Design and implementation of wireless home network system using Home Network Control Protocol

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Abstract: This paper describes the design and implementation of a wireless home network system using Home Network Control Protocol (HNCP) called the wireless HNCP home network system. For wireless interfaces of HNCP, IEEE 802.11b and IEEE 802.15.4 standard protocols are considered. With the implementation of the wireless HNCP home network system, a simple analysis about coexistence between IEEE 802.11b and IEEE 802.15.4 is achieved. Through the implemented wireless HNCP home network system and the analytical results about the coexistence between both two different wireless protocols, the feasibility of the wireless HNCP home network system is shown.

Keywords: Home Network Control Protocol(HNCP), IEEE 802.11b, IEEE 802.15.4, Coexistence

1. Introduction

Several attempts to construct a home network system through proprietary solutions and standards have been considered[1]. As there is no dominating technology or standard in the home network system, it is expected that two or more home network technologies or standards are used to implement the home network system. The home network system is categorized by its application such as a multimedia network, a data network, and a control network. Among three networks, the control network is one of essential solutions for controlling and monitoring the networked home appliances(NHAs). There are several demands and restrictions such as easy-installation, easy-understanding, and easy-maintenance in the control network [2]. To meet these demands and restrictions, power line communication (PLC) technologies and wireless technologies have become a keen interest issue for the home network system.

Home Network Control Protocol (HNCP) for controlling and monitoring NHAs mainly targets on low-speed control network based on PLC in a home network. HNCP has already chosen as the de facto standard for home network protocol in republic of Korea. HNCP has the four-layered protocol architecture. To guarantee the flexibility of HNCP, the physical layer and the MAC link layer are not specified. HNCP specifies the only guidelines of these layers[3]. Because of the flexible characteristics of HNCP, HNCP supports and adopt various physical mediums. According to this point, several wired and wireless technologies can be adopted to physical medium of HNCP.

Recently, the home network system exhibits a tendency to the integration of the wired and wireless home network system. The need of integration of wired and wireless home network system using HNCP is required. Therefore, this paper proposes the wireless HNCP home network system.

There have been many wireless standards such as IEEE 802.11b(WLAN)[4], IEEE 802.15.1(Blutooth)[5], IEEE 802.15.4[6], HomeRF[7], HiperLAN[8], and so on. Among them, IEEE 802.11b is the most popular wireless protocol for wireless LAN communications, tested and deployed for several years in corporate, enterprise, private and public environments (e.g. hot-spot areas), and is one of the favored technologies for home networking[9]. IEEE 802.15.4 is a protocol and the interconnection of devices via radio communication in a personal area network (PAN). IEEE 802.15.4 is being designed to be used in a wide variety of applications which require simple wireless communications over short-range distances with limited power and relaxed throughput. Therefore, this paper uses IEEE 802.11b and IEEE 802.15.4 for the implementation of the wireless HNCP home network system.

In addition, with the implementation of wireless HNCP home network system, the simple analysis about the coexistence between IEEE 802.11 and IEEE 802.15.4 is achieved.

This paper is organized as follows. In Section 2, the overview of the HNCP is briefly presented. The design and implementation of wireless home network using HNCP is presented in section 3. In Section 4, the analysis about the coexistence between the IEEE 802.11b and the IEEE 802.15.4 is presented. Finally, a conclusion is given in Section 5.

2. Overview of HNCP

HNCP has several key features as follows,
- Multi master structure
- Four-layered protocol architecture
- Categorized address system
- Standard message set
- Standard device-modem interface structure

2.1. Multi-Master Structure

HNCP has multi master structure. In home environment, several home appliances, such as refrigerator, TV, and PC have their own user interface, and they are very intelligent systems that can control other devices. To enable user convenience, it should be guaranteed.

2.2. Four-Layered Protocol Architecture

HNCP is four-layer protocol, physical layer, data link layer, network layer, and application layer. However, to guarantee the flexibility of modem, physical layer and MAC sublayer are not specified. HNCP only specified guidelines of these layers. Fig. 1 is each layer's protocol data unit format.

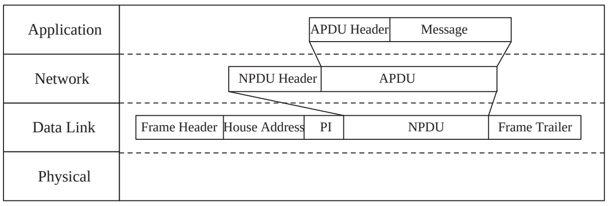

Fig. 1. Four-layered protocol architecture

2.3. Categorized Address System

The address of network node is categorized with product code, and location code or logical code that is defined by flag. Server can make group addresses by simple bit operation. Fig. 2 shows the structure of address field.

