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# ZigBee Network Tree Routing Algorithm based on Energy Balance

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***Abstract***

*ZigBee is a relatively recent rise of short-range wireless communication standard, due to the energy resources ZigBee nodes in the network, computing power and bandwidth are very limited, which determines the ZigBee network protocol stack layers are designed to be energy effectiveness led to the design elements. The primary design goal is to establish a network layer path of energy efficiency, reliable data forwarding mechanism of formation and prolong achieve network lifecycle. Aiming at non-optimal and some nodes may be depleted prematurely because the business is too large battery energy issues ZigBee network routing tree routing algorithm, an improved routing algorithm for ZigBee network tree. Achieve network load balancing, saving overall energy consumption of the network, and maximize the lifetime of the network. Finally, the simulation of energy balance ZigBee tree routing algorithm implementation and simulation results.*

***Keywords:*** *ZigBee, energy balance, tree routing algorithm*

## 1. Introduction

Today's society is the most dynamic IT technology, but also the tallest and fastest developing technology. In recent years, the rapid penetration and the development of wireless communication, applied to various fields. Especially the portable personal wireless communications devices, such equipment requirements for short-range wireless connectivity, making the short- distance wireless communication has been rapid development. Today supports more extensive short-range wireless communication technology with infrared technology [1], ultra-wideband technology, home appliances and radio frequency technology, Bluetooth technology and the latest ZigBee technology. ZigBee technology compared to several other communication technology, its main application is the low rate of wireless devices and wireless sensors, it produces a low cost to meet the needs of those connected to the miniaturization of devices, which can in agriculture, industry and other areas to be widely used. Large number of applications at the same time promoting the ZigBee ZigBee technology continues to refine and improve the future of wireless technology will become a star.

In recent years, ZigBee technology is a new wireless communication standard. ZigBee is the real source of bees, at the time when the bees collecting pollen through a dance called ZigBee to inform fellow own position, so as to achieve the exchange of information, this is a convenient way to "Wireless "Communication [2]. Because of the short time ZigBee study, so the main standards developed by the ZigBee Alliance and IEEE802.15.4 standard hardware group to develop software standards, while in December 2000 established the 802.15.4 group, specifically for ZigBee physical layer and media storage control layer development of relevant standards, while in May 2003 adopted the standards. The ZigBee Alliance is together founded in October 2002 by Invensys, Motorola, Mitsubishi, Philips, Honeywell, while ZigBee specification version 1.0 by the end of 2004.Announced. Although ZigBee technology in a variety of large-scale production has not been applied, but it’s rising is beyond doubt. In April 2005 the ZigBee

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Alliance has already produced a number of products for compatibility testing and validation. Member of the ZigBee Alliance is currently showing the growing strength of the trend, and now has more than one 200, ZigBee Alliance while in November 2006 announced the 1.1 version of the specification.

The main is a big advantage and development space in the transmission data rate and transmission distance wireless communication network technology, but as industrial inspection, agricultural testing, commercial and environmental testing and other applications, wireless sensor networks have been widely used. Because it is a small amount of data transmission, the transmission rate is low, but also the need for an apparatus for real-time communication, they are battery powered devices. This low-cost, low power consumption characteristic of a good make ZigBee technology has been widely applied. Sometimes traditional wireless communication technology occasionally to meet certain requirements, but their bulky equipment, with high power consumption, cost and other issues, making people more inclined to use ZigBee technology and new technology to replace the traditional wireless technology. British mlnvensys, United States Motorola, Japan's Mitsubishi Electric and Philips of the Netherlands was established in 2002 ZigBee technology alliance to jointly complete for technology research and development of ZigBee [3].

Currently ZigBee technology has become a focus of the study, which is generated in the short-range wireless communications technology, I believe that in the near future, research ZigBee technology will be a new wave, and its products will bring you more the ease and convenience, its technological development actuation of the Internet and computer integrated into everyone's daily life.

