Toward IP Converged Heterogeneous Mobility: A Network Controlled Approach

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Abstract

Envisioning a future where mobile terminals equipped with one or more network devices are able to roam across wireless or wired networks, in a diverse macro and micro wireless cells environment, requires the development of enhanced methods to control IP based mobility. These methods should consider traditional terminal mobility (mainly due to user movement) as well as mobility across heterogeneous networks in the presence of semi-static users. For this to become reality, a cross layer interaction is required starting from a potentially large diversity of layer two access technologies up to the common IP layer, allowing the exchange of messages between terminals and network components. Furthermore, traditional host mobility driven concepts need to evolve, and include more stringent mobile operator requirements in context of fully driven network controlled mobility. This paper presents and evaluates a novel framework design, based on the IEEE 802.21 future standard, encompassing network driven as well as host driven mobility [1]. This paper evaluates signaling aspects, algorithm design and performance issues.

Key words: IP Mobility, Vertical Handovers, IEEE 802.21, Network Controlled Handovers, Network Initiated Handovers

[1] This work was supported in part by IST FP6 Integrated Project DAIDALOS. DAIDALOS receives research funding from the European Community's Sixth Framework Program. Nonetheless, the European Commission has no responsibility for the content of this paper.

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1 Introduction

IP Mobility has been widely explored in the research community. IETF [2] protocols, such as [1], [2], [3], [4] and their extensions or optimizations [5], [6], are becoming mature and implementations are already available for deployment. This is being fostered by large scale ambitions for future generation networks, which will require synergy across multiple technology aspects [7]: liaisons between standardization bodies are happening with increasing frequency. As examples, 3GPP [3] (defining architecture reference scenarios for next generation Mobile Operators networks), the WiMax forum [4] (defining the WiMax mobile reference architecture) and the IEEE [5] 802.21 working group (defining standards for enhanced vertical handover strategies) are actively discussing liaisons with IETF to agree on a common set of requirements to ensure the compatibility between architectures and protocols for mobility [8], [9], [10]. In other words, while IETF mobility protocols use the IP layer as convergence layer, it still has to be practically proved i) that these protocols suit physical architecture requirements and ii) that these protocols can easily operate in heterogeneous wireless access networks.
Enhanced methods to control user mobility, across these multiple environments, are a requirement for an expected future in which terminals equipped with one or more network interfaces [8], [9] roam across networks, in a multi-diversity of macro and micro wireless cells, the so-called "4G networks" environment. These mobility methods should consider both traditional terminal mobility (mainly due to user movement), and mobility across heterogeneous networks [10] in novel scenarios, where network load balancing or user context preferences may require mobility triggers also in the network side. To combine these different triggers, there is a need of a cross layer approach, starting from a potentially large diversity of layer two access technologies up to the common IP layer, to exchange messages between terminals and network components. Traditional host mobility driven concepts need therefore to be combined with more stringent mobile operator requirements of network controlled mobility [11]. Thus, users on the move, while enjoying seamless services, can take advantage of optimal mobility choices, eventually mainly computed by network components.
Following this orientation, in the concept behind this paper we evolve standard mobility mechanisms by adding network intelligence able to i) understand the diversity of layer two wireless cells, and ii) converge new mobility services on top of an IP common layer. In this work, mobility is not regarded anymore as a pure reaction upon terminal movement, but rather as a potential service that

[2] http://www.ietf.org
[3] http://www.3gpp.org
[4] http://www.wimaxforum.org
[5] http://www.ieee.org

future Mobile Operators might offer to customers in different forms and multiple degrees of complexity. Thus, terminal mobility can be either controlled by the network (upon network detection triggers coming from the terminal) or fully initiated from the network (supporting optimizations where required). We argue that 4G networks will require this combination as personalization in the user's terminal and resource usage optimization by the network will have to be integrated at a consistent control plane. Also, the expected mobility dynamics, cell coverage, and multi-technology environment is different from the traditional scenario of current cellular networks, and thus the results of network initiated handover in these networks may not be directly applicable to 4G networks. To efficiently cope with these novel 4G mobility scenarios, in this paper we propose a flexible framework combining the global IP mobility management protocol (Mobile IPv6 [1]) and the future standard for enhanced vertical handover execution (IEEE 802.21 [12]), with embedded network controlled capabilities. The performance of our proposed framework is evaluated through simulation, considering WLAN and cellular systems, and we show that our mobility framework provides standards-based mobility support, with added flexibility while keeping insignificant signaling overhead.

Furthermore, it should be noted that having addressed the benefits of network controlled/initiated handovers and analyzed associated scenarios in [13], this paper proposes a framework to efficiently implement network controlled handover strategies. This study does not conclude that network controlled handovers outperform mobile terminal controlled handovers in all conditions, rather that when applied, this optimal implementation meets the requirements on seamless mobility (user experience) and operators' policies.

The remainder of the paper is organized as follows. Section 2 presents a brief overview on (ours and others) work in the area. Section 3 introduces the network technologies basis for our framework, namely IEEE 802.21 and Mobile-IP. Section 4 describes our framework design and architectural choices. Section 5 and Section 6 respectively present the simulation setup, including functional components' design, and associated results. Section 7 derives considerations to be accounted for future 4G networks design, and Section 8 concludes the paper.

2 Related Work

As explained in section 1 several protocols have been standardized in IETF [1], [2], [3], [4] to support IP mobility. The research community has been quite active in the past years in understanding limitations and possibilities of these upcoming solutions [5], [6]. As an example [14] provides a complete solution to efficiently manage host mobility across WWAN and WLAN networks. This paper presents an optimized terminal architecture covering layer two issues (such as WLAN sensing and thresholds configuration) by means of a connection manager and layer three issues (such as IP addressing and configuration upon handover) by means of a virtual connectivity manager. The paper further shows performance aspects of the implemented architecture. It should be noted, however, that the roaming decision maker is only terminal based. Although one of the parameters took into account for handover decision making is network load, this is an information sensitive to network operators and it will not be disclosed. Hence, a network controlled handover environment would be able to perform more optimized decisions without revealing sensitive data to roaming subscribers. ***Previous authors' work [13] already demonstrated the benefit of applying network controlled mobility in specific scenarios, achieving increases in accepted number of users of up to 25% in certain scenarios. The paper showed that network controlled/initiated handovers can improve the global utilization of a network as compared with an environment based on mobile initiated handovers without network control. That is, while the network can serve an increased number of customers, mobile operators gain control on roaming mobile devices by executing optimized handover target selection. It should be noted that policies for candidate selection (e.g. load balancing, roaming agreements, service requirements) are operator dependent and for simplicity [13] considers load sharing scenarios. To this aim the work gives insights on deployment characteristics leading to increased benefit of applying network controlled strategies. The simulation scenario shows that the gain in network performance depends on the percentage of wireless overlay cells and quantitatively investigates the challenges (e.g. blocking probability, handover overhead) that network controlled handover strategies impose. Note that this conceptual work, although it mentions IEEE 802.21 as a possibility for building a framework for network controlled handovers, does not address any particular solution for implementing the needed functionalities. In fact, the simulation results provided do not consider any signalling between the network and the terminals, but an ominsciant entity that has a complete view and can move the terminals.***

On [15] and [16] the authors analyze different aspects of mobile initiated handovers (without network control) in heterogeneous wireless environments. The first proposes a terminal architecture based on IEEE 802.21 and Mobile IPv6, and studies an algorithm for mobile initiated handovers using different signal level thresholds, and the interaction with Mobile IPv6 operations. The second one, building on the previous results, studies the effect in the algorithm of changing terminal speeds. Note that neither network control nor 802.21 signalling between the network and the terminals are included in these studies.
On [17] a framework based on IEEE 802.21 for mobile devices supporting

network controlled handovers is proposed, analyzing, by means of simulation, when the required signalling between the terminals and the network must be initiated for efficient handover operation.
The work presented in this paper, also considers an architecture based on IEEE 802.21 and Mobile IPv6, and further extends the [17] results by adding: a study of the signaling overhead that the network controlled approach based in 802.21 causes in the network, an extension of the mobile initiated handover algorithm presented in [16]to account for network control, an algorithm for network initiated handovers considering mobile location (signal levels) and load in APs, a simulation performance analysis of network initiated handovers for load balancing and how it increases network utilization with negligible overhead, a detailed analysis of the different timings involved in the different parts of the signaling required for network controlled handovers, and an analysis of the upper bound in speed of the terminals for stable network controlled handover procedures.

