Research on Wireless Sensor Network System Based on Zigbee Technology for Short Distance Transmission

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Abstract. Based on ZigBee technology and the development of ARM technology and the demand of the wireless data transmission system, this paper proposes a wireless sensor network based on ZigBee and ARM design scheme of system mainly include ZigBee node and ZigBee base stations, using MSP430F149 framework and CC2420 ZigBee nodes, with embedded ARM7 chip STR710FZ2T6 framework and CC2420 ZigBee base station node, a hardware platform of low power consumption, low cost, and USES the partial mesh topology, Z-Stack protocol Stack Development of software and on-demand routing algorithms, embedded Tiny OS system, ZigBee-based wireless data transmission system. At the same time, aiming at the wireless sensor network (WSN) in the process of clustering nodes distribution imbalance problem affecting the service life of the network, an improved particle swarm (IPSO) algorithm combined the technology of distributed spatial analysis (DSA) of wireless sensor network equilibrium density clustering method, in order to promote the network equilibrium distribution of energy consumption, avoid the working life of the hot issues and maximize the sensor network. The experimental results show that the proposed method is effective for energy balance clustering of network nodes, and has lower power consumption than other clustering techniques, so the network life is longer. Peer-to-peer communication can be realized between point to multi-point and two points, automatic configuration and automatic recovery of fast networking, and data communication can be realized through coordination between nodes.

Keywords: Wireless sensor network, ZigBee technology, short distance transmission, improved particle swarm optimization algorithm, network system.

1. Introduction

WSN is a network that obtains basic data through a large number of sensor nodes deployed in the monitoring area, and collects and transmits data information among nodes in a cooperative and self-organized manner. As the sensor technology, network technology, embedded technology and the development of SOC chip technology and the power consumption of wireless sensor nodes, volume, information collection and processing speed, WSN is in rapid development, has been widely used in agriculture, transportation, logistics, intelligent household and other related industries, and at the same
time we also can predict with the deepening of the Internet of things technology application, lower cost, WSN will get more extensive application.

With the development of the information age and the emergence of the Internet of Things, the research of wireless sensor network has attracted great attention. Sensor nodes used in the network have been widely used in various applications because of their unique characteristics. These nodes can detect and monitor the changes of physical phenomena. But there are two problems with their design: (1) the limited life of the sensors because they are powered by small batteries; (2) To select the deployment method for the application, the most important part is the clustering process, and one of the important factors influencing the clustering process is the distribution of Cluster Head (CH) nodes. Therefore, it is of great practical significance and practical value to study the clustering method in WSN. Some scholars proposed an energy saving clustering protocol, which selects from a group of randomly selected candidate nodes as nodes with high residual energy among their neighbours based on the competition mechanism [1]. The remaining nodes are added to the cluster based on the cost function, but the candidate CH nodes initially selected randomly may produce uneven distribution. Therefore, the above methods still have a certain space for innovation and improvement. To solve the above problems, an improved particle swarm optimization (PSO) combined with DSA technology is proposed for the balanced density clustering of wireless sensor networks, which is effective for the energy balanced clustering of CH nodes in the network.

2. Characteristics of wireless sensor network

2.1. the confidentiality
In the process of sensor data transmission, some sensitive data are often encountered. If these data once stolen by criminals, it will give the security of the entire network system buried hidden trouble. Therefore, in order to ensure the security of these data, confidential processing of these data is very necessary. During the protection of these data, encryption is used to protect the data. Only after entering the correct password can these data be obtained, thus ensuring the information security of these data.

2.2. the authenticity
For some traditional sensor networks, it is very convenient to apply authentication method to obtain data. However, due to the limited storage space of the sensor, it brings some troubles to the authentication method. Therefore, in the current wireless sensor network, we can use the authentication method of data source to obtain data information. If the criminals want to steal the relevant data, if the authentication is not reasonable, it will automatically set up a protection device, so as to ensure the security of the data and information [2].

