Energy efficient routing protocol of wireless sensor network

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Abstract

The characteristics of traditional wireless sensor network (WSN) determine the constraint of its various properties. Combining the advantages of energy balanced and cross-layer optimized routing protocols, the paper proposed multiple-hop routing protocol of energy balancing, in which cross-layer optimization as well as multi-hop factor as a measure of the residual energy of cluster head nodes to make a reasonable judgment on its forwarded data. The constraint of multi-hop factor made cluster head nodes unable to forward information to the base station, thus balancing the energy consumption of the whole network and further optimizing the lifetime of sensor network nodes. Simulation results showed that the routing protocol could balance the energy consumption of the entire sensor network, which greatly prolonged the life cycle of wireless sensor network.

Keywords: wireless sensor network, energy balanced, routing protocol

1 Introduction

Wireless sensor networks have been applied to a wide range of military and civil fields due to its low power consumption, low cost, multi functions and other advantages since they are constituted of a large number of sensor nodes deployed in the monitoring area or proximity. Because once sensor nodes are deployed, the node energy is generally not able to be secondarily supplemented, the network node energy will be prematurely drained, leading to split of the entire network or death of nodes. Thus node energy directly affects the entire life of the sensor network, which requires the sensor network routing protocol to be energy efficient. A new energy balancing cross-layer optimized routing was studied to achieve the balance of energy consumption of sensor nodes, to prevent early exhaustion and death caused by excessive sent or received data energy, while there are many other problems of residual energy with other nodes. All nodes energy in the sensor network has been fully utilized through energy equalization algorithm, extending the life of the entire sensor networks. Modern sensor networks, especially mobile Internet sensor network is a special sensor network based on the traditional wireless sensor networks, providing multi-information acquisition, high-quality video surveillance, high-precision positioning, and complex task handling. Compared to traditional wireless sensor networks, middle and high-speed sensor networks have added camera, microphone, and other parts to process or acquire large amount of data media information of video, images, audio and others with particular emphasis for required sensor modules, and require to achieve high-precision, fine-grained, real-time data acquisition and monitoring.

In the study course of energy efficient routing of wireless sensor network node, scholars home and abroad have put forward a lot of research results.

In the high-speed sensor networks, sensor networks can divide routing protocols into several parts according to the topological structure of network: clustering routing protocols and plane routing protocols [7]. Aa key issue in clustering protocol is how to choose N nodes quickly to serve as the next cluster head with constantly decreasing residual energy of network nodes, which can both reduce energy consumption of network nodes within the family and make cluster head node equally distributed in sensor network. So that the energy consumption of the entire sensor network can be balanced, so solve the NP problem [8].

CCRP routing protocol uses the data transmission balance mechanism from the cluster head to the base station and improved cluster head election algorithm [1]. CCRP routing protocol can solve the limit of LEACH routing protocol. CCRP routing protocol is divided into multiple rounds to run. In each round, the configuration and establishment of sub-clan parameters were made at the beginning, and then it entered a stable stage, in which data was transmitted to the base station. Its energy consumption model is basically consistent with the classic wireless network energy consumption model in literature [2]. Literature [3] discussed the feasibility of cooperation acceptance of WSN nodes, i.e., using a variety of processing algorithms to improve the signal reception ratio of sensor node, reducing the amount of data interference and transfer within the family, and enhancing the energy consumption of nodes to make energy-saving effect. It also increased the sensitivity of network nodes and expanded the size of the network. Literature [4] verified the analytical model of BCH clusters based on Markov chain model like having increased the complexity of data

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proceeded by node and the cluster family communication. This model combined Chapman Kolmogorov Equation and used Markov process to explain the monitoring issue in three-dimensional space of network cluster. Experiments were also made to prove the situations for this model to be applied to changes of the state of cluster, to extend the life of the sensor network.

