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The Energy Consumption Research of Sensor Network Nodes Based on Economic Theory

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Abstract: The core of this paper is to improve network energy efficiency effectively, to reduce energy consumption of nodes, and to extend network lifetime, surrounding the subject of taking energy effectiveness and proportionality of wireless sensor network into account in routing, adapting neural networked mathematical model as the analysis tool based on economic theory, this paper premises on studying system architecture of sensor network, dissecting the hardware structure and design of sensor nodes, the main algorithm and protocol of each level, common used sensor networked energy consumption technologies and strategies one by one, and analyzing the main cause of energy consumption from hardware and protocol stack these two levels. *Copyright © 2013 IFSA.*

Keywords: Wireless sensor network, Economic theory, Energy consumption of node.

1. Introduction

Sensor network is the one based on application, compares with traditional wireless communication network, it has the characteristics of big node scale, multihop self- organization, unattended operation, and no communication infrastructure, while energy constraint from beginning to end is the bottleneck of limiting the developing and using of sensor network technology. Sensor network is a very complicated network structure, which has lots of similarities with human society economy system, thus this paper solved several problems of energy consumption of node in sensor network with the help of economic theory [1].

This paper aims to the main factors which influence energy consumption, analyzed the massive structure, node structure, communication mode and network coverage of sensor network, this paper gives the mathematical model of energy consumption of wireless transmission based on economic theory. On the basis of the summary of key energy consumption technology of sensor networks such as single node energy consumption technology, data fusion technology and cross-layer energy consumption technology, focused and compared several types of classical media access controls, protocols in sensor network; analyzed resolved problems in energy consumption algorithms, protocols and strategic functions of wireless sensor network at present.

2. Energy Consumption Analysis of Wireless Sensor and Sensor Node

2.1. Energy Consumption Analysis of Wireless Sensor and Sensor Node

All levels of wireless sensor network are the concrete realization based on network architecture, because the self-characteristic of sensor network, its

concerned issues are different from the traditional wireless communication network. The layered architecture of wireless sensor network is as Fig. 1.

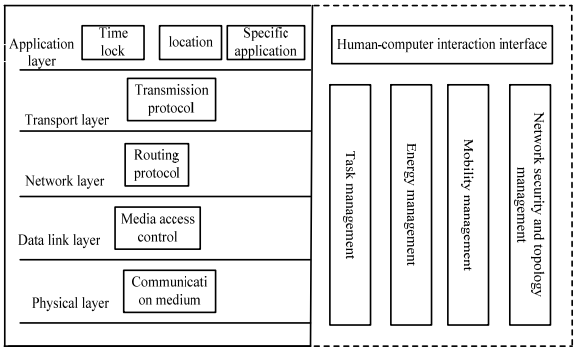

Fig. 1. Layered architecture of wireless sensor network.

The concrete realized functions is referred to the sensing, processing, analyzing, comparison and data transmission facing to sensor nodes, specific application is the remote operation and maintain sensor network facing to user terminal, the most important feature of sensor network is energy constraint [2]. Therefore, the object of the protocol based on traditional wireless sensor network is to obtain high QOS, while the object of the protocol based on sensor network is to reduce energy consumption.

2.2. Wireless Sensor Network Structure

Wireless sensor network structure is showed as Fig. 2, the entire network constitutes of sensing node, host node or aggregation node, base station controller, base station transmitting.

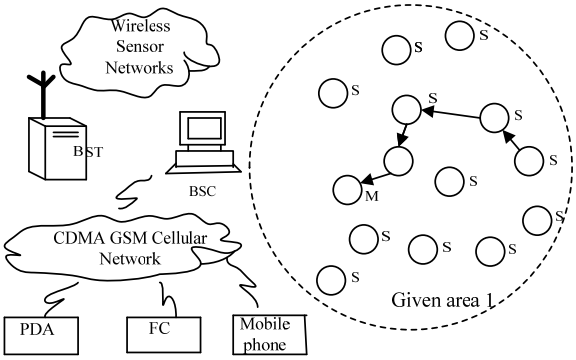

Fig. 2. Structure diagram of wireless sensor network.

