On the Empirical Analysis of Handover Latency Reduction by Means of Multi-RAT Devices: A Prototypical Approach

David Gómez[1], Ramón Agüero[1], Jesús Herrero[2], Bruno Cendón[2], and Luis Muñoz[1]

[1] University of Cantabria, Santander, Spain
[2] TST Sistemas, Santander, Spain
{dgomez,ramon,luis}@tlmat.unican.es,
{jherrero,bcendon}@tst-sistemas.es

Abstract. In this paper we present an fully empirical assessment of the possibilities which are brought about by an architecture able to handle multiple wireless access technologies. Heterogeneity is believed to play a key role in forthcoming communication scenarios and therefore some entities able to appropriately tackle the new challenges are deemed necessary. Although reaching the *Always Best Connected* paradigm has gathered the interest of the scientific community, many of the existing works are descriptive (architectural papers) or based on simulation and/or emulation. In this paper we go a step beyond this and starting from the architecture proposed in the Mobilia Celtic project, we deploy a real platform to showcase two illustrative handover examples, triggered either by the end-user and the network. Additionally, we use the same platform to quantitatively analyze the enhancement which the use of multi-RAT devices may provide, in terms of the handover latency reduction.

1 Introduction and Objectives

The advent of new wireless technologies has paved the way of a largely heterogeneous wireless communication environments, where new challenges emerge. One of the most remarkable ones is the need to foster the *Always Best Connected* paradigm, where the end user is always served with the most appropriate access alternative, depending on a set of factors. These embrace user preferences and policies, requirements from the current services, as well as the particular conditions of the available networks and access alternatives. On the other hand the existence of agreements (cooperative) between different entities must also be considered. Mechanisms which are available at the time of writing clearly do not fulfil with this requirements and usually require the direct involvement of the end-user.

Opposed to that we present an architecture able to deal with the large heterogeneity which will characterize forthcoming wireless communication scenarios, since it offers the end-user with the most appropriate access. The proposal is the cornerstone of the *Mobility concepts for IMT-Advanced (Mobilia)* project,

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belonging to the CELTIC programme. In particular, in this work we present a real platform which has been used so as to assess the feasibility of the this proposal. We describe two use cases, illustrating different ways to trigger access selection procedures (initiated either by the network or by the end-user). In addition, the paper also illustratively shows the gains which could be expected if taking full advantage of the possibility of having multi-RAT devices, in terms of the latency reduction during a handover event.

In order to tackle the aforementioned objectives, the paper has been structured as follows: Section 2 discusses related work, paying special attention to other works which have pursued an experimental approach; Section 3 presents the architecture which has been designed in the framework of the Mobilia project. Section 4 describes how this architecture was translated into a real platform, depicting the use cases which have been used to challenge its feasibility, while Section 5 presents a set of results achieved with such platform, to highlight the enhancements that the smart use of multi-RAT devices (conveniently fostered) in terms of latency reduction during handover events. Finally, Section 6 concludes the paper, advocating some items for future work.

2 Related Work

During the latest years, the presence of heterogeneous wireless networks has gathered the attention from the scientific community. As a result, there are a number of proposals which have tackled the problems that arise in such scenarios. Some of them share many of the characteristics of the Mobilia architecture, and therefore they are worth mentioning herewith.

Two of the most complete ones are the *Common Radio Resource Management (CRRM)* and *Joint Radio Resource Management (JRRM)* (see e.g. [8,3] and the references therein) and the *Multi-Radio Resource Management (MRRM)* ([9] and references therein). Both of them assume the presence of an entity which harmonizes the information from the lower layers, so that it can be compared on a technology-agnostic way. Afterwards, a smart entity, using such information, together with other requirements takes a decision on the most appropriate available access to serve the current demand.

In parallel, the growing heterogeneity has been also addressed by the relevant standardization bodies. In this sense, the IEEE 802.21 has defined the *Media Independent Handover Framework (MIHF)*, whose main goal is to provide some means to transport relevant signalling information which should be taken into consideration during handover procedures [10,1]. One of the distinguishing characteristics of the Mobilia architecture is that we have considered the use of IEEE 802.21 as a focal aspect; therefore, we do not consider it *as a signalling transport mechanism*, but we extend its original scope and we provide APIs for the various entities which are part of the proposed architecture. The idea is that we do not establish any bounds on where and how to use such facilities. The Mobilia architecture will also consider the possibility to support cognitive radio capability, since this feature is believed to play a key role in future wireless communication networks.

