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THE TECHNOLOGY PROGRAMME Project Monitoring Form

Technical Report

INDEEDNET SIMULATION REPORT

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1. Project Overview

The IndeedNET (Integration and Demonstration of Energy Efficient Dwelling Networks) project is funded by DTI under the Technology Programme -6th Call (Sustainable Production & Consumption: Energy Efficient Technologies) 2006. The objective of this project is to develop and demonstrate wireless sensor/actuator networks for energy saving in smart home environments.

The increasing uses of electronic home appliances are improving lives of human beings. But the usage of these devices has exceeded the control range of normal people, such as refrigerator, microwave oven, TV, dishwasher, central heating, and washer and so on. At most of the time, the incorrect operation on the home appliances will cause unnecessary energy use which will cost users too much. For example, if someone forgets to turn off the central heating and the windows are left open when the person is not at home, the electricity or gas will be consumed uselessly. The IndeedNET project aims to help people save energy consumption by using wireless technology. All available appliances in the home will be organized into a wireless sensor network and controlled by a certain device. Sensors in the network can provide the information of the home environment for users and help users adjust the status of home appliances. It can also be accessed remotely from anywhere of the world through Internet, then users can monitor their home even they are on travelling.

1.1 Purpose, Scope, and Objectives

- The purpose of software simulation in this state is to design the architecture of wireless communication in a home environment. According to the requirements of the project, each device inside the home must be applicable to communicate wirelessly. Since the wireless communication is hardware (home appliances) independent, we do not need practical appliances in this state. The simulation work is based on software and communication modules.
- The scope of simulation work is defined below:
  - Two-way communications between Zigbee [1] network devices (see section 2.2.3).
  - Simple information displaying for interaction with users
  - Multiple services simulation:
    - Central heating temperature check
    - Virtual windows control service
    - Light control service
- The main objective of the simulation work is to develop a Zigbee module based communication system and use pre-defined virtual home environment so as to validate the effect of communication system operation. This will enable the communication ability for the existing “isolated” home appliances in the next state.

1.2 Assumptions, Constraints

- The assumptions of software simulation are listed below:
  - Each home appliance is equipped with Zigbee module. Therefore, all information, including manufacture information, start signal, stop signal and any others needed by users about the appliance, can be formatted and recognized by Zigbee application.
  - The network is assumed to be applied for one home use, not for multiple homes sharing.
  - All controllable services are assumed to be managed by one local controller which aims to provide convenience for users.
  - The power supply of each communication module is two AAA batteries. The energy consumption of communication module will not be considered in this state.
- The constraints in the stimulation state are listed below:
  - We have four Zigbee modules and the simulated "virtual home appliances" can only be two (one module for coordinator, one for controller and the rest two for appliances).
  - Since the communication architecture is hardware independent; we will not apply practical hardware during software simulation. The status of assumed home appliances is expressed by some meaning events e.g., switch on/off the integrated light on the development board to express that the real light is on/off.

1.3 Software Simulation Deliverables

- The deliverables of software simulation are:
  - Create and demonstrate a home appliance network whose communications are driven by Zigbee wireless technology.
  - Create and demonstrate the communication between local controller and other networked appliances.
  - Demonstrate the ability to use local controller to monitor other appliances wirelessly.
  - Demonstrate a simple user interface applied to build interaction between users and systems.
- Platform for running demonstration:
  - The demonstration runs on four Zigbee development boards: one board for coordinator being responsible for organizing network, one board with screen for local controller, two boards for home appliances.
  - The application is programmed with C language.
- The instruction of program installation will be described in Appendix A.

1.4 References

[1] http://www.zigbee.org/en/index.asp

[2] http://www.jennic.com/

[3] W.C.Craig, "Zigbee: Wireless Control That Simply Works"

http://www.zigbee.org/en/resources/whitepapers.asp

[4] Zigbee Specification, Zigbee Document 053474r13

[5] Jennic Application Note: JN-AN-1035

http://www.jennic.com/files/support_files/JN-AN-1035%20Calculating%20802-15-4%20Data%20Rates-1v0.pdf

[6] Jennic: Application Note: JN-AN-1001

http://www.jennic.com/files/support_files/JN-AN-1001-Power-Estimation-1v3.pdf

1.5 Definitions and Acronyms

- **BOS** **Basic Operating System**
- **IP** **Internet Protocol**
- **MAC** **Media Access Control**
- **NWK** **Network**
- **PHY** **Physical Layer**

2. Summary of Software Simulation

The software simulation of IndeedNET project is to design the Zigbee Home Network architecture and simulate the Zigbee wireless communications between different devices. Section 2.1 introduces the design of system architecture; section 2.2 describes the Zigbee network and the two-way communications. Section 2.3 explains the use of the simulation devices.

2.1 IndeetNET System Architecture

Figure 1 illustrates the system design of the Zigbee Home Network.

