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Research Article

Adaptive Reliable Routing Based on Cluster Hierarchy for Wireless Multimedia Sensor Networks

Kai Lin,[1] Min Chen,[2] and Xiaohu Ge[3]

[1] *School of Computer Science and Technology, Dalian University of Technology, Dalian, Liaoning 116024, China*
[2] *School of Computer Science and Engineering, Seoul National University, Seoul 151-742, Republic of Korea*
[3] *Department of Electronics and Information Engineering, Huazhong University of Science and Technology, Wuhan, Hubei 430074, China*

Correspondence should be addressed to Kai Lin, link@dlut.edu.cn

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As a multimedia information acquisition and processing method, wireless multimedia sensor network(WMSN) has great application potential in military and civilian areas. Compared with traditional wireless sensor network, the routing design of WMSN should obtain more attention on the quality of transmission. This paper proposes an adaptive reliable routing based on clustering hierarchy named ARCH, which includes energy prediction and power allocation mechanism. To obtain a better performance, the cluster structure is formed based on cellular topology. The introduced prediction mechanism makes the sensor nodes predict the remaining energy of other nodes, which dramatically reduces the overall information needed for energy balancing. ARCH can dynamically balance the energy consumption of nodes based on the predicted results provided by power allocation. The simulation results prove the efficiency of the proposed ARCH routing.

1. Introduction

With he development of inexpensive multimedia hardware, wireless multimedia sensor networks (WMSN) have recently emerged as an important technology, which is a novel derivative network on the basis of wireless sensor network (WSN). In general, the sensor nodes of WMSN are equipped with CMOS camera, microphone, and other kinds of sensors for achieve the fine-grained, accurate information in a comprehensive environmental monitoring. Compared with traditional wireless sensor network, WMSN can capture the surrounding environment in a variety of media information and has outstanding performance in multimedia signal acquisition and processing. It cannot only enhance existing sensor network applications, but also enable several new applications, such as multimedia surveillance sensor networks, advanced health care delivery, industrial process control, and so on [1–4].

As an energy sensitive noninfrastructure network and the nodes of WMSN are generally distributed in unattended environments to complete the assigned task. Although WMSN is developed from WSN, its energy limitation is even more severe than that of WSN due to the high quantities of data that are included in multimedia content. Different from WSN, the energy consumption in WMSN is not mainly consumed in communication. Sometimes, sensing and processing multimedia data in WMSN may consume more energy than transmitting the same data. Hence, it is not adoptable in WMSN to simply ignore these two kinds of energy consumption like WSN does. Moreover, the multimedia sensor nodes are deployed in sparseness for their strong directives and far-field of view, which results in the big difference of network coverage model between the WMSN and WSN. This difference will also affect the network topology structure and the increased distance results in the energy consumption increased dramatically.

Owing to the above reasons, the design of WMSN routing mechanism with high energy efficiency is still very important and face more challenges than WSN. The design of WMSN routing concerns energy constrains, limited computing power, and memory availability of the sensor nodes. By far, the resource consumption is not the only design target, a certain level of Quality of Service (QoS) is also needed to guarantee delivering multimedia content, such as communication reliability, real-time, and so on. Obviously, it is a trade-off problem that the transmission of multimedia data should meet the requirements of energy efficiency and QoS assurance, which seriously increases the difficulty of routing design. According to the status of sensor nodes in the process of network operation, routing can be divided into flat routing and clustering routing. Clustering routing first appears in cable network, and it is also adaptable for WSN on account of the good flexibility and high communication efficiency. Similar to WSN, the WMSN routing is always built on a hierarchical architecture, comprising several clusters in almost same size where each cluster has several sensor nodes and a cluster head. The obvious advantages of hierarchical architecture in WMSN are as follows. First, for a real WMSN contains hundreds or thousands of multimedia sensor nodes, hierarchical architecture is efficient to divide and rule for the application of distributed computation and QoS management. Second, the sensory data are in high relativity because the sensor nodes are unavoidable to be distributed in redundancy. The unnecessary data transmission can be reduced by data fusion process of cluster head node. Third, most of sensor nodes can turn off radio model to reduce energy consumption and communication conflicts in a quite long period which can significant prolong the lifetime and improve the QoS of the whole network. For these reasons, the clustering routing is much suitable for WMSN than flat routing, specially in large scale network.

The crucial guaranteed requirement of Qos is whether the sending data from source data can be effectively received by destination nodes. Since there are distortion, multipath interference, and multitone jamming in wireless channel, the package loss is unavoidable during transmission process. To improve the network performance and meets the application requirement, we make the reliable transmitting of end-to-end as QoS requirement in our research. Although it is an easy method to satisfy the reliability requirement by selecting a much reliable route for data gathering, the energy of some nodes will be used up quickly if only the quality of communication is considered. Hence, the other important problem we must concern is how to balance the energy consumption of network. Aiming at the requirements of energy equilibrium and reliability, we propose an adaptive reliable routing based on cluster hierarchy(ARCH) for WMSN. The ARCH routing can balance the energy consumption with meeting the need of reliability between the source and destination node. Moreover, we design a power allocation mechanism to adjust the transmitting power of nodes and an energy prediction mechanism to realize energy aware among nodes. The main contributions of this paper are summarized as follows.