3 Network technologies

The IEEE 802.21 [12], [18] (or Media Independent Handover (MIH)) technology is an enabler for the optimization of handovers between heterogeneous IEEE 802 systems as well as between 802 and cellular systems. The goal is to provide the means to facilitate and improve the intelligence behind handover procedures, allowing vendors and operators to develop their own strategy and handover policies. Furthermore, IEEE 802.21 is potentially usable in multiple mobility scenarios, both mobile and network initiated, and it is independent of the location of the mobility management entity.

Figure 1 depicts the 802.21 communication model with functional entities and

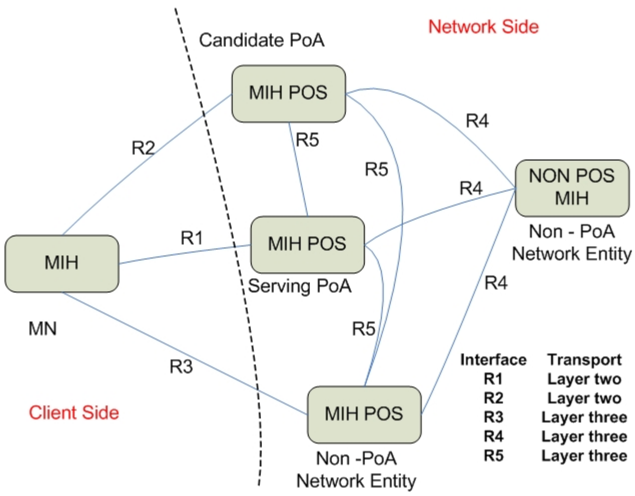

Fig. 1. IEEE 802.21 Communication Model

associated interfaces, where the MIH technology is implemented in the mobile nodes and network side components, both being MIH-enabled. Network side components are classified either as Point of Attachment (PoA), where the MN is directly connected to at L2, or non-PoA. At the same time, MIH Network Entities can be divided into Points of Service (PoS), which provide any kind of mobility service directly to the MN, or non-PoS, which do not exchange MIH messages directly with MN, but only with other MIH Network Entities. The transition between PoAs, and its optimization, is technology specific in intra technology handovers (e.g. fast BSS transition in 802.11). However, in heterogeneous wireless access technologies scenarios, cross layer communication and handover optimizations are required, and are not trivial tasks (due e.g. to the link diversity).

For this purpose, the IEEE 802.21 aims at optimizing the handover procedure between heterogeneous networks by adding a technology independent function (Media Independent Handover Function, MIHF) which improves the communication between different entities, either locally (mobile node) or remotely (network functions). The share of information and the use of common commands and events allow handover algorithms to be sufficiently intelligent to guarantee seamlessness while moving across different PoAs.

MIH defines three main mobility services. The Media Independent Event Service (MIES) provides event classification, event filtering and event reporting, corresponding to dynamic changes in link characteristics, link status and link quality. The Media Independent Command Service (MICS) enables MIH clients to manage and control link behavior related to handovers and mobility. It also provides the means to mandate actions to lower layers, in a local or in a remote protocol stack. Lastly, the Media Independent Information Service (MIIS) provides details on the characteristics and services provided by the serving and surrounding networks. The information enables effective system access and effective handover decisions.

The information exchange occurs between lower layers and higher layers, taking always the MIH Function as reference. Furthermore, the information can be shared locally, within the same protocol stack, or remotely, between different network entities. As shown in figure 1, interfaces R1 and R2 are specified at layer two, while interfaces R3, R4 and R5 are specified at layer three aiming at technology independence. For analyzing vertical handovers between WLAN and cellular systems, our framework exploits the communication exchanged over interface R3, implementing the necessary events and command services for link detection and handover initiation and execution. As stated in section 4.5 (where an accurate analysis of the required packet sizes is reported) we argue that the cost in terms of bandwidth to implement such interface is negligible with respect to data traffic flowing from/to the terminal.

Our control plane for optimized vertical handover management exploits IEEE 802.21, but is complemented by the Mobile IP (MIP) protocol. MIP provides Internet connectivity to mobile nodes roaming from one access router to another, regardless of the access technology supported in the router. It is based on the existence of a Home Agent, the creation of a Care Of Address when roaming, and the establishment of tunnels and/or specific route updates mechanisms that reroute the traffic from the home to the visited network, based on a binding between the Home Address and the obtained Care Of Address. This binding is executed through the use of Binding Update and Binding Acknowledgement messages, as per RFC3775. From a IEEE 802.21 viewpoint, MIP (as a Mobility Management Entity in the mobile node) can be regarded as a high-level entity which uses the services provided by the MIHF layer, i.e. it is a MIH-user. These services include, amongst others, the means to control L2 handover initiation and attachment, as well as link layer events that can be used as triggers to initiate the L3 handover procedures.

4 Framework Design

As mentioned above, our framework exploits the R3 (IP based) interface in IEEE 802.21, between the MN and the PoS (central entity), integrating the control signalling with Mobile IP signalling for data plane update. For simplicity (and due to its current industry relevance) we will discuss our proposal only applied across WLAN and cellular technologies.
In our scenario, global coverage from cellular technologies is always available, and enhanced coverage is available in multiple WLAN hotspots, a common situation currently. The mobile terminal typically performs a soft-handover (meaning that the new link is established before releasing the old one) between different interfaces, although our framework could be adapted to hard-handovers (in which the connection is set up through the new interface after closing the previous one in use). This framework defines two network operational modes. On both cases the handover decision is taken by the network, so following the definitions on [19], both modes are cases of Network Controlled Handover (NCHO). Namely the operational modes are i) Mobile Initiated and ii) Network Initiated and Mobile Assisted.

4.1 Mobile Initiated

This operational mode places the handover initiation decision in the Mobile Node (MN). When the MN reaches a WLAN cell and estimates there are favorable conditions, it will inform the network (PoS) of the new link detected, waiting for a confirmation from the network which allows or denies the execution of the handover procedure. This way the final decision of performing a handover is taken by the network. The analysis of Mobile Initiated handovers will then assess the impact of the proposed IEEE 802.21 signalling compared to old scenarios of pure host driven mobility, which do not have the overhead of decision making signalling and no network cost exist.

4.2 Network Initiated and Mobile Assisted

This operational mode places both the handover decision mechanism and the handover initiation decision in the PoS. The MN assists the handover decision mechanism by providing measurements of the environment where it is currently situated. This operational mode has been studied considering two aspects. First we analyzed the impact of signalling on handover performance (as in the previous operational mode). In a second stage, a load balancing mechanism has been developed and tested, exploiting mobile node interface diversity for network optimization. The load balancing mechanism is explained in detail together with the signalling flow in section 4.5. The analysis of network controlled and initiated handovers will then show how network decisions can impact terminal mobility, and which associated functionalities are required for these operations.

4.3 Signalling flows

Figure 2 presents the IEEE 802.21 signalling flow developed to perform a handover. This signalling is explored in both network modes, with small differences. The detailed list of parameters included in each message is presented in subsection 4.5.

