Design and Implementation of ZigBee based URC Applicable to Legacy Home Appliances

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Abstract — *There are many various CE (Consumer Electronics) home appliances being controlled and managed with each different remote control unit based on IR(Infra-Red) signal in our home environments. A universal remote control (URC) unit is an integrated device for controlling these various devices (with a single one). To control them based on IR control signal, the URC unit has to have many pre-programmed control codes for controlling them because each home appliance is controlled with each its identical IR control profile. In case of appliances from different vendors, the IR profile for two different CE devices may be represented with different format even though the type of these appliances is same, such as television sets.*

In this paper, we propose a novel ZigBee based URC, called Z-URC in this paper, applicable to multiple legacy home appliances. The proposed Z-URC controls dynamically multiple legacy IR controllable digital CE appliances based on IEEE802.15.4, especially ZigBee protocol. The proposed scheme consists of two main components; Z-URC(ZigBee based Universal Remote Control) and Z2IR(ZigBee to IR) conversion module. The one is an integrated remote control unit using ZigBee based wireless network technology, WPAN(wireless personal area network) and the other is a Z2IR(ZigBee to IR) conversion module which converts a control message transferred through the ZigBee network into an IR typed control signal.

In the proposed scheme, the list of CE devices to be controlled by the proposed URC is dynamically reconfigured. It is based on his location as a consumer with the proposed Z-URC goes from a room to any other place in his house. The Z-URC gets some information for its controllable devices' product identifier (ID) and vendor ID from WPAN (wireless personnel area network) based on ZigBee. A user may configure the two IDs for his CE appliances. Based on this feature, the module informs the Z-URC a target appliance's information. And, we apply a novel mechanism to our proposed scheme to minimize power consumption of the Z2IR module, which is based on ZigBee devices' ON/OFF control mechanism using multiple timers. [1]

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Index Terms — Infra-Red, Universal Remote Control, ZigBee, IEEE802.15.4, WPAN, Power Consumption

I. INTRODUCTION

Many various home appliances, most of which are controlled by IR(Infra-Red)[1][2] signal based remote control unit, are used in today's digital home environments. A universal remote control (URC)[3] unit is an integrated device for controlling many different consumer electronics (CE) home appliances with a single one. To control these various CE devices based on IR control signal, the URC unit has to have many pre-programmed control codes for controlling them because they are controlled with many different types of IR profile stated with leader code, control code, carrier frequency, duty cycle, duration and so forth. In addition to this difficulty, the IR based URC can control any devices under the only condition of line of sight.

In this paper, we propose a dynamic control scheme for controlling and managing IR controllable multiple legacy CE appliances, which is based on IEEE802.15.4[4]-[6], especially ZigBee[7] protocol. The proposed scheme uses two types of main components. One is a URC unit using ZigBee based wireless network technology, WPAN(wireless personal area network)[4][7][8]. Another is a Z2IR(ZigBee to IR) conversion module which converts a control message transferred through the ZigBee network into an IR typed control signal. The ZigBee based URC, called as Z-URC(ZigBee based universal remote control), operates as a ZigBee coordinator in our proposed scheme, while Z2IR modules, which are attached to target appliances, operate as ZigBee devices.

In the proposed scheme, the list of CE devices to be controlled by the Z-URC is dynamically reconfigured. It is based on his location as a consumer with the Z-URC goes from a room to any other place in his house. That is to say, the Z-URC shows a list of CE devices to be controllable with it. The proposed Z2IR contains only a specific IR control code for its target appliance, which codes is initialized and installed to the Z2IR module during setup procedure. A user may configure its product and vendor identifiers (IDs) of the home appliances to be controlled by the IR control signal from the module. Based on this feature, the module informs Z-URC target appliance's information and takes its IR control codes for its target appliance through ZigBee WPAN. And, we apply a novel mechanism to minimize power consumption of the Z2IR module, which is based on ON/OFF mechanism of ZigBee devices using

multiple timers. This paper show the implementation of the proposed ZigBee based URC mechanism applicable to legacy IR controllable CE devices.