ZigBee technology leap in the development and improvement, it must be at the forefront of the development of digital technology, it is apparent power, cost, low rate advantage makes its application must be extensive. Expected in the next few years, the global ZigBee products each family will be over 60, the ultimate goal is to reach 100 expectations, I believe that in the near future, there will be more high-tech ZigBee product was added to our lives, as facilitate work and daily life.

Today, as a research hotspot of ZigBee short-range wireless communications technology research by various companies and research institutions, the prospects are very broad, in the near future there will certainly be a lot of associated wireless sensor products, bring to life convenient. But now through the study of the ZigBee Alliance analysis found that domestic research ZigBee technology is not perfect, the lack of studies comparing the architecture, it also does not have a big influence on product technology appear.

ZigBee network, while having a low-cost, low -power, low-rate features, but battery-powered feature, which means the energy of the whole network, computing power and bandwidth will be limited. Therefore, the design ZigBee network, the energy factors must also be considered as a key. In the physical layer and link layer media considered mainly low-power system design, at the network layer is designed to be reliable and energy -optimized design data forwarding, so that you can extend the life cycle of the entire network. ZigBee networks are battery -powered systems, and therefore the lifetime of ZigBee network nodes is very dependent on the battery. In the initial development stage of ZigBee in routing perspective, the key consideration is the traditional control overhead, average end delay and packet delivery ratio, but it lacks the consideration of energy, energy optimization. If in a network, the energy nodes are not guaranteed, the entire network cannot be normal communication, more reliable data forwarding node cannot imagine, but when some nodes energy depletion, when the nodes become death, but also lead to network segmentation, the overall performance of the network devastating blow. Therefore, energy optimization an important role in the ZigBee network is a must to get attention.

Next add in the ZigBee network can imagine the energy optimization mechanism

related to the energy of the entire network to bring a maximized savings, then the entire network life cycle will be significantly increased. So research ZigBee network energy optimization is a subject of great significance. This article is specifically optimized for energy ZigBee network to study.

## 2. Related Works

Abroad, zigBee research much earlier than domestic, and the results of the study also relatively abundant. In August 2002 the establishment of the ZigBee Alliance, a number of companies jointly established the ZigBee Alliance, in order to promote the development of ZigBee network technology, as companies have to provide their own technical Chaddrcon, Ember, Freeseale, Honeywe11, Motorala, Philaddrs, Sansung and so on. Not only that, while the development of ZigBee technology also introduces hundreds of little league IC, home appliances, and other products of the communications industry, members of the ZigBee Alliance currently has more than more than 300, but there are more ready to join the manufacturers and products [4].

Because ZigBee Alliance is composed of major companies for the purpose of non-profit Xie Hui, and serve for the development of ZigBee wireless technology, makes zigBee technology can be fully exploited in all walks of life, such as home appliances, energy, environment, industry, connections, sensors use of agricultural and other wireless networks and related standards. ZigBee technology is currently the fastest growth of the place is America, there is half the league members are from there, and the Pacific and Asia as well as Africa and Europe are only occupied the third. Union membership is not only more current but are from different industries, including software, chips, systems, terminals and other service providers, and are involved in a variety of industries, and is growing in. In China, the current is not so hot, participating enterprises and industries are generally relatively small.

Currently ZigBee market is still dominated by foreign manufacturers with, independent research and ZigBee wireless communication technology products in the country is still generally low, domestic research more to stay in academic research. Today, the major trend of ZigBee wireless sensor technology, has begun to have a lot of research institutes with universities began a product -oriented research, such as wireless sensor networking, wireless application technology as well as short-range wireless sensor networks, these technologies can be related products is associated with our lives, such as wireless meter reading, smart home, wireless logistics management and other aspects of " the country with the Research Institute of the University has begun to use the technology platform and foreign developers build their own chip ZigBee network [5].

