Application of ZigBee Wireless Sensor Network in Smart Home System

Wei LIU, Yuhua YAN

School of Information and Electronics Engineering, Shandong Institute of Business and Technology, Yantai, P R CHINA, 264005, liuweiyyjn@126.com
Shandong Business Institute, Yantai, P R CHINA, yanyuhua@126.com
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Abstract
In this paper, current technologies which can be used in the wireless home networking area are reviewed and compared. Then a solution of smart home system based on ZigBee technology is put forward and discussed. The hardware design of ZigBee wireless sensor network based on CC2430 chip and embedded home gateway based on S3C2440 is also given in detail. The software workflow of coordinator and router are discussed and user-defined frame format is further described. Experimental results show that the solution of smart home system mentioned above can be served as practical application reliably.

Keywords: Smart Home System, Wireless Sensor Network, Zigbee, CC2430, Coordinator, Router

1. Introduction
Recently, development of comfortable and intelligent home network has received increasing attention due to the rapid advances in wireless communications and information technology. Smart home, which is the integration of technology and services through home networking for a better quality of living, enter people’s horizons gradually. For example, we can manage a home security system, control appliances and perform many other tasks through wireless communication or internet. A lot of technology related to smart home is emerging. Smart home network can be broadly divide into two categories- wired and wireless. Most of researches and solutions for smart home are based on wire system. All of the devices and appliances in our home must be connected with cables in order to access Internet. For newly built house and new appliances, we can implement wired home network during constructions, however, it is hard to realize for the old houses and electronic devices. Nowadays, wireless technologies are considered as the silver bullet which may push home networking to the new level [1-4].

This paper tries to design and implement a solution of ZigBee-based smart home system. The remainder of the paper is divided as follows: first, we introduce the main wireless technologies and current application in Section 2. Then we discuss the components of smart home solutions. Section 4 gives the design of ZigBee-based smart home in detail. Finally, the conclusions and remarks for the future research are presented.

2. Wireless technologies
Several wireless technologies of varying bandwidth, operating range and power consumption are emerging for the smart home system. The widely-used wireless technologies include Bluetooth, ZigBee, UWB, Wi-Fi and WiMAX etc. [5]. Each technique has its own characteristics. Bluetooth is the first wireless interface for the mobile personal devices, and since the moment of unveiling, standard is ahead of the time. However, bandwidth requirements of the home networking increase dramatically in the last couple of years. For example, modern printer can operate data faster than Bluetooth enabled device sends it. UWB technology is designed for low-power, short range, high-speed, wireless area networks. Operational range for UWB is up to 10 meters, and original specification is based on IEEE 802.15.3 standard which uses carrier-based 2.4GHz radio. Wi-Fi is the brand name licensed by the Wi-Fi Alliance for wireless local area networks technology based on the IEEE 802.11 specifications. Although it typically covers an entire house, the data rate is reduced to 1Mbit/s and below at the far distances. Whereas high bandwidth and greater coverage is required, additional Wi-Fi access points
can be installed. In context of the home networks, Wi-Fi is mainly used for interconnecting different devices and for internet access provisioning. WiMAX is in development by WiMAX Forum since June of 2001 and is aimed at wireless broadband access provisioning as an alternative to the cable connections. As shown in Table 1, it can be seen obviously that the power consumption of ZigBee is less than other technologies, which can decrease the radiation effect and save the cost of energy. Meanwhile, its transmission distance is about 100m, which is quite suitable for home environment.

Compared with other wireless network techniques, the only weakness of ZigBee is the low transmission rate. However, the low speed applications are easier to control than the rapid ones [6-8]. Smart home network is characterized by relatively few communication nodes within a 60 to 500 m² area, in which each node only communicates every 5 to 15 minutes. Because of the characteristics mentioned above, ZigBee emphasizes a market of low-cost, low-power and easy integration into smart home control system.