(1) We design a self-adaptive power allocation mechanism, which can make sensor nodes meet the reliability requirement by adjust their transmitting power dynamically. It is very suitable for sensor node to meet the low cost requirement of WMSN, too.

(2) We proposed prediction method of energy consumption for WMSN, which can makes the sensor nodes predict the remaining energy of other nodes. The introduced prediction mechanism dramatically reduces the overall information needed for balancing energy consumption.

(3) We propose an adaptive reliable routing based on cluster hierarchy(ARCH) for WMSN. By using power allocation and energy prediction mechanism, the ARCH routing can balance the energy consumption with meeting the need of reliability between the source and destination.

(4) We perform extensive simulation experiments to evaluate ARCH by several performance indexes. The results show that ARCH performs high efficiency in wireless multimedia sensor network.

The rest of this paper is organized as follows. In Section 2, some related works on the WMSN routing protocol are presented. In Section 3, the system models and problem statement are described. In Section 4, an adaptive power allocation mechanism is explained. We proposed an energy prediction mechanism for WMSN in Section 5. In Section 6, the ARCH routing is presented. The simulation results are given in Section 7. Finally, Section 8 concludes our paper.

2. Related Works

In wireless multimedia sensor network, the routing design need to guarantee delivering multimedia content with a certain level of Quality of Service (QoS), such as communication reliability, real-time, and so on. Although providing QoS guarantees in WMSN during data gathering is a very challenging problem, some approaches have been proposed in the literature for QoS support. Especially, many researchers have proposed some routing protocols with the ability of energy apperceiving and QoS. These protocols can meet the requirements of real-time and reliability in WMSN. According to the different QoS, they are mainly divided into two parts.

2.1. Reliability Routing Protocol. The typical protocols are AFS [5] and ReInforM [6]. In AFS, the rank of QoS is introduced and the transmission reliability is guaranteed by self-adaptive retransmitting mechanism. In ReInforM, the transmission reliability and routing load are guaranteed by multirouting and random retransmitting mechanism. ReInforM considers the importance of the data in the packet and can adapt to channel errors. ReInforM can send multiple copies of a packet along multiple paths from the source to the sink so that the data can be delivered with the desired reliability. ReInforM uses the concept of dynamic packet state in the context of sensor networks to control the number of paths required for the desired reliability based on local knowledge of the channel error rate and topology. However, this protocol only addresses QoS in terms of reliability, disregarding energy issues. In addition, this protocol does not consider route delays when selecting multiple paths. In 2006, Felemban et al. propose MMSPEED routing protocol [7]. MMSPEED considers the needs of real-time and reliability, adopting the design conception of MAC layer and network span. By localization algorithm and multirouting mechanism, MMSPEED has good properties of QoS and expendability. MMSPEED can well support flow media and meet the needs of graphic and video to real-time and reliability in WMSN. The drawback of MMSPEED is complex algorithm, large energy consumption, which limits its wide application in WMSN. The QoS routing approach presented by utilizing the geographic location of sensor nodes as well. This protocol assigns an urgency factor to every packet depending on the remaining distance and the time left to deliver the packet. It determines the distance required for the packet to be sent closer to the destination in order to meet its deadline. Each node assigns a priority to all of its neighbors, according to their residual energy and delay, as well as the priority of the packets, and packets are forwarded to the highest priority nodes. Packets are sorted in two different queues, one for nonrealtime traffic, and the other one for real-time traffic. Real-time traffic is prioritized based on its urgency factor, scheduling those packets with more aggressive deadlines first for transmission. Reliability is achieved by using duplication of information at the source node. However, the protocol does not consider data aggregation and the network lacks a good decongestion scheme.

2.2. Real Time Routing Protocol. The typical ones are SAR [8], RAP [9], and SPEED [10]. Here, SAR is a kind of routing protocol with energy aware of QoS. Sensor nodes can send the information met the needs of tree to the sink node based on the path source, additional QoS measure, and package priority rank. RAP uses a velocity monotonic scheduler to prioritize packets and schedules them on the basis of their required transmission speed. This protocol does not consider energy issues and the number of hops executed by the packets. SPEED is the first real-time routing protocol for WMSN. It introduces a soft realtime end-to-end to support all nonrealtime MAC protocols, providing the management of controlling network traffic and multirouting overload. A Weighted Fair Queuing (WFQ) approach is used in every node to provide the required share of bandwidth for both traffic classes. Path generation is performed in a centralized manner, at the base station using an extended version of Dijkstra's Algorithm. The advantage of this algorithm lies in the fact that it provides a guarantee for best-effort transmission, while simultaneously trying to maximize real-time traffic throughput. The main drawback is that the algorithm requires complete knowledge of the network topology at the base station to calculate multiple routes, thereby limiting the scalability of this approach. An energy aware QoS routing protocol for real-time traffic generated by a wireless sensor network consisting of image sensors is proposed by Akkaya and Younis in [11]. This approach finds multiple network routes by using a minimum path cost. Such kind of cost is a function of distance between nodes, node residual energy, energy transmission, and error rates which meet the requested end-to-end delay constraints. All traffic is divided into best effort and real-time classes.

