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Network controlled handovers: challenges and possibilities

T. Melia · A. de la Oliva · I. Soto · P. Serrano · R. Aguiar

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Abstract The concept of network controlled handovers is commonly used in cellular technologies. With multi-mode terminals, using layer-2 techniques, this concept can only be applied inside each technology, which impairs the full exploitation of multi-access support. We discuss a layer-3 technique able to operate across technologies, and present an analysis of the performance advantages this technique brings. In general, an increase around 25% in system usage is achievable. The paper further analyses some cell characteristics that impact on the performance improvements achievable by network controlled handovers.

T. Melia (✉)
NEC Europe Ltd, Network Laboratories, 69115 Heidelberg, Germany
e-mail: telemaco.melia@netlab.nec.de

A. de la Oliva · I. Soto · P. Serrano
Universidad Carlos III de Madrid, Madrid, Spain
e-mail: aoliva@it.uc3m.es

I. Soto
e-mail: isoto@it.uc3m.es

P. Serrano
e-mail: pablo@it.uc3m.es

R. Aguiar
Universidade de Aveiro, Aveiro, Portugal
e-mail: ruilaa@det.ua.pt

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1 Introduction

Public mobile network access is gaining increased diversity, both in terms of the types of access technologies, in terms of the diversity of the offer (with clear separation of roles between access and service providers), and in terms of the size of that offer. This diversity has been compounded by increasing number of multi-mode capable terminals (e.g. terminals equipped with WiFi, WiMax, and 3G wireless support), and of operator-provided multi-technology mobile connection software, targeting IP internetworking. Overall, this creates a complex environment, where the mobile terminal might not have enough information or even the possibility to make an intelligent handover decision (as is often the case of operator-provided software). In fact, in multi-access environments, handover decisions, and thus network selection, is not necessarily anymore based on access availability but further depends on policies and roaming arrangements at access network, access provider and service provider levels. On top of it all, this information can be dynamic: the information required for target network selection might change periodically with such a frequency that maintaining all knowledge (and intelligence) in the mobile node might not be viable anymore, especially since some of this information is only available to network elements.[1]

Current standardization activities recognize new requirements for future Mobile Operator Networks, aiming at a network-based control of mobile devices roaming across several wireless technologies. Examples are the IETF Netlmm Working Group (WG) and the IEEE 802.21 WG, currently undergoing standardization of new protocols. In this paper we focus on one particular aspect of such new trends, namely the capability of network functionalities to initiate and control mobile devices' handover procedures across heterogeneous networks. We propose and analyze the potential of network-initiated handovers (NIHO) through an extensive simulation study, highlighting scenarios and deployments where the technology significantly improve network performance. The remainder is organized as follow. We present a short state-of-art in Sect. 2, and indicate in Sect. 3 a set of features desirable in future networks in order to be able to exploit multi-access terminals. We show benefits and limitations of the NIHO approach leading to a set of recommendations for future deployment in Sects. 4 and 5. Finally Sect. 6 presents our conclusions.

2 State of the art and upcoming standards

Technology-centric mobility protocols have obvious limitations across technologies. Thus, although multiple proposals have shown increased benefits of spectrum and network usage [9,16,18], they cannot be directly used in a multiple technology environment. Layer 3 protocols are required for this environment, and in particular IP-based protocols. *IP mobility (namely Mobile IP [5])* provides Internet connectivity to mobile nodes roaming from one access router to another, regardless of the access technology supported in the router. *Mobile IP* 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 update mechanisms that reroute the traffic from the home to the visited network. To reduce handover latency and increase scalability, extensions have been developed (e.g., [7,13]). Although some of these approaches [7] may potentially support network initiation of the handover procedure, none of them takes into consideration the existence of a backend combining mobility, resource management and roaming scenarios. Previous work [2] shows the advantages of having a mobile initiated handover considering information provided by the network, in wireless LAN environments where HMIPv6 is implemented. Both implementation and simulations results are provided, however the system considers only wireless LAN, and handovers are triggered only by terminal mobility. In Ref. [12], the IP2 Mobility Management Protocol was developped to satisfy mobile operator's requirements for next-generation mobile networks. IP2MM exploits the network controlled approach instead of a terminal controlled mobility management. The main conclusion is that with this type of protocols a better performance of the network can be achieved but the paper mostly addresses the performance in mobility control and packet throughput.

Increased development efforts are currently being done in order to stratify mobility in local and global aspect, present in many IP-mobility proposals [5,7,11,13]. Local mobility *(mobility within a domain)* can be handled independently of global mobility. Local mobility mainly optimizes control signaling by reducing the need to update the home/visited network about user mobility. Examples are [6] and [14] where mobile devices are able to move across an access network by reducing to the minimum the complexity in the terminal itself. However, it should be noted that none of the mentioned approaches consider a scenario in which mobile initiated handovers (MIHO) are combined with NIHO. We argue that 4G networks will require this combination, allowing personalization in the user's terminal (network preferences) and resource usage optimization by the network. Also, the dynamism, cell coverage, and multi-technology environment is different from the traditional scenario of cellu-

[1] A good example is radio resource management, expected to be a task of major relevance in future heterogeneous wireless environments. Mechanisms for RRM exploiting these concepts have been proposed in several technologies [9,16,18] but are constrained to technology-specific mechanisms.

lar networks, thus the results of network initiated handover in those networks are not directly applicable to 4G networks. In Ref. [1] initial simulation results and implementation experiences prove the feasibility of the 4G approach covering a wide range of access technologies.

