Seamless Handover Using Out-Of-Band Signaling in Wireless Overlay Networks

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Abstract: The demand for better telecommunication services has led to the development of a number of radio access technologies and wireless overlay networks. A variety of new services including preference- and presence-based communications and seamless connection services on the move have become available, but their further development calls for both technological advances and economic restructuring. The use of an out-of-band signaling path apart from data paths enables flexibility in developing new services for wireless overlay networks. We developed an out-of-band signaling system based on the tunneled network model. The system enables the handing over of connections from one radio access network (RAN) to another seamlessly and it makes it possible to save power by turning off all the RAN interfaces except for the one used for signaling. In this paper, we describe the performance of this system and describe its use.

Keywords: wireless overlay, heterogeneous networks, seamless handover

1. Introduction

The demand for better telecommunication services has led to the development of a number of wired and wireless access technologies including modem, DSL, FTTH, CATV, Ethernet, wireless PAN (Bluetooth, ZigBee, UWB), wireless LAN (WiFi, HiperLAN, MMAC), wireless MAN (WiMAX), cellular (IEEE802.20, 2G, 3G, and 4G), and broadcasting/multicasting systems (satellite, DVB/DAB, HAPS).

Each access technology has a different data rate, network latency, interaction capability, mobility support, and cost per bit because each has been designed with specific services in mind. To meet the diverse and growing needs for telecommunication services, more specific and heterogeneous access technologies must be developed because there can no longer be a multipurpose access technology that can meet all user requirements at a reasonable cost. New wireless access networks will be laid over existing ones. In such wireless overlay networks, the integration of several access networks effectively supports a broad mix of services.

In 2000 we embarked on a research project called “MIRAI” [1], which is part of a bigger project for the development of fourth-generation wireless networks [2]. The goal of the MIRAI project is to design a flexible and open architecture for a variety of different wireless access technologies as well as for applications with different QoS requirements and different protocols. We have developed three experimental systems [3,4] that are based on different network models and that share a common functionality that allows users to establish, apart from connections for data transfer, an out-of-band network connection for signaling. This out-of-band signaling enables flexible communication services through wireless overlay networks.

We begin by describing wireless overlay networks and then introduce the concept of MIRAI, which is followed by a description of network models for integrating wireless overlay networks. After that, we describe a system we designed, which is based on the tunneled network model, and present results of its performance evaluation.

2. Wireless Overlay Networks

The following applications are possible with multiple RANs.

RAN discovery: A user at a specific geographic location who wants to start communication first needs to find out which RANs are available in that area. This, however, can be a time- and energy-consuming process because the user would need to search for all RANs.

Preference-based communications: A user who wants to access a network at the lowest possible cost, irrespective of communication speed, needs to know the communication charges of all available RANs. Some users believe that communication speed is important, others attach more importance to reliability. Connectivity, availability, and fault tolerance are some of the other parameters defining users’ preferences. The use of preferences allows users to select RANs based on the content of communication. For example, users can receive all voice/video calls through cellular-based systems, which can more effectively handle real-time application traffic. All non-real-time traffic like emails can be transferred through wireless LAN-based data networks.

Presence-based communications: A user who wants to make a call only if the callee can receive it needs to have information about the presence of the callee. This includes information about the callee’s location (e.g., in the office or in a meeting room), the callee’s availability (e.g., whether the callee can receive the call), and network availability (e.g., high-speed wired or low-speed wireless). The use of preferences makes it possible for users to upgrade applications, for example, from voice to video when the callee can get access to a high-speed network that enables video communication.

Seamless handover to different RANs: A user who wants to access a network while driving a car in a rural area may need that the connection be handed over from a cellular system to a satellite system. Always-on services for cars, ships, and airplanes need a seamless handover functionality.

In order to meet these requirements, a number of technologies must be developed, which include fast and power-efficient radio system discovery systems, preference- and presence-based connection setup systems, systems that enable seamless and secure handover between different RANs in an administrative domain and across different administrative domains, as well as small and energy-efficient handheld terminals accessing multiple RANs.

3. Concept Behind MIRAI

The main advantage of MIRAI is that the signaling and data paths are separate (see Fig. 1). Out-of-band signaling, which is called “basic access signaling” (BAS), is provided through a basic access network (BAN). The BAN is one of the RANs used as a signaling channel. This idea is described in Ref. [6].
The purpose of BAS is to provide a set of functions necessary for heterogeneous wireless networks to operate in an integrated manner. The functional set includes RAN discovery, RAN selection, inter-RAN handover, location updates, paging, and AAA. The BAN should have a broad coverage area, preferably larger than that of the other RANs, and a reliable communication means for signaling transmission where a high data rate is not necessary.