4.3.1 3G⇒WLAN Handover

The signalling flow for the 3G⇒WLAN handover supposes a MN that is connected to 3G and is approaching a WLAN cell (figure 2). The scenario considers a mobile node connected to a 3G link, crossing zones where Access Points are present, allowing for vertical handover opportunities. We focus on a single PoA (AP) per vertical handover opportunity, in a scenario featuring multiple PoAs.

As soon as an access point (AP) is detected as result of the Active Scanning procedure, the MIH Function at the MN receives a corresponding indication from the link layer and sends message (1) to the PoS, encoding the MAC address of the AP in a UDP packet. This message is followed by message (2), where information related to the change in signal strength is supplied to the PoS. The PoS is then able to verify information related to that target, such as the load value. In the same way, Access Points (or PoAs in this scenario) are able to provide link events, via 802.21, indicating their load value to the PoS. In this way, the PoS is able to have an up-to-date information about the load

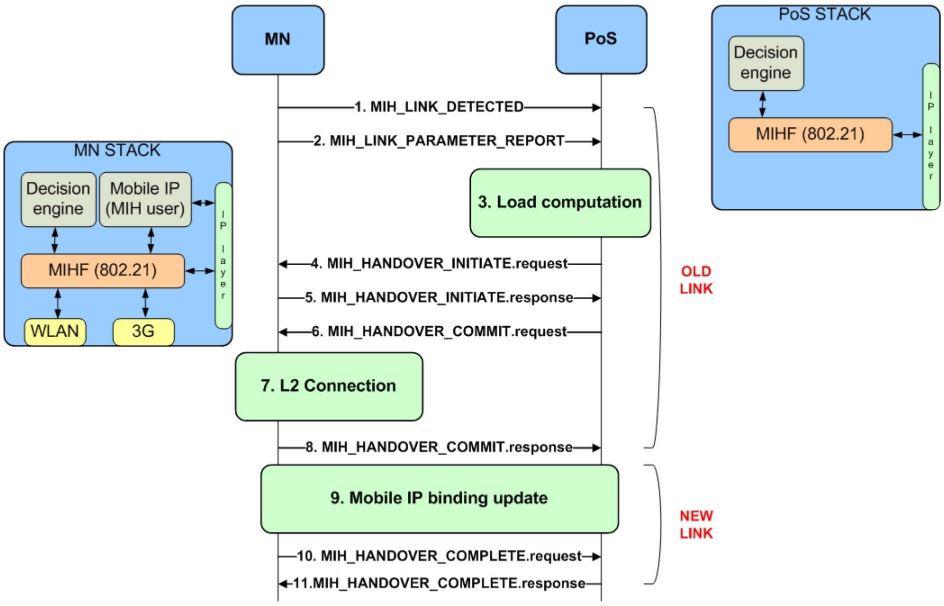

Fig. 2. Handover Signaling for WLAN⇒3G and 3G⇒WLAN handovers

of the PoAs, and use this information as an input to the handover decision. Upon load evaluation (3) at the PoS, message (4) is received in the MN, which replies with message (5), informing if the handover is possible or not. Note that e.g. the handover target in the handover request might not correspond to the one the MN is located at, in case of network handover initiation (e.g. because of terminal mobility). The PoS, upon reception of this message, sends message (6). The MN processes this datagram in the MIHF, sending a local link command to the wireless interface, in step (7) to start the L2 association procedure. In this case, the standard IEEE 802.11 association state machine is used, because this is a WLAN association. However, an important factor to retain here is that the network PoS is able to issue a remote 802.21 command towards the mobile node, an that command is translated by the MIHF into a specific technology command. In this case it is 802.11, but it could be 3G, 802.16, etc. Upon successful L2 association[6], message (8) is sent to the PoS. If the signal strength conditions are still favorable, the MN can execute a L3 handover (9) (a MIP registration) through the new link. Upon successful MIP registration, message (10) is sent to the PoS, which replies with message (11). Finally the MN is able to receive L3 traffic as result of the MIP binding procedure. Note that the difference between a soft and hard handover is only related with the moment when data is not further received through the old link, and does not affect the signalling flow.

[6] Please note that in the simulator an active scanning procedure has been implemented to guarantee favorable radio conditions.

4.3.2 WLAN⇒3G Handover

This case supposes a MN associated to an AP, and the MIH Function continuously evaluating the signal level supplied by beacon messages. When the WLAN⇒3G threshold value is crossed, the MIH sends a Link_Parameters_Report (2) to the PoS, indicating deterioration of the received signal level. This will start a signalling exchange with the same messages and sequence as the 3G WLAN handover, except for (1) MIH_Link_Detected that is omitted, since the 3G leg[7] is assumed always active (i.e. PDP context always active).

4.4 Load Balancing Mechanism

As stated before, a load mechanism has been implemented for the operational mode Mobile Assisted and Network Controlled/Initiated. The use of this mechanism entails several changes in behaviour and signalling, presented in the following paragraphs.
Upon receiving indication from the MN of favourable link conditions, the PoS takes into account the load value of the handover target. Message 2 sent by the MN might not produce a reaction from the PoS, due to the target PoA being at high capacity. Thus a timer (to retransmit the Link Parameter Reports) is specified in order to refresh the PoS that the necessary handover conditions are still valid. The time value chosen for the timer is related to the RTT of the link, as recommended in the 802.21 specification.
For the load balancing procedure, each AP has an associated load value. The MN is also accounted in this load, affecting the value of the AP identified in the Link ID parameter of the respective MIH messages. An additional feature introduced by load balancing capabilities is the ability of triggering handovers for a MN when the load reaches the maximum value in a specific region of the WLAN network. This possibility supports scenarios of preferring 3G coverage to a WLAN hotspot with a large load. In the considered scenario, high load in the AP means that video feeds would reach the MN with increased delay, packet loss, etc. So, when the MN is in WLAN, and the load at that PoA is greater or equal than the maximum allowed value, the PoS sends an unsolicited handover initiate message to the MN, forcing a WLAN⇒3G handover. Note that the reverse case is the usual behaviour of the handover process described in section 4.3. Through the use of events received from the MN, the PoS is aware of the MN being inside a WLAN cell. Hence, when the PoS verifies that the MN is connected to the 3G leg and the load value of that AP is low enough to admit a new entry (part of the operation shown in figure 2,

[7] The 3G leg means the 3G part of the network, more concretely, the network point of attachment where the terminal connects to the 3G technology. This term is commonly used in 3GPP specifications.

step 3 *"Load Computation"*), the PoS will initiate a 3G⇒WLAN handover, by sending message (4). Upon reception of this message, the MN will determine if the signal level is good enough for a handover.
In case a handover is both initiated by the MN and the PoS, to avoid concurrency problems, the event sent by the MN is ignored, and the handover initiated by the network continues normally.

