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## Design of an Integrated Controller based on ZigBee Wireless Network

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### **Abstract**

*There are many different home appliances in our home, for example Lamps, Television, DVD player, etc. Moreover, the appliances are usually controlled by different controller using IR (Infra-Red) signal. This brings our life many inconveniences, and many resources are wasted. Therefore, we propose an integrated controller. It can control these various appliances, only a single one. In order to realize the purpose, the integrated controller must have previous preparations, because the appliances have their different IR controlling signals. Therefore, the integrated controller must “learn” the IR signals from their own controllers, and save them inside. Because the radiation range of IR signal is limited, and the appliances are distributed in different rooms, we propose a novel wireless network based on IEEE802.15.4, especially ZigBee protocol, to transmit the controlling signals from the integrated controller. The proposed scheme consists of two main parts. The one part is the hardware design, include the integrated controller with ZigBee transmission device and the terminal control module with ZigBee-IR conversion, which converts a control signal transferred through the ZigBee network into an IR typed control signal. The terminal control module is based on CC2430 as the controller core. The other is the software design. The software part uses IAR Embedded Workbench. Based on Zstack-1.4.2-1.1.0 protocol provided by TI, man can program the control codes of the system. The proposed scheme can also provide the well-defined interface and the necessary basis for preparing the smart home system.*

**Keywords:** *integrated controller, ZigBee, IEEE802.15.4, CC2430, WPAN*

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### **1. Introduction**

There are presently many home appliances in digital home environments, most of which are controlled by IR signal from their own remote controller. However, when we want to control these home appliances, we must first find their own controller. This brings our life many inconveniences and causes some resources are wasted. Therefore, we propose an integrated controller in this paper, which can control all appliances based IR signal. In order to realize the purpose, the integrated controller must make some previous preparations because every digital appliance hat different type controlling IR profile, for example leader code, control code, carrier frequency, etc. Therefore, the integrated controller must “read” the information from the relative controller, and save it inside. Additionally, IR signal hat another shortcoming, the radiation range. It can only be transferred in LoS (Line of Sight) range. We propose a novel wireless network based on IEEE802.15.4, especially ZigBee protocol, to transmit the controlling signals from the integrated controller. The method is not only clever and expedient, but also hat easy installation and convenient maintenance.

Wireless sensor network is a novel technology of obtaining and processing information, which is composed of many distributed nodes, which have sensing, computing and communicating abilities. So it is widely used in environmental protection, medical and health, military application, smart space fields. ZigBee is a very important communicating and networking technology in wireless sensor network.

ZigBee is a specification for a suite of high-level communication protocols based on an IEEE 802.15.4 standard for wireless personal area networks (WPAN) [1]. ZigBee hat the following features: low-cost, low power, large network capacity, high security and low transmission rate, etc. The low-cost allows the technology to be widely used in wireless control. Low power usage allows longer life with smaller batteries. Short-distance allows building WPAN.

However, ZigBee is not a completely new technology and protocol. Its physical layer, MAC (medium access control) layer and data-linker layer are defined in IEEE802.15.4-2003. ZigBee Alliance defines network layer and application layer. The following Figure 1 shows architecture of ZigBee Protocol. IEEE802.15.4-2003 specifies 3 radio bands; 868 MHz in Europe, 915MHz in the USA and Australia, and 2.4GHz in most jurisdictions worldwide. Data transmission rates vary from 20 to 900 kilobits/second [2].