3. System Models and Problem Statement

3.1. System Models

3.1.1. Network Model. In this paper, we adopts a WMSN formed by n random deployed multimedia sensor nodes, m gateway nodes, and one sink node. All the sensor nodes are used for data collection in the monitoring area and do not move after the deployment. The network architecture is depicted in Figure 1. The sensor nodes are grouped into clusters based on many criteria such as communication range, number and type of sensors and geographical location. Each cluster has a gateway node that manages the sensor nodes in the cluster, which are significantly less energy-constrained than sensor nodes. The gateway node will take charge of sensor organization and network management based on the QoS requirement and available energy in each sensor node. All the sensor nodes are isomorphic with the same initial energy and the same capacity of sensing, computation and communication. The sink node is not limited by energy and capacity. Each multimedia sensor node can adjust the transmission power to save energy consumption and the links are symmetrical. If the receiver knows the transmission power, then the receiver can calculate the distance to the transmitter by the intensity of the received signal.

3.1.2. Transmission Error Model. In our research, we assume that path loss is close to log-normal shadow model [12], which is

$$G(d)[\mathrm{dB}] = G(d_0) + \eta \log_{10}\left(\frac{d}{d_0}\right) + X_\sigma, \tag{1}$$

where G_d is path loss, d represents the distance between transmitter and receiver, d_0 is the reference range, η is the coefficient of path loss. X_σ is distributed in $(0, \sigma^2)$ following Gaussian random process. The relationship between Packet reception rate and SNR(signal to noise ratio) is as follows

$$\mathrm{prr} = \left(1 - Q\left(\sqrt{2\gamma \frac{B_N}{R}}\right)\right)^{8\rho F}, \tag{2}$$

where $Q(x) = \int_x^\infty (1/\sqrt{2\pi}) \exp(-x^2/2)dx$, γ represents SNR, R is the noise bandwidth, ρ is data rate, F is code rate, and F is data frame length.

3.2. Problem Statement. Now we begin to formulate the problem. As shown in Figure 1, the network consists of a series of multimedia sensor nodes, one sink node, and some gateway nodes. These gateway nodes act as cluster head nodes, which need to manage and collect the data sent from the nodes in their clusters. Multimedia sensor nodes complete monitoring task and send their data to gateway nodes. In each cluster, the sensor nodes are the source nodes and the gateway node is the destination node. Due to communication capacity limitation, most of the senor nodes need to send their data by multihop method to the gateway node. There is at least one routing existed to collect data between each sensor node and gateway node in one cluster.

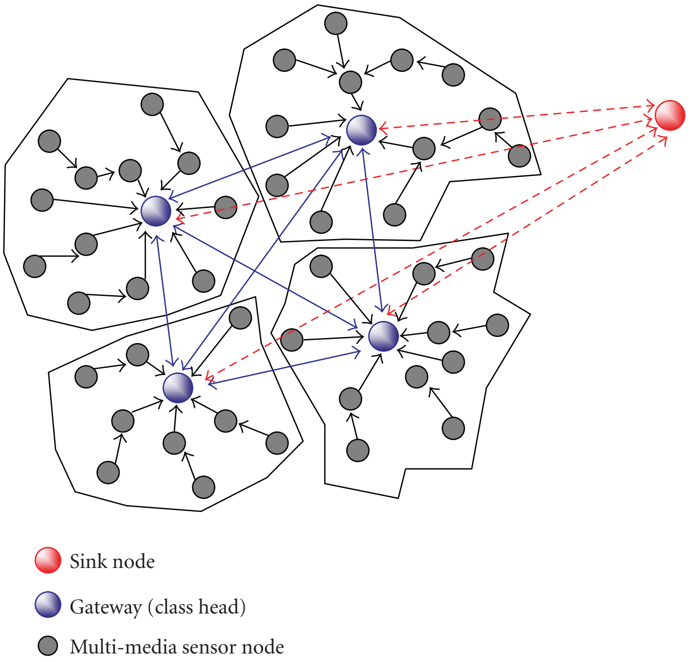

Figure 1: Network architecture.

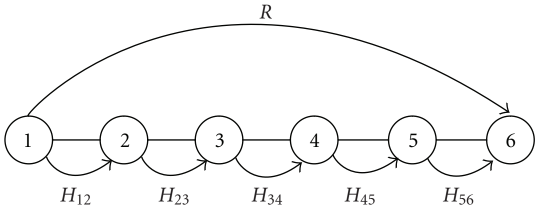

Figure 2: Reliable requirement for multihop path.

Although the transmission of multimedia data does not require 100% reliability, it is still necessary to guarantee the reliability of end-to-end. As the energy of sensor node and bandwidth are both limited, it is difficult to transmit large data of streaming media and needs more investigation to design a novel routing to realize the reliable transmission in network. We assume that there is one multihop path as shown in Figure 2. The reliability between random neighbor node i and j is H_{ij}, the reliability of the requirement from node 1 to 6 is R. Obviously, the data transmission should meet the needs as follows:

$$\left.\begin{aligned} H_{ij} &\ge r_{ij}, \\ \prod H_{ij} &\ge R, \end{aligned}\right. \quad 1 \le i \le 5,\ i+1 = j. \tag{3}$$

As the above description, it has to consider the energy equilibrium of nodes besides of the reliability for the sake of avoiding the energy hole resulted from some nodes running out of their energy too fast. Based on the above two points, our optimization object is to design a routing protocol that can guarantee the reliability of data transmission and balance the energy consumption while delivering data from all source nodes in S to the sink node. This problem can be formulated as follows

$$\begin{aligned} \min \quad & \sum_{u \in S} \left(Eu - \overline{E} \right)^2 \\ \text{s.t.} \quad & \text{for } \forall u \in S,\ p_{\text{ru}} = Q, \end{aligned} \tag{4}$$

where E_u represents the remaining energy of node u and $\overline{E}$ represents the average remaining energy of all nodes. p_{ru} represents the probability of data from node u that can be correctly received. Q represents the reliable requirement of data transmission. The constraint specifies that it should guarantee the ensuring end-to-end reliability from each source node to sink node.

