A Flexible Framework for the Support of Heterogeneous Wireless Networks

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***Abstract*— In this paper, we present the design principles of a mobility architecture for heterogeneous wireless networks support. These principles are the basis of the architectures implemented by the Daidalos (FP6) and Rhodos (RNRT) projects. The central concept around which these architectures are built is the design of an Abstraction Layer. The Abstraction Layer offers to the upper layers a common interface for all technologies while hiding the specifics of the underlying wireless technologies. Such a modular design greatly simplifies the implementation of upper layer modules (as they do not need to account for the details of the underlying wireless technologies) and facilitates the inclusion of new wireless technologies into the architecture. The paper describes the design of the Abstraction Layer and its implementation for a number of wireless technologies. Future work directions, including extension of functionality and new wireless technologies, are pointed out.**

***Index Terms*—Heterogeneous wireless networks, Abstraction, Access Technology, Handover, RRM**

I. INTRODUCTION

END-USER Mobile Terminals are becoming more and more complex. Part of this complexity is caused by the objective to access heterogeneous networks mixing cellular, enterprise and broadcast networks and so, to include the devices necessary to support more than one access technology. As applications should remain independent of this evolution, the need arises to design abstraction modules, providing a generic interface to the upper layers and taking care of the complexity of operating the various interfaces.

This paper presents a flexible framework for the support of heterogeneous wireless networks in a Mobile Terminal, based on a decoupled architecture, described in section 2. Next sections show how it could fit into two different requirements, the first being mobility in the IST project Daidalos presented in section 3, and the second being Radio Resource Management (RRM) in the French RNRT project Rhodos, described in section 4. In section 5, we envision two possible evolutions of this framework and finally, we draw our conclusions in section 6.

II. OVERALL ARCHITECTURE

A. Objective

We consider a generic architecture to allow a terminal to be connected to several access technologies. These may be wireless or fixed. Depending on the application requirements, intelligent interface selection is needed while the system is in operation. At the same time the specificities of the access technologies must be hidden to the applications. In particular radio resources of cellular, broadcast and short range radio connections are allocated using different algorithms. A decoupling approach has been followed in order to ease the process of incorporating future evolutions of access technologies. Seamless handover between heterogeneous access points can be implemented using uniform mechanisms and Quality of Service (QoS) management can be coupled with Radio Resource Management. The proposed architecture is shown in Fig 1.

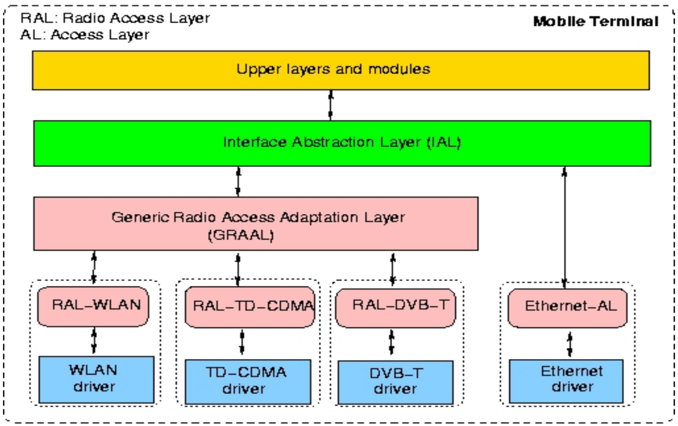

Figure 1: General architecture

It is split into an Interface Abstraction Layer (IAL) which is common to all the access technologies, then a Generic Radio Access Adaptation Layer (GRAAL) which harmonizes the radio QoS control of the wireless

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technologies.

B. IAL

The IAL module has two interfaces: one with the upper layer modules (e.g. Mobile Terminal Controller, MTC) and the other one with the GRAAL module. Unix stream sockets are used to communicate with MTC and GRAAL modules. Each radio technology is controlled by a specific module called RAL (Radio Access Layer) which activates/deactivates the interface and reports measurements to IAL through GRAAL.

IAL is stateful which means that it has always an up-to-date view of existing interfaces, scanned access points, and the quality of the received signal for each BS. It maintains also information about the current activated technology and the Link Layer Identifier of the selected BS. When there is a meaningful change on the signal quality of at least one BS, a meas_indicate message is sent back to the MTC.

IAL receives four different requests from the MTC (power-up, meas_request, select-interface, deselect-interface) and forwards them to the GRAAL module after updating its internal state.

