6-3 Context-Aware Service Mobility and Smart Space

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Various wireless and wired terminals have been well developed, but there are big differences between a compact mobile phone and a desktop PC connecting to the high-speed Internet, on their performances and qualities. If we could switch among those different terminals adaptively according to availability, quality, cost and usability, the most appropriate terminal can be always used. In the ubiquitous network environment, various sensors and actuators will be connected to the networks and new communication services are expected to come out. As a new communication service candidate, in this paper, we show cross-device handover technology which switches an on-going multimedia communication session from an actuator to another actuator. We also show a context sensing platform for providing context-aware services to the mobile users. We realize a ubiquitous network application that the sensors collect the user's current information, a server in the network estimates the user's context, and appropriate information is provided to the user by the optimum way according to the contextual information.

Keywords
Ubiquitous networks, Mobile networks, Service mobility, Context-awareness, Smart space

1 Introduction

Various wireless systems have been developed such as cellular phones, wireless LANS, Bluetooth etc., which have variety of transmission speeds, coverage area size, etc. These various wireless systems all have different features. For example, cellular phone systems with a large coverage area are now available in nearly any location, but these systems are not capable of ultra-fast transmissions, as is the case with wireless LANs, and such service is also relatively expensive. In contrast, wireless LANs offer low-cost, high-speed communication, but the coverage area is extremely small. Accordingly, our group is currently undertaking research, development, and standardization of seamless networking technologies have been undertaken that enable adaptive switching between different wireless devices; the aim of these efforts is to ensure constant optimal performance in the wireless environment using a single terminal.

On the other hand, terminals with access to networks are also diversifying, much as in the case of wireless systems. The selection of portable mobile terminals available to the user is also increasing, including cellular phones, PDAs, and notebook PCs, and all of these terminals feature different wired/wireless network interfaces, user interfaces, and processing power. It is expected that, in a ubiquitous network environment, all devices and sensors will be connected to the network, and that a completely new mode of network utilization will emerge as a result. As with the differences among the wireless systems cited above, such devices also have a range of different features. For example, cellular phone terminals can access a network from any location, even while moving at high speeds. However, transmission speeds are low with these devices, service is costly, and—due to their small size—the user interfaces (i.e., monitor displays) are small and feature low processing power. On the other hand, terminals such as fixed desktop PCs are connected to fast, wired Internet services and may be connected to large, high-resolution monitor display units. In these cases, the mobile user will normally use the wireless cellular terminal while in motion, but will move to the high-speed, high-quality communication accessible through his desktop PC when he returns to his desk, to benefit from a higher-quality communication environment. Cross-device handover technology will make this switch possible, allowing the user to choose the most suitable communication mode according to the status of his terminal, from a wide selection of available communication devices.

Research on sensor/actuator networks has recently come into focus as an important component technology in the realization of a ubiquitous network environment. Our group is currently examining a ubiquitous-network architecture that will use sensors to acquire information on the user's current status, and the corresponding actuator will provide the user the information he needs in the most appropriate manner. Through this study, we have proposed a method for selecting the most appropriate terminal for handling incoming transmissions according to the user's status, and enabling optimal handover between devices. Information acquired by multiple positional sensors of differing types will be collected by a server to estimate the user's contextual situation and actuator nodes will provide information to the user in accordance with this situation. By coupling the user's contextual information with the cross-device handover procedure, it will be possible to perform the optimal switchover, according to the user's location.

In Section **2**, we will present two methods for the proposed cross-device handover technology. Section **3** will introduce the sensor technologies essential to context-aware networking, the user-context information management platform, the sensor-actuator network node, and the smart-space testbed, which integrates all of the foregoing. Finally, Section **4**, will address the direction of future research.