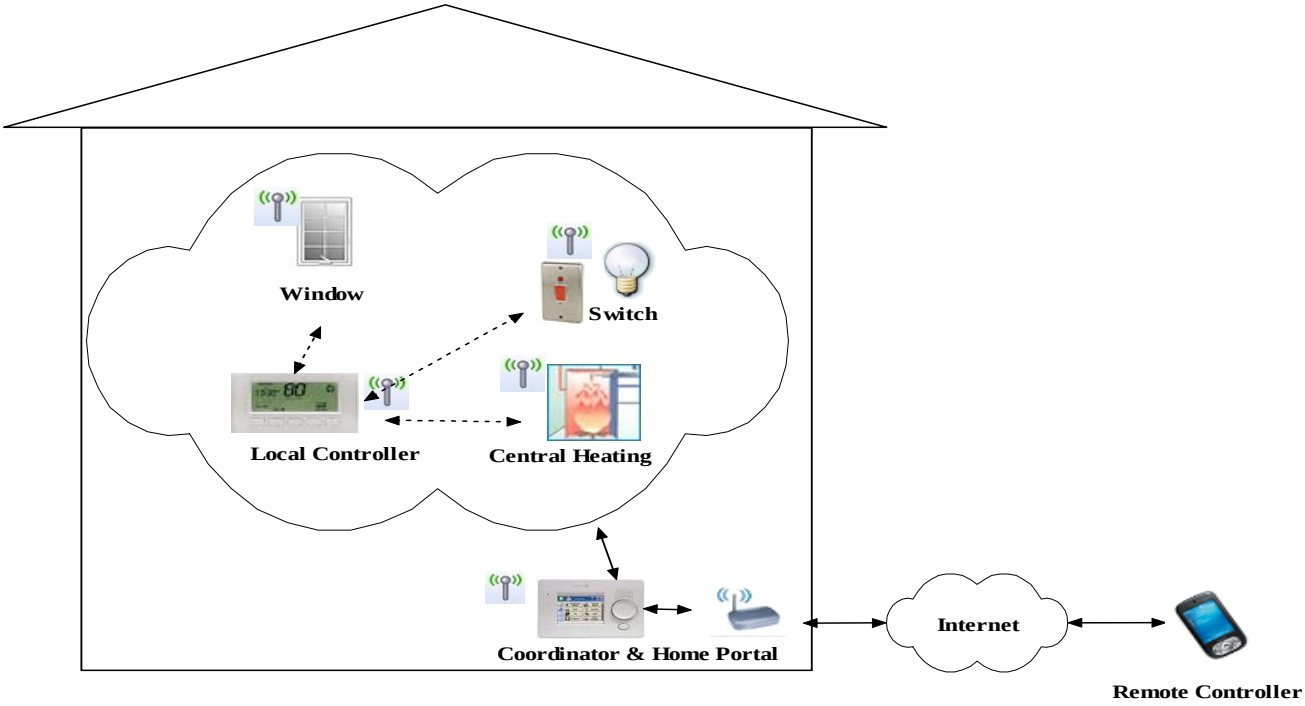

Figure 1: The system architecture of the Zigbee Home Network

The System is composed of four main parts: Zigbee network, home portal, Internet access and remote device.

2.1.1 Zigbee Home Network

The Zigbee Home Network works within the user's home, including Zigbee Coordinator, Zigbee Local Controller and Zigbee Enabled Home Appliances.

- The Zigbee coordinator is the main part of the Zigbee network and is responsible for network and devices management.
- Zigbee local controller is designed for users to control home appliances at home. It combines the control interface of all the home appliances and makes users easy to manage those devices.

- Each home appliance is enabled with Zigbee module which provides the network communication ability.

The Zigbee network will be detailed described in section 2.2.

2.1.2 Home Portal

Home Portal is the main entry point of the home network. It can be a router which has been used by most of the broadband users. The use of the home portal is to make conveniences for accessing in the Zigbee network through other networks, such as Internet, local area network and so on.

2.1.3 Internet Access

One of the main features promised by IndeedNET project is to make users control their home network anywhere any time. To achieve this, Internet access is indispensably. Because of the technical reason, Zigbee networks are limited to be used locally. We still need another ways to let users reach a certain Zigbee network when they are outside. As the most widely used communication way, Internet can use unique IP address to locate a target. Consider about the prevalence of broadband use, many homes have had an Internet address (static or dynamic) already. Whenever users want to check their home state if they are not at home, Internet access can be the easiest and cheapest solution.

2.1.4 Remote Device

The concept of remote device includes PDA, mobile phone, laptop and any device provided with Internet access ability. Many mobile devices which people have been familiar with already have been integrated with Internet accessing functions. For example, users can use their Wi-Fi enabled mobile phone to access in their home network when they are waiting for planes at an airport (most airports have provided Internet access point for their customers).

2.2 Zigbee Network Communication

The wireless communication applied by the project is supported by Zigbee technology. The development toolkits we use are manufactured by Jennic Company [2] and fully support Zigbee specification. The running of Zigbee module is managed by a default application framework. The detail working procedure of Zigbee application will be mentioned in section 3.

2.2.1 Zigbee network features

Zigbee technology is developed and spread by Zigbee Alliance. It is an innovative network technology with low cost, low data-rate and long life time features. It is especially suitable to be applied for application whose main purpose is to control equipment [3] [4]. Using Zigbee as the communication technology is based on 4 points below:

1. High network capacity. Zigbee network uses a 16-bit network address to identify devices, which means a single network can hold up to 65,535 devices theoretically (2^{16}=65,535). This is sufficient for most of home automation use.

