A FRAMEWORK FOR SEAMLESS ROAMING ACROSS CELLULAR AND WIRELESS LOCAL AREA NETWORKS

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Wireless and mobile users will have increased demands for seamless roaming across different types of wireless networks, QoS guarantees, and support for a variety of services. The authors propose a global mobility management framework to support seamless roaming across heterogeneous wireless networks.

ABSTRACT

In the future, wireless and mobile users will have increased demands for seamless roaming across different types of wireless networks, quality of service guarantees, and support for a variety of services. This awareness has led to research activities directed toward intersystem and global roaming, and can be noticed in numerous products like multimode handsets, interworking gateways, and ongoing standards and research work on intersystem roaming. The authors of this article proposed a global mobility management framework to support seamless roaming across *heterogeneous wireless networks*. In this article we provide details on the use of the framework to support roaming across cellular and wireless local area networks. Highlights of the framework include a robust architecture for mobility management for varying user mobility spans, provisioning for QoS mapping, intersystem message translation, and mechanisms in the WLAN to support user-subscribed services. Performance aspects related to handoff delays, data redirection, and processing overheads are presented and discussed. Performance comparison of intersystem roaming between cellular and WLAN with and without the framework is presented.

INTRODUCTION

In the near future, with the deployment of IMT-2000, fourth-generation (4G) networks, and the proliferation of wireless LANs (WLANs), it is to be expected that wireless or mobile users will place greater demands on support for different types of services, quality of service (QoS) guarantees, and seamless roaming across different types of wireless networks. The advantages of combined services, rich in features and attractive cost-wise, that can be achieved by integrating cellular and WLAN is spurring numerous activities in this direction. Besides supporting call ini-

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tiation from any network, seamless roaming should also provide for roaming across different wireless networks during an active voice call (or data connection). This requires new concepts and approaches in location management schemes and strategies [1, 2] with QoS mapping and support.

The existing location management schemes in cellular networks have certain limitations. First, the two-database approach based on home location register (HLR) and visitor location register (VLR) will not be efficient in supporting seamless roaming. The centralized location database (i.e., HLR) is a potential bottleneck of the network with a growing mobile user population. Databases of more than one network have to be involved to provide seamless roaming across networks. Second, to hand over calls smoothly as the user roams across wireless networks requires some *interface units* between the two networks to provide message translation and QoS mapping, and facilitate predictive handoff. Lastly, user mobility spans are highly variable requiring hierarchical mobility control. Taking these factors into consideration, a suitable global roaming framework has to be hierarchical and distributed in architecture, and span wireless networks participating in global roaming. The distributed nature of the framework has further advantages of being a robust solution while imposing reduced loads on the participating entities.

Numerous efforts toward integrating disparate wireless networks can be found in the literature [3, 4–6]. Seamless handoff is also an important topic of research when resolving integration issues [7–9]. However, the work proposed in this article addresses this problem by providing solutions that have the features enumerated above. The basic concepts of this framework were introduced in [10]. Introduced in this article are features of the framework specific to roaming support across cellular and WLAN, which can be accomplished under the infrastructure provided by the global roaming framework. They are:

- An entity that performs message translation and QoS mapping

- A predictive handoff scheme for smooth hand-off of calls across cellular and WLANs
- A bicasting mechanism via mobility agents to achieve layer 3 handoff with the least quality disruption
- Swap databases at often roamed visiting networks of the mobile user to speed up handoff
- A mechanism to support user-subscribed services in WLAN

The scope of the rest of the article is as follows. To ease understanding, the framework of [10] is explained briefly. The features of the framework for integrating cellular and WLAN are given. Simulation details of the framework are presented. A performance comparison of integrating cellular and WLAN with and without the framework is given. We then present our conclusions.

THE FRAMEWORK

Figure 1 shows the framework used for integrating cellular and wireless LANs.