IAL and GRAAL modules allow the integration of heterogeneous technologies thanks to:

- the transparency of existing radio technologies due to the architecture design including GRAAL and RALs,
- the mapping of the signal quality measured by each RAL into a generic and unified quality level: bad, good, very good, excellent,
- the addition of a new radio technology is transparent to IAL and upper layers as GRAAL provides a generic interface which could be used by every radio system,
- the periodic measurement of the signal quality by each RAL and the report of measurement to IAL through GRAAL which decides to inform the MTC or not for possible handover execution.

C. GRAAL

The GRAAL module has several interfaces: an interface per radio access technology and an interface with IAL as described above. Hence, every message received by IAL from the MTC is forwarded to the GRAAL module. When it receives a message from IAL, GRAAL first determines the destination radio technology and then forwards the message to the corresponding RAL. In order to send a meas-report to IAL, the GRAAL module has to wait for meas-reply messages from all active RALs and merge these messages into a single meas-reply to be sent to the IAL module.

A single unix stream socket is used to communicate between GRAAL, IAL, and the RALs.

D. RALs

In this architecture, the RALs are the components responsible for the specific access technology drivers. A RAL is active only if the corresponding technology is present in the Mobile Terminal. Each active RAL receives the generic requests from the GRAAL for measurements or interface control and converts them into commands understandable by the driver in terms of contents and format. The RAL is also responsible to retrieve by its own means the status of the interface and the measures available from the driver. It provides theses measures to the GRAAL in a generic scale going from 0 (signal lost) to 100 (max signal strength available). Some additional features may be introduced according to the technology and will be described in the specific RAL sections below.

In the related projects, there are three access technologies: WLAN (Wireless Local Area Network, IEEE 802.11), TD-CDMA (Time Division-Code Division Multiple Access) and DVB (Digital Video Broadcast), with a RAL each. For all three technologies, the interface with the driver has been implemented using kernel IOCtl's

1) RAL-WLAN specificities

The RAL-WLAN component provides an interface between the GRAAL and the WLAN driver, by listening for messages coming from GRAAL, performing the required actions in the WLAN card – through the WLAN driver – and providing back an answer. This answer may consist just in a result indication of the requested action, or in a message conveying the solicited information. Besides, if the signal level of current Access Point perceived by the terminal is below a certain threshold, this event triggers an unsolicited message to be sent to GRAAL.

The WLAN driver used in Daidalos is a modification of the Host AP driver [1], for Prism based cards. By jointly using RAL-WLAN and WLAN driver components, the following features are available:

- Separation of scanning and Layer 2 (L2) handover functionalities. Automatic scanning (e.g., periodic or scanning started when signal level is low) is disabled, reducing in this way the L2 handover latency (scanning is no longer needed before performing a L2 handover) drastically.
- Full control on scanning and L2 handover operations provided at user level.
- Scanning in any subset of channels, instead of the default 14 channels mode, reducing drastically the latency due to scanning.

2) RAL-DVB specificities

The RAL-DVB component implements the same type of mechanisms as the RAL-WLAN. The DVB driver used in Daidalos comes from the LinuxTV project [2]. By jointly using RAL-DVB and DVB driver components, the following features are available:

- Once started, RAL_DVB scans continuously the complete TV band and stores the QoS results (signal strength, C/N) and, on request from upper layers, sends back a QoS parameter derived from the measurements done on the requested TV channels.
- Scanning a subset of channels is possible, if requested by upper layers, minimising the scanning time.
- Once the DVB activation is requested from the upper layers (IP data reception through DVB-T), RAL_DVB stays locked on the requested TV channel and monitors continuously the link quality. QoS results are sent on

request of the upper layers, or with unsolicited messages if the quality decreases too much. Optionally, the QoS measurements on alternative channels could be done regularly if the targeted service can support some packet losses. This is possible with carousel applications, but not for video streaming. Next step to replace DVB-T with a DVB-H transmission will allow the use of this scanning function without packet losses and offer seamless handovers.

3) RAL-TDCDMA specificities

The UMTS access is provided by the Eurecom TD-CDMA platform [3], which performs a direct inter-connection between UMTS and IPv6 using an inter-working function located in the device driver, as described in [4]. This function includes the middleware for interfacing IPv6-based mechanisms for signalling and user traffic with 3GPP-specific mechanisms for the access network. The platform is completed by a 3GPP Access Stratum (AS), compliant with the UMTS specification [5], except for the Radio Resource Control (RRC) which has been adapted to the IPv6 direct inter-connection.