4. Self-Adaptive Power Allocation Mechanism

Most transceiver chip supports programmable transmit power. The transmit power level can be adjusted by configure the corresponding status register. Take Cyclops based on mica2 platform for an example, the power range of communication module CC2420 is in $[-25\,\text{dBm}, 0\,\text{dBm}]$, including eight levels. The energy consumption of transmitting data is

$$E^{\text{tx}}\left(P^{\text{tx}}\right) = \frac{8f}{R}\left(P^{\text{cir}} + \frac{P^{\text{tx}}}{\eta P^{\text{tx}}}\right), \tag{5}$$

where P^{cir} is the circle power and η is the conversion efficiency of power amplifier. The energy consumption of receiving data is

$$E^{\text{rx}} = \frac{8f}{R} P^{\text{rx}}, \tag{6}$$

where, P^{rx} represents the receive power.

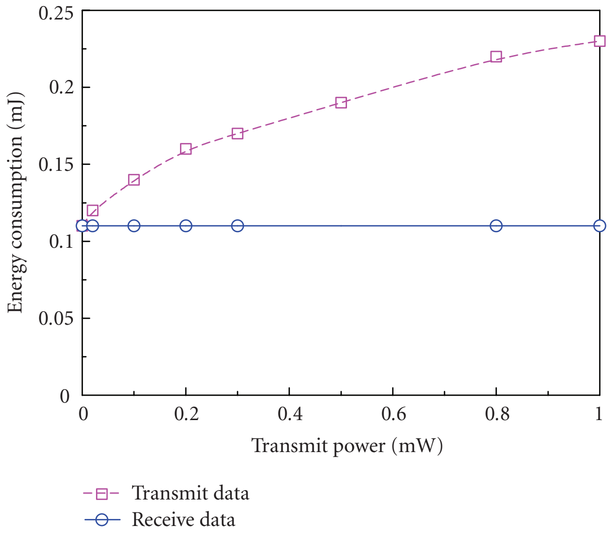

Figure 3: Energy consumption with different transmit power.

To have an intuitive expression on energy consumption of data transmission, let $f = 128$ bytes, $P^{\text{cir}} = 26.5$ mW, $\eta(P^{\text{tx}}) = 0.06e^{0.095P^{\text{tx}}(\text{dBm})}$, $P^{\text{rx}} = 28$ mW, $R = 256$ kbps. The relationship between transmit power and energy consumption is shown in Figure 3.

As mentioned above, there must be at least one route between each source node and the sink node to complete the data gathering. We use $R(u,p,h)$ for representing the route p from node u to the sink node with h hops. For the purpose of energy conservation and reducing communication conflict, we also assume that the same data packet using only one route to send. Considering the average rate of data reception by single hop transmission, we use G_i and L_i for representing the power gain and transmit power level on the hop i of route p, respectively. The reliable transmission rate is $p_i(G_i, L_i)$, which is related to G_i and L_i. G_i is a Gaussian distributed random variable. When G_i is independent and identically distributed, it is necessary for the reliable transmission rate to meet the transfer request from node u to the sink node by the route p is

$$P(u,p,h) = \prod_{i=1}^{h} p_i(G_i, L_i) \geq R, \tag{7}$$

where R is the lowest reliable requirement.

SNR increases with the increasing of transmission power, which results in the improvement of transmission reliability. In (7), $P(u,p,h)$ is determined by each $p_i(G_i, L_i)$ of route p. When we use a higher L_i, a higher $p_i(G_i, L_i)$ will be obtained. The increments of reliable transmission rate by increasing one level transmit power is defined in:

$$\Delta Ri = \frac{P_{\text{rr}}(G_i, (L_i + 1))}{P(G_i, L_i)}, \quad L_i \in [1, 2, 3, \dots, L]. \tag{8}$$

It can be known from Figure 3 that the increasing of transmit power level will result in more energy consumption. In order to save more energy of the network, we use the critical condition of (7) and introduce the power control algorithm presented by Kwon H [13]. The reliability is guaranteed by gradually increasing the transmit power level. If all the nodes adopt the maximum transmit power level and still cannot meet the reliable transmission requirement, it has to rebuild another route.

According to (5), our optimization target is to guarantee the reliability of end-to-end and balance the energy consumption of nodes in the network. To achieve the optimization target, we can allocate higher transmit power level to the multimedia sensor nodes with more remaining energy. Obviously, we must solve the problem that how to realize energy aware between nodes in priority.

5. Energy Prediction Mechanism

In order to achieve the energy equilibrium, we first need to know the remaining energy of each multimedia sensor node. However, the energy aware among nodes is difficult to be achieved in WMSN, which is due to the high communication cost for constituent updating their remaining energy information. At the same time, some problems are also brought, such as network congestion and transmission delay. To solve this problem, we propose an energy prediction mechanism for WMSN, which can make sensor node know the remaining energy of other nodes without constituent updating.