2.3. Sensor Node Structure

Sensor node mainly consists of sensor unit, processor unit, communication unit and power supply unit these four elementary unit, within the dashed box is the auxiliary unit of sensor node, which includes positioning unit, moving unit, communication unit and power supply unit, we can choose and conFig. These three units according to the different application scenarios .Its structure chart are showed as Fig. 3.

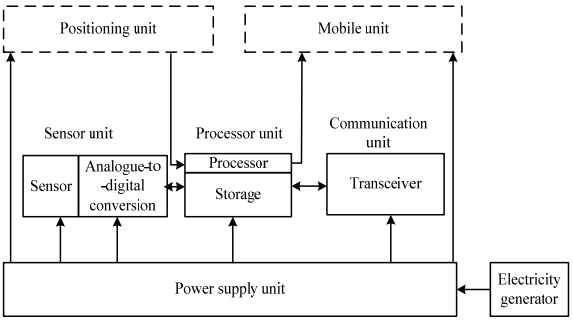

Fig. 3. Structure chart of sensor node.

2.4. Sensor Node Communication Mode

The communication unit in sensor node is transceiver module, which can adapts active or passive light wave module, looking from the application of wireless sensor angle, data transmission mainly divides into continuous sending type, event driven type, query driven type and mixed type [3]. Looking from the node data communication of sensor direction, can divide into Node-BS and BSC-Node two types.

2.5. Energy Consumption Analysis Based on Hardware Nodes

The energy consumption of sensor node is higher than the energy consumption of sensing, processing , space and dormancy, as Fig. 4 shows:

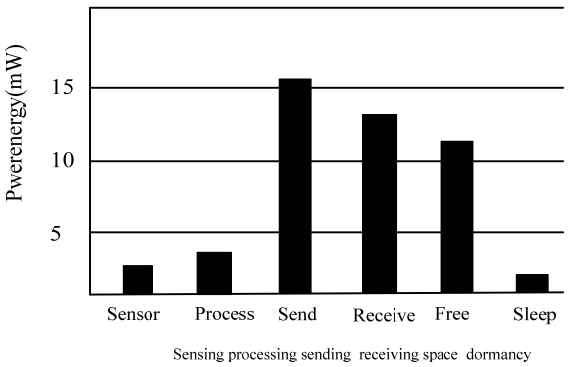

Fig. 4. Energy consumption distribution diagram of communication unit.

Total energy consumption formula of computer transceiver module in wireless communication:

$$P_C = N_T[P_T(T_{on} + T_{st}) + P_{out}(T_{on})] + N_R[P_R(R_{on} + R_{st})] \quad (1)$$

where P_T and P_R are the power dissipation of transmission and sending respectively, P_{out} represents the output power of transceiver, T_{on} and R_{on} are the online duration of transmission and sending, T_{st} and R_{st} are the starting time of transmission and sending respectively, N_T and N_R are the conversion times of transmission and sending within unit interval, which is determined by task management strategy and MAC, in the newest wireless transmission transceiver with l. we energy consumption at present, P_T is about 20 dBm, P_{out} approaches to 0 dBm.

Energy consumption module of single node wireless communication shows as Fig. 5, in the condition of single hop, no data fusion and only simply receive and transmit, here m=n, the energy consumption E_b of each bit in data transmission is :

$$E_b = E_{tx} + E_{rx}, \tag{2}$$

$$E_{\text{tx}} = E_{\text{te}} + E_{\text{t}\alpha}\text{d}^{\beta}, \tag{3}$$

where E_{tx}, E_{rx} is the energy consumption of receiving and sending one bit of data, E_{tx} is the energy consumption of node sending module successfully sends a data, E_{rx} is he energy consumption of node receiving module successfully receives a data, $E_{\text{t}\alpha}$ is the energy consumption of successfully sending a data for one meter, is the physical distance from node sending module to another node receiving module. β is the energy-consumption path, which is a constant, and connected to geography and transmission condition.

