(6) Ubiquitous Interface Technologies

Ken Ohta, Yoshinori Isoda and Shoji Kurakake

In the pursuit of new human-oriented mobile communications, we are conducting research on technologies called ubiquitous interfaces to make ubiquitous resources including various devices and wireless access measures available to users efficiently and flexibly without forcing them or applications to undergo troublesome setup and operation.
This article proposes the Mobile Adaptive Terminal architecture as an interface that autonomously adapts to the dynamic environment in which the user moves and the state of resources changes, to provide services in a seamless manner.

1. Introduction

Ubiquitous, high-speed wireless access environments are becoming a reality, along with the dissemination of Wireless Local Area Network (WLAN) access and the 3rd-Generation (3G) mobile communications system referred to as International Mobile Telecommunications-2000 (IMT-2000) in all sorts of places, including outdoor, home and office environments. Rapid progress is also being made in the research and development of information appliances, home networks and sensor networks, toward ubiquitous computing environments. At the same time, mobile hosts like handsets and PDAs are also becoming sophisticated in terms of functionality, although they are still extremely limited compared to such devices as information appliances and PCs in terms of resources such as Central Processing Unit (CPU), memory, battery, etc. and the quality of the interface (built-in display, speaker and camera, etc.), due to size requirements and cost constraints. Therefore, in order to provide services that require many resources and high-quality interfaces, such as video conferencing and music on demand, our approach should provide methods for MHs to utilize TV sets, video cameras, surround speakers and other devices with rich input/output (I/O) and processing power in the vicinity, in addition to the sophistication of the MHs themselves. In an environment where networked devices are embedded all over the place, it is possible that people will be able to make voice calls by such ubiquitous devices while moving around without holding his/her handset.

Devices (I/O interface) and wireless access points (network interface) are diverse network resources that are location-dependent in that their range of availability is restricted, and have different attributes in terms of capability and functionality. As the availability of resources changes when a user migrates, it is necessary to switch (handoff) resources in the course of providing a service, based on dynamic discovery and monitoring of resources. Handoff requires complex session management that involves control of multiple media streams (voice or video) forwarded to and from various devices (internal devices, external devices or corresponding hosts) through heterogeneous network interfaces (such as cellular, WLAN or Bluetooth[*1]). Furthermore, discovery of appropriate resources and selection algorithms are essential because the type of resources required varies from application to application, and each user has preferences regarding the choice of resources to be used and will choose a policy based on the user's circumstances (such as the location and the existence of other persons).

This research aims to develop a ubiquitous interface technology infrastructure that autonomously adapts to changes in the availability of ubiquitous resources and the user's circumstances learned from the sensor network to provide seamless services. In a complex and dynamic ubiquitous environment, users are forced to undergo troublesome setup and selection operations, and applications are required to incorporate customized resource selection and complex session management mechanisms, which worsen development complexities. Moreover, the setup latency of devices and wireless access measures during handoff as well as session re-establishment delays can disrupt the forwarding of media streams consisting of voice and video, which are not tolerant to interruption.

This article proposes the Mobile Adaptive Terminal architecture (MAT), which is built up around an agent employed to reflect the chosen policy and adapt to changes in the environment as well as conceal complexities, on behalf of the user and the application developer. The agent running on an MH monitors the availability of resources and handles handoff and modality (described in Section 3.3) according to the policy and the user's circumstances, and then performs signaling and routing control for inter-terminal session management in an end-to-end fashion. MAT introduces the concept of virtual sockets, which are independent of physical resources, in order to conceal address changes of sockets in the session from the applications. Further, MAT incorporates a proactive soft-handoff method, through which it is possible to set up nearby resources proactively and simultaneously use both new and old resources, to conceal the disruption in media streams during handoff. This article also describes a testbed we have developed based on MAT and an example of an implemented test application, *"Follow-me Music Service."* This involves automatic handoff between WLAN and cellular devices, and audio-output switching to a nearby speaker device in an experimental house environment, where various network resources including devices, Radio Frequency IDentification (RFID) tags, and visual sensors are installed ubiquitously.

*1 Bluetooth: Bluetooth™ is a trademark owned by Bluetooth SIG, Inc. and licensed to NTT DoCoMo.

