Dynamic Controller Selection in Smart Home Networks

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ABSTRACT
Many kinds of electrical devices are available at home and most of them are equipped with micro computers. These devices have been autonomously controlled. According to the highly advanced computer network technology, these devices are connected to a computer network. Here, these are controlled and managed through the network for sup-porting network services efficiently. Such kind of computer networks are named home networks. For providing ser-vices to home network users, it is critical to support the lo-cation information service, that is, the location of the users are required to be recognized by the system in real-time manner. This paper proposes a novel location information system for home networks by using speaker recognition, wireless LAN protocol, network management technique in TCP/IP networks.

KEY WORDS
Network Services, Location-based Services, Home Net-work, Wireless Communication

1 Background and Objective

There are many kinds of electric household appliances and most of them are controlled by embedded micro– computers. Until now, these appliances are controlled in-dependently. However, due to highly developed network technology, it is possible to connect the appliances to a computer network. Hence, remote control and maintenance of the appliances become possible and efficient and inte-grated services are realized by cooperation of multiple net-worked appliances. A computer network with such electric household appliances and computers for control the appli-ances is called a home network. Here, sensors for achieving user's requirements, controllers for issuing instructions to network appliances based on the achieved user's require-ments and network appliances providing services accord-ing to the instructions from controllers are primitive enti-ties.

Here, we pay attention to the fact that location of a user is critical to decide services provided to a user and most appliances required to be controlled for provid-ing services are near the user and propose a novel dis-tributed home network architecture which consists of mul-tiple home network devices which are combination of a sensor and a controller and exchanges messages with each other by using a short–range wireless LAN protocol such as Bluetooth[10]. The device does not achieve user's ex-plicit requirements but guesses user's implicit requirements based on a location of a user by achieving voice and sound of the user. In order to determine the location of the user, information of the achieved voice and sound in multiple home network devices are required to be gathered through a wireless network. Here, it is critical to select a controller to which the information of voice and sound is gathered and in which location of the user is guessed, providing ser-vices are selected and required instructions for network ap-pliances are issued. In this paper, we propose the dynamic controller selection where the nearest home network device to the user serves a roll of the dedicated controller for sup-porting services provided to the user.

The roll is transfered to another home network de-vice as the user changes its location. However, the dedi-cated controller is possible to be selected based on the gain power of voice and sound of the user and most of the pro-vided services are realized by functioning appliances near the user. In order to decide the dedicated controller dy-namically by exchanging messages carrying information of voice and sound and transmit instructions for network appliances, communication among home network devices and network appliances is required to be supported. For easily installation, wireless communication is reasonable. Especially for avoidance of contention and collision in or-der to reduce transmission delay for realizing timely ser-vices, Bluetooth protocol is applied to the communication. Control and management of network appliances are real-ized by SNMP(Simple Network Management Protocol)[3] in TCP/IP networks. Finally, by an experiment, we show that the bandwidth achieved by Bluetooth is enough for message transmission according to SNMP to control net-work appliances in the proposed dynamic controller selec-tion architecture.

2 Home Network Services

2.1 Classification

Services provided in a home network are classified into the following two categories according to relative locations be-tween a user and appliances controlled according to user's requirements.

[Remote Control out of House]

As shown in Figure 1(a), there is a home gateway which is a kind of server computer[7, 8, 13, 14]. A home gateway serves a roll of a gateway between a home network and the Internet. A user controls network appliances by issuing instructions explicitly by using a cellular phone, a portable computer and a PDA and transmitting the instructions through the Internet, the home gateway and the home network. For example, reservation of video recording[13, 14] and locking doors from out of a house are implemented.

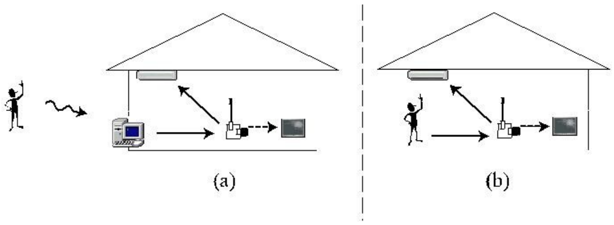

Figure 1. Home network services.