4.5 Signalling Overhead

Given our reliance in 802.21 signalling for the network operation, it is required to evaluate the associated signalling overhead. IEEE 802.21 specifies a set of messages exchanged between the network and the terminal in order to perform a handover. The 802.21 frame is composed by header and payload. The header consists of two parts: a fixed header which carries information related to the type of message and entity which is addressed to, and a variable header which helps in parsing the content of the payload. The first part is always present in any 802.21 message and has a fixed length of 8 bytes, while the second part carries information such as Transaction ID, Session ID or synchronization information and has a variable length.
In our study we suppose that the variable header is always present in the messages (worst case assumption) and its size is 8 bytes. The 802.21 message is completely defined in the payload, which is situated after the variable header. Inside the payload block, TLV encoding is used and the size of the payload block could be variable depending on the message and the parameters used. For each parameter, 5 more bytes should be added in order to complete the TLV format. Alignment to 32 bits is done by means of padding.
Table 1 specifies the messages and all parameters used in this study, with the respective sizes of each parameter. Although there is not any transport

MIHF Protocol Message	Parameter Name	Type	Size
MIH_LINK_DETECTED	Link ID	Network type	4
	MacNewPoA	MAC Address	6
MIH_LINK_PARAMETER_REPORT	LinkParameterType	Link Quality Parameter Type	1
MIH_HANDOVER_INITIATE.request	Handover Mode	Handover Mode	1
	SuggestedMacNewPoA ID	Mac Address	6
	CurrentLinkAction	Link Action	4
	SuggestedNewLink ID	Network Identifier	4
MIH_HANDOVER_INITIATE.response	Handover ACK	Handover Mode	1
	Preferred Link ID	Network Identifier	4
MIH_HANDOVER_COMMIT.request	NewLink ID	Network Identifier	4
	NewPoAMAC	Mac Address	6
	CurrentLinkAction	Link Action	4
MIH_HANDOVER_COMMIT.response	OldLinkAction	Link Action	4
MIH_HANDOVER_COMPLETE.request	Handover Status	Status	1
MIH_HANDOVER_COMPLETE.response	ResourceStatus	Resource Retention	1

Table 1
Messages and associated parameters (size in Bytes).

protocol defined yet for 802.21 datagrams, there are proposals that use UDP [20] (general design considerations are given in [21] based on a common set or requirements [22]). In our framework all the signalling has been performed over UDP/IPv6. For each packet a calculation of the packet size has been performed in the following way:

$$Length{=}IPv6{+}UDP{+}FixedHeader{+}VariableHeader{+}TLV\ params \quad (1)$$

The signalling messages per handover sum 672 bytes, from which, in the case of 3G to WLAN, 528 bytes correspond to signalling deployed through the 3G and 144 bytes correspond to signalling through the WLAN. In the case WLAN to 3G the numbers are reversed.
To get an understanding of the cost in terms of signalling when using 802.21, several calculations of the bandwidth used for signalling have been performed, taking into account the handover probability of our model. Studies like [23], argue that the average number of users in a 3G cell varies up to 52 users. For different numbers of users, the bandwidth used for signaling can be calculated and is depicted in table 2.
In this table, it can be seen that the signalling load increases with the number

	2m/s		5m/s		10m/s	
N° User	WLAN	3G	WLAN	3G	WLAN	3G
20	6.6±0.6	24.4±2.2	27.7±1	101±3	40.9±2	150±7.6
40	13.3±1.2	48.8±4.5	55.3±1.9	203±7	81.9±4.2	300±15

Table 2
Signalling Bandwidth cost in Bytes/sec in function of mobile node speed in m/sec

of users and their speed of movement, but in all cases, signalling load remains very low. In the worst case (40 users moving at 10 m/s) the required signalling corresponds to 300 bytes/second in average, delivered through the 3G link; and 82 bytes/second, delivered through the WLAN. This result corresponds to handovers from 3G to WLAN. The inverse case (WLAN to 3G) has similarly corresponding values.
We argue that the signalling specified in IEEE 802.21 is loading the network very lightly and is enough to support a high number of users performing handovers between different technologies like WLAN and 3G. This supports our intention of exploiting 802.21 MIH functionalities to aid heterogeneity mobility.

5 Simulation Setup

In this section we present the simulation environment used to evaluate our framework, which also requires the detail of some of the entities involved in mobility management. Our study was conducted by simulating the movement of a MN attached to a 3G network and performing several handovers between 3G and WLAN hotspots, varying terminal speed and coverage threshold values.

The simulation scenario considers wide space with indoor characteristics (such as an airport) in which the user can move at different speeds and it closely follows the network scenario mentioned in section 4. It consists of an environment with a partial area of non-overlapping WLAN cells [8] and full coverage of 3G technology. The WLAN coverage is supplied by Access Points, each connected to an Access Router. The scenario also features a Home Agent for the MIP Registration process, an audio server which streams audio traffic to the MN [9], and the PoS which is the central network entity that exchanges MIH messages with the MN. This adds the network part of the IEEE 802.21, under standardization, to our model, thus creating a framework suited to model Network Initiated and Assisted handovers. Through the rest of this section several details of the model and the specification of the algorithm which conform the PoS and MN behavior, are provided.

This simulation scenario is similar to the one presented in [16] and [15] with the difference that in those contributions only Mobile Initiated Handovers, and without any network control, were considered. As a consequence there was neither the concept of central entity (the PoS) controlling mobility, nor IEEE 802.21 signalling over the air between the mobile node and the network. The OMNeT++ [10] simulator was selected as the primary tool for this study, with each simulation run for 60 random seeds. This number was chosen as a tradeoff between simulation time and confidence interval size. As for the IPv6 neighbor discovery configuration default host/routers parameters values according to RFC 2461 have been adopted. With respect to the WLAN layer two attachment characteristics the simulation considers the typical IEEE 802.11 association state machine, where a layer two association/handover lasts approximately 220ms. More information related to the related to the IPv6 stack and on the IEEE 802.11 Omnet++'s implementation may be found on [24] and [25].

Movement Pattern

The movement pattern selected is the Random Waypoint Mode. The MN moves between uniformly distributed waypoints, at speeds of 2m/s, 5m/s and 10m/s targeting to model speed scenarios that will be the usual worst case in WLAN environments, including the border between WLAN and 3G (the focus

[8] The setup features four access points distributed in a square area of 500X500 meters.

[9] The traffic studied is a downstream audio, with a packet size of 160 bytes at application layer and interarrival packet time of 20 ms (83 kbps). Notice that usual VoIP codecs generate bit rates around 80 kbps and therefore their traffic pattern is very similar to the simulated one.

[10] http://www.omnet.org

of our simulations). In section 7, the effect of higher speeds is also studied.

WLAN Model

The WLAN Model used is the one implemented in OMNeT++ based on free space losses with shadowing and a variable exponential coefficient. Each simulation was run with 3G⇒WLAN and WLAN⇒3G thresholds varying between -75dBm and -65dBm.

Load Factor

For the load balancing optimization, a birth-and-death Poisson process is used, caped at a maximum number of clients per AP. We have simulated different user inter-arrival rates varying network load from 50% up to 100% of the maximum system capacity.

The 3G Channel Model

The 3G channel has been modeled as a PPP channel with a connection time of 3.5 seconds, disconnection time of 100 ms, bandwidth of 384 kbps (downlink) and variable delay of 100 to 150 ms per way [11]. Although the above model takes into account the connection time, in our simulations we have assumed that the PDP context is always active, so the value of the connection time does not have any impact. Indeed, our simulations are based on the following two assumptions i) full 3G coverage and ii) 3G link always on,which we argue that are realistic assumptions in typical scenarios.

Metrics used in the study

The main focus of our simulation work in this paper is to verify that the introduction, in a threshold based handover algorithm, of the IEEE 802.21 signaling that enables network control, does not hinder the ability to achieve a good use of the wireless cells. For exploring this issue we used the following parameters:

- Mean percentage of L2 handover without MIP registration (failed handovers)
- Mean number of 3G⇒WLAN handovers
- Mean number of WLAN⇒3G handovers
- Mean wireless utilization time

Regarding the first metric, a failed handover is a situation in which the mobile node detects the WLAN cell and starts the signalling procedure in figure 2 but, after receiving message 6 the signal level never goes over the 3G⇒WLAN

[11] Measurements have been taken with a commercial 3G data card.

threshold, and the procedure is not completed, in particular a layer three registration to send the traffic to the WLAN interface does not take place. Notice that this situation does not imply any connectivity problem, as communication continues normally using the other interface. The second and third metric are related to the mean number of 3G⇒WLAN and WLAN⇒3G handovers, respectively. Lastly, we also account for the mean wireless utilization time.