2. Low data rate. Zigbee network support up to 250kbps data rate theoretically, in the practical test, it is about 100kbps [5]. Although it is less than some popular technology like Wi-Fi (802.11a/b/g/n) or blue tooth (802.15.1) whose typical data rate is 54/11/54 Mb/s or 1Mb/s, the rate is fast enough for normal control application. Additional transfer capacity will cause unnecessary energy cost.

3. Low energy consumption. Zigbee technology is originally designed for sensor network which is suppose to work over years without recharging. According to the reference manual, the Zigbee module that we are using can work for over three years under normal circumstance [6]. It is possible for users to forget to change battery or feel inconvenient to do it. A long time sustainable use of communication technology is suitable for users' benefits.

4. Support multiple network topologies. Zigbee supports three kinds of network topology, star, tree and mesh. Figure2 shows three topologies simply.

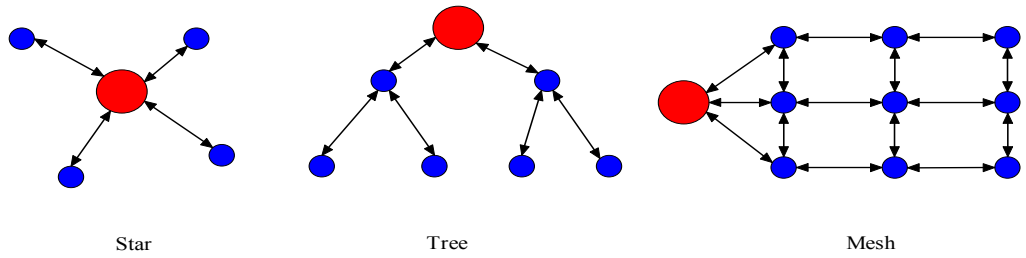

Figure 2: Three topologies supported by Zigbee

In our simulation, we choose mesh topology to build home network. The mesh topology does not have special requirements when devices are deployed. It accords with the normal use of home appliances.

2.2.2 Jennic Zigbee stack

- Jennic Zigbee stack fully supports Zigbee specification. The stack takes charge of PHY layer, MAC layer and NWK layer automatically, and users only need to focus on application layer development.

- The running of Zigbee stack can be divided into two main parts: Initialization State and Loop.
  - The Initialization state consists of two functions: AppColdStart and AppWarmStart. The AppColdStart is used when the device is powered up or wakes up from sleep. The AppWarmStart is used when the device wakes from sleep with memory hold.
  - Loop consists of "Application to Stack" and "Stack to Application" functions. "
    1. Applications to Stack functions include JZS_u32InitSystem, JZS_vStartStack and vAppSaveContexts. "
    2. Stack to Application functions include JZA_boAppStart, JZA_vStackEvent, JZA_vPeripheralEvent, JZA_vAppDefineTasks, JZA_bAfkvpObject, JZA_vAfkvpResponse, JZA_bAfMsgObject and JZA_vZdpResponse.
- All functions mentioned above are organized and managed by BOS. Figure 3 shows the relationship of these functions briefly. After the initialization, the BOS takes charge of calling other user tasks circularly. Developers' work is to put application programme into suitable functions