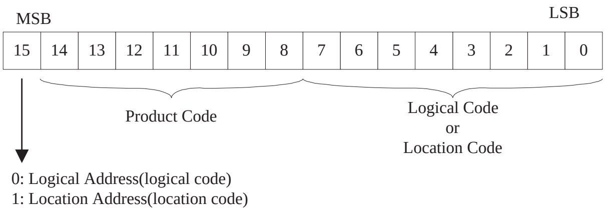

Fig. 2. Categorized address system

2.4. Standard Message Set

Each message is composed of message code, input augments, and return augments. Message code represents command of action in home appliances. The received device may response with return augments. Three message sets are classified in HNCP, general message set, device specific message set, and vendor-specific message set.

2.5. Standard Device-Modem Interface Structure

In HNCP, a standard device-modem interface is specified as HNCP interface protocol (HIP) which is an additional protocol of HNCP. The interface between a device and a modem is generally implemented by RS-232C serial communication in low-rate PLC. In HIP, the request/response message with ACK primitives is used, and the HIP message sets for the initialization and the information exchange between the device and the modem are specified.

3. Implmentation of Wireless HNCP Home Network System

3.1. Implementation of Wireless Home Network System using IEEE 802.11b

For the development of the wireless HNCP home network system based on IEEE 802.11b, the wireless PCI adapter (DWL-520+) as a WLAN card are used, and HNCP layer including APDU, NPDU, and DPDU is implemented on the network device.

Fig. 3. D-Link Wireless PCI adapter(DWL-520+)

Fig. 3 shows the D-Link Wireless PCI adapter(DWL-520+). The chip of the board is D-LINK's ACX100 chipset. This is for high rate data transmission among computers. The wireless HNCP home network system based on IEEE 802.11b is developed by using Socket protocol of Linux system; Gentoo Linux system (kernel version2.6.5) and WLAN Linux driver (acx100-0.2.0-pre6_plus_fixes_15.tar.bz2)[10].
Fig. 4 shows the network architecture on Linux system for wireless HNCP home network system. Because development environment is Linux system, the HIP of the HNCP structure is not implemented.

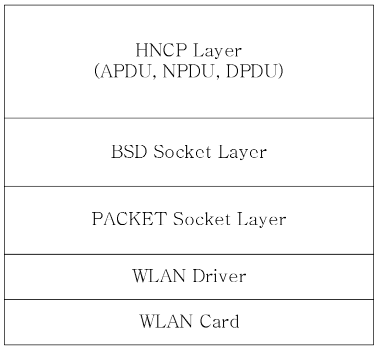

Fig. 4. Network architecture on Linux system for wireless HNCP home network system

As shown Fig. 4, the HNCP frame is directly transmitted to WLAN driver through the socket interface supporting Linux system. BSD socket layer exists to support the interface of system. PACKET socket layer serves as the interface transmitting HNCP frame from upper layer to the network device.
Fig. 5 shows the basic network flow based on socket between Master and Slave for HNCP frame transmission.
Master and Slave are connected with network devices through socket() and bind() for network communication, and use sendto() and recvfrom() for transmission and reception of the HNCP frame. The socket() is composed of three factor; addr_ family, type, and protocol. the addr_ family, the type, and the protocol define protocol family, socket type, and used socket's protocol respectively. To connect with PACKET socket layer and transmit the HNCP frame through the network device, the bind() is needed. The factor of the bind() assumes the form of the address structure.
According to the registration sequence, network devices are

