Abstract— Application of the home network is the most important factor to make the future home network environment pervasive. Although home network environment allows us to control appliances, actuators and monitor appliances, sensors in our home anywhere, any time you want, it has not yet been accepted by consumers due to a lack of killer applications. In this paper, we describe the verification of the application acceptability in the future home network environment for the purpose of searching for the killer applications, which are utilized daily among ordinary households, through the development of home network testbed and evaluation of its applications.

I. INTRODUCTION

The dreams of home networking such as remote control of home appliances, remote monitoring, home automation, coordination with other sensors and so on, have been chased by consumer electronics manufacturers since 1980’s including the TRON Intelligent House designed by the TRON project [1]. Recently ECHONET [2] compliant networked home appliances have been commercialized [3], [4]. ECHONET is a standard specification for controlling and monitoring of home appliances, especially white goods, by the ECHONET Consortium, which was established by several major Japanese consumer electronics manufacturers and other organizations in 1997. However the dreams of home networking have not come true yet from a business perspective. This is attributed to the absence of killer applications that would benefit the end-user.

Wide-ranging applications in the future home network environment have been proposed [3], [4], [5]. However, there were little discussions on whether the home network application is acceptable or not, while the technical aspect of the proposal such as hardware and middleware on the home network infrastructure. We think discussions about applications are as important as discussions about infrastructure technologies to find killer applications that consumers want to use, because they pay money.

In the remainder of this paper, we present home network requirements in terms of system architecture, applications and user interface in Section II. Section III describes a home network system under development, which consists of a Gateway (GW), Network Remote Controls, and Wireless Adapters. Section IV describes the outline and the result of the verification experiment of the application acceptability. Section V discusses the evaluation of home network applications.

II. HOME NETWORK REQUIREMENTS

A. Architecture

We are aiming at penetration of home networks among ordinary households for the purpose of providing more users with peace of mind, safety and comfort in their home life.

The problems of commercial home network systems are not only the absence of killer applications as mentioned in Section I, but also the relatively high price of the equipment and the limitation of the model. This is because extensive hardware and software modification is required to allow existing equipment to be home network compliant. As for home networking through cables, it will not be realistic, since wiring becomes complicated. In addition, equipment management of home network system, such as adding and deleting equipment, joining and leaving the network, will be big problems when the number of equipment is growing. Thus, many problems still exist when creating home network system.

Since our targets are not newly built houses but ordinary households as mentioned above, requirements for home network system and solutions are proposed below:

- Low cost of the system: A GW, which consists of a several software programs installed on ordinary PC, organizes the proposed home network architecture. Adapters offer simple serial links between appliances and the applications software to control and monitor the appliances on the GW. MPU, equipped in the appliances, or another communication controller is connected to the adapter. Thus minimal hardware and software modification is required to allow existing appliances to join the home network.
• Simple installation: The adapters provide wireless communication between the appliances and the applications software on the GW.

• Simple configuration: Universal Plug and Play (UPnP) is a promising technique in the PC and AV world for connecting home devices as simple as possible [6]. Our platform supports UPnP communication protocol. However it is not so simple for home appliances and/or wireless adapters to implement UPnP. So the GW provides non UPnP-based appliances with network functions, which is consistent with UPnP communication protocol. The application software on the GW is an UPnP individual emulator to control and monitor each existing appliance as a UPnP device from a UPnP Control Point.

The home network protocol stack architecture based on the above-proposed solutions is shown in Figure 1.

Figure 1. Communication protocol stack for proposed solutions

B. Application

The process for assuming the applications, which it would be nice to have, is as follows: First of all, questionnaires of life patterns during a day were collected from three or more users. After extracting the features of applications by analyzing life patterns, specific applications have been assumed based on the features.

Table 1 shows envisioned 17 applications. “Anywhere anytime control”, “Monitoring”, “Total control”, and “Messaging” of the first line in Table 1 represent the features of applications, and the lines of the second line or less show specific applications. For example, the applications with the feature of "Anywhere anytime control" of the first row are following: "Lighting operation", "TV operation", "A/C operation from outside", and "A/C timer setting from outside".

The features of applications are described below:

- Anywhere anytime control: These applications are what users want to control domestic appliances anywhere regardless of the inside or outside of their houses.

- Monitoring: These applications are what users want to display monitoring information on their user interface devices.

- Total control: These applications are what users want to control two or more equipment at the same time according to the situation. We examined four scenes such as “Get up”, “Go out”, “Go home” and “Go to bed” as shown table II.

- Messaging: These applications are what users want to call attention to themselves. “Messaging” is sent to their user interface devices as events from equipment.

