A case study: IEEE 802.21 enabled mobile terminals for optimized WLAN/3G handovers

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Wireless LAN hotspots are becoming widely spread. This, combined with the availability of new multi-mode terminals integrating heterogeneous technologies, opens new business opportunities for Mobile Operators. Scenarios in which 3G coverage is complemented by Wireless LAN deployments are becoming available. Therefore all IP based networks are ready to offer a new variety of services across heterogeneous access. However, to achieve this, some aspects still need to be analyzed. In particular, how and when to execute handovers in order to minimize service interruptions and maximize the use of the most appropriate technologies according to user's preferences (for example, a user may prefer to use a lower cost technology if available). This paper presents a simulation study of handover performance between 3G and Wireless LAN access networks. The mobile devices are based on the IEEE 802.21 cross layer architecture and use Wireless LAN signal level thresholds as handover criteria.

I. Introduction

In the recent past wireless broadband internet connectivity has been massively deployed. Wireless LAN (WLAN) Hotspots are nowadays available in most public environments either for business or for entertainment. With wireless broadband access, based on WLAN technologies and ADSL wired connections, it is becoming less expensive to provide mobile users with a wide variety of services every where and every time. There is also a trend towards more sophisticated mobile devices incorporating different technologies, such as WLAN, UMTS or DVB-H, each being useful under different circumstances. However, real integration of the different technologies requires providing "seamless end to end services" with ubiquitous use of the heterogeneous technologies. This is especially important when considering real time services such as video or voice real time streams (e.g. VoIP, Mobile TV). In this environment, mobile devices have a combination of macro and micro cells of different technologies available, and a critical issue is how to choose the most suitable network, taking into account network availability, user profiles and application requirements among other criteria.

An important effort to deal with these challenges is undergoing at the IEEE 802.21 [1] proposed standard. The IEEE 802.21 Working Group is specifying a method to provide enhanced vertical handover mechanisms across the 802.x and the 3GPP/3GPP2 family of networks and defining internetworking functionalities. The 802.21 solution is based on a 2.5 middleware (the Media Independent Handover Function, MIHF) that abstracts layer-2 specific characteristics to upper layers (namely layer-3). Thus, IP based protocols are provided with a method to control the underlying technologies by means of a set of appropriate SAPs (Service Access Points). For example, a variety of parameters useful for selecting a handover target are defined in an abstract way, and the levels above layer-2 only need to deal with these abstract parameters.

The IEEE 802.21 work provides a useful framework to efficiently implement solutions for inter-technology seamless handovers and internetworking, but concrete solutions are out of its scope: 802.21 does neither specify which parameters should be taken into account nor how those parameters should be used.

The mixed WLAN-3G environment is going to be an important and widespread case in the near future and it is the focus of this paper. Existing solutions for handover decision in WLAN environments have been based mainly on signal level. In this mixed WLAN-3G environment we argue that WLAN signal level will be the most critical parameter in network detection and selection. A typical scenario will be

3G universal coverage and a preference for WLAN access when available. Therefore, it is essential to characterize how the use of WLAN signal level thresholds influences the performance of handovers between WLAN and UMTS cells. This is the objective of this paper. Through an extensive simulation study, and using an IEEE 802.21 architecture for the mobile device, we provide insightful guidelines on how the use of signal level information and how the chosen criteria impacts the performance of handover between WLAN and UMTS. Performance is analyzed in terms of packet loss and achieved utilization of the WLAN networks. This has a direct impact on business models and users' requirements such as mobile phone bill costs.

References [7], [6] and [13] analyze performance issues of handovers based on Mobile IP between cellular networks. However these works only study the problems related with upper layers (mainly TCP) due to the differences between the two involved technologies. Some previous works (e.g. [5]) analyze the integration of WLAN hotspots into 3G networks. These works however, in contrast with our own, are not based on the 802.21 framework. The first paper, to the best of our knowledge, that treats the specific problems of intertechnology handovers based on IEEE 802.21 is [9], but in contrast with our work, in this paper SIP (Session Initiation Protocol) is used as mobility handler. The WLAN signal level model used in our paper is based on [15] and [12].

The remainder of the paper is organized as follows. Section II gives an overview of the upcoming IEEE 802.21 draft standard. Section III briefly summarizes Mobile IPv6 operations. Section IV describes an architecture for mobile devices based on the IEEE 802.21 draft standard, and an algorithm for handover execution decisions. Section V depicts the simulation setup and section VI illustrates the obtained results. Finally we conclude with section VII.

II. IEEE 802.21 overview

The goal of the IEEE 802.21 (Media Independent Handover) group is to develop a standard that supports handovers between heterogeneous networks. Its aim is to provide link layer intelligence and related network information to upper layers to facilitate vertical handover operations. This includes links within cellular networks specified by 3GPP[1], 3GPP2[2] as well as both wired and wireless networks in the IEEE 802.x family. The standard may play an important role in future 4G networks as well, supporting the integration of WLAN networks in 3G cellular technologies like UMTS.

The 802.21 standard supports handovers for both mobile and stationary users. For mobile users, handovers may occur either due to changes in the wireless link conditions or due to a signal level degradation as a result of terminal mobility. For stationary users, handovers may be required when the network environment or the users' requirements change. For instance, a user may require a higher data rate channel when starting the download of a large data file.

The aim of the handover procedure is to maximize the service continuity by providing seamless maintenance of active communications when the user changes its point of attachment to the network, either wired or wireless. To avoid unacceptable disruptions to ongoing communications, the network should establish the link to the new point of attachment prior to releasing the previous link. Such soft handover would prevent any perceptible interruption, for example during a voice call.