2 Cross-device handover

In order to execute handover of an ongoing communication session between terminals belonging to different systems, the network must first recognize the terminal that is the target of the handover and acquire information such as terminal address, protocols available for use, and format. Next, the network must notify the target terminal of the session transfer to prepare for transmission. The network will then switch to the address of the target terminal to complete the handover. Two methods for switching the terminal address are under examination; one involves forwarding packets at the intermediate node (similar to the operation of mobile IPs), while the second method involves controlling end-to-end communication via signaling, as with an SIP. In the former case, it is possible to make changes not only to the terminal IP address, but also to the format and protocol on the network side as well, and so no modifications are required to existing servers or the communication applications on the corresponding peer device in the given session. This structure enables a cross-device handover that conceals from the peer information regarding the handover. In contrast, in an end-to-end communication handover, both parties must use a special communication application, and at least one of the parties involved must be capable of using multiple communication protocols compatible with communications via a heterogeneous terminal. However, this method permits constant communication using the optimal path. In the present study, use of a service-mobility proxy is proposed for an intermediate node method, and for the end-to-end communication handover method, we propose the use of the

MIRAI signaling network.

2.1 Service mobility proxy

Here we introduce a method referred to as a "service-mobility proxy", in which relay nodes are used to perform the cross-device handovers shown in Fig. 1. This method enables handover between terminals on the user side while maintaining an ongoing session above the L 3 level with the peer. The ongoing session is terminated between the correspondent node and the relay node (Service Mobility Proxy), and the session is resumed after the method of session establishment has been switched adaptively, according to the terminal to be used. During the cross-device handover, the target terminal is switched by changing the destination address to the terminal to be used at the relay node, similar to the operation of a mobile IP. If this process involves a change in the type of terminal used, the relay node switches the transmission method to one that the target terminal of the handover is capable of handling. In a mobile IP, the network interface in a single user terminal at Layer 3 is switched to conceal the change in address from the higher layers. However, in the case of cross-device handover, the communication session itself will be handled by a different terminal; thus, the timing of the execution of the communication application by the target terminal of the handover must be taken into account when performing the relay to the target terminal. Figure 2 shows an example of the handover sequence. The parameters for the terminal information include display size, types of communication applications available for use, types of protocols available for use in establishing the session, and IP address. The handover is made by selecting the most appropriate transfer method in terms of service mobility, based on the acquired information.