### Table 1. Comparison of wireless technologies

<table>
<thead>
<tr>
<th>Protocol standard</th>
<th>Bluetooth</th>
<th>ZigBee</th>
<th>UWB</th>
<th>Wi-Fi</th>
<th>WiMAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency band/Hz</td>
<td>802.15.1</td>
<td>802.15.4</td>
<td>802.15.3</td>
<td>802.11b, 802.11g</td>
<td>802.16</td>
</tr>
<tr>
<td>Rate/bps</td>
<td>2.4G</td>
<td>868/915M, 2.4G</td>
<td>3.1-10.6G</td>
<td>2.4G/5G</td>
<td>2-11G</td>
</tr>
<tr>
<td>Power consumption</td>
<td>&gt;10mW</td>
<td>&lt;10mW</td>
<td>&gt;10mW</td>
<td>&gt;10mW</td>
<td>&gt;10mW</td>
</tr>
<tr>
<td>Security</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Transmission distance</td>
<td>10m</td>
<td>100m</td>
<td>40m</td>
<td>200m</td>
<td>30Km</td>
</tr>
</tbody>
</table>

### 2.1. ZigBee technology

ZigBee uses small, low-power digital radios based on the IEEE 802.15.4 standard, which is intended to be used by home embedded appliances requiring low cost and very low power consumption. The price of each chip is about two dollars and ZigBee protocol is also royalty-free. ZigBee operates in the unlicensed 2.4GHz, 868MHz and 915MHz frequency bands and works in a lower rate of 20–250Kbps, which meets the low-speed transmission data applications. Usually, a pair of small batteries can support a ZigBee device to work half a year to two years, or even longer, so the low power consumption makes ZigBee products very convenient for maintenance.

Furthermore, due to the mesh network architecture, ZigBee has the characteristics of self-organizing, self-healing and less interference, which is suitable for smart home system particularly.

ZigBee is compatible with IEEE 802.15.4 which is illustrated in Figure 1.
2.2. ZigBee network nodes

ZigBee network is composed of up to 65,536 nodes, which include three types of devices, that is, coordinator, router and end device.

Every ZigBee network must have one and only one coordinator. The coordinator is the first device on the network which starts, configures and manages the network. This also selects the network identifier which is the Personal Area Network (PAN ID) and one amongst the 16 channels in the range of 2.4-2.4835GHz. When the coordinator is ready, the other devices can join this network. ZigBee supports various network topologies such as star, peer-to-peer, cluster tree and mesh. A coordinator is a special router. In addition to router traffic, the coordinator is responsible for forming the whole network. At first, it must select the appropriate channel and extended network address. And then it is used as the trust center for authenticating new nodes and distributing network keys to new nodes as they join the network.

Routers are responsible for routing traffic between different nodes. Routers may not sleep, so they are not a suitable choice for battery operated devices. Routers are also responsible for receiving and storing messages for their children nodes and allowing new nodes to join the network.

End devices may be mobile devices and cannot route traffic. Because they may sleep, end devices are a suitable choice for battery operated devices. Hence, all traffic to an end device must be first routed to its parent node. The end device is responsible for requesting any pending messages from its parent node. However, it must inform the network to rejoin to a new parent node if an end device has been moved.

3. Solution of smart home system

The solution of smart home system is proposed as shown in Figure 2. Users log in management system through Web explorer on PC platform and remote access embedded home gateway, which sends commands to the coordinator in ZigBee network with UART interface and control home electronic devices.

From Figure 2, the smart home system is composed of client management system (CMS), embedded home gateway (EHG) and ZigBee-based home wireless network. CMS consists of User-Interface (UI) and Common gateway interface (CGI) program, through which users can monitor and control the home appliances at any place where Internet is accessible. EHG is an entrance of home network, which is a bridge between External Internet network and internal home network. At the one hand, EHG provides Web service and allows users to remote access home network. On the other hand, it serves as routing, protocol conversion etc. As a core of smart home system, the whole home network acts as a wireless local area network composed of ZigBee nodes. The coordinator in home network receives remote messages replying by EHG and sends to the corresponding router nodes for monitoring and controlling home appliances. With the ZigBee receiving module, the controllers of home appliances can be used as end devices of ZigBee wireless sensor network (WSN).

![Figure 2. Solution of ZigBee-based smart home system](image-url)
The solution of smart home system via ZigBee WSN not only avoids cabling, but also offers greater convenience and flexibility. Furthermore, ZigBee-based appliances develop a standard communication protocol allowing the various vendors to produce their products in accordance with uniform standards, which also accelerates the popularization of smart home system [9].