ZigBee standard research perspective views of the system, there have been a lot of research began, and obtain the corresponding results. Time ZigBee wireless network synchronization issues, security issues, such as broadcasting, but also in the development process, various problems have been a very good improvement also began to offer more and more powerful. Although ZigBee development trend is good, but it also exists some problems, mainly:

1. An extended study of ZigBee technology: With the current technology, and other applications ZigBee technology is now the new direction. Wireless communication systems such as Linux / DSP and ZigBee together constitute the, Web / GPRS and ZigBee wireless network management system combined.

2. ZigBee technology is currently applied research: Today at home and abroad there are a large number of companies and research institutions, and they have put a lot of applications, such as: intelligent transportation, smart home, sensor network applications and embedded applications. Meanwhile Jennie in environmental monitoring and data collection and street lighting control production line are a combination of RFID applications ZigBee technology.

3. Performance ZigBee network: current research is focused on the performance of ZigBee networks in 802.15.4 ZigBee networks, competitive energy consumption and throughput times, in different communication parameters, stability and ZigBee communication status of the entire network. In the case of low load, ZigBee network in order to increase the life cycle of the network to adjust the energy consumption of the node.

4. ZigBee network routing algorithms: ZigBee -based network routing algorithm is AdHoc demand distance vector (AODv algorithm), so zigBee network in the establishment of a mesh network and data transmission more similar with AdHoc. From the traditional path algorithm AODV route discovery and overhead perspective, a dense network node will directly affect end packet delay and delay, the performance of the network will have some interference, so improving the efficiency of routing algorithm is very necessary, nowadays many domestic journals and papers already have made a very good improvement for the AODV routing algorithm.

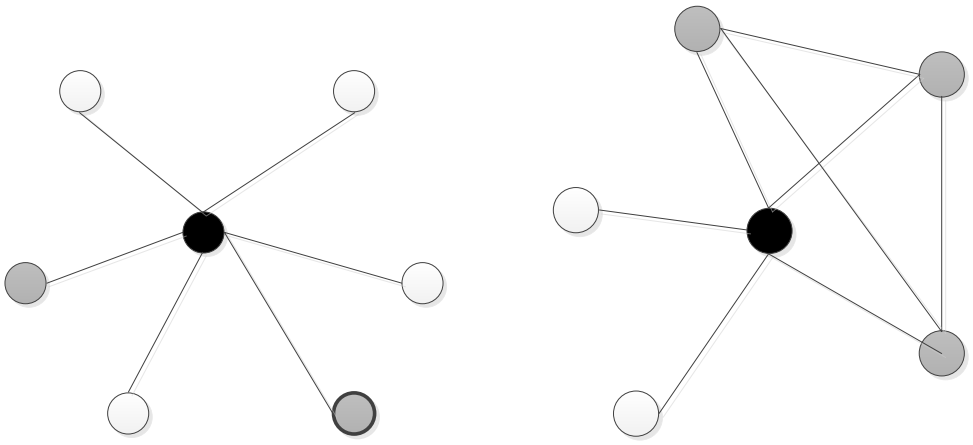
It seems safe, ZigBee wireless communication technology network using a shared radio channel, so certainly there are some security risks, such shared wireless channel is vulnerable to outside attack and difficult to carry out prevention and tracking.

In the Access Control view, there are many problems, typically a terminal exposure, presence of multi-network sharing, fairness and other access methods, although more or less provides some techniques and methods, but still not well solution.

It seems in energy control, wireless sensor networks there is no fixed infrastructure support, and the power supply system is only powered by batteries, so it is easy because the node excessive energy consumption and death. Therefore, the energy consumption of the network, network energy efficiency, network segmentation and avoid premature depletion of energy nodes is the focus of the study. Energy for the primary current control mode network with nodes in the sleep state to selectively adjust the output power, and the use of some of the energy saving node routing mechanism [6].