During the operation process of WMSN, the energy consumption of multimedia sensor nodes is not stable but depends on the their working states. Energy consumption of sensor node depends on the different working states. Nodes can turn to sleep when they have no any task. The working state conversion is necessary to save energy for WSMN, but it also increase the difficulty for predicting energy consumption. In traditional sensor node, the energy is mainly consumed on receiving and transmitting process, where the energy consumption on data sensing and processing can be neglected. However, the total energy consumptions of multimedia sensor nodes in WMSN increase greatly as the nodes need to collect the data from audio, video, and graphic. It consumes much more energy of sensing and processing than those of communication.

According to the operation of multimedia sensor nodes under the clustering hierarchy in WMSN, we design a state conversion model for intracluster nodes as shown in Figure 4. There are seven working states in this model.

1. In sleep state, the sensor and communication module are close, the sensor nodes have no any task.
2. In sense state, the sensor module is close and the communication module is open, the sensor nodes collect the multimedia.
3. In idle state, the sensor module is close and the communication module is open, the sensor nodes monitor communication channel.
4. In receive state, the sensor module is close and the communication module is open, the sensor nodes receive data from other nodes.

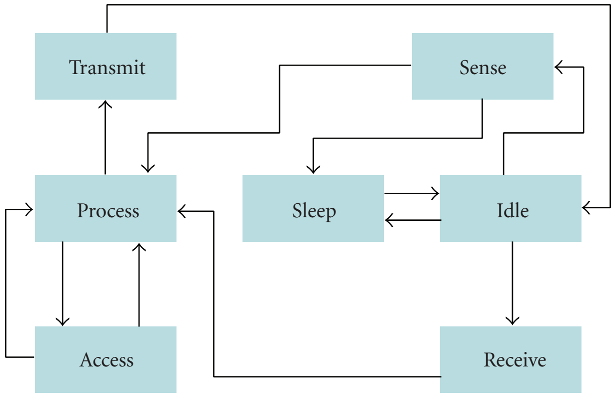

Figure 4: Model of working state conversion.

(5) In transmit state, the sensor module is close and the communication module is open, the sensor nodes transmit data to other nodes.

(6) In process state, the sensor and communication module are close, the sensor nodes process multimedia data.

(7) In access state, the sensor and communication are close, the sensor nodes complete reading and writing memory.

All the working state conversion occurs only at the end of one time-step. It is worthy mentioning that in transmit state, the energy consumption of node is different for transmitting data by various power level.

Based on this state conversion model, we can realize the energy aware among nodes. Similar to [14], we use Markov chain to simulate the working states of multimedia sensor nodes. Each node has a series of random variants $X_0, X_1, X_2, \ldots$, which describes different working states. P_{ij} is further defined as one-step diversion probability, which can be expressed by

$$P_{ij} = P\{X_{m+1} = j \mid X_m = i\}. \quad (9)$$

The N-step diversion probability is defined in:

$$Pij(n) = \sum_{k=1}^{M} P_{ik}(r)P_{kj}(n-r), \quad \text{for } 0 < r < n. \quad (10)$$

If the node is currently in state i, the number of time-slot that it will stay in state s in the next T time-step can be expressed as $\sum_{t=1}^{T} P_{is}(t)$. We use E_s for representing the energy consumption of node staying at state s in one time-step. Then, the total energy consumption in the next T time-step can be calculated by

$$E_T = \sum_{s=1}^{M} \left(\sum_{t=1}^{T} P_{is}(t) \right) \times E_s. \quad (11)$$

On the basis of working states statistic, the nodes can calculate the energy consumption of itself or other nodes in the next T time-step by (11) [14]. The accuracy of energy prediction is influenced by the validity of the probability diversion matrix.

6. ARCH Routing

In this section, we propose an adaptive reliable routing based on cluster hierarchy(ARCH) for WMSN. The above mentioned self-adaptive power allocation and energy prediction mechanism are both used in ARCH. To obtain a better performance, the cluster structure is formed based on cellular topology. The design objective of ARCH is to guarantee energy balance and meet the needs of reliability between the source and destination.

6.1. Establishment of Routing. With the existence of gateway node, we can easily establish the cluster structure for purpose. Here, the cluster structure is generated by cellular topology. In this structure, the monitoring area is divided into cellular virtual unit cells with same size. At the center of each unit cell, a gateway node plays as cluster head node and the rest ordinary nodes as member nodes belong to the unit cell.

In the initialization phase, each gateway node sends one ADV message including the ID of this node and the multimedia sensor nodes receive these ADV messages. In general, each sensor node can receive more than one ADV message. At this time, the sensor node needs to compare the signal strength of the received messages and select the gateway node with strong signal to join in its cluster. If the gateway node is located at the right position, we can establish an ideal cluster structure based on cellular topology by this way.

Considering low cost in network, the amount of gateway node should be as few as possible. We adopt a intracluster multihop communication method. To guarantee all the sensory data can be successively transmitted to the sink node, at least one route is necessary to be established for each source node to reach its cluster head node. According to the communication ability of sensor nodes, each cluster is divided into many concentric coronas with the center of gateway, denoted as $C_1, C_2, \ldots, C_N$. For avoiding the loss of efficiency data, we set the width of coronas equaling to the communication distance by using lowest transmit power level. From corona C_1, the nodes in corona C_{i-1} send ADV messages with the node ID to corona C_i. By these ADV message, each node in corona $C_i(2iN)$ can find a relay node from the corona C_{i-1}. All the nodes in the corona C_1 can communicate with the gateway node directly. Figure 5 shows the intracluster multihop routing.