The functions offered by the middleware interface cover control and status of the network attachment, list of the available radio bearers with their properties, requests for the latest measures, retrieval of the L2 Identifier [2]. The requests received from the GRAAL are forwarded directly to this interface, after a translation into the appropriate format.

Some periodic polling is introduced for the retrieval of measurements. The level of signal used is actually the RSSI value measured by the AS, integrated with former values to avoid instability and converted into the generic [0-100] level. If it shows a dramatic change, such as signal degradation, the event is immediately notified to the GRAAL, otherwise, the value is stored to be provided at next request. The period of the polling had to be tuned to avoid overloading the driver, but yet having in store a fresh value.

The UMTS connection setup procedure requires several exchanges between the Mobile and its Base station, which may take some time. The RAL has to poll the driver until the Mobile is actually attached to the network and has a signalling radio link setup before answering successfully to the GRAAL.

III. Application to Seamless Handover between Heterogeneous Wireless Networks

A. The EU project Daidalos

The European Union project Daidalos [3] aims at improving usability of European telecommunication technologies by integrating mobile and broadcast communications and following a user-centred, scenario-based approach to deliver ubiquitous end-to-end services across heterogeneous technologies. This paper focuses the project's approach to integrate and support heterogeneous access technologies, as well as to perform both, horizontal and vertical handover efficiently.

B. Daidalos Terminal Mobility simplified architecture and handover scenario

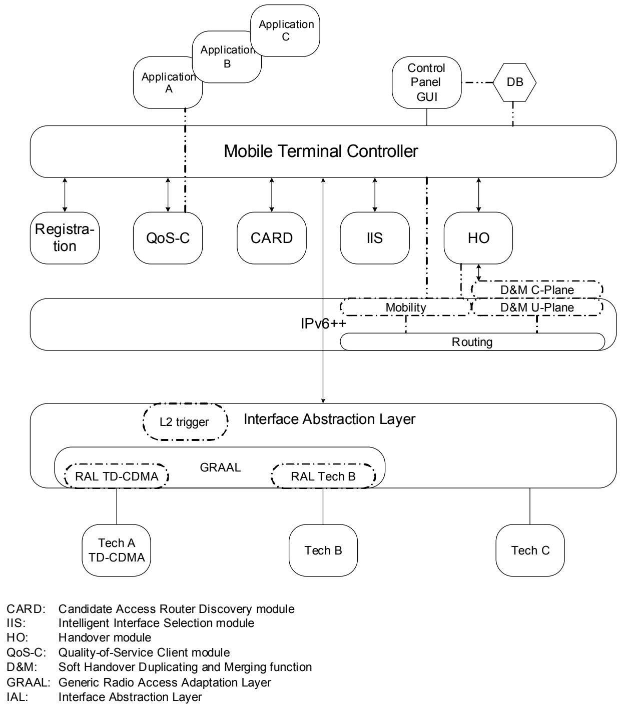

Figure 2 : Functional design of the Daidalos mobile device.

Fig. 2 illustrates a simplified design of the Daidalos mobile device. Overall control about power up, general initialization, as well as handover preparation and execution is assigned to the MTC, which interfaces directly with the functional modules. A direct interface to the IAL allows control of heterogeneous access technologies without taking too many technology specifics into account at the MTC. The MTC has an interface with the Registration Module for security-related functions and with the QoS-Client (QoS-C) for control of selected technologies' L3 and L2 resources. The IETF's protocol for Candidate Access Router Discovery (CARD) [7] serves as base protocol to support media-independent handover preparation. With the help of the integrated CARD module, the MTC can learn about handover candidates' characteristics, such as Access Routers' IP address and Access Points' channels. After these characteristics and local measurements have been retrieved, the MTC makes use of the Intelligent Interface Selection (IIS) function to determine an appropriate handover candidate based on a set of parameters. When it has been selected, the MTC requests the Fast Handover (FHO) module to perform the handover and locally controls a change in Access Point or even in technology via the IAL. The FHO module performs Layer-3 signalling with the network and collaborates with a data packet Duplication&Merging (D&M) function [8] on the mobile device to achieve seamless handover.