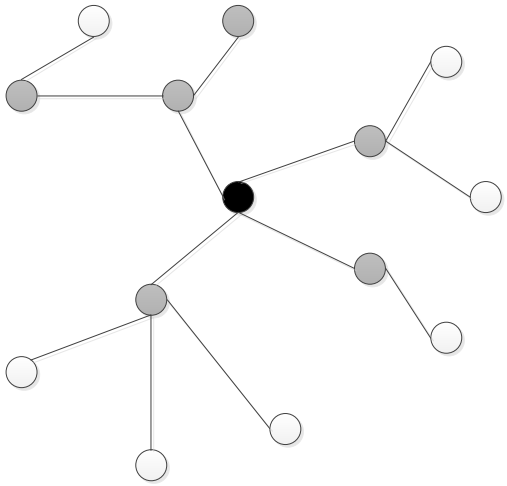
## 3. Proposed Scheme

ZigBee network layer specification developed by zigBee Union, it is primarily to achieve the formation of the network, the new node joins the network to assign addresses, route discovery and route maintenance and other functions, can support a variety of network topologies. ZigBee ZigBee routing algorithm is the core of the network layer. ZigBee network supports three major network topology: Star (Star), tree (Cluster-Tree), mesh (Mesh) structure. Figure 1.



**Star Structure** **Net -shaped Structure**



**Tree -shaped structure**

**Figure 1. ZigBee Network Topology**

### 3.1 ZigBee Network Networking

In zigBee network, only the central coordination point can create a new ZigBee network. When the central coordinator wanted to create a new network, first, the probe scanning IEE802.15.4 energy (energy detection scan), and the active scanning (active scan), the network is not detected to select a free channel or at least the detected channel network, and then determine their 16-bit network address, network PAN identifier (PANIdentifier, pANID), network topology parameters, wherein the unique identifier is a network PANID this channel, this channel should not therefore PANID detected PANID conflict network. After the parameters selected, ZigBee center coordinator will be able to accept other nodes to join the network [7].

When a node in the network does not want to join the current network to join, they would nodes in the network sends an association request, if the request is received by the node associated with the ability to accept the other node to its child nodes, on this node is assigned a unique network the 16-bit network address, and send the associated response, after receipt of the response associated with this node successfully joined the network, and can accept the associated other nodes. After a node joins the network, his PANID flag is set and the center coordinator the same identity. Whether a node having the ability to accept the other node associated with it, this node depends on the available resources, such as storage space, or energy. If the nodes in the network wants to leave the network. You can also send a request to disassociate the parent node, the parent node receives disassociated response after they leave the network can succeed. However, if this node has one or more child nodes, in which from before opening the network, we must first release all child nodes and their associated, shown in Figure 2.

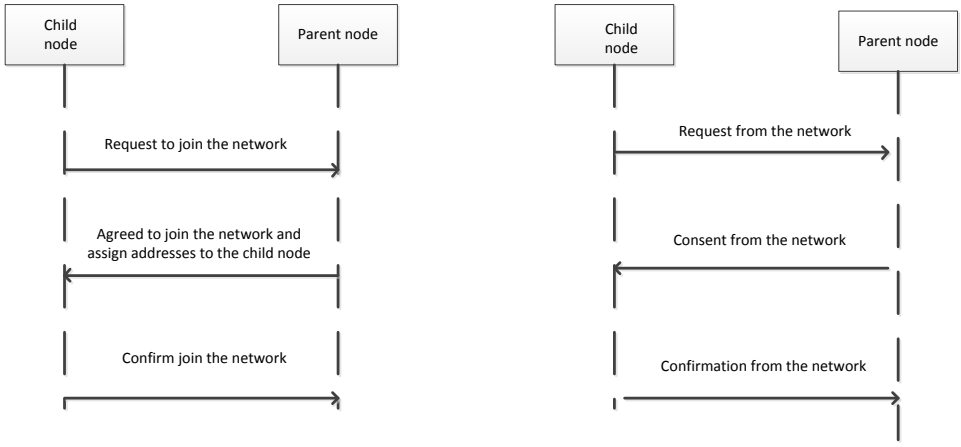



**Figure 2. Nodes Join and from the Network Diagram**

### 3.2 Classification of Energy Efficient Routing Algorithm

Nodes in the network, either in the communication state, or in idle state. When the node data is being transmitted or received, the communication state; data transmission is not performed when the node is in an idle state, but this time also consumes energy. According to node status of different energy efficient routing algorithms can be divided into two categories: energy consumption saving routing algorithm under the communication status and saving routing algorithm energy consumption in idle state.