Literature [5] proposed the use of effective data fusion with independent degree in the cluster. The method used the mobile principle of Sink node and also chose a cluster-based self-directed directional parameters for the adaption to the change of network environment. Each sensor node has its own degree of freedom. This reduced data communication, effectively reducing energy consumption. Literature [6] proposed a method of energy-saving sub-cluster routing protocol based on node timing, which added a node timing arrangement mechanism to the sub-cluster routing protocol, and each cluster to arrange cluster timing according to a fixed interval schedule: to keep half of the nodes active and the rest in sleep mode for the number of available nodes in each of the cluster family [9-11]. After a fixed time interval, the states of the nodes were exchanged. When the sensor nodes were in sleep state, the energy consumption of the nodes was very small; therefore, compared with LEACH protocol, this protocol greatly saved energy consumption of nodes and increased the network lifetime by 50%.

The above literature mainly pursued the reduction of energy consumption in searching for the best relay node or clustering method in the process of clustering, but ignored the fact that relay node could not guarantee the optimal route to be required in a short time when facing multiple requirements under the circumstances of massive nodes. Therefore, this paper proposed an algorithm based on the multi-hop factor in routing as the main factor to assess relay node, thus reducing energy consumption. Moreover, this paper also adopted the thinking of cross-layer optimization, which further decreased energy consumption from the routing protocol itself.

2 Energy efficient routing protocol

Since the establishment of the cluster is based on election, each round of cluster will re-elect a cluster head, and members of the same cluster will also change with the re-selected cluster head. Also, optimization of cross-layer design to sub-cluster protocol was studied based on the wireless sensor network after the optimal domain clustering of residual root node energy. The optimization of data sharing methods on top of each layer in the sub-cluster mountain improved the self-adaption of wireless sensor networks [12-15]. It can be concluded that both the SP (Sensor Protocol) (Figure 1) and TinyCubus (Figure 2) protocols in the sub-cluster routing enhance the inter-level operability of watts to achieve enhanced sensor network adaptability. SP protocol adds the abstraction layer of sensor network protocols (Sensor-Net Protocol) to achieve the level of IHI's data sharing. TinyCubus protocol achieves data sharing H by introducing Tiny Cross-layer Framework (TCF) components. Both cross-layer design methods involve the application of a variety of wireless sensor networks, while SP protocol adapts to the ffl issue of wireless sensor networks through Sensor-Net Protocol layer, and TinyCubus adapts to the different application problems in the wireless sensor network by Tiny Configuration Engine (TCE).

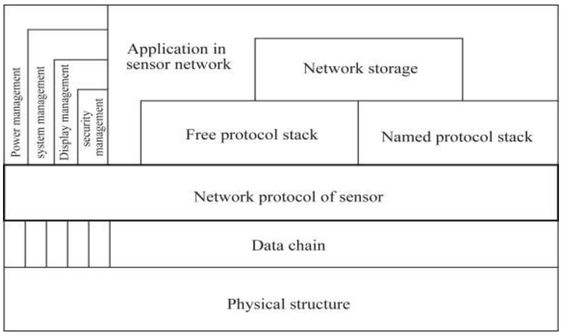

FIGURE 1 SP (Sensor Protocol) cross-layer protocol

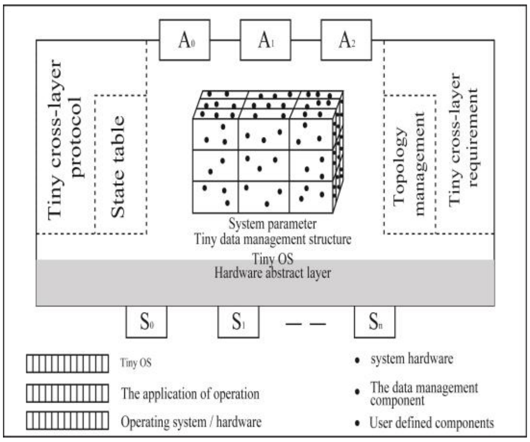

FIGURE 2 TinyCubus cross-layer protocol

Among them, SP protocol is designed based on an independent platform; TinyCubus protocol is designed based on TinyOS platform. Both protocol designs have encountered the problem of how to solve the network interface, but so far there is no concrete solution because it requires in-depth research on different platforms and network requirements. Both cross-layer design architectures are relatively complex, with the purpose to improve the five maneuverability of sensor network, enhance the adaption of sensor networks, but no energy efficiency is designed for sensor network. Due to the physical characteristics of wireless sensor network nodes and the limitations of TinyCubus protocol to the platform, SP protocol is adopted here to achieve cross-layer operations of wireless sensor networks.