A first effort to study the heterogeneous handover problem proposing a framework to overcome the afore mentioned limitations, is currently undergoing in the IEEE 802.21 WG. The IEEE 802.21 [4] [or Media Independent Handover (MIH)] framework enables the optimization of handovers between heterogeneous IEEE 802 systems as well as between 802 and cellular systems,[2] IEEE 802.21 aims at providing the means to facilitate and improve the intelligence for handover execution. It adds a technology independent function, the MIHF, optimizing the communication between different entities, either locally (the terminal, or a network component) or remotely (between network functions and the terminal). The MIH is composed of three services: (1) the Media Independent Event Service (MIES) which provides classification, filtering and reporting of events; (2) the Media Independent Command Service (MICS) which enables local or remote high-level entities to control, manage, and send actions to lower layers; (3) The Media Independent Information Service (MIIS) which provides details on the characteristics and services available in the serving and surrounding networks. These three services allow collection and sharing of heterogeneous information for handover optimization, as well as the means to command those handovers, in a technology independent way.

The IEEE 802.21 communication reference model (Fig. 1) specifies interfaces between mobile devices and points of attachment to the network and between network nodes in the network. A MIH Point of Service (PoS) is a network MIH-enabled entity that exchanges MIH signaling with a MIH-enabled terminal providing, for instance, MIIS information services located deeper in the access network. 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 Fig. 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, thus allowing approaches as NIHO. By exploiting such technology independence, in Sect. 3 we derive a set of functionalities and associated procedures framing mobile terminal initiated handovers as well as centralized network initiated handovers for future 4G networks. We show how the upcoming standard for vertical handovers can be enhanced to support mobile operators' requirements in the context of network controlled mobility. Abstracting from technology and signaling procedures, this paper further aims at quantifying the benefit (relevant metrics are presented in Sect. 4.4) of applying network initiated handovers in environments where mobility is mostly host driven.

3 Handover framework for MIHO and NIHO

Traditional Mobile Initiated Handovers are triggered by mobile devices upon collection of events such as radio signal level degradation, application requirements or the like. MIHO mechanisms can be further improved by retrieving from the access network information [8] about available bandwidth, network load in a specific access point/access router, etc. However, we argue that disclosing such information to mobile devices is subject to access network policies and might not always be possible to provide such data. It would be desirable to gather information in the access network about load conditions (in a network-to-network relation) as well as from mobile devices (in a mobile to network relation) leading to the composition of an accurate and dynamic map that handover decision engines (located in the access network) could benefit of. Hence, NIHO via a centralized approach aims at improving network operations where required. The concept of MIHO and NIHO applies to both intra-technology case or inter-technology case, the former being potentially layer two specific, the latter leading to an IP based approach. We argue that understanding the benefit of NIHO, focusing on the intra-technology case does not affect the validity

[2] Third Generation Partnership Project (3GPP), www.3gpp.org.

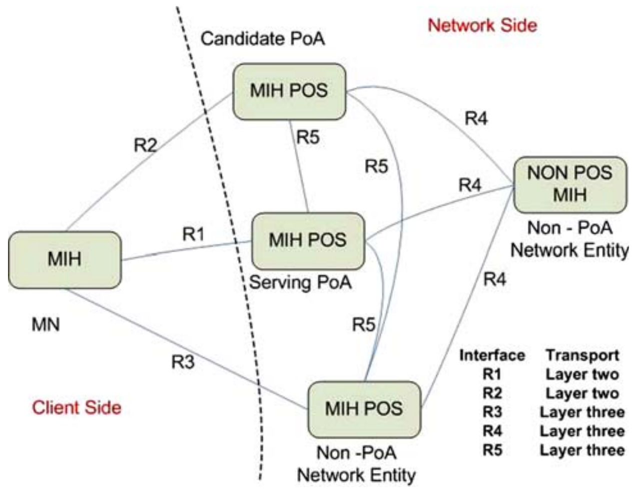


Fig. 1 IEEE 802.21 reference model

of the results. That is, without loss of generality, the simulation study focuses on the intra-technology case, providing considerations for the framework design also at layer three.

A set of functionalities and associated protocol operations are required to support, in a common framework, MIHO and NIHO. The architecture specifies modules implemented in the terminal side, in the access part of the network and in the home domain. The mobile device offers a cross layer two/layer three design for wireless/wired technology management, compounded by an intelligent module for interface selection based on several parameters spanning from layer two related information up to user preferences and context aware applications. Protocol communications between the mobile device and the access router (first layer-3 hop in the access network) allow exchange of information for neighbor discovery, handover preparation and handover execution. Handover target selection is done by combining mobility and resource management mechanisms such as admission control. That is, handovers could potentially be denied to mobile devices. To improve performance and avoid as much as possible these situations the architecture further proposes the possibility to initiate handovers from the network upon for instance load detection or conditions changed due to the availability of new access technologies.