In the MIRAI concept, we assume that the MIRAI agent has the latest information about each user’s profile, policy, presence, and preferences, which is periodically reported through the BAN from the multi-service user terminal (MUT) of each user. When a user receives a call, the MIRAI agent, which knows where the user is and which RANs are available to the user, pages the user using the BAN connection and notifies the user. When a user receives a call, the MIRAI agent, which knows where the user is and which RANs are available to the user, pages the user using the BAN connection and notifies the user that a call has been made. The MIRAI agent also helps the user receive the call and set up a connection by showing all available RANs or suggesting the most suitable one for that call (in this context, the word “call” includes multimedia applications such as voice communication, video communication, email, and file transfer). The concept, architecture, and functions of MIRAI are fully described in our previous papers [1,4].

Besides the seamless handover between different RANs, MIRAI also enables reducing the power consumption. The use of out-of-band signaling enables reducing the power consumption by turning on only the BAN interface and turning off all other unused interfaces. Communication necessary before setting up a connection, such as call initiation, authentication, and paging, is done through the BAN, while the interfaces of all other RANs are switched on only when data packets to be transferred have been generated.

4. Network Models

Several alternative models for the internetworking of heterogeneous wireless networks have been developed [1,5]. The four most typical models designed for the internetworking of RANs A and B are illustrated in Fig. 2.

In the tunneled network model, a user has independent service agreements with the operators of several RANs. The optimal RAN for the requested service is selected, and the hybrid core tunnels the user traffic through the Internet and the selected RAN to the mobile node. This model requires no modifications to existing RANs.

In the hybrid core model, the hybrid core between the RANs and the Internet offers advanced transport services on the network (e.g., better handover between the RANs).

In the common core model, common core networks deal with all network functionality and operate as a single network.

In the integrated network model, the mobility-enabled Internet offers the same functionality as do the hybrid and common cores in the other models. Only the access points that offer physical and link layer functionalities are connected to the Internet and are managed in a distributed manner.

Because the optimal migration path is determined by a number of factors including economic, technological, and financial ones, it is hard to say at present which network model is the most promising or what the best migration path is. It is, however, obvious that the tunneled network model is the most realistic and feasible, albeit short-term, solution, because it requires the fewest number of modifications to the existing systems and networks. On the other hand, the common core model could provide more flexible services and better performance than the tunneled model although it does call for a new business model and technological advances.

In our project, we first created a novel MIRAI concept and developed it based on the common core network model [1]. We then implemented the MIRAI functionality on a hybrid core-based network [4] because of the technical difficulties in developing physical and link layer equipment necessary for the common core model. Also we developed two demonstration systems based on the tunneled network model: one employs a two-way paging system as a BAN [3] and the other allows a user to choose one RAN for a BAN. In this paper, we describe the second system.

5. Implementation

5.1 Design Principles

In designing the demonstration system based on the tunneled network model, we thought that the system should be designed in such a way as to allow users to easily access a network or change between networks if there are two or more access net-
works. The system should also be able to clarify the feasibility of MIRAI-related technologies include RAN discovery, RAN selection, inter-RAN handover, and location updates.

To implement the system, we used existing radio access networks including wireless LAN, PHS, and 2G and 3G cellular systems. We used a mobile IP, which is the de facto protocol providing mobility in IP networks; it enables handover between different RANs. Micro-mobility within radio access networks was assumed to be offered by each RAN. In heterogeneous radio environments, multi-homing is a typical problem. In this system, we assumed that each MUT had only one IPv4 home address in it and that an MUT obtained a care-of-address from a RAN after it had established a connection with it. The PHS and 2G and 3G networks were commercial public networks; such networks do not provide foreign agent services in a mobile IP scenario.

5.2 Configuration

Figures 3 and 4 show, respectively, the network configuration and the functional architecture of the MIRAI system designed based on the tunneled network model. The MIRAI server and the resource server are two major logical components on the network, which compose the hybrid core network in the tunneled network model. We implemented all the functions necessary for the MUTs on a laptop PC (IBM T30) and a PDA (HP iPAQ H3970). Five kinds of networks including Ethernet, WiFi, PHS, 2G cellular, and 3G cellular were used as (radio) access networks.