Figure 1 presents an example of the imple-

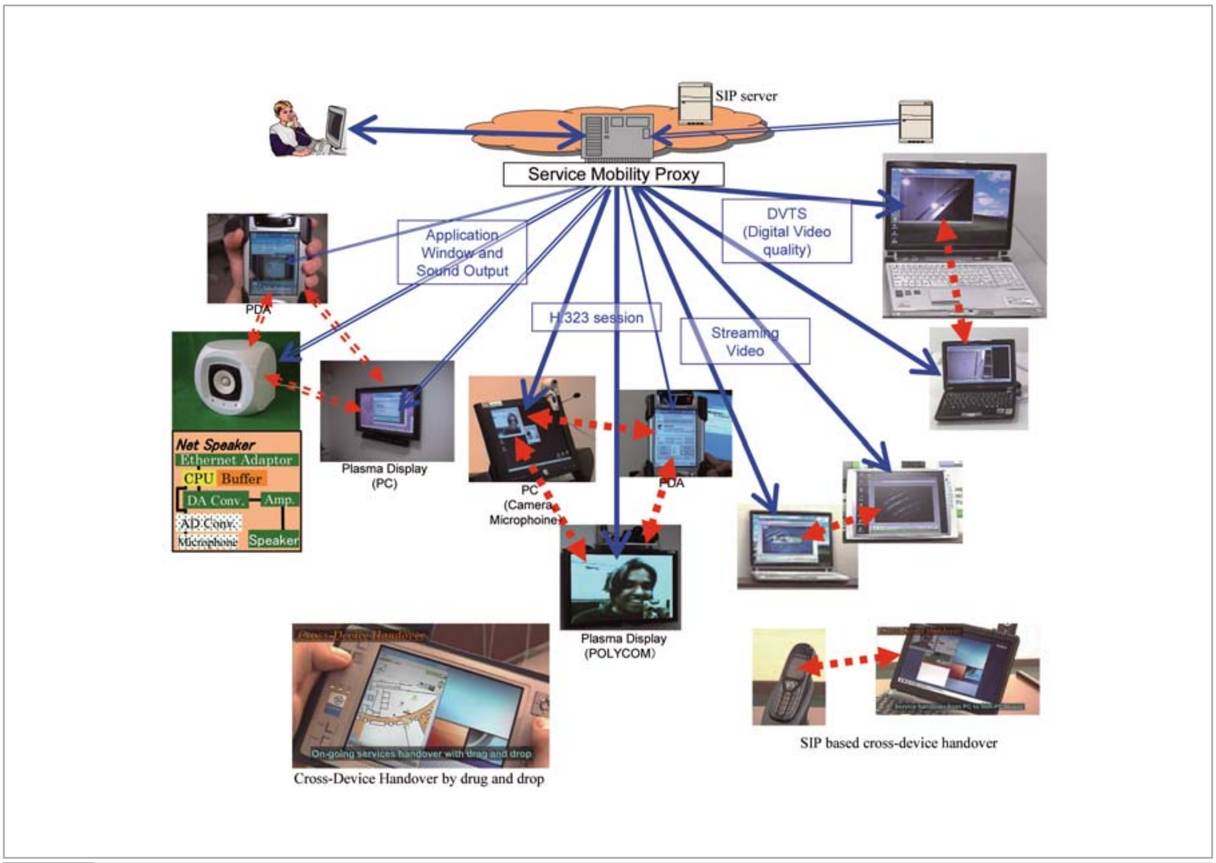

Fig. 1 *Example of handover by service-mobility proxy*

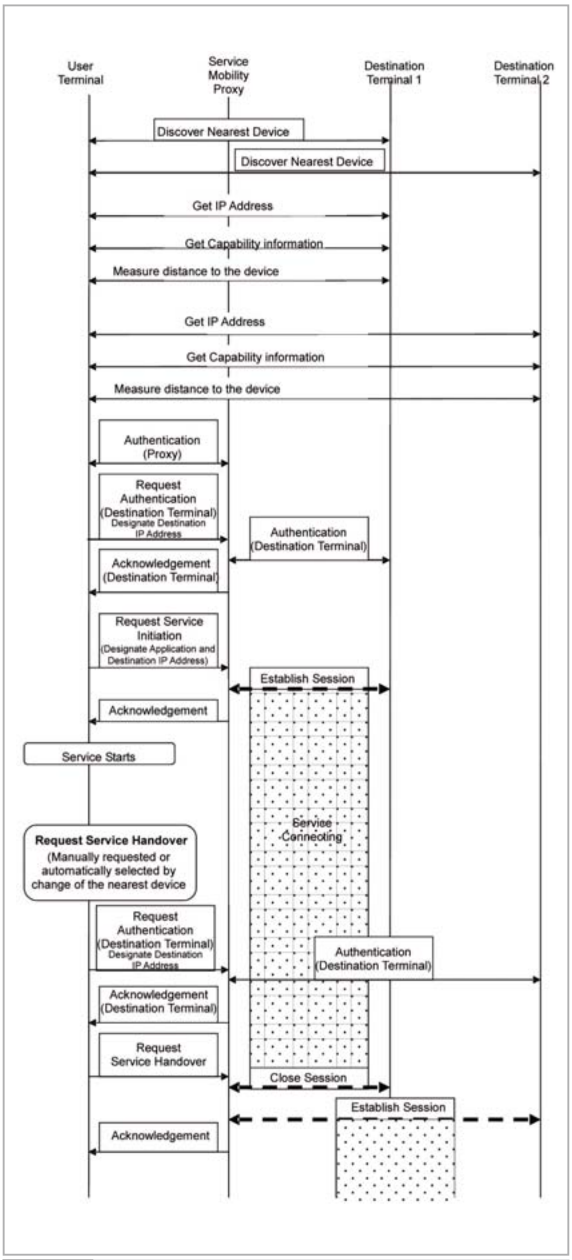

Fig.2 Handover sequence for service-mobility proxy

mentation of a service-mobility proxy supporting multiple communication applications. In the present study, we have generated methods for handing over H.323 sessions, DVTS streams, and application windows.

