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Ubiquitous Networking System for Seamless Communications Across Heterogeneous Networks and Devices

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Abstract—**This paper describes the design and implementation of a ubiquitous networking server that enables cross-device as well as cross-network mobility by using an out-of-band signaling method with a location sensing system for context-aware seamless network services. The context includes the user's presence, position of the user and neighboring devices, network interfaces attached to the mobile terminal, availability and available bandwidth of each network, priority in selecting networks, capabilities of the mobile terminal and devices, and installed applications. The server is designed to be placed not in operators' networks but in users' local networks such as home and enterprise networks to provide users with Mobile IP-based handover capability between radio networks in a distributed manner. This would accelerate the introduction of Mobile IP to network services, offering flexibility in creating user-centric network services. The out-of-band signaling method we propose exchanges information between mobile terminals and the network about user and device authentication, session initiation protocol (SIP) signaling, Mobile IP signaling, the position of users and devices, and signaling for cross-device mobility. These features provide us unprecedented flexibility in communication.**

Keywords: seamless, mobile, ubiquitous, context, IP, handover, heterogeneous, location

I. Introduction

Several years have passed since IP Mobility Support (RFC2002) [1] and IP Mobility Support for IPv4 (RFC3344) [2] were presented as requests for comments in the Internet Engineering Task Force. Several trials of Mobile IP have been done in commercial networks. Mobile IP, however, has not come into widespread use yet in commercial networks other than CDMA2000 networks. One reason for the delay is that in mobile data communications, the demand for mobility across different radio networks without losing IP connectivity is still weak, although roaming features across different Internet service provider (ISP) networks are offered. This will gradually change as terminals get smaller and mobile phones featuring voice-over-IP and wireless network interfaces become popular. Another reason for the delay in the spread of Mobile IP is the cost of deploying systems and providing services. Providing such services requires network operators to deploy and operate highly reliable, highly fault-tolerant, and high-capacity Mobile IP servers. Ubiquitous networking servers are designed for home and enterprise environments to provide cross-network and cross-device mobility in a decentralized manner. For instance, in the home, a ubiquitous networking server would be placed between the Internet and the home network. IP mobility would be provided by the server to the users of the home network. Deploying servers in such a decentralized manner would accelerate the introduction of Mobile IP to commercial network services, allow users to get mobile network services, and offer flexibility in creating user-centric network services. Indeed, this would avoid having a single point of failure in a centralized ISP's service architecture. Placing cross-network or IP macro-mobility functions in edge networks is one idea that distinguishes this study. We present an overview of the whole system and focus on the cross-network mobility functions. First, we describe the design principles of the system and the background of this study. Then, the implementation is presented in terms of network and functional configurations, context processing procedures for determining available applications, and graphical user interfaces (GUIs).

II. Design Considerations

The final target of our research is to create networking technologies that allow users to access the network without being aware of individual networks and devices. Toward this target, we had been studying separate technologies for cross-network handovers [3-6], cross-device handovers [7], and a location-sensing platform [8]. Then, we came to integrate these technologies to provide users with context-based cross-network and cross-device mobility. While designing this system, we kept in mind that active users of the mobile communications driving the R&D of the new technologies would probably continue to have both a mobile phone and a laptop PC, while all-purpose small terminals with ultrahigh-performance chips and software-defined radio modules are expected to become more readily available. We also assumed that those mobile phones and laptop PCs would be used in combination: connected to one another through a personal area network (PAN) and to outer networks with network interfaces such as wireless LANs and cellular networks. We provided an out-of-band signaling method (to be introduced later) between the laptop PCs and a signaling server on the infrastructure network via mobile phones with always-on connections to the network. The following introduces the three technologies we integrated into one system.