2. Background

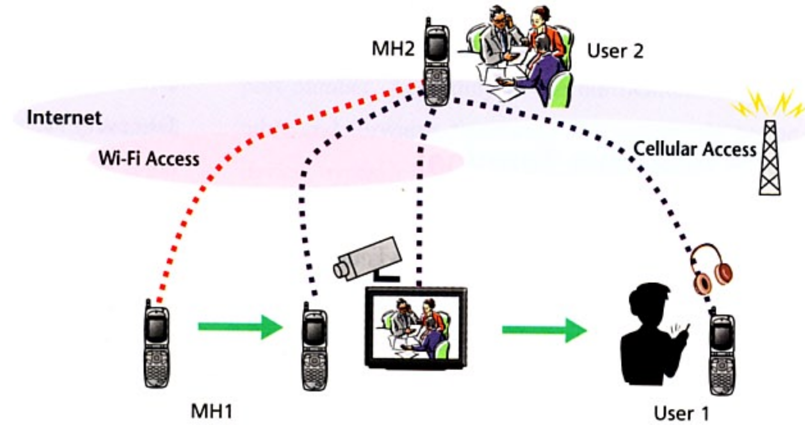
This chapter presents the assumptions and the required functionality in the research based on a scenario involving mobile video conferencing over the Internet (**Figure 1**).

2.1 Scenario

Firstly, User 1 activates a video conference application in the mobile host (MH1) and calls the mobile host of his/her communication partner (MH2). It is assumed that each MH has one or more global IP addresses, and when the IP address changes due to migration, it will perform a dynamic Domain Name System (DNS) update to maintain reachability between the hosts. It is also assumed that MH1 and MH2 have multiple network interfaces, have one or more private IP addresses through which to use local resources on home networks and Intranets, and can acquire information on the user location from the Global Positioning System (GPS) and sensor network. Meanwhile, it is assumed that there are two types of devices: global devices, which have a global IP address that is reachable from hosts in external networks; and local devices, with which direct communication is impossible from the outside, such as devices with a private IP address and non-IP devices.

As shown in Figure 1, in the passage, MH1 detects that WLAN (Wi-Fi) access is available by monitoring the network interfaces in the vicinity, and establishes a video and voice I/O session with MH2 via Wi-Fi access. Then, as the user enters the conference room, MH1 discovers an external display and a set of speakers connected to LAN, and a Bluetooth camera, by monitoring the I/O interfaces. Based on the chosen policy, MH1 decides upon a handoff of video and voice I/O from its internal devices to the external camera, display and speakers. MH1 informs MH2 of the global IP address and the port numbers of the external display and speakers to forward the video and voice output bypassing MH1. Meanwhile, for the Bluetooth camera, which is not equipped with a global IP address, MH1 receives the video data via Bluetooth and selects a path via Wi-Fi to forward it to MH2.

When the user leaves the conference room, MH1 detects itself leaving the service areas of the external device and Wi-Fi, and switches the video and voice I/O session to its internal devices via a cellular interface.



	Passage	Conference Room	Outdoors
Network Interface	Wi-Fi (WLAN)	Wi-Fi (Bluetooth employed to connect camera)	Cellular (Bluetooth employed to connect headset)
Video	Built-in Display	External Display	Built-in Display
Output	Built-in Camera	Bluetooth Camera	Built-in Camera
Video Input	Built-in Speaker	External Speaker	Bluetooth Headset
Voice Output	Built-in Microphone	Built-in Microphone	Bluetooth Headset

Figure 1 Seamless Video Conference

2.2 Research Background

Technologically, switching wireless interfaces to connect a different type of wireless access points is generally called "vertical handoff," while switching devices supporting a service in progress is referred to as "service mobility." The MAT architecture proposed here is a cohesive architecture that supports the switching of both.

(1) Vertical Handoff

Research on vertical handoff mainly focuses on Mobile IP that is a network-layer mobility solution. Conventionally, extensions based on Mobile IP have been made to accelerate handoff, minimize packet loss and reduce signaling traffic. Vertical Handoff [1] proposes soft-handoff and buffering at base stations. IP micro-mobility protocols propose the localization of signaling based on a hierarchical architecture. In contrast, MAT does not assume support for network-layer mobility (such as Mobile IP) akin to the end-to-end approach [2].