To further show how NIHO technology can be efficiently supported in next generation mobile operator networks, modification and extensions to the ongoing IEEE 802.21 standardization effort have been proposed. Such extensions are based on the existence of a centralized entity and on the collection of relevant events from mobile devices. The proposed modifications are gathered in Ref. [17] explaining how the network configures the devices and how the intelligence triggers handover procedures. To better understand functionalities, Fig. 2 shows a high level signaling flow (for further details in [17]). The mobile node architecture recognizes the need for the abstraction layer design implemented by the MIH layer.[3] Such layer is also implemented in the network side components to provide 802.21 protocol operation exchange. The Mobility Management Entity (MME) implements the intelligence required for centralized handover decision. The novelty of the approach consist in a scalable event-driven notification system the network can leverage for detecting critical conditions either in the terminal or in the network. The proposal [17] in fact extends the current standard by adding network to network reporting capabilities. Steps 1–3 (in Fig. 2) are required for threshold configuration and event reports triggering. Since, reports might potentially trigger NIHO procedures, it is fundamental to understand how often the intelligence can be triggered. The study in Sect. 4.4 analyses several timer values emulating different timings. Steps 5 and 6 are required for load evaluation and to collect input parameters for the handover decision engine. Step 7 is evaluated upon the algorithm

[3] An optimized implementation for cellular/WLAN handover has been proposed in Ref. [10] and [3].

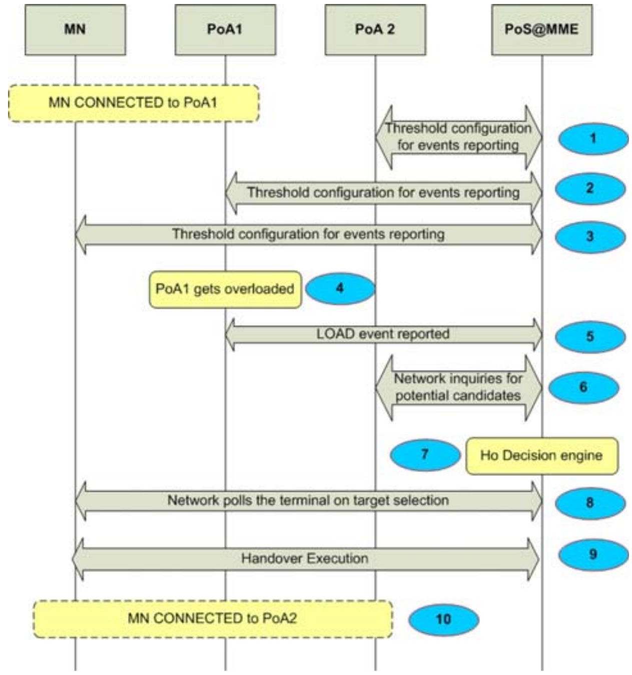


Fig. 2 High level procedures

selected for NIHO triggering (in the current work, the algorithm selected is shown in pseudocode 2, Sect. 4.3). Finally steps 8 and 9 evaluates if handover is possible from the terminal perspective. Step 10 concludes the handover procedure.

4 NIHO versus MIHO

Based on the definition of NIHO and MIHO in the previous sections we present in the following a simulation study by comparing network performance when MIHO and NIHO techniques are applied. NIHO provides improved resource allocation when heterogeneous wireless/wired access technologies are deployed. We aim at quantifying the benefits of this approach and at identifying conditions that affect the relevance of NIHO support. It should be noted that NIHO-related signaling performance per itself is not addressed in this work. Nevertheless, the simulation model emulates conceptualized versions of the protocol developed in Ref. [17]. Although the scenarios and the model used are mono-technology and simple, just showing the benefits of a combined solution of NIHO + MIHO is worthy, since this indicates a lower bound to the benefits achievable using this paradigm.

4.1 Simulation setup

Although this work is centered in inter-technology handovers, processed at IP-level, the design of such a test network, considering multiple technologies (such as WiFi, 3GPP, etc.), with different cell sizes, present simulation problems in terms of channel propagation models, layer-2 protocols, and overall cell interplay. For simulation purposes, we decided to simplify our model, and as such was developed a special-purpose simulator in C++, considering a single technology, and regular cell placements. Thus, the reference simulation scenario is composed by *six access points* deployed in a hexagonal grid. It should be noted that even if we use the term Access Points, the simulator does not contain technology dependent definitions and the scenario presented is valid for any technology mix (provided path loss models are consistent). During the simulations two studies have been performed:

1. First, simulations have been performed in scenarios where only MIHO is used. This provides reference results for the scenarios.

