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 multi-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 starting from a potential large diversity of layer two access networks up to the common IP layer is required, allowing the exchange of messages between terminals and network components. Therefore, traditional host mobility driven concepts need to meet 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].

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

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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 already first implementations are available for deployment. This is being paralleled by large scale ambitions, 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 the standard 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 realized 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. These mobility methods should consider both traditional terminal mobility (mainly due to user movement), and also mobility across heterogeneous networks [10] in novel scenarios, where network load balancing or user context preferences may require mobility triggers also in the network. To combine these different triggers, there is the need of a cross layer approach, starting from a potentially large diversity of layer two access networks 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 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 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 future Mobile Operators might offer to customers in different forms. In this context,

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[2] http://www.ietf.org

[3] http://www.3gpp.org

[4] http://www.wimaxforum.org

[5] http://www.ieee.org

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 mobility control plane. Also, the expected mobility dynamics, cell coverage, and multi-technology environment is different from the traditional scenario of current cellular networks, thus the results of network initiated handover in these networks are not directly applicable to 4G networks. To efficiently cope with these novel 4G mobility scenarios environments, in this paper we propose a flexible framework combining the global IP mobility management protocol Mobile IPv6 [1] and the IEEE 802.21 [12] future standard for enhanced vertical handover execution, 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 preserving from significant signalling overhead.

The remainder of the paper is organized as follows. Section 2 introduces the network technologies basis for our framework, namely 802.21 and Mobile-IP. Section 3 describes our framework design and architectural choices. Section 4 and Section 5 respectively present the simulation setup, including functional components' design, and associated results. Section 6 derives considerations to be accounted for future 4G networks design and Section 7 concludes the paper.

2 Network technologies

The IEEE 802.21 [12], [13] (or Media Independent Handover (MIH)) technology enables 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 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

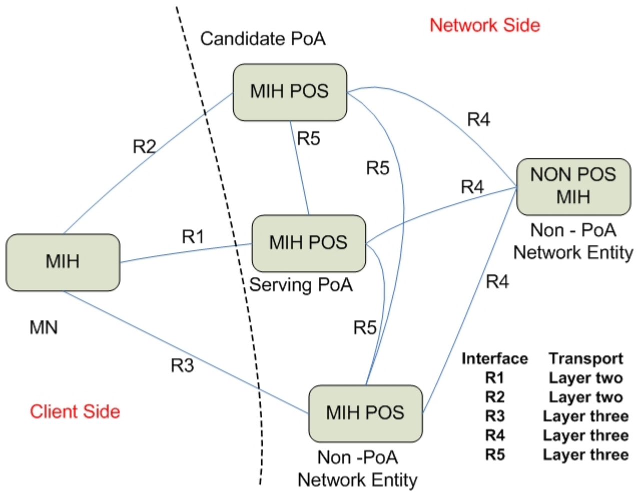

Fig. 1. IEEE 802.21 Communication Model

MIH messages directly with MN, but only with other MIH Network Entities. The transition between PoAs and its optimization is technology specific (e.g. fast BSS transition) in intra technology handovers. 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 as a reference the MIH Function. 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 work 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 3.5 (where an accurate analysis of 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.
The control plane for optimized vertical handover management exploits IEEE 802.21, but 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.

3 Framework Design

As mentioned in section 2, 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 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 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). Two network operational modes are defined, namely (i) Mobile Initiated and Network Controlled and (ii) Mobile Assisted and Network Controlled/Initiated handovers.

3.1 Mobile Initiated and Network Controlled

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. The PoS assumes that resources at the target PoA are always available, not considering network load for the handover decision. The analysis of Mobile Initiated and Network Controlled handovers will then assess the impact of the proposed IEEE 802.21 signalling compared to old scenarios where pure host driven mobility, which do not have the overhead of decision making signalling, is used.

3.2 Mobile Assisted and Network Controlled/Initiated

This operational mode places the handover decision mechanism 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 following two trends. 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. The analysis of network controlled and initiated handovers will then show how network decisions can favourably impact terminal mobility, and which associated functionalities are required for these operations.

3.3 Signalling flows

Figure 2 presents the exploited IEEE 802.21 signalling flow 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 3.5.