Cross-network handover was enabled with a seamless networking platform called MIRAI [3] in which a MIRAI agent provides functions necessary for cross-network mobility with an out-of-band signaling method in heterogeneous wireless networks. The main advantage of MIRAI is that it separates data paths and the signaling path. The out-of-band signaling system, called Basic Access Signaling (BAS), exchanges control messages between mobile terminals and the network through a Basic Access Network (BAN). The signaling method was originally developed to perform functions such as location update, paging, and handover management in heterogeneous network environments. The BAN is a radio access network (RAN) used as the signaling channel. The previous MIRAI platform, developed in 2003 [2], allowed context-based adaptive networks and application control. The context includes the user's presence, location, available network interfaces, network availability, network priority, communication status, terminal features, and installed applications. For instance, the system can show the caller and its callee the applications they can access through the network before communication occurs. Changes in the context can cause the on-going application to switch during communication.

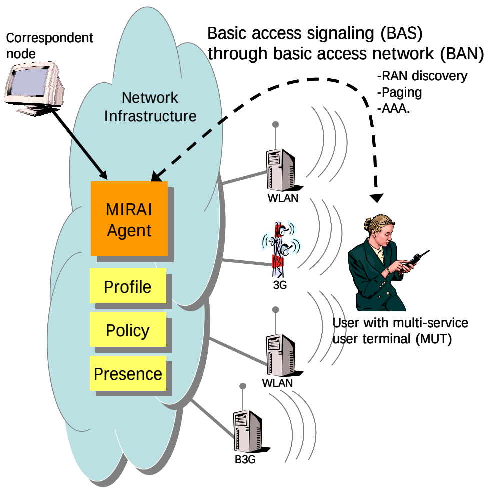

Figure 1. Concept for out-of-band signaling (BAS) on BAN in MIRAI platform.

Cross-device handover [7] was provided by a service mobility proxy (SMP), which is placed on the network between a user's network and his/her correspondent terminal and manages the connection between the SMP and the end device the user specifies. The device could be a PC, AV appliance, or any piece of electronic equipment able to communicate over the network. The SMP hands the connection over from one device to another, transcoding the contents according to the capabilities of each device.

A location-sensing platform was also studied [8]. This platform collected information from sensing devices such as WiFi access points, radio-frequency tag (RF tag) readers placed inside the NICT office building, and foot-pressure sensor carpet to calculate the locations of users. Location information was recorded in a universal position identifier (UPI) format we developed. The location-sensing platform returned the UPIs of users to the ubiquitous networking server.

We integrated the server functions offered by the MIRAI agent and the SMP by logically re-organizing the software and adding new features to make one functional entity, creating a ubiquitous networking server. The client functions of the two systems were also integrated.

The ubiquitous networking server is designed to be at the entrance of a home or enterprise network (Fig. 2). A mobile phone and a mobile terminal comprise a PAN that moves outside and inside the local network. The PAN is always connected with the ubiquitous networking server through a basic access network (BAN), which is a favorable network selected by each user. The signaling path is shown as the green line, and 3G is used as the BAN. Bluetooth is one possible wireless network connecting the mobile phone and the mobile terminal. The ubiquitous networking server forwards packets to the PAN through a network chosen for the position of the PAN using the cross-network handover capability. It also forwards the packets to any device the user specifies, such as PCs and AV appliances, using the cross-device handover capability.

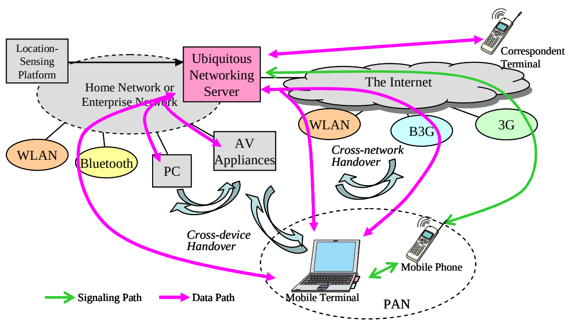

Figure 2. Network configuration.

Because mobile terminals with Bluetooth and 3G interfaces are becoming popular and people like making full use of mobile devices and computers, we believe BAS will fill their need for seamless mobile communications. For instance, paging, which is less efficient with WLANs than with cellular systems, is performed through the BAN, or 3G, to request that the mobile terminal receive the call.

