in the equal position of the line AB, the point-to-point transmission of total energy consumption is the minimum. By node A, B and all $k_{opt} - 1$ forwarded location path become desirable minimum energy consumption path. However in the actual situation, due to the limit of the node density, we found that such an optimal path is not realistic. But it can guide that search for the actual routing. The minimum energy consumption multi hop routing process is shown in Fig.1

![Figure 1. Minimum energy consumption multi hop routing process schematic diagram.](image)

Step 1 (1) node A based on (2.1) calculation of the characteristic distance $d_{opt1hop}$ and the distance $d_{AB}$ between node A and B. According to the node location A $(x_A, y_A)$ and B $(x_B, y_B)$, node A calculate the optimal next hop forwarded location $O_1 (x_{o_1}, y_{o_1})$. $O_1$ is just an ideal location which is not an actual cluster head. Among

$$x_{o_1} = x_A + \frac{d_{opt1hop}}{d_{AB}} (x_B - x_A)$$

$$y_{o_1} = y_A + \frac{d_{opt1hop}}{d_{AB}} (y_B - y_A)$$

(2)

The probability of a new node link to an already existing node $i$ is to be satisfied with the degree of the node $k_i$:

$$\prod_i = \frac{k_i(t)E_i}{\sum_i k_i(t)E_i} * \frac{(d_{ih})^{-1}}{\sum_i (d_{ih})^{-1}} * \frac{1}{R_i}$$

(3)
In the formula parameters, $E_i$ means the residual energy of node, $k_i$ represents the current degree of node, $d_{i0}$ means the actual distance between the node $i$ and the new node. The competition radius $R_i$ can be expressed as:

$$R_i = \left[ 1 - c \frac{d_{\max} - d(v_i, \sin k)}{d_{\max} - d_{\min}} \right] R_{\max} \quad (4)$$

In the formula, $d(v_i, \sin k)$ is the distance between the node $v_i$ and the gateway; $c$ can control the size of the constant radius of the competition between the size of 0~1.

In the actual wireless sensor network, each node's energy is limited, to ensure that the network survival time, the node energy of consumption must be considered, this model take full account of the nodes through the optimal multi hop mechanism so that the nodes have the minimum energy consumption when its transfer data.

**Network Analysis**

In order to respond to the network performance, in this part, we give the theory analysis, and data simulation of the statistical parameters: degree distribution $P(K)$.

Degree distribution $P(K)$ is defined as the probability that a randomly selected node of degree in the network is $K$. $P(K)$ usually is used to as an important condition to distinguish the performance of the scale free network. In this paper, we use mean field theory to analyze the variation of $P(K)$, in the case of different parameters as $c, R_{\max}$.

Initial network has $m_0$ nodes, with $e_0$ edges. At the moment of $t$, the degree of the node $i$ is $k_i(t)$, when $t$ is big enough, we can ignore the edge of the initial network. When a new node is added to the system, the node degree $k_i(t)$ change with time $t$ based on the mean field theory,

$$\frac{\partial k_i}{\partial t} \approx m \prod_{i=m}^{k_i(t)} \frac{k_i(t)E_i}{\sum_{j} k_j(t)E_j} \cdot \frac{(d_{i0})^{-1}}{\sum_{j} (d_{i0})^{-1}} \cdot \frac{1}{R_i} \cdot A = \frac{(d_{i0})^{-1}}{\sum_{i} (d_{i0})^{-1}} \cdot B = \frac{1}{R_i} \quad (5)$$

Eq.5 reflects the change of the degree of node $i$, $A$ represent $(d_{i0})^{-1} / \sum_{i} (d_{i0})^{-1}$, $B$ represent $1/R_i$ when a new node joins the system.