Fig 4 depicts a detailed signalling flow in case of inter technology handover between WLAN and TD-CDMA. The picture only describes local communication focusing on the cross layer design interactions. MTC triggers the FHO client module {FHO_HO_INITIATE – FHO_L2_DISC}. These messages exchanged with the appropriate network components in the Access Routers (AR) and QoS functionalities implemented in the access network, (Daidalos developed a tight coupling QoS aware fast mobility scheme) ensure handover can be performed to the selected target Access Router. Upon a positive feedback from the network the abstraction layer module triggers the specific technologies for channel selection and radio configuration. The RAL WLAN module is responsible for the activation of the WLAN chipset and channel configuration. Upon a successful WLAN activation (IAL_INTERFACE_STATUS) the FHO client is notified about the connectivity on the new link. Thus, configuration of layer three takes place (normal neighbour discovery procedures and address configuration).

Once the terminal is connected to the new link and network components are updated (e.g. ARs and QoS brokers) the terminal receives information about stopping the merging process for the data plane packets. This is an indication the handover has been completed. The abstraction layer finally notifies the TD-CDMA driver about disconnection and channel release. Communication can proceed on the WLAN link.

IV. Application to Radio Resource Management

A. *The Rhodos project*

The Rhodos project was funded by the French RNRT and completed in December 2005. One of the objectives was the deployment of a hybrid network with UMTS/TDD and WLAN segments to validate and integrate optimization studies on features enabling Radio Resource Management (RRM), Mobility and End-to-End QoS Management. This network would also contain some innovative real-time services including video conferencing and video stream distribution, both having some QoS requirements for dynamic adaptation of the flow, based on resource allocation.

B. *Radio Resource Management in Rhodos*

The Rhodos network architecture is illustrated in Fig. 3. The Mobile Terminal (MT) includes both a WLAN adapter with its driver and a UMTS board. The Abstraction Layers presented in section 2 interface a SIP User Agent (UA), which is triggered by the real-time applications. An UMTS Radio Gateway and some WLAN (802.11) Access Points provide the connectivity towards the IP network. The centralized CRRM (Common Radio Resource Management) component is responsible to compute the distribution of the radio resources available in its domain, even if they belong to different Radio Access Technologies (RATs). The CRRM is assisted by two sub-components, one for each RAT.

In this architecture, the interface between the (UA) and its Proxy Server (PS) is used to transfer standard SIP (Session Initiation Protocol) signalling to establish the session, but also some measurements performed at the Mobile to help the RRM entities obtain the "Mobile view" of the heterogeneous network and distribute the available radio resources. The result of the RRM algorithm is the computation of radio resource parameters, which are transferred back to the related interface in the MT and activated with requests issued by the IAL.

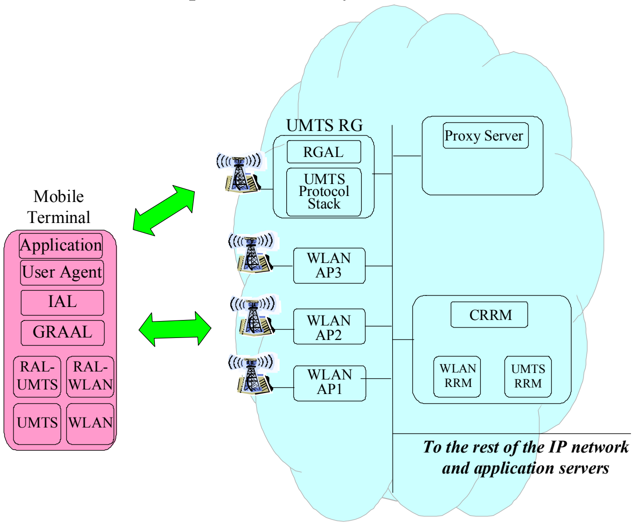

Figure 3 : Rhodos network architecture.

As was described before, it was possible in this project to use this Abstraction Layer architecture to provide the functions needed by the CRRM, e.g. measurement retrieval and establishment of resources. The only changes were applied to the UA and the PS, which add on top of their SIP functionality the capacity to forward the measures from the interfaces to the CRRM and the responses on the way back. The interfaces defined for the Abstraction Layer modules remained unchanged and the RRM entities were the only entities aware of the various RATs activated in the Mobile.

We have shown here that the exactly same generic architecture could fit in a totally different objective compared to the Daidalos project.