2.2 End-to-end handover control and terminal management network

Unified management of the user session can be executed even when the session is switched between various networks and terminals, by using an independent common-signal-

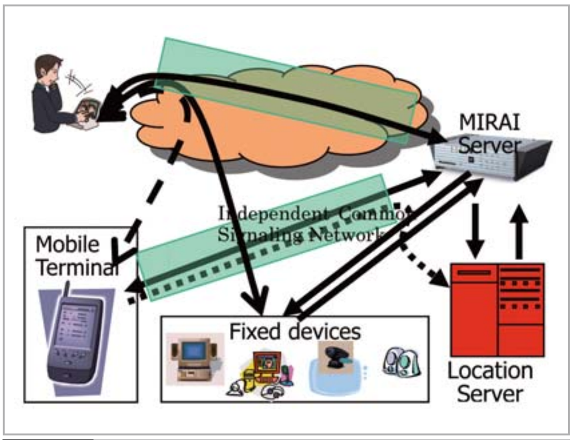

Fig.3 Common signaling and cross-device handover using MIRAI architecture

ing network and the MIRAI server featuring the MIRAI architecture[1]. Here, we propose a method for end-to-end cross-device handover control using this signaling network[2]. As shown in Fig. 3, the MIRAI server is in charge of the control and management of each terminal, and the MIRAI client on each of the fixed terminals provides information regarding the terminal, prepares the terminal for a session based on commands from the MIRAI server, and manages the applications. In an end-to-end cross-device handover, all fixed terminals must have the appropriate communication applications for the end-to-end communication; however, here, functions for establishing multiple sessions are given only to the terminals of the user and the user's peer counterpart in communication. In this system, when there is a change in the user terminal, the change in the available communication quality and protocol is notified to the MIRAI server; information on the optimal session establishment method and the new forwarding address is then sent to the peer and also to the target terminal of the handover. This establishes the session between the target terminal and the peer and completes the cross-device handover process. Two methods can be considered for searching for the target terminal nearest the user for this cross-device handover: a method using a location server as shown in Fig. 3, and a method using short-distance radio[3]. Details on the location server will be given in

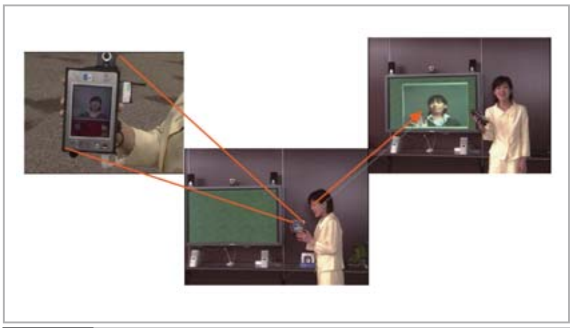

Fig.4 Controls are executed to ensure that the most appropriate communication quality is selected based on transmission speed and display size of the target terminal in the cross-device handover

Section **3.2**. Figure 4 shows an example of cross-device handover between a small wireless mobile terminal and a fixed, large display used in the present study. The small terminal is equipped with a wireless LAN having a maximum rate of 11 Mbps. Image quality is reduced to adapt to the small screen size, but when the handover is made to the large screen (connected to a wired network), the MIRAI server instructs that the session be conducted at higher resolution and quality.

As shown in Fig. 3, handover can be made between any type of device connected to any type of network, as long as the terminal can be controlled to establish a session, as in Fig. 3. In the examples given so far, the networks involved were all IP networks; however, if gateways can be installed between IP networks and circuit-switching networks, similar methods can be used to bilaterally execute cross-device handover between these networks. Figure 5 shows an example of a cross-device handover of a videophone session between a circuit-switching cellular phone and a notebook PC connected to the Internet. Such handover between heterogeneous circuit types is made possible by controlling the session establishment process of the end terminal using the MIRAI architecture[4].