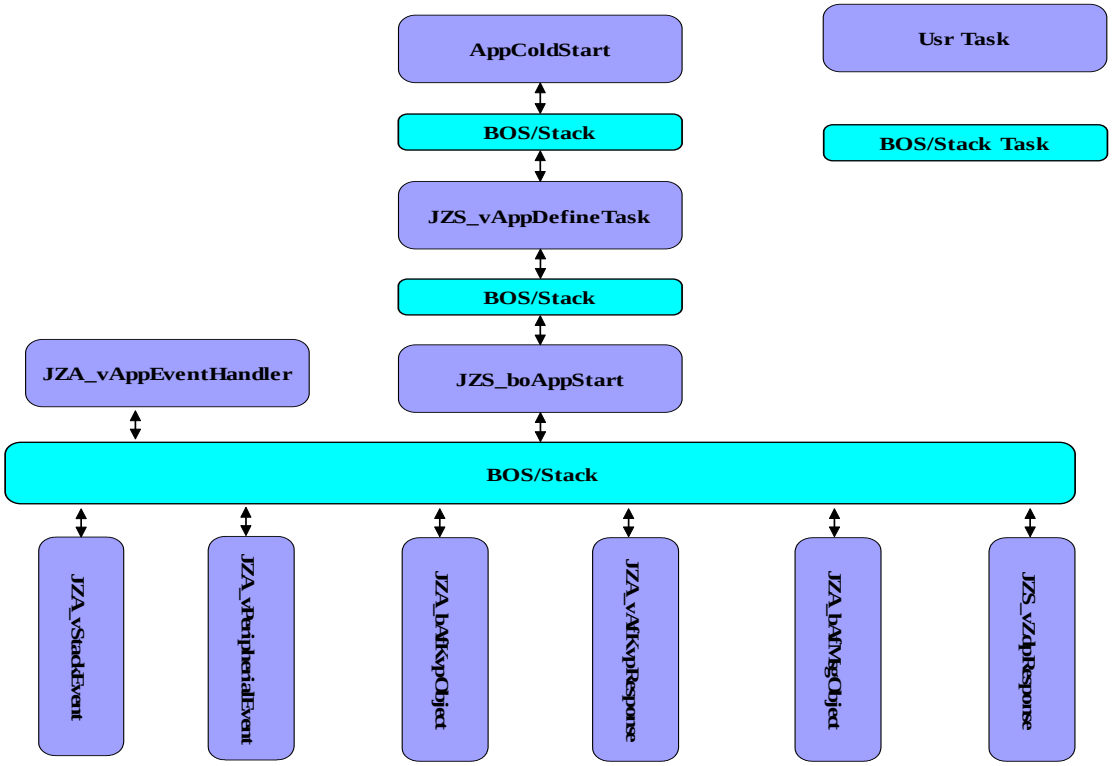

Figure 3: General flow chart of application

2.2.3 Two-way Communications

Inside the Zigbee home network, two-way communications are required between devices below:

- Zigbee Home Coordinator and Zigbee Home Appliances.
- Zigbee Home Coordinator and Zigbee Home Controller.
- Zigbee Home Controller and Zigbee Home Appliances.

Because all the home appliances need to be managed by the coordinator or the local controller, the communication between devices below is not required:

- Zigbee Home Appliance and Zigbee Home Appliance.

2.3 Home Appliances Simulation

To validate the effect of the communication, we need some "virtual home appliances" to respond the command signal sent through the network. Due to the constraints of devices, we only can set the state (on/off) of on-board light to show the result, and the responses from the "virtual home appliances" will be displayed on the screen to interact with the users. Two kinds of home appliances are to be simulated ---- local controller and virtual home appliances.

2.3.1 Local Controller

Like most of home appliances, our system needs to provide users a local controller. The local controller is one of the devices which belong to the home network. The difference between our local controller and traditional controllers is that it can communicate with all networked devices whose communication modules are driven by Zigbee technology. Normally existing controller can only work with the bundled device. Users have to hold more than one controller to control devices. It is not convenient for users, especially the working rang of the controller is limited by the distance between itself and the device. Zigbee local controller provides a universal solution for this problem. A single controller can control all the devices because of the use of the same communication technology independent from certain devices. And the support of mesh topology makes the Zigbee controller have ability to operate on devices at anywhere inside or near the home.

2.3.2 Virtual Home Appliances

Although the kinds of home appliances are various, the communication module can be separated from devices. If the internal information of the devices can be formatted and supported by the communication protocol, any device can join the Zigbee network easily. That is one of the reasons our team work on software simulation first.

In the software simulation, we abstracted the use of the home appliances. We ignored the internal structure of the home appliances and treated them as two states, on or off. If the right led on the right board can be chosen to execute the right command (turn on/off), we will think the device can be controlled. The board with integrated led can be seen as a virtual home appliance.

3. Software Design

The software designs of simulation includes coordinator, router, controller and "virtual home appliances" (end device).

3.1 Coordinator

Coordinator is the main component of the Zigbee network. Its responsibility is to create the network, allocate network ID, channel, allow other devices to connect to the network and give them corresponding network address. Figure 4 shows the working flow of the coordinator.

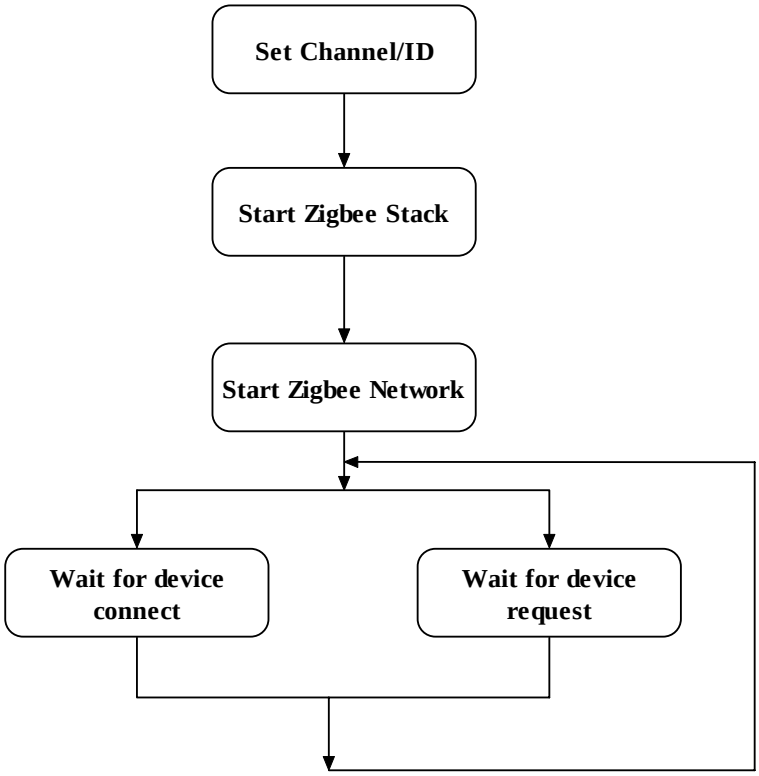

Figure 4: Working flow of Coordinator

- Set Channel/ID: Before starting Zigbee network, the working channel and network identification should be set first. After that, all network devices which belong to this network will work within the same channel and use the same ID to identify.
- Start Zigbee Stack: Initialize and start the Zigbee stack.
- Start Zigbee Network: Network started. After stack initialization, the network organized by the coordinator is created and wait for devices to join.
- Wait for Device Connect: The coordinator will wait for handling joining request from devices. If the request is passed, the device will get a network address which can be thought as its identification. These

acceptance and allocation works are processed by Zigbee stack which are running on the coordinator and devices. No user interruptions are required.