2.1 ELECTION OF CLUSTER HEAD

Wireless sensor network nodes are clustered according to the principles of literature [3]. Distributed competing methods are adopted here to form a family. The selection of cluster head is done in accordance with the reference of the number of neighbor nodes and the remaining energy of nodes. Based on the rule of optimal number of cluster heads and asynchronous updating rules, it can be concluded whether the node can become the current-round cluster head when Tc is:

$$T_c = \left[\alpha * \frac{N}{N_{\max}} + \beta * \left(1 - \frac{E_{res}}{E_{avg}} \right) + \gamma * T_{random} \right] T(n). \quad (1)$$

It can be drawn from the above equation, nodes with more neighbor nodes and below-average residual energy need longer time to participate in the completion of cluster head; thus the probability of it becoming instrument head is relatively low in the competition. After all other nodes get their T_c, the sensor network will conduct time synchronization for each node to countdown. When the node countdowns to 0, the following Equation (2) becomes the radius of the cluster head competitions:

$$R_{comp} = \left[(1-\omega_1) * \frac{dist(i,BS)}{dist_{\max}} - \omega_2 \left(1 - \frac{E_{res}}{E_{avg}} \right) - \omega_3 * \frac{N}{N_{\max}} \right] R_c \quad (2)$$

Next, this round is elected as broadcast messages of cluster head node for the remaining nodes. Other nodes in the network randomly determine the cluster they belong to according to the intensity of received information and notify the corresponding cluster head, thereby establishing a cluster. In the steady-state phase, data information collected by member nodes of the cluster will be sent to the cluster head, which will integrate the data sent by member nodes of the cluster, meaning to compress data into a single composite signal through the integration mechanism, and then send the composite signal to the receiver; after a certain period of stability, the next round will begin and each node will decide whether to send information for the cluster head node of this round.

2.2 ANALYSIS OF ENERGY CONSUMPTION

In the node of wireless sensor, there are three modules for major consumption of energy: (1) the processor module; (2) the sensor module; (3) the wireless data communication module. With the development of technology, integrated circuit technology has made great progress; the energy consumption of the processor module and the sensor module becomes very low and most energy consumption is focused on the wireless sensor data communication module.

It can be divided into two kinds of channel models: Multi-Path Fading model and FreeSpace model. When the cluster member node sends a data packet with the length of k, the transmission distance of d, the energy consumption is:

$$E_{Txd}(k,d) = \begin{cases} kE_{elec} + k\varepsilon_{amp} d^2 & d < d_0 \\ kE_{elec} + k\varepsilon_{afs} d^4 & d \geq d_0 \end{cases}, \quad (3)$$

$$E_{Rxd}(k) = kE_{elec}. \quad (4)$$

Node energy consumption is closely related to the length of data sent and the distance of sending. 15 "^ node energy consumption and data transmission distance increase exponentially, thereby reducing data transmission distance to reduce the energy consumption of nodes by a large amount. Clustering method is used to narrow the distance of data transmission. In the cluster, information collected by cluster member nodes is directly forwarded to the cluster head, and the cluster head conducts data fusion and passes send it to male station via multi-hop distribution of cluster nodes. For this, the energy consumption of data integrating interface type should also be considered for the data fusion. EDA is used to show the energy consumption in data fusion for single information. If the number of members of the cluster is *N*, the k units of data sent by *N* members to the cluster and the k units of data will be infused into a valid signal with the consumed energy of:

$$E_{Ax} = k * (N+1) * E_{DA}. \quad (5)$$

2.3 MULTI-HOP ROUTING FACTOR

After data fusion, cluster head needs to send data to a base station, while the distance from the base station to the cluster head varies, which requires it to be forwarded by other cluster heads. When the cluster head is forwarding data to the base station, the base state that it is directly sent to is called 1 hop; when m cluster heads are required to be forwarded to base station, it is called m hop, namely multi-hop. Assuming the node number of a cluster is 16 including the head, then the address length of cluster member will be 4; assuming that clusters are evenly distributed in the network, then the number of cluster heads m hop from the base station is:

$$CH_m = \frac{N_m}{16}. \quad (6)$$

Thus, the multi-hop factor μ is introduced according to the relation of consumed energy to the base state and information after data fusion of cluster head multi-hop forward; multi-hop factor μ can choose cluster head as the multi-hop forward route to the base station. Thus the multi-hop factor μ can be defined as:

$$\mu = \alpha A_e / \frac{CH_m}{N} \left(1 - \frac{1}{T_c \sqrt{2\pi}} \right) e^{-pR_{comp}} \cdot E_{Txd}(k,d). \quad (7)$$

The route of cluster head energy above the node section is selected according to μ, and cluster head is continued to be selected as the number of forward hop for corresponding node sections. If the residual energy of cluster head is below the section of μ, the cluster head will be marked, meaning that the energy of this chain route is relatively low. Then it won't be used at multi-hop data forward. Instead, routing will be re-established by other cluster heads above the energy section. In this case, the path with less energy cannot be used in the multi-hop selection process, thus ensuring that low energy cluster head will not die quickly and extending the survival period of wireless sensor networks. The energy consumption by multi-hop forward of cluster head to base station after cluster head integrating data collected by members of the cluster is in the same way with the energy consumption of cluster member nodes' forwarding to cluster head, which will not be discussed herein.

3 Simulation analyses

In order to evaluate the performance of multi-hop wireless sensor network routing protocol for energy-balanced cross-layer optimization, this protocol is compared with the classical LEACH network protocol in sensor networks. Simulation environment is set as follows: in an area of 400×400m, there are 600 wireless sensor nodes placed randomly, the base station position fixed, the energy of base station considered to be infinite. The simulation parameters are shown in Table 1.

TABLE 1 Simulation parameters

Parameter name	Parameter value
Total number of nodes (N)	600
Location coordinates of sensor	1.0j
Length k of data package	(0,0)-(400,400)
Consumed Energy ETxd of electron emission	5000bit
Coefficient of close transmit amplifier	50nJ/bit
Coefficient of distant transmit amplifier	0.0013pJ/bit/m2
Optimized percentage number of cluster	100pJ/bit/m2
Multi-hop factor μ	10%
Limitation for sensor distance d0	[0.5, 1.0]
Radius of block adjustment	To be fixed after random distribution

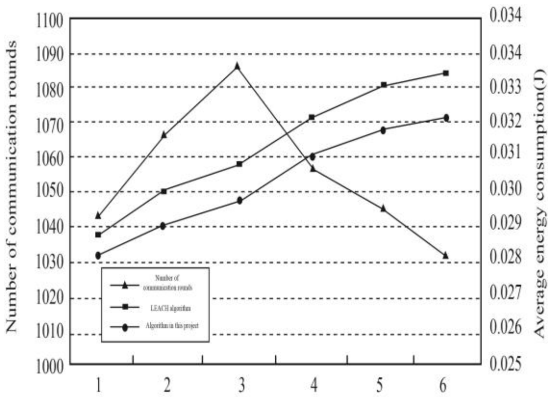

FIGURE 3 Routing list

1) Size of the routing list.

In the multi-hop routing protocol of energy-balanced cross-layer optimization for wireless sensor networks, the size of the routing list is designed on the basis of the density of randomly distributed network nodes and the broadcast radius of cluster head nodes. Once the cluster radius within the cluster is determined, the total number N of the network nodes within the radius of the broadcast will be determined accordingly, and the total number of sensor nodes in the routing list of network nodes will not exceed N. Figure 3 shows the size of routing list.