Extended Terminal Architecture for NIHO support

The terminal's architecture includes a subset of the Media Independent Handover Protocol defined in [12]. In this paper we focus on the impact of the required signalling to perform handovers while mobile terminals move at different speeds, thus MIH capability discovery and remote registration are supposed to already have occurred.
The handover algorithm in [16] reacts to events resulting from the analysis of the signal strength in the WLAN interface. A MIH implemented in the MN supplies triggers to a local decision engine, based on 3G⇒WLAN and WLAN⇒3G thresholds, possibly resulting in a handover. In this paper we complement this algorithm with MIH signalling between the terminal and the PoS. Figure 3 depicts the message exchange intelligence residing in the MIH

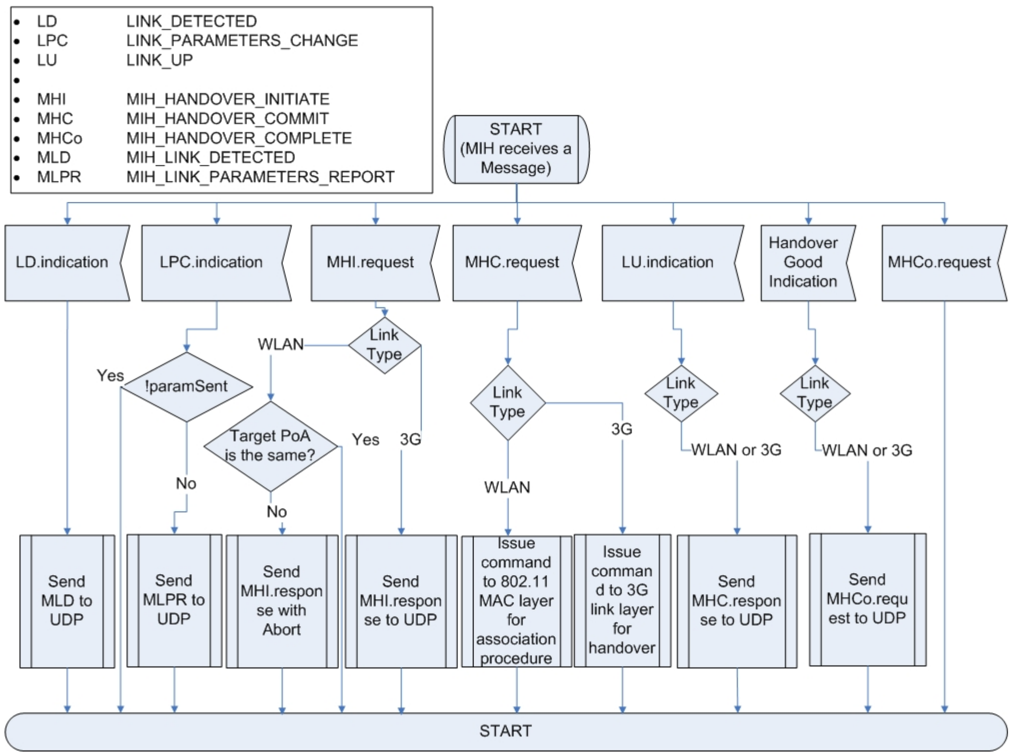

Fig. 3. MIH Intelligence at the MN

layer at the MN. The figure explains how the MIHF residing in the mobile node reacts to link layer events and remote MIH commands received from the network. The events are used to convey up-to-date link behavior to the network decision point, enabling it to acquire information regarding the terminal's point of view of the network. (Next follows an explanation of these events and commands, following the order in figure 2).

These events are 1) LINK DETECTED when the terminal detects a new WLAN cell, 2) LINK PARAMETERS CHANGE when the received signal level crosses a configured threshold, and 3) LINK UP that indicates a successful L2 connection establishment. In case of 2), a safeguard was implemented so that this event is only sent once per threshold crossing. The rationale for this is that, prior to attachment, the terminal is actively scanning the air medium and continuously verifies the signal conditions of the detected point of access, which would result in a large overhead of LINK PARAMETERS CHANGE messages over the air. After reception of these events in the MIHF, they are conveyed to the PoS using the 802.21 protocol message format. In the same way, MIH commands are sent by the PoS towards the mobile node. These commands are received and analysed by the MIHF and can be 1) MIH HANDOVER INITIATE requesting the mobile node to initiate handover procedures, either to a WLAN or 3G cell, and 2) MIH HANDOVER COMMIT requesting the mobile node to execute the required link procedures to commit to the initiated handover. In case of 1), the MIHF verifies the link type (WLAN or 3G) and, in case of WLAN, if this is a repeated MIH HANDOVER INITIATE command. In both cases, the result is a MIH HANDOVER INITIATE response message towards the PoS, indicating if the handover is feasible or not. In case of 2), the MIHF issues a link command (specific to the handover target technology) to initiate the L2 attachment procedures. After these procedures are finished, a LINK UP is received in the mobile nodes's MIHF from the link layers. This trigger is used to send a MIH HANDOVER COMMIT response towards the PoS, indicating that the L2 handover was successful, and also as an internal trigger to initiate the L3 handover procedures. Finally, when these procedures are done, an indication that the handover is finished is collected by the MIHF, which will produce a MIH HANDOVER COMPLETE message that is sent towards the PoS, informing it of the handover success.

Due to the configured 3G⇒WLAN threshold, and also to the movement of the node and the delay caused by the signalling, a layer two handover might not lead to a Mobile IP registration (this is one of the metrics of our simulation model, which is extensively studied in section 6). Since we analyse inter-technology make-before-break handovers, the MN will attempt to establish the new link before releasing the old one. When the MN is connected to the WLAN, and the MIH Function verifies that the received signal strength is not favorable anymore, a WLAN⇒3G is triggered. Thus, the MN starts the MIH signalling to the PoS, potentially initiating a handover to the 3G leg.

While evaluating the more suitable algorithm for the MN, we decided to perform the MIH signalling once the MN reaches the WLAN cell. Thus, when the signal level crosses the 3G⇒WLAN threshold, MIP signalling is sent to complete the layer 3 handover. The use of this model leads to higher MIH signalling load upon cell detection, but avoids possible delay for signalling completion between layer two link detection and the layer three handover processes.

PoS Design

The PoS is a network entity whose MIHF is registered to the MN's own MIHF, receiving subscribed events. Through the received messages, the PoS tracks down the terminal's position and the quality of its received signal strength. Then, the PoS can supply a remote command for handover initiation depending on the load value in that AP. The PoS intelligence depicted in figure 4. This is implemented as a network node with a full 802.21 MIHF stack, having the ability to send and receive MIH signalling encapsulated in UDP packets [19], and a decision engine for handover execution.
The PoS also has two operational modes depending on the active simulation scenario, where load processing can be active or not. In this last case (Mobile Initiated Mode) it always supplies an affirmative handover command when called. The reason for this behaviour is to avoid admission control mechanisms.
Figure 4 relates to the input received at the PoS from the MIHF residing at that network entity, and the verification if a handover is feasible. It is possible to verify that the PoS reacts to three different inputs: 1) reception of a LINK PARAMETERS REPORT from the mobile node, 2) load decreased in a AP, and 3) load increased in a AP. Regarding 1), the PoS is confronted with an indication that a mobile node has detected a network point of access and it's signal quality is good enough for handover. In case the handover target technology is WLAN, it will verify the load value for the access point whose MAC address is included in the LINK PARAMETERS REPORT message. If it verifies that the load value is below a pre-defined threshold, it will initiate the handover signalling. For 2), the PoS obtains an indication from an access point, that the load value has decreased. The intelligence in PoS begins by evaluating if the load has decreased below a pre-defined threshold, verifying the the load change has been high enough to admit more mobile nodes to be attached. If that evaluates to true, the PoS will then verify if it has recently received an indication from a mobile node indicating that it would like to handover to that newly available access point. In case the PoS has not received indication that the mobile node has left the cell range, it will trigger a handover procedure. The rationale for this is as follows: if a mobile node attempts to handover to an access point with too much load, a handover will not occur, and the mobile node will remain attached to the 3G leg, but within range of a WLAN cell. If the MN is still within range, and the PoS detects that the load value is now favorable, since WLAN is preferred to 3G, it will try to initiate an according handover. For 3, it is the opposite action: the PoS detects that the load, where the mobile node is currently attached, has increased beyond a pre-defined threshold. With that, it will initiate a handover procedure for that node towards the 3G leg, since 3G is proffered to a congestioned WLAN.