When each node finds its relay node, the establishment of routing in cluster is finished. Gateway node is responsible for gathering and processing all the sensory data, then send these data to the sink node. If the network scale is small, each gateway node can communicate with the sink node directly. If the network scale is large, even though gateway nodes have stronger ability than those of ordinary sensor nodes, they

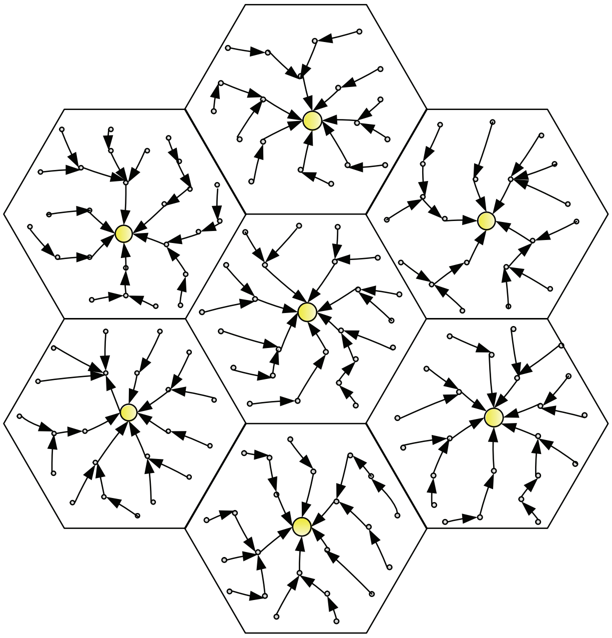

Figure 5: Intra-cluster multihop routing.

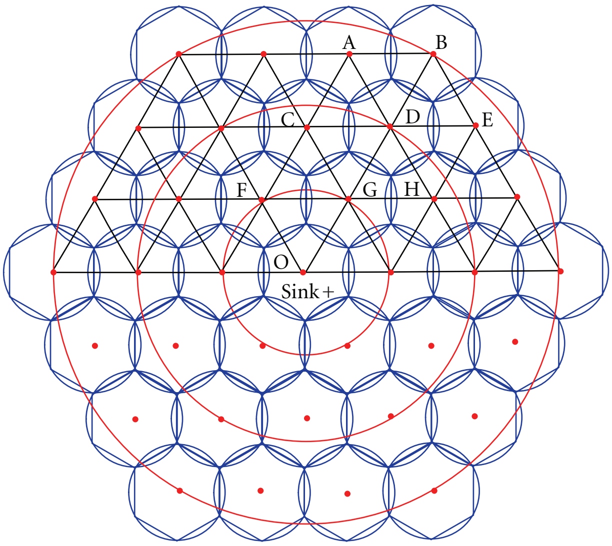

Figure 6: Inter-cluster multihop routing.

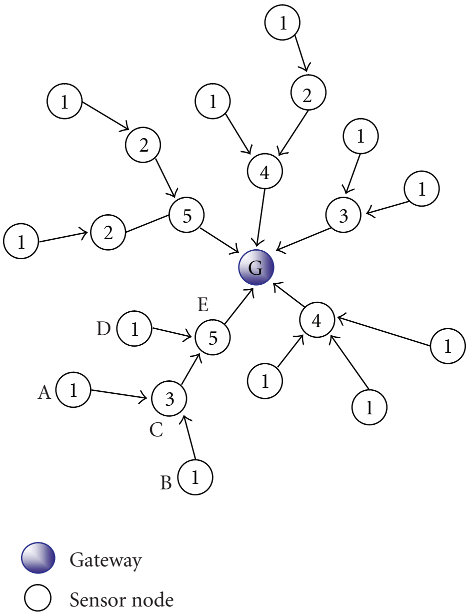

Figure 7: Intra-cluster time-slot distribution of multihop.

still need using multihop method to transmit their data to the sink node. We can form robust inter-cluster multihop routings according to the property of cellular structure. As shown in Figure 6, there are six gateway nodes with the same distance to the center node O (sink node). They can send data to the sink node directly. The external data can be transmitted by more than one pathway to guarantee the success delivery to the sink node. For example, the gateway node A can send data to O by different pathways: $A \rightarrow C \rightarrow F \rightarrow O$, $A \rightarrow D \rightarrow G \rightarrow O$, $A \rightarrow B \rightarrow D \rightarrow G \rightarrow O$, or $A \rightarrow C \rightarrow D \rightarrow G \rightarrow O$. When a pathway is broken, it is convenient to find another pathway as alternative. Additionally, some important data can be sent by more than one pathway to guarantee its successful transmission to the destination node.

6.2. Time-Slot Assignment. To avoid the conflicts during data transmission, the gateway nodes need to set up a table of time division multiple access (TDMA) to distribute the time-slot for sensor nodes belonging to its cluster. According to the TDMA table, the member sensor nodes can turn off their radio module in the nontransmission period to reduce their energy consumption.