- Wait for Device Request: This part is for application use. During the simulation, devices often need to communicate with the coordinator and ask coordinator to execute some user instructions. The coordinator always keeps listening to these requests.

3.2 Local Controller

The local controller is designed to be used by users to control home appliances. Figure 5 shows the flow chart of the local controller.

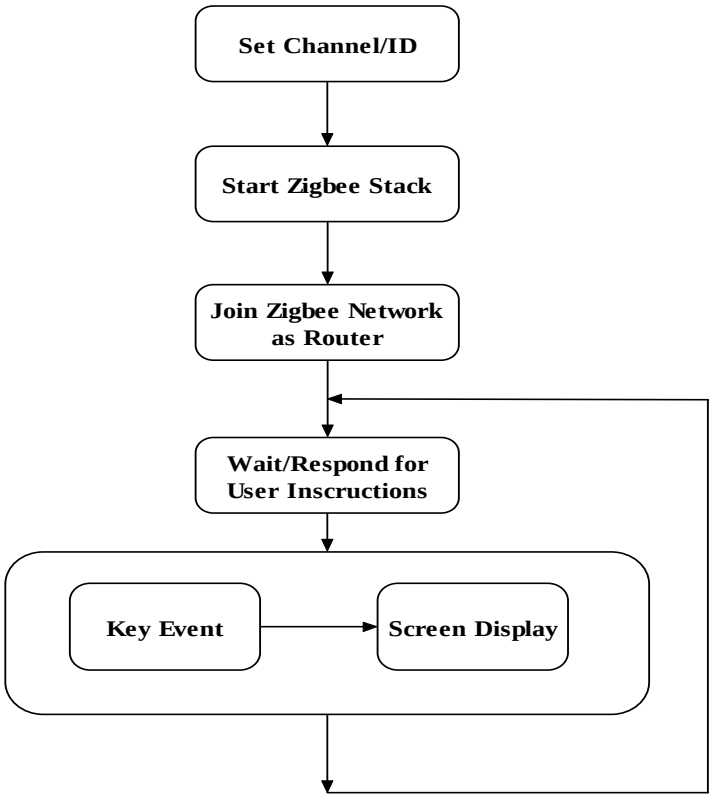

Figure 5: Flow chart of local controller

- Set Channel/ID: Initially, the controller sets the working channel and identification which are the same as what the coordinator use. The purpose is to make the coordinator recognize and accept it.
- Start Zigbee Stack: Start the Zigbee stack running on the controller. This stack will manage the processing of lower layer (MAC, PHY and NWK layer).

- Join Zigbee Network as Router: After the start of Zigbee stack, the controller will be accepted by the Coordinator and get a network address allocated by the coordinator.
- Wait/Respond for User Instructions: After joining the network, the controller is set to wait for user instructions and shows related display continuously. This includes Key Event & Screen Display. The controller is mostly used by the user to control the home appliances. The user instructions are recognized by the controller through pressing on-board keys. These keys are programmable and have certain meanings, e.g., up, down, back or enter. Each time the keys are pressed or some responses have been sent back from other devices, the screen will display corresponding content which can help users to make decisions.

3.3 Home Appliances

The home appliances are the target devices to be controlled by the controller or managed by the coordinator. In this simulation, we create some virtual home appliances according to the features of Zigbee technology. The method used by Zigbee technology to manage different applications running inside the application framework is to treat them as different "endpoint". Each Zigbee application can have up to 240 endpoints. Each endpoint is an independent instance which can be related with a corresponding sub-application running on one device. Figure 6 shows a brief relationship between endpoints. The 16-bit network address is the network identification of a Zigbee device allocated by the coordinator. Using the network address, other devices can find out the specified device easily. When the instructions from users reach the specified device, they can choose to communicate with a certain endpoint "inside" the device based on users' purposes.

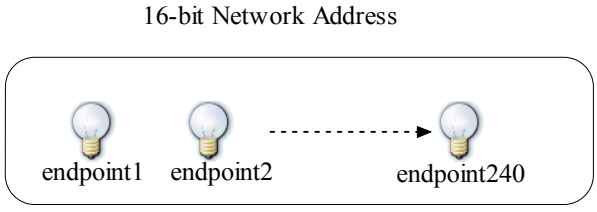

Figure 6: The brief relationship of endpoint

We suppose three kinds of services to run on one device: lights control service, windows control service and central heating temperature check service. Figure 7 shows the work flow of home appliances.