The remainder of this paper is organized as follows. We first describe and review 'IR remote control' being used in most CE appliances to control them and introduces URC to control many home appliances with a remote control unit. Next, we propose a ZigBee based URC including system configuration and its algorithm to control dynamically multiple IR controllable CE appliances. We then show the implemented hardware results and illustrate their operation. Finally, we present our conclusions.

II. REALTED WORKS

A. IR Remote Control

To help the user's control to many various home appliances without touching directly, most of them are controlled and managed by remote control mechanism. IR based remote control mechanism is a representative one of remote control for CE devices. Fig. 12 shows a typical frame structure for the IR control stream used in IR remote control mechanism. In general, the control stream consists of lead code to indicate the starting point of an IR control frame, custom code and data code. 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' or '0', for each field [1][2].

Unfortunately, there are some problems in implementing a URC to control all CE appliances with only a single remote control. The reason is that all IR based remote control don't have same characteristics in these above components; carrier frequencies, existence of lead code, signal definition for logic '1' or '0', signal duration, and so forth. Additionally, there are some differences even in codes for control message [1][2]. That is to say, the frame structure of an IR remote control shown in Fig. 1 is only for reference.

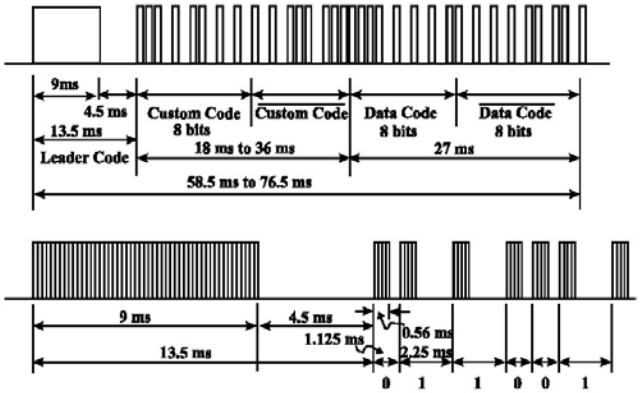

Fig. 1. Typical frame structure IR signal stream for controlling a CE appliances

B. Universal Remote Control (URC)

In these days, there are many different vendors and different product types of home appliances and systems in digital home environment. As described in previous section, most of them are controlled and managed with IR based remote control. We therefore can consider that these CE home appliances being controlled by legacy IR control scheme are working under the control of only a single URC using legacy IR control as shown in Fig. 2.

All CE devices and systems are normally controlled by legacy IR signal, but their control codes are not same format; whether the lead code exists or not, carrier frequency, each bit's duty cycle, duration, and so forth. To control them based on IR control signal, the URC unit has to have many pre-programmed control codes for controlling them. In case of ones from different vendors, the IR profile for two different CE devices may be represented with different format even though the type of these appliances is same, such as television sets.