When the intracluster single-hop communication method is adopted, the TDMA table is a simple one variable linear table and each member sensor node can be distributed an isometric time-slot. But for ARCH with intracluster multihop communication method, this kind of distribution is not suitable any longer. Here, the cluster head node will not distribute time-slot for all the member sensor nodes, but only for the member sensor node with one hop. If a member node does not contain any son node, its time-slot is distributed as 1, then notify to the upper sensor node. If the member node contains only one son sensor node, they will set the time-slot distribution as same as the son sensor node. If the member sensor node contains more than one son node, the time-slot of this member node is distributed as sum of all its son nodes. Figure 7 shows an example of intracluster the time-slot distribution.

For node A, B, and D do not have any son nodes, they are assigned one time-slot for transmitting their data. Node C serves as a relay node for node A and B, so it is assigned two time-slots. Node E serves as a relay node of node C and D, so it is assigned three time-slots. In this example, the gateways node informs each node in its cluster of the time-slots it is going to receive packets from other nodes and the time-slots it can use to transmit the packets.

6.3. Realization of Optimization Target. In order to reduce energy consumption, transmit power level L_i should be set as 1 for all multimedia sensor nodes. Then, the intracluster routing starts to be established. As mentioned above, all the nodes in corona C_i select their relay nodes in corona C_{i-1}. If the routing is failed to be established, the L_i of nodes in this transmitting direction will be set as 2. If it is still not successful until L_i of these nodes equal to L, the process of routing establishment will stop.

For an established route, it needs to determine whether it is satisfy for (7). If the route does not meet the condition, the power allocation algorithm will be started. In network initialization phase, all sensor nodes have the same remaining energy. We can randomly select routing nodes and increase their transmit power level until met the requirement.

To achieve energy aware, According to (12), each node calculate its own energy consumption rate as $\Delta E = E_T/T$, then notify it to other nodes on the route. Each node can predict the remaining energy of other nodes by ΔE, avoiding a large amount information exchange. To eliminate the unavoidable predicting error, each node should keep its recent ΔE and recalculate it when error occurs, then notify it with its current remaining energy to the other nodes on the route. To reduce updating number, we set an error threshold F. Only when the predicting error is higher than the value threshold, sensor nodes need to resend the message.

In order to balance the network energy consumption, we dynamically adjust the transmit power level of sensor nodes based on their remaining energy. We use S_p for representing the node set on route p. For any node i belonging to S_p, if it met the following (12), the transmit power level of all nodes in S_p will be reallocated.

$$\sum_{i\in S_p}\left(\frac{E_i}{\overline{\overline{E}}_i}-1\right)^2 > D, \qquad (12)$$

where D is a configurable threshold. Obviously, increasing energy consumption of the node with more remaining energy can meet our optimization goal. Under the premise of meeting (7), the nodes with higher remaining energy will be allocated higher transmit power level, while the nodes with low remaining energy just need to adopt transmit power level which can satisfy the requirement of single-hop reliable transmission.

7. Simulation and Analysis

In this section, we evaluate the performance of the ARCH via simulation experiments. We assume that 400 multimedia sensor nodes and 8 gateway nodes are uniformly deployed into a circle with diameter of 200 m, where a sink node is at the center of circle. The initial energy of each senor node has 50 J. All the sensor nodes are the source of information and can be the relay nodes. The original packet is 128 bytes generated by each sensor node. Referred to the index value of CC2420 chip, configure eight transmit power level: −25 dBm, −15 dBm, −10 dBm, −7 dBm, −5 dBm, −3 dBm, −1 dBm, and 0 dBm.

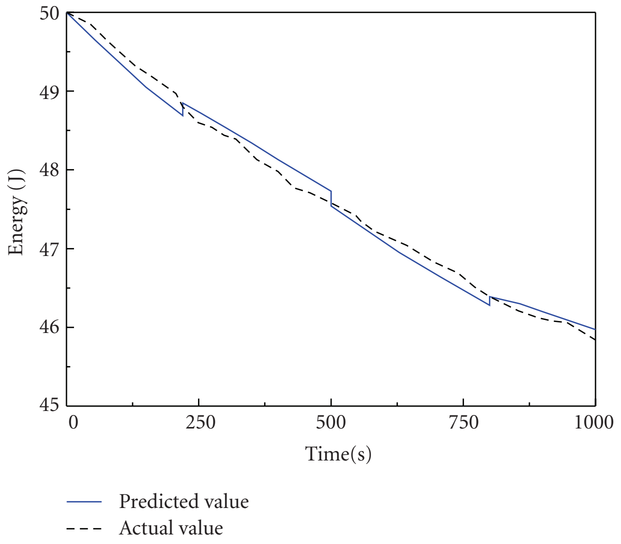

Figure 8: Predicted value and actual value.