3.3.1 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. 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. 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 com-

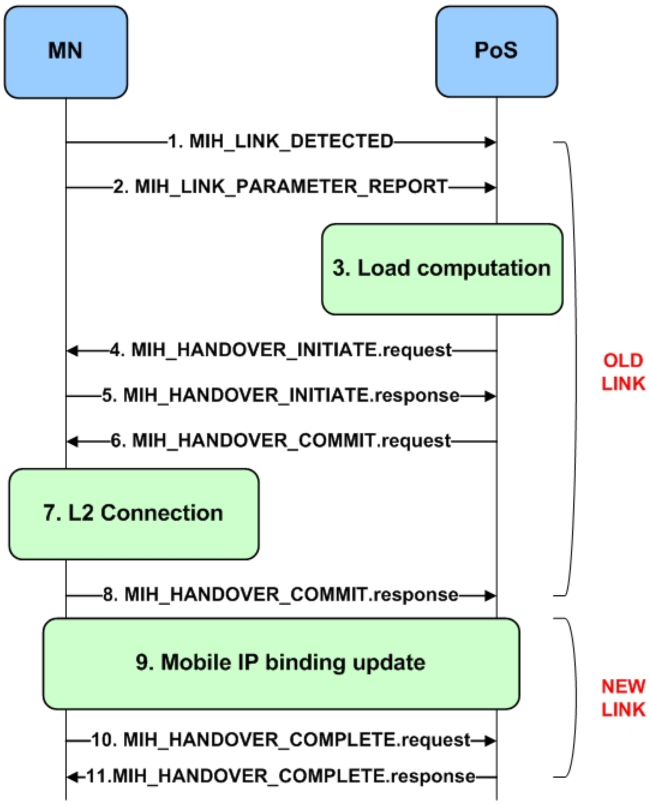

Fig. 2. Handover Signaling for WLAN⇒3G and 3G⇒WLAN handovers

mand to the wireless interface, in step (7). 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.

3.3.2 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 is assumed always active (i.e. PDP context always active).

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

3.4 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 can emulate the scenario of preferring the 3G coverage to a WLAN hotspot with a large load. In the considered scenario, high load in the AP means that video feeds could 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 3.3. 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 presents itself good enough to admit a new entry (part of the operation in (3) 2), 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.

3.5 Signalling Overhead

Given our reliance in the 802.21 signalling for the network operation, it is required to analyse 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 achieved 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 protocol defined yet for 802.21 datagrams, there are proposals that use UDP [14] (general design considerations are given in [15] based on a common set or requirements [16]). 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:

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).

$$Length = IPv6 + UDP + FixedHeader + VariableHeader + TLV\ params \tag{1}$$

The signalling messages per handover sum 672 bytes, 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 [17], 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 of users and their speed of movement, but in all cases, signalling load remains very low. In the worst case (40 users and 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.

	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

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.

4 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 3. It consists of an environment with a partial area of non-overlapping WLAN cells[7] 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

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

MN[8], 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 [18] and [19] 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++[9] 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.

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 of our simulations). In section 6, 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

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[8] 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

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

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[10]. 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.

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 [18] 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 layer at the MN. This message exchange allows the MN to supply fresh information about current link conditions to the PoS, as well as to receive remote commands for handover initiation. The message exchange is triggered upon signal level threshold crossing and generates local link events. 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. These events are collected in the MIHF of the MN and conveyed to the MIHF in the PoS.

The first two events supply to the PoS an indication that favorable handover conditions are available to the MN, and may result in signalling between the two entities for a handover initiation. When the necessary message for handover initiation is received from the PoS, the MN is able to perform the L2 handover. The terminal keeps analyzing the signal level and when a configured 3G⇒WLAN threshold is crossed, a layer three handover can occur. In this phase, the MIP signalling takes place updating in the HA the new MN's CoA. 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 5. Since we analyse inter-technology make-before-break handovers, the MN will attempt to estab-