III. IMPLEMENTATION

A. *System Configuration*

The setup of our experimental network and the functional configuration of the system are shown in Figs. 3 and 4.

On the basis of the architecture shown in Fig. 2, we constructed an experimental network. We created a home network and a foreign (public) network with a kiosk terminal and a public SIP phone. In the upper part of the home network in Fig. 3, sensing devices and a location-sensing platform server are denoted. The server collected information on the positions of users and devices from on-the-network sensing devices such as wireless LAN access points, RF-tag readers, ultrasonic position sensors, and floor panels with pressure sensors. The mobile phone in the PAN had an accelerometer and a direction sensor as well as RF and ultrasonic tags. We installed SIP phones, a Polycom tele-conferencing system, and desktop and laptop PCs to the network as the end devices for cross-device handovers. We also installed a NetSpeaker, which receives IP packets of digitized audio information and plays the decoded analog audio sound. We integrated functions that future mobile phones will probably have into a mobile terminal, which was a small PC running Windows. The mobile terminal had a W-CDMA or an EV-DO data card to connect to the 3G network. Wireless LAN ad-hoc mode was used to connect the mobile terminal and the mobile PC.

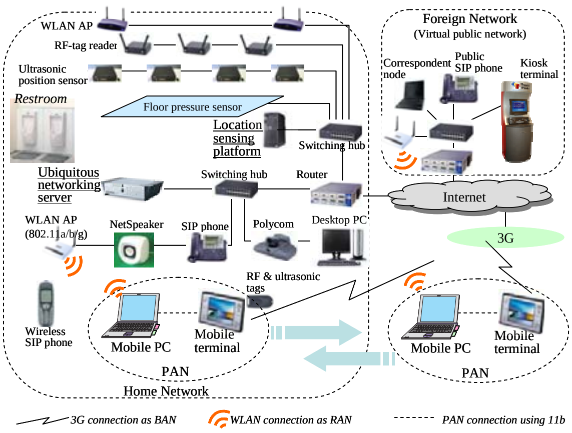

Figure 3. Experimental network setup.

The main functional components of the ubiquitous networking server, the mobile terminal, and the mobile PC are shown in Fig. 4. The components of the ubiquitous networking server included a MIRAI agent, service mobility server, and content server. The MIRAI agent included a BAS management function that managed information about users and devices stored in the database, a BAS server that communicated with the mobile terminal, neighboring devices, and the location sensing platform, a SIP server that relayed SIP signaling messages and presence information between SIP clients, and a Mobile IP home agent for IP-level cross-network mobility.

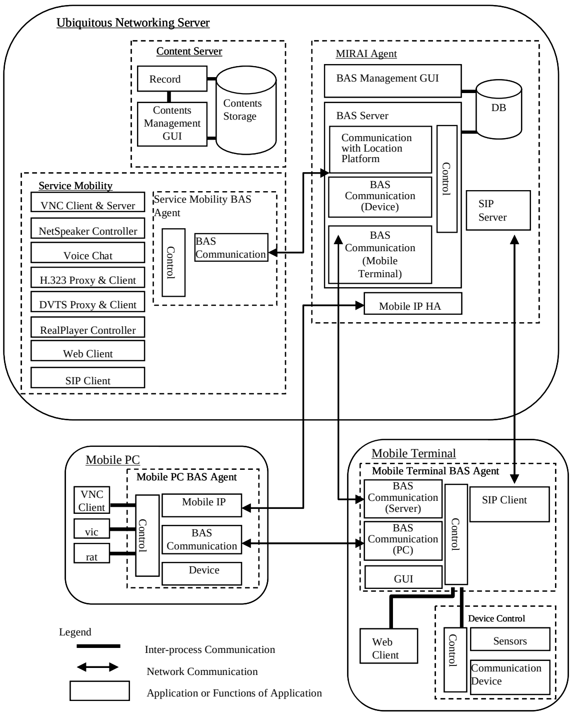

Figure 4. Functional configuration.