The IEEE 802.21 standard envisions the cooperative use of both mobile terminals and network infrastructure for making vertical handovers. The mobile terminal is assumed to be multi-mode, i.e. to support different radio standards. The network is composed by both micro cells (IEEE 802.11 or IEEE 802.15 coverage) and macro cells (3GPP, 3GPP2 or IEEE 802.16), which typically overlap. In scenarios where there is not enough overlap between different cells, disruption in the communication is unavoidable.
The cooperation between terminal and network in 802.21 includes the following functions. The Mobile Node detects available networks. The network infrastructure stores overall network information, including neighborhood cell lists and the location of mobile devices. Then, the handover process is (typically) sustained by the information supplied from network to the terminal, in addition to the information that the terminal collects from the link layer. This information includes signal quality measurements, synchronization time differences, maximum data rates, higher layer capabilities. Supporting handover decision with these data contributes to the optimization of handover algorithms.
Note that the 802.21 standard does neither specify rules or policies for handover decisions nor determines whether the handover has to be terminal or network initiated. Instead its aim is to specify an architecture to

[1] http://www.3gpp.org
[2] http://www.3gpp2.org

allow and facilitate such decisions. Concrete rules and policies are out of the scope of the standard and their definition and specification is up to the user (Wireless Service Provider).

Figure 1 depicts the role of the 802.21 standard within the framework of IEEE and it shows where the new functions reside. Note that standardization work is currently ongoing and the presented 802.21 architecture might be affected by updated functionalities introduced in future documents.

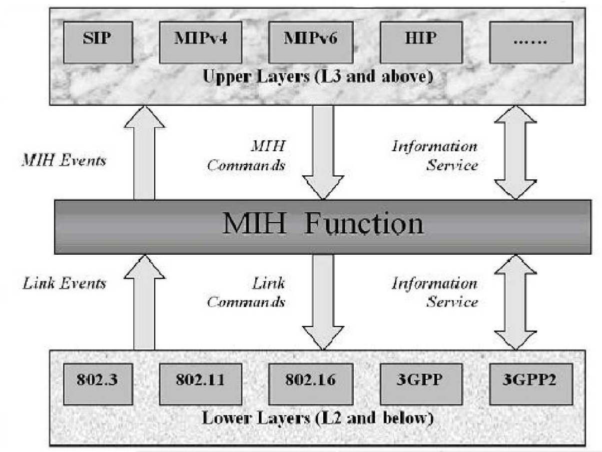

Figure 1: IEEE 802.21 MIH reference model

III. Mobile IPv6

Mobile IPv6 [10] is the standard the facto for IP mobility, adopted by the main standardization bodies such as IETF and 3GPP2, and it is one of the protocols proposed in 802.21. It allows nodes to remain reachable across heterogeneous access technologies.

In Mobile IPv6, Mobile Node (MN) is identified by a Home Address (HoA), regardless of its current location and point of attachment to the Internet. When the MN visits a Foreign Network, it configures a Care-of Address (CoA), which is the address used to reach the MN while visiting the Foreign network.

IPv6 [8] packets directed to the Mobile Node's Home Address are transparently routed to the new location by the use of an IPv6 over IPv6 tunnel. The entity in charge of forwarding the packets to the Mobile Node is called Home Agent (HA). This entity captures the packets directed to the Mobile Node's Home Address and forwards them to the Care-of Address. In order to inform the Home Agent of the new Care-of Address of the MN, a control handshake is defined. The Binding Update (BU) carries the information about the Home Address/Care-of Address association. The Home Agent completes the handshake with a Binding Acknowledgment (BACK).

Mobile IPv6 defines a Route Optimization mechanism by which the Correspondent Node (CN) can communicate directly with the Mobile Node. In this work we have not taken into account the possibility of route optimization because operators have some security concerns with this procedure. In any case, we do not expect that the use of the route optimization would affect the results presented in the paper.

IV. Model overview

In this section we present the model we have used in this paper. The section contains the following three parts:

- 802.21 Model
- Modification to the Mobile IPv6 stack
- Handover algorithm

IV.A. 802.21 Model

The Media Independent Handover (MIH) functionality has been implemented in the OMNET++[3] simulation tool. It consists of three elements: the MIH Function, the Service Access Points (SAPs) with their correspondent primitives and the MIH Function Services. This is shown in Figure 2.

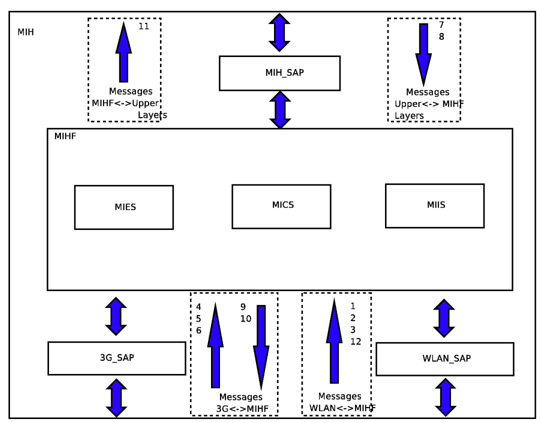

Figure 2: IEEE 802.21 MIH OMNET++ model

The MIH Function (MIHF) is defined in the current specification [1] as a logical entity and the specific MIH implementation of the Mobile Node and the network are not included. In fact, it is important to notice that in order to facilitate the overall handover procedure, the MIH Function should be implemented following

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

a crosslayer design, allowing the communication with the management plane of every layer within the protocol stack. Hence, the intelligence of the handover, (described in section IV.C), has been realized as part of the MIH Function.