Derived from the mean field theory,

$$\frac{\partial k_i}{\partial t} = m \frac{k_i(t)E_i}{\sum_{i} k_i(t)E_i} \cdot A \cdot B = m \frac{k_iE_i}{2mEt} \quad (6)$$

When there are initial conditions for, $k_i(t_0) = m$ Eq.6 is,
\[ k_{i(t)} = m * e^{\frac{E_i A B}{2E}(1-t_i)} \]  
\[ \text{If } \beta = E_i A B / 2E \text{ When } t \to \infty, \text{ degree distribution } P_K \text{ is,} \]
\[ P(k_i(t) < k) = 1 - P(t_i > t - \frac{1}{\beta} \log \frac{k}{m}) = 1 - \frac{1}{m_0 + t} * \frac{1}{\beta} \log \frac{k}{m} \]  
\[ \text{At the same time interval, } t_i \text{ have the probability density } p(t_i) = 1 / (m_0 + t), \text{ thus we can get,} \]
\[ P(k) = \frac{\partial P(k_i(t) < k)}{\partial k} = \frac{1}{m_0 + t} * \frac{1}{\beta} * \frac{m}{k} \]  
\[ P_K \text{ is accord with power law distribution.} \]

**Simulations and Analysis**

In this section, we want to compare the parameter \( c \), and \( R_{\text{max}} \), and those parameters effect the performance of the whole network. Our simulation tool is Matlab2011b, a Monte Carlo procedure times is 300 times, the simulation of initial parameters are setting as follows:

**Table 1.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Significance</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>Total number of nodes</td>
<td>1400</td>
</tr>
<tr>
<td>( m_0 )</td>
<td>Number of nodes in the initial network model</td>
<td>50</td>
</tr>
<tr>
<td>( m )</td>
<td>The network increases the number of edges every time</td>
<td>3</td>
</tr>
<tr>
<td>( E_{sc} )</td>
<td>Transmission circuit energy consumption</td>
<td>50 ( nj / bit )</td>
</tr>
<tr>
<td>( E_{tc} )</td>
<td>Energy consumption of amplifying circuit</td>
<td>10 ( pj.bit^{-1}.m^{-2} )</td>
</tr>
<tr>
<td>( E_{rx} )</td>
<td>Energy consumption of receiving circuit</td>
<td>50 ( nj / bit )</td>
</tr>
</tbody>
</table>

In this paper, the uniform distribution of node energy is selected \((0j,0.5j)\), and the simulation area is \(400*400 \) square region. Firstly, we use non uniform clustering algorithm WUCA to cluster nodes in the region.
Figure 2. \( c=0.4, R_{\text{max}}=35 \), based on the WUCA algorithm to cluster the nodes in the region.

In the Fig.2, we can see clearly in the detection region of the backbone network composed of cluster head nodes, the distribution characteristics of the cluster head nodes is centered on the location of the sink node, the distance between the sink node and cluster head node is closer, the number of cluster head nodes are more intensive, whereas the more loose. The distribution of the cluster head is in accord with the idea of non uniform clustering algorithm.

As formula, \( c \in [0,1] \), if \( c = 0 \), the network is according to uniform clustering; otherwise it is non uniform clustering. Fig.3 shows the variety number of clusters \( n \) when the maximum cluster radius, \( R_{\text{max}}\), and \( c \) have different values.

Figure 3.

The Fig.3 shows that the line of WUCA non uniform clustering are higher than the line of uniform clustering algorithm, if the value \( c \) is larger, with the same maximum cluster radius conditions, it can produce more clusters. Thus, it proves that the front analysis, a network with a
small clustering radius must produce more clusters to cover the entire network. When $R_{\text{max}}$ is fixed, with increasing of $c$, Cluster radius $R_i$ has reduce, the number of cluster heads produced by clustering algorithm increases with the increase of the parameters $c$.

