Realization of Intelligent Household Appliance Wireless Monitoring Network Based on LEACH Protocol

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Abstract: The intelligent household appliance wireless monitoring network can real-time monitor the apparent power and power factor of various household appliances in different indoor regions, and can realize the real-time monitoring on the household appliance working status and performance. The household appliance wireless monitoring network based on LEACH protocol is designed in the paper. Firstly, the basic idea of LEACH routing algorithm is proposed. Aiming at the node-distribution feature of intelligent home, the selection of cluster head in the routing algorithm and the data transmission method at the stable communication phase is modified. Moreover, the hardware circuit of power acquisition and power factor measurement is designed. The realization of wireless monitoring network based on CC2530 is described, each module and the whole system were conducted the on-line debugging. Finally, the system is proved to meet the practical requirement through the networking test. Copyright © 2014 IFSA Publishing, S. L.

Keywords: Wireless monitoring network, Power acquisition, Power factor, LEACH.

1. Introduction

As an important application of wireless sensor network, the design goal of the intelligent home is to link various home devices in the residence, enable them to run automatically and collaborate mutually, and provide the convenience and comfort for the habitants as much as possible. Embedding the sensor node in the home appliance and furniture, and linking the wireless network with the Internet can provide a more comfortable, convenient and humane intelligent home environment for people. Real-time monitoring the power and power factor of the household appliances, grasping the operation situation of the electrical appliances in different indoor areas, and intelligently starting various household appliances according to the real-time pricing and gradient pricing can not only realize the green lighting, but also achieve the energy saving and safe usage of electricity, and it plays an important role to realize the intelligent home.

In the household appliance wireless monitoring system in the intelligent home, for the layout structure locality in the room is more obvious, it is usually divided into the living room, bedroom, dining room and balcony, etc. In the living room, the household appliances of television, air conditioning and electrolier lamp; The refrigerator and eating lamp are usually set at the dining room, therefore, combined with the current mainstream house type, the system node distribution can be abstracted as the network structure as shown in Fig. 1, and it can be divided into seven partitions. Each partition has one and the only one cluster head,
the cluster head sends the data to the aggregation node via single hop or multi hops. The aggregation node uploads the data to the main control computer reliably via the internet access or serial port or other wired modes, and sends the indoor information to the user through GPRS module. In this way, it can achieve the wireless monitoring of the household appliances.

2. System Routing Algorithm Analysis

Restricted by the cost and volume and other factors, the energy limitation of wireless sensor network is the most significant feature of sensor network. The sensor network is usually applied in the occasion with harsh environmental condition, and the node energy can not be replenished, therefore, one of key technologies in the wireless sensor network is to save the network node energy. G. J. Pottie, W. J. Kaiser proved that the energy consumed to transmit a bit was greater than to process a bit through the experiment [1], the low-power dissipation adaptive clustering LEACH algorithm proposed by W. B. Heinzelman [2] and others made each node as the cluster head through the random rotation mode, thus effectively saving the energy consumption, while the node within the cluster sent the data to the cluster head via one hop communication, the cluster head realized the communication with the base station via single hop. In this way, the node with a far distance with the cluster head would wear out own energy quickly, and a large number of residual energy in the network was not utilized. Zhao Minchao and others proposed a kind of LEACH algorithm to collect the intelligent home data in literature [3], and provided a good idea for the system routing algorithm.

The basic idea of improved LEACH algorithm is still loop clustering reconstruction, the concept of “round” is cited when reconstructing each cluster. Each round can be divided into two stages to establish the cluster and transmit the data. In order to save the cost of resource, the time in the stable phase is greater than that in the establishment phase [4].