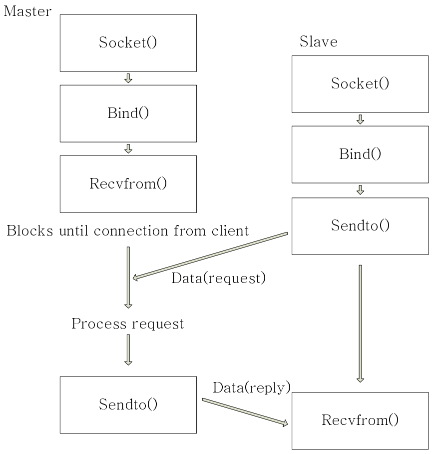

Fig. 5. Basic network flow for HNCP data relay

named by "wlan0, wlan1,...". To transmit the HNCP frame to the network device, the sendto() supported by BSD socket is available. The address type between TCP/IP and Packet socket layer is different in the sendto(). The address in TCP/IP is the destination address. However, one in Packet socket layer is the network device address connected with Packet socket layer. An program example for the implementation of the wireless HNCP home network system based on IEEE 802.11b is presented as follows.

```
#define WLAN_P_HNCP      0x809D   // protocol value for wireless hncp
 main() {
   int fd;
   fd = socket(AF_PACKET, SOCK_PACKET, htons(WLAN_P_HNCP));
   .....
   // define which network device driver is used for packet_socket
   my_addr.sa_family = AF_PACKET;
   my_addr.sa_data = "wlan0";

   // bind the socket into the network device
   bind(fd, (struct sockaddr *)&my_addr, sizeof(struct sockaddr));
   .....
   // hncp data generation
   .....
   // transmission of hncp data
   sendto(fd, hncp_data, data_len, 0, (struct sockaddr *)&my_addr, sizeof(struct sockaddr));
   .....
 }
```

After receiving the HNCP frame to the network device through the wireless channel, this frame is transmitted by the recvfrom(). The recvfrom() has the behavior of stand by mode until receiving HNCP frame. Also, the recvfrom() has same address concept with the sendto().

Also, because WLAN driver supported in [10] is used for TCP/IP, the modification of WLAN driver is needed so that the HNCP frame is transmitted to the network device directly. The HNCP frame transmitted from upper layer to the network device should be convert into the WLAN frame. The function that is responsible for this service is acx100_ether_to_txdesc() for transmission. In the opposite direction, acx100_rxdesc_to_ether() is for reception.

3.2. Implementation of wireless Home Network System using IEEE 802.15.4

The wireless HNCP home network system on network devices supported IEEE 802.15.4 is implemented with Korwin Zigbee development kit as shown in Fig. 6.

The MCU of the development kit is Atmel's ATMEGA128L which has 128K bytes of programmable flash and 4Kbytes of

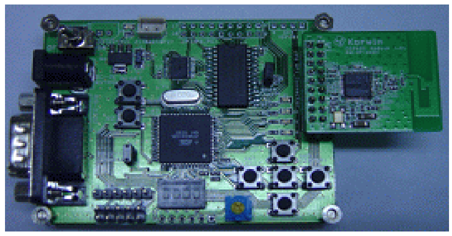

Fig. 6. Korwin zigbee development kit

data memory. The radio transceiver on the development kit is CC2420 made by Chipcon which is a 2.4GHz RF transceiver for IEEE 802.15.4. The development kit offers the similar function such as power-line modem.

Fig.7 shows the structure of the implemented wireless HNCP home network system using IEEE 802.15.4. It has a Master/Slave structure including a home server and a NHA(an air conditional). In Fig. 7, the home server configures the network, controls, and monitors NHA.

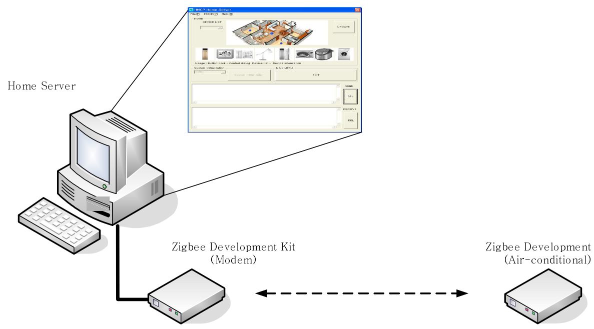

Fig. 7. Structure of wireless HNCP home network system based on IEEE 802.15.4

Fig. 8 shows the architecture of HNCP based on IEEE 802.15.4. The communication between a host and HNM is accomplished by RS-232C serial interface. The HIP is used to guarantee the interoperability, and to support the function of host-HNM initialization, transparent communication and information exchange between the host and the HNM. As shown in Fig. 8, the architecture of HNCP based on IEEE 802.15.4 is divided into two parts; HNCP frame such as APDU, NPDU, and DPDU, and HIP frame related with serial interface between the host and the HNM. The HIP is implemented in HNCP based on IEEE 802.15.4. As the physical layer and the MAC link layer are not specified in HNCP, HNCP based on IEEE 802.15.4 uses physical layer and MAC layer of IEEE 802.15.4. When a user transmits a message, the message and the arguments are appended into the HNCP Tx function. After encapsulating the message and the related arguments to HNCP Tx frame format, it is appended into the HIP Tx function. After getting the HNCP Tx frame, the packet length, and the packet type, the HIP generates and transmits the HIP Tx frame while it runs the ACK waiting function which is run for the ACK Time Out period. In the HIP, only one packet retransmission is allowed.