The focus of this paper is to present the real platform which was deployed in order to assess the feasibility of the proposed architecture and, using such framework, provide illustrative figures of the gain which could be expected if taking full advantage of wearing multi-RAT devices. In particular, the paper will provide some performance figures of the latency which might be expected during a handover process. It is important to highlight that all the results are completely based on real components and their performances and no emulation has been employed.

There are some works which also seek the real implementation of this type of architectures. For instance, in [2] the authors present a real platform which reflects the Multi Radio Architecture which was proposed in the framework of the Ambient Networks project. However, no results are presented, and the different entities were not included in the network elements (access points and base stations), thus limiting the possibility to initiate handovers from the network. Other works from the same project, e.g. [6,7] analyze the overhead during a vertical handover process, based on the *Host Identity Protocol (HIP)* mobility solution; they use real heterogeneous technologies (namely 3G and IEEE 802.11), but they do not incorporate any functionality within the network elements and therefore the use cases which are analyzed are always triggered at the end user device. The solution is based on a triggering entity which delivers events to interested entities.

Another completely different approach is the use of large testbeds which emulate the behavior of heterogeneous wireless networks; one of the most relevant ones is the AROMA platform [4], which has been used to analyze the performance of the aforementioned CRRM. In these approaches, the goal is to perform an exhaustive performance analysis, usually mimicking the role which traditionally has been assigned to simulators, but offering a greater degree of flexibility and accuracy; however, they need to incorporate different models for the movement partners, traffic sources, etc. Opposed to that we have a more concrete scenario, which we use to characterize specific procedures, studying the enhancements which might be brought about when using different access discovery and selection mechanisms over real platforms.

3 Mobilia Architecture

Mobilia is trying to face the new challenges appearing with the forthcoming wireless communication scenarios, where heterogeneity is one of the most common factors. One important goal in this project is supporting an efficient and transparent cooperation between heterogeneous access networks, following the concept of Always Best Connected. For that reason, a great effort has been made working in the definition of an architecture which enables to deal with the selection of access networks in highly heterogeneous environments. The global framework proposal is based on various principles, such as the abstraction of the subjacent technologies, the consideration of a number of metrics in the selection procedures and the use of the signaling framework, proposed by Media

Independent Handover (MIH), as the transport medium for the exchange of information between different entities in the network [1]. This signaling framework is being standardized by the IEEE 802.21 working group and means the distinctive feature to be explored in Mobilia. The IEEE 802.21 signaling is based on a Type-Length-Value (TLV) codification, which offers different advantages from the implementation point of view. The next figure shows the global architecture to be implemented in the mobile user involved in the platform implementation. In addition, it would be necessary to include some of these functionalities in another entities appearing in the prototype, such as the Access Points and the Network Server.

Several entities have been presented in Figure 1 in order to ensure a suitable management of vertical handover situations. The next paragraphs make a short description of the functionalities associated with each of them.

Link Layer. Based on the MIH_LINK_USER SAP defined on the IEEE 802.21 specification, it facilitates to the different Radio Access Technologies (RATs) the data exchange with the Abstraction Layer.

Media Independent Handover Function (MIHF). It is the core element of the architecture; its main function is to enable, either locally or remotely, the exchange of information and commands between the different devices involved in making and executing handovers decisions. The MIHF enables a fair and technology-agnostic comparison of the characteristics of the subjacent radio

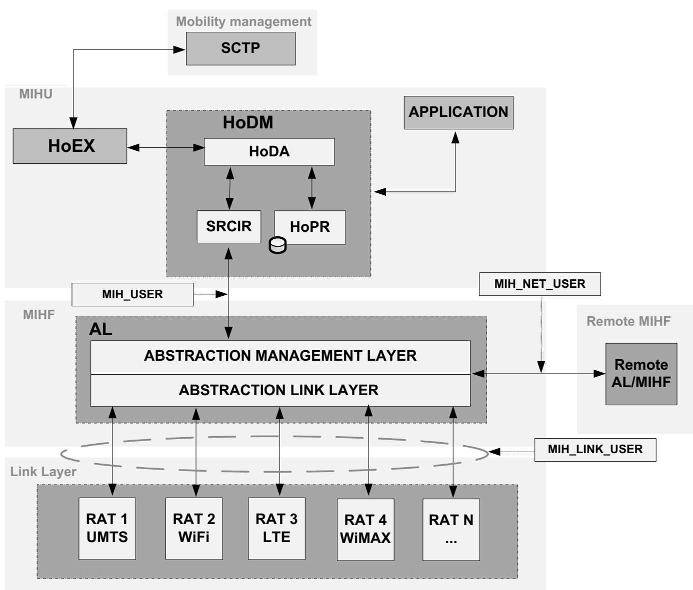

Fig. 1. A global vision of the architecture proposed by Mobilia to handle vertical handover situations