Save routing scheme of the energy consumption of communication state includes two aspects: one is to find the source node to the destination node route with the lowest overall energy consumption. The specific method is to control the transmission power of the node to ensure the normal transmission of data packets to reach minimum power, by reducing the total transmission power of the path to save battery energy of the node, so as to reduce the energy consumption of the overall purpose of the network, if each node same transmission power, looking for the smallest total transmission power routing becomes to find the minimum number of hop routing. This type of routing protocols MTPR (Minimum Total Transmission Power ROuting), PARO (Power Aware Routing Optimization) and COMPOW (Common Power) algorithm.

On the one hand is to make the network node balanced energy consumption, requires looking to select a high residual energy involved in relaying node routing, while avoiding the use of the remaining battery energy shortage added routing node, to avoid depletion due to low power nodes battery energy exits the network caused by network segmentation phenomenon. This type of routing protocols LEAR (Loeal Energy-Aware Routing), EDDSR (energy-dePendentDSR), MBCR (Minimum Battay Consumption Routing) and so on.

Save energy consumption routing protocol major consideration in the idle state without affecting the normal communication, try to adjust to the sleep mode or shutdown mode to save energy consumption. This type of routing protocols GAF (Geographic Adaptive Fidelity), based on the coordination of energy, such as geographic routing algorithm span.

### 3.3 Energy Efficient Routing Algorithm Strategy

Routing algorithms typically use some traditional metrics to select the route, such as DSR, TARO, AODV so as to minimize the number of hops routing strategy; DARPA (Defense AdVanced Research Project Agent) combined with a minimum number of hops and link quality for the selection of routing policy; SRA (Shortest Routing Algorithm) places the message and delay overhead as routing policy and so on. In these routing protocols, traffic more or participate more data packets and control packet forwarding

node easy compared to other nodes in the network run out of battery power too quickly may cause network segmentation, have a negative impact on the life of the network. Following a brief introduction of several considerations node energy efficient use of routing policies [8].

(1) minimizing the total energy consumption path

This is a more direct method of network energy consumption savings. The basic idea is to make the packet through the path of the total energy consumption of all links is minimized. If each link is equal to the energy consumption, the index corresponds to the minimum number of hops. This strategy allows the total energy consumed by each packet is minimized, but its main disadvantage is that the nodes in the network may result in uneven consumption of energy, leaving the part of the node depletes battery energy faster than other nodes.

In the network topology shown in Figure 3, if the two want to send data node sending data node 5, node 3 node 6 will want to select a node O as an intermediate routing node, so that node 0 would be premature because the business is too large depleted their energy, resulting in network partitioning, so you cannot really achieve the purpose of the extension nodes and network lifetime.