The Service Access Points (SAPs) are used to enable the communication between the MIH Function and other layers. In the presented implementation there is one technology independent MIH_SAP which allows the communication between the MIH function and upper layers, namely IP, transport, and application. Two technology dependent SAPs are also implemented: WLAN_SAP and 3G_SAP, which communicate the MIH Function with the management plane of the 802.11 link layer and the 3GPP link layer, respectively. Note that every SAP defines certain number of primitives that describe the communication with the services in the MIH Function. Since the implemented scenario does not cover all possible use cases, we have defined here only the primitives needed for our scenario.

The MIH Function is supported by three basic services: events (Media Independent Event Service, MIES), commands (Media Independent Command Service, MICS) and information (Media Independent Information Service, MIIS). These services can either be local or remote. We say that a service is local when the origin and the destination of the service are the same MIH entity, while we say that it is remote when the origin and destination are different entities (e.g., the origin is the mobile terminal and the destination is an Information Server located at the operator network). The focus of this paper is on a specific scenario where the terminal neither needs to discover nearby MIH remote Information Services nor to receive remote events/commands. Accordingly, hereafter we only take into account local services.

The Media Independent Event Service (MIES) (2) has been implemented to process the following events from the link layers:

- MIH_WLAN_BEACON_IND: This message is sent by the WLAN_SAP to the MIH Function when no beacon frame has been received within a period of 3 seconds while being connected through the WLAN (Msg 1 in Figure 2). This prevents the case of a sudden disconnection from the Access Point (AP) where no disconnection message has been received by the WLAN interface.
- MIH_WLAN_LINK_ON: This message is sent to the MIH Function by the WLAN interface as soon as the WLAN interface receives an association confirmation from the AP (Msg 2 in Figure 2).
- MIH_WLAN_LINK_OFF: This message is sent by the WLAN_SAP when the WLAN signal quality is below a certain threshold (Msg 3 in Figure 2). This events can trigger an active or passive scan.
- MIH_3G_LINK_ON: This message is sent to the MIH Function when the 3G interface is informed that the PDP (Packet Data Protocol) context is started after the activation procedure (Msg 4 in Figure 2). At this point data through the 3G interface can be sent.
- MIH_3G_LINK_OFF: This message is sent to the MIH Function when the 3G interface is informed that the PDP context has been released. (Msg 5 in Figure 2).
- MIH_3G_LINK_GOING_ON: This message is sent to the MIH Function after the 3G interface has sent a connection request to the 3G network (Msg 6 in Figure 2). Communication is still not possible.
- MIH_IP_HO_SUCCESS: After a Binding Acknowledge (BACK) is received by the Mobile IP entity, this message is sent by the MIH_SAP to inform the MIH Function of the handover success (Msg 7 in Figure 2).
- MIH_IP_HO_FAILURE: After the expiration of the timeout defined to receive a BACK in the Mobile IP entity, this message is sent by the MIH_SAP to inform the MIH Function of the handover failure (Msg 8 in Figure 2).

The Media Independent Command Service (MICS) provides the means to upper layers to configure, control and obtain information from lower layers. These are the commands defined in our model:

- MIH_CONNECT_3G: This message is sent by the MIH Function to the 3G_SAP to notify the 3G interface that a connection procedure must be initiated (Msg 9 in Figure 2).
- MIH_DISCONNECT_3G: This message is sent by the MIH Function to the 3G_SAP to inform to the 3G interface that a disconnection procedure must be initiated (Msg 10 in Figure 2).
- MIH_INITIATE_L3HO: This message is sent by the MIH function to inform the Mobile IP entity that a layer 3 handover has to be initiated. The

interface towards which the handover has to be executed (i.e., WLAN or 3G) is specified as a parameter of this command (Msg 11 in Figure 2).

The goal of the Media Independent Information Service (MIIS) is to create a schema of available neighboring networks with accurate and up to date characteristics values of both upper and lower layers (e.g. Quality of Service (QoS) on the link, Mobility protocols available in a specific network). Our scenario, as mentioned before, does not require remote communication (we assume network information available at the terminal) but local, and the information implemented is the following:

- MIH_WLAN_RSSI: This message is sent by the WLAN interface to the WLAN_SAP, in order to report the signal strength of the current link. The WLAN_SAP forwards this information to the MIH Function (Msg 12 in Figure 2).

The MIH Function has always up to date information of the state of both higher and lower layers. Therefore, it will be able to decide when and how a handover procedure should be carried out.

IV.B. Modification to the Mobile IPv6 stack

In order to have a reasonable control over the handover performance, some modifications to the Mobile IP stack have been implemented.

Mobile IPv6 signalling (Binding Update BU and Binding Acknowledge) sent by a node for WLAN-3G interworking, could be lost in the network before reaching the destination or could be lost in the wireless medium when the Mobile Node suffers from poor signal conditions. Taking into account that the signalling is always sent through the new link in our implementation, a signalling loss may occur due to varying WLAN signal conditions when moving from a 3G to WLAN. Notice that, as detailed later, we assume in our model no packet loss in the 3G channel. When a BU or BACK is lost the handover at layer 3 is supposed to fail. When the handover fails, the state of the signalling flow can be:

- The BU has not arrived at the Home Agent: the packet flow is reaching the Mobile Node through the old link so no packet loss happens (no handover).
- The BU reaches the Home Agent but the BACK is lost: in this case the packet flow starts arriving to the Mobile Node through the new link. There could be packet loss if the Mobile Node experiences sudden signal condition variation.