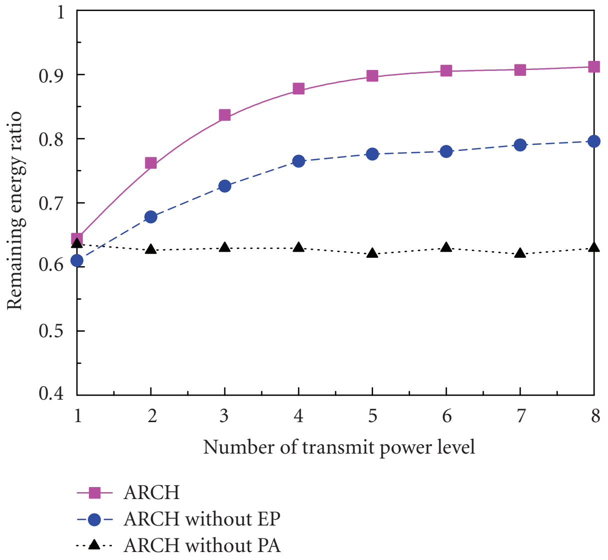

Figure 9: Remaining energy ratio with different number of transmit power level.

Figure 8 records the node's remaining energy and the value of predicted result in 1000 s by ARCH. It can be seen that the value of predicted result is very close to the actual value. There are only three times that the error exceed when the threshold is set at 3%. When the error exceeds the threshold, the nodes will recalculate the parameter of energy prediction and make the current actual value as the initial value for the next prediction.

Figure 9 shows the normalized remaining energy with different number of transmit power level during 1000 s. It can be seen that the normalized remaining energy by ARCH increased obviously with increasing the number of transmit power level. If the energy prediction or power allocation mechanism are not adopted (ARCH without EP or PA), the

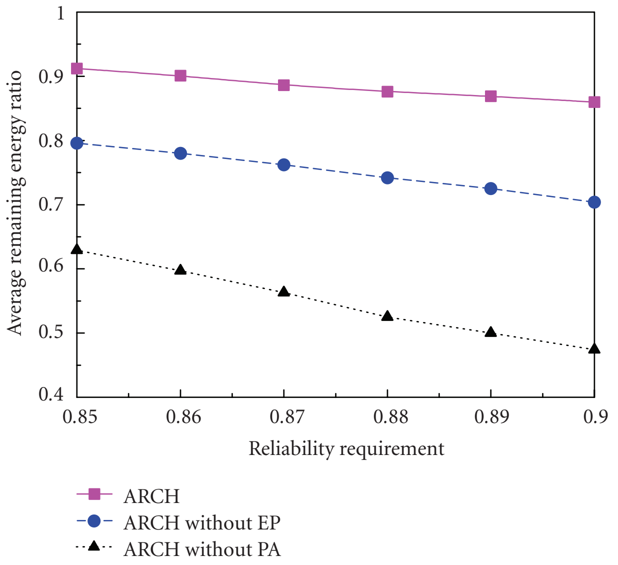

FIGURE 10: Remaining energy ratio with reliability requirement.

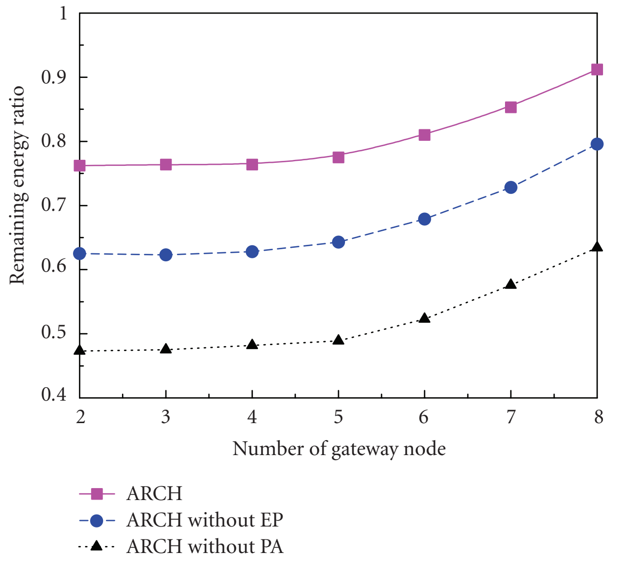

FIGURE 11: Remaining energy with different number of gateway node.

remaining energy of nodes decreased obviously. Specially, the energy consumption of network is slightly influenced by number of transmit power level for ARCH without PA.

Figure 10 shows that the increasing reliability requirement will lead to declining remaining energy. Although a higher transmit power level will increase energy consumption, the reliability of end-to-end will be effectively enhanced by the power allocation. The increased energy consumption for a high reliability is far less than that of retransmission energy with a low reliability. Therefore, the remaining energy of ARCH is much more than that of ARCH without PA.

Figure 11 shows that the normalized remaining energy with different number of gateway nodes during 1000 s. It can be seen that the remaining energy of network increase with increasing the number of gateway nodes. The increased number of gateway nodes decreases the area of cluster, hence the intracluster transmission hop is also reduced, which is benefit for saving energy.

8. Conclusion

As a resource-constrained network, wireless multimedia sensor network should try to reduce the unnecessary energy consumption. In this paper, we study the optimization of balancing energy consumption with reliable data transmission. Aiming at the needs of energy equilibrium and reliability, we propose an adaptive reliable routing based on cluster hierarchy(ARCH) for WMSN. The ARCH routing can balance the energy consumption with meeting the need of reliability between the source and destination. To achieve better performance, we form the cluster structure by cellular topology. Moreover, we design a power allocation mechanism to adjust the transmitting power of nodes and an energy prediction mechanism to realize energy aware among nodes.We perform extensive simulation experiments to evaluate ARCH by several performance indexes. The results show that ARCH performs high efficiency on energy equilibrium and reliability in wireless multimedia sensor network.

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