Two cellular networks, *cellular1* and *cellular2*, with minimal network elements like mobile switching center (MSC)/VLR, radio network controller (RNC), and base transceiver station (BTS) are shown. In the figure HLR and gateway functions are assumed to be collocated with the MSC. A WLAN with an access point (AP) connected via a *gateway* to the IP core network is included. A *profile server*, details of which are provided later, is shown collocated with the authentication, authorization, and accounting (AAA) server.

The framework functions are implemented in selected entities (nodes) in the core network and wireless networks. These entities are the white and blue oblong blocks in Fig. 1.¹ The software in these selected nodes (represented in blue) perform the framework functions to execute seamless roaming. The hierarchical intersystem mobility agents (HIMAs) act as interface units, mentioned earlier. The HIMA functions are shown collocated with routers in the IP core network to ease their deployment. The hierarchy of HIMAs shown interact with each other to perform hierarchical handoff for a wider span of user mobility. The mobile user has to register with an appropriate primary HIMA and request its services as a mobility agent. Highly mobile users and those receiving a number of calls from a wider footprint of networks should select an HIMA at a higher level. HIMAs under the primary HIMA, if any, will facilitate the mobility management functions of the primary HIMA.

The software modules at the selected nodes are the components (GMCP) of a global mobility management protocol. *GMCP-macro* performs macromobility-related functions and will interact with MobileIP. *GMCP-macro-micro* shown at gateways and MSCs relate micro- and macromobility functions for smooth handoff. *GMCP-micro* shown at the RNC will trigger the macromobility management function (at the GMCP-macro-micro in the MSC) based on its interaction with the legacy micromobility functions at the RNC. The interaction between the GMCP and the legacy mobility management schemes in the wireless and core networks is indicated via thick arrows.

Figure 1. The framework.

The HIMA may be configured to perform:

- Intersystem message translation
- Predictive handoff
- QoS mapping and negotiations
- As a proxy HLR
- As an anchor or crossover point to forward data as the user moves from one wireless network to another

Some other important features of HIMA are:

- The duration for which HIMA acts as a primary agent to any mobile user is timed to accommodate a changing user roaming profile.
- The registration/preliminary handoff process will be initiated at the HIMA, by messages from a mobile user who enters the boundary cells of his/her current network that border a neighboring network if the mobile user has a service profile for traveling across the concerned networks and has an active call.
- As part of the preliminary handoff process, once the HIMA receives preliminary handoff messages from the mobile, it will trigger bicasting² and act as an anchor or crossover point.

REGISTRATION AND PRELIM-HANDOFF

The edge BTS or transceiver systems will be used to broadcast the presence of an adjacent network different from the current one.³ On hearing this broadcast, and based on its mobility profile, the mobile makes the decision to initiate a request for intersystem handoff/registration if it has an active call. The request is forwarded to the HIMA. On receiving this request the HIMA gets ready to perform QoS mapping and initiate bicasting to facilitate smooth and seamless call handoff across the different wireless networks.

THE INTEGRATION FEATURES

In this section we present the details of the topology, the predictive handoff scheme without HIMA, the predictive handoff with HIMA, a data redirection process for TCP

¹ Not all entities are shown for the sake of picture clarity.

² Bicasting was first proposed in [11] to avoid delays in layer 3 handoff, especially in IP networks.

³ This is possible if multi-mode handsets are able to perform switching across the two technologies.

With efforts for QoS support in 802.11 networks via the latest standards like 802.11e, it is expected that QoS guarantees and support for user-subscribed services in WLAN will become important.

■ Figure 2. Topology and predictive handoff without HIMA.

data that is required if the framework is not implemented, the AAA/profile server, and the swap databases.

