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Home control system based on ZigBee wireless sensor networks

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Abstract: A new scheme of the home control system based on ZigBee wireless sensor networks is presented. The design and development of the software and hardware of the proposed system are given. In addition to the basic data acquisition and processing functions, the gateway supports the Bluetooth-based local interface and the general packet radio service (GPRS)-based remote interface. Users on the client service side can use a pocket PC or notebook PC to achieve real-time data acquisition and control instruction implementation, or remotely control the home control system through a mobile phone by sending a short message. The Labview graphical development environment is adopted to create PDA applications running on pocket PCs and monitoring platform established on notebook PCs. Except for the gateway, other nodes in the system work in sleep mode most of the time on the system, and thus it improves the lifetime of the whole system efficiently.

Key words: home control system; ZigBee; wireless sensor networks; pocket PC; Labview

Due to advances in wireless communications and electronics over the last few years, the development of home networks which are comfortable, intelligent, and easy-to-use has received increasing attention. In the past, the wireless home network technology has mainly focused on high-speed applications. The research works have placed emphasis on how to improve the communication bandwidth. For instance, the IEEE 802. 11 standard increases from 802. 11's 2 Mbit/s to 802. 11b's 11 Mbit/s, and then 802. 11a's 40 Mbit/s[1-2]. The HomeRF standard increases from the HomeRF1. 0's 2 Mbit/s to HomeRF2. 0's 10 Mbit/s[1,3]. The HiperLAN standard also increases from HiperLAN1's 20 Mbit/s to HiperLAN2's 54 Mbit/s[1,3].

However, the low speed applications are easier to control than the rapid ones. A home control network is characterized by relatively few nodes (20 to 200) within an 80 to 600 m^2 area in which each node communicates relatively infrequently—every 5 to 15 min[4]. A typical communication consists of 4 to 6 bytes of payload (i. e., turn on, set dim level, read temperature, read door status, etc.). Due to the characteristics mentioned above, ZigBee technology emphasizes a market of low-cost, low-power, reliability, and easy integration into new and existing home control products[5-8].

1 System Architecture

As shown in Fig. 1, the architecture of the home control system (HCS) based on ZigBee wireless sensor networks (WSN) is divided into two parts: interconnected equipment side (IES) and client service side (CSS). The communication between both sides depends on the ZigBee gateway (ZG) which is also the ZigBee coordinator (ZC) of the ZigBee WSN. In a medium-sized home, two nodes that need to communicate may be beyond direct communication range. So the rest of the nodes are adopted to configure as ZigBee routers (ZR) except the ZC. In this case, all the nodes in the IES build up a mesh network structure enabling the two nodes to use other nodes as routing nodes.

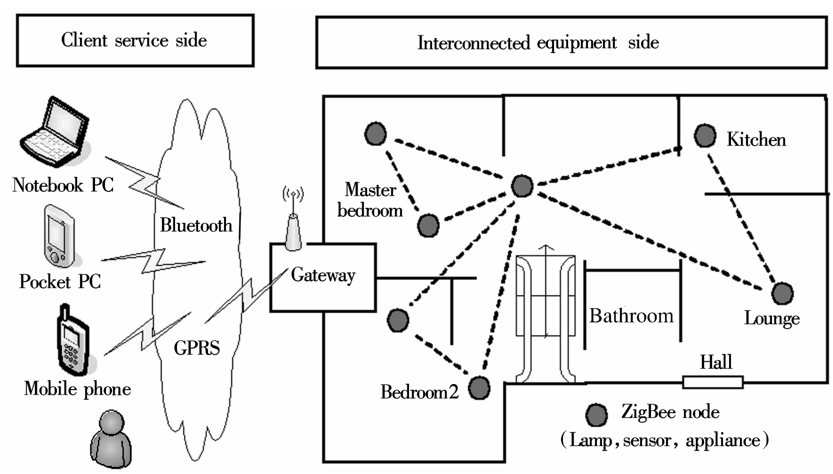

Fig. 1 Home control system based on ZigBee wireless sensor network architecture

The CSS supplies the user with monitoring and network management services. A personal digital assistant (PDA)-type device can not only control the home electronic equipment but also show the real-time collected information of the house. In addition, users in other places can know the real-time environment status of the IES by sending short messages, and the alarm information (e. g., high temperature alarm or low temperature alarm) can automatically be sent to the mobile phone of the user or the supervision cen-

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ter so as to be fixed up immediately.

2 Hardware Design and Realization

2.1 ZR device

Fig. 2 shows the structure of the ZR device. ZR nodes which are powered by DC or batteries are installed at different places in the house or attached to alarm devices and home appliances. They receive and identify control commands, read data from the on-board sensors and transmit the data to the ZC via the ZigBee WSN. Simultaneously, the ZR also needs to act as the intermediate router, passing data from other ZR nodes or reacting to communication requests from the ZC.