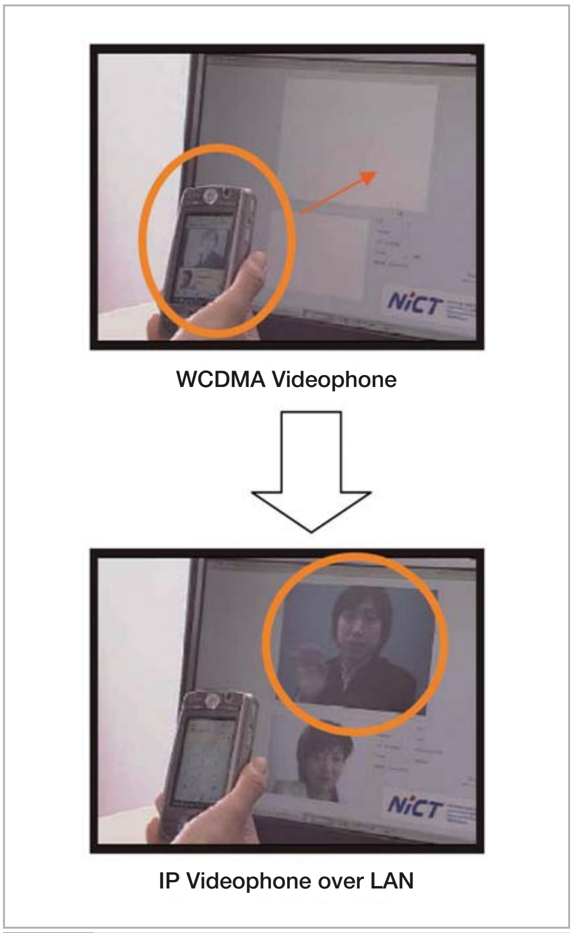

Fig.5 Inter-terminal handover between a WCDMA cellular phone and a notebook PC

3 Smart-space and location detection

Research on architectures for managing a network having various types of connected sensors and actuators and user-context sensing technologies will become crucial as component technologies in a ubiquitous network environment. By coupling such technologies with the cross-device handover technologies described in the previous section, it will be possible to select automatically the most appropriate terminal according to user status. This section will summarize the state of user location detection technology, a context information management framework, and a smart-space testbed that implements the necessary functions.

3.1 Location Detection Sensor

Various methods are available for detecting the location of the user, both indoors and outdoors. Table 1 compares installation costs, user-tag costs, power consumption of the tags, and the positioning precision of the various methods. Some methods employ radio waves, ultra-sonic waves, and images, and each has its advantages and drawbacks. For example, a location sensor using ultra-sonic waves offers exceptionally good position precision (within approximately 10 cm), but specialized tags and sensors must be newly installed for such a system, leading to high installation costs. In contrast, location sensors that use wireless LAN technology (which has recently become widely available) has relatively low cost in practical applications, but power consumption during communication is significantly high compared to when using RFID tags, and positional precision is also low.

Among the methods that employ radio waves, Bluetooth technology is currently becoming popular, with widespread installation in cellular phones and headsets for hands-free communication. Furthermore, this method consumes less power than wireless LAN sensors. There are two methods in location estimation using wireless LAN—one using the difference in propagation times of radio waves and another using a received signal strength indicator (RSSI). Generally, the former method is able to measure position (i.e., distance) with higher precision. However, this method requires a special module for measuring delay time, while the RSSI method requires only a commercial wireless LAN card and can be implemented simply by installing software[5]. Progress has been made in improving the detection precision of the RSSI method through a "learning function" with respect to radio wave conditions[5], and software for similar methods has already been commercialized. On the other hand, a Bluetooth positioning method is also available that uses the propagation time difference of radio waves, but commercially available Bluetooth modules cannot yet be used for this purpose. Therefore, in the present study, a positioning method is proposed that uses an RSSI value that can be acquired from a common Bluetooth module[6]. In fact, RSSI cannot be used for positioning in Bluetooth v.1.1 in the same way as in a wireless LAN, due to the nearly 3 seconds required for terminal detection and the "Golden Range" phenomenon featured in the RSSI to control transmission power. The excessive time required for terminal detection means that extensive time will be required for switching between multiple access points during positional estimation, and so this method will prove impractical in tracking the position of a user in motion. The "Golden Range" phenomenon refers to a flat portion of the actual signal strength having an RSSI value of 0, as shown in Fig. 6. When the signal strength stays within this range, linear changes in RSSI cannot be detected on the application level, and so positioning cannot be performed. Furthermore, with methods using signal strength, there is a general problem in the reflection and