technologies and it has been structured into two different components: the Abstraction Management Layer (AML) which is in charge of managing the User MIH interface (MIH_SAP) and the remote interface (MIH_NET_SAP) and the Abstraction Link Layer (ALL) which manages the interfaces with the Link Layer (MIH_LINK_SAP).

Media Independent Handover User (MIHU). The MIHU is performed by two elements: The Handover Decision Manager (HoDM) and the Handover Execution Manager (HoEM). The HoDM is the most important part of this entity, being the element with the final responsibility during the execution of the handover. All the data meaning and decision criteria are located at this level of the architecture. It is composed by the following elements:

– Handover Decision Algorithm Module (HoDA) which includes the necessary intelligence to decide when a handover shall be done.
– Handover Policies Repository (HoPR), which is used by the HoDA to set the basis of the conditions to order a handover. This information is combined with the one provided dynamically by the Service Requirements Collector Information Repository (SRCIR).
– Service Requirements Collector Information Repository (SRCIR), which implements the MIH_USER interface to the AL/MIHF and act as a dynamic repository for the information collected from the MN and the Network. This information is used by the HoDA.

The HoEM interfaces directly with the MIHF through the SRCIR to manage the primitive exchange in order to execute the handover. This element owns the necessary intelligence to manage the event reporting and error handling that the handover procedure might create.

Remote MIHF. It provides the framework with the capabilities to share relevant information with remote elements.

Stream Control Transmission Protocol (SCTP). It is a reliable, general-purpose transport layer protocol for use on IP networks that addresses mobility needs [2] and allows high availability, increases reliability, and improves security for socket initiation.

4 Demonstration Setup

As it was previously discussed, one of the main goals of this work is to carry out an empirical assessment of the architecture presented in the previous section, thus filling the gap which exists regarding this type of approaches. However, this poses several constraints that need to be taken into account: first, the availability of the wireless technologies is limited; although there are various *off-the-shelf* wireless technologies available, most of them do not offer the flexibility which we deem necessary to challenge the Mobilia architecture. Basically, this embraces the availability of appropriate drivers and the possibility to introduce modifications at the network side (i.e. at the access element). Considering these intrinsic limitations, the platform is based on the IEEE 802.11 technology; we emulate

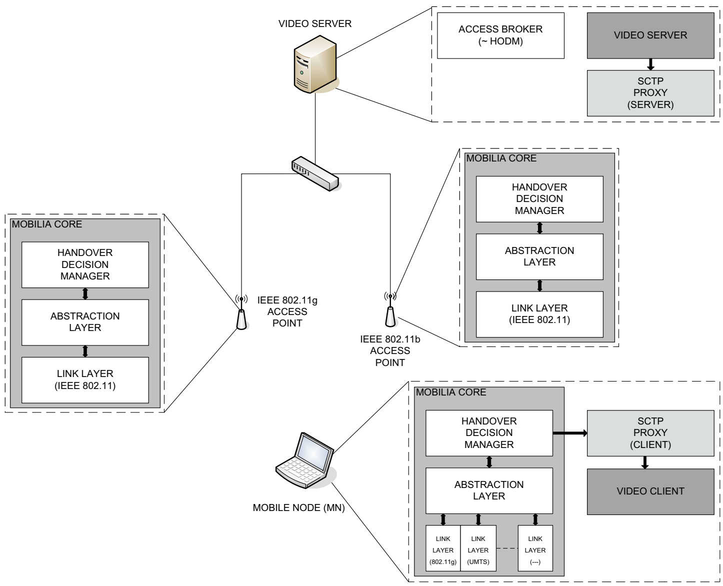

Fig. 2. Demonstrator platform

the presence of heterogeneous networks by deploying two access points, configured in two orthogonal channels, which take the role of access elements. This approach, which undoubtedly present some limitations, also has clear advantages: the support of the corresponding drivers is quite important, and available interfaces allow the user obtaining several pieces of information (which can be used as elements to be considered during the access selection process); in addition, by means of the `madwifi` project [5], it is possible to use a regular laptop to deploy an access point, therefore bringing about the possibility to introduce deployments at the network side.