THE TOPOLOGY

Figure 2 shows the topology used with predictive handoff messages for roaming *without* HIMA. The topology shows a minimal configuration with only three networks and a single hierarchy of HIMA to limit presentation. The topology has two cellular networks, one of which is the home network, the other the visiting network. A WLAN is the future network to which the mobile will roam. Each network and its components are shown within the darker ellipse. Although part of the core network, the gateway General Packet Radio System (GPRS) support node (GGSN) and gateway are shown within the coverage of the wireless networks. The broad double-edged arrows show the general communications flow between the different network entities. For *data call* studies, a GPRS with serving GPRS support node (SGSN) and GGSN is superimposed on the 3G cellular network. For simplicity, in each cellular network only one SGSN and GGSN are shown. The BTS and base station controller (BSC) are collocated. So are the HLR and VLR in the cellular networks and the AAA server and profile server in the WLAN. For testing the topology without the HIMA, the HIMA functions were suppressed and the HIMA was used as a simple router. Hence, as the user moves from one network to another in Fig. 2, data is forwarded from the old GGSN to the gateway of the WLAN via the thicker arrows.

With efforts on QoS support in 802.11 networks via the latest standards like 802.11e, it

is expected that QoS guarantees and support for user-subscribed services in WLAN will become important. Works proposing solutions for QoS guarantees and channel reservations⁴ in 802.11 networks can be found in the literature [12, 13]. Hence, a *profile server* to store and handle user/service profiles is essential at the WLAN.

The profile server is an entity introduced to store the user service profile and allow the mobile user access to his/her subscribed services in a WLAN. When the mobile roams into the WLAN, the user's profile from his/her *home network* can be downloaded into the profile server.

PREDICTIVE HANDOFF: NO HIMA

The handoff scheme proposed in this work applies for roaming across different cellular networks and across cellular to WLAN. Figure 2 shows the information flow for predictive handoff as the user roams from the visiting cellular network to the WLAN superimposed on the topology picture. Not all messages could be shown in Fig. 2, so Fig. 3 is included to clearly show all messages in time sequence. The reader can trace the corresponding messages in Figs. 2 and 3.

The information flow diagram given in Fig. 3 is self-explanatory. As the handoff is predictive, when the HO_req messages are forwarded from the current visiting network to the future WLAN, authentication with the home network is initiated, before resource allocation to the mobile user is done. After authentication, reserved channel and frequency details are forwarded to the mobile in an HO_reply message. Before changing its frequencies and channels to the future network, the mobile sends an

⁴ In this work, it has been assumed that some channel reservation mechanisms are available in the WLAN.

■ **Figure 3.** Signal flow for predictive handoff without HIMA.

HO_cmp message to the current network and then makes the frequency changes.

In Fig. 2 the HO_request or HO_reply message is used to trigger packet storage for redirection in the old network.⁵ The HO_cmp message triggers the data redirection process in the old network. Details about the redirection process are given in the next subsection.

In Fig. 4 the HO_cmp messages sent up to the GGSN in the previous visiting cellular network help to clear all the data packets stored temporarily for redirection. The handed_over message is used for location update at the home network and to clear the user profile from the VLR of the previous visiting network.

DATA REDIRECTION: NO HIMA

The rationale behind introducing a data redirection process was to avoid TCP packet loss during handoff and subsequent retransmission over the Internet.

Figure 4 shows a process designed to handle temporary packet storage and redirection to the new network. Timers are used to time the duration of handoff and packet storage. Packets from the queues are discarded on expiration of the timers, which could happen if the handoff were not successful. The entities in the cellular network that were involved in the storage and retransmission of the IP packets are the BTS, SGSN, and GGSN.⁶

A number of first-in first-out (FIFO) queues were used for this purpose. While there is only one queue at the BTS, two queues are shown at the SGSN and GGSN. One queue is for storing data as it flows down, the second is for storing the data as it is cleared from the entities downstream to be forwarded to the new network. This facilitates sequential data packet delivery from

the old network, which is important for TCP type data, as packets not in sequence can trigger retransmissions.

The numbers in small ovals along the arrows indicate the sequence in which the different processes are invoked. Activities having double digits are invoked by the activities with single digits that match the first digit of the double-digit activities. For example, activity 1 invokes activity 11, which in turn invokes 12, which then invokes 13.