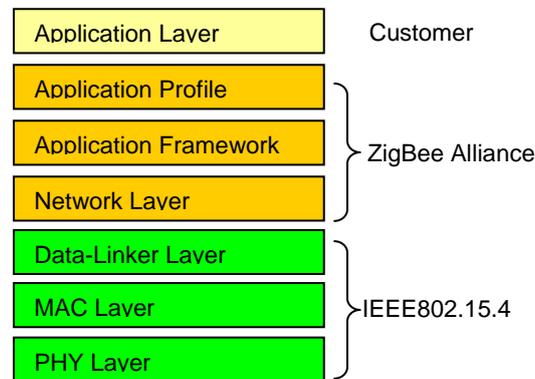


Figure 1. Architecture of ZigBee Protocol

When a device unit in ZigBee network is independently able to work, it can be called node. ZigBee network consists of Coordinator node, Router nodes, End-Device nodes. ZigBee Coordinator and Router are Full Function Device (FFD), while End Device is Reduced Function Device (RFD). Coordinator node has the strongest function in ZigBee network, is responsible for initializing, maintaining and controlling the whole network. When using encrypted communication, it is the Trust Center of ZigBee network, manages joining new nodes, and allocates secret keys. Router node is a relay node of network, is responsible for forwarding information, and allows new nodes to join in the network. End-Device node can only communicate with its related router node, but not forward information to other nodes. In addition, it can intermittently sleep to save energy.

## 2. Hardware Design and Implementation of the Integrated Controller

### 2.1. Related Previous Preparation Works

Along with economic development and improvement of living standard, more and digital appliances move into people's life. In order to expediently control them, man adopts IR remote control mechanism, because it is the cheapest mode in LoS (Line of Sight) range. At present, there are many different communication protocols in the world, for example ITT Protocol, NEC Protocol, Nokia Protocol, etc. We take NEC protocol as an example, which frame structure stream is shown in Figure 2.

In Figure 2 we can see, a typical pulse train of the NEC protocol consists of a 9ms AGC burst, Address and Command, which are transmitted twice to guarantee the transmission quality. We can classify the IR control stream into two major components, carrier and control signal parts. The carrier signal is to transfer an IR control stream with a specific frequency, otherwise the control signal part is to define the value, being specified with logic '1' and '0', for each field [3, 4].

In this paper, we propose a novel integrated controller to manipulate all home appliances. Nevertheless, in actual operation there are some difficulties. The reason is that each appliance has its own IR remote control signal, for example carrier frequency, lead code, signal definition for logic '1' or '0', etc.

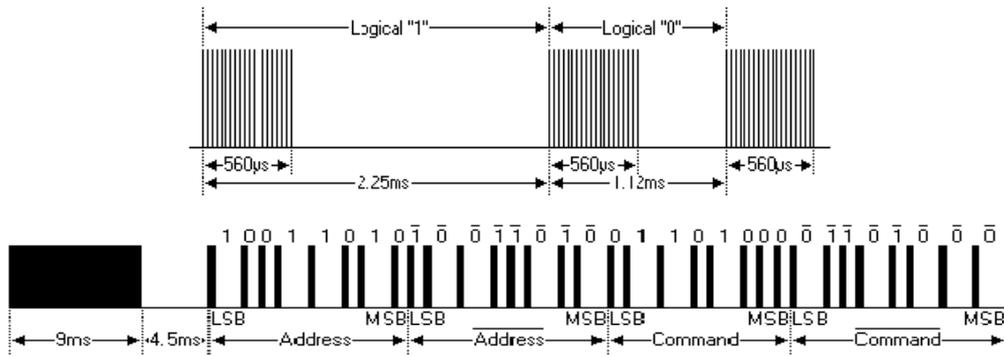


Figure 2. Typical Frame Structure IR Stream of NEC Protocol

In these times, more and more different home appliances move into our digital home environment. As everyone knows, they are controlled and managed by IR remote control with their own carrier frequency, lead code and definition for ‘1’ and ‘0’. Additionally, these appliances are distributed in different rooms. In order to control them with only one integrated controller, we must complete two works. First is that the integrated controller must have previous preparations, for example, that the integrated controller must “learn” the other IR signals from their own controllers, and save them. Second is how we can control other appliances in other rooms with the integrated controller based on IR signal. Usually we choose one of wireless network technologies, for example Wi-Fi, Bluetooth, ZigBee, etc. In this paper, we adopt ZigBee technology, because of the advantages as described in above section. Through building a WPAN based on ZigBee, controlling messages from the integrated controller are transmitted into other rooms. In Figure 3 shows the whole architecture in smart home system.