With the aforementioned limitations in mind, the proposed (minimum) platform comprises four laptops, as can be seen in Figure 2. Their role is briefly introduced below.

– **Mobile Terminal (MT).** It takes the role of the device which an end-user would carry; its main characteristic is that it might include more than one wireless interface.
– **Access Elements (AE).** These two boxes emulate the role of any network element providing access (Access Point, Base Station, etc.); in order to emulate heterogeneous technologies, the two access elements are configured to work in orthogonal (non-overlapping) wireless channels.
– **Access Broker (AB).** In order to promote an efficient management of the available resources, the role of an access broker (either centralized or distributed) might be fundamental; in the deployed framework, this box

is connected with the two access elements by means of an infrastructure network (Ethernet); in addition, it includes some of the applications which will be used to generate traffic during the various experiments.

Both the **MT** and the **AE** incorporate the whole Mobilia architecture, while the **AB** only includes an instantiation of the *HoDM* module, since it does not directly manage any wireless resources, and thus it does not need to incorporate the *AL* nor any *LL*. In addition, in order to follow the demonstration on a friendly way, each of the elements incorporate a *GUI* which graphically shows the most relevant events and can also be used so as to configure some of the parameters.

As it was briefly introduced before, the platform adopts SCTP as the mobility solution. More precisely, it includes a SCTP proxy in both sides of the communication (both the end-user and the video server); this proxy basically forwards the traffic through a *tunnel*, while the real end-point can be dynamically adjusted by means of proprietary commands (those were implemented through `ioctl` after the commands sent by the corresponding Mobilia entities).

Two different use cases are challenged over this platform: the first one mimics a traditional handover triggered by the end-user when he detects a decrease of the link quality with the current access element; in the second case, the network decides to initiate a handover, due to a high congestion situation.

The detailed message interchange flow chart is shown in the following section.

4.1 Use Case 1: End-User Initiated Handover

In this case, the device perceives a decrease on the link quality with the current access network; as a consequence, it triggers a handover request, which might eventually lead to a change on the serving network.

There are two specific aspects which are worth highlighting: first, all the process is handled by the different elements of the Mobilia architecture and, therefore, the end-user should not perceive any quality of service degradation; furthermore, we benefit from the *GUI* and we emulate the link quality indicator (e.g. *RSSI*)[1].

Once the end-user is connected, and a video streaming session is initiated from the server, the *HODM* configures the *AL* so that to receive notification when a predefined threshold is crossed (this configuration can be done from the *GUI*, which uses a proprietary message to the *HODM*). By using the link quality emulation facility of the *GUI*, the link quality is decreased, and the corresponding event (*LINK DOWN*) is generated from the *LL* and travels up to the *HODM*. In this case, there are various alternatives, depending on the particular capacities of the device: if it has more than one interface, the end user would be able to benefit from this, minimizing the latency during a handover event; another possibility would be to use some sort of control channel to retrieve

[1] This is done as a means to facilitate the whole demonstration process since the **LL** is able to get the estimation provided by the subjacent wireless cards; it has to be considered that nowadays, wireless activity is usually rather heavy, and this might lead to undesirable fluctuations.

information from the network, which might provide location-aware data to ease the access selection procedure. In the particular case of this work, since there are two interfaces, the change of access takes place without any service disruption (carrying out a *make-before-break* handover); before actually changing the video flow, the device connects to the destination network, and once this is ready, the flow can be changed. In the demo, the SCTP proxy is in charge of finishing the handover.

The detailed interchange of primitives between the involved entities is depicted in the following section.