<table>
<thead>
<tr>
<th>Anywhere anytime control</th>
<th>Monitoring</th>
<th>Total control</th>
<th>Messaging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting operation</td>
<td>Confirm door locks</td>
<td>Get up</td>
<td>Don’t forget to turn off the A/C</td>
</tr>
<tr>
<td>TV operation</td>
<td>Confirm on/off status of house</td>
<td>Go out</td>
<td>Message from A/C timer setting</td>
</tr>
<tr>
<td>A/C operation</td>
<td>View images from outside</td>
<td>Go home</td>
<td>Don’t forget to put out the fire</td>
</tr>
<tr>
<td>A/C timer setting from outside</td>
<td>Go to bed</td>
<td>Close the door of refrigerator</td>
<td></td>
</tr>
</tbody>
</table>

TABLE II. TOTAL CONTROL APPLICATIONS

<table>
<thead>
<tr>
<th>Total Control</th>
<th>Applications</th>
<th>Lighting</th>
<th>A/C</th>
<th>TV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Get up</td>
<td>On</td>
<td>On</td>
<td>On</td>
<td>On</td>
</tr>
<tr>
<td>Go out</td>
<td>Off</td>
<td>Off</td>
<td>Off</td>
<td>Off</td>
</tr>
<tr>
<td>Go home</td>
<td>-</td>
<td>On</td>
<td>On</td>
<td>On</td>
</tr>
</tbody>
</table>

C. User Interface

We propose a Network Remote Control as the user interface of the home network system. Functional requirements for the Network Remote Control which are led from the above mentioned applications are as follows:

• Instruction function for controlling appliances

• Display function for monitoring information

• Message receiving function

• Wireless communication function

• Internet connection function

We think the Network Remote Control is not only a user interface of home network system but also a killer application itself. The example of the Network Remote Control is introduced in Section III.

III. DEVELOPMENT OF HOME NETWORK TESTBED

The developed home network system, which is based on the architecture described in Section II, allows us to have total control of a house in remote location and inside the house, using the internet, wireless communications systems...
and home network. Therefore, it provides interactivity and security of the house.

PDA and Cellular Phone were adopted as the Network Remote Control. This is because you can control and monitor appliances and receive messages from appliances, from anywhere inside the house using 802.11b wireless LAN of PDA and anywhere outside the house using Internet of Cellular Phone. Security cameras were set in the living room and the entrance to look inside the house in remote location.

IV. VERIFICATION EXPERIMENT

A. Scenario based Experiment

We conducted a verification experiment using the constructed home network testbed to verify the acceptability of home network applications. The outline of the experiment is as follows:

- The subjects are nineteen students and a staff of the Graduate School of Information Science at NAIST. The attributes of the subjects are show in table III.
- We prepared three kinds of documents as follows: 1) an experiment instruction document, which states the objective of the experiment and the outline of the system, 2) a task document, which describes a scenario of a day from going home to going to work the next day, so that the subject can experience the system, 3) a questionnaire to evaluate the applications. We prepared a different task document for each Network Remote Control: PDA and Cellular Phone.
- Each subject tried the system based on the task document. All subjects did the task for both two kinds of Network Remote Controls: PDA and Cellular Phone. The questionnaire and interview were conducted after the task.
- “Messaging” applications were evaluated through the software generation of messaging, when conducting the questionnaire.

<table>
<thead>
<tr>
<th>No</th>
<th>Age</th>
<th>Sex</th>
<th>Nationality</th>
<th>Are you interested in Home Network?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>24</td>
<td>Male</td>
<td>Japanese</td>
<td>Yes</td>
</tr>
<tr>
<td>2</td>
<td>24</td>
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<td>Yes</td>
</tr>
<tr>
<td>3</td>
<td>33</td>
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<td>Japanese</td>
<td>Yes</td>
</tr>
<tr>
<td>4</td>
<td>25</td>
<td>Female</td>
<td>Japanese</td>
<td>Yes</td>
</tr>
<tr>
<td>5</td>
<td>24</td>
<td>Male</td>
<td>Japanese</td>
<td>Yes</td>
</tr>
<tr>
<td>6</td>
<td>25</td>
<td>Male</td>
<td>Japanese</td>
<td>Very interested</td>
</tr>
<tr>
<td>7</td>
<td>23</td>
<td>Male</td>
<td>Japanese</td>
<td>Yes</td>
</tr>
<tr>
<td>8</td>
<td>23</td>
<td>Male</td>
<td>Japanese</td>
<td>Yes</td>
</tr>
<tr>
<td>9</td>
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<td>Male</td>
<td>Japanese</td>
<td>Yes</td>
</tr>
<tr>
<td>10</td>
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<td>Korean</td>
<td>Yes</td>
</tr>
<tr>
<td>11</td>
<td>28</td>
<td>Male</td>
<td>Indonesia</td>
<td>Average</td>
</tr>
<tr>
<td>12</td>
<td>24</td>
<td>Male</td>
<td>Japanese</td>
<td>Average</td>
</tr>
<tr>
<td>13</td>
<td>24</td>
<td>Male</td>
<td>Japanese</td>
<td>Very interested</td>
</tr>
<tr>
<td>14</td>
<td>23</td>
<td>Male</td>
<td>Japanese</td>
<td>Very interested</td>
</tr>
<tr>
<td>15</td>
<td>23</td>
<td>Male</td>
<td>Japanese</td>
<td>Very interested</td>
</tr>
<tr>
<td>16</td>
<td>24</td>
<td>Male</td>
<td>Japanese</td>
<td>Yes</td>
</tr>
<tr>
<td>17</td>
<td>23</td>
<td>Male</td>
<td>Japanese</td>
<td>Yes</td>
</tr>
<tr>
<td>18</td>
<td>23</td>
<td>Male</td>
<td>Japanese</td>
<td>Yes</td>
</tr>
<tr>
<td>19</td>
<td>27</td>
<td>Male</td>
<td>Chinese</td>
<td>Very interested</td>
</tr>
<tr>
<td>20</td>
<td>26</td>
<td>Male</td>
<td>Japanese</td>
<td>Very interested</td>
</tr>
</tbody>
</table>