A service mobility proxy (SMP) had been designed to be placed at a fixed position on the network to enable cross-device mobility. We extended its function to enable any PC (with proxy functions installed) to be selected as a proxy, depending on the capability of the end device or terminal. Cross-device mobility without a proxy was also available in some cases by using SIP. Details will be reported in other papers.

The mobile terminal components included a mobile terminal BAS agent and a device control. Using the information from the BAS server on the network, the mobile terminal BAS agent controlled all communications of the terminal and presented information about neighboring devices on the screen. With this terminal, the user was able to control the functions of the content server in the ubiquitous networking server; for instance, the user was able to record a TV program and replay it. Based on information such as the status of the networks and the type of services the user initiated, the agent asked the mobile PC to change its network. The SIP client in the mobile terminal BAS agent obtained context information from other users. The device control collected information from sensors on the mobile terminal or on the user including an accelerometer, a direction sensor, an RF tag, and an ultrasonic tag, then periodically sent it to the mobile terminal BAS agent. It was then forwarded to the location-sensing platform through the MIRAI agent. The device control also managed the network interfaces.

The mobile PC BAS agent in the mobile PC switched networks when asked by the mobile terminal and reported the status of each network to the mobile terminal.

B. *Contexts and their Processing*

The process of determining the available applications on each terminal (the mobile PC, mobile terminal, and their neighboring devices) is illustrated in Fig. 5. The process of determining the context information that was shown on a caller's display is illustrated in Fig. 6. In the previous MIRAI system, the available applications (such as "leave a message," "voice phone," and "video phone" were determined based on the user's presence, location, available network interfaces, network availability, network priority, communication status, terminal features, and installed applications. One problem was that a callee might not want to accept the application the system chose based on the context and offered to the callee. Only callers were able to select applications. One significant feature of our new system is that callees were able to select applications in advance, based on their contexts. For instance, it was possible for a user to accept no calls when he/she was in a restroom or to accept only chat applications when in public transportation systems such as busses and trains. Although it was technologically possible to set different preferences for different persons, this feature was not included because of its complexity.

Applications available on each terminal were first determined following the process shown in Fig. 5. To determine networks available to each terminal at its geographical position, various pieces of network information were collected. The mobile PC collected information about the types of WLANs whose radio signals were detected and whose service set identifiers (SSIDs) were confirmed to be safe by the ubiquitous networking server through the BAS, and about whether or not wired LAN (Ethernet) was available. The type of network used as a BAN was checked by the mobile terminal. These pieces of information were used to determine networks available at the current position. The logical AND operation was performed between the available networks and the available networks with remaining battery energy for each terminal, producing a preliminary list of available applications. By taking into account the remaining battery energy and the capabilities of each terminal, the applications available on each terminal were finally determined.

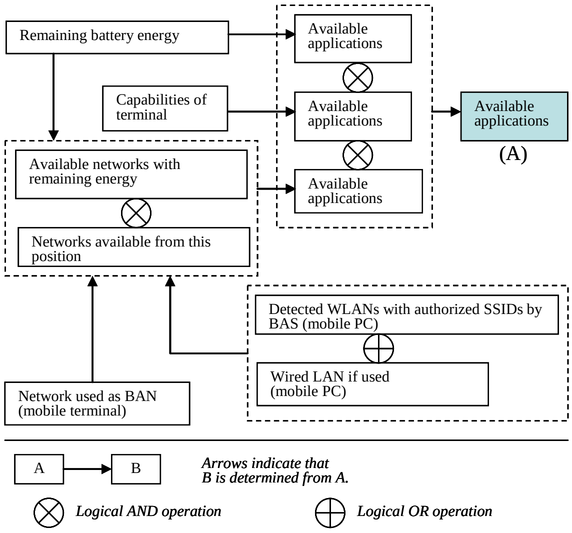

Figure 5. Process of determining applications available on each terminal.