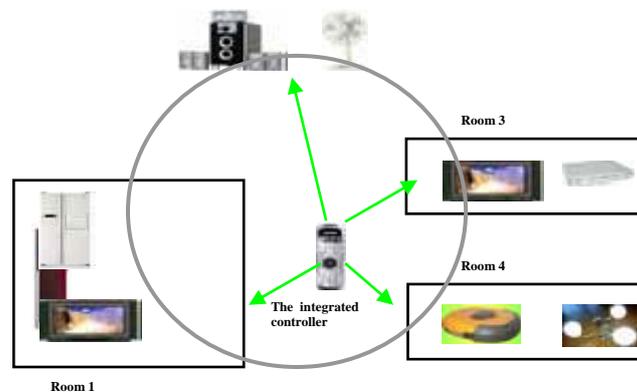


Figure 3. The Whole Architecture in Smart Home System

**2.2. Related Hardware Design Work**

The hardware implementation includes two main parts. One is the building ZigBee network, which transmits the controlling messages. The other is the integrated controller and the ZigBee-IR modules, which can convert the ZigBee signals to IR signals. Figure 4 shows the whole system configuration. In this figure, the integrated controller is the controlling signals generator of the whole system.

Based on ZigBee technology, the smart-home wireless control network consists of End-Device (RFD) installed in ZigBee-IR modules, controlling and monitoring center (FFD) and wireless network system (Router). The End-Device (RFD) contains communication controller system and DC power, etc. By the automatical routing function of Routers, the system can build the communication between Routers and RFD nodes to implement the wireless automatic control of smart home system.

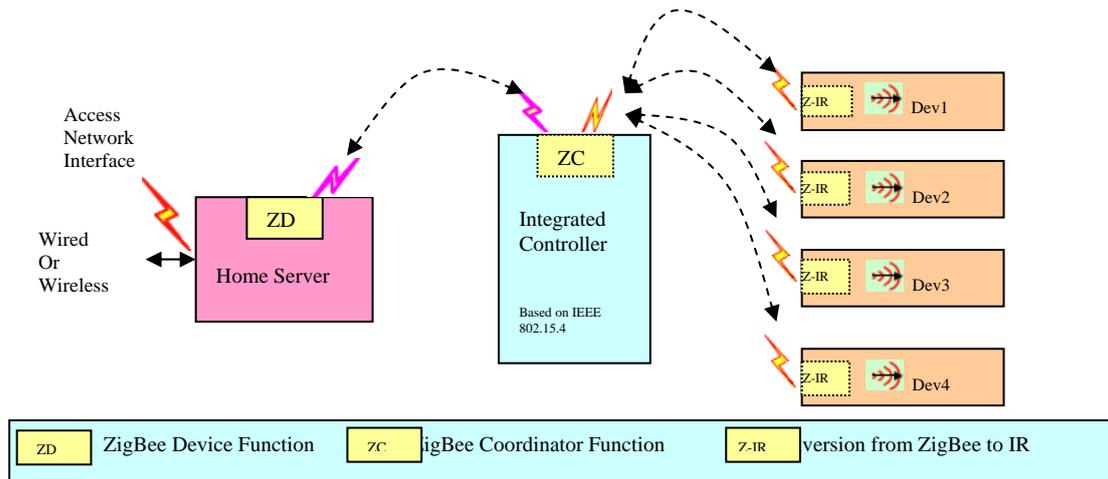


Figure 4. System Configuration to Control Home Appliances based on ZigBee Network

This network has a coordinator what controls the monitor system. The coordinator manages the network, displays the net-working information and the working state of smart home system and controls the switching state of the whole network. And the system has also some Routers, that work as the relay controller of wireless nodes for the remote control. Meanwhile, the Routers are used as RFD nodes, too. Additionally, the system has many End-Devices, that receive only the wireless signals from WPAN to control the working state of WPAN.

ZigBee supports many network topology structures: star and tree typical networks, and generic mesh networks, etc. Because the system is used in home environment, it adopts star-network structure, shown in the following Figure 5.