(2) Service Mobility

Service mobility systems such as the Mobile People Architecture (MPA) [3] and the Internet CEllular BEyond the thiRd Generation (ICEBERG) [4] architecture deploy agents in the network who manage the user location and policy and forward calls, thereby enabling the session-initiating/terminating device to be switched between a fixed-line phone, mobile phone and PC. While they do not support switching devices during a session, the Session Initiation Protocol (SIP) [5] system and the mobile agent system for location-oriented multimedia proposed in [6] do so by a session re-establishment mechanism. Developments in device-switching systems include the ResOurce-aware Application Migration (ROAM) system [7] supporting migration of Java*2 applications between mobile terminals and PCs and the Browser State Repository Service [8] enabling devices to be switched while sustaining the web session state.

However, none of the existing session management technologies support the simultaneous use of multiple devices or the connection between local devices and external hosts. Therefore applications themselves are required to deal with such functionality. Another issue is the compatibility with existing systems, as they assume that home information appliances, sensors and other devices have session management functions. MAT solves these problems by a terminal-oriented session management technology. Furthermore, existing technologies are exposed to the risk of disruption of media streams in video and voice communication if the Wi-Fi network or the external device being used becomes unavailable before the completion of handoff to a cellular or internal device. This problem is caused by device warm-up, setup of the cellular interface including dial-up connection, and delays attributable to session re-establishment.

*2 Java: An object-oriented programming language suited for use on networks, developed and advocated by Sun Microsystems in the U.S.

MAT solves these problems by setting up nearby resources proactively and simultaneously using both new and old resources.

3. Mobile Adaptive Terminal Architecture (MAT)

Figure 2 (a) shows the configuration of MAT, in which the agent constitutes the middleware. This section explains each MAT module according to the handoff procedures shown in **Figure 2 (b)**, and then describes the seamless handoff procedures. "Table" in the figure refers to the session management table binding the virtual socket with devices and wireless access, while "policy" refers to a list of preferences and requirements of a user and applications. While a communicating program generally executes communication processes using the socket library, MAT provides a virtual socket library to assist the development of applications for media input/output. Processes such as the setup and release of resources, routing in the event of session change and the creation/disposal of sockets are concealed inside the virtual sockets, relieving the application of complex session management.

3.1 Configuration

(1) Interface Monitoring

The Interface Monitoring module monitors the network interface and discovers available resources and resources in use that have become unavailable through the use of service/device discovery protocols such as Service Location Protocol (SLP), Jini[*3], Universal Plug and Play (UPnP), Universal Description, Discovery and Integration (UDDI) and Bluetooth Service Discovery Protocol (Bluetooth SDP). When changes are detected, it activates the Handoff Control module. The metric used to judge wireless access availability is usually the received signal strength and the frame error rate. On the other hand, the typical metric used to determine the availability of devices is the relative positioning and the distance between a user and a device. Each device registers its IP address and port number for media input/output, transport/control protocol, and service area to the Service Directory. The service area is specified either by the name of a place or by coordinates (e.g. latitude and longitude).

(2) Handoff Control

The Handoff Control module decides whether to hand off resources according to the policy, based on the information about resources that are available at that time and place, and updates the corresponding entries in the session management table according to the information on resources to which handoff is executed. For example, if a video-conference user has a priority-based policy on the choice of the video input interface, the higher-priority camera will be selected in a room where more than one camera is available. In addition to simple priority, it is conceivable to have rules using attributes such as display size, surround-sound functions, transmission speed and

*3 Jini: A Java-based distributed system technology advocated by Sun Microsystems in the U.S.