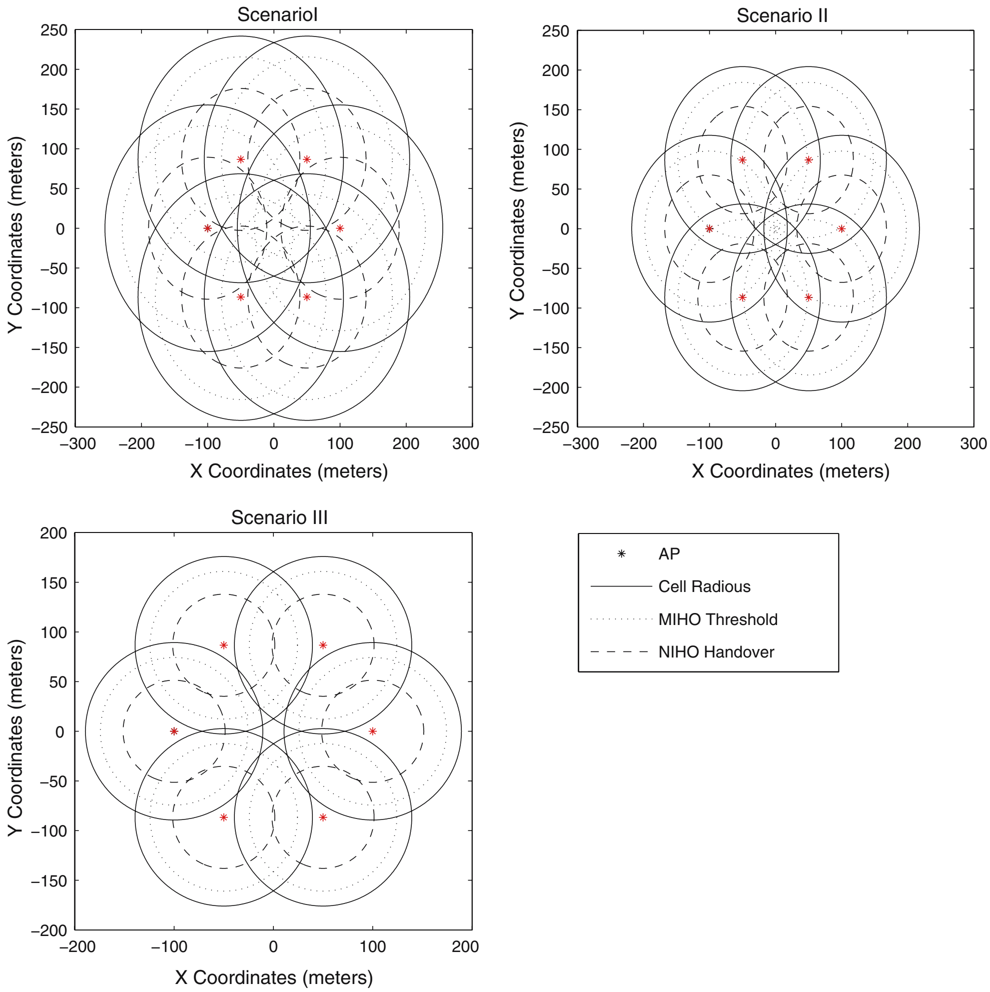


Fig. 3 From *left* to *right*: overlapping Scenario I, overlapping Scenario II, overlapping Scenario III

2. In a second stage, the simulations combine both MIHO and NIHO techniques, which are then compared with the previous reference results.

In both simulations, Mobile Nodes appear and disappear (corresponding to service calls) according to a Poisson process, with variable frequency (variable system loads). The lifetime of the Mobile Node follows an exponential law with mean 180 s, but if no service can be provided (that is, the service call is rejected) the Mobile Node is immediately removed from the system. To cover different types of mobility, the speed of the Mobile Nodes has been selected randomly between 2 and 5 m/s. The Random Way-Point mobility model has been selected for both cases, MIHO and NIHO. During a simulation if the Mobile Node reaches a scenario boundary, the mobility pattern is altered and a new destination target is computed. The maximum number of users per Access Point is set to 10. Results are averaged for 30 simulation runs, taking confidence intervals of the 95% in all the data presented in this study. The Path Loss model used in the simulator is based on the Omnet++ Wireless LAN Path loss model, expressed by Eq. 1.

$$Losses(\mathrm{dB}m) = 40 - 10 * \rho L \exp * \log(\mathrm{distance})$$
$$\rho L \exp = 2.5 \tag{1}$$

4.1.1 Studied scenarios

To study the impact of wireless overlapping regions on the NIHO performance improvement, three different scenarios were evaluated. Figure 3 shows

Table 1 Threshold values for the different scenarios

Threshold	Scenario I	Scenario II	Scenario III
Sensitivity	−90 dBm	−87 dBm	−84 dBm
MIHO	−88 dBm	−85 dBm	−81 dBm
NIHO	−84 dBm	−81 dBm	−78 dBm

the three scenarios. The difference between them is the wireless coverage area. Each of the Access Points in Fig. 3 shows three different circles: (from outside to inside) sensitivity, MIHO and NIHO thresholds. This set of thresholds is needed since in our analysis we consider very simple algorithms for triggering the handover, based on the load of the Access Points and received signal levels. The algorithms used for NIHO and MIHO and the relation with the thresholds presented above will be explained in Sects. 4.2 and 4.3. Threshold values are displayed in Table 1. These values were selected in order to evaluate all possible cases of overlapping areas for NIHO, leading to scenarios with different characteristics.

Scenario I models a system with a high number of overlapping areas. Due to this, the results derived from the execution of MIHO should be quite near to the optimal behavior of the system, and probably will not leave much room for system optimization, without complex management algorithms. Scenario II shows a system with an average degree of overlapping areas. In this system, the introduction of NIHO should outperform MIHO-only performance. This is the expected usual scenario. Scenario III corresponds to a (atypical) poor overlapped scenario, where the Access Points do not present an overlapping enough degree to enable system wide optimization. In this case the nodes can only be moved between adjacent Access Points. Moreover, the NIHO overlapping thresholds do not cover the center of the scenario providing a "hole" in the grid that may produce strange behaviors. We will show that even in the worst case scenarios the usage of NIHO will still be advantageous, improving both Mobile Node service probabilities and overall system performance.