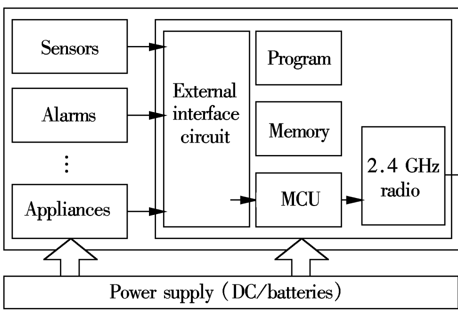

Fig. 2 Structure of the ZR device

2.2 ZG device

The ZG plays the key role in our proposed mesh network system to manage all home appliances. Fig. 3 shows a two-stack structure of the ZG device.

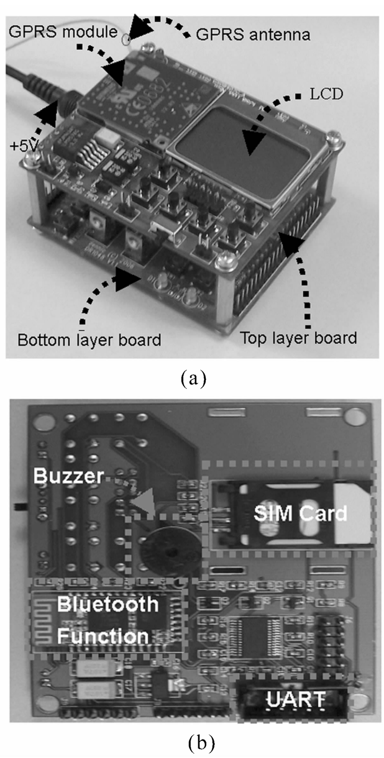

Fig. 3 Structure of the ZG for the proposed control scheme. (a) The architecture overview; (b) Rear view of the top layer board

The bottom layer is the ZC functional board, and the top layer is the external communication board which integrates with the functions of Bluetooth, the GPRS, the power supply and the human-machine interface (keyboard and LCD). Besides using the wireless access of Bluetooth, the ZG which monitors the real-time status of the IES exchanges data with the host computer through a serial port line. Data are both transmitted at 19200-8-N-1.

3 Control Flow and Procedure

The design and implementation workflow of real-time data acquisition is shown in Fig. 4. In the system, the ZR spends most of its time working in sleep mode. In this case, responsibility should be given to the ZC to query data when the ZR is able to transmit. Therefore, the ZC polls the ZR for data, which then checks whether data is available and, if so, transmits a data frame. A live connection between the ZC and the pocket PC is proposed by the Bluetooth module which supports the two data flows in our system; one is the downward data flow for data request, and the other is the upward data flow for data collection. Either of them is achieved by writing or reading the virtual serial port provided by the pocket PC.

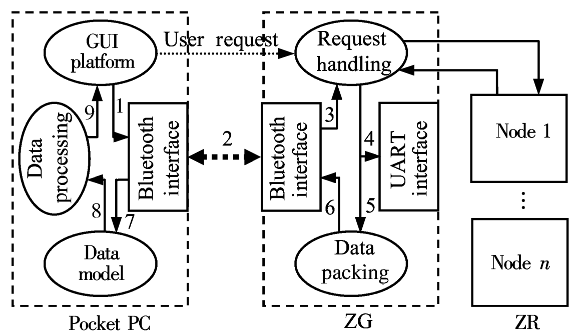

Fig. 4 Real-time data acquisition workflow

Through the ZigBee WSN, the ZR receives the control command from the ZG for the home appliances which are attached to it. The definition of this control command in the HCS is shown in Fig. 5. And the returned data format of the ZR is described in Fig. 6.

As shown in Fig. 5 and Fig. 6, the parameter u8DataLen means the length of the packet which is behind itself. The parameter u8CommandType equals 0x01, 0x02 and 0x03 which represent handshake instruction, collect command and on-off control, respectively. The parameter u8CommandPart implies the particular parameters of the home environment and the home appliances which need to be controlled.

The communication flow of the ZG is shown in Fig. 7. The start procedure is to finish the initialization, and then goes into the applied event handler function which consists of some stack events, some peripheral events and a data handler object. All of them are scheduled by a basic operating system (BOS). The stack event mainly deals with some network events (e. g., a new node joins the ZigBee network, a layer data transmission is acknowledged or a data packet is transmitted). The peripheral event mainly includes timer events and some port events. And the data handler object carries out the data transmission.

The ZR in the system mainly executes the on-off control and ADC data acquisition. The operating procedure of the ZR is configured as follows:

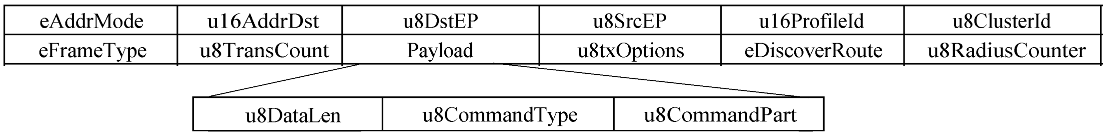

Fig. 5 Frame format of the control command in the HCS

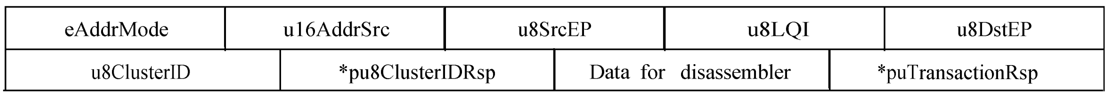

Fig. 6 Frame format of the returned data in the HCS

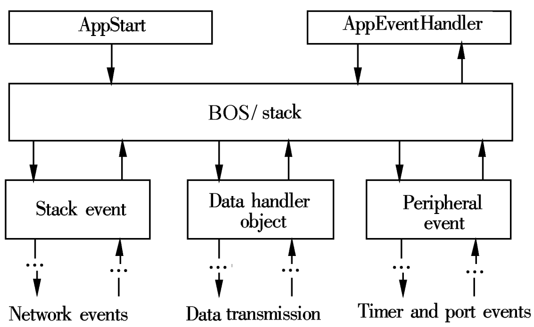

Fig. 7 ZG communication flow

1) If a user wants to control a specific node (or several nodes) with the ZG, he selects it (or them) by using the pocket PC and pushing the "OK" button in order to send a control command (shown in Fig. 5). The selected command is transferred to the gateway based on the Bluetooth protocol.

2) The command code is transmitted and implemented via the gateway's ZigBee function module, and the control menu for his target device is visualized on its LCD.

3) The target node implements the control command and transmits corresponding data through the ZigBee mesh network. The timer1 is configured to cause the ZR nodes to enter the "soft sleep phase", and automatically wake-up into working state every T1 time and checks a command from the ZG so as to minimize power consumption.

4) Finally, the real-time return data implement pack, Bluetooth communication, data unpack, and display in the pocket PC which can also transmit to the notebook via the UART interface. This procedure consists of the multi-step functions which are described as 4 to 9 in Fig. 4.

4 Experimental Result

In order to verify the proposed ZigBee-based HCS with the structure of a multi-hop mesh network, we implement the system by the designed method described in sections 2 and 3. Tab. 1 shows the networking configuration and performance of our prototype system.

The software design of the host computer includes two parts: a pocket PC and a notebook PC. Dopod 818 is selected as the pocket PC to display the collected data in our system whose development platform is Labview visual instrument software developed by American National Instrument (NI). Fig. 8 shows the graphical user interface (GUI) of the monitoring system running on the pocket PC. The functions of the monitoring software include data acquisition and management, graphic displays, and alarm functional configurations.

Tab. 1 Networking configuration and performance of the proposed HCS

Parameters	Value	Description
Frequency band/GHz	2.4	Communication channel number is 18
Antenna/dB	3/5	ZR(3 dB)/ZG(5 dB)
Coverage range/m	>80	Open spaces, TX power: +3 dBm
	20	Two walls, TX power: +3 dBm
	30	Eight walls, TX power: +19 dBm(3.6 V)
Multi-hop capability (packet loss)/%	0 to 0.5	One-hop communication
	0 to 3	Two-hop communication
	0 to 4.5	Three-hop communication

(a) (b)

Fig. 8 GUI of the networked monitoring system at the CSS on the pocket PC device. (a) Setting parameters; (b) Monitoring the real-time data from ZR

At the same time, the energy consumption experiment of the ZR device working with sleep management was carried out with thirteen test points in 1 min (as shown in Fig. 9). The experimental results demonstrate that the power consumption of the ZR using the sleep management method can be reduced effectively, which can ultimately improve the lifetime of the whole system.

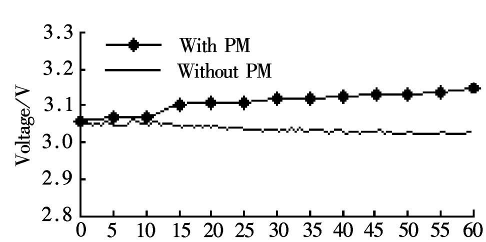

Fig. 9 Analysis with power management

Moreover, the power of the nodes applied in practical network deployment should be supplied adequately, and the packet loss rate is serious when the power level is below 2.5 V through our tests.

5 Conclusion

In this paper, we propose an intelligent home control system based on ZigBee WSN, and implement two kinds of hardware components: a ZG and some ZR nodes. With the mesh network structure and humanized operation, users in the local place and remote places can control the home devices easily and reliably through the ZG. The implemented home control system is proved to be efficient in performing home monitoring tasks, and it is ready to be used in various home automation applications with little modification.

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基于 ZigBee 无线传感器网络的家庭控制系统

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摘要：提出了一种基于 ZigBee 无线传感器网络的家庭控制系统，给出系统的软、硬件设计. 所设计的网关节点具备网关的基本功能，并结合了 Bluetooth 和 GPRS 通信功能，可以支持近程和远程的综合接入. 用户可以采用 Pocket PC 或者笔记本电脑实现实时数据的采集或者控制指令的执行，也可以通过发送短消息的方式实行远距离的控制操作. Pocket PC 的软件开发平台（包括笔记本电脑监控平台）采用的是 Labview 图形开发软件. 除了网关以外的其他节点都采用了休眠管理来降低能耗，并最终有效改善了整个系统的生命时间.

关键词：家庭控制系统；ZigBee；无线传感器网络；Pocket PC；Labview

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