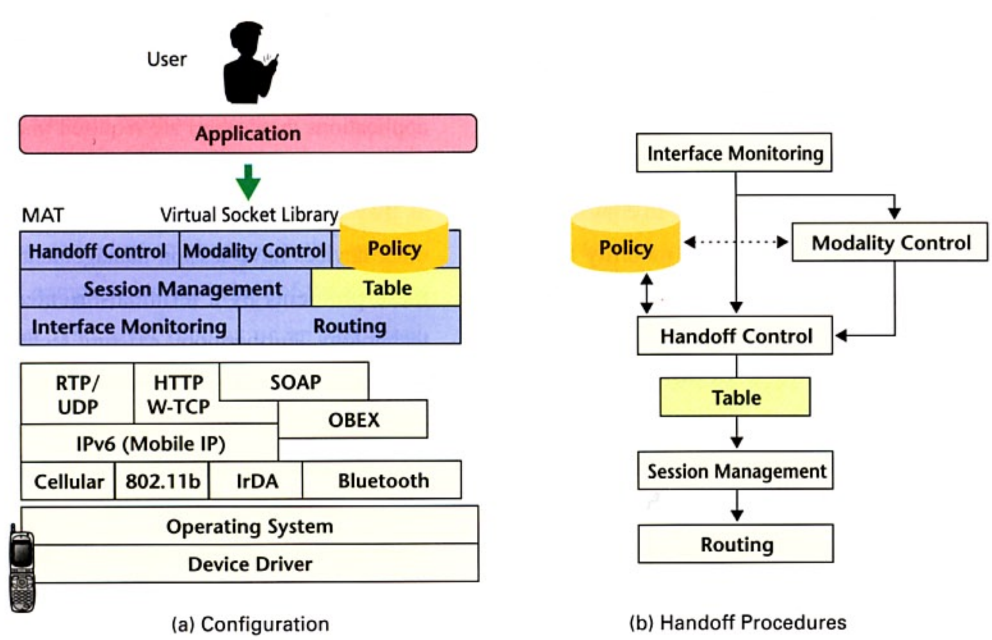


Figure 2 Mobile Adaptive Terminal Architecture (MAT)

costs, and algorithms based on the user's circumstances learned from the sensor network.

(3) Modality Control

If the sensor network can supply the agent with detailed information about the situation, for instance, whether the user is walking or sitting down, or whether there is another person nearby, it may be possible to select devices more meticulously, and control the ways in which the media content is shown and how input is received from the user (modality). For example, you will be able to control the options in cases where a mail application presents an incoming mail using a device near the user: if the user is not stationary, an external display nearby can show the entire text; if the user is walking, external speakers can play it back by voice; if there are other persons nearby, the built-in display of the handset can display a summarized version of the text. However, it is difficult to describe the rules throughout the environment by common expressions and conditions of sensor data, because the types of sensors, the way in which the user's situation is recognized and expressed, and the control conditions of the application (such as the settings of volume for reading mail) vary from area to area within the ubiquitous computing environment.

In this research, this problem is tackled by making the user and the developer define sets of local rules based on the combination of the sensor values and the application control conditions in each area in the environment. By setting rules that reflect the sensors specific to each area and the meaning and characteristics of that place, it is believed that a robust working system could be realized even in a diverse real-world environment. However, it will be necessary to consider an autonomous mechanism that indicates and corrects the behaviors and reflects them in the rules while the system is operating, in order to alleviate the user and the developer's burden of adding rules.

(4) Session Management

The Session Management module is triggered by a table update by the Handoff Control module. **Figure 3** shows the session management sequence in the event of output-interface handoff. In cases where a global device is involved (Figure 3 (a)), MH1 sets up the device, and then notifies MH2 of its IP address and port number. According to the notification, MH2 updates its table and forwards the media stream directly to the external device, bypassing MH1. In the event of input-interface handoff, the difference is that MH1 informs the device of the IP address and port number of MH2 and the device directly forwards the media stream to MH2. In cases where a local device is involved (Figure 3 (b)), MH1 updates its table and relays the media stream from MH2 to the device. Similarly, in the event of input-interface handoff, MH1 updates its table and relays the input from the device to MH2. In contrast, network-interface handoff only involves signaling between MH1 and MH2. As MH1 informs MH2 of the IP address of the new network interface, MH2 scans its table and updates all entries including the IP address of the old network interface of MH1.

Major functions of session management such as selecting a path, maintaining the table, and holding the session state are handled by end-to-end terminals; therefore required session capability of devices is minimized. We have minimum assumption that an output device can receive a stream through the port specified by a host, while an input device can send a stream to the destination specified by a host. In addition to the end-to-end model, this architecture also supports the proxy model for conventional hosts with no agents, in which case the session management is performed between MH1 and the proxy in a manner