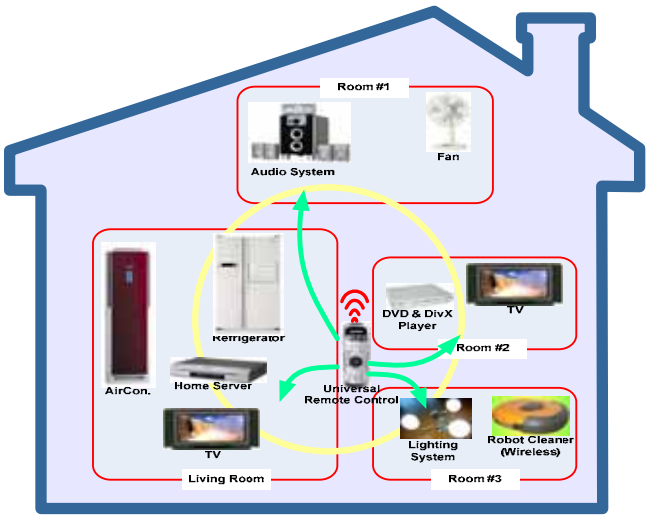

Fig. 2. IR based CE Devices Control by Universal Remote Control Unit

Let's consider our home environments that all these various devices are deployed and used at any spaces; living room, room #1, room #2 and room #3 in our home as shown in Fig. 2. In the home environments shown in Fig. 2, we have to be able to control and manage all four home appliances of an air conditioner, a home server, a refrigerator and a television set with a single URC unit in the living room. To control all four devices with the only URC unit, the URC has to have four different groups of IR control code for each appliance. And, a user has to select his necessary device and its vendor from URC's complex menu.

If a user with the URC moves to room #1, #2 or #3, the embedded IR control code group is to be changed respectively into new IR control code group to control the devices in new room. If the URC contains all IR control code group for controlling the CE appliances to be used and deployed in the home environments, we can control all

devices wherever the user is. But, the user has to select his target item to control from the many contents on the URC's control menu according to its philosophy. Most current URC using above operating method is still bothering to consumer.

In this paper, we want to propose a novel scheme to resolve effectively this inconvenience. Our proposed control scheme is to overcome some problems and some inconvenience owing to these environments. In addition to this concept, we are going to add a solution using ZigBee network mechanism.

III. Proposed ZigBee based Universal Remote Control

A. Overall System Configuration and Control Architecture to Control CE devices with Z-URC

In this paper, we propose a novel control mechanism based on ZigBee WPAN network for various legacy consumer appliances and show its implementation. Fig. 3 shows the overall system configuration for the proposed ZigBee based URC for controlling multiple legacy IR controllable CE devices with only single Z-URC. All control commands to control these multiple CE appliances are generated by this single remote control unit. The generated control command from the Z-URC is then transferred to a Z2IR(ZigBee to infra-red) module over ZigBee based WPAN network. The control message is finally converted into an IR typed control stream in the Z2IR module for controlling a target device. Internetworking between a home server[9]. The proposed Z-URC may get the control profile and provide other services, VoIP(voice over IP) and user interface (UI) functions such as keyboard and mouse for home server. Communication between a Z-URC and Z2IR modules is based on IEEE802.15.4 ZigBee WPAN network as shown in Fig. 3. The WPAN network is dynamically reconfigured depending on the location of a user with the Z-URC.

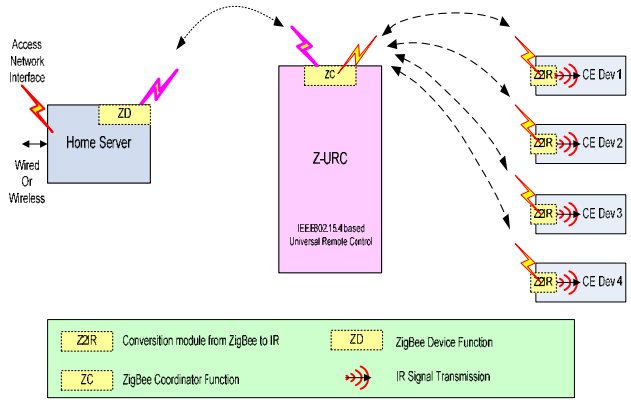

Fig. 3. System Configurations to Control Multiple Legacy IR Controllable Consumer Appliances with Z-URC

B. Control Signal Conversion Module

Fig. 4 shows an example of CE home devices with a Z2IR module in the system configuration for the proposed Z-URC based control scheme. As shown in Fig. 4, each Z2IR module is attached on each CE home appliances. Each Z2IR conversion module can be configured with two configuration parameters, vendor and product IDs. The two types of ID are transferred to the Z-URC to inform some information about the CE home devices using bidirectional communication characteristics of ZigBee WPAN network. Based on these two IDs, the Z-URC can update the list of CE home devices that it can control.