Table 1 Various location sensors

Location Detecting Technology	Setting Cost	Cost of User's Tag	Power Consumption of User' Tag	Accuracy
GPS (outdoor)	none (satellite)	low	medium	medium (outdoor only)
Cellular Base Station Information	none (base station)	none (base station)	none (base station)	low
Active RFID Tag	high	low	low	medium
Image (Camera)	high	none	none	high (no ID)
Floor Sensor	high	none	none	high (no ID)
Ultra Sonic	high	medium	medium	high
Wireless LAN (Time of Arrival)	high	low	medium	medium
Wireless LAN (Received Signal Strength)	low	low	medium	low
[+Learning algorithm]				[medium]
Bluetooth (Time of Arrival)	high	low	low	medium
Bluetooth(Received Signal Strength)	medium	low	low	low
[+Learning Algorithm]				[medium]

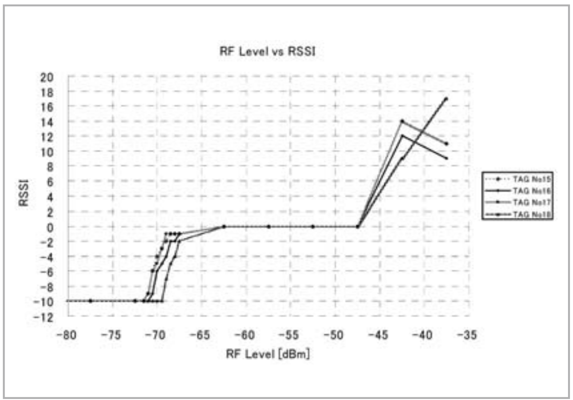

Fig.6 *Relationship between actual received signal strength and RSSI value for Bluetooth version1.1*

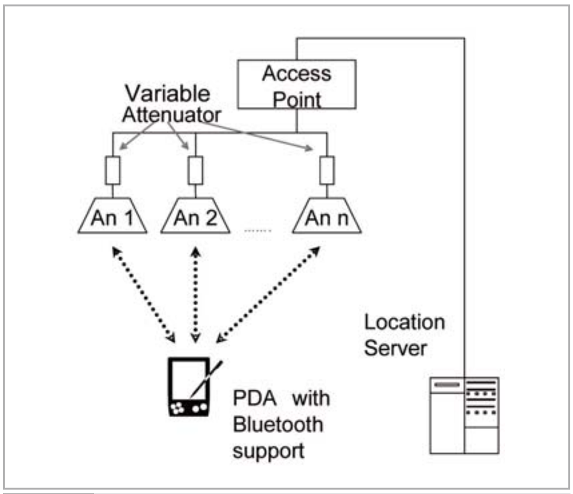

Fig.7 *Location sensing system using Bluetooth*

phasing of radio waves, which makes it difficult to perform precise positioning in small rooms.

In order to overcome these three problems, the present study (1) applies a method that switches between multiple antennas during a single session to resolve the problem of search time, (2) introduces variable attenuators to avoid trapping communication in the Golden Range, and acquires RSSI with varying the attenuation values, and (3) applies a learning algorithm to improve the precision. Figure 7 shows the architecture of the proposed location sensing system. This system performs location sensing by switching between antennas from a single base station. Furthermore, a variable attenuator is installed in each antenna, and the actual signal strength is estimated by varying attenuators. Table 2 shows the success rate of the present system in determining position within a 2-meter margin of error. The first four cases correspond to conditions in which the attenuator level was fixed at 0, 3, 6, and 9 dB, and the case labeled “proposed” corresponds to one in which the attenuator level was varied to acquire RSSI, as in the proposed method. The proposed method results in 92 % of the positioning attempts falling within the two-meter error range when tested in the testbed room shown in Fig. 10, representing a significant improvement in precision.