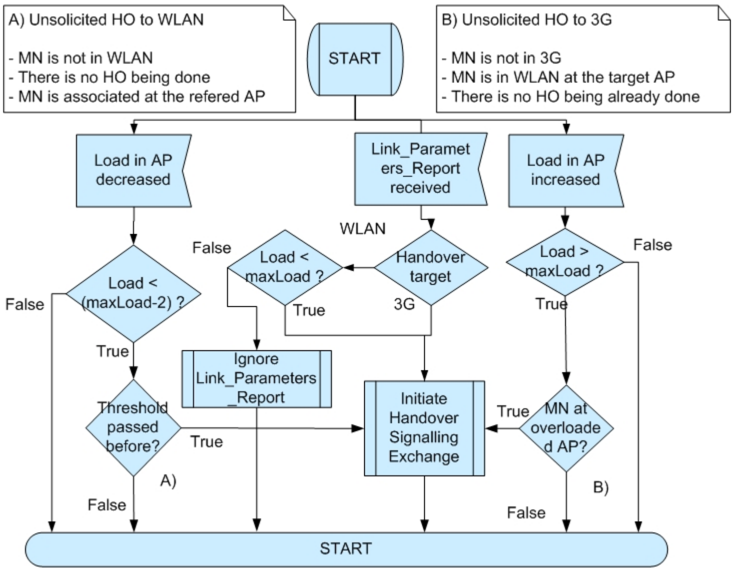

Fig. 4. PoS Intelligence

6 Results Evaluation

We first present the Mobile Initiated and Network Controlled scenario where no admission control mechanism is applied. Figure 5 depicts the percentage of failed handovers. Three speeds have been considered namely, 2, 5 and 10 m/s targeting indoor scenarios. From the graph we can see that by varying the threshold 3G⇒WLAN from -75 up to -65 dBm the percentage of failed handovers as defined above increases to almost 65% in case of 10 m/s. The curves follow a similar shape for 2 and 5 m/s. As can be noted, the curves show a trend to increase while the 3G⇒WLAN threshold value is increased.

When the mobile node detects the WLAN cell starts the signalling procedure of figure 2. After receiving message 6, the mobile node checks the signal level received from the WLAN AP and waits for this level to be over the 3G⇒WLAN threshold for continuing with the signalling. If the signal level never reaches a value over the 3G⇒WLAN threshold, we have a failed handover. This can happen naturally because of the mobility pattern. The mobile approaches the WLAN cell, but because its movement direction, it never reaches the position in the cell where the signal level is above the threshold. Of course, as the 3G⇒WLAN threshold is higher, this happens more often, as can be observed in figure 5. Faster speeds also increase the number of failed handovers, because in more occasions the mobile is not enough time in the zone inside the threshold.

An important point for us is the impact of the delay introduced by our required signalling in this procedure. Without the signalling to enable network control (figure 2), the mobile node is ready to perform the handover immediately after detecting the WLAN cell. With the signalling, we introduce a delay (the time between message 2 in figure 2 and receiving message 6) in

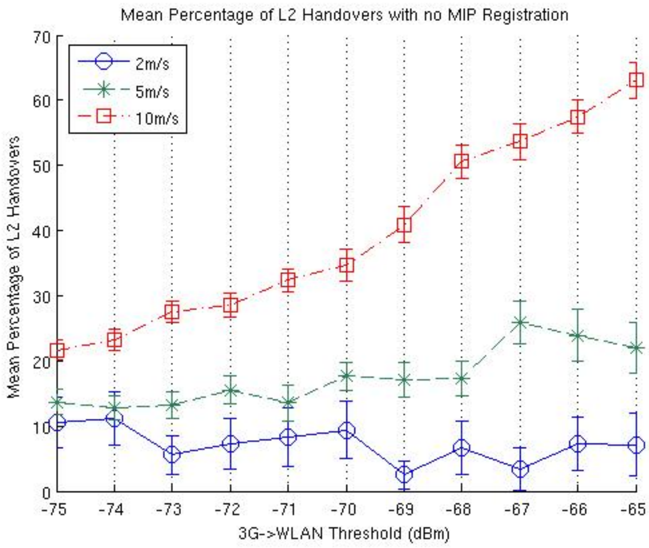

Fig. 5. Mean percentage of layer two associations not followed by a layer three handover when WLAN⇒3G thresholds configured at -75 dBm

which, even if the signal level crosses the threshold, the mobile node cannot perform the handover because it has to wait to complete the signalling with the network. If the delay introduced by the signalling is larger than the time needed to cross the 3G⇒WLAN threshold, the handover is delayed or in the worst case could never happen. We explore this issue in table 3 in which the delay from sending message 2 to receiving message 6, and from sending message 2 to finishing step 7, is compared for different speeds and 3G⇒WLAN thresholds. The signalling delay is much lower than the time needed to cross the threshold and completing step 7, showing that the signalling does not interfere with the handover performance. So we argue that the mobile node to network communication is suitable both from a signalling overhead point of view (table 1) and from handover performance point of view (table 3).

Figure 6 depicts the mean number of layer three handovers obtained by vary-

Speed \ Threshold	-75dBm	-72dBm	-69dBm	-66dBm	-65dBm
Time from sending message 2 to receiving message 6 (3G⇒WLAN)					
2m/s	0.43 ± 0.0002	0.43 ± 0.0002	0.43 ± 0.0002	0.43 ± 0.0005	0.43 ± 0.0002
5m/s	$0.422 \pm 4.5 \times 10^{-5}$	$0.422 \pm 4.8 \times 10^{-5}$	$0.422 \pm 9.8 \times 10^{-5}$	$0.422 \pm 5.5 \times 10^{-5}$	$0.422 \pm 4.1 \times 10^{-5}$
10m/s	$0.421 \pm 2.8 \times 10^{-5}$	$0.421 \pm 2.8 \times 10^{-5}$	$0.421 \pm 3.03 \times 10^{-5}$	$0.421 \pm 3.4 \times 10^{-5}$	$0.421 \pm 3.3 \times 10^{-5}$
Time from sending message 2 to finishing step 7 3G⇒WLAN)					
2m/s	13.6 ± 0.4	20.6 ± 0.8	25.5 ± 1.3	27.1 ± 1.5	28.9 ± 2.2
5m/s	4.4 ± 0.07	6.1 ± 0.1	7.6 ± 0.2	8.5 ± 0.2	9.0 ± 0.3
10m/s	2.1 ± 0.03	2.9 ± 0.05	3.7 ± 0.07	$4.1 \pm 0.1 \times 10^{-5}$	4.3 ± 0.08

Table 3
Time required in performing signaling depicted in figure 2 for selected 3G⇒WLAN thresholds.

ing the 3G⇒WLAN threshold. The impact of the speed affects the metric in different ways depending on the considered configuration. At the value -75 dBm the number of handovers is quite large especially considering high mobility level, while decreases and converges for greater values of the threshold. The decay in the slope of the different speeds is related with the failures of performing the layer three handover shown in figure 5. The graph shows how the values tend to converge, when the 3G⇒WLAN threshold is increased. The graph presenting the number of handovers from WLAN to 3G is symmetric due to the scenario symmetry. It is interesting to note that the closer the mobile node to the access point, the lower the chance of having complete handovers. This is complementary to the previous graph, as the metric is mostly affected by the mobility pattern and not from the signalling required for mobile to network comunication.