3. System structure design

3.1. Overall design
Through the sensor, the wireless data transmission system converts the captured field signals to generate electrical signals. After ADC sampling, converter and coding, the signals are regenerated into digital signals, which are stored in the data memory and sent to the receiving end by wireless means. The system is based on ZigBee technology and adopts direct sequence spread spectrum technology. The system includes ZigBee base station nodes and ZigBee nodes, as shown in Figure 1. Among them, ZigBee base station nodes are responsible for communicating with the outside world and obtaining data from sensor nodes, so the embedded method is adopted to design this node.
The system is composed of a number of self-powered ZigBee nodes, each of which can collect data from the surrounding environment, perform simple calculation and communicate with other nodes and the outside world. The multi-node nature of ZigBee network enables a large number of sensors to conduct high-quality sensing through collaborative work, forming a fault-tolerant acquisition system. For example, system node A can be transmitted to the base station node through C or connected to the base station node through D-C, that is, there are multiple ways from node A to the base station node [3]. Therefore, for the packet to be transmitted, it jumps to another node through one node and finally reaches the base station node. The base station node summarizes the data of each node and transmits it to the server, PC or network terminal. If there are bad nodes, channel blocks, or path attenuation, the signal can constantly attempt to travel through other paths.

3.2. ZigBee node
The function of ZigBee nodes is to collect the required data and send the data to the base stations of each sensor node group. ZigBee node is mainly composed of sensor module, MCU module, ZigBee receiving and receiving module, storage module and power management module, including power module indicator light/switch, sensor module interface, RS-232 interface, etc., as shown in Figure 2.
The sensor module is responsible for information acquisition and data conversion within the monitoring area. In this design, temperature and humidity sensors are used in the data acquisition unit. MCU module is responsible for controlling the processing operation, routing protocol, synchronous positioning, power management and task management of the whole node. ZigBee transceiver module is responsible for wireless communication with other nodes, exchanging control messages and receiving and collecting data. The storage module is responsible for storing the collected data; The sensor used in the power management module is composed of 2 1.5V alkaline batteries [4].

3.3. ZigBee base station nodes
The hardware part of ZigBee base station node is mainly composed of ARM module, storage module, ZigBee transceiver module, sensor module and power management module. ARM module adopts STR710FZ2T6 microprocessor, STR710FZ2T6 is ARM processor based on ARM7 instruction set, with 256KB Flash and 64KB SRAM on the chip, and the processor integrates many peripheral interfaces, including USB2.0 interface and Ethernet interface. The design block diagram of ZigBee base station node is shown in Figure 3.

![Figure 3. Schematic diagram of ZigBee Base Station](image)

4. System software design

4.1. ZigBee node design
In terms of software design, Z mainly includes upper layer protocol, user program, IEEE802.15.4 and Tinos system design. The upper protocol adopts the protocol Stack with strong compatibility and reliability, such as Z-Stack. The user program USES API functions provided by various manufacturers to realize ZigBee functions according to ZigBee specifications; The MAC layer and physical layer functions of IEEE802.15.4 are provided by RF chip CC2420.

4.2. ZigBee Protocol stack design
The ZigBee protocol stack applies the Microchip protocol stack, which belongs to the streamlined protocol stack and can realize most functions of the system. IEEE802.15.4 defines the MAC layer and the physical layer. On this basis, ZigBee Alliance established the application layer and network layer framework. The application layer mainly includes the application support sub-layer. ZigBee's manufacturers and device objects define the application objects. As defined by the ZigBee specification, the Microchip protocol stack divides it into multiple layers, each of which has its own layer of code in a separate source file. In the header file, application and service program interfaces are
defined. To achieve its modularity and abstraction, the top layer and the next layer interact with each other through well-defined application program interfaces [5]. For a particular layer, the layer C header file defines all the application interfaces supported by that layer; The application layer interacts with supporting and user applications all the time. According to the simple C language macro to each layer provides a large number of applications and service interfaces, can be called to the lower-level functions.

4.3. ZigBee Routing algorithm AODV
The system structure is part of the network topology interface, using AODV routing algorithm. The so-called AODV refers to an on-demand routing algorithm based on distance vector, which maintains the required routes and does not require node maintenance for routes that fail to achieve their goals in the communication process. Unlike the source node route, the node only needs to be surprised to remember, not the entire route. Therefore, the algorithm can realize self-starting and dynamic hop-by-hop routing of each mobile node in the network. If the link is broken, the affected nodes will receive AODV notification and the system can confirm that these nodes are invalid. For AODV, damage to the mobile node response link is allowed, and the network topology can be updated in a timely manner [6].