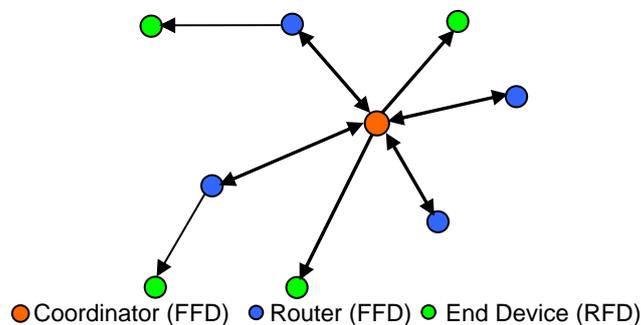


Figure 5. Architecture of WPAN in this Work

The network hardware adopts the wireless transceiver-CC2430. It is developed by Chipcon company in Norway. It is a true System-on-Chip (SoC) solution for 2.4GHz IEEE802.15.4. It has the following characteristics: low power, high receiving sensitivity, strong anti-interference, etc. It integrates ZigBee Radio-Frequency (RF) front-end, memory and microcontroller. It uses a 8-bit Microcontrolunit (MCU)-8051, and has 128Kb programmable Flash and 8Kb RAM. Additionally, it has also 14 bit Analog-to-Digital Converter (ADC), 4 Timers, Watch-Dog timer, and 21 programmable I/O pins [5].

CC2430 needs only few peripheral components to build a hardware circuit. Its peripheral components include the two parts, one is crystal clock circuit, the other is RF Input/Output matching circuit. The intrinsic signal of the chip is provided by external active-power crystal, or internal circuit. The RF Input/Output matching circuit has a main purpose to match the Input/Output resistance of the chip. Meanwhile, it can provide the DC bias for internal PA and LNA of the chip.

The CC2430 hardware circuit is shown in the figure 6. The circuit adopts a nonequilibrium antenna, what connects a nonequilibrium transformer to improve the

performance of the antenna. The nonequilibrium transformer consists of capacitor C341, inductor L341, L321, L331 and a microwave transmission line. The whole circuit can meet the requirement, that the RF Input/Output matching resistance is  $50\Omega$ . R221 and R261 are the diverging resistance. R221 works for providing a suitable current for 32MHz-crystal oscillating circuit. This oscillating circuit consists of a 32MHz-quartz crystal (X1) and two capacitors (C191 and C211). A 32.768KHz quartz crystal (X2) and two capacitors (C441 and C431) compose a 32.768KHz crystal oscillating circuit. The voltage regulator supplies power for all demanding 1.8V pins and internal circuit. C241 and C421 are decoupling capacitor, that realize supply power filter to improve the stability of the chip.

In order to reduce the external interference and improve the performance of RF, the anti-interference measures must be implemented for the design of analog part. For example, magnetic bead or inductor is added for the analog power; the analog grounds and the digital grounds are separately; the filter capacitors are as much as possible close to the chip;