[Comfortable Environment within House]

As shown in Figure 1(b), a location of a user is achieved by a certain method, e.g. Active Badge[9], Active Bat[2], CoBIT[6] and RFID. Each user carries some device with a unique identifier and the identifier is achieved by a sensor. Then, a controller determines services provided to the user according to the location of the user and issues some instructions to appliances for the services. For exam-ple, on and off of electric lights and control of air condition-ers based on a location of a user are such a kind of services. This paper discusses how to provide services in the latter category. That is, required services are determined by a lo-cation of a user and appliances around the user (and some-times appliances far from the user, e.g. in another room) are controlled. Here, since it is unacceptable for a user in a house to always hold some device for sensors to deter-mine a location, another method without such a device is applied[5].

2.2 Service Determination

In a home network, there are two categories of services as discussed in the previous subsection and this paper discusses the latter category where user's requirements are implicitly suggested and required services for a user are guessed with many parameters. However, a location of a user, history of changes of user's location and the current time are the most critical parameters. For simplicity, we assume that required services are determined by a current location of a user. An extension based on the two additional parameters is easily realized.

For achieving a location of a user, most of conventional methods require for a user to always hold some device. However, in a house, it is desirable for a user not to require to hold such a device. Video image achieved by using video cameras is a candidate for getting a location of a user. By using video image, identification of a user and achieving detailed location of a user are realized. However, installation cost for setting multiple video cameras in order to avoid blind spots is high. In addition, detailed location information is not needed. Usually, required granularity for identification of user's location is with a unit of a room.

Another candidate is voice and sound of a user. By using voice and sound for determination of a location of a user, there are much less blind spots than by using video image. Even if a certain obstacle exists between a user and a sensor, a microphone in this case, voice and sound of a user is achieved by the sensor. In addition, detailed loca-tion information is not achieved by voice and sound, how-ever, it is sufficient for determination of services in a home network. Voice and sound of a user has another desirable property; the gain power of voice and sound in a micro-phone depends on the distance between the user and the microphone. Based on the gain power, a location of a user is determined and a dedicated controller supporting the user is dynamically selected as discussed later. To get a user's location, information achieved from voice and sound are required to be exchanged among home network devices. Hence, a communication network for home network de-vices is important to get a user's location. Even if some device fails to get user's voice and sound, those achieved by other devices help to determine a user's location.

3 Distributed Controller Architecture

In order to realize a home network system in which user's requirements are achieved and network appliances are controlled to satisfy the requirements, we propose a distributed controller architecture where multiple home network devices, which have ability (1)for achieving information related to a location of a user, (2)for exchanging the achieved location related information and (3)for issuing instructions to control network appliances based on the location information, are installed. Basically, a home network system consists of sensors to get information related to user's requirements, controllers to decide how to control network appliances based on the user's requirements and to issue instructions to control and network appliances function-ing according to the instructions. Architectures combin-ing these entities for providing intelligent and integrated services are classified into the following: centralized and distributed controller architectures.

[Centralized Controller Architecture]

As shown in Figure 2(a), information related to user's requirements achieved by sensors is gathered to a dedicated server computer (controller) and providing services are decided in the server based on the gathered information. Then, an application program for providing the selected services is executed on the server computer and instruc-tions to control network appliances are issued. All required information is gathered to the server and all calculation of user's requirements and all execution of an application program are supported by the server. Hence, management of

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the system is easily realized. However, computation and communication overhead for exchanging information related to user's requirements, execution of an application program and resource management are only on the server computer. In addition, it is possible for the home network system to be suspended due to fault of the server computer or of a part of a communication network.