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

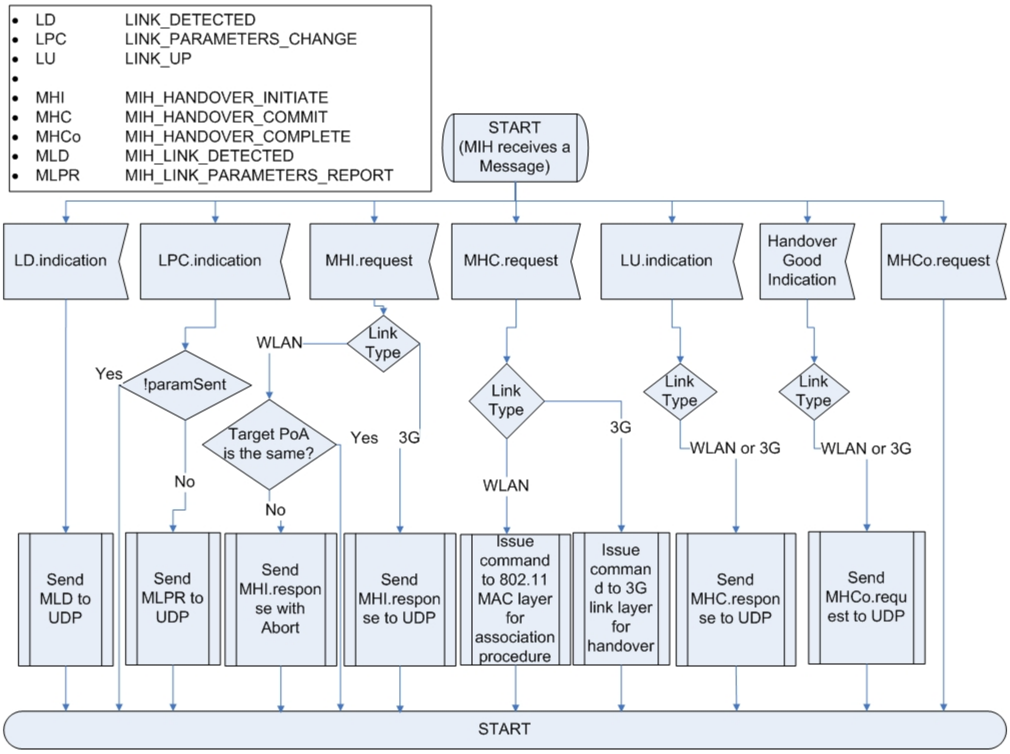

Fig. 3. MIH Intelligence at the MN

lish 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, 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 it always

supplies an affirmative handover command when called.

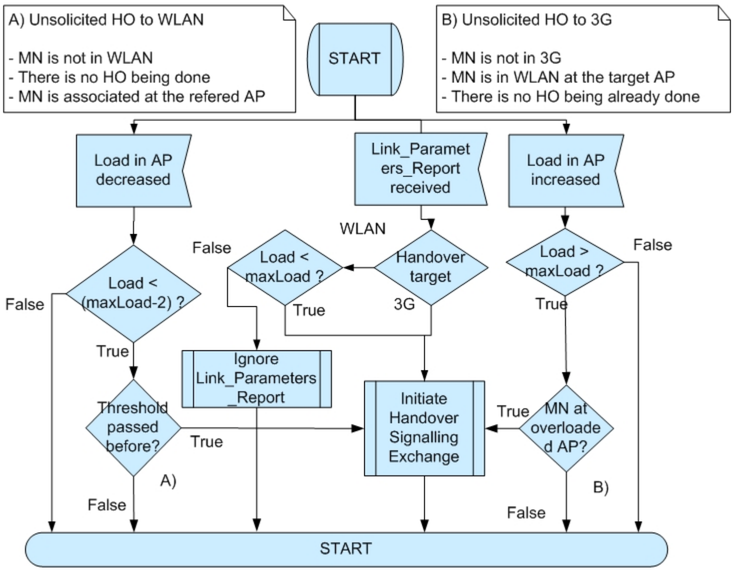

Fig. 4. PoS Intelligence

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
- Mean number of 3G⇒WLAN handovers
- Mean number of WLAN⇒3G handovers
- Mean wireless utilization time

5 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. 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 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. 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 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