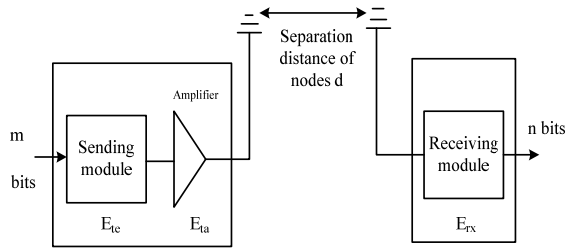

Fig. 5. Energy consumption module of wireless communication in sensor node.

After increasing the starting energy consumption, the energy consumption E_b of data transmission is:

$$E_b = E_{tx} + E_{rx} + \frac{E_{dec} + E_{st} + E_{sr}}{l}, \tag{4}$$

3. Wireless Sensor Data Fusion Module Based on Economic Theory and Artificial Neural Network

2.1. Data Fusion

The study of applying data fusion into wireless sensor network is properly extensive, especially the routing algorithm and protocol in network layer data-centered, data fusion is an interdisciplinary comprehensive theory and method, it can use several technologies and methods of other fields for reference [5].

2.2. Economic Theory

The distinguishing features of the application of economic theory and wireless sensor are: following the "high quality and favorable" principle of resources, encouraging the nodes with resources can put more better resources to network, and gaining profit from providing services; allowing the tasks of users to find appropriate resources according to QoS requirement, which not only meet the demands of users, but also reduce the wasting of resources as much as possible, if the price of resources are determined according to the internal performances, then the matching resources are nearly the optimal solution found in resource management, through economic ways to process a uniform processing to all the resources, the transaction goods can include computing power, internal memory, storage capacity, network bandwidth, data, devices and instruments and so on.

2.3. Artificial Neural Network

Artificial neural network has the features of distributed and parallel processing, non-linear mapping, adaptive learning, strong robustness and fault tolerance, which makes its neural computation got widely values in data fusion field.

The basic principles of artificial neural network are similarity to the processing of human brain synthesizes data or information, in the routing without using neural network fusion technology, and between the sensor nodes in network exists much redundancy information transmission, which increases the working strength, processing time and communication frequency of data.

2.4. Routing Algorithm of Sensor Network

Routing algorithm of sensor network can divide into plane formula routing, hierarchical formula routing and location-based routing according to topological structure. Aiming to the routing

algorithm of sensor network, two types of basic protocols were proposed: direct communication protocol and minimum transmission energy protocol, the basic block diagram of its network topology structure based on SOMDF algorithm is showed as Fig. 6:

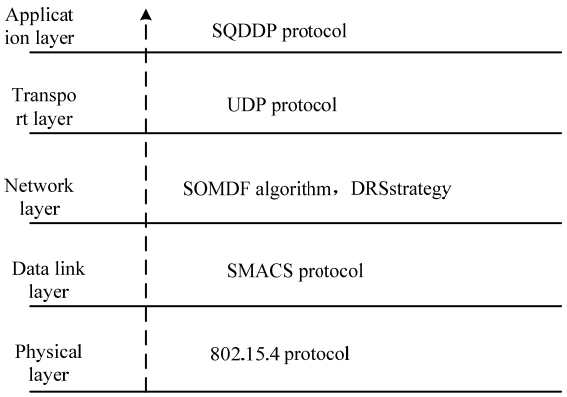

Fig. 6. The basic block diagram of network topology structure.

2.5. Mathematical Model of SOM Network

SOM is a kind of unsupervised clustering neural network with crossrange associative ability, its main function is mapping the n-dimensional data to a lower dimensional input [7]. SOM model imitates the structure of neuron two dimensional space lattice structurally and imitates clustering, fusion function, self-organization and self-learning function of brain's information processing through the interaction and competition between neuron in network, its pie graph is showed as Fig. 7.