2.1. Determination of Cluster Head

The system gateway stores the number of the partition and the specific coordinate of each region in advance according to the indoor node layout. When the node sends the information to the gateway, the gateway parses the node coordinate, and assign a unique ID number Gateway_ID (unique in the network) and regional ID number Area_ID (calibrate according to the different partitions in Fig. 1) for each node. When selecting the cluster head, on the basis that there is one and the only one cluster head in each partition, and an energy factor is added in the original algorithm, the cluster head selection will be regulated by the residual energy, and the threshold T(n) is calculated as follows:

\[
T(n) = \begin{cases} 
\alpha*P_{\text{ch}}/(1-P_{\text{ch}}*[\text{Round}\mod(1/P_{\text{ch}})]) + 
(1-\alpha)*(1-\beta)*N, & \text{if } n \in G, \\
0, & \text{otherwise}
\end{cases}
\]

(1)

where \(\alpha\) is the weight parameter, \(0 \leq \alpha \leq 1\); \(\beta\) is the constant representing the influence that the node residual energy becomes the cluster head, \(0 < \beta < 1\); \(\lambda\) represents the ratio between the node current residual energy and the average residual energy of all nodes in the cluster:

\[
\lambda = \frac{E_{\text{current}}}{\bar{E}} = \frac{\sum E_{i}^\text{current}}{N}\cdot
\]

(2)

where \(N\) is the number of node within a certain regional cluster, when \(E_{\text{current}} = \bar{E}, \lambda \rightarrow 0\), the probability for the node to be elected as the cluster head is very small; when \(E_{\text{current}} = \bar{E}, \lambda \rightarrow N\), the probability for the node to be elected as the cluster head is very large.

2.2. Cluster Formation

In the system design, the node is divided into seven distinct regions, there is one and the only one cluster head in each region, while in the determination process of the above clusters, when calculated according to the equation (1), it is inevitable that more than one or zero cluster appears in a certain region (living room No. 1 region). The former can result in the waste of energy caused by many cluster heads in a region, and cause the premature death of the network; while the latter is impossible to realize the partition cluster obviously, and the data in the region can not be sent to the aggregation node.

Aiming at the situation that there are many cluster heads in a certain region (assuming \(N\)), the following
treatment can be conducted: After selecting the node at each region in each round of the cluster head, it sends a broadcast frame to the region, and other nodes are in the listening state. If N (N>1) clusters are produced in the region in the round, the node with the largest value of $\lambda$ in Formula (1) is selected as the cluster head in the round; while if there is zero cluster in the region in the first round, all nodes in the region shall be conducted the T(n) and random number according to formula (1), and the above selection process shall be repeated until some nodes are selected as the cluster head, and sends a broadcast frame to the region.

After the cluster head is determined, the non-cluster head node receives the cluster head broadcast message. Combined with own Area_ID, the non-cluster node selecting to join will select the proper cluster head as own cluster head and notify the cluster head to become the member of the cluster. After the cluster head node receives the feedback information from all nodes wanting to join in the cluster, it will create TDMA time slot table according to the amount of the node in the region to notify all nodes in the region when to start the transmission of the data.

2.3. Stable Transmission of Data

Once the cluster is established in the network, it will enter into the stable communication phase. According to the received TDMA time slot table, the node in the cluster will send the collected data to the cluster head within the prescribed time. In order to avoid the mutual interference when transmitting the data among different clusters, the system adopts TD-FDMA technology, different nodes will select different channels (such as 2.4 G frequency band, 16 channels can be selected) to transmit the data according to own Area_ID. After the cluster head node receives the data of all nodes in the cluster, the data will be analyzed and mixed [5-6], and it will be sent to the gateway node after the package.

3. Design of Sampling Node of the Household Appliance Power

The power sampling node can mainly realize the power sampling, power factor measurement and data transmission. The node adopts CC2530 from TI company as the node master controller, the chip integrates ZigBee RF front end, memorizer and microcontroller. It has 12-bit sampling A/D device, and integrates 51 core.