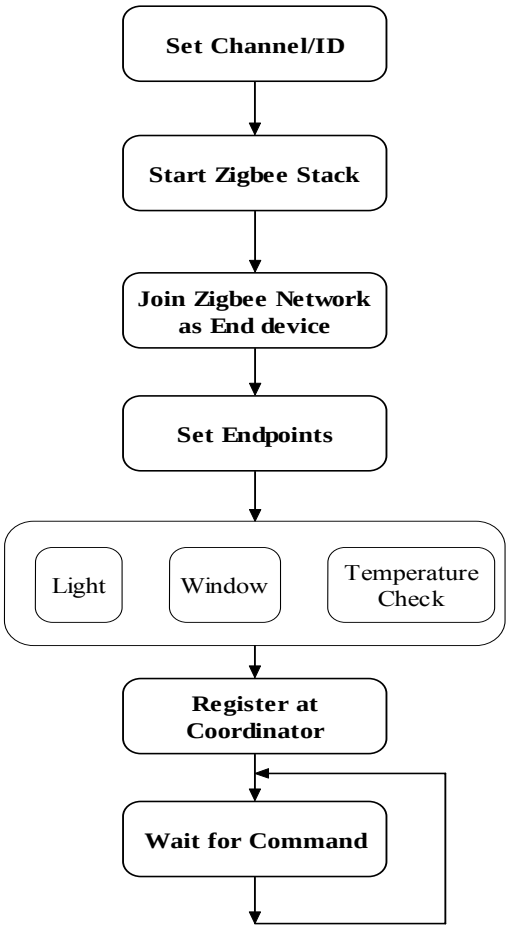

Figure 7: Work flow of home appliance

- Set Channel/ID: To make the coordinator recognize the home appliance, working channel and network identification need to be set first.
- Start Zigbee Stack: Start the Zigbee stack running on the home appliances. This stack will manage the processing of lower layer (MAC, PHY and NWK layer).
- Join Zigbee Network as End device: When related initialization work has been completed by the started stack, the home appliances devices join the network and get the network address meanwhile.
- Set Endpoints: After joining the network, the home appliances devices need to set up the virtual services. Numbers from 1 to 240 (inclusive) can be used as the service identification.
- Register at Coordinator: The home appliances need to register at the coordinator to make convenience for managing.

- Wait for Command: After all initialization work has been completed, the home appliances enter into the waiting state to prepare for receiving users' commands.

3.4 Router

The use of router in this simulation is to validate the extension ability of the network. Sometimes those unpredictable things may block the wireless signal, e.g., wall, stairs, door. Router can be seen as a kind of "repeater" when the end device is out of the range of the coordinator and it can help the coordinator to extend the network. There is no special application running on the router. Figure 8 shows the work flow of router.

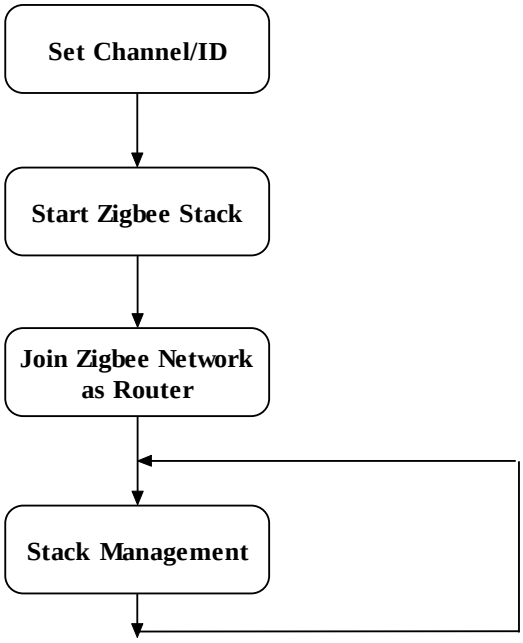

Figure 8: The work flow of Router

- Start Channel/ID: To make the coordinator recognize the router, working channel and network identification need to be set first.
- Start Zigbee Stack: Start the Zigbee stack running on the router. This stack will manage the processing of lower layer (MAC, PHY and NWK layer).
- Join Zigbee Network as Router: After the start of Zigbee stack, the router will be accepted by the Coordinator and get a network address allocated by the coordinator.

- Stack Management: When the router joins the network, the Zigbee stack designed for router will take charge of management. All messages needed to be routed will be handled automatically by the stack.

4. Simulation Process

In this section, we will introduce the process of simulation. Section 4.1 illustrates the deployment of all devices. Section 4.2 is a step-by-step explanation of simulation. Section 3 describes the simulation with router.