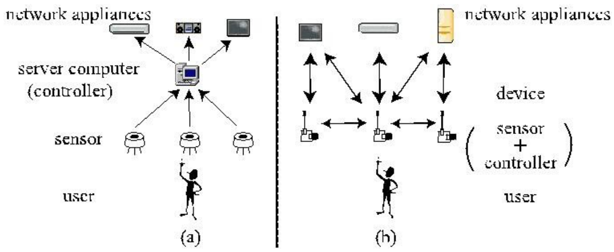

Figure 2. Centralized and Distributed architectures.

[Distributed Controller Architecture]

As shown in Figure 2(b), there is no server computer and each controller manages localized information and controls appliances around the controller. That is, an application is executed autonomously and distributedly. Providing services are determined based on the information related to user's requirements achieved by sensors around the user. Here, since most of the services control appliances around the user, controllers are desirable to be located around sensors and appliances nearly located to the user. This is because required traffic of control messages gets reduced and response time for control of network appliances for requirements of a user becomes shorter. In addition in a distributed controller architecture, even if a part of a home network system suffers fault, services are continuously provided and whole suspension of the system is avoided, i.e. highly available home network systems are realized.

Therefore, we propose to introduce a home network device which is combination of a sensor and a controller and discuss a distributed architecture using the home network devices.

4 Dynamic Controller Selection

In the previous section, two home network architectures are explained. For realizing a home network service, achieving a location of a user, which is equivalent to achieving user's requirements as discussed in section 2, and issuing instructions for controlling network appliances are two important functions. For each of the two functions, different processing architectures might be implemented; i.e. centralized and distributed. Especially for the distributed architecture in a home network, additional classification is possible to be considered. an all-device category and a nearby-device category. In the former, information related to requirements of a user is distributed to all home network devices. On the other hand, in the latter, information is transfered to a home network device the nearest located to a user. This seems to be a centralized architecture; however, the controller sup-porting the user is dynamically selected in accordance with a location of a user. Therefore, as shown in Figure 3, there are 9 possible architectures for home network systems; 3 possible controllers for gathering location information to get user's requirements and 3 possible controllers for issu-ing instructions to control appliances.

instructions / location	server computer	all devices	device nearest located user
server computer	(a)	(b)	(c)
all devices	(d)	(e)	(f)
device nearest located user	(g)	(h)	(i)

Figure 3. Home Network Architectures.

(a) Centralized Architecture: A server computer gets a location of a user, calculates user's requirements and issues instruction. Every home network device achieving information of voice and sound of a user transmits the information to the server computer. The server computer calculates a location of a user based on the gathered information and guesses user's requirements. Then, it transmits messages carrying instructions to network appliances. Here, since network traffic is congested around the server, many contentions and collisions might occur and transmission de-lay gets longer. In addition, since sensors around the user get voice and sound information and network appliances around the user are likely to be controlled, unnecessary net-work traffic is required in this architecture. Finally, as men-tioned before, it is impossible to provide highly available system due to point of a failure in a server computer.

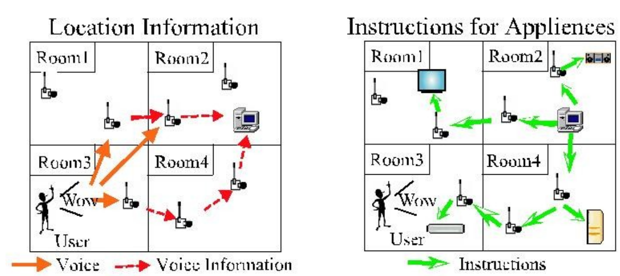

Figure 4. Architecture (a).

(b) Information of voice and sound is gathered to a server computer and calculation of a location of a user is exe-cuted in the server. Then, the location information is dis-tributed to all home network devices. Each device guesses user's requirements and issues instructions to network ap-pliances around it. Here, high control message traffic might be required in case that the server is far from the user. In addition, for realizing consistent services with multiple controllers, the location information should be broadcasted with an atomic broadcast protocol which requires some ad-ditional communication overhead. Even though the infor-mation is atomically broadcasted, only a limited number of devices use the information, i.e. only a limited num-ber of devices issues instructions to network appliances. Here, this architecture requires needless communication overhead. In addition, the server is a point of failure in the system.