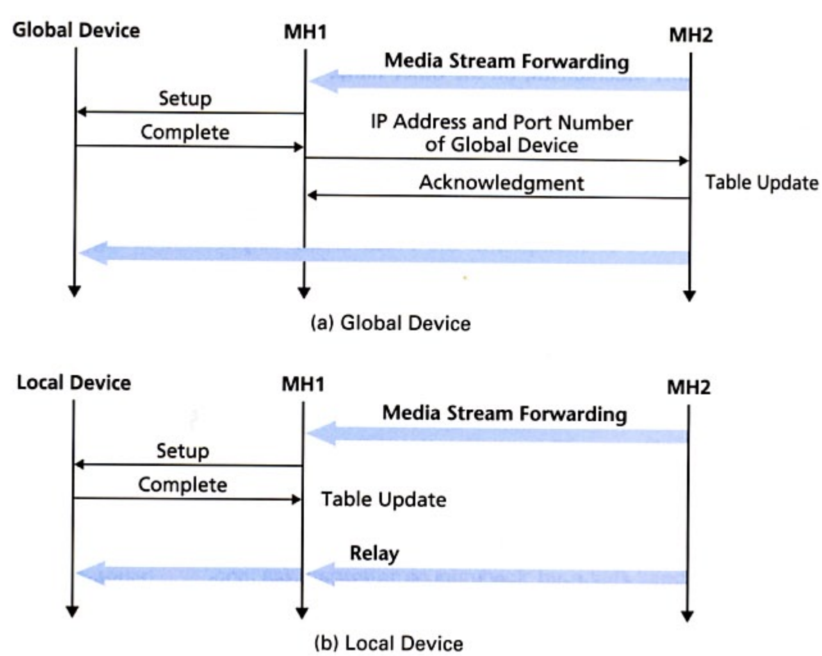


Figure 3 Session Management Sequence for Output-Interface Handoff

hidden from the conventional host.

3.2 Seamless Handoff

There are two ways to achieve undisrupted handoff: reduce the latency of setting up the interface and signaling involved in session management; or conceal the latency by proactive processing and redundant usage of resources. The former approach is problematic due to issues of applicability to existing systems and cost concerns, as it requires reduced latency of setting up commercial cellular services and devices. The proactive soft-handoff method proposed in this article is based on the latter approach, and combines the proactive setup of nearby resources (proactive control) and a soft-handoff mechanism which redundantly uses both old and new interfaces during handoff.

The proactive control is incorporated into the Handoff Control module. In advance, it sets up resources in neighboring areas to which the user might migrate in the future (referred to as "prepared areas"). The prepared area is specified in terms of distance from the user, chosen as a policy of the user or an application (e.g. within a 20-meter radius of the user, or within two blocks of the user). The Handoff Control module acquires information on the resources existing in the prepared area by querying the Service Directory, and proactively executes setup exclusively with respect to resources that comply with the handoff policy (such as high-priority devices, and network interfaces that should be selected in that area). Furthermore, it releases previously set-up resources that are no longer within the prepared area.

The soft-handoff mechanism, on the other hand, is incorporated into the Session Management module, where it makes multiple redundant paths available by adding a new session while maintaining the old session in the session management table during handoff. For example, in the event of the output-interface handoff referred to in Figure 3, MH1 sets the soft-handoff flag and informs MH2 of the IP address of the device; then, MH2 establishes a session with the global device while maintaining the session involving the media stream forwarded to MH1. At this point, MH2 sets both MH1 and the device as transmission targets in its table and executes redundant forwarding. When MH1 informs MH2 of the completion of handoff, the old session is removed and the soft-handoff is terminated. The same applies to network-interface handoff: when MH1 informs MH2 that a soft-handoff from Wi-Fi to cellular platform should take place, the cellular session is added to the table while maintaining the session including the Wi-Fi interface. MH2 then executes transmissions to both network interfaces of MH1 according to this new table status. Similarly, both interfaces are used for transmissions from MH1 to MH2.

4. Implementation and Evaluation

A MAT-based testbed was built in the experimental house, and the *"Follow-me Music Service."* was implemented as its application.

4.1 Testbed

A mobile laptop computer equipped with cellular and Wi-Fi interfaces (MH) executes an application program with MP3 player function, which receives and plays back Real-time Transport Protocol (RTP) packets from the MP3 Streaming Server (CH). Two models were implemented: an end-to-end model in which an agent operates on the Server (Figure 4), and a model in which an agent is deployed in a proxy.

The agent in MH queries the Location Server about the user location every second and the Service Directory about resource information through the SLP to monitor the interfaces and execute handoff control. The Location Server receives User IDs read by RFID readers whose locations are already known, and updates the user location information. The testbed also realizes location tracking through the detection of differences between images captured by six wide-angle cameras installed in the ceiling of each room.