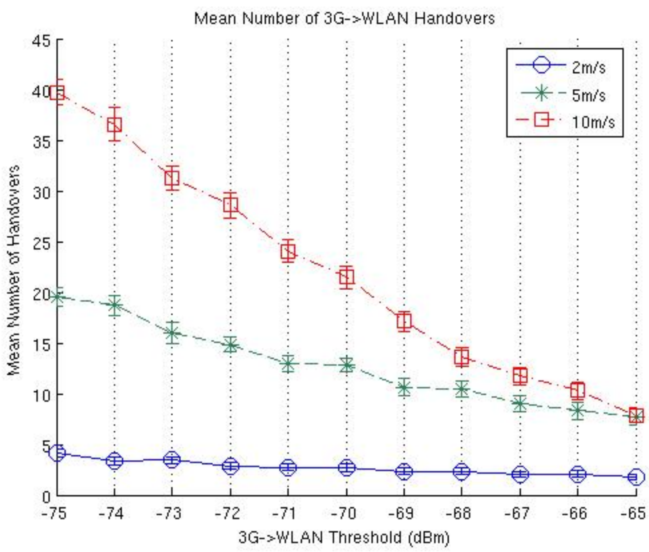

Fig. 6. Mean number of 3G⇒WLAN handovers when the WLAN⇒3G threshold is configured at -75dBm

Figure 7 shows the mean wireless utilization time according to the three different speeds. The general observed behaviour is a flat response with the increase of the 3G⇒WLAN threshold. As the primary goal of this study is the maximization of the wireless utilization time, and thus to reduce the number of handovers which do not result in a long term stay inside the cell, figure 7 demonstrates that the signalling does not impact the mean wireless utilization metric. In fact, the relative magnitude between the different lines shows that the metric is mostly impacted by the time the user resides in the wireless cell, which result in a higher utilization time at lower terminal speed. This conclusion further supports the explanation of figure 5 where the mobility pattern represent the dominant effect on the system.
The results above presented demonstrated that if values in table 3 are verified the cost of mobile to network signalling for network controlled and initiated handovers is negligible. We argue this is an insightful result, especially considering environments (e.g. WLAN hotspots) where network controlled mobility is not yet considered as core technology to improve both user experience and

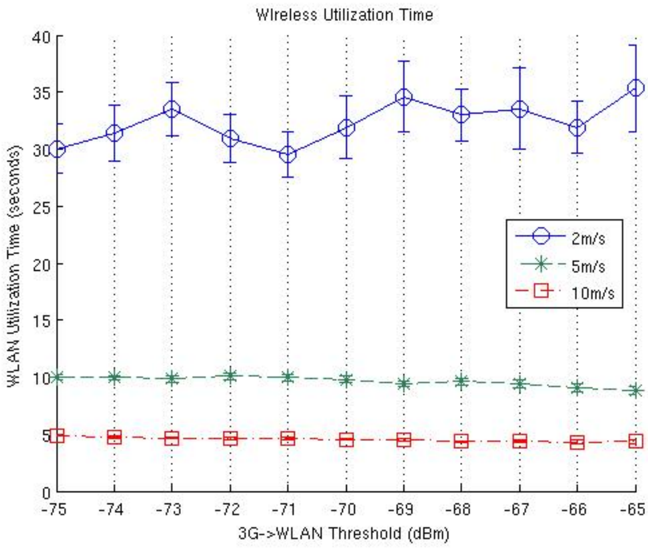

Fig. 7. Mean wireless utilization time (units of time per handover)

network resource usage. We now further show the results obtained for the load balancing scenario defined in 4.4 taking as a reference figure 5, figure 6 and figure 7.

Figure 8 represents the number of failed handovers as defined above, while load balancing is applied. The behavior is similar to the one in figure 5, since

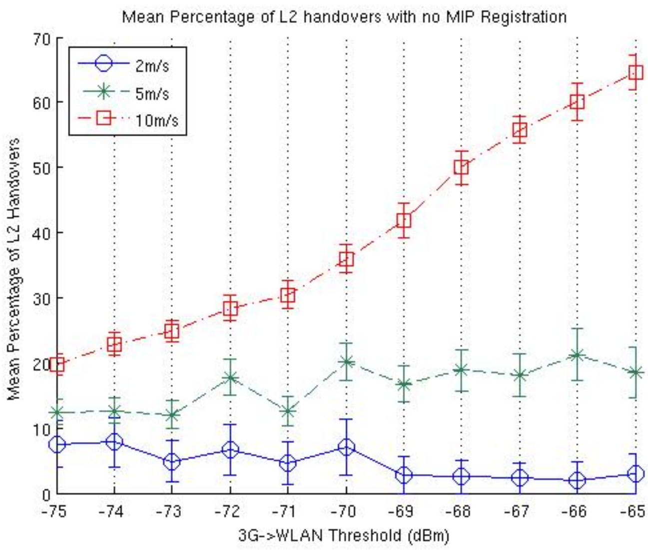

Fig. 8. Mean percentage of layer two associations not followed by a layer three handover when WLAN⇒3G thresholds configured at -75 dBm. Load balancing scenario.

the framework for network initiation accounts the terminal for the most up to date report information. The percentage of failed handovers due to wrong location report is around 3%, which seems an acceptable result. Figure 9 accounts for the number of handovers to the WLAN. The metric is directly

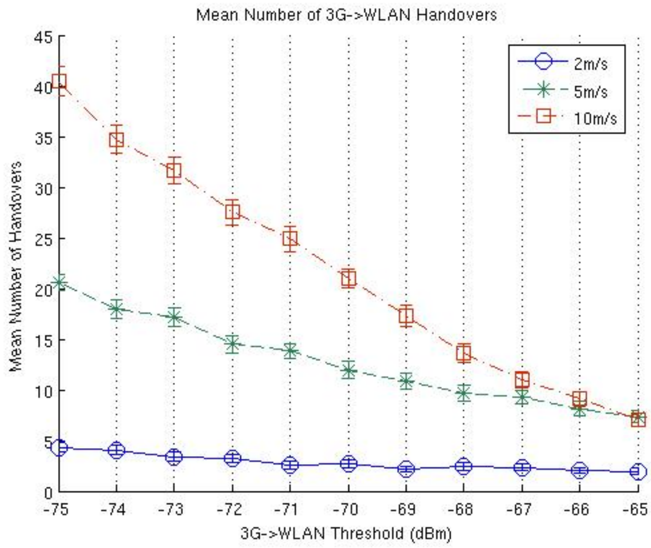

Fig. 9. Mean number of 3G⇒WLAN handovers when the WLAN⇒3G threshold is configured at -75 dBm. Load balancing scenario.

impacted by the admission control mechanism and the load generated on the different access points, where a slightly smaller number of handovers can be verified between figure 9 and figure 6. It is worth noticing how the load balancing mechanism is not affecting lower speeds (2m/s and 5 m/s) as much it is affecting 10 m/s. The values for these two lower speeds are not changing in a noticeable way between figure 9 and figure 6. We argue that the result (a desired one from the authors' perspective) proves the validity of the approach making load balancing scenarios attractive from an operator point of view.

Table 4 compares the wireless utilization time with and without load balancing, considering capacity usage of 50% and 100%. By comparing these results, we would expect that the wireless utilization time decreased, but as can be noted, the utilization time is not decreasing equally for all speeds, and the 10 m/s speed is the one most affected. This behaviour can be explained with the fact that the help of network initiated handovers reduces the overall number of performed handovers and at the same time increases the overall wireless utilization time. This is a desirable feature in next generation networks where minimizing the network overhead is a must, especially in last hop wireless channels.