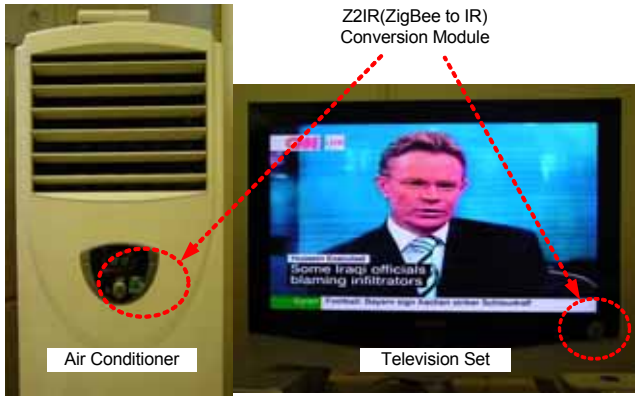

Fig. 4. Example of CE Devices with Z2IR for the Proposed Control Scheme

Throughout the ZigBee WPAN network, the Z2IR module receives a control command from the Z-URC for the CE home device to which is attached. Based on these two IDs, product ID and vendor ID, preconfigured by user operation or automatically for CE home appliances, the Z2IR module generates an IR typed control stream applicable to manage its target CE device. Using this mechanism, we can control and manage all CE home appliances with only a Z-URC.

C. System Operation and Control Flows

As shown in Fig. 5, the system operation consists of two phases, one is to configure a WPAN described as ① to ⑥ in Fig. 5, and the other is normal operation phase described as ⓐ to ⓖ in Fig.5.

The first phase, WPAN configuration phase, operates as following descriptions in detail. The Z2IR module monitors periodically whether a configuration command from a Z-URC for a new WPAN is or not. According to the configuration phase shown in Fig. 5, the Z-URC configures a new WPAN if a Z2IR module receives a WPAN configuration command during the interval for checking a new WPAN configuration command from any Z-URC. This configuration command is generated on receiving a new configuration command from a user to visualize all controllable CE devices or periodic self-created command based on a timer. The message is transferred using a broadcasting mechanism over ZigBee WPAN network. On receiving the configuration command, the Z2IR module

then requests to be registered as a member of the WPAN to Z-URC. Then, the Z-URC informs that the Z2IR becomes a member of the WPAN. After updating home devices' list to be controlled and control information, the Z-URC finally displays the list of home appliances that it can control through normal operation described below.

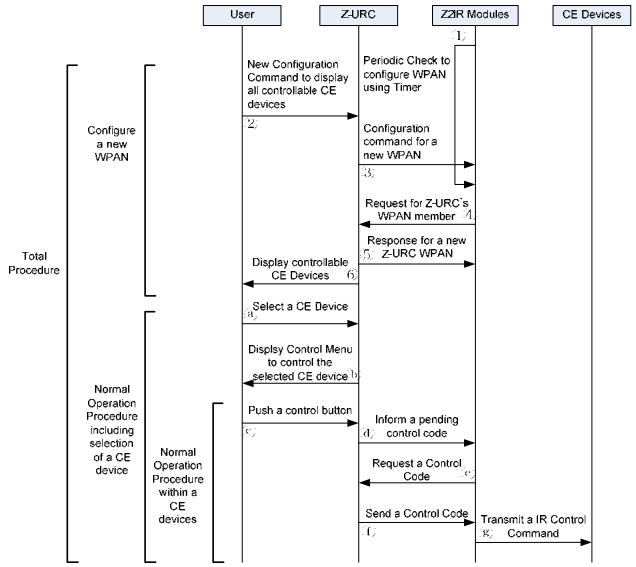

Fig. 5. Overall Control Procedure using Z-URC

The second phase, normal operation phase, is configured as follows.