On the other hand, the lounge in the experimental house accommodates two sets of speaker devices equipped with an audio output interface (global and local devices) and Wi-Fi access points. The service area of the devices is registered to the Service Directory as the lounge, while the service area of Wi-Fi is registered as the lounge and the entrance hall next to it. The cellular interface and internal speakers are available both inside and outside of the experimental house. An MP3 player program that can receive RTP packets is installed on the device as well.

4.2 Experiment

Using the testbed, we tested the behavior of the session management mechanism, and evaluated the performance of the handoff method. The user policy was set to give priority to Wi-Fi and the external speakers, and the prepared area was set to be within one block of the user. As shown in **Figure 4**, when the MH-carrying user migrates from the lounge to the entrance hall,

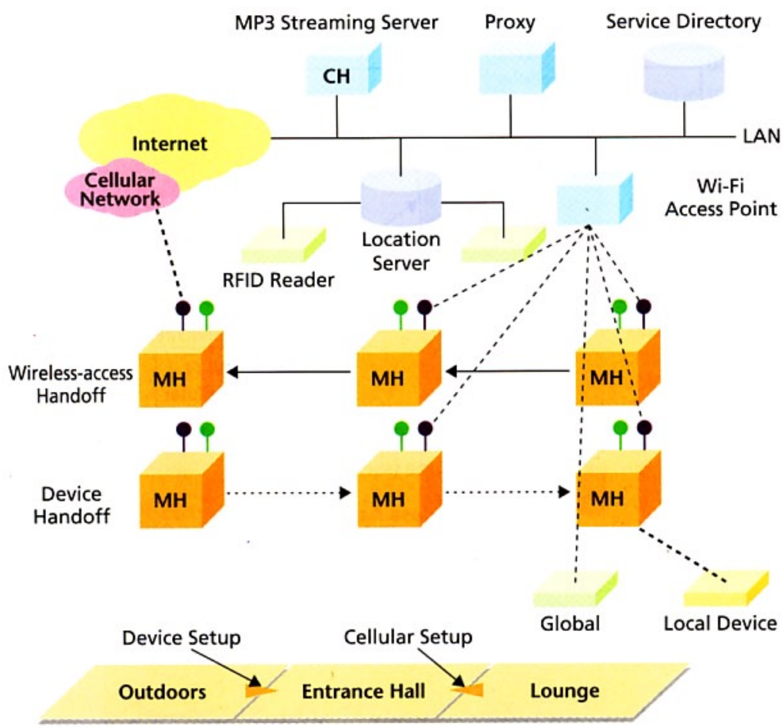


Figure 4 Testbed

the cellular interface (which should be chosen outdoors) is set up proactively, as it is within one block of the user. On the other hand, when the user enters the entrance hall from outdoors, the external device in the lounge is within one block of the user and is therefore set up proactively.

Firstly, we tested wireless-access handoff: **Figure 5** shows the changes in the throughput of each radio interface when the user migrated from the lounge to the entrance hall, and went outside as illustrated in Figure 4. When the user migrated from the lounge to the entrance hall, proactive control was triggered and the setup process of dial-up cellular connection began. About 10 seconds later, the connection was established. Then, the user was detected to have gone outside at 37 seconds. After signaling soft-handoff by the Simple Object Access Protocol (SOAP), which took approximately two seconds, packet reception began via the cellular network at 39 seconds. Despite the subsequent deterioration in Wi-Fi quality, stable throughput was provided by the cellular interface, thereby achieving seamless handoff.

In contrast, the conventional method—implemented for comparison purposes—monitors the Wi-Fi interface speed every second, and executes handoff to cellular when the speed falls below 2Mbit/s due to quality deterioration. Speed deterioration detected at 43 seconds triggered the setup process of dial-up cellular connection. Then reception over the cellular interface started at 57 seconds, indicating a lengthy disruption.

Secondly, we tested handoff between an internal device and a global device: **Figure 6** shows the throughput when the user walked in from the outside, through the entrance hall, and into the lounge as illustrated in Figure 4. While the user was in the entrance hall, the device was set up proactively (which took approximately eight seconds), and when the user entered the lounge (at eight seconds), handoff was completed immediately after a two-second delay in soft-handoff signaling. The experiment confirmed that the RTP stream from the Streaming Server could be redirected directly to the global device, and that audio-output handoff automatically took place from the internal device to the external speakers. In addition to this, handoff to a local device was achieved as MH relayed the stream via a Wi-Fi interface connected to the same LAN.