4.1 Simulation Illustration

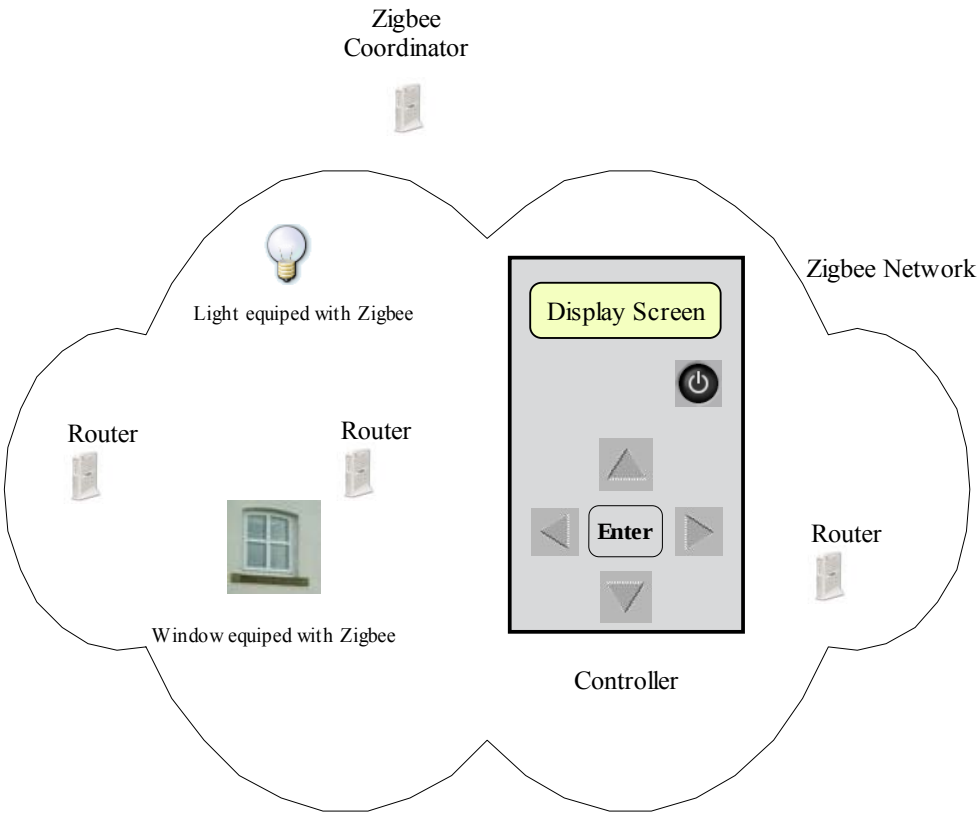

Figure 9: The illustration of deployment of home network

Figure 9 is the illustration of deployment of home network. There are no restricted rules to deploy the home appliances. The advantage of Zigbee technology is its support for mesh network. Wherever the devices are deployed, they always can find a way to connect to the network. Sometimes this connection needs the help of routers if the distance between the appliances and the coordinator is too far away.

4.2 Simulation Process

4.2.1 Simulation Devices

Figure 10 shows the devices we use in the simulation. There are one coordinator, two end devices and one controller. Figure 11 describe the detail of the controller. It consists of one screen and four pre-defined buttons. Navigation button is used to choose items. Back button is used to back to the last page. Enter button is used when an item is chosen. Reserved button is for future use.

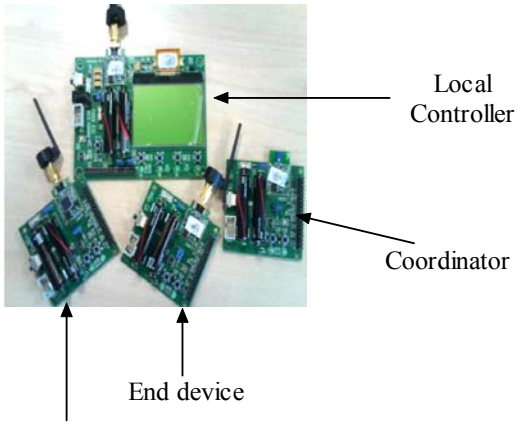

Figure 10: Simulation devices

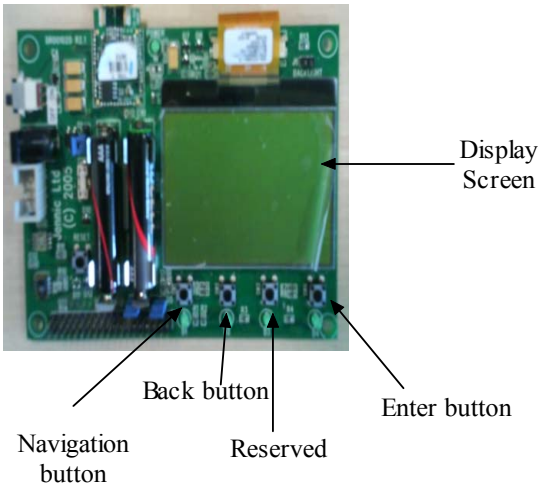

Figure 11: Controller detail

4.2.2 Simulation

When the coordinator, controller and two devices started to work, the screen of the controller will display the current state of the operation. The first display is the introduction screen. When users press "start" (enter button), the controller will try to communicate with the coordinator and get the available services which have registered. Figure 12 and figure 13 show the introduction screen and the available services.

Figure 12: Welcome display

Figure 13: Available services

If users choose the "Central Heating" service and press "enter" button, the screen will display the two rooms which provide the selected services. User can choose one room and press "enter" button again, the selected "room" will send back the current temperature reading instantly. Actually the temperature reading is from the temperature sensors integrated in the selected device. Figure 14 and figure 15 show the room selection and temperature reading.

Figure 14: Room selection

Figure 15: Temperature reading

Then we press “back” button to the available service display and choose “Windows Control” service. The room selection is still the same as the choice before. When the “Windows Control” service is selected, the current state of the “Windows Control” will be displayed. Figure 16, 17, 18 shows the service choice. In figure 17, the right light on the end device is defined to indicate the state of the windows control service.

Figure 16: Windows Control Service is chosen

Figure 17: Room selection

Windows Control State Indicator

Figure 18: The state of the windows control service

When users choose to press “Change” button (enter button), the state of the windows control service will change. In figure 19, the light is on which indicates the change of the service state. The screen also displays the change.