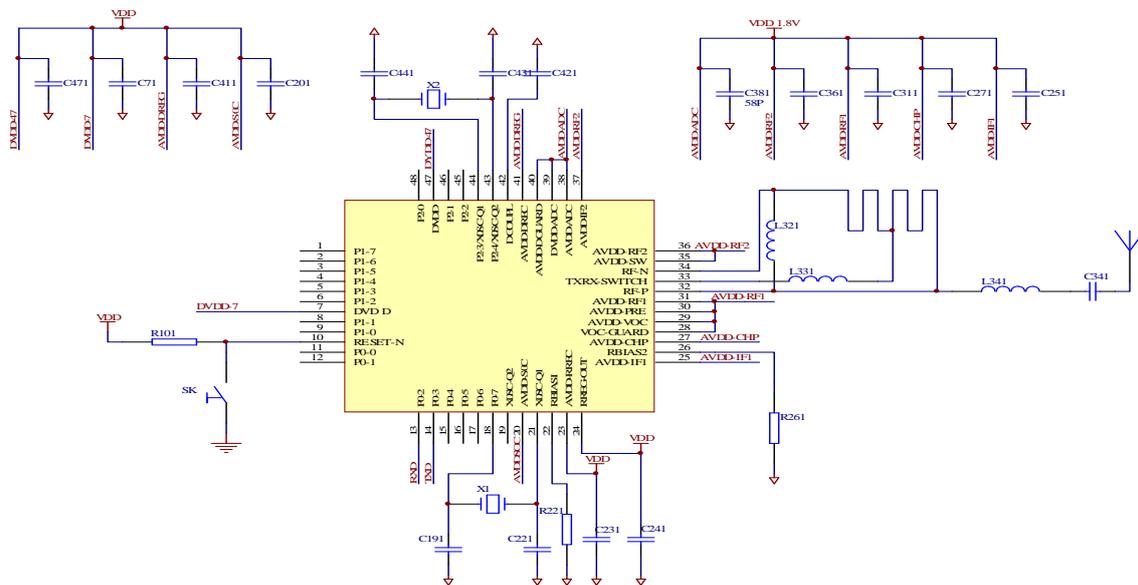


Figure 6. Diagram of CC2430 Hardware Application Circuit

The coordinator of the wireless control system needs display the present network state. So the coordinator consists of CC2430, serialport part, keys and LCD. Its diagram is shown in Figure 7. RFD nodes and Router nodes consist of CC2430, serial extended interface, ZigBee-IR circuit, shown in the following Figure 8.

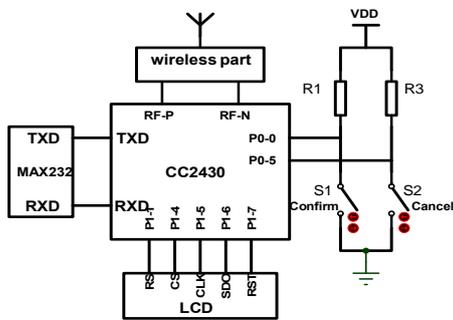


Figure 7. Diagram of Coordinator Circuit

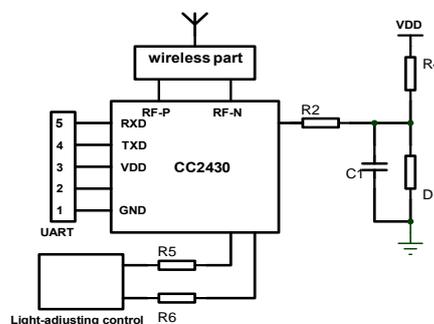


Figure 8. Diagram of RFD and Router Circuit

### 3. Software Program Design

In this paper, we adopt “IAP Embedded Workbench” development environment. And based on ZStack-1.4.2-1.1.0 provided by TI, the application program of the system is written. ZStack provides also some application interfaces, for example `aplFormNetwork()`, `aplJoinNetwork()` and `aplSendMSG()` functions, etc. User can write their development and application program by calling these functions.

#### 3.1. Software Flow

During working of the system, the coordinator of the wireless network will periodically detect whether keys are pressed to implement the relevant power ON/OFF commands. When the coordinator is idle, it is able to monitor wireless signals in the air. Then it judges whether new nodes want to join in the network, and if yes, allocates new IP addresses for the new nodes. Its software flow chat is shown in Figure 6.

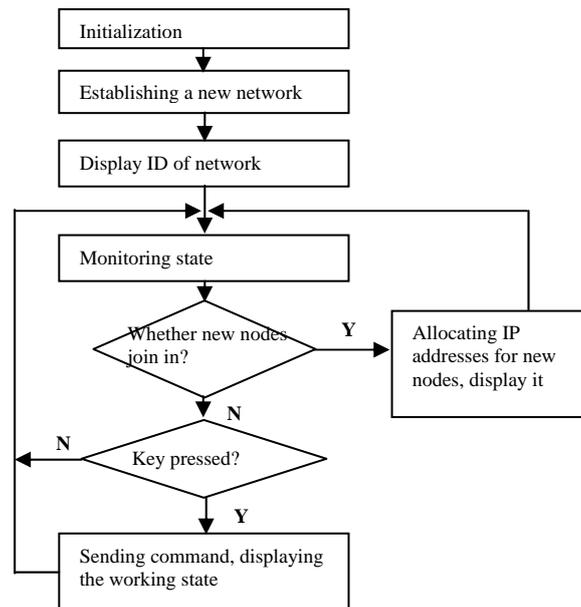


Figure 9. Flow Chat of Coordinator

Router is usually in the monitoring state. If it receives the power-ON command, it executes the command, and decides to retransmit or not. Meanwhile, according to the present light intensity, it decides turn on or not home lamps. RFD nodes are easy. They receive only the commands from WPAN, and implement them. The software flows of the 2 kinds devices are separately shown in Figure 7, Figure 8.