In contrast, the conventional method initiates setup at eight seconds and the handoff is not completed until at 18 seconds. Moreover, the audio output suffers disruption during device handoff due to signaling latency. The experiment confirmed that the proposed method can improve the system's responsiveness relative to user mobility through a proactive control, and can conceal disruption in playback by a soft-handoff mechanism in which the external speaker generates output alongside the internal speaker.

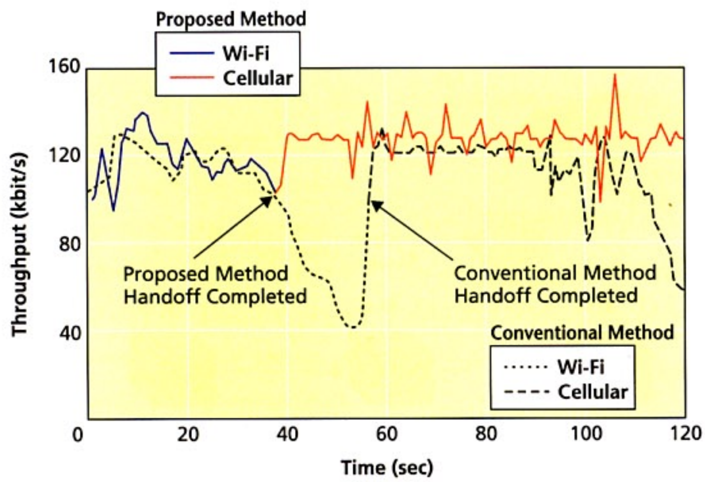


Figure 5 Wireless Access Handoff

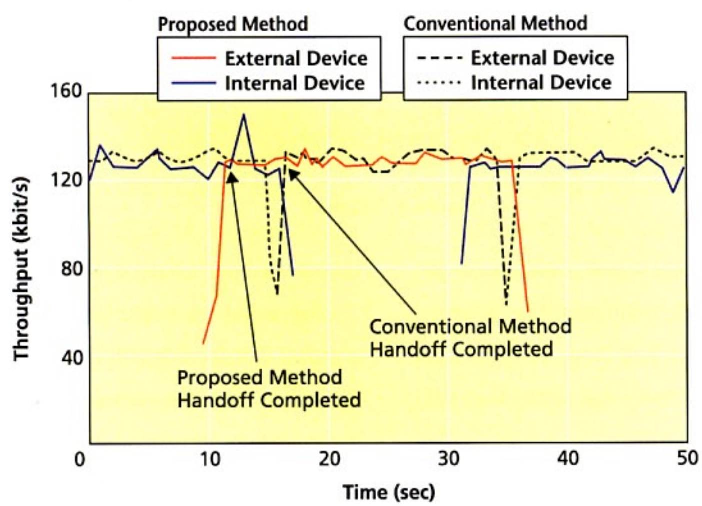


Figure 6 Device Handoff

5. Conclusion

This article proposed the Mobile Adaptive Terminal architecture (MAT) as a ubiquitous interface technology for autonomously adapting to changes in ubiquitous resources such as devices and wireless access and providing services in a seamless manner. It also proposed a terminal-oriented session management technology and a seamless handoff system, and confirmed their effectiveness through implementation and experimentation.

Future issues include secure session handoff, the introduction of a transcoding mechanism to support devices of diverse I/O quality, and the examination of media synchronization between multiple I/O devices.

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GLOSSARY

Bluetooth SDP: Bluetooth Service Discovery Protocol
CPU: Central Processing Unit
DNS: Domain Name System
GPS: Global Positioning System
ICEBERG: Internet CEllular BEyond the thiRd Generation
IMT-2000: International Mobile Telecommunications-2000
IPv6: IP version6
IrDA: Infrared Data Association
LAN: Local Area Network
MAT: Mobile Adaptive Terminal architecture
MPA: Mobile People Architecture
OBEX: OBject EXchange protocol
RFID: Radio Frequency IDentification
RTP: Real-time Transport Protocol
SIP: Session Initiation Protocol
SLP: Service Location Protocol
SOAP: Simple Object Access Protocol
UDDI: the Universal Description, Discovery and Integration
UDP: User Datagram Protocol
UPnP: Universal Plug and Play
W-TCP: TCP Profile over W-CDMA
Wi-Fi: Wireless Fidelity