Figure 19: Windows control service change state

Return to the service page, we choose to enter “Light Service” and the “Hall” room. Figure 20, 21 and 22 show the selection.

Figure 20: Choose light service

Figure 21: Room selection

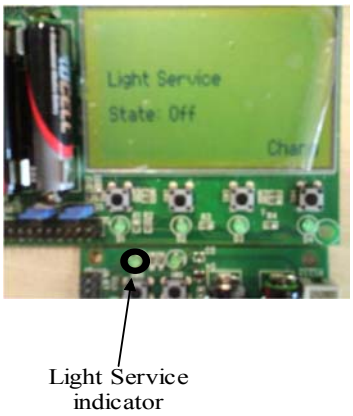

Figure 22: Current state of the light service

In figure 22, the left light is used to indicate the state of the light service. This is different from the use in "Windows Control Service". The reason is that we make these two lights work as two separate end points. They can be treated as two different and independent sub-applications running on the same device. The use of end points shows that Zigbee technology gives each device a potential to extend services.

If users choose to press "change" button, the state of the light service will be changed. Figure 23 shows the change.

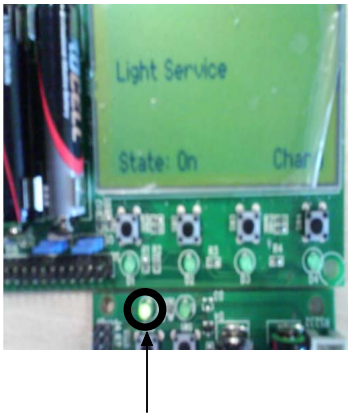

Figure 23: The change of light service

4.2.3 Simulation with Router

To test the effect of the communication when the controller is far away from the devices, we did the simulation again with the use of router device. As mentioned above, the router device is a "repeater" which helps transfer radio signal by routing messages. Figure 24 is the illustration of simulation with router. We did this simulation in two steps:

- Step I: Start the coordinator, light service and controller. As the distance between the light service and the controller is too far away, the controller can not find out the light service.
- Step II: Start the router. After that, the controller found out the service successfully, and can control the service like the simulation did in section 4.2.2.

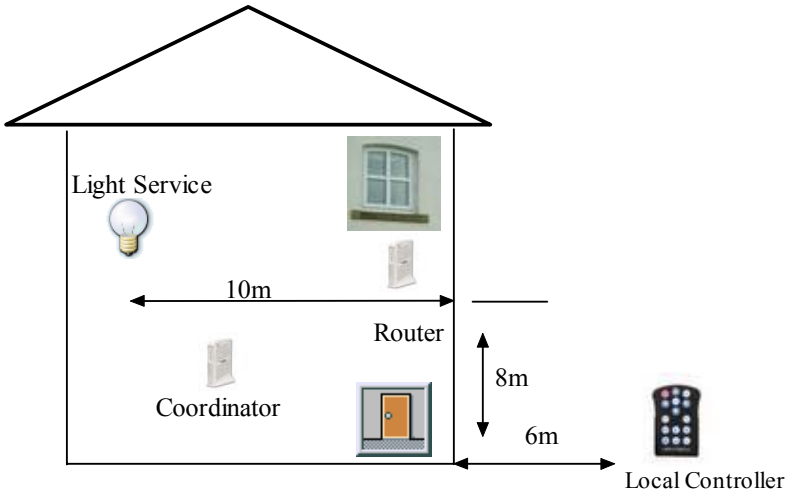

Figure 24: Illustration of simulation with router

5. Simulation Result

The software simulation in this state is to establish the two-way communication between the controller and "virtual home appliances". Using the Zigbee technology, we have achieved this purpose and provided a simple control model for application use.

This achievement is based on three main points:

- Zigbee stack help developers to manage the NWK layer, MAC layer and PHY layer. Developers do not have to attach much attention on these bottom layers and can devote their minds on application development.
- The use of end points extends the usability of the applications and makes the device control easy to be achieved.
- The use of router device helps the network extend its coverage. Since the processing of routing protocol is handled by the Zigbee stack and it does not need developers' manual operation, the difficulty of application development will not be affected.

6. Contribution to the Next State

Two contributions are made by the software simulation work for the next state of the project:

1. Validate the feasibility of two-way communication which will be applied for home applications.

2. The simple control model provides a reference for the more complex application development in the next state.

Annex A

Build and Install Application

The application code is suitable for Jennic Zigbee Evaluation Toolkit JN5121-EK010.

The folder containing this report includes a sub-folder whose name is “HomeController”.

Copy this sub-folder in to the development directory:
<JENNIC_DEVELOP>\SDK\Application

Then do the following step:

Step I: Start Cygwin and navigate to the folder:
<JENNIC_DEVELOP>\SDK\Application\build

Step II: Build the code for all devices (HomeController.bin, HomeCoordinator.bin, HomeEndDevice.bin, HomeRouter.bin) by typing command:

make clean

make

Step III: Using Jennic Flash Programmer to download binary file to the target device.

The development software can be downloaded using the link below:

http://www.jennic.com/support/view_file.php?fileID=0000000115