3.1. Power Sampling Circuit Design and Reality

The electrical power has the difference of apparent power, active power and reactive power, and the active power refers to the energy consumed by the component; the reactive power refers to the exchange between the component and energy; while the apparent power reflects the maximum energy provided by the circuit. The system tests the apparent power of the electrical appliance, then the active power and reactive power can be obtained through the power factor. There are 3 kinds of common methods to test the apparent power: 1) measure the voltage at the two ends of the electrical appliance and the current passing the electrical appliance, $P=UI$; 2) measure the current and resistance of the electrical appliance, $P=I^2R$; 3) measure the voltage at two ends of the electrical appliance and the resistance of the electrical appliance, $P=U^2/R$. It is hard to rapidly measure the resistances of different electrical appliances and measure the current or voltage in the same circuit, therefore, the system adopts the first program to collect the data of the current and voltage. A voltage value will be output at the two ends of the sensor, A/D conversion multiplication is conducted on the collected current and voltage through CC2530 chip to obtain the power. The current and voltage acquisition circuit principle is as shown in Fig. 2.

![Fig. 2. Current and voltage acquisition schematics.](image-url)
The current sensor selects ACS758LCB-050 from Allegro company as the service entrance current sensor test. When \( V_{CC} = 5V \), the sampling voltage \( V_{out} = \frac{V_{CC}}{2} \approx 2.5V \), after LM348N and R2 constitute the voltage follower, it will be input in CC2530 memorizer through P1_0, and the tested current is:

\[
I_x = \frac{V_{out}}{0.04} = \frac{2.5}{0.04} = \frac{25}{0.04}, \quad (3)
\]

The voltage acquisition circuit is mainly composed by the transformer module, precision rectifier module and filtration module, and the original ratio of the transformer is 10:1. The integrated arithmetic amplifier U3A and D1 and D2 compose the half wave rectifier circuit, U4A and R6, R7, R8 and others constitute the inverse proportion operational amplifier circuit, and the magnification time is 2 to jointly realize the function of full-wave rectification, the capacitor C2 plays the role of the rectification. The rectified direct voltage is input to CC2530 memorizer through P1_1. From Literature [7], we can know that the relationship between the load voltage \( V_L \) of the capacitance filter and the input voltage \( V \) after the voltage transformation is:

\[
V_L = \frac{1.1}{1.2} V, \quad (4)
\]

From Equations (3) and (4),

\[
P_x = 8.33 \frac{V_{out}}{25}V_{out} = 0.625W, \quad (5)
\]

### 3.2. Design and Implementation of Power Factor Measurement Circuit

In the AC circuit, the cosine of the phase difference (\( \phi \)) between the voltage and current is called the power factor expressed with the symbol of \( \cos \phi \), the system adopts the circuit shown in Fig. 3 to test the phase difference between the voltage and current, wherein, the integrated operational amplifier U1A and U2A realize the zero-crossing detection of the voltage and current, 74LS74D can realize the detection of phase different, and the waveform is shown in Fig. 4. In the figure, Signal \( V \) is the input voltage signal, and Signal \( I \) is the input current signal, Phase \( O \) is the phase difference output signal.

![Fig. 3. Voltage and current phase difference detection diagram.](image)

![Fig. 4. Voltage and current phase detection output waveform diagram.](image)

From the Fig. 4, \( \phi = 2\pi \frac{T_1}{T} \), it is easy to obtain the power factor of the electrical appliance through seeking the duty ratio of Phase \( O \) signal.

### 4. Data Fusion System

Data integration is the core of the wireless monitoring and control systems, sensor nodes send data collected by wireless transmission up crew, due to factors such multipath propagation, external noise,
etc., can cause data loss or produce large errors, leading to control system accuracy is not high, can not meet the actual demand. The system uses KF (Kalman Filter Algorithm) algorithm for multi-sensor data collected for processing, thereby improving system control precision.