5.3 Multi-Service User Terminals (MUTs)

The laptop PC-type MUT operating on Redhat Linux 8.0 with middleware HUT Dynamics Mobile Node 0.8.1 for IP mobility could have, at most, five interfaces with the 3G (FOMA data card P2401 provided by NTT DoCoMo), 2G (cdmaOne data card C315SK provided by KDDI), PHS (Air H" data card AH-H401C provided by DDI-Pocket), WiFi (IEEE802.11b device embedded in the PC) and Ethernet (100Base-TX embedded device) networks.

We made a special external jacket for the PDA-type MUT (see Fig. 5), which enabled the MUT to have, at most, four PCMCIA cards including 2G (PDC data card DopaMAX 2896F provided by NTT DoCoMo), PHS (Air H"), WiFi (IEEE802.11b), and Ethernet cards. Familiar Linux 0.5.2 with the same HUT mobile IP middleware was running in the PDA-type MUT. All the cellular cards were used in the packet mode.

When we did the outdoor experiments, GPS devices were attached to both MUTs to provide their location information. In the indoor experiments, the software in the MUTs generated this information virtually.

The mobile IP client middleware in each MUT operated in a co-located care-of-address mode where a client serves not only as a mobile IP client but also as a foreign agent. This was done because at present, having a foreign agent in every RAN is not feasible.
Figure 6 shows a graphical user interface (GUI) of the seamless client application illustrated in Fig. 4. When you push the “Available” button in the “RAN List” area, the MUT automatically connects to a pre-selected RAN as a BAN and receives a list of all available RANs from the resource server through the MIRAI server using a BAS protocol. The black circle in the GUI shows that 2G cdmaOne is used as the BAN. If you start data communication, the MUT selects a RAN from the list of available RANs according to user preferences and establishes a connection through the RAN. The white circle shows that the MUT uses Ethernet (IEEE802.3u) for data transfer. This GUI can also show maps of the area around the user or any other point the user specifies.

5. 4 MIRAI Server

The MIRAI server provides both a basic access signaling (BAS) server function, which enables BAS message exchange between MUTs, and a mobile IP home agent function. The BAS protocol uses four types of messages: registration, location update, wireless resource discovery (WRD), and area movement. With these messages, an MUT reports its location and user preferences to the MIRAI server, while the server informs the MUT of available RANs. The server may also request the MUT to change the RAN being used when the MUT is in the boundary area of the RAN and is about to leave that area. We used HUT Dynamics Home Agent 0.8.1 as the mobile IP home agent "core" middleware for the MIRAI server. We also implemented additional software to provide simultaneous binding function to the server. With this function, the server can transmit a packet stream to an MUT through a RAN and a copied stream through another RAN. Even if the MUT receives duplicate packets, the mobile IP client middleware accepts one packet and eliminates the other.

5. 5 Resource Server

The resource server has two active tables, an MUT status table and an MUT configuration table, in the database. The MUT status table has the following fields: MUT home IP address, core-of-address for the BAN, location, location update period, RAN in use as the BAN, RAN in use for data transfer, and user preferences (this system has five preferences: communication charge, communication speed, coverage, reliability, and power efficiency). The MUT configuration table lists MUT home IP addresses and available network interfaces.

The resource server also has information about the coverage of every RAN, thus making it possible to display the coverage of the RANs and the position of the MUTs on any map. This information makes it possible to determine which RANs are available to the user. The resource server can exchange information with the MIRAI server.

5. 6 Features

This system can be operated in either a basic or an advanced mode. The basic mode is used when neither BAS nor GPS is available, while the advanced mode is used only when both are available. The basic mode is designed to hand over data paths from one RAN to another as seamlessly as possible even when both BAS and GPS are unavailable. In this mode, the power for the RAN interfaces that are not used is turned off to avoid wasting the energy of the MUT. A handover is triggered only when the RAN interface used for communication becomes unavailable. An alternative RAN is then chosen from a table that lists all available RANs in a predetermined order preferred by the user.

In the advanced mode, users can select their favorite RAN to be used as a BAN from the list. A table with alternative lists is automatically created according to users’ preferences with regard to the communication charge, bandwidth (speed), coverage, reliability, and power consumption. For example, if a user prefers a high-speed connection, wired LAN, wireless LAN (IEEE802.11b), 3G, 2G, and PHS systems are listed in this order. In this mode, users can tell the network their location information obtained by the GPS. The resource server can tell the user that it is about to leave the boundary area of the RAN coverage. This notification triggers a binding update of the mobile IP. In the update operation, the “S” bit in the header of a mobile IP binding update packet, which indicates the selection of the simultaneous-bindings option, is usually set to 0 to delete the old binding and register a new one. In this system, however, we set S to 1 to register a new binding while keeping the old one to temporally multicast a packet stream to both the old and the new binding addresses so as to avoid packet loss.