Binding Updates are usually retransmitted upon timeout. If a Binding Ack is not received after a timeout expiration, a retransmission is scheduled and the next timeout is set to the double of the original one. This policy is kept until the timeout reaches a maximum (MAX_BINDACK_TIMEOUT is 32 seconds as specified in the Mobile IP RFC [10]).

As the Mobile Node has no way of knowing if the Binding Update has reached the Home Agent or not after a handover failure, the handover algorithm must proceed with an action to stabilize its state. This action is to perform a handover to the 3G leg.
The major modification introduced into the Mobile IP stack is in the way the retransmission of the Binding Updates is handled.As in the 802.21 model the decision of the handover must be handled by the MIH layer, the retransmission algorithm of Mobile IP has been omitted. When a Binding Update is sent, triggered by the MICS module, the Mobile IP module sets a timeout of 1.5 seconds (timeout of the first BU transmission as specified in [10]). After this timeout expires, a message indicating the failure of the handover is sent to the MIH layer, which takes the required actions (namely rolling back to the 3G channel).

IV.C. Handover Algorithm

Our handover algorithm is based on signal thresholds. It relies on the information provided by the Media Dependent layers and the Mobile IP Layer. A complete flow diagram of the handover algorithm is presented in Figure 3.

The handover algorithm reacts upon the reception of three possible signals, *i)* an RSSI (Received Signal Strength Indicator) sample, *ii)* a notification about the status of the handover and *iii)* a wireless LAN link Off message.

The handover algorithm is based on two thresholds. The first one, $3G \rightarrow WLAN$ threshold, defines the minimum wireless LAN signal level that must be received in the Mobile Node to trigger a handover from the 3G to the wireless LAN. The second one, $WLAN \rightarrow 3G$ threshold, defines the wireless LAN signal level below which a handover to the 3G leg is triggered. A handover to the wireless LAN is performed when the signal level reaches the value specified by the $3G \rightarrow WLAN$ threshold. The mean

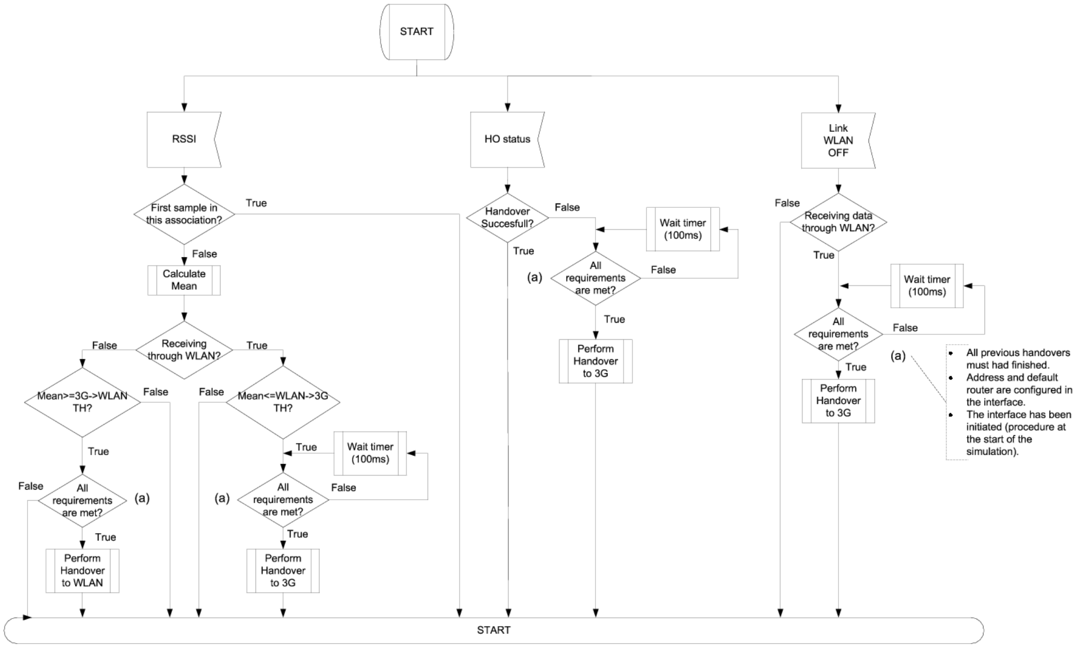

Figure 3: Handover Algorithm Flow Diagram

value of the two last samples of signal level is taken in order to measure the signal level; with this the signal level variability is decreased. A handover to 3G is performed when the signal level goes below the $WLAN \rightarrow 3G$ threshold, or when a wireless Link Off message is received.

After the MICS triggers a handover to the Mobile IP Layer, the handover algorithm is not allowed to perform another handover until the reception of a handover status message informing of the last handover result. If a handover is not successful, the algorithm performs a handover to the 3G part to fix the state of the algorithm. There are different causes for the failure of a handover. The BU may not reach the Home Agent or the BU reaches the Home Agent but the Binding Ack is lost.

Before performing a handover some conditions must be satisfied. The interface should be completely configured, with a global routable IPv6 address (Duplicate Address Detection (DAD) procedure completed) and default router associated. Also, all previous handovers should have been completed. If these conditions are not fulfilled the handover is delayed. In the case of handover to WLAN, if the conditions are not met, the handover is skipped until another signal sample arrives. In the case of handover to 3G, the handover is delayed by a timer, waiting for the conditions to be satisfied. The timer has been fixed to 100 ms. The value of 100 ms is the default period of the beaconing in WLAN. The retrial of a handover to the 3G is performed each time the signal level goes down the $WLAN \rightarrow 3G$ threshold. If any of these trials is successful before this timer expires, the timer is cancelled. The main purpose of this timer is to assure the retrial even if the MN is out of the wireless LAN cell, in this case the Mobile Node will not receive a frame in the 100 ms period and the timer will retry the handover even if no power indication arrives.