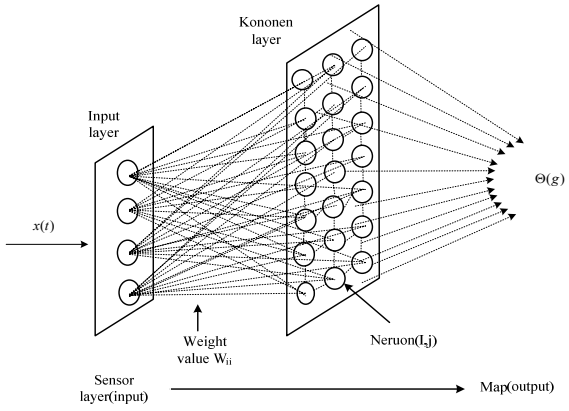

Fig. 7. SOM pie graph.

2.6. Introduction of Sensor Node Neuron

The basic idea of SOMDF algorithm is as follows: based on a certain number of sensor node samples, when sometime happens in surveyed area, the source node v_i of detection event random chooses a neighboring node transmission data package ,after neighboring nodes receiving source node data, through every sensor node of package should detect the quality of surrounding neighbor nodes, its structure is shown as Fig. 8.

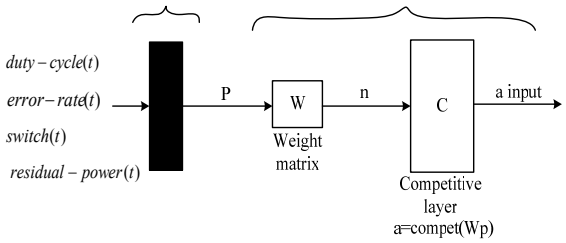

Fig. 8. Network structure sketch map of SOMDF algorithm.

Defining four inputs in SOMDF algorithm are;

$$X(t) = [duty\text{-}cycle(t), error\text{-}rate(t), switch(t), residual\text{-}power(t)], \quad (5)$$

Where duty-cycle (t) represents duty cycle, error-rate (t) represents the error rate of node transmission.

In SOMDF algorithm, adapting minimum Euclid distance to find best matching unit $i(X)$. Namely meets the following unit $i(X)$ as the best matching unit:

$$i(X(t)) = \arg\min \left\| X(t) - W_j \right\|, (j = 1,2,3,4), \quad (6)$$

Suppose h_{ij} is the topology field of winning neuron centered on i, d_{ij} represents the lateral distance between winning neuron i and excitatory neuron j, the typical function of h_{ij} chooses Gaussian function;

$$h_{ij} = \exp(-\frac{d_{ij}^2}{2\sigma^2}), \quad (7)$$

The Gaussian function h_{ij} is shown in Fig. 9, parameter σ is the "effective breadth" of topology field.

Although determines the best matching neuron i(X) during competition process, its weight vectors can not fully express the vector X, in order to make weight vector express input vector fully, then we must process self-organization learning to weight, and request the synapse weight vector changes with the input vector X:

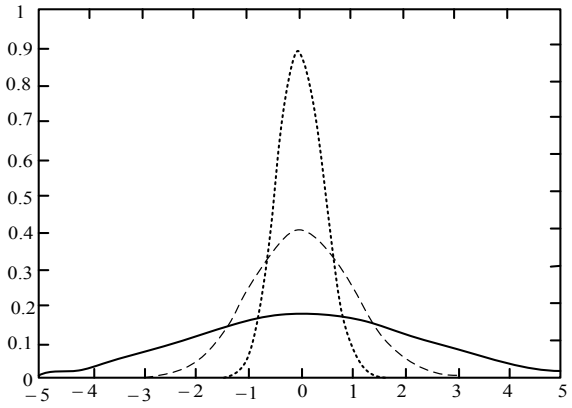

Fig. 9. Gaussian field function.

$$\begin{aligned} {}_{i}w(q) &= {}_{i}w(q\text{-}1) + a(p(q)\text{-}{}_{i} \\ w(q\text{-}1)) &= (1\text{-}a)\,{}_{i}w(q\text{-}1) + ap(q) \end{aligned}, \quad (8)$$

where area $N_{i^*}(d)$ includes all the neuron subscripts located in the winning neuron with the center of i*, radius of d.:

$$N_{i^*}(d) = \{\mathrm{j}, \mathrm{d}_{\mathrm{ij}} \le \mathrm{d}\}, \quad (9)$$

2.7. Analysis of Performance

2.7.1. Algorithm Convergence

The convergence of algorithm determines the executional and feasibility of algorithm, as shows in Fig. 10, with the increasing of node number ,the convergence speed of algorithm reduced, the primary causes of the reduction of algorithm convergence speed are: he increase of the number of total nodes will lead to the increase of number of neighbor node, and the curb between nodes is also increasing, which leads to the update speed of weight is slow.