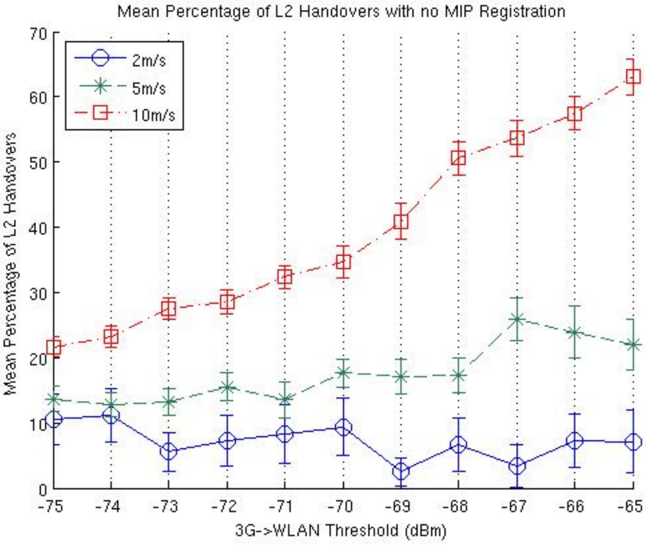

Fig. 5. Mean percentage of layer two associations not followed by a layer three handover when WLAN⇒3G thresholds configured at -75 dBm

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 varying 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 being the metric mostly affected by the mobility pattern and not from the signalling required for mobile to network comunication.

Threshold Speed	-75dBm	-72dBm	-69dBm	-66dBm	-65dBm
Time from sending message 2 to receiving message 6 (3G⇒WLAN)					
2m/s	0.426±0.0002	0.426±0.0002	0.426±0.0002	0.426±0.0005	0.426±0.0002
5m/s	0.422±4.509e-5	0.422±4.761e-5	0.422±9.758e-5	0.422±5.460e-5	0.422±4.083e-5
10m/s	0.421±2.797e-5	0.421±2.834e-5	0.421±3.028e-5	0.421±3.418e-5	0.421±3.290e-5
Time from sending message 2 to finishing step 7 3G⇒WLAN)					
2m/s	13.635±0.382	20.580±0.766	25.555±1.282	27.106±1.516	28.944±2.170
5m/s	4.383±0.074	6.127±0.127	7.610±0.209	8.506±0.202	9.020±0.261
10m/s	2.175±0.025	2.971±0.048	3.686±0.069	4.177±0.099e-5	4.294±0.071

Table 3

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

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. Being the primary goal of this study to maximize 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 order of 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 leads to 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

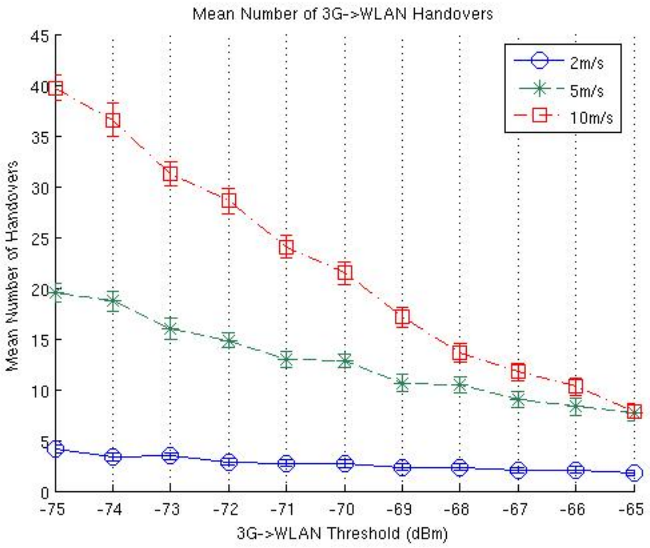

Fig. 6. Mean number of 3G⇒WLAN handovers when the WLAN⇒3G threshold is configured at -75dBm