- If a user with the Z-URC wants to control a specific CE device, he selects it from controllable device list which is displayed on the Z-URC. The control list is configured automatically based on ZigBee WPAN network in above the first phase.
- A control menu for his target device is visualized on the Z-URC's LCD(Liquid Crystal Display).
- On selecting a command from the control menu on the Z-URC by user, the selected command is transferred to target Z2IR conversion module based on IEEE802.15.4 ZigBee protocol. This procedure consists of the multi-step functions which are described as ⓓ to ⓕ in Fig. 5.
- Finally, the target Z2IR module makes and transmits a corresponding IR command stream to the control command received from ZigBee based WPAN.

The operation procedure for the proposed Z2IR conversion module is shown in Fig. 6. The procedure consists of two phases, 'initialization and configuration' phase and 'normal operation' phase. The normal operation phase is specified in detail on the right side in Fig. 6. The proposed algorithm working with multiple timers is designed to minimize the power dissipated in the Z2IR conversion module. The 'initialization and configuration' phase consists of following three steps.

- step 1 : Configure vendor ID and device ID
- step 2 : Z-URC detection phase
- step 3 : Configure IR profile

The module always works based on three steps whenever it finds initialization condition.

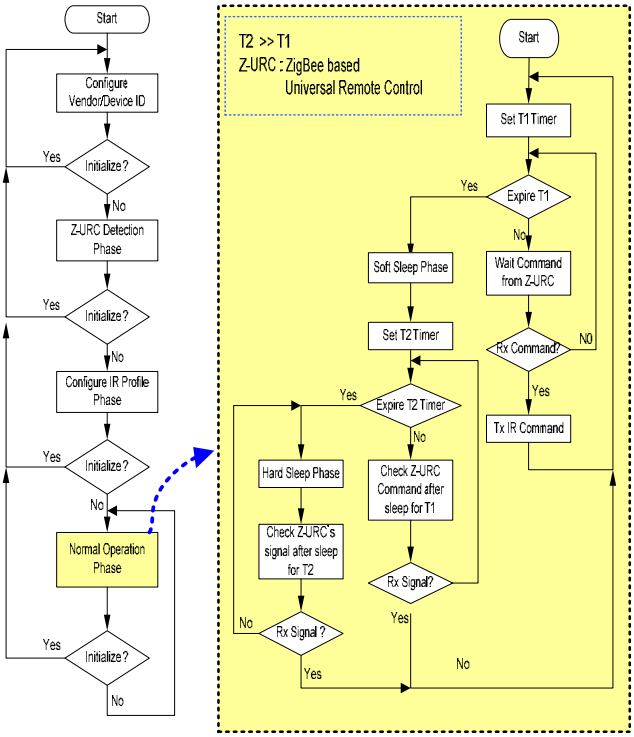

Fig. 6. Operation Procedure for Z2IR Module

In normal operation phase, the Z2IR module uses two timers with different size, T_1 and T_2. If the Z2IR module doesn't find a command from the Z-URC before T1 timers expires, the Z2IR module goes to 'soft sleep' phase. Otherwise, the Z2IR module transmits an IR typed control stream on receiving a command from the Z-URC. At the same time, the T1 timer is initialized with T1.
The Z2IR module in 'soft sleep' state becomes 'ON' state every T1 time and checks whether a command from Z-URC exists or not for T2 time. During this operation, if the timer T2 expires, the Z2IR module goes 'hard sleep' state. Then, the Z2IR module in 'hard sleep' state wakes-up into 'ON' state every T2 time and checks a command from the Z-URC. If the Z2IR module detects a command from Z-URC at any state, 'soft sleep' or 'hard sleep', it goes to 'normal operation' state. This mechanism minimizes the power dissipated in the Z2IR module.

IV. System Implementation

We implemented two hardware components to verify our proposed ZigBee based universal control scheme applicable to legacy IR controllable home appliances. These are ZigBee based universal remote control(Z-URC) unit and ZigBee to Infra-Red(Z2IR) conversion module.