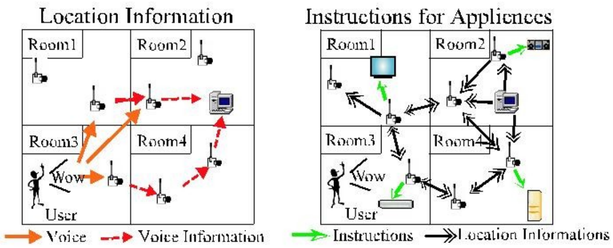

Figure 5. Architecture (b).

(c) Out of consideration due to inefficiency.
(d) Out of consideration due to inefficiency.
(e) Completely Distributed Architecture: All home net-work devices gather information of voice and sound of a user, calculate a location of a user, guess user's re-quirements and issue instructions to network appliances around themselves. Here, the location related information achieved by a sensor (i.e. a microphone) in each device is broadcasted to all the devices. Hence, in a home network system with n devices, k broadcasts are invoked where k is a number of devices getting voice and sound of a user. k is approximately proportional to n and each broad cast requires $O(n)$ messages for achieving atomicity, totally $O(n^2)$ messages are required. Though a highly available home network system is realized, required communication overhead is also high. Same as (b), most of computation in all devices for achieving a location of a user and guess of user's requirements is wasted.

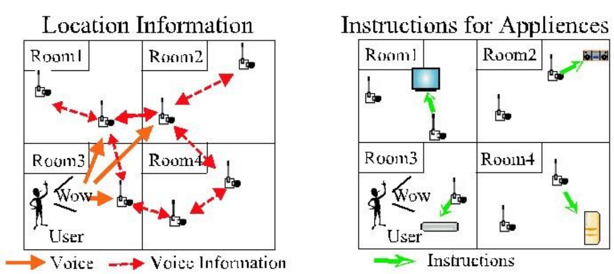

Figure 6. Architecture (e).

(f) This is considered a subset of (e). A location of a user is calculated by all the devices with high network traffic to get consistent location information. However, user's require-ments are gained only by a dedicated device which is the nearest to the user. Only the controller issues instructions to network appliances. It is reasonable since the controlled appliances are usually near the user. However, high traffic for achieving a location is critical.

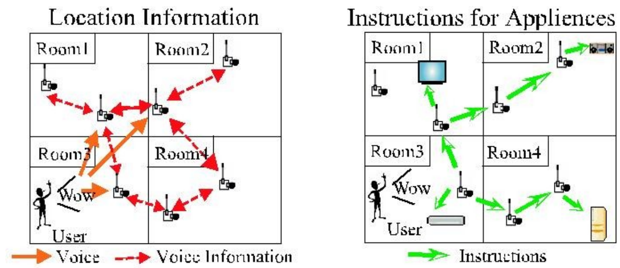

Figure 7. Architecture (f).

(g) Out of consideration due to inefficiency.
(h) Information of voice and sound of a user is gathered to a home network device nearest to the user and a location of the user is calculated. Then, the location information is broadcasted to all the devices in the home network system. On receipt of the information, each device issues required instruction to network appliances around it. Here, voice and sound of the user is gained by devices around the user since the gained power gets lower as the distance between the user and the device gets longer. Thus, gathering the in-formation to the nearest device to the user is reasonable in terms of reduction of network traffic. However, by broad-casting the location related information to all the devices are required with the property of existence of target appli-ances around the user.

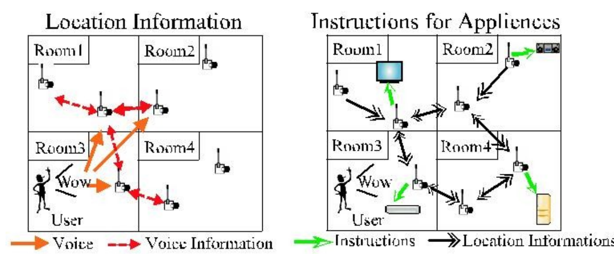

Figure 8. Architecture (h).