Table 2 *Results of experiment*

Att level [dB]	Precision
0	38%
3	39%
6	72%
9	22%
Proposed System	92%

3.2 User-context management framework

As shown in Table 1, various methods are available for location sensing. It is extremely difficult to cover both indoor and outdoor conditions using a single method. GPS technology can detect positions anywhere outdoors, but once the user is indoors (or underground), user positional tracking must be passed to a different sensor. Thus, seamless operation of multiple sensors will be required. Furthermore, some sensors can detect the position of a target (human) with high precision, such as floor sensors and images, but lack user ID information. One method to overcome this problem is to couple the sensing function with an object (human) recognition technology, while another feasible method is to couple the sensing function with a different type of sensor having ID information, thus arriving at high-precision data paired with ID information. Here, we propose a user-context estimation platform that enables switching and fusion between multiple

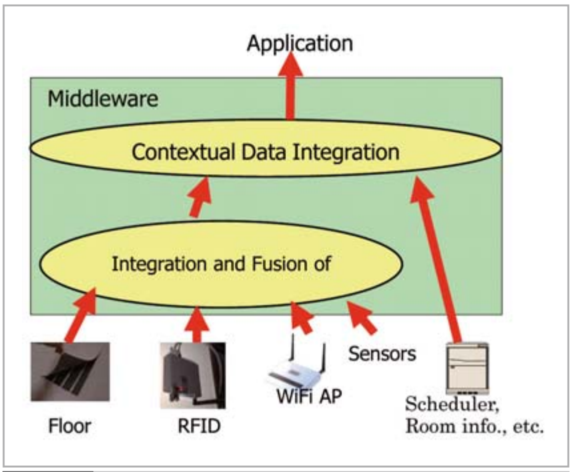

Fig.8 User-context management platform that integrates data from multiple sensors

location-sensor systems, to arrive at such high-precision data. Figure 8 shows the architecture of such a system. The data obtained by various sensors are integrated and information is provided to the application based on the estimated user context. In order to perform a correct estimation of user status, additional information (such as scheduler status and room conditions) are integrated and fused. For example, by transmitting contextual information to a service-mobility proxy and a MIRAI server that manages the cross-device handover described in Section **2**, it will be possible to execute context-aware handovers and determination of recipient terminal.

3.3 Sensor/actuator network nodes

In the present study, investigations were also performed on the sensor node, which collects information, and the actuator node, which provides this information to the user. The main focus in this sensor network study is a power-efficient protocol that collects information by installing sensors aboard a wireless ad hoc network node, but in practical use, the most appropriate network and nodes will vary depending on the purpose and type of data to be acquired. In this study, we propose a method in which service and data near the user is promptly acquired[7] and an actuator node that provides the user with the required information.

Here, nodes using IP technology are considered as candidate sensor/actuator nodes. Real-world information for sensing will be acquired as analog values by the sensors and the A/D-converted values will be collected on the network. The actuator node performs D/A conversion on the digital information acquired from the network, and outputs the data via the actuator to real space. If, for example, a sensor such as a microphone is installed on such a node, it will be possible to retrieve sound data from remote positions via the network. If a speaker is installed, it will be possible to output sound data through the network. By expanding on this principle, we have implemented sound transmission and reception functions in a virtual sound device on the PC, as shown in Fig. 9, to allow sound data to be input/output from any application on the PC to remote actuators. This virtual sound device generates PCM sound signals and then forwarding application adjusts the timing and transmits the packets to the IP address of the terminal to reproduce the sound. The sound is only reproduced at the intended actuator terminal, and it will also be possible to switch