4.2 Mobile initiated handover algorithm

For the MIHO study, the Mobile Nodes perform a handover when the MIHO threshold is crossed. In this case the Mobile Node evaluates both the signal and load conditions of every neighboring Access Point. The handover will be performed to the Access Point with the best signal level providing required capacity is available. Notice that we are considering the best case of MIHO, i.e. a MIHO that is performed not only based on information available in the mobile node but is also aided information provided by the network. The information needed to evaluate the algorithm presented, such as the Access Point's load, is expected to be provided by a framework such as IEEE 802.21. Pseudocode 1 shows the algorithm the Mobile Node executes when reaches a MIHO threshold. A similar procedure is followed when a new Mobile Node is created in the system.

```
for all AP seen by this Mobile Node{
    if load of this AP is lower than MAXLOAD{
        add AP to the Available APs list
    }
} get AP with best signal from the list of
available APs
do handover to the AP with best signal
```

Pseudocode 1: MIHO Algorithm

4.3 Network initiated handover algorithm

When the combined solution of MIHO and NIHO is applied, the algorithm explained in Sect. 4.2 is still applied by the Mobile Node. However, now the network also can move target Mobile Nodes each time a timer expires (corresponding to an optimization run in many RRM proposals [9,16, 18]). Mobile Nodes reallocation can be potentially implemented according to more complex or simple algorithms. In our case, when the timer expires, all the Mobile Nodes that are inside a NIHO threshold of a target Access Point are moved to that Access Point, provided the load is less than the load of the current Access Point the Mobile Node is attached to. In case of having several overlapping NIHO thresholds, the one with best signal level is selected. Note that this NIHO algorithm is quite simple, and results presented are probably a lower bound on overall system performance improvement. The timer on which NIHO depends is one of the critical variables studied during the simulations. Pseudocode 2 shows the algorithm executed each time the timer expires (emulating events report triggering).

```
for all Mobile Nodes{
    get the list of APs which this MN is
    inside their NIHO threshold for all
    APs in the list{
        if the load of this AP is lower than the
        load of the current AP
        the MN is connected to{
            add AP to the Available APs list
        }
    }
    get the AP with best signal from the list
    of available APs
    do handover to the AP with best signal
}
```

Pseudocode 2: NIHO Algorithm

4.4 Metrics

The performance metrics analyzed are the following:

1. Mean number of users in the system.
2. Probability of Rejection at first connection.
3. Probability of Rejection while performing handover.
4. Decrement in the number of Handovers (Mobile Initiated) between MIHO and MIHO plus NIHO.
5. Ratio between Mobile Initiated Handovers and Network Initiated Handovers in the MIHO plus NIHO case.

For each of these metrics, a study on the effect of the degree of overlapping, system load, and the effect of the timer duration has been performed. It should also be noted that all the mobile nodes in the system have equal priorities and similar profiles, i.e., no gold/silver/bronze users are considered, and are generating the same type of traffic. As a general consideration we have to note that, for completeness, the system is also analyzed in saturation conditions. When the system (all the cells) operates close to 100% of the total load, resource optimization techniques (NIHO) are not expected to provide additional benefit, but simulations have been run nevertheless.

4.5 Mean number of users in the system

Figure 4 shows the mean number of users in the system for the three different scenarios depicted in Fig. 3. The system designed closely follows an M/M/1 system, with differences due to the removal of the users when they are rejected. The maximum number of users depends on the degree of overlapping in the system. In a system with a 100% of overlapping between all the Access Points the maximum number of users in the system is equal to 60. In fact, by decreasing area overlap, the mean number of users decreases as well (since users' mobility becomes constrained). Figure 4 shows how the use of a combined solution of MIHO and NIHO produces an increment of the number of users that can be supported by the system. The maximum difference between MIHO and MIHO + NIHO appears in the Scenario II (Fig. 3) and corresponds to just 6%. Although the maximum performance improvement between MIHO and MIHO + NIHO appears for the usual Scenario II case, the maximum number of users in absolute values is reached for the Scenario I. The effect of changing the overlapping area corresponds to a flattening of the curve in Fig. 4, showing that the maximum number of users is reached with lower frequencies. The maximum number of users reached for the different overlapping areas decreases with the overlapping.

Figure 5 shows the effect of increasing the timer which triggers the execution of NIHO. Decreasing the timer does not affect the maximum number of users although the utilization of the system is slightly higher when shorter values for the timer are used. This is due to the fact that, in the case of small inter-arrival times, the system with shorter timers (e.g., more constant optimization updates) supports more users.