In the case that the host receives the packet from the HNM, the HIP Rx function in the host run firstly. As soon as the packet is received, the HIP tries to verify whether it follows the HIP frame format checking STX, ETX, CheckSum, and PktLength. The HNCP Rx function checks if the received address is its own address. If the received address is the same to its own address, the packet is disassembled and finally the message and its related arguments are extracted and are reflected into the user interface.

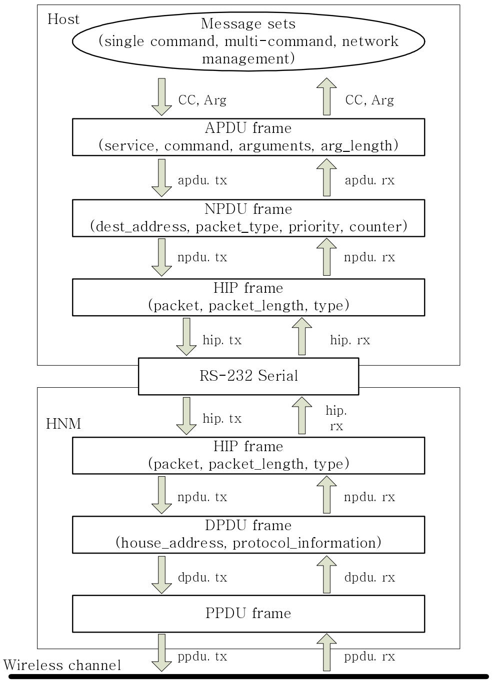

Fig. 8. Architecture of wireless HNCP

For transaction between MAC sublayer of IEEE 802.15.4 and HNCP layer, two functions are used; mcpsDataRequest() and mcpsDataConfirm(). The mcpsDataRequest() is generated when the HNCP frame is to be transferred to a peer service specific convergence sublayer(SSCS) entity. On receipt of the mcpsDataRequest(), the MAC sublayer begins the transmission of the supplied HNCP frame. On the other hand, the mcpsDataConfirm() is generated by the MAC sublayer in response to an mcpsDataRequest(). The mcpsDataConfirm() is used to inform a status of HNCP frame transmission from the server to NHA. On receipt of the mcpsDataConfirm(), the SSCS of the initiating device is notified of the result of its request to transmit. The result is transferred from MAC sublayer to HNCP layer.

Fig. 9 shows the screenshot of the home server and the device dialogs.

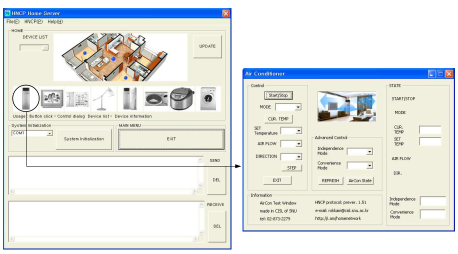

Fig. 9. Screenshot of a home server and device dialog

Fig.10 shows the demonstration of wireless HNCP home network system based on IEEE 802.15.4. Two boards in front of home server computer are a Korwin zigbee development kit.

Fig. 10. Demonstration of wireless HNCP home network system based on the IEEE 802.15.4

4. Coexistence analysis between IEEE 802.11b and IEEE 802.15.4

There are transmission failures on environment of wireless HNCP home network system, because IEEE 802.11b and IEEE 802.15.4 are commonly used in the 2.4 GHz ISM band(i.e., 2.400-2.4835GHz) and are expose to a high level of interference mutually. IEEE 802.11b is used more popular than IEEE 802.15.4. Therefore, in this section, interference analysis of IEEE 802.11b in IEEE 802.15.4 environment is considered.

4.1. Bit Error Rate Evaluation of the IEEE 802.11b under the IEEE 802.15.4

The physical layer of IEEE 802.11b provides data rates until 11 Mbit/s by a CCK modulation. Denoting by E_b/N_o, the ratio of the average energy per information bit to the noise power spectral density at the receiver input, in the case of an additive white Gaussian noise (AWGN) channel, the bit error rate (BER) can be expressed as follows.

$$P_B = 1 - \frac{1}{\sqrt{2\pi}} \int_{-X}^{\infty} \left(\frac{1}{\sqrt{2\pi}} \int_{-(v+X)}^{v+X} \exp\left(-\frac{y^2}{2}\right) dy \right)^{\frac{N}{2}-1} \cdot \exp\left(-\frac{v^2}{2}\right) dv \quad (1)$$