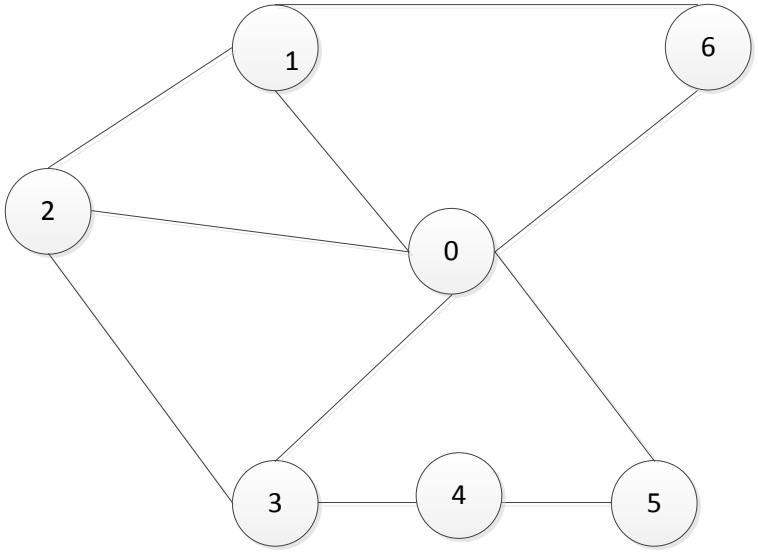



**Figure 3. Energy Efficient Routing Strategy Schematically**

(2) maximize the time delay network split occurs

The goal of the strategy is to make the energy consumption of nodes in the network balanced as much as possible to postpone the moment network segmentation arise. The basic approach is likely to cause the network to find the split node, to minimize the traffic to these nodes, to maximize the life of these nodes, thereby maximizing the time the network partition occurred. However, if the request meet the high throughput and low latency, which is difficult to be optimized.

(3) Minimize residual energy level between nodes

The policy requires the residual energy of nodes in the network as much as possible to maintain the same, and thus life as equal as possible to ensure the nodes in order to achieve balanced network energy consumption and prolong the life of the destination network. But the path of the total energy consumption of the policy may not be possible to select the least.

(4) The maximum and minimum residual energy routing

There are multiple nodes on each path, and the residual energy of nodes may differ from each path selected minimum energy remaining nodes to represent the path of the

available energy. Maximum and minimum residual energy strategy is to choose the path of maximum available energy path.

(5) Minimizing the overhead of each packet

Assuming the cost function $f(x_i)$ represents the node i, where $x_i$ in the value of the residual energy of the current node, then after the node $n_1, n_2 ... n_k$ (the source node $n_1$ to the destination node $n_k$ ) the packet overhead j is:

$$C_j = \sum_{i=1}^{k-1} f(x_i)$$

This policy aims to minimize the overhead $c_j$ of packet j, so you can define the cost function represents the probability of participating nodes to forward packets size, the smaller $f(x_i)$ the greater the probability of participating nodes to forward packets, defined as follows

$$f(x_i) = \frac{1}{x_i}$$

$$C_{warming} = \frac{\beta}{f(x)} \sqrt{energy}$$

$$f(x) = \frac{N_{\text{total}} \times x}{N_{\text{total}} - x} \left(1 \le x \le N_{\text{total}}\right)$$

At this time, if the residual energy value is larger, the smaller the node cost, the possibility of greater involvement of the packet forwarding the contrary, if the value of the residual energy is smaller, the greater the cost of the node, the greater the possibility of involvement of the packet forwarding small, you can try to avoid the use of this strategy routing node residual energy value is small, thereby maximizing the life of all the nodes in the network.

In short, no matter what kind of energy efficient routing strategies are not guaranteed at all of the network scenario is optimal under these different circumstances the performance demonstrated by the routing algorithm is different, depending on the network and therefore the need to choose what kind of energy efficient routing algorithms.

### 3.4 Improved Algorithm Proposed

ZigBee tree routing algorithm only considering the relationship between the forwarding node and parent and child nodes between nodes, but ignored the neighbors. So there are some problems, for example, even if the destination node within hop on the sending node, the data packets must be transmitted to the destination node along the tree topology, but cannot be directly transferred to the destination node. In addition, if you frequently need some nodes transmit data, these nodes may prematurely exhausted battery power, resulting in network shortened life expectancy.

However, if the node is only considered when selecting routing hops, but also easy to make some nodes due to the larger volume of business and prematurely depleted battery power. Node receiving and forwarding packets need to consume battery power, battery power is depleted node can no longer participate in forwarding packets. Run out of battery power nodes can easily affect the performance of the network, on the one hand, the depletion of battery power node itself will not be reused; on the other hand, network connectivity will deteriorate easily lead to network partitioning.