4.6 Rejection probability in first connection and during a handover

Figure 6 shows both the Probability of Rejection at first connection (Fig. 6a) and the Probability of Rejection during a handover (Fig. 6b) for the scenarios depicted in Fig. 3. The Probability of Rejection at first connection represents the probability of a Mobile Node not finding a free Access Point when arriving at the system. As can be seen, the combined solution MIHO + NIHO decreases this probability when the load starts to reach values higher than 60% of the maximum load in the

Fig. 4 Mean number of users

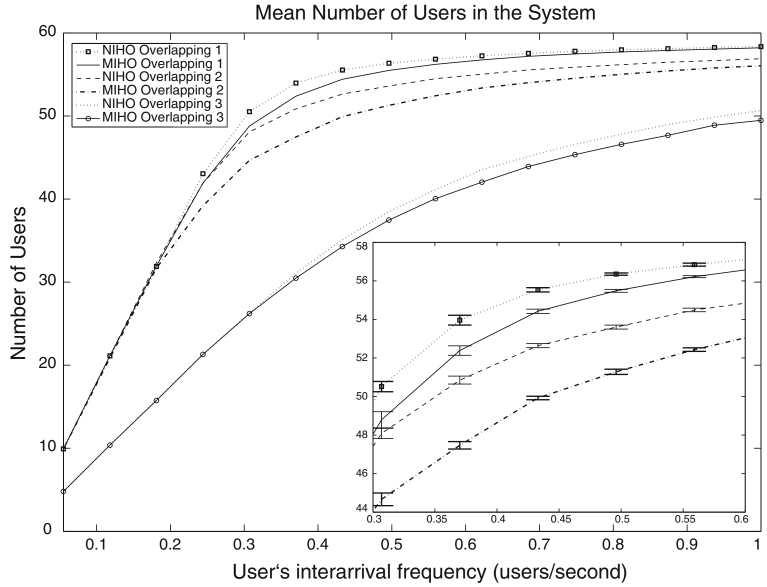
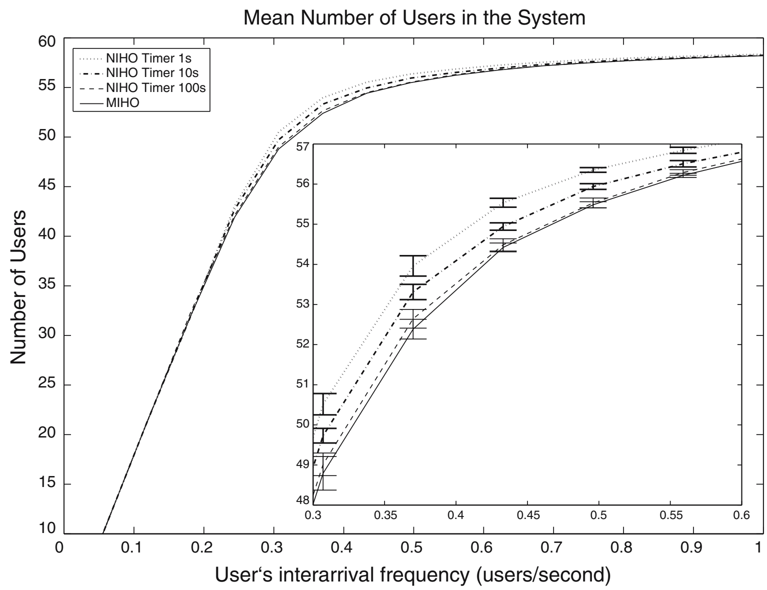


Fig. 5 Number of users (varying timers)



system. For instance, for the second scenario, heavily loaded (90%), this probability is decreased by 50%. When area overlap is decreased, similar behavior is noticed. The graphs tends to smooth, achieving the form of the graph corresponding to the Scenario III as system becomes saturated, and no more Access Points are available. The *Probability of Rejection during a Handover* represents the probability of the handover being rejected due to admission control when the Mobile Node is performing a Handover. In this figure we can see how the probability decreases always when MIHO + NIHO is used, and the difference is appreciable for loads higher than 60%. In the case of load 90% the second scenario is decreasing the rejection probability in 64%. The effect of the overlapping on the Probability of rejection during a handover, is to increase the blocking probability while decreasing the overlapping. This is due to the fact that as less overlapping exists in the system, the load balance mechanism works worse, so the Access Points have higher loads and the blocking