4.4. ZigBee base station node and upper computer software design
The software design of base station node is relatively simple, mainly including embedded system Tinos design, hardware driver design and protocol stack design, in which the protocol software development tool USES Z-Sticklike protocol. As the core equipment in the control, the upper computer must be able to realize the functions of data processing, network wake-up and problem maintenance, so in the design of the upper computer system, Microsoft’s Visual Basic, delphi and C++Builder can be used as the system development tools. In this system, Delphi is used as the development tool of upper computer software design.

5. Hardware design
The hardware structure diagram of the communication station is shown in Figure 4, which is mainly composed of the motherboard, wireless transceiver module, optical fibre transceiver module and power supply module. The wireless receiving module receives the data collected by the wireless vibration sensor and transmits the received data to the motherboard through THE USB bus. The motherboard processes, stores and sends the information uploaded by the wireless transceiver module; The optical fibre conversion module can convert the electrical signals from the main board network port into optical signals from the optical fibre outlet, so that the 10/100 base-TX cable network can be extended to the optical fibre network of 40km. The power supply module provides the required voltage for the normal operation of each module in the communication station [7].

![Figure 4. Block diagram of hardware structure of communication station](image-url)
5.1. Motherboard selection design
The motherboard is emcore-I2501 embedded motherboard. The motherboard USES Intel's N2600 processor, which is mainly used in process automation, Internet and other fields. The main performance parameters are shown in Table 1.

| The serial number | The performance parameters | Performance indicators |
|-------------------|-----------------------------|-------------------------|
| 1                 | The processor               | Intel/N2600/1.6 GHz     |
| 2                 | network                     | 2 gigabit Ethernet ports|
| 3                 | storage                     | 1 SATA interface, 1 CFast slot |
| 4                 | USB bus interface           | USB2.0 interface        |
| 5                 | The power supply            | +12VDC                  |
| 6                 | Operating temperature range | -20-70 °C               |
| 7                 | Operating humidity range    | 0% - 90%                |
| 8                 | size                        | 146 mm * 102 mm         |

5.2. Wireless transceiver module design
The main chip of rf circuit adopts TI company's CC2530F256. The chip is a 2.4ghz RF chip conforming to IEEE.802.15.4 standard, operating frequency range 2400-2483.6mhz, data transmission rate up to 250kbps, integrated RF Cast transceiver, and enhanced 80C51MCU kernel. The wireless receiving module is powered by USB on the main board. The working voltage of CC2530 is 2.0-3.6VDC, so voltage conversion is needed to convert the 5V voltage to 2.0-3.6VDC. The power chip AMS1117-3.3 is a three-terminal power chip with adjustable or fixed output voltage of 3.3V. The chip is internally integrated with overheat protection and current limiting circuit [8].

5.3. Selection of fibre optic conversion module
To ensure the remote transmission of stored data, optical fibre conversion is adopted. The selected optical fibre conversion module can extend the 10/100 base-TX cable network to the 40km optical fibre network, and provide common connectors:ST, SC, MT-RJ, VF-45. Optical fibre transceiver module with optical fibre port (receiving and sending), an RJ45 port, can realize the information transfer between the motherboard and optical fibre transceiver module [9]. The main performance parameters are shown in Table 2.

| The serial number | The performance parameters | Performance indicators |
|-------------------|-----------------------------|-------------------------|
| 1                 | Communication standard      | Ieee.802.3 U /IEEE.802.3 Protocol /UTPRJ45 connector |
| 2                 | Optical fibre type          | Single-mode fibre       |
| 3                 | Environmental requirements  | Operating temperature :0-45°C; Humidity :5%-90% without condensation |
| 4                 | The power supply requirements | De power supply: 5V DC   |

6. Wireless sensor network optimization algorithm
6.1. Algorithm Improvement
In wireless sensor networks, active region levels need to be determined first and particles deployed, where the number of particles is equal to the number of sensor nodes in the region. The particle flight rules should be modified appropriately. When the particle position is the same as the sensor node, the
movement will stop and the position will be fixed. The other particles that have not reached the same position as the sensor node will continue to fly according to the established rules until they coincide with the corresponding sensor position node [10]. When all the particles stop moving after the position overlap, the algorithm completes the clustering and moves to the next level region to continue the clustering operation. After modified by the improved PSO algorithm, the particle population 
\( C_i (i = 1, 2, ..., n) \) with \( k \) clusters in the corresponding ranking region can be expressed as:

\[
v_{i+1} = wv_i + c_1r_1(p_{\text{best}}_i - x_i) + c_2r_2(p_{\text{best}}_j - x_i)
\]