The process of determining the context information that was shown on a caller's display (Fig. 6) began with the user specifying his/her preferred applications for each position. Real-time position information came from the location-sensing platform described in the Universal Position Identifier (UPI) format. As an example, we were able to represent a point in the NICT premises as UPI://nict/3f/301/(10735,2089,0), which denotes the three-dimensional geographical point (10735, 2089, 0) in room 301 on the 3rd floor of the NICT building.

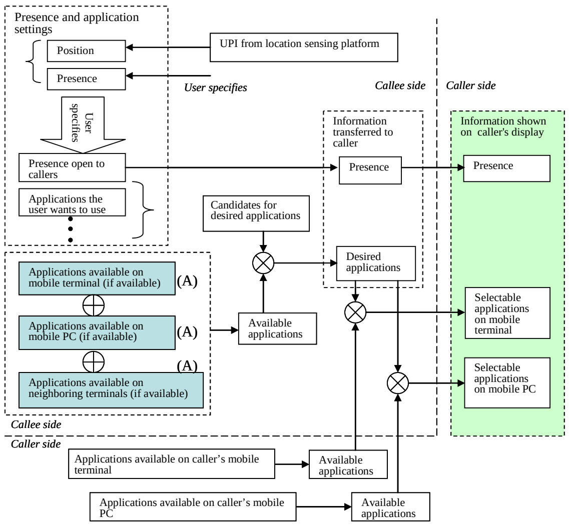

Figure 6. Process of determining the context information shown on the caller's display.

The logical OR operation was performed on the lists of available applications (determined by the process in Fig. 5) on terminals neighboring the user, and the AND operation was performed on the resulting list of available applications and the list of desired applications. This determined the information to be transferred to the caller, including the presence of the callee and his/her desired applications. Finally, the AND operation was performed between the desired applications of the callee and the available applications of the caller to determine selectable applications for the mobile terminal and mobile PC.

Let us consider one example. User A makes a call to user B. User B is attending a meeting and his/her desired applications are e-mail and chat that are available on his/her mobile terminal, mobile PC, and neighboring devices. When user A selects user B in the GUI on the mobile terminal, the GUI shows that user B is in a meeting and selectable applications are e-mail or chat.

C. Graphical User Interface

The GUI for the BAS control application was displayed on the LCD monitors of mobile terminals. When the telephony tab was selected, the GUI shown in Fig. 7 was displayed; otherwise, that in Fig. 8 was displayed. The upper part of Fig. 7 shows the status of the user while the lower shows that of a selected member. The user's position came from the location-sensing platform. Below the position, the user specified his/her presence and preferred applications. In the lower part, the applications that the selected member preferred were shown.

In device mode, a map showing the user's position was displayed. The estimated position and direction of the user was indicated. The positions of neighboring devices and other members were also shown. Users were able to distinguish between available and unavailable devices through their colors. When one device on the map was selected, the image and the name were displayed in the upper part of the screen. If the selected device was receiving or sending packets, the user was able to switch the connection from that device to another using a device switcher.

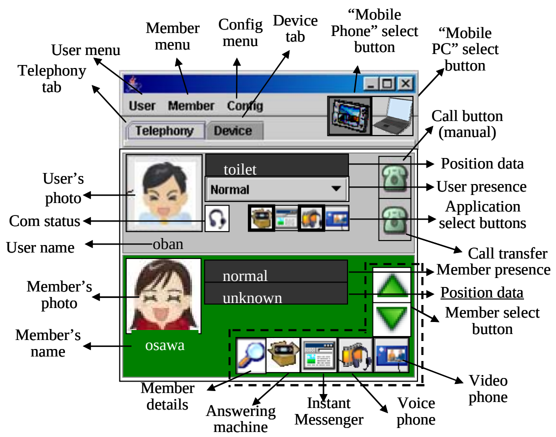

Figure 7. GUI for BAS control application in telephony mode.