4.2 Use Case 2: Network Initiated Handover

In this case, the handover is triggered by the network; in this sense, an overload situation is emulated by means of the *GUI* of the current serving access element[2]. Again, once a predefined threshold is crossed, the *LL* notifies this situation to the *AL*, which passes it to the *HODM*. In this case, we assume that there is not any established agreement between the two access elements and therefore, the current serving one asks the access broker about the possibility to change the flow. Since the access broker is aware of the whole network topology (it would know e.g. whether there are enough resources in the networks which are accessible from the end-user position) will instruct the end-user to initiate the handover (this message goes from the *HODM* at the access broker to the *HODM* at the end-user device, through the current access element (which still gives access to the end-user). From this moment, the procedure looks like the previously described handover. Again, we benefit from the advantages brought about by the fact of having two interfaces so as to reduce the latency during the handover procedure.

5 Results

This section starts from the demo setup detailed in Section 4, evaluating the delay suffered by a mobile node when executing a user-transparent vertical handover from an access element to another one.

Specifically, we will challenge four different situations, which are briefly described below. It is worth highlighting that the main goal would be to assess the benefits that the use of multi-RAT devices may bring about.

A. The first one consists of a device with a single IEEE 802.11 interface (thus illustrating the case of most terminals at the time of writing), therefore it must carry out the whole handover process and all the involved tasks, such as scanning for networks and connecting to a new cell. This case can be described as the least desirable one, since it breaks the connection twice (see Figure 3), but it is included for comparison purposes. In this case, we assume that the IP address on the new access is statically configured and hence, there is not any additional delay due to IP assignment.

[2] Again this is just a simplification for the sake of demo purposes, since the *LL* of the access element is able to measure the load by means of the number of associated clients or using the size of the transmit buffer.

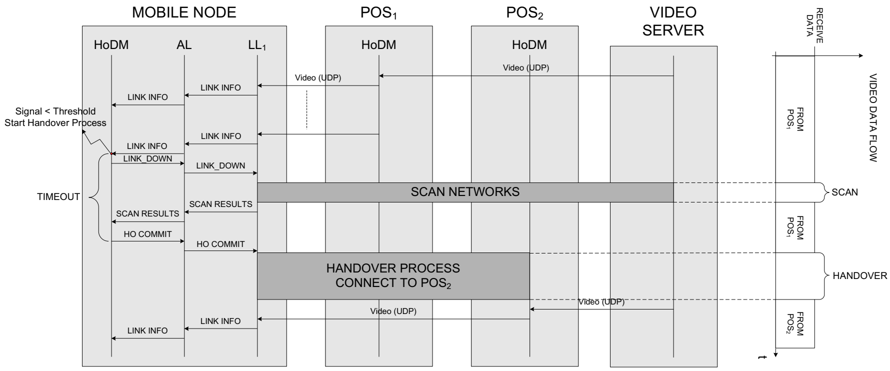

Fig. 3. Flow chart for the single-interface case

B. In this case a new IEEE 802.11 interface is added to the device. One of the available RATS is used for connecting to a new network, whereas the new one would only act when a scanning task is required. Hence, the data flow only stops at the handover process, saving the time waisted for looking for available networks. This situation also reflects what would happen if the network could provide location-aware information through a common transport channel (provided it is available), since this would allow the mobile to change the access element without scanning for other networks.

C. For this case, we take advantage of the fact that the device has more than one interface, so we can make a soft-handover, where the second interface is used for connecting to a new network when a LINK_GOING_DOWN message is received from the HODM, while the data flow continues through the other interface. Once the whole handover process is completed, the mobile node instructs the video server to modify the destination IP address[3], so the packets change the route to the new one, thus saving the additional time introduced by the 'standard handover', as can be inferred by looking at Figure 4. This technique is also known as *make-before-break*.

D. As we have already mentioned, in the previous three cases it is assumed that the assignment of IP address does not consume any additional time; this might not be realistic, and therefore, in this last case we would like to analyze the overhead caused by a legacy DHCP IP assignment. We take the first case as the starting point, and we configure the interface so as to request for an IP address once it is connected to the new network; needless to say, this increases the handover latency, as can be seen on Figure 5. It is worth mentioning that this delay would not affect any of the other cases, since the DHCP procedure might be running in background, and only when it is fully accomplished, the handover takes place.

[3] The default video server is not able to change an IP address by itself (while the application is running, so (as already mentioned before) we have introduced a proxy SCTP component in order to sort this out.