On initiating an HO_request, the BTS starts directing the packets into a queue for the mobile (activities 11, 12, and 13). The HO_request is forwarded to the SGSN and GGSN, which in turn start redirecting the packets to Q1. When the mobile receives a HO_reply with the new network channel details, it sends an HO_cmp message to the old network elements that were storing the data packets. On receiving the HO_cmp message, the BTS clears its queued packets to Q2 of the SGSN (activities 41, 42, and 43). The SGSN waits until it has received all the packets from the BTS for that mobile, after which it will first clear Q2, as they are the earlier packets, and then clear Q1, sending these packets to Q2 in the GGSN. The GGSN adopts a similar procedure, but starts clearing its queues only after receiving the handed over message from the new network. Thus, the packets are streamed in sequence to the new network.

The data redirection process may or may not be implemented; this is up to the discretion of the network and service provider. It is a neat solution to avoid loading the Internet heavily with retransmission packets. There is, however, a non-zero probability that the remote TCP server may time out and resend a few packets.

While there is only one queue at the BTS, two queues are shown at the SGSN and GGSN. One queue is for storing data as it flows down, the second queue is for storing the data as it is cleared from the entities downstream to be forwarded to the new network.

⁵ In the study conducted by us, HO_request was used, which results in more packet handling at the old network. If HO_reply were used, it was noted that some data packets were en route over the wireless media, while the HO_reply, if carried on a signaling channel, arrived early at the mobile. This resulted in lost data packets en route as the mobile changed frequencies on receiving the HO_reply packet.

⁶ In the WLAN, the gateway and AP provide such facilities.

As the HIMA is acting as a proxy HLR, the update of the mobile's latest network is done at the HIMA and no information flow to the HLR is required. This mechanism also reduces the signaling and processing overheads at the entities forwarding the signaling messages.

■ Figure 4. Data redirection process (no HIMA).

PREDICTIVE HANDOFF: WITH HIMA

Figure 5 shows the information flow superimposed on the topology picture for predictive handoff with the HIMA functions turned on. The time relational flow for these messages is similar to that shown in Fig. 3 and hence is not provided. The noticeable differences are:

- The HIMA acts as proxy HLR, so the authentication details can be forwarded to the new network along with the HO_request or in a separate message.
- The HIMA bcasts messages (indicated by thick arrows) in both networks once it receives an HO_reply⁷ from the new network.
- On an HO_cmp message being sent by the mobile, the old BTS stops sending packets over the air.
- When the AP receives the handed_over message it starts forwarding the packets for the mobile.
- The handed_over message sent from the new network also travels to the previous network, stops bcast, and discards the bcasted packets. Wasteful transmission of packets over the air has been avoided.

SWAP DATABASES

Another contribution of the work was *swap databases*. The concept of swap databases [14] is simple and yet very powerful, especially if mobile users have typical roaming routines.

At the VLRs and AAA/profile servers in visited networks, the mobile's service profile is stored in a secondary database when it leaves

the network. When it re-enters the network, its user's profile can quickly be retrieved from secondary to primary storage on receiving a predictive HO_request from the previous network. The duration for maintaining the secondary database can be timed. This will save the HIMA processing capacity in terms of its functions as a proxy HLR. As the HIMA is acting as a proxy HLR, the update of the mobile's latest network is done at the HIMA, and no information flow to the HLR is required. This mechanism also reduces the signaling and processing overheads at the entities forwarding the signaling messages.

SIMULATIONS

Simulations using the OPNET tool were conducted on the presented integration scenarios. For voice calls, the SGSN performs the functions of the MSC and the GGSN acts as the gateway. The trajectory of the mobile covers a span across three networks, with the first cellular acting as the home network. The HIMA functions can be turned off for it to perform as a normal router. In the simulation model, the HIMA also simulates the remote end server, generates packet streams for the mobile, and sinks packets delivered from the mobile.

The mobile was modeled to set up a GPRS data session and also an association/authentication-based session with WLAN. Each data session duration is modeled with a negative exponential distribution. Packets of fixed size⁸ are sent at exponentially distributed interarrival times during a data session. The mobile was also

⁷ Note that using the HO_reply in this case will not result in problems faced in the normal hand-off scheme, and less processing capacity will be wasted processing the extra packets during bcast.