V. Future Work

Previous sections have shown the flexibility of this architecture in terms of technologies and functionality. A prototype implementation for proof of concept has been implemented and tested in both projects, showing the expected results [9]. It could evolve to offer new capabilities:

A. *New access technologies*

The initial idea for extending this architecture would be the support of other RATs, either existing such as GPRS, or upcoming such as WiMax (IEEE 802.16). The only constraint is to have at one's disposal some interface providing the retrieval of signal measurements and start/stop commands. Adding another technology would require mostly to implement a new RAL, with exactly the same primitives (but different values) on the upper interface to the GRAAL, and a specific customization on the lower interface to talk with the new access technology device driver.

B. *Merge with other abstraction layers*

In addition to the Abstraction Layer described above for mobility purposes, the Daidalos architecture also includes another Abstraction Layer, the QAL (QoS Abstraction Layer), which has been defined for QoS purposes. Specifically, the QAL provides the upper layers with services related to QoS provisioning. The reader is referred to [10] for a detailed description of the QAL design.

Following the design principle of the Abstraction Layer described in here, the QAL has been designed with the goal of providing a unique interface to the upper layer modules of the architecture while hiding the specifics of the underlying technologies. This technology-independent interface greatly facilitates the design of the upper layer modules since they do not need to account for the technology specifics.

In the future, we plan to merge the two Abstraction Layers (the one described here and the QAL) into a single one. The resulting Abstraction Layer will offer the upper layer with a complete view of the underlying wireless interfaces, including both mobility and QoS aspects. Following the philosophy of the legacy Abstraction Layers, this new Abstraction Layer will offer a technology-independent view.

We believe that the Abstraction Layer resulting from this merging will proof a powerful tool for wireless architecture design, as it will provide the upper layers with an abstract but fully functional view of the underlying technologies. It will also move this framework closer to the work under progress in IEEE 802.21 [11], a comparative evaluation being planned as one of the future work items.

VI. Conclusion

This paper presented a flexible framework for the support of heterogeneous wireless networks in a Mobile terminal, based on a decoupled architecture which contains an IAL interfacing the upper layers, a GRAAL that selects the target access technology and several RALs that interface the various network device drivers. The interfaces between the modules of the proposed architecture have been designed in a way to allow an easy addition of new radio technologies such as WiMAX. We have shown how this framework has been adapted to two projects with different objectives thanks to its flexibility and generic design. Finally we have presented ideas about some possible evolutions, by extending the range of supported technologies, or by including QoS capabilities, moving it closer to the work being conducted in IEEE 802.21.

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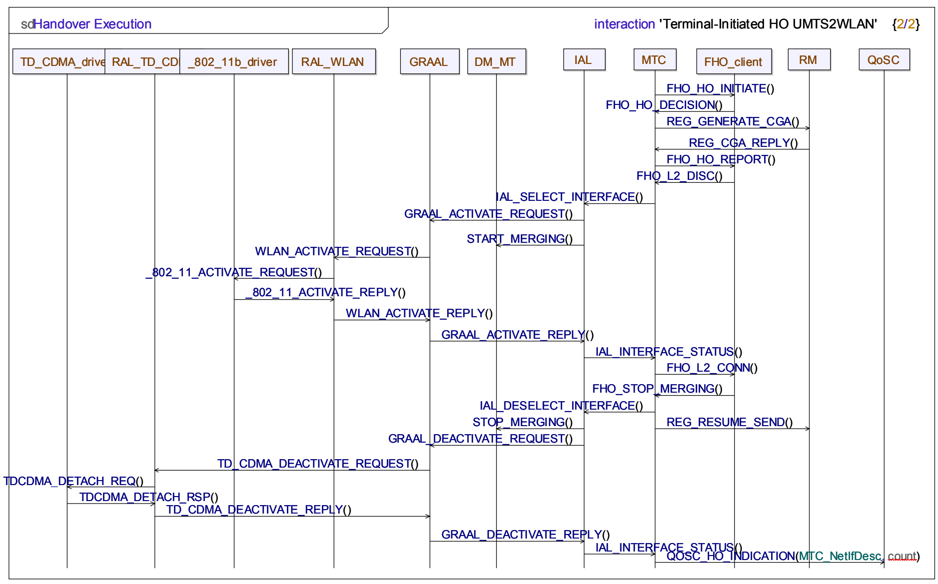

Figure 4: Handover signalling flow