V. Simulation Setup

The handover study is conducted by simulating a mobile node attached to the 3G network and performing several handovers between 3G and wireless LAN.

The specific scenario analyzed is based on an indoor environment with several non-overlapping wireless LAN cells and a full coverage of 3G technology. We argue that this represents a scenario that will be a typical deployment in the future. Please note that this paper does not cover the WLAN to WLAN handover case. The reader is referred to [4] for an extensive study of WLAN to WLAN handover which complements the work presented here. This work considers a wide space with indoor characteristics in which the user could move faster than walking speed, such as in an airport using, for example, an electric vehicle.

The Mobile Node speed is fixed to 10 m/s. This value represents an upper limit of the speed expected in the big size indoor scenario. Indeed, all pedestrian speeds are well below this threshold.

The movement pattern selected is the Random Way-Point Model. With this model each node moves along a zigzag line from one waypoint to the next one, all the waypoints being uniformly distributed over the movement area.

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. 60 simulation runs were performed for each experiment. This number was chosen as a tradeoff between simulation time and confidence interval. In Figure 4 a schematic view

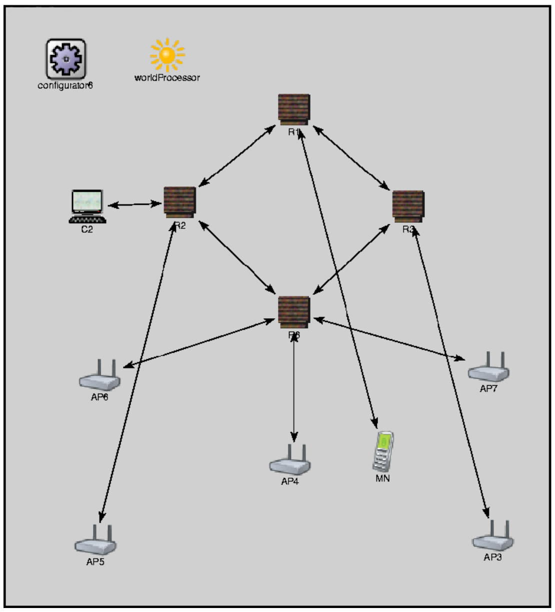

Figure 4: Simulated Scenario

of the simulation scenario is shown. The audio server is the node C2, the Home Agent is the Router R1 and the Mobile Node is the phone MN. The line connecting MN and R1 is the emulated 3G channel. The Round Trip Time between the node C2 and the Mobile Node has been taken equal to 350ms for the 3G leg of the the MN and equal to 150ms for the Wireless LAN. The RTT of 150ms using the WLAN leg is higher than most real scenarios, and is chosen to test our algorithm in a worst case situation.

V.A. WLAN Model

The standard wireless LAN propagation model defined in OMNET++ is based on free space losses with shadowing and a variable exponential coefficient. The original model implemented in OMNET++ is suitable for studies that do not analyze in depth the effect of the signal variation. However, the objective of this paper is to have a realistic wireless LAN model, suitable for indoor scenarios based on empirical results. For this purpose, we used the empirical model in [11], which includes variation in the signal due to shadowing and different absorption rates in the materials of the building. The path loss model is the following:

$$
\begin{aligned}
Losses &= 47.3 + 29.4 * log(d) + 2.4 * Y_s \\
&+ 6.1 * X_a * log(d) + 1.3 * Y_s * X_s \\
X_a &= normal(0, 1) \\
Y_s &= normal(-1, 1) \\
X_s &= normal(-1.5, 1.5)
\end{aligned} \tag{1}
$$

being *d* the distance between the Access Point and the Mobile Node.

The power transmitted by the AP and Mobile Node are defined in the UMA specification [3], [2]. The AP transmission power is 15dBm while the Mobile Node transmission power is 10 dBm. Following these specifications, the AP antenna gain is set to 0 dBi while the Mobile Node antenna gain is set to -10dBi. The transmission rate of the wireless LAN is fixed to 11 Mbps.

The OMNET++ wireless model defines two thresholds, the Sensitivity threshold and the Active Scanning threshold. The Sensitivity threshold is the minimum level of signal that the receiver can detect. Real products specifications set this level of signal to -90 dBm[4]. This is the value that we have used in our simulations. The Active Scanning threshold defines when the wireless card starts scanning for other APs in order to perform a WLAN to WLAN handover. When this level of signal is reached the Mobile Node detaches from the current AP. The IEEE 802.11b specification does not specify the value for this threshold, its value being design dependant. In the model presented, this value is set to -80 dBm. This value was selected after analyzing via simulations the maximum variability of the wireless LAN signal model. With this threshold we gain that the Mobile Node disconnects from the AP before reaching the sensitivity threshold.

V.B. 3G channel Model

The 3G channel has been modelled as a Point to Point Protocol (PPP) channel with a connection time of 3.5 seconds, disconnection time of 100 ms, bandwidth of 384 kbps (downlink) and a delay of 150 ms per way

[4]SMC Networks SMC2532W-B

(300 ms Round Trip Time (RTT)). The above PPP channel models the 3G channel when the Protocol Data Packet (PDP) context is activated. The disconnection and connection times were measured in different locations of an office building with a commercial UMTS data card. The round trip time is tuned to a typical value of delay in this kind of channel under the same conditions. The connection time is measured as the time elapsed between bringing up the card and the moment when an IP address is assigned to the Mobile Node (activation of a PDP context). Although the model takes into account the connection time, we have assumed that the PDP context is always active, so the value of the connection time does not have any impact on the simulations.