#### 3.4.1 Neighbor Table Design

If two nodes can communicate directly within the hop range, we say that two nodes are neighbors. Due to the small storage capacity RFD devices, so only FFD device storage for

its entire neighbor list, RFD devices do not need to store their neighbor list.

Each node in the network through the neighbor list FFD nb-list, record the points and other points of adjacency. The neighbor list entries as shown in Table 1:

| ADDRnb | DT | Npower |
|---|---|---|

In nb-list, there are three fields:
ADDRnb: neighbor node address.
DT: make Japanese home node device type, l said the neighbor nodes FFD device with routing function ; O indicates that the neighbor node D devices that do not have routing capabilities, carried only send and receive data.
Npower: residual energy value of the neighboring nodes.

### 3.4.2 Node Residual Energy is Defined

We first node is divided into two different regions in accordance with its remaining battery power:

(l) Standard Area: If the residual energy value is greater than the current node $C_{warming}$, it is located in the standard area. FFD node can participate in the region of the forwarding data.

(2) the warning area: If the residual energy value is less than the current node $C_{warming}$, it is located in the warning area. When the data transmission node try to avoid the area.

Initial energy is assumed that the node energy, $C_{warming}$ are set as follows:

$$C_{warming} = \frac{\beta}{f(x)}\sqrt{energy}$$

Where $\beta$ in for a particular coefficient, the value function is to slow the rate $C_{warming}$ of decrease ( the value of the simulation experiment, we set $\beta$ = 2 ). Is a function $f(x)$ that varies with the change in x, which is set as follows:

$$f(x) = 1 \quad \text{when} \quad x=0$$

$$f(x) = \frac{N_{\text{total}} \times x}{N_{\text{total}} - x}\left(1 \le x \le N_{\text{total}}\right)$$

Which $N_{\text{total}}$ refers to the total number of nodes in the network, is a constant and x is a variable.

Since $C_{warming}$ an inverse relationship with the formula $f(x)$, can be introduced $C_{warming}$ as a decreasing function with respect to x, $C_{warming}$ with the increase of x decreases, while $N_{\text{total}}$ decreases to a certain level, some of the nodes may be located in the warning region has become the standard of the node to continue to be used. When x is close to $N_{\text{total}}$, $N_{\text{total}}$ close to zero, then you can put the death is still below the node $C_{warming}$ as a node, and the $C_{warming}$ decreasing magnitude smaller. This descending speed is set in line with the actual condition of the network nodes of energy, energy is more adequate start node, can be relatively fast, but the node $C_{warming}$ is generally lower in the case of energy.

### 3.4.3 Routing Initialization Algorithm

In the initialization phase, the center coordinator network is assigned a unique network address for each node based on network address allocation mechanism described in the previous section. Each network node itself FFD initialization neighbor list nb-list, to record information about all neighbors. FFD node and each of the remaining energy will

be the value of its threshold value $C_{warming}$ has been defined in comparison, it is determined that the node is located in the region so that when the data transmission is involved in the forwarding of data is determined.

FFD node such standard zone when it receives a packet, it can find its neighbor list, select the FFD node all standard areas, and in which to select a small number of routing hops neighbor as the next hop.

## 4. The Experimental Results and Analysis

For general computer network, we usually adopt the applicability of simulation and actual physical measurements to measure a combination of new protocols and methods. But for ZigBee networks, due to its own characteristics, physical measurements in many environments is not feasible, then the computer simulation becomes an important means of ZigBee sensor network performance evaluation.

Our study OMNET ++ (Objective Modular Network TestBed in C ++) network emulator as a simulation tool. It is the Budapest University of Technology Telecommunications Institute developed an object-oriented distributed event simulation tools. It can be used for communication protocols, modeling and simulation of multi-processor computer networks and distributed systems, management systems and so on. It provides support for wireless network simulation, in the current theoretical research of wireless networks, are widely used.