TABLE III. ATTRIBUTES OF THE SUBJECTS

Figure 2. Schematic diagram of home network system to be developed

Figure 3. Layout of the room with the home network system testbed

A. Home Network System

The home network system consists of GW Software, Application Software (per home network application), Wireless Adapters, Network Remote Controls, and appliances shown in Figure 2. The GW Software implements the gateway functions, which connect the home network to other information networks. Application Software (per home network application) implements each home network application, such as TV, A/C, Lights, Events, Macros for “Total control” and Cameras, as UPnP emulation. The Wireless Adapters and Application Software allow non UPnP-based appliances to join the network as described in Section II. The Network Remote Control, which is implemented via Cellular Phone and PDA, is the user interface of this home network system. The Network Remote Control may be implemented via specialized devices.

B. System Construction

We arranged a room as a model of ordinary house for evaluating the proposed home network system testbed. The layout is shown in Figure 3. Similar to the average house, the testing room has a entrance, living room, bed room and kitchen.

In this testbed the GW Software was installed on a desktop PC. 17 applications described in Section II.B were implemented and A/C, TV, Lights and Cameras were prepared as appliances, which could be controlled through the GW by the Network Remote Controls. All applications of “Messaging” and “Confirm door locks” of “Monitoring” were implemented in software.
B. Questionnaire

All subjects answered the questionnaire of two patterns in the case of "living with family" and "living alone". The items of the questionnaire are listed below:

- Attributes of the subject
- Price evaluation of the home network system
- Price evaluation of each application
- Five-stage evaluation of each application where one is strongly negative: "I don’t want it", three is neutral, and five is the most positive: "I want it very much"
- Equipment that needs to be connected to home network: devices, sensors, appliances and so on
- Five stage evaluation of each Network Remote Control: specialized device, Cellular Phone, PDA and TV

```plaintext
giving alone”.

Figure 4. Proportion of the subjects who accepted the application

Figure 5. Price evaluation of each home network application
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C. Results

The results of the experiment are shown in Figures 4 and 5. Figure 4 shows the proportion of the subjects who answered “4” and “5” of the five stage evaluation. Figure 5 shows the price evaluation of each application. “Confirm door locks” of “Monitoring” and “Don’t forget to put out the fire” of “Messaging” were accepted by 93% of the subjects living alone and “Confirm on/off status of house” of “Monitoring” was 85% of subjects living alone. The highest price of all applications was 2,465 yen for “View images from outside” of “Monitoring” and the second was 2,408 yen for “Confirm of door locks” of “Monitoring”. The third was 2,203 yen for “Confirm on/off status of house” of “Monitoring”. The most preferred device for use of the Network Remote Control was Cellular Phone.

The average price idea of the home network system was as follows: the application set was 17,875 yen; the GW Software was 22,439 yen; the Wireless Adapter per each was 2,558 yen; and the Network Remote Control was 4,615 yen.

V. DISCUSSION

The applications of “Monitoring” and “Messaging” were very high reputation values in the both the five stage evaluation and the price evaluation of each application. Especially, the applications with the feature of crime and disaster prevention were the highest reputation values.

The subjects of this experiment were interested in home networking as shown in table III. However they didn’t show great interests in the both applications of “Anywhere anytime control” and “Total control”. And the subjects living with family gave all applications lower marks than the subjects living alone did as shown in Figure 4. We had expected “Total control” applications would have been given higher marks than they were. We think the applications on “Control” should be reexamined, including use cases in the case of living with family.

VI. CONCLUSION

In this paper we described the verification experiments for 17 envisioned applications through the development of home network testbed. The results showed that the applications of “Monitoring” and “Messaging” with the feature of crime and disaster prevention are acceptable, if the cost requirements are met based on the proposed architecture.

ACKNOWLEDGMENT

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REFERENCES