⁸ Variable sizes could be used without affecting the performance of the processes discussed in this article.

Delays incurred in storing and retrieving from the queues during data redirection were modeled using a separate queue, because the loads and service time for this process could be different from the database related processes.

■ Figure 5. Topology and predictive handoff with HIMA.

modeled to start voice calls of varying time duration with Poisson arrivals.

MODELING DELAYS

The handoff and data redirection delays were estimated by implementing queues in the OPNET model. Four delays were considered for studying the performance of the scenarios. These delays are explained in the following subsections.

The delay models for all packet/protocol processing, databases, and so forth were assumed to be M/G/1 queue [7], where the service time is considered a general distribution and the arrival of jobs (packets) Markovian.

For an M/G/1 queue, system time Γ can be obtained using the following equation:

$$\Gamma = 1/\mu + \omega, \quad (1)$$

where ω is the waiting time and can be obtained using the Pollaczek-Khinchin equation,

$$\omega = \frac{\eta \cdot (1/\mu^2 + \sigma^2)}{2 \cdot \left(1 - \frac{\eta}{\mu}\right)}. \quad (2)$$

In the equations σ is the variance, η is the arrival rate of jobs or packets and is given in packets per second, and μ is the service rate of the queue server.

Packet and Protocol Processing Delays — As the packet is handled by different nodes involved in the handoff or redirection process, there is “protocols or packet” processing delay, as the packet flows via various protocol layers. For simplicity, all the protocol delays in one node were lumped into one queue.

Database Delays — These are the delays incurred while accessing/storing information from/to the databases (HLR, VLR, and profile server).

Store and Retrieve Delays — Delays incurred in storing and retrieving from the queues during data redirection were modeled using a separate queue, because the loads and service time for this process could be different from the database related processes.

Channel and Allocation Delay — Channel allocation delay was introduced to model the time taken by the BTS/BSC or AP in making decisions for channel reservation for the new mobile that was getting handed off.

PERFORMANCE COMPARISON

The performance presented in this article is restricted to one scenario where the load in every node is uniformly varied from 70 to 95 percent in steps of 5 percent. The offered load is $\eta \cdot 100/\mu$ and in the graphs the ratio is used. The first set of performance is discussed for the integration scenario without the framework, with predictive handoff and redirection. The performance includes the handoff delays and redirection delays for various offered loads at the nodes for data sessions with varying data arrival rates. This is followed by the processing overheads if the data redirection process were implemented, which is estimated in terms of wasted processing times at the different nodes. An estimate of lost data packets if the data redirection were not implemented is then provided. The performance for handling voice sessions is then presented. This is followed by the performance of the same integration scenario but with the framework and HIMA implemented. In this case, there are no redirection delays. However, processing overheads due to bicasting and QoS loss in handling voice sessions are presented.

■ Figure 6. Handoff and redirection delay vs. offered load.

SIMULATION PARAMETERS

For the simulations, the values for σ were maintained at 0.01 in Eq. 2, and the service rates μ were uniformly assumed to be 1 job/ms for all queue models. The values for η were varied from 0.7 to 0.95 in steps of 0.05 to study the performance under varying load conditions.⁹ The data arrival from the source was varied from 100, 200, 500, and 1000 packets/s. The packets within a voice session were maintained at a constant bit rate of 64 kb/s.

HIMA OFF

Data Session

Handoff and Redirection Delays — Figure 6 shows the handoff and redirection delays under the stated offered loads. The graphs were obtained based on simulations repeated with different seeds. The effect of the different seeds is not noticeable in the handoff delay graph but clearly noticeable in the redirection delay graph. The maximum handoff delay suffered under high load conditions is around 170 milliseconds. The redirection delay accordingly peaked at 300 milliseconds. The handoff delay depends only on the load at the different nodes and not on the data arrival rates.