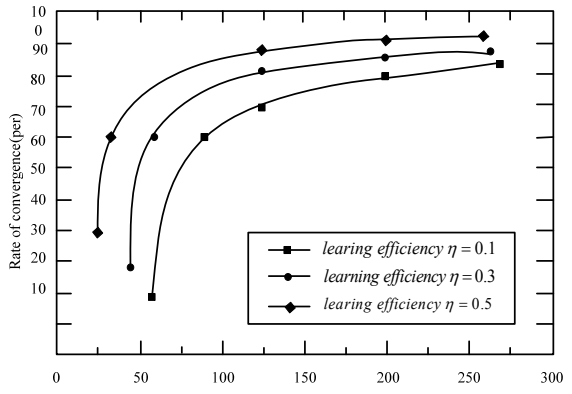

Fig. 10. The relationship between algorithm convergence speed and learning efficiency.

2.7.2. Data Fusion on Sensor Node

Suppose node A, B processes data transmission with the way of single hop. Then the transport delay $T_{DelayA\to B}$ of node B can define as:

$$T_{DelayA\to B} = T_{Data\_Fusion} + \frac{R_{node} \times E_{press}}{Bandwith}, \quad (10)$$

$$T_{DelayA\to B\to C} = T_{Data\_Fusion} + \frac{2(R_{node} \times E_{press})}{Bandwith}, \quad (11)$$

Suppose node $A \to B \to C$ processes data transmission between neighbor nodes with the single hop way, suppose among node $A \to B \to C \to \ldots \to Sink$ processes data transmission between neighbor nodes with the single hop way, and defines the hop count of node $A \to \ldots \to Sink$ is i, then the transport delay $T_{DelayA\to \mathrm{Sink}}$ of node Sink and transport delay $T_{DelayA\to BSC}$ of BSC can be defined as:

$$T_{DelayA\to \mathrm{Sink}} = T_{Data\_Fusion} + \frac{R_{node} \times E_{press}}{Bandwith} \times i, \quad (12)$$

$$T_{DelayA\to B\mathrm{SC}} = T_{Data\_Fusion} + \frac{R_{node} \times E_{press}}{Bandwith} \times (i+1) \quad (13)$$

The data transmits to Sink through each node, the fusion only operated on Sink or BSC, definition $i_{\min}$ is the minimum hot count of $A \to \ldots \to Sink$, at this moment the transport delay $T_{DelayA\to \mathrm{Sink}}$ of Sink is:

$$T_{DelayA\to \mathrm{Sink}} = \frac{R_{node}}{Bandwith} \times i_{\min}, \quad (14)$$

where the relationship between network width and the average delay of data transmission is showed as Fig. 11.

4. Energy Consumption Analysis

3.1. Performance Index of Wireless Sensor Network Routing Algorithm

It should be noticed that when aiming to the self-characteristic of sensor network to process routing algorithm design: (1)The energy consumption is limited and general without external energy supplement, which requests routing protocol efficient uses energy; (2) the number of WSN node is very large, and node only can get local topological structure information, routing protocol should choose compatible route on the basis of network local information; (3) Sensor network has a strong

application correlation, the routing protocol in different application may have a big difference, thus not a universal routing protocol meet different application; (4) The routing mechanism of sensor network is also often connected with data fusion technology, through reducing total communication of nodes to reduce energy consumption.