A. *ZigBee based Uinversal Remote Control Unit*

Fig. 7 shows a Z-URC implemented to control multiple IR controllable CE devices and to provide some additional home network function including VoIP and control of home server. As its control menu shown in Fig. 7, the implemented Z-URC can control several digital home devices such as television set, air conditioner, DVD player, CATV setop-box, and so forth. The list of controllable devices is varied dynamically based on user's location with the Z-URC. That is to say, the list may be reconfigured based on information acquired from ZigBee WPAN between a Z-URC and multiple Z2IR conversion modules. In case of our home server, it functions as keyboard and mouse using ZigBee networking.

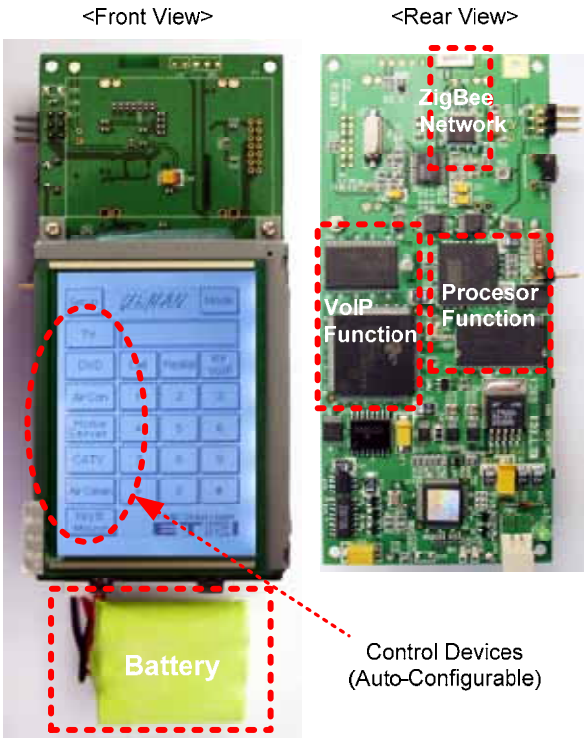

Fig. 7. ZigBee based Universal Remote Control(URC)

B. *ZigBee to IR Conversion Module*

Fig. 8. ZigBee to IR(Z2IR) Conversion Module

We implemented a prototype hardware and software for the URC to control all kinds of CE appliances with only a single one. As described in previous section, our proposed control scheme is based on ZigBee WPAN and a 'ZigBee to IR' conversion module, called as a Z2IR, is used. The conversion module does a key role in our proposed dynamic control system to manage all home appliances. Fig. 8 shows two kinds of solution implemented for this conversion function.

The implemented solution uses 2.4GHz band of RF frequency. The implemented hardware is installed to a target CE appliances nearby IR receiver as shown in previous Fig. 4. It receives a control message from a Z-URC and sends an IR typed control signal to its target home device after some processing. The processing is done on embedded processor. The embedded processor processes the ZigBee software based on the proposed algorithm with a 'ON' and 'OFF' control scheme to minimize power consumption in Z2IR module. It is based on two different timers as illustrated in previous section and shown in Fig. 6.

V. Conclusion

In this paper, we proposed a novel control scheme to control dynamically many different CE appliances, controlled with legacy IR remote control, with only single remote control device. The scheme is based on IEEE802.15.4, especially ZigBee protocol. We implemented two kinds of hardware components, a Z-URC and a Z2IR conversion module. The implemented Z-URC controls multiple IR controllable CE devices based on IEEE802.15.4 and provides some additional home network function including VoIP and control of home server.

In the proposed scheme, the list of CE devices to be controlled by the proposed URC is dynamically reconfigured. It is based on his location as a consumer with the proposed Z-URC goes from a room to any other place in his house. The Z-URC gets some information for its controllable devices' product identifier (ID) and vendor ID from WPAN (wireless personnel area network) based on ZigBee. A user may configure the two IDs for his CE appliances. Based on this feature, the module informs the Z-URC a target appliance's information. And, we apply a novel mechanism to our proposed scheme to minimize power consumption of the Z2IR module, which is based on ZigBee devices' ON/OFF control mechanism using multiple timers.

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