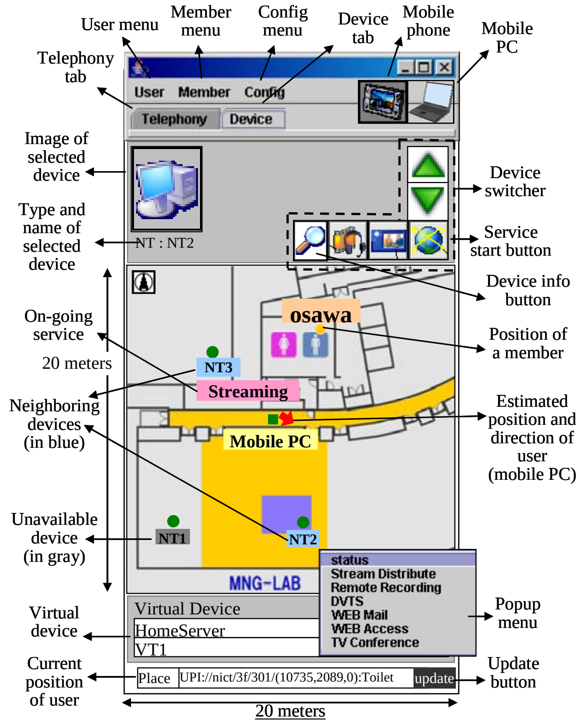

Figure 8. GUI for BAS control application in device mode.

D. Features

This is a summary of the major features not included in the previous MIRAI system [6].

- We integrated cross-network handover and cross-device handover, which were formerly performed by separate mobile terminals, into one virtual PAN terminal composed of a mobile terminal and a mobile phone.
- A function was added that allowed users to inform their callers of their preferred applications. This avoided initiating undesired applications.
- A new location-sensing platform with various sensors gave precise position information about users and devices to the ubiquitous networking server more frequently.

One application of this system is watching video files. The user can preview a TV program stored in the content server anywhere, anytime, and with any terminal. If a kiosk terminal is available and the user is permitted to use it, he/she can switch the preview terminal from his/her terminal to the kiosk. In a home network, he/she can switch the end device for the audio signal from his/her terminal to the NetSpeaker and the visual information to a large screen.

In the following, we show photographs of the system demonstrating two distinctive features: cross-device handover of video phone session and media adaptation based on context.

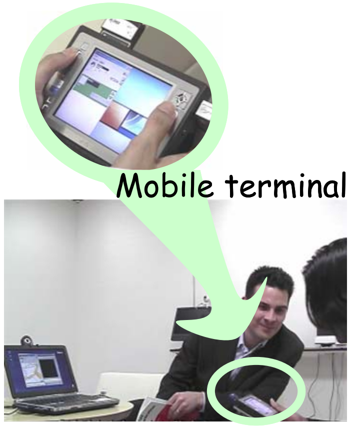

Figure 9. A user is receiving a video phone call on his mobile terminal.

Figure 10. He has switched the session from the mobile terminal to the desktop PC to show the video image to his friend.

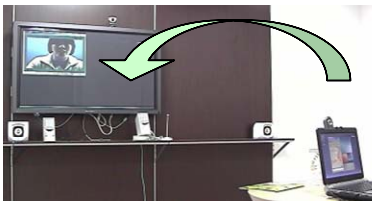

Figure 11. He has switched it to the plasma display to make the video window larger.

CONCLUSIONS

We described the concept of a decentralized ubiquitous networking server for context-aware seamless services. Decentralized deployment of the Mobile IP home agent would accelerate the introduction of IP mobility features to network services and would offer flexibility in creating user-centric novel network services. The server was built on the enhanced MIRAI platform that provides context-aware cross-network handover capability together with a service mobility proxy for cross-device handover capability and a location-sensing platform for precise position tracking. By integrating these technologies into one packaged system, communication can be initiated in a style that the recipient prefers and connections can be seamlessly handed over from one network to another and from one terminal to another. The system allows users to enjoy communicating without being concerned about their positions and the availability and performance specifications of individual networks and neighboring devices.

Figure 12. The system controls video quality according to network bandwidth. When a user unplugs the Ethernet cable from the PC, the video phone session is handed over to a wireless connection, and, at the same time, the quality of video image becomes lower.

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