Our simulations are based on i) full 3G coverage and ii) 3G link always on, which we argue that are realistic assumptions in typical scenarios.

VI. Evaluation of the results

The results obtained can be classified in three different categories. First, an analysis of the *Wireless LAN utilization time versus the number of handovers* is presented, as a metric of the performance of the algorithm. Second, an analysis of the *probability of losing a Binding Update is performed*, to understand the effect of the algorithm on the control plane.
The packet loss due to *signal variation* and its behavior as a function of the threshold are analyzed to detect the impact of the different thresholds in a realistic environment modelled by the wireless signal model used. Finally, the *percentage of the different contributions to the packet loss* is studied to find the right tradeoff between seamlessness requirements and packet loss. The study is complemented with an *analysis of the performance of the algorithm in the configuration for zero packet loss*. The simulations have been divided in two stages. First, we evaluated a wide interval for both thresholds (i.e. $3G \rightarrow WLAN$ in the interval [-80, -65] dB and $WLAN \rightarrow 3G$ in the interval [-80, -70]) to understand the trend of the algorithm's behavior. In a second stage we selected relevant points to find the threshold values that achieve zero packet loss, this metric being the final goal of simulation study.

VI.A. Wireless LAN utilization time

Figure 5 shows the time the wireless LAN is used per handover and the number of handovers performed for several combinations of both thresholds.
It can be seen that as the threshold $3G \rightarrow WLAN$ (in dBm) increases, the number of handovers decreases, but

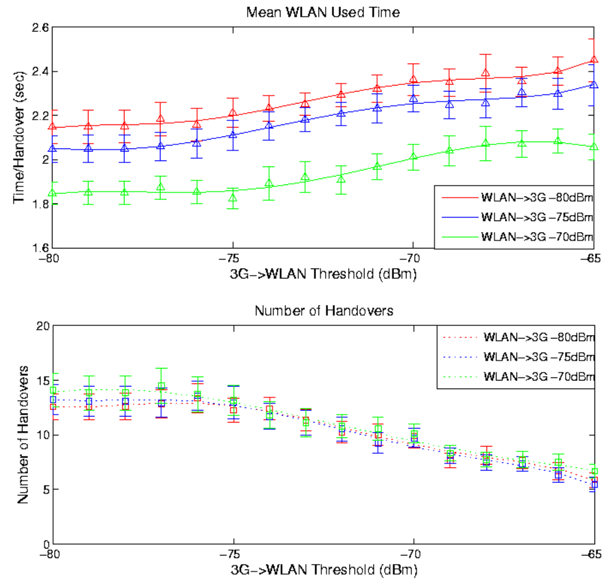

Figure 5: Wireless LAN Time usage and number of handovers

the time a station stays in the WLAN increases. This shows that, by setting the $3G \rightarrow WLAN$ thresholds to a value large enough the algorithm can be configured to avoid useless handover. In this way, only handovers that allow the Mobile Node to be connected for a longer time to the WLAN APs are performed while excluding short stays. This feature is desirable and ensures that only handovers increasing user WLAN experience are performed.
Although the number of handovers only depends on the $3G \rightarrow WLAN$ threshold, the wireless LAN utilization depends on the $WLAN \rightarrow 3G$ threshold too. As expected, in the figure we can observe that the wireless LAN utilization time increases as the $3G \rightarrow WLAN$ threshold increases (in dBm). This growing trend is maintained while increasing (in dBm) the $WLAN \rightarrow 3G$ threshold.

VI.B. Binding Update loss probability

The main reason for BU losses is caused by the fact that the MN tries to perform a handover to wireless LAN when the signal level is not good enough. In this situation the BU or BACK can be lost. The data losses associated to this event occurred because the Home Agent cannot send data through the wireless LAN link, when the MN is not present on the cell or even when it is present but the signal level is poor.

Figure 6 plots the probability of losing a Binding Update for varying thresholds. For all the configurations simulated there is one threshold that allows all handovers to be performed without losing any Binding

Update. For completeness all the possible configurations of the thresholds have been simulated. In Figure 6 (and all successive) it must be noted that the number of packets lost is always minimized under the condition $3G \rightarrow WLAN(dBm) > WLAN \rightarrow 3G(dBm)$. This is because when $3G \rightarrow WLAN(dBm) <= WLAN \rightarrow 3G(dBm)$ there is a ping pong effect in the 3G to WLAN handover, the mobile device executes a handover from 3G to WLAN because the WLAN signal level is greater than the $3G \rightarrow WLAN$ threshold, but immediately handovers back to 3G because the WLAN signal level is below the $WLAN \rightarrow 3G$ threshold.