6. Evaluation

In this section, we show the advantage of MIRAI in terms of handover completion time and packet loss during handover. Figures 7 and 8 show the completion time in handover from a wireless LAN to a PHS, a 2G (cdmaOne), and a 3G (FOMA) network without a BAN and with the use of PHS as a BAN, respectively. The use of the PHS-BAN reduced by about five seconds the completion time of handover from the wireless LAN to the 3G network. Almost zero completion time was obtained for the handover from the wireless LAN to the PHS with the use of a BAN because the PHS had been connected as a BAN before the handover was initiated.

Figures 9 and 10 illustrate the number of lost packets during handover with and without a BAN, respectively. We recorded the number of lost packets displayed in the statistics window of the RealPlayer client application on the laptop-based MUT. The RealPlayer client received packets of a video stream sent from a server on the Internet. The streaming rate varied because the server adaptively changed the transmission rate according to the network bandwidth. The average bit rates were 41.6 kbps for the wireless LAN, 3.6 kbps for the PHS, 7.1 kbps for the 2G, and 40.6 kbps for the 3G networks. It is obvious from Figs. 9 and 10 that the packet loss performance was greatly improved with the use of the BAN. This is because packets were temporarily transmitted through the BAN until the handover was completed, while in the handover without a BAN, there was a period when no connection was available.

Figure 11 shows the effect of the out-of-band signaling path on the power consumption. The vertical axis indicates the remaining power [Joules] of the battery, and the horizontal axis shows the battery lifetime in hours. We assume that a user who has an MUT with a 16000-Joule battery makes 300-second-long calls an hour. The battery capacity is about the same as that of Sony’s PDA “CLIE”. We also assume that calls are encoded and transferred using 8-kbps voice-over IP (VoIP).

Here, we compare the following three operation modes: (A) When a user is waiting for a call, the wireless LAN interface of the MUT is in an idle state and does not have a power saving function. When the user receives or makes a call, the WLAN interface goes into an active state to receive and transmit the packets. (B) The WLAN interface has a power saving function in an idle state, which means that power saving is expected during the call waiting period. (C) When the user is waiting for a call, only the PHS interface is ‘on’ while the wireless LAN interface is ‘off’. The wireless LAN goes into an active state only when the user receives or makes a call whose packets are transmitted through the wireless LAN interface.
From the data obtained by the measurements, we estimated that the power consumption was about 0.66 Watt for the wire-
less LAN without a power saving function in an idle state, about 0.22 Watt for the wireless LAN with a power saving
function in an idle state, about 0.75 Watt for the wireless LAN in an active state, and 0.2 Watt for the PHS in an idle state.

From Fig. 11, it is clear that operation mode C, which uses PHS as a BAN, consumes the least amount of power, which
results in the longest operation, although the difference be-
tween operation modes B and C is small because the power
saving function in wireless LANs greatly reduces the power consumption.

7. Service Scenario

With the MIRAI architecture, hyper-roaming is possible. The relationship between a travel agency, transportation com-
panies, and a user is a good analogy for the demonstration of hyper-roaming with MIRAI. If a user asks the travel agency to
make an itinerary, the agency arranges it according to the user’s preferences. All the user has to do is pay for the service, and
to not each transportation company but to the agency alone.

Hyper-roaming service providers will be offering a variety of wireless services to users. A hyper-roaming service provider
integrates a number of wireless services provided by different wireless Internet service providers (WISPs) into a package
according to the user’s needs. The user does not need to make a contract with each individual WISP. We believe that this
scenario is possible because it appears to be a possible exten-
sion of mobile virtual network operator (MVNO) services that
have already become common.

8. Conclusion

The greatest advantage of MIRAI is in the separate use of out-of-band signaling networks and networks for data transfer,
which allows for flexibility in the development of new communication services for wireless overlay networks. We devel-
oped a demonstration system based on the tunneled network model and evaluated its performance. The use of out-of-band
signaling reduced the amount of time needed for handover, the number of lost packets during handover, and the power
consumption.

References

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