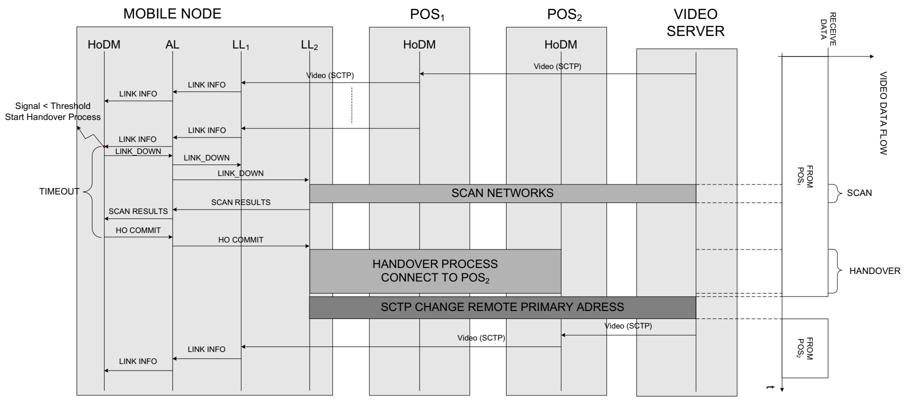

Fig. 4. Flow chart for the dual-interface case with SCTP

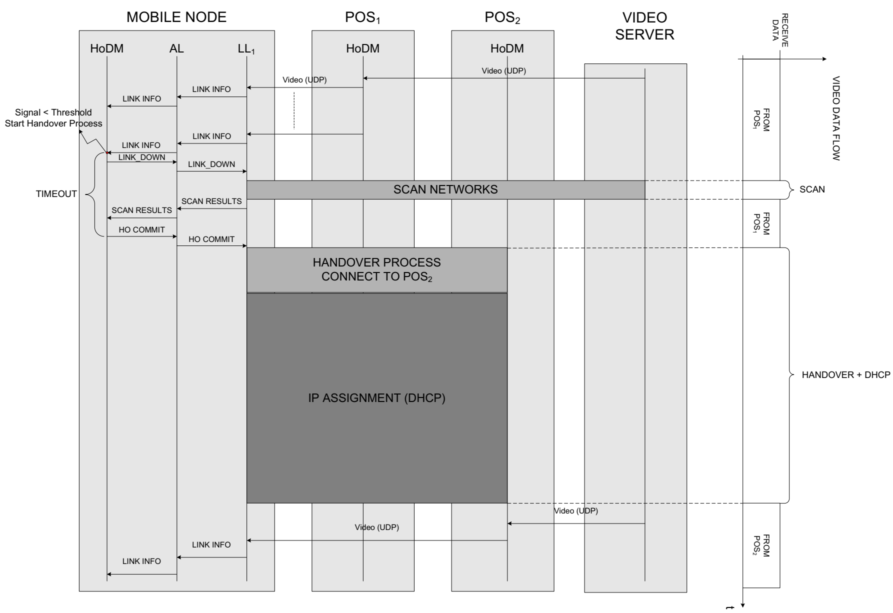

Fig. 5. Flow chart when IP address is automatically assigned with DHCP

Figure 6 shows the average handover latency and the 95% confidence interval (obtained by means of the *t-student distribution*) of a series of 10 independent measurements[4]. It is worth highlighting that, although 10 measurements might seem not to be enough, all the values were really close to each other, so we could conclude that the average performance figures are accurate.

[4] Without considering the time lost in carrying out the network scanning (since, it only affects case A).

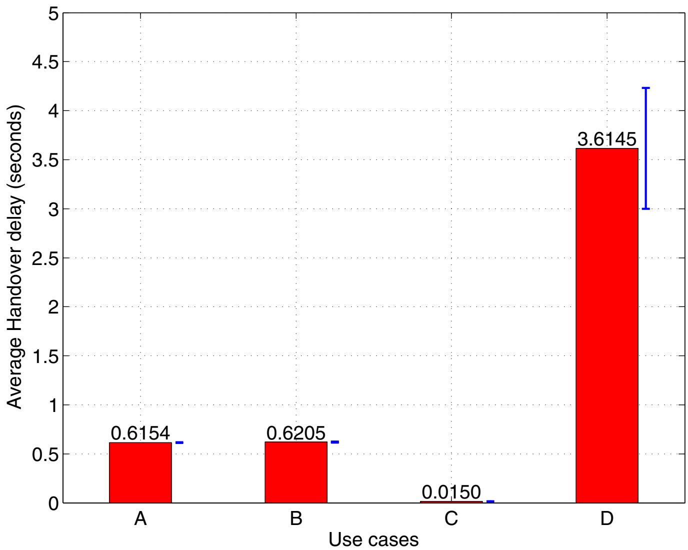

Fig. 6. Average handover latencies

These experiments have been measured at the Mobile Node by using the `Wireshark` [11] packet capture tool. The handover latency has been calculated as the interval between the reception of the last packet via the old link and the first packet received though the new one.