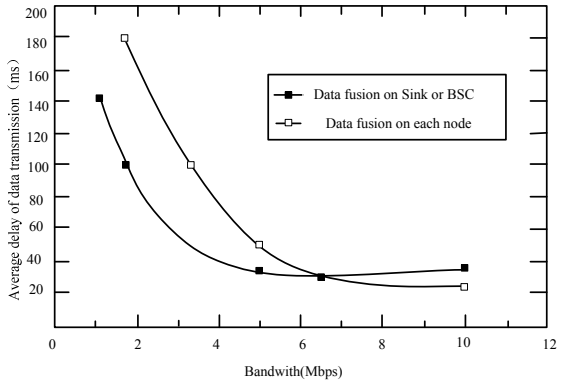

Fig. 11. Relationship between network width and the average delay of data transmission.

3.2. Topological Structure of Sensor Network Node and Node Energy Consumption

Topological structure of sensor network node determines the performances of routing protocol, the node distribution can be frozen-in distribution, also can be self-organization distribution.

The condition of node energy consumption influences the set up procedure of routing in sensor network, according to the application scenarios of sensor network, the transmission mode of rendezvous point or host node can be serial transmission, event driven transmission, queue driven transmission and mixed type.

3.3. Communication Energy Consumption Analysis of SOMDF Algorithm to Reduce Node

Adapting SOMDF algorithm can reduce the communication energy consumption of nodes effectively, data fusion technology is used on Sink node to compress and integrate the data transmitted in nodes.

Suppose α is the proportion of working time within one frame, P_{work} is energy exhausts of the work, P_{sleep} is the energy exhausts of dormancy, P_{idle} is the energy exhausts in idle condition, then the average energy exhaust $\overline{P}$ can be defined as:

$$\overline{P} = \alpha P_{work} + (1-\alpha)P_{sleep} + P_{idle}, \quad (15)$$

Considering:

$$\overline{P} = \alpha P_{work} + (1-\alpha)P_{sleep}, \quad (16)$$

The wireless communication energy consumption P_{frame} within one frame can be :

$$P_{frame} = (P_{tx} + P_{rx} + \frac{P_{dec} + P_{st} + P_{sr}}{l}) \times W_b \quad (17)$$

,

where P_{tx} is the energy consumption in sending, P_{rx} is the energy consumption in receiving, P_{dec} is the energy consumption of decoding one bit package in decode, P_{st}, P_{sr} is the energy consumption of sending start and receiving start, l is the effective data bit, W_{bit} is the bit of one frame data.

Therefore, the average energy consumption $\overline{P}$ of node is :

$$\overline{P} = \alpha \times (P_{tx} + P_{rx} + \frac{P_{dec} + P_{st} + P_{sr}}{l}) \times W_{bit} + (1-\alpha)P_{sleep} \quad (18)$$

So it can be seen that after adapting data fusion technology in Sink, because eliminating the redundancy control bit, therefore the effective data bits in data package is permanent, thus making the bit of one frame data reduce obviously, if maintain the other energy consumption of communication in node invariant, then the average energy consumption of node reduced obviously, after adapting data fusion technology the average energy consumption can be reduced 10 % in Sink.

4. Conclusion

Sensor network as a burgeoning, which will change the interactive mode between human and real physical world technology, synthesizing sensor technology, embedded computing technology, distributed information processing technology and communication technology, and plays an important role in military, industry, medical treatment, transportation and environmental protection, which has a extensive application prospect and huge commercial value, wireless sensor network has been the research emphasis and hotspot in IT field at home and abroad.

This paper takes improve network energy efficiency effectively, reduce node energy consumption, extend network lifetime as the core of research work, with the help of methods of economic theory, artificial intelligence technology and data fusion, set about from the perspective of improving routing algorithm in network layer, carried analysis and research to the energy consumption issue of

sensor node based on the both energy effectiveness and balance of sensor network.

This paper analyses resolve issues of energy consumption algorithm, protocol, strategy of wireless sensor network at present, emphasizes the routing technology of wireless sensor network, and explains some classical algorithms systematically, detailed contrasts and explains the inscape, applicable scenario, request and effect of nodes, designed a nerve network fusion algorithm SOMDF of self-organization mapping module based on artificial neural network, and detected its performances.

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