4. Design for ZigBee-based smart home

4.1. Hardware design of ZigBee WSN

The design for ZigBee module uses CC2430 chip made by Texas Instruments, which is a true system-on-chip solution specifically tailored for IEEE 802.15.4 and ZigBee applications. CC2430 combines the excellent performance of CC2420 RF transceiver with an industry-standard enhanced 8051 MCU, 32/64/128KB flash memory, 8KB RAM and many other powerful features. Combined with the industry leading ZigBee protocol stack (Z-Stack), the CC2430 is highly suited for systems where ultra-low power consumption is required and provides the market’s most competitive ZigBee WSN solution. With very high integration, there are rarely external components required for networking and wireless transceiver. Figure 3 gives the schematic diagram of coordinator and router.

![Figure 3. Schematic diagram of coordinator and router](image)

The coordinator includes minimum system with CC2430 chip, antenna module, LCD and RS232 interface. With RS232 interface, the coordinator can communicate with EHG. The router only includes minimum system with CC2430 chip and antenna module.

4.2. Hardware design of EHG

With Ethernet interface, EHG is responsible for receiving commands of external network and sending to coordinator through RS232 interface after processed. Then, the returning real-time information from home network will be received and transmitted to external network by EHG. EHG uses S3C2440 chip made by Samsung as control processor. The S3C2440 is developed with ARM920T core, 0.13 μm CMOS standard cells and a memory compiler. By providing a complete set of common system peripherals, it minimizes overall system costs and eliminates the need to configure additional components. In this paper, EHG is based on Mini2440 development platform integrating with SDRAM, Flash, TFT LCD, Ethernet and RS232 interfaces, etc. Figure 4 shows the total circuit framework of smart home system.

4.3. Software design of smart home system

The software design of smart home system is divided into three layers, including hardware layer, software layer and application layer. The hardware layer implements the data acquisition, command transmission. Software layer is responsible for transplanting Z-Stack protocol to achieve the data
Processing and transmission. Application layer runs user programs including the control and manage the ZigBee appliances, which is mainly discussed in the next sections [10].

**Figure 4.** Circuit framework of smart home system

**Figure 5.** Workflow of coordinator

**Figure 6.** Workflow of router
4.3.1. Workflow of coordinator

The coordinator is a core of ZigBee WSN, which is responsible for establishing network, address assignment and data transmission, etc. In addition, it communicates with EHG through RS232 serial port. The workflow of coordinator is illustrated in Figure 5.

4.3.2. Workflow of router

The routers are the most nodes existing in ZigBee WSN. They are responsible for receiving messages from the coordinator and executing relative commands to control different devices, while they forward messages from other nodes in order to increase routing channels. Furthermore, they also gather some environmental information for real-time monitoring. Figure 6 shows the workflow of routers.

4.3.3. User protocol

In order to transmit data reliably, it is necessary to define user protocol. The protocol frame consists of frame header, data and frame end. The uplink frame format of user protocol is defined as Table 2.

<table>
<thead>
<tr>
<th>Frame Header</th>
<th>Data</th>
<th>Frame End</th>
</tr>
</thead>
<tbody>
<tr>
<td>0xAA</td>
<td>Address</td>
<td>Frame type</td>
</tr>
<tr>
<td>1 Byte</td>
<td>1 Byte</td>
<td>1 Byte</td>
</tr>
</tbody>
</table>

From Table 2, the frame type is divided into uplink frame and downlink frame, which is denoted by 0x01 and 0x02 respectively. The uplink frame is used to transmit data of devices to remote users and the downlink frame is used to send control commands to ZigBee nodes. Besides control word, the downlink frame format is the same as uplink frame.

5. Experimental results

This paper takes CC2430 ZigBee WSN development system as experiment platform, with integrated with IAR Embedded Workbench IDE. The ZigBee appliances nodes are simulated by MCU system. The MCU system use development kit with STC89c52 platform. Linux system has been transplanted into EHG and embedded Web server has also configured. In this experiment, remote user can control and manage home appliances at any time, such as set temperature of “air condition”. They also query the working state of home appliances when MCU system uploads its information to ZigBee routers. The experiment shows that the ZigBee-based smart home system put forward by this paper can fulfill the task successfully.

6. Conclusion

In this paper, we overviewed current technologies which can be used in the wireless home networking area. Then we put forward and discusses a solution of smart home system based on ZigBee technology. The hardware design of ZigBee WSN and embedded home gateway are also given. The workflow of coordinator and router are discussed in detail. User-defined frame format is further discribed. We believe that the smart home system based on ZigBee will developed considerably.

7. Acknowledgement

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8. References