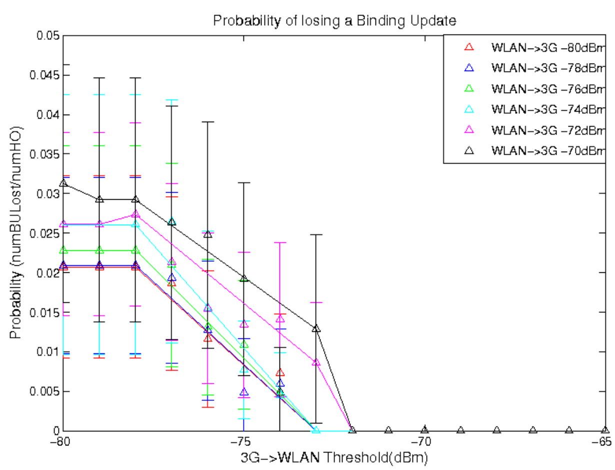

Figure 6: Probability of losing a Binding Update for several thresholds

The Binding Update losses depend heavily on the $3G \rightarrow WLAN$ threshold. It can be seen in Figure 6 that there is a level of this threshold (-74 dBm) in which Binding Update losses are reduced to zero. In the figure we can see also a dependency of Binding Update losses with the $WLAN \rightarrow 3G$ threshold, this is only because the ping pong effects explained before if $3G \rightarrow WLAN(dBm) <= WLAN \rightarrow 3G(dBm)$.

VI.C. Losses due to signal variation

The losses due to signal variation appear as an effect of the oscillation in the signal level. Even when the wireless signal level is not sufficiently weak to trigger a handover to the 3G leg, fading or a high negative variation of the signal produces a loss of several packets. These losses depend on the distance to the Access Point. Fading can happen by a third moving object (e.g. a person walking near the AP) or by the movement of the MN (i.e., when going through a metal door or wall).

Figure 7 shows several histograms for the packet loss due to variation of the signal. The X axis represents the

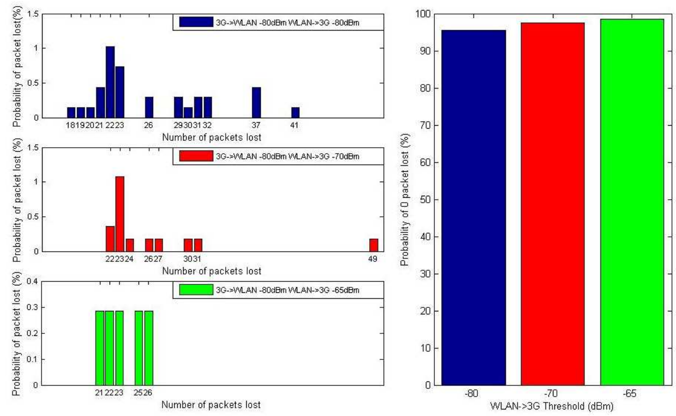

Figure 7: Effect of the thresholds in the packet loss due to variation of the signal level

number of packets lost (each time a loss due to signal variation occurs). The Y axis represents the probability of this packet loss. As the threshold $3G \rightarrow WLAN$ (in dBm) is increased for a fixed $WLAN \rightarrow 3G$ threshold the losses due to signal variation vary from the positive values to zero. This behavior is the expected one since the signal variation depends on the distance between the Mobile Node and the AP. If the $3G \rightarrow WLAN$ threshold increases, these losses decrease. In Figure 7, the right hand histogram shows how the probability of zero packet loss increases when the $3G \rightarrow WLAN$ threshold is configured to trigger handovers only when the terminal is close to the AP.

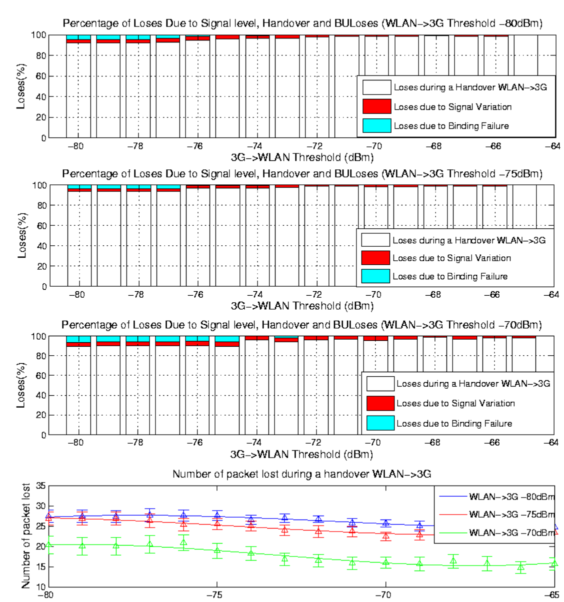

Figure 8: Study of the different contributions to the packet loss

VI.D. Study of the different contributions to packet loss

Figure 8 shows a study of the different contributions to the global packet loss for three different thresholds. The major reason for packet loss in all the configurations is the handover to the 3G leg. Losses due to signal variation, that start just before a handover to 3G and finish after the Home Agent has received the Binding Update (and the packets are sent through the 3G channel), are accounted. The contribution to the packet loss because a Binding Update procedure fails, is less relevant. It tends to disappear after the threshold of -74 dBm is crossed. The loss due to signal variation appears for all thresholds but its effect decreases when the $3G \rightarrow WLAN$ threshold increases (in dBm). The losses in the case of handover to the 3G channel are mostly affected by the $WLAN \rightarrow 3G$ threshold, as can be seen in the bottom graph of Figure 8.

In all the studies performed the minimum packet loss is of 14 packets/handover, a quantity that can be supported by an appropriate buffer in the application layer in most scenarios, although it can be a problem for applications with delay requirements. In next sub-section we explore the needed thresholds to achieve zero packet loss.

Note that the time required by the mobility signaling does not have an impact on the packet loss, since the MN keeps using the old interface until the handover is completed. Hence, there is no interruption on the packet flow while the handover is ongoing.