4.1. KF Principle

Kalman filter is actually working process is to obtain the recursive calculation process Wiener solution [8]. Wiener solution derived from the Kalman filter is actually the case after the end of the process to achieve steady-state Kalman filter, when the result of the Wiener Solution KF is the same [9]. Specifically derived as follows:

\[ \dot{x}(n|n-1) = x(n) - \dot{x}(n|n-1) + G_f(n), \]  
\[ e(n) = x(n) - \dot{x}(n|n), \]  
\[ e(n) = E[e^2(n)] = \min \rightarrow G.F. (f=a(1-cG)), \]  
where a and c are known. Since

\[ \frac{\partial x}{\partial x} = 0, \]
\[ \frac{\partial x}{\partial G} \Rightarrow G, f, \]  
then

\[ \dot{x}(n|n) = x(n-1|n-1) + G(n)[y(n) - a \cdot c \cdot \dot{x}(n-1|n-1)] \]

\[ \text{are positive} \]
\[ P[n] = a^2 x(n-1) + Q, \]  
\[ \text{are positive} \]
\[ G[n] = \frac{CP(n)}{R+CP^2(n)}, \]
\[ e(n) = P \cdot G(n) = [1 - CG(n)] - P(n), \]
where \( y(n) \) can be time-varying non-stationary random process, \( G(n) \) is the amount of change with time, it will be adjusted each input and output, and gradually forcing the gain of Kalman Filter, and \( \dot{e}(n|n-1) \rightarrow e(n) \downarrow \)

When the error value is stable convergence is given by the following formula:

\[ e^2 = \frac{1}{a^2} \cdot \frac{C^2 Q}{C^2 a^2} - \frac{Q}{C^2 a^2}, \]
In which, as shown in a flow chart to calculate the estimated filter in Fig. 5.

\[ X(k|K-1) \downarrow \rightarrow X(k|K) \rightarrow F(k) \rightarrow K \rightarrow K + 1 \]
\[ (k) \rightarrow X(k|K) \rightarrow \]

Fig. 5. A flowchart of filter estimates.

It can be obtained from the above analysis that the filtering process is not repeated essence is to "predict – Fixed" recursive manner taking into account [10], calculated perform predictive value, and then by the observation deserves to gain new information and KF, the predicted values correction. Worthy to be filtered prediction [11], may also be worthwhile to predict the filter, the interaction between, does not require any stored data observed with good real-time.

4.2. KF Programming Algorithm

Kalman filter equations give the concept of an application state variable. Moreover, unlike other recursive filter structure, it only needs to remember the estimated results by step. Consider the process noise and measurement noise of two random variables state model called the random state model. System using C language programming to achieve KF, the algorithm process is as follows:

1) Pre-estimate

\[ \hat{x}(k) = F(k, k-1) \cdot X(k-1) \]

2) Calculate the estimated covariance matrix

\[ C(k) = F(k, k-1) \cdot C(k) \cdot F(k, k-1)^T + T(k, k-1) \cdot Q(k) \cdot T(k, k-1)^T \]

\[ \hat{Q}(k) = U(k)^T U(k) \]

3) Kalman gain matrix calculation

\[ K(k) = C(k) \cdot H(k) \cdot [H(k)^T \cdot C(k) \cdot H(k) + R(k)]^{-1} \]

\[ \hat{R}(k) = N(k)^T N(k) \]

4) Updated estimates

\[ X(k) = X(k)+K(k) \cdot [Y(k)-H(k) \cdot X(k)] \]

5) After calculating the matrix update estimated to defend poor

\[ C(k) = [I - K(k) \cdot H(k)] \cdot C(k) \cdot [I - K(k) \cdot H(k)] + K(k) \cdot R(k) \cdot K(k)^T \]
4.3. KF Workflow

Work flow diagram of the Kalman filter is shown in Fig. 6.

![Diagram](image)

Fig. 6. Work flow diagram of the Kalman filter.

5. Design of Wireless Sensor Networking

5.1. Design of Cluster Building Phase

In the system design, 7 different regions are divided according to Fig. 1, each region is a cluster, the different electrical appliance in the region is the member node, and the modified LEACH algorithm cluster building stage software process is as shown in Fig. 7.