(i) Dynamic Controller Selection Architecture: Same as (h), information of voice and sound of a user is gathered to a home network device nearest to the user and a loca-tion of a user is calculated. Then, different from (h), user's requirements are guessed and instructions to network ap-pliances are issued only by the device. Gathering voice and sound of a user is realized with low communication over-head as mentioned in (h). In addition, since most of the target network appliances are around the user, issuing in-structions only by the device is also reasonable. In addition, there is no point of failure and highly available home net-work system is achieved since the dedicated home network device is the nearest one among the available devices, i.e. dynamically selected. Hence, even the current nearest device fails, the next nearest device is dynamically selected as the dedicated device among the available devices and ser-vices are continuously provided to the user. Therefore, the dynamic controller selection architecture is the most suit-able with location identification by voice and sound of a user.

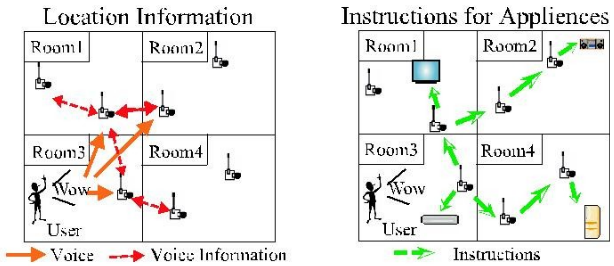

Figure 9. Architecture (i).

5 Wireless Communication

As discussed in section 4, in order to control network appliances for satisfying user's requirements, communication among home network devices and network appliances are required to be supported. Our proposed home network devices are required to be easily installed. Hence, it is about 3 5cm cube and is plugged into a wall outlet. Thus, the most reasonable communication method is a wireless LAN protocol. By using a wireless LAN protocol, easy and rapid installation is available without wiring. A series of IEEE802.11[1] and Bluetooth are wireless LAN protocols based on broadcast communication. Here, contention and collision of multiple message transmission reduce performance of the system. Hence, a short–range wireless LAN protocol is desirable. Even if a message transmission range of a wireless LAN device is not so long, density of wireless LAN devices, i.e. home network devices and network appliances, are high and connectivity of them is high. Therefore, Bluetooth is one of the best candidate for communication in a home network system. Since a message transmission range of a Bluetooth device is about 10m, low occurrence of contention and collision is achieved. In addi-tion, since few messages reach out of a house, it has prop-erty of secure communication. In our proposed architec-ture, a dynamic controller selection, each home network device transmits a message including information of voice and sound of a user with other devices. A message format is defined as shown in Figure 10. There are 4 data fields; user identifier, observing time, gained power and device identifier. A device identifies a user by using observed voice and sound. If it observes voice and sound and does not identify a user, a value meaning anonymous user is stored into the field. Since voice and sounds are observed continuously, the peak gain power and the time of receipt of the peak gain

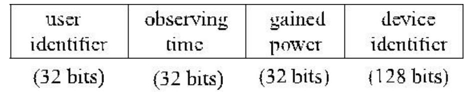

Figure 10. Message format.

power during predetermined interval are stored into the observing time field and the gained power field, respectively. A unique identifier is assigned to each device. Here, an IPv6[4] address assigned to a Bluetooth interface is used. For controlling a network appliance, a device transmits a message including instructions to the network appliance. Here, SNMP is applied. SNMP is widely used protocol for managing networked products. A data structure MIB (management Identifier Base) is defined for shoring state information of the product. In order to get the state information of the product, a get request message with a identifier of the store information of SNMP is transmitted and a get reply message with the value representing the state information is returned. On the other hand, in order to set some value as the state information to control the product, a set request message with the value and an identifier of the store information is transmitted and a get reply message is returned. Figure 11 shows message format of SNMP.