Improved algorithms by simulation and traditional tree routing algorithm compared, the focus is to compare the overall network energy consumption and the number of nodes in the transmission failure. Simulation results show the effectiveness of the improved algorithm.

The simulation tool uses Omnet ++ 3.2pl. Network covers an area of 500 * 550m, the number of network nodes is set to 30, the data length of the bag are 512B, channel bandwidth of 3Mbps, the initial energy of the nodes are 10000J. We set Cm = 4, Rm = 3, Lm = 4. The simulation results shown in Figure 4 and 5.

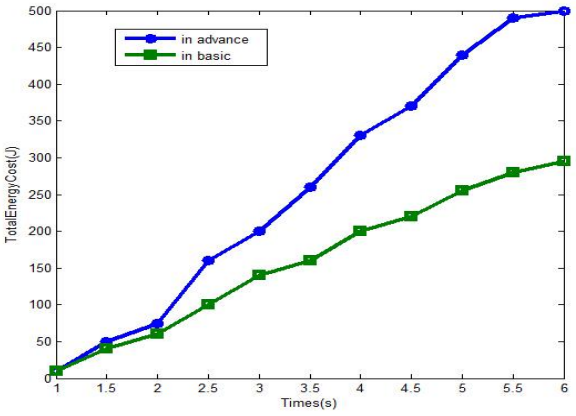



**Figure 4. Network's Overall Energy Consumption Curve Changes Over Time**

In Figure 4, the curve 1 represents the conventional tree routing algorithm runs that overall energy consumption of the network, the curve 2 represents the improved algorithm runs herein the total energy consumption of the network. Since the introduction of the improved algorithm neighbor list, in the routing process took into account the routing hops and node residual energy, try to choose a path to a local minimum routing hops for data transmission, while avoiding the transmission of data to lower energy nodes, thereby saving energy.

In Figure 5, curve 1 represents the number of deaths traditional tree node network

routing algorithm is running, Curve 2 represents the death of the number of nodes in this article to improve the algorithm runs the network. Initial stage, the energy of each node are sufficient, the node does not produce the death, with the growth time for the network, some of the node as a forwarding node frequently consumed a lot of energy, a conventional tree routing algorithm does not consider the residual energy of the node time value, so there are deaths node earlier than the proposed algorithm. Improved algorithm of this paper to avoid the residual energy due to the low node, select the node energy more data forwarding, so avoiding premature death of individual nodes, the survival time load balancing of the network, to maximize network.

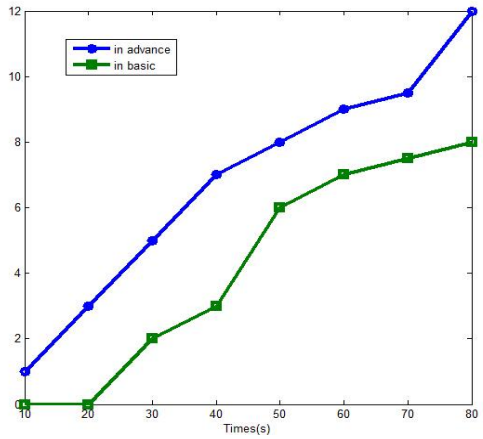



**Figure 5. Died in Network Nodes is Changing with Time Curve**

## 5. Conclusion

For traditional ZigBee tree routing, we propose an energy -balanced ZigBee tree routing based on improved algorithm based on the traditional tree routing algorithm, the introduction of a neighbor table, in the data transfer process, considering the routing hops and node residual energy, and timely adjustments to the critical value $C_{warming}$, which makes the energy consumption of the network to reach equilibrium. Simulation results show that the algorithm can effectively avoid the low-energy nodes transmit data, saving overall energy consumption of the network, extend the life of the network. However, the algorithm in the routing process is considered only a partial routing hop optimized routing hops without considering the entire path optimization. In future work, to provide more in-depth study of routing hops, making ZigBee tree routing more optimized.

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