5.2. Design of Data Transmission Stage

The data transmission stage mainly realizes the data transmission. Firstly, Sink node sends the data request. When a cluster head node receives the data request, it will send the data request to the member node. After each member receives the request signal, it will send the information to the cluster head node according to own TDMA time slot. After the cluster head node receives the data, it will integrate the data and send to Sink node [12,13]. The sampling node software process at the stable data transmission stage is as shown in Fig. 8.

In the data transmission process, in order to improve the signal-to-noise ratio and bandwidth efficiency of the transmission signal, OQPSK modulation technique is adopted to modulate the power and power factor to be transmitted, TD-FDMA method is adopted to realize the data transmission [14].

With the formula \( f_i = 2405 + 5i \text{ (MHz) } \) , each different region is assigned a different carrier frequency. \( i = 0, 1, ..., 6 \) represents the channel number corresponding to the Areas ID in the partition; \( f_i \) is the central frequency corresponding to the channel.

![Diagram](image)

Fig. 7. System LEACH algorithm cluster forming stage flow chart.
6. System Test and Analysis

Finally, the model machine is used to conduct the networking test for different electrical appliances in different regions. The standard equipment adopts PA310 high-precision digital power meter from Guangdong Zhiyuan Electrical Company. The power meter can directly test the active power and power factor of the electrical appliance, and the test results are shown in Table 1 and Table 2, wherein the air conditioning is the refrigeration state, the soybean milk machine is heating state, and the washing machine is the dehydrated state.

<table>
<thead>
<tr>
<th>Electrical appliance name and model</th>
<th>PA310 (Unit: W)</th>
<th>Test result (Unit: W)</th>
<th>Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refrigerator (BCD-196TMP1)</td>
<td>156.00</td>
<td>150.00</td>
<td>3.80</td>
</tr>
<tr>
<td>Soybean milk machine (DJ13B-D08D)</td>
<td>738.00</td>
<td>726.00</td>
<td>1.62</td>
</tr>
<tr>
<td>Air conditioning (KFR-50LW/07EAC12)</td>
<td>1612.00</td>
<td>1634.00</td>
<td>1.36</td>
</tr>
<tr>
<td>Electric water heater (F60-21WB1)</td>
<td>3567.00</td>
<td>3621.00</td>
<td>1.51</td>
</tr>
<tr>
<td>Washing machine (MB55-V3006G)</td>
<td>351.00</td>
<td>362.00</td>
<td>3.13</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Electrical appliance name and model</th>
<th>PA310</th>
<th>Test result</th>
<th>Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refrigerator (BCD-196TMP1)</td>
<td>0.58</td>
<td>0.57</td>
<td>1.72</td>
</tr>
<tr>
<td>Soybean milk machine (DJ13B-D08D)</td>
<td>0.96</td>
<td>0.94</td>
<td>2.12</td>
</tr>
<tr>
<td>Air conditioning (KFR-50LW/07EAC12)</td>
<td>0.88</td>
<td>0.87</td>
<td>1.13</td>
</tr>
<tr>
<td>Electric water heater (F60-21WB1)</td>
<td>0.95</td>
<td>0.93</td>
<td>2.10</td>
</tr>
<tr>
<td>Washing machine (MB55-V3006G)</td>
<td>0.56</td>
<td>0.55</td>
<td>1.79</td>
</tr>
</tbody>
</table>

From the experimental results, we can know that the maximum error to test the system power is 3.80 %, and the maximum error of the power factor is 2.12 %, and it basically meets the actual requirement.

7. Conclusion

The test on the power acquisition and power factor for main electrical appliances in the intelligent household appliance wireless monitoring sensor network based on LEACH protocol is realized in the paper. The system has not only completed the monitoring on multi-use electrical parameter networking, and ensured the signal timeliness and accuracy. The realization of the wireless sensor network can real-time monitor the various environment parameters (temperature, humidity, luminosity) in the intelligent home, and it is meaningful to promote the application of Internet of Things in the intelligent home.

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