, where $X = \sqrt{2 \cdot E_b/N_o}$, and N equal to 8 in the case of 11 Mbit/s:

When the bandwidth of IEEE 802.15.4 is overlapped with one of IEEE 802.11b, the interfering signal can be considered as the partial band jammer noise. For the partial band jammer, the signal to noise and interference ratio can be defined as

$$SNIR = \frac{P_C}{P_{N_0} + \sum_{k=1}^{N_I} P_i(k)} \quad (2)$$

where P_C is the power of the desired signal, P_{N_o} is the noise power and $P_i(k)$ is the power of the k-th interferer for $K = 1, \dots, N_I$, with N_I denoting the number of active interferers. By replacing SNIR to E_b/N_o, the BER of the IEEE

802.11b under IEEE 802.15.4 can be obtained. In this paper, Free Space Path Loss model is used as path loss model.

4.2. Interference Model of the IEEE 802.11b and the IEEE 802.15.4

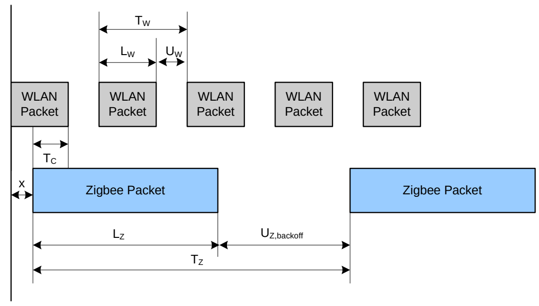

Fig. 11. Interference Model between IEEE 802.11b and IEEE 802.15.4

The interference model can be illustrated like Fig. 11. Let T_W and T_Z be the inter-arrival time of IEEE 802.11b and IEEE 802.15.4 respectively. L_W and L_Z are the packet duration of IEEE 802.11b and IEEE 802.15.4 respectively. U_W and U_Z are the average random backoff time of IEEE 802.11b and IEEE 802.15.4 respectively. T_C is the collision time that overlap IEEE 802.11b packets and IEEE 802.15.4 packets in time.
Then, the collision time, T_C can be obtained as :

$$T_C = \begin{cases} L_W - x & 0 \le x < L_W \\ 0 & L_W \le x < U_Z \\ x - U_Z & U_Z \le x < U_Z + L_W \\ L_W & U_Z + L_W \le x < T_Z \end{cases} \quad (3)$$

In this paper, x is assumed to be a random variable that is uniformly distributed between zero and T_Z. The packet error rate (PER) is obtained from the BER and the $T_C^{(b)}$; T_C/T_b. The PER is as follows.

$$\begin{aligned} P_P &= 1 - P\{correct\ IEEE802.11b\ packet\} \\ &= 1 - (1 - P_B)^{T_C^{(b)}} \end{aligned} \quad (4)$$

,where T_b is the bit duration of IEEE 802.11b.
Fig.12 shows the PER of IEEE 802.11b under the interference of IEEE 802.15.4 with the same center frequencies. As shown in Fig.12, if the distance between two devices of IEEE 802.11b and IEEE 802.15.4 is longer than 4 m, the performance of IEEE 802.11b doesn't decrease in the interference of IEEE 802.15.4.

5. Conclusion

HNCP is one of good solutions for a home network system which requires a light resource overhead and low cost for NHAs. This paper proposed the design and implementation of a wireless HNCP home network system for extension of HNCP based on PLC, and showed the feasibility of the HNCP through the implementation. Because the mutual interference is occurred during the implementation of wireless HNCP home network system, the simple analysis about the coexistence between the IEEE 802.11b devices and the IEEE 802.15.4 devices was achieved.

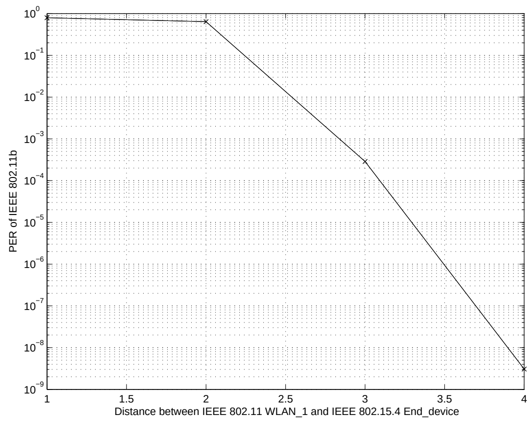

Fig. 12. PER of IEEE 802.11b under interference of IEEE 802.15.4

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