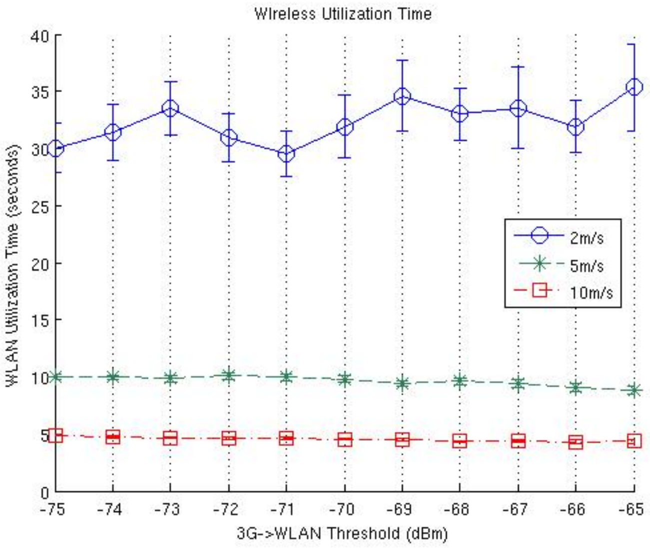

Fig. 7. Mean wireless utilization time (units of time per handover)

the cost of mobile to network signalling for network controlled and initiated handovers is negligible. We argue it 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 network resource usage. We now further show the results obtained for the load balancing scenario defined in 3.4 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 the framework for network initiation accounts the terminal for the most up

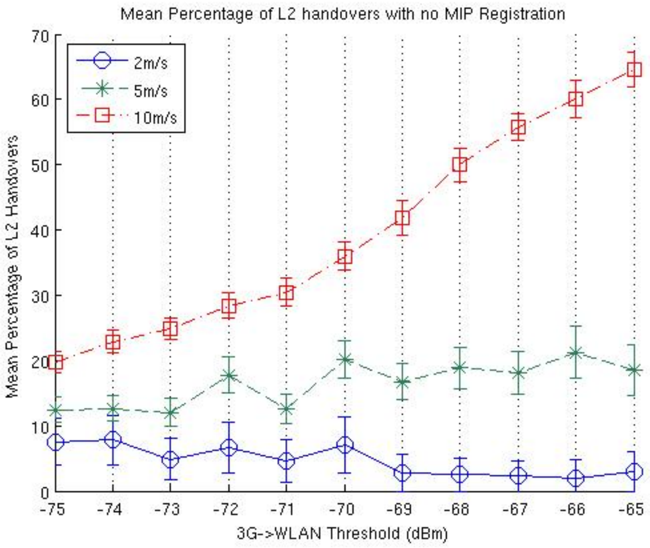

Fig. 8. Mean percentage of layer two associations not followed by a layer three handover when WLAN⇒3G thresholds configured at -75 dBm. Load balancing scenario.

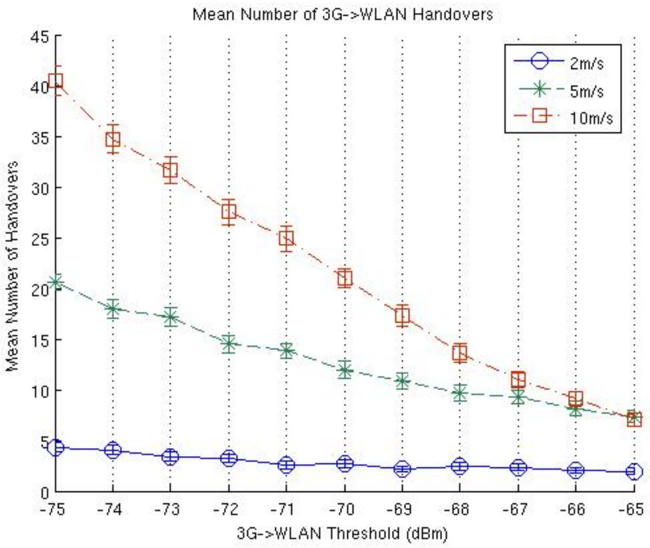

Fig. 9. Mean number of 3G⇒WLAN handovers when the WLAN⇒3G threshold is configured at -75 dBm. Load balancing scenario.