2) Analysis on energy consumption of node

According to the conclusion with the setting of routing list and delayed time, it is assumed that the cycle of each network round is 30s, and the point of cluster member collects data information every 3s and sent to cluster head, then each cluster member will send data to cluster head 10 times per cycle. Cluster head receives data, conducts data fusion and multi-hop data sending 10 times. The protocol proposed in this paper is compared with LEACH protocol in transmitting 1 unit of 500 bit data through optimized route, which can reach the sum of consumed energy by fixed points set on the entire chain route. As LEACH, the protocol put forward hereby also adopts sub-cluster, only with the difference that this protocol adopts energy-balanced multi-hop cluster head pattern for data forward when setting cross-layer self-adaption of sensor network and the self-adaption adjusts the data-transmitting route of cluster head. This makes some cluster head nodes with threshold value below the section of μ ignored to be selected as the multi-hop forward route of cluster head, thus considerably extending the lifetime of sensor network. In LEACH protocol, however, all the nodes can be set as data forward nodes without considering the residual energy of nodes, which leads to imbalanced use of sensor node energy; some nodes prematurely demise due to excessive data forward, resulting in the split of the entire sensor network or even death. Figure 4 shows that energy consumption on different routes of cluster head nodes.

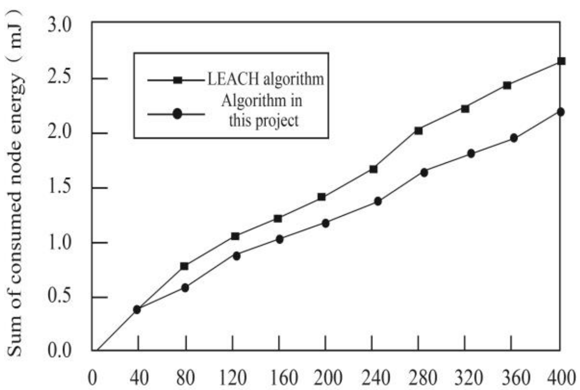

FIGURE 4 Energy consumption on different routes of cluster head nodes

3) Figure 5 describes the life of two sensor networks. It can be seen that with increase of election rounds for cluster heads, the survival nodes in sensor network of this protocol is more and the cycle of sensor network is longer than LEACH protocol. That is because the nodes in this project not only elect cluster heads according to sub-cluster, but also consider the residual energy of the next hop cluster head in the meantime of data forward by cluster head. If the energy of cluster head node is small enough, cluster head nodes nearby with larger residual energy will be selected, thus preventing rapid demise of node energy for cluster heads and the paralysis of sensor network.

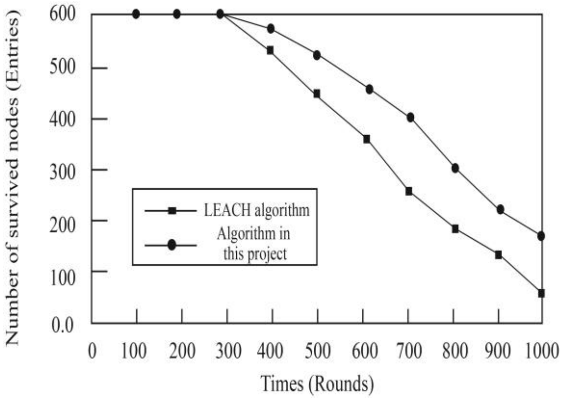

FIGURE 5 Difference in network

4 Conclusion

Multi-hop routing protocol with energy-balanced cross-layer optimization is a protocol integrating energy-balanced and cross-layer advantages. The protocol considers the total energy consumption for self-adaption of sensor network nodes. It ensures the balance of energy consumption for cluster head in the premises of guaranteed optimization of connectivity and transferred energy consumption for cluster head with reference to the data forward by multi-hop factor for cluster head, thus obtaining a data transmission route with excellent energy consumption. Data forward by cluster head nodes with extremely low energy can be avoided to enhance the self-adaption of wireless sensor network and balanced use of sensor node energy.

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