As can be seen, case A and B follow the same handover process, so the results are almost equal (the difference lies in which interface is in charge of scanning for the neighbor networks, breaking the connection for a while if it happens through the same interface), stopping the traffic for roughly half a second. Nevertheless, case C provides the system a smart handover process, avoiding the loss of connectivity due to the fact that the active connection is broken before changing to a new access element. Finally, case D shows the delay resulting between a link layer handover and the link layer IP address negotiation, which introduces a significant increase on the overall latency.

6 Conclusions

This paper has presented a real platform, based on the architecture proposed by the Mobilia Celtic project to showcase access selection procedures over heterogeneous wireless networks. In particular, we have presented two illustrative handover procedures: the first one is initiated by the end-user device (after a decrease on the link quality with the current serving network), while the second one mimics a situation where the handover is triggered by the network, after the access element detects an overload.

The implementation is afterwards used to analyze the improvements which might be brought about by the smart usage of multi-RAT devices; the handover latency of four different cases is empirically studied; the measurements show that taking advantage from having more than one interface might lead to remarkable performance enhancements.

In the future we plan to extend the platform in various ways: first, the signalling between all the different entities will be based on the IEEE 802.21 standard; furthermore, since the Mobilia architecture is rather orthogonal to the mobility solution, it would be interesting using other alternative solutions, like Mobile IP or HIP.

Acknowledgements

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References

1. IEEE standard for local and metropolitan area networks- part 21: Media independent handover. IEEE Std 802.21-2008 (2009)
2. Aguero, R., Gebert, J., Choque, J., Eckhardt, H.: Towards a multi-access prototype in ambient networks. In: 16th IST of Mobile and Wireless Communications Summit (2007)
3. Giupponi, L., Agusti, R., Perez-Romero, J., Salient, O.: Improved revenue and radio resource usage through inter-operator joint radio resource management. In: IEEE International Conference on Communications, ICC 2007 (June 2007)
4. López-Benítez, M., Bernardo, F., Vucevic, N., Umbert, A.: Real-time emulation of heterogeneous wireless networks with end-to-edge quality of service guarantees: The AROMA testbed. EURASIP Journal on Wireless Communications and Networking (2010)
5. Madwifi Project: Madwifi – Multibrand Atheros Driver for Wireless Fidelity, http://madwifi.org/
6. Paakkonen, P., Salmela, P., Aguero, R., Choque, J.: An integrated ambient networks prototype. In: 15th International Conference on Software, Telecommunications and Computer Networks, SoftCOM 2007 (2007)
7. Paakkonen, P., Salmela, P., Aguero, R., Choque, J.: Performance analysis of HIP-based mobility and triggering. In: WOWMOM 2008: Proceedings of the 2008 International Symposium on a World of Wireless, Mobile and Multimedia Networks (2008)
8. Perez-Romero, J., Sallent, O., Agusti, R., Karlsson, P., Barbaresi, A., Wang, L., Casadevall, F., Dohler, M., Gonzalez, H., Cabral-Pinto, F.: Common radio resource management: functional models and implementation requirements. In: IEEE 16th International Symposium on Personal, Indoor and Mobile Radio Communications, PIMRC 2005 (2005)

9. Sachs, J., Aguero, R., Daoud, K., Gebert, J., Koudouridis, G., Meago, F., Prytz, M., Rinta-aho, T., Tang, H.: Generic abstraction of access performance and resources for multi-radio access management. In: 16th IST of Mobile and Wireless Communications Summit 2007 (July 2007)
10. Taniuchi, K., Ohba, Y., Fajardo, V., Das, S., Tauil, M., Cheng, Y.H., Dutta, A., Baker, D., Yajnik, M., Famolari, D.: IEEE 802.21: Media independent handover: Features, applicability, and realization. IEEE Communications Magazine 47(1), 112–120 (2009)
11. Wireshark – The Network Protocol Analyzer, `http://www.wireshark.org/`