to date report information. The percentage of failed handovers due to wrong location report is around 3%, which we argue is an acceptable result. Figure 9 accounts for the number of handovers to the WLAN. The metric is directly 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 as 2m/s and 5 m/s as 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 (desired 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 most affected one. 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	32,35s	30,9s	25,87s
5	9,65s	9,46s	9,05s
10	4,53s	4,55s	4,45s

Table 4

Wireless usage with and without load balancing

6 Impact on 4G design

The results presented in the previous section validate the framework design showing the feasibility of a new approach for mobility and handover management. Specifically the IEEE 802.21 signalling, while introducing minimized network overhead, leads to optimal network control of terminals 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 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 the 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 a detailed 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 the lower the WLAN⇒3G threshold is. 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 [18]).

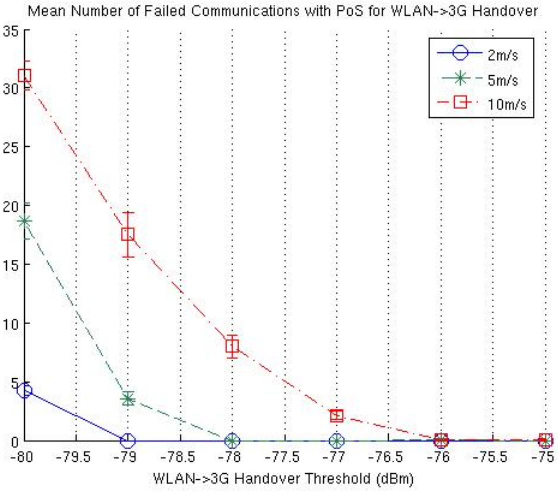

Fig. 10. Effect of the -80 dBm threshold on handover signalling

MIH Functions existing at the MN and PoS can optionally implement the 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 bases 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 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 freshness 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 bases on the assumption the IP layer is the common convergence layer across heterogeneous technologies. In case the signalling is applied to devices integrating broadband wireless access technologies such as WLAN and WiMax it would be desirable to identify what is the upper bound in terms of stability and reliability not affecting performance of the handover procedures. To achieve this we analyze a modified scenario of the one presented in section 4 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 speed 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 represent the highest speed at which handovers finish successfully for different 3G⇒WLAN thresholds. As can bee seen, it shows that the performance of the system rapidly decreases crossing the -65 dBm threshold. This is the expected behavior being the failures 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 useful insights on the applicability of the technology in speedy scenarios providing wireless broadband access.

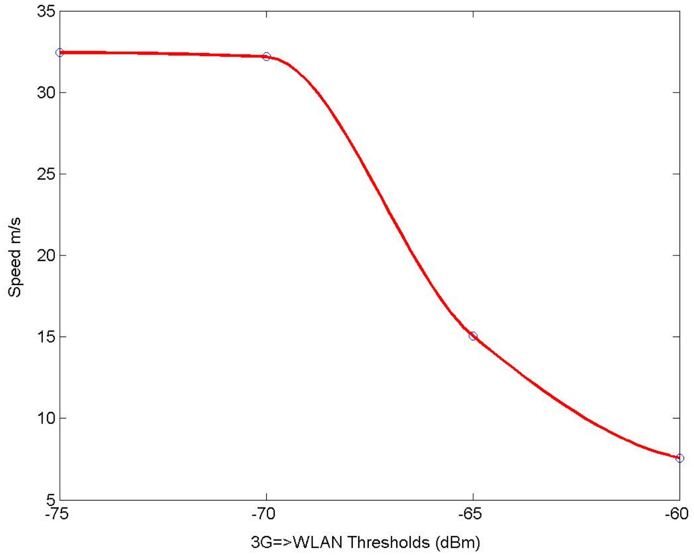

Fig. 11. Interpolation of values showing system breakdown based on the speed.

7 Conclusions

The paper presents a framework that integrates 802.21 and Mobile IP for heterogeneous networking. This framework is evaluated in the common situation of mixed 3G and WLAN environments. The results show that the 802.21 usage does not impose large network load, and that the network handover initiation features provide improved mobility behavior. To the best of author's knowledge this is one of the first studies encompassing handover management, heterogeneous networking and decisions making procedures implemented in the network diverging from more classic host based solutions.

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