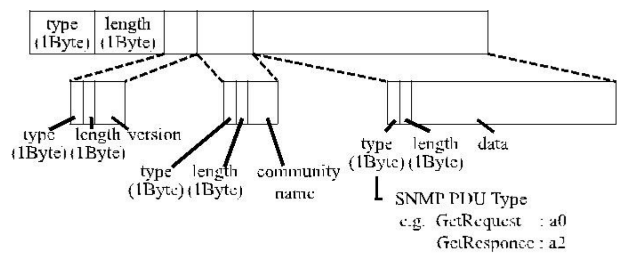

Figure 11. Message format of SNMP.

6 Prototype and Evaluation.

Figure 12 shows an overview of a prototype system with 2 handheld PCs with Linux operating system whose distribution is Red Hat Linux 9(kernel-2.4.21). One represents

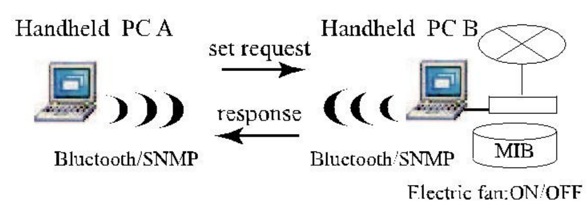

Figure 12. Overview of a prototype system.

a home network device and the other represents a micro–computer embedded to a network appliance. They communicate though a Bluetooth adapter Planex GW–BH02U and a Bluetooth protocol stack Bluez[11]. Bluez includes a module Bluezpan supporting TCP/IP communication. In addition, net–snmp[12] is installed for SNMP message transmission. The latter PC representing an embedded micro–computer has an extended MIB to control an elec-tric fan which is connected to the PC. Figure 13 shows achieved throughput in Bluetooth communication by us-ing netperf. As shown in Figure 10, the length of a mes-sage carrying information of voice and sound of a user is 224bits. Hence, one–hop transmission delay for the mes-sage is only 1.49msec if the distance between two neighbor devices is 10m. Hence, even if multi–hop transmission is required to reach the information to the nearest device to the user, at most 10msec is needed. On the other hand, a

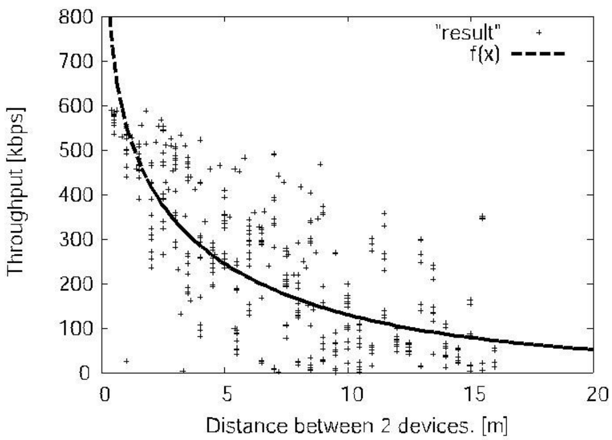

Figure 13. Throughput in Bluetooth communication.

frame containing SNMP message to control an electric fan is about 100 300 byte long. This is includes IP header, UDP header and SNMP message consisting of a set of TLV (Type–Length–Value) style data. Here, one–hop transmis-sion delay is about 5 15msec in case of communication with 10m away appliance. Thus, totally less than 100msec is required for achieving voice and sound of a user and con-trolling required appliances. That is, performance of Blue-tooth is reasonable to control network appliances in a home network with a dynamic controller selection architecture.

7 Concluding Remarks

In this paper, we propose the dynamic controller selection where the nearest home network device to the user serves a roll of the dedicated controller for supporting services provided to the user. Here, we show that the bandwidth achieved by Bluetooth is enough for message transmission according to SNMP to control network appliances in the proposed dynamic controller selection architecture.

In future work, we propose the protocol for decision to the services to users.

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