VI.E. Zero Packet Loss

Figure 9 shows the wireless LAN utilization time, the number of handovers performed and the packet loss trend when a the threshold configuration for zero packet loss is considered. Zero packet loss can be achieved when a high $3G \rightarrow WLAN$ (in dBm) (namely $3G \rightarrow WLAN$ values is -55 dBm) threshold is used, to eliminate the losses due to Binding Update losses and signal variation. Also a high $WLAN \rightarrow 3G$ (in dBm) threshold is needed to reduce packet losses due to signal variation, although this threshold must be lower than the $3G \rightarrow WLAN$ threshold to avoid ping-pong effects. In the results obtained, with the values $3G \rightarrow WLAN = -55dBm$ and $WLAN \rightarrow 3G = -66dBm$, we achieve seamless handovers.

The penalty imposed for the use of such high thresholds is clear since the number of handovers is drastically reduced. Note that the plots shown correspond to samples where handovers had taken

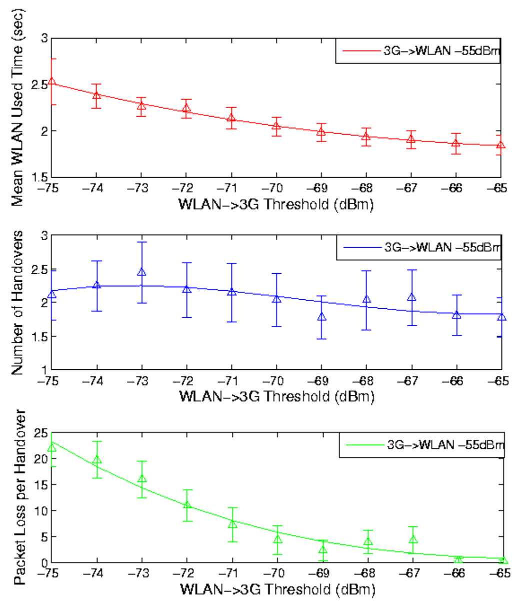

Figure 9: Study of the performance obtained for 0 packet loss

place. A 30% of the samples obtained, did not contain any handover, in contrast with the other configurations showed previously where all samples presented handovers. The plots therefore represents relative values to such conditions.

The Mean Wireless Utilization Time, shown in Figure 9, depicts a decreasing slope while the $WLAN \rightarrow 3G$ increases (in dBm). This behavior was noticed previously. The Wireless Utilization Time for a given $3G \rightarrow WLAN$ (in dBm) threshold decreases while increasing the $WLAN \rightarrow 3G$ (in dBm) threshold.

The number of handovers presents a stable shape, as the difference between the thresholds is greater than the signal variation, no ping pong effect occurrs. The absolute number of handovers is small (approximately 2 handovers) and depends on the $3G \rightarrow WLAN$ threshold. If this threshold is high (in dBm), the Mobile Node must be very near the AP to perform a handover.

The packet loss per handover decreases dramatically until the $WLAN \rightarrow 3G$ threshold reaches -70 dBm. It then tends to zero for $WLAN \rightarrow 3G = -66dBm$.

VII. Outlook and conclusions

There is a growing trend in mobile communications towards overlay networks and mobile devices with the capability of using different access technologies. In this scenario the mobile device must choose the right access technology taking into account user preferences and guaranteeing service continuity. In the short term, the combination of WLAN and 3G (UMTS) technologies is of the utmost importance.

The IEEE is working on the specification of the 802.21 standard, that defines an architecture for terminals to support handovers between heterogeneous networks in a technology independent way. The architecture is based on an intermediate layer between layer 2 and upper layers; this is the layer where handover decisions are taken. This intermediate layer interacts with upper layers and with technology dependent lower layers. On the other hand, the IEEE 802.21 draft standard does not define how the handover decisions should be made. In this paper we analyze and implement architectural issues and integrate, in a simulation environment, layer two and layer three functionalities. Within this framework an algorithm is evaluated taking into account several metrics such as WLAN utilization time while minimizing the number of handovers and packet loss.

The work presented in this paper studies, by means of simulation (using OMNET++), a typical scenario with UMTS universal coverage and islands of WLAN coverage. If WLAN coverage is available, it is preferred because of cost and bandwidth reasons. We have defined an architecture for the mobile terminal based on the IEEE 802.21 work and the use of Mobile IPv6 to manage IP mobility. Handover decisions are taken by means of two WLAN signal level thresholds, one to decide a handover from 3G to WLAN, and a different one to decide when to handover from WLAN to 3G. The algorithm for handover decision has two objectives: maximize WLAN utilization and minimize service discontinuity. In the paper we have explored the influence of the thresholds for handover decision on these parameters, namely, WLAN utilization and packet loss, taking into account the interaction with Mobile IPv6 behavior.

The results obtained allow to observe the trade-off between service continuity and WLAN utilization. The two defined thresholds proved flexible enough to manage this trade-off, allowing configurations with packet loss and high WLAN utilization, and also configurations with zero packet loss although achieving a much lower WLAN utilization. In this way, we showed that, by configuring the two thresholds, we can adapt the mobile terminal behavior, with respect to handover decisions and to user preferences. Another interesting result of the work was to see the flexibility that the IEEE 802.21 architecture showed for implementing policies for handover decisions managing the interaction with upper and lower layers.

The mobile terminal speed used in the simulation study (10 m/s) can be considered a worst case for the studied scenario (pedestrian speed or slow moving vehicles are below that speed). We are currently working on studying the behavior with lower speeds and trying to extract a general relationship between speed, signal level thresholds, and achieved WLAN utilization and packet loss. This would allow us to define algorithms for handover decision that are based on signal level thresholds and terminal speed, and how they must be configured to achieve some level of WLAN utilization and service continuity.

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