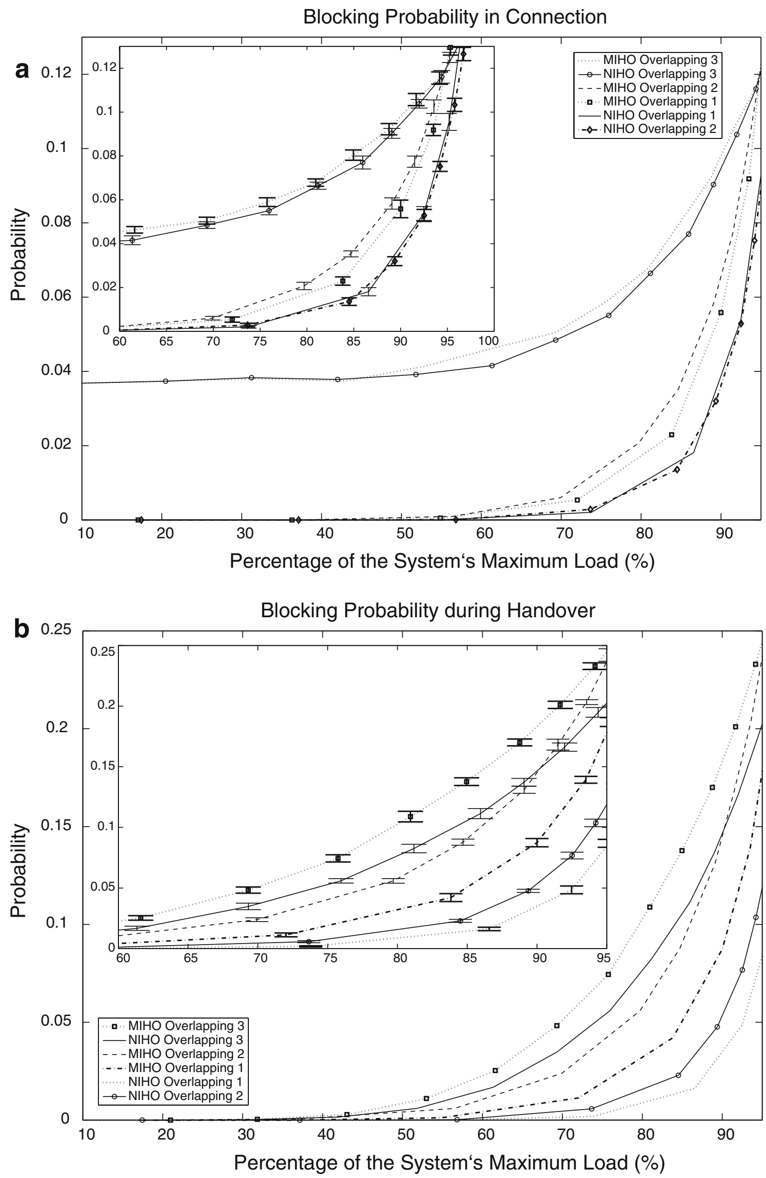


Fig. 6 (**a**) Probability of Rejection in first connection. (**b**) Probability of Rejection during a Handover

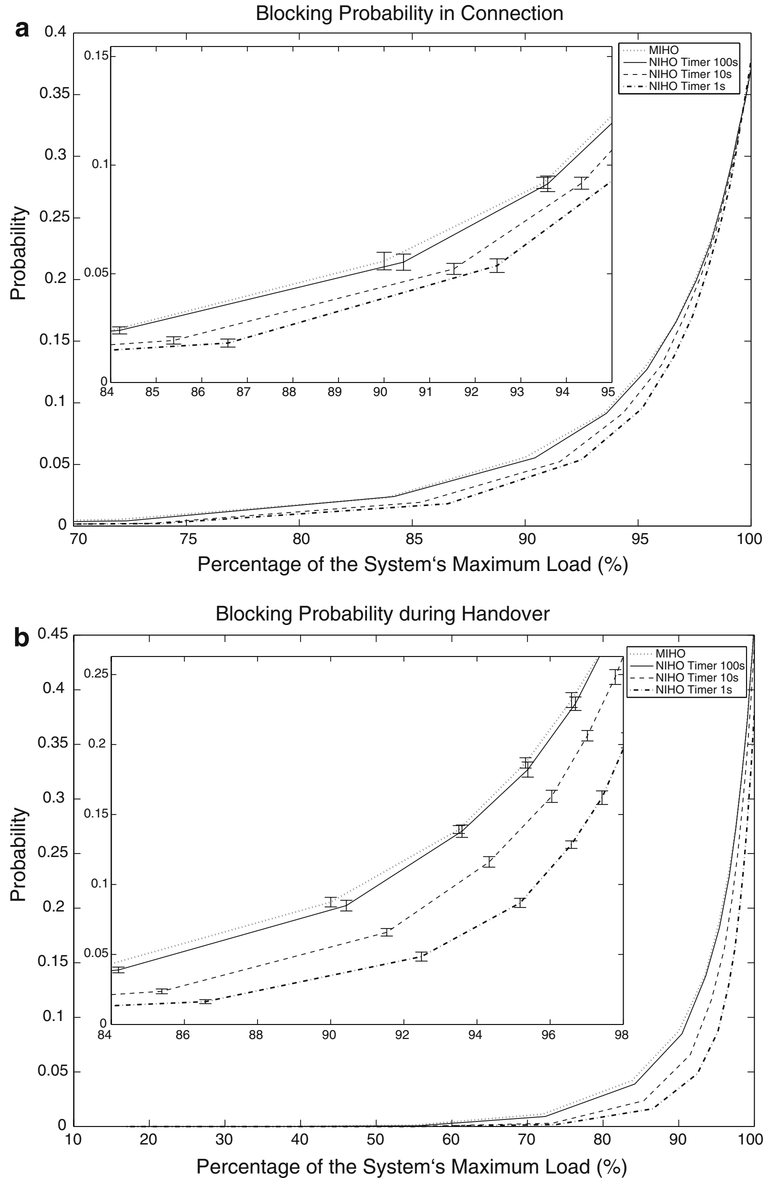
probability in connection increases. The same effect can be observed in the *Blocking Probability during a Handover*. It is worth to notice the important reduction in the probabilities achieved using MIHO + NIHO, although the number of users is increased by a 6%, the probability of rejection in connection is decreased in a 50%. Being this decrement in the probability and increment in the number of users, very important from the operators' point of view.

Figure 7 shows the effect on the Blocking Probabilities at first connection (Fig. 7a) and during a handover (Fig. 7b) for variable NIHO timer values. As can be seen, the effect of increasing this timer corresponds to increase the blocking probability in both situations, bordering the MIHO behavior when the timer is very long (100 s).