#### 3.2. Establishing a Network

In ZigBee network, the coordinator has the following functions: establishing a new network, allocating IP address, allowing the connect between MAC Layer and Application Layer, etc. After the initialization of the coordinator, it will call `aplFormNetwork()` to establish a network. The coordinator builds a network through scanning a empty channel. Then it chooses a random PANID to monitor the channel. The establishing-network program is shown:

```

void main (void) {
    .....
    hallnit();
    aplInit();
    .....
    aplFormNetwork();
}
  
```

```

while(apsBusy()) {apsFSM();}
while(1) {apsFSM();}
..... }

```

### 3.3. Joining in a Network

After building a network, it is considered, how Router nodes and RFD nodes can join in the network. They can do it through calling `aplJoinNetwork()` function. They scan channels to find the coordinator. Then they obtain the IP address of the coordinator, and send their IP addresses to it. After joining in the network, the network nodes are in dormant state, until commands or data need be sent. The program of joining in a network is shown:

```

void main (void) {
.....
hallnit();
aplInit();
.....
do{
aplJoinNetwork();
while(apsBusy()) {apsFSM();} }
while(aplGetstatus()!=WXLPAN_STATUS_SUCCESS);
while(1) {aplFSM();}
.....}

```

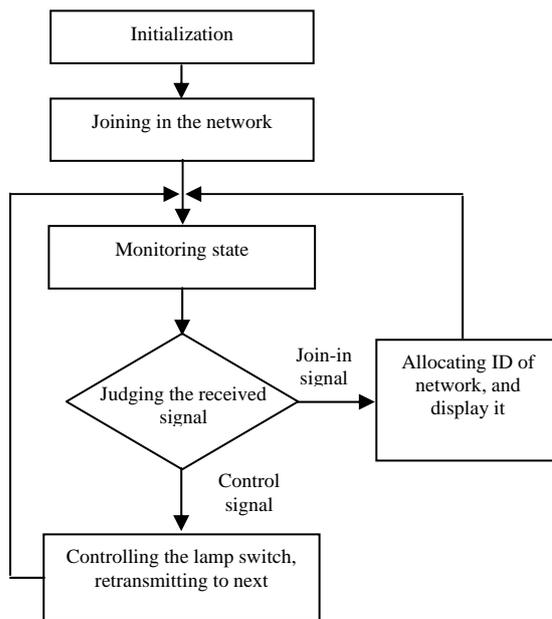


Figure 10. Flow Chat of Router

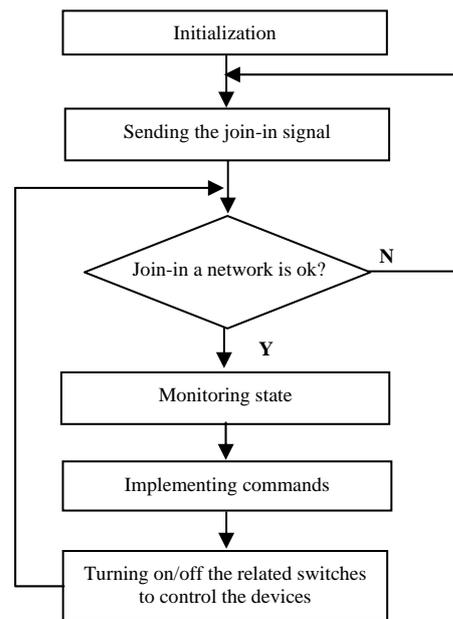


Figure 11. Flow Chat of RFD

## 4. Result

We test the network building delay of the system, data transmission rate, and the influence of communication distance to data transmission, etc.