With the variation of $c$, $R_{\text{max}}$, the degree distribution $P(K)$ change as follow,

![Figure 4. $R_{\text{max}} = 10$.](image)

![Figure 5. $R_{\text{max}} = 50$.](image)

![Figure 6. $R_{\text{max}} = 80$.](image)

By the above three figures, when the value of $R_{\text{max}}$ is small, the number of cluster head occur in the entire region of have lager, degree distribution $P(K)$ of the network of the crest is low,
the degree of nodes in the network mostly between 2 and 10, and when the value of $R_{\text{max}}$ is larger, with the decrease in the region of the cluster head nodes, the peak will rise to about 0.5, and the most of node degrees in network are between 2 and 10. When for smaller values of $R_{\text{max}}$ and unchanged, with the increasing of $c$, the heterogeneous cluster head of will gradually increase, within the region closer to the sink node, cluster head node will become more and more dense, and from the sink node is far away, the cluster head nodes will gradually sparse. Because when the value $c$ is gradually increasing the heterogeneity of the cluster head position will become more obvious, the heterogeneity of the cluster head position will be more obvious, the cluster head nodes which are far away from sink node, need transmit information to the sink node through more other relay cluster head. However the cluster head nodes which closer to the sink node, only need transmit information by single hop to sink node, so closer to the sink node of the cluster head corresponding with a greater degree. From the above three pairs of graphs can be seen that when the $c$ gradual increase, the probability of the degree distribution of the network which have high value will be more generous. When $c=1$, and $R_{\text{max}}$ is smaller, the peak is the highest, and the and the $c=0.5$ is the lower, $c=0$ is the lowest. And in the larger value of $R_{\text{max}}$, with the change of $c$, when $c=1$, the peak is highest, when $c=0.5$, the peak is lowest.

Under random attack, the change of the network coverage $C$ [9]:

$$C(T) = \sum_{i=1}^{n} k_i(T) / N(N-1), T \geq 1$$ (10)

$T$ is the maximum number of hops allowed for the integration of information between nodes, $N$ is the number of initial network nodes. $k_i(T)$ is the number of nodes whose distance to node $i$ that $l \leq T$. The meaning of the indicators is that the network have effectively connected unit ratio after attacking.

![Figure 8. $R_{\text{max}}=50$.](image8.png)

![Figure 9. $R_{\text{max}}=80$.](image9.png)

The three figures show, when the value of $R_{\text{max}}$ is very small, in the remaining 80% of the cluster head node network, the network have low coverage which remained at around 55%,...
while with increasing of $R_{\text{max}}$ and remaining 80% of the cluster head node network, the network coverage rate of around 60%. For very small values of $R_{\text{max}}$, $c$ will not affect the value of coverage; and when to a large value of $R_{\text{max}}$ and kept constant, along with the increasing of $c$, the network coverage rate decrease.

**Summary**

In this paper, we introduce a model of wireless sensor network based on non uniform clustering mechanism, the best hop mechanism is used in the network growth stage. When the distance between nodes exceed the threshold distance that will calculate optimal relay node location. The data would firstly forward to a relay node and then the relay node transmit the data to the next node, so as to avoid excessive energy consumption when the data directly transmit to the next node.

We analysis of the degree distribution of the whole network with changing of the competition radius based on the mean field theory, and we use the software simulate that the number of cluster head, degree distribution, and network coverage in random attacks with the change of $c$ and $R_{\text{max}}$. We find that with the fixed $R_{\text{max}}$ and increasing of $c$ the number of cluster heads increases. With $c$ gradual increasing, the probity degree distribution of the network will be larger. In random attacks in the network nodes, the network coverage rate in the value is very small and the remaining 80% of the cluster head nodes in the network, coverage is low, maintained at around 55%, and increased when, in the network remaining 80% of cluster head nodes and coverage at around 60%. When the value is small and constant, the change of the value will not affect the change of the coverage rate; however, with the increase of the larger value, the network coverage is reduced.

**Acknowledgement**

This work was supported by the National Natural Science Foundation of China (grant No. 61163061, No. 51264037, No. 61461056, No. 61540063). Corresponding author is Fan Jing.

**References**