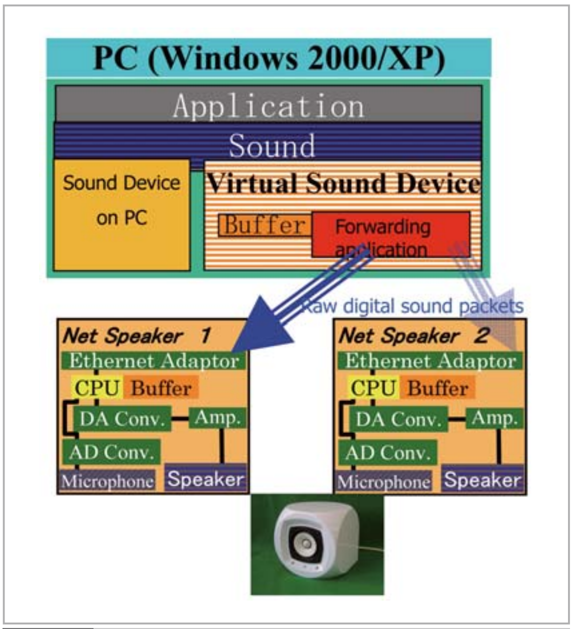

Fig.9 Terminals with speakers connected to a corresponding actuator node and the system architecture

the output terminal or send the sound data to multiple speakers simultaneously for reproduction of the source sound signal.

3.4 Smart-space testbed

It is extremely important to construct and conduct validation experiments on ubiquitous network technologies and context-estimating technologies such as those described above in practical environments, if we are to demonstrate the usefulness and feasibility of these technologies. Validation experiments using testbed rooms have been conducted at various research institutes. In the present study, we constructed the testbed room shown in Fig. 10 for this purpose. The room has floor sensors installed in the floors, RFID tags, Bluetooth location sensors, and ultrasonic location sensors in the ceilings, and various actuators in the walls, such as displays and network speakers. Wireless LAN access point information is also used for positioning. RFID tag readers are installed in the hallways of the building, and the data collected by all sensors are transmitted to the server, as described in Section **3.2**. The user carries a terminal equipped not only with an RFID tag, an ultrasonic transmitter, and a wireless LAN, but also a GPS, an azimuth sensor, and an accelerometer, and the data from these devices will also be sent to the server.

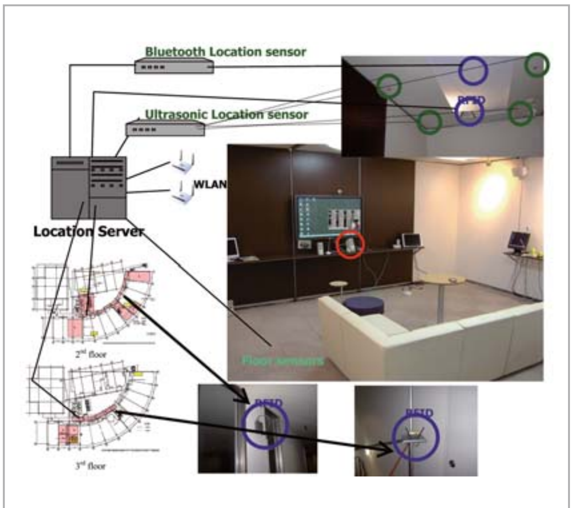

Fig.10 *Smart-space testbed*

This context-estimating server will send parameters defining the user position and status to the MIRAI server, as well as to a service-mobility proxy, such that these devices will make the appropriate selection and handover of terminals and switching of applications according to user location.

4 Conclusions

In this paper, we have presented a number of methods for user-context acquisition and management, as well as an actuation method for the user based on the estimated information, as part of an overall aim of arriving at context-aware communications. In order to enable the practical application of these new methods of network utilization, we must examine their use in actual everyday conditions. Specifically, we have investigated more in-depth technical proposals: cross-device handover between ad hoc network terminals when a single user has several mobile terminals (such as cellular phones and notebook PCs)[8]; methods of authorization of and changes to context-aware communication services according to user status[9]; and a method of providing information by selecting the optimal timing method, according to the user's status[10].

This paper has mainly dealt with info-communication terminals such as PCs and PDAs, but in order to make the present cross-device handover technology applicable in practice, we must construct a method that will enable communication among more general devices and home appliances. For example, in recent years, standardization of home information appliances has progressed significantly, and it may be expected that these devices, too, will be connected to the network. Thus, by establishing methods of terminal handover and information transfer using standard protocols that may be applied to such appliances, we will be able expand the range of selected terminal use.

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