Finally and for completeness, evaluation of RTT was considered, taking into consideration its effect on the 3G link. Simulations where RTT values varied between 200ms and 300ms showed only quantitative differences, maintaining the general behaviour of the previous graphs.

Speed (m/s)	No Load Balancing	Load Balancing 50% capacity	Load Balancing 100% capacity
2	32,4s	30,9s	25,9s
5	9,65s	9,46s	9,05s
10	4,53s	4,55s	4,45s

Table 4
Wireless usage with and without load balancing

7 4G Design Considerations

The results presented in the previous section validate our framework design showing the feasibility of this new approach for mobility and handover management. Specifically the IEEE 802.21 signalling, while introducing minimized network overhead, leads to optimal network control of terminal mobility. The comparison of simulation results with and without network load knowledge shows a negligible impact on the chosen metrics. However, when considering future 4G networks and wide scale deployments there are some further issues that should be accounted. That is, the configuration of optimal thresholds for WLAN⇒3G handovers is critical to avoid signalling packet loss and should be complemented with accurate methods for out of cell detection. These issues are briefly described in the following.

Optimal configuration for WLAN⇒3G Handover

The case analyzed is the worst case condition when the terminal performs handover from the wireless LAN to the 3G leg. Since the 802.21 signalling is always performed through the current link there might be conditions in which the signalling could not be completed, and added mechanisms are required as fall back solutions. We present here an analysis of the problem deriving an optimal configuration to avoid such conditions. Although a transport protocol will introduce ACKs and retransmission of the lost packets, the effects shown in this section must be taken into account or the transport reliability will introduce undesired delays. Figure 10 shows the effect of the WLAN⇒3G threshold on the signalling between the MN and the PoS. The picture shows, for each simulated speed, the number of signalling failures to perform handover from the WLAN leg to the 3G leg fails. The results indicate that at high speeds (10m/s) we obtain a high mean number of interrupted/failed signalling flows with the PoS.

This number increases with decreasing the WLAN⇒3G threshold. This behaviour can be explained as the result of the MN going out of the cell before the signalling flow ends. As the WLAN⇒3G threshold increases (in dBm) the signalling between the PoS and the MN starts before and the probability of going out of the cell decreases. Regarding the MIH functioning on interrupted signalling, this occurrence falls back on transport issues, which incorporate delay and loss of messages (as stated in [16]).

MIH Functions existing at the MN and PoS can optionally implement the

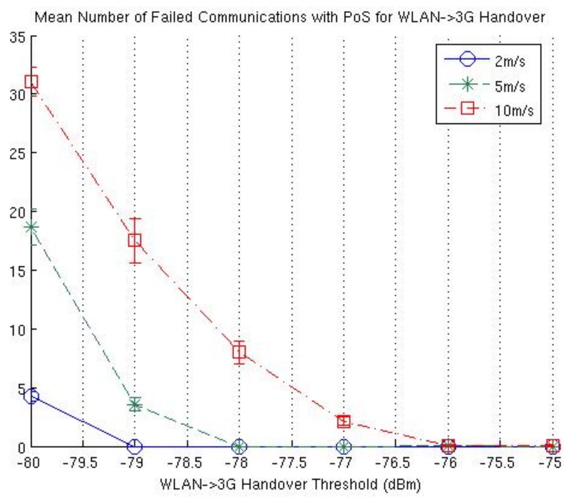

Fig. 10. Effect of the -80 dBm threshold on handover signalling

optional Acknowledgement mechanism. In the case of interrupted signalling, this event would be dealt as if messages where lost. Also, the behaviour from the terminal in case a LINK_DOWN is received in the MIH is implementation dependent. For example, upon connection to a new available link, the MIH at the terminal can send a MIH message to the PoS requesting a handover rollback for freeing resources previously reserved for the handover that failed. This behaviour can free the resources faster than waiting, for example, for a timeout.

Out of cell mechanism detection

The load balancing mechanism studied previously is based on the assumption the PoS has available the current location of the terminal. We propose to exploit 802.21 capabilities to update the PoS with the information on the current location. The mechanism is based on the fact that the terminal (via internal state machine) can determine with the help of the MIH function whether he is approaching a WLAN cell or if he is leaving a cell previously visited. Since the terminal can determine with acceptable accuracy the RSSI from the visited cell, we propose to convey this information to the PoS to enable better target choice while performing load balancing. The rational behind is as follow. In order to successfully move terminals form one cell to another to optimize network load the network has to determine the current location of the terminal. Indeed, the selected cell should also be visible from the terminal point of view. Nevertheless the accuracy of that information is crucial in the decision process although a trade off between freshness of the information and signalling overhead in the network must be considered.

Speedy handovers: an upper bound

The approach described in this paper is based on the assumption tha the IP layer is the common convergence layer across heterogeneous technologies. In case this signalling is applied to devices integrating broadband wireless access technologies, such as WLAN and WiMax, it would be desirable to identify what are the upper bounds in terms of stability and reliability not affecting performance of the handover procedures. To achieve this, we analyze a specific scenario featuring one single WLAN cell that the mobile node crosses following a straight line. This movement pattern is similar to automotive/train scenarios where vehicles/trains can move only along predefined paths. The experiments have been performed for selected thresholds letting the mobile node moving with increasing speeds, up to 35 m/s. We argue this setup is sufficient to investigate how the threshold based algorithm and 802.21 signalling perform in such speedy scenarios.

The graph in figure 11 presents the result of the study. In this graph we depict the highest speed at which handovers finish successfully for different 3G⇒WLAN thresholds. As can bee seen, it shows that the performance of the

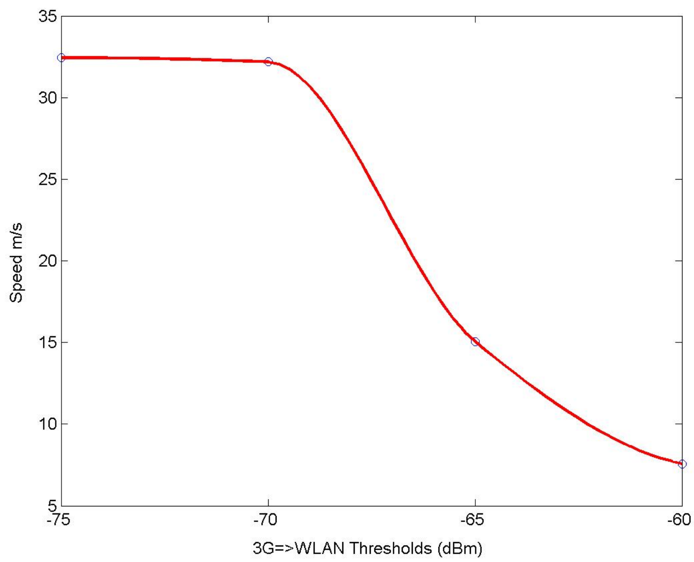

Fig. 11. Interpolation of values showing system breakdown based on the speed.

system rapidly decreases crossing the -65 dBm threshold. This is the expected behavior, as the failures are function of the speed. It should also be noted that the study in figure 11 considers the results shown in figure 10 where the optimal threshold configuration guaranteeing no packet loss due to WLAN signal fading is configured at -75dBm. This study completes the results presented in the previous section giving insights on the applicability of the technology in speedy scenarios providing wireless broadband access.

8 Conclusions

The paper presents a framework that integrates 802.21 and Mobile IP for heterogeneous networking. This framework is evaluated in the usual situation of mixed 3G and WLAN environments. Our results address handover management, heterogeneous networking and decisions making procedures implemented in the network diverging from more classic host based solutions. The results show that the 802.21 usage does not impose meaningful network load, and that the network handover initiation features provide improved mobility behavior. We further present several considerations relating MN speed and network design parameters which can be exploited for 4G network design.

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