The redirection delay plot shows the trend of the delay variation for increasing loads. A number of graph points can be noticed for this plot, which are for varying data arrival rates. The spread, however, is primarily due to the different simulation seeds used. For example, the points close to the x-axis indicate 0 redirection delay. This is because for these particular seed values and under the given load conditions, there were no packets for redirection. This happens as the packet arrivals were exponentially distributed and the probability of a high interarrival time is non-zero. The handoff took place in one of these high interarrival periods; hence, there were no packets for redirection. Another interesting observation made

was that the redirection delays depend only on the loads in the network, not at the data arrival rate. This is because of the way the redirection process was implemented. However, the time wasted in redirecting the packets will depend on the number of packets and hence on the data arrival rates. An estimate of this follows.

Processing Overheads — The processing overheads addressed are primarily due to the redirection process. This has been calculated as wasted processing time to handle the redirection of packets over the handoff interval. For a given offered load of 75 percent (i.e., $\eta = 0.75$ at all nodes) the wasted time increases from BTS to SGSN to GGSN. This is because the packets processed at the BTS have to be processed at the SGSN and GGSN. Similarly, the packets processed at the SGSN have to be processed at the GGSN. Over the handoff interval, for a data arrival rate of 200 packets/s, 5 ms of SGSN time and 25 ms of GGSN time were wasted. While for a data arrival rate of 100 packets/s, only 10 ms of GGSN time was wasted. There were no packets for redirection in the BTS and SGSN.

The total number of packets retransmitted was 25 packets and 10 packets for arrival rates of 200 and 100 packets/s, respectively.

Voice Session — The handoff delays for voice sessions will be the same as for data sessions under the given load conditions. However, redirection of voice packets is not feasible, and packets sent to the old network must be discarded. The estimated voice packets lost varied from 11, 6, 8, 8, 16, and 31, respectively, over load variation from 70–95 percent (in steps of 5 percent). Packet loss dependence on the load was felt only under high load conditions (i.e., beyond 90 percent).

HIMA ON

Data Session

Handoff Delays — Figure 6 also has the graph for handoff delay with the framework implemented. The maximum delay suffered is seen to be 100 ms compared to a maximum delay of 170 ms without the framework. However, even this will not be felt by the mobile as it experiences seamless and packet lossless handoff due to bicasting. The throughput may go down slightly during the handoff period, as the remote server may back off when it does not receive acknowledgments for packets sent.

Processing Overheads — The processing overheads in this case is due to the bicasting process and was calculated as wasted processing time at the different nodes. It was noted that there is constant wasted time of 4 ms and 10 ms at each of the nodes (i.e., BTS, SGSN, and GGSN) for data arrival rates of 100 and 200 packets/s, respectively, over the handoff period. The value is constant because all the packets sent to the old network reach the BTS and are eventually discarded. However, before reaching the BTS, the packets are processed at the SGSN and GGSN. These readings were for a typical load of 75 percent on all nodes. Data arrival rate affects this parameter profoundly; offered load does not.

⁹ Note that the performance studies were conducted primarily under heavy load conditions.

Voice Sessions

Handoff Delays — In voice sessions, although there is a handoff delay (as for data sessions), the user does not feel the effects of the handoff as no voice packets are lost or delayed. Packet numbering was implemented at the application level for the voice sessions to help the mobile discard packets duplicated due to multicasting. For uniform load of 75 percent on all nodes, the number of duplicated packets was 3.

CONCLUSIONS

In this article we have introduced a framework that can be used for integrating cellular and WLANs. The main features of this framework are its hierarchical and distributed architecture, which provides robust and scalable solution to seamlessly roam across a number of WLANs and cellular networks while supporting call continuity through predictive handoff, QoS mapping, intersystem message translation, and provision in the WLAN for user-subscribed services. The framework has been evaluated using OPNET simulations and performance comparisons made for varying load scenarios for integration with and without the framework. If a mobile had a larger mobility span and a primary HIMA at a higher hierarchical level, the comparative performance improvement achieved would be much better.

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ADDITIONAL READING

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BIOGRAPHIES

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Among the main features of this framework is its hierarchical and distributed architecture, which provides robust and scalable solution to seamlessly roam across a number of WLANs and cellular networks.