Where: 
- \( W \) represents the inertia factor; 
- \( v_i \) represents the particle movement speed of the \( i \) particle swarm; 
- \( x_i \) represents the current position of the particles in the \( i \) particle swarm; 
- \( c_0 \) represents the initial cluster centre; 
- \( r_0 \) represents the initial clustering radius; 
- \( c_j \) represents the cluster centre of all \( j \) particle swarm; 
- \( r_j \) represents the clustering radius of all \( j \) particle clusters; 
- \( p_{\text{best}}_i \) represents the optimal position obtained by searching in the \( i \) particle swarm; 
- \( p_{\text{best}}_j \) represents the optimal position searched in all \( j \) particle swarms.

The fitness of particles was evaluated according to the class similarity and the spacing between classes, and the clustering quality measured by the Euclidean distance was used as the optimization objective function, which was specifically expressed as follows:

\[
S = 1 / \left( \sum_{i=1}^{K} \sum_{x \in C_i} \text{dist}(c_i, x)^2 \right)
\]

Where: 
- \( \text{dist} \) is the standard Euclidean distance between the measured objects; 
- \( X \) is the individual particle; 
- \( K \) is the cluster number.

6.2. Use DSA to achieve energy consumption balance

The DSA technique relies primarily on performing prior spatial analysis of the network prior to clustering, based on some global information that BS provides to each node in the network, and also expects to retain the number of deployed nodes because any node must have a connection to BS to be considered a working node in the network. By broadcasting these two values at the beginning of the clustering process, each node can start the DSA. Internal conditions can be tested based on the condition that the sum of the three angles drawn from each vertex node of the triangle and centered around the internal node is equal to 360 degrees. Nodes that do not meet internal conditions are classified as boundary nodes. Using a distance that can be calculated based on the received signal strength indicator (RSSI), the internal conditions can be written as follows:

\[
\cos^{-1} \left( \frac{X^2 + Y^2 - c^2}{2XY} \right) + \cos^{-1} \left( \frac{X^2 + Z^2 - b^2}{2XZ} \right) + \cos^{-1} \left( \frac{X^2 + Z^2 - c^2}{2YZ} \right) = 360^\circ
\]

6.3. Algorithm Simulation

Simulation experiments are carried out to verify the effectiveness of the proposed method. Preview the distribution of the resulting cluster after each protocol of the round is applied to the same deployment network. In DSA, a member node belonging to any CH is the set closest to it, and other techniques cannot control the distance between CH and the member. As a result, some members are located in distant clusters and are vulnerable to high communication energy consumption. In addition, there are differences in the size of clusters in all technologies except DSA. Figure 5 shows the total network energy consumption for the 160 deployment nodes. These values are calculated according to Equation
(2) to carry out the same round communication [11]. Compared with other technologies, DSA technology achieves lower energy consumption rate.

Figure 5. Energy consumption of different communication cycles

Figure 6 shows the maximum utilization rate of network links when two algorithms choose to open the same number of DSA nodes. It can be seen from the figure that DSA algorithm has better load sharing capability than PPV algorithm when performing the same transmission task, thus reducing the maximum bandwidth used by the link in the network. If the number of selected nodes is more than 3, the maximum utilization rate of the link in this algorithm is lower than 7.87% of PPV on average, and the maximum difference is 14.58%. Calculate the average network transmission delay under the circumstance of opening different number of DSA nodes. According to the operation results, DC-DSA chooses a better node to open THE DSA function, so that the service can choose a shorter transmission path and thus reduce the average network transmission delay. DC-DSA algorithm reduces the delay by 18.5% compared with PPV algorithm. Moreover, when more nodes can turn on THE DSA function, the DC-DSA algorithm reduces the delay by 9.9ms compared with PPV algorithm due to the increase of the selection margin.

Figure 6. Average network transmission delay
7. Conclusions
ZigBee technology, as a short distance, low complexity, low power consumption, low data rate and low-cost wireless network technology, effectively makes up for the vacancy of low cost, low power consumption and low-rate wireless communication market. In this paper, an improved particle swarm optimization (PSO) algorithm combined with DSA is proposed for balanced density clustering in wireless sensor networks, which can effectively improve the energy consumption rate. Compared with other clustering technologies, it achieves lower power consumption, so the network life is longer and performs well in low density and high-density networks.

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