For single coordinator and single node, the using time of building network is 20s. For scanning 16 channels, the average using time is 150s. The using time in first time is longer, mainly because of waiting for beacon frames, determining the channel of the coordinator. Under the condition: ca. 10m indoor distance and no partition board, data transmission rate is 250kbps. In vacancy outdoor environment and distance between 35m and 70m, the rate is

40kbps. When the distance is 300m, the rate is 20kbps. Additionally, the working current of the system is 25.7mA (sending), and 29.3mA (receiving). When it is idle, the current is only 2.5 $\mu$ A.

## 5. Conclusion

In this paper, we propose a novel integrated controller to control the different home appliances, instead of the traditional controllers. The scheme is based on IEEE802.15.4, especially ZigBee protocol. This work consists of two main parts, one is hardware design, and the other is software design. In the hardware field, there are two kinds of hardware parts to design and implement. One is the integrated controller, and the other is ZigBee-IR module. The integrated controller is the controlling signals generator of the whole system. The signals are transmitted in WPAN, based on IEEE802.15.4. The functions of the integrated controller can be expanded, for example controlling the home server, voice controlling, data-exchange with handy, etc. The ZigBee-IR module can convert the signal mode from ZigBee to IR, because the home appliances are controlled and managed by Infra-Red signals. Additionally, the scheme decreases the resource waste and cost of the system. The developed system has the following advantages: low power, low cost, easy installation, maintenance convenience, etc. So the scheme will be widely used, and provides the well-defined interface and the necessary basis for preparing the smart home system.

## References

- [1] IEEE Std 802.15.4 Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LR-WPANs). 2003.
- [2] P Baronti, P Pillai, V Chook. Wireless sensor network: a survey on the state of the art and the 802.15.4 and ZigBee standards. *Computer Communications*. 2007; 30: 1665-1695.
- [3] Intark Han, Hong-Shik Park, Youn-Kwae Jeong, Kwang-Ro Park. An Integrated Home Server for Communication, Broadcast Reception, and Home Automation. *IEEE Transactions on Consumer Electronics*. 2006; 52(1): 104-109.
- [4] Jin-Shyan Lee. An *Experiment on Performance Study of IEEE 802.15.4 Wireless Networks*. Proceedings of 10th IEEE Conference on Emerging Technology and Factory Automation. 2005; 2: 4511-458.
- [5] Bo-Teng Huang, Ko-Yen Lee, Yen-Shin Lai. *Design of a Two-Stage AC/DC Converter with Standby Power Losses Less Than 1 W*. Proceedings of Power Conversion Conference. 2007; 1630-1635.
- [6] Joon Heo, et al. Design and Implementation of Control Mechanism for Standby Power Reduction. *IEEE Trans. on Consumer Electronics*. 2008; 53(1): 179-185.
- [7] Jui-Yu Cheng, Min-Hsiung Hung, Jen-Wei Chang. *A ZigBee-Based Power Monitoring System with Direct Load Control Capabilities*. Proceedings of the 2007 IEEE International Conference on Networking, Sensing and Control, London, UK. 2007.
- [8] JD Lee, KY Nam, SB Choi, HS Ryoo, DK Kim. *Development of ZigBee based street light control system*. IEEE Power Systems Conference and Exposition, PSCE'06. 2006; 1: 2236-2240.
- [9] Sensor Network Analyzer (SNA), <http://www.daintree.net/products/sna.php#visualize>
- [10] Niels Aakvaag, Mogens Mathiesen, Gilles Thonets. *Timing and power issues in wireless sensor networks - an industrial test case*. Processings of International Conference Workshops on Parallel Processing (ICPP). 2005; 419-426
- [11] Zhenghua Xin, Hong Li, Liangyi Hu. The Research on CC2530 Nodes Communicating with Each Other Based on Wireless. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2012; 11(1).
- [12] Qin Danyang, Wang Huiwu, Ma Lin, Ding Qun. Research on Topology Property for Wireless Multi-hop Communication Network. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2013; 11(1).