4.7 Number of handover operations

Figure 8 shows the metrics related with the number of handovers performed. These two graphs show the NIHO impact from the perspective of

Fig. 7 (**a**) Probability of Rejection in first connection (varying timers). (**b**) Probability of Rejection during a Handover (varying timers)



the user and of the network. The decrement in the number of Handovers shows how the Network Initiated Handovers are decreasing the number of Mobile Initiated Handovers due to mobility. This decrement shows that the NIHO algorithm used always improves the receiving situation of the Mobile Node, by moving it to a position where the probability of doing another handover due to signal conditions is lower or equal than in the previous situation. As in the previous graphs, the percentage of decrease depends on the load of the system and as it increases the performance of the combined solution NIHO plus MIHO decreases. It is worth to notice the important reduction in the number of handovers due to mobility that occurs for the first scenario, where up to 28% of reduction is achieved. As the overlapping decreases the reduction in the number of handovers also decreases. This is due to the fact that there is less area where NIHO is usefully exploited. As the area is smaller, the effect of NIHO is diminished providing only movement between adjacent Access Points. In the

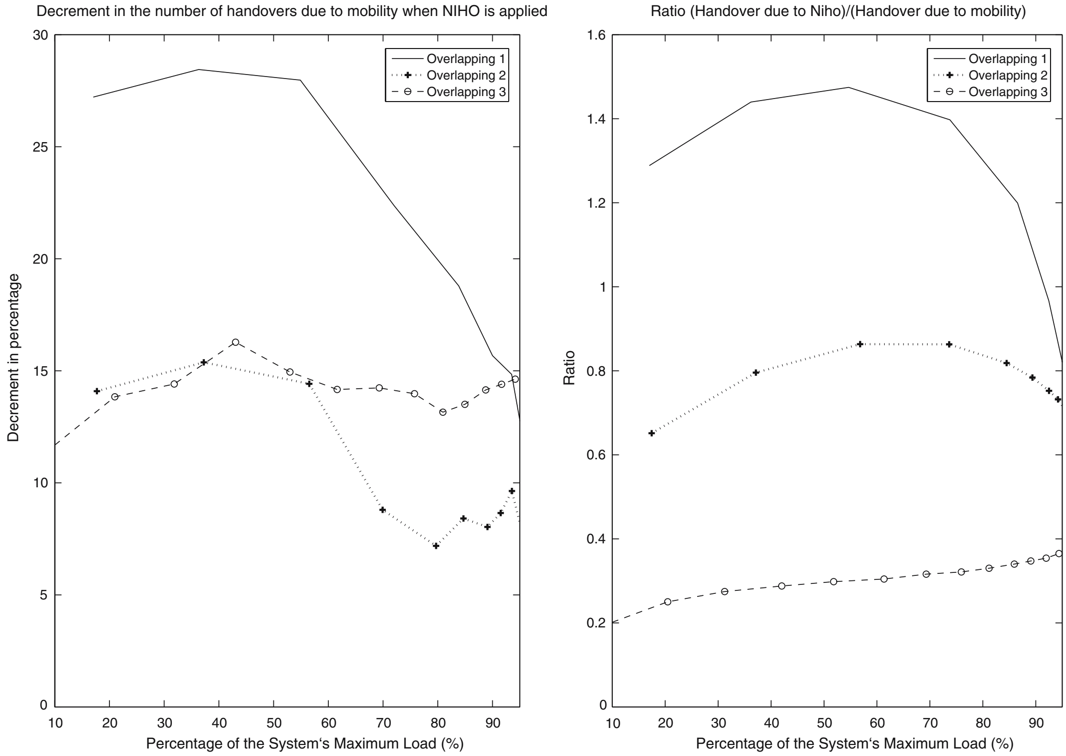


Fig. 8 From *left* to *right*: decrement in the number of handovers (Mobile Initiated) between Miho and Miho + Niho, Ratio between Mobile Initiated Handovers and Network Initiated Handovers in the Miho + Niho case

limit, in the case of the third scenario, the decrease in the number of handovers is roughly constant, and to some point independent of the load in the system.

The Ratio between Mobile Initiated Handovers and Network Initiated Handovers presents the relative cost of applying NIHO to the system. It represents how much the total number of handovers is increased when NIHO is applied. As can be seen, for the Scenario I the peak is situated in 1.5, which means that the total number of handovers in the reference scenario is multiplied by this quantity while using NIHO. As in all the previous graphs, as the system becomes saturated this ratio decreases because the possibilities of moving a node decreases. As the overlapping area decreases this ratio decreases because Network Initiated Handovers are performed with greater difficulty. Figure 9 presents the effect in the metrics related with the number of handovers when the timer is increased. As expected the decrease in the number of Mobile Initiated Handovers is reduced while the timer is larger. This effect is similar in behavior as when the overlapping is decreased. As the timer is larger the number of Network Initiated Handovers diminishes and the Mobile Nodes are situated in the area of influence of NIHO less frequently. The Ratio between Mobile Initiated Handovers and Network Initiated Handovers presents the same effect decreasing with the load of the system and with the duration of the timer. Through this results we argue that the use of NIHO created an interchange between handovers performed by the terminal and handovers performed by the network. When the NIHO effect is greater the number of handovers due to mobility decreases and the number of handovers performed by the network increases. Although it could seem that this interchange does not provide any benefit to the provider, is worth to notice that the fact that the network is controlling the handover gives several benefits for QoS and load balance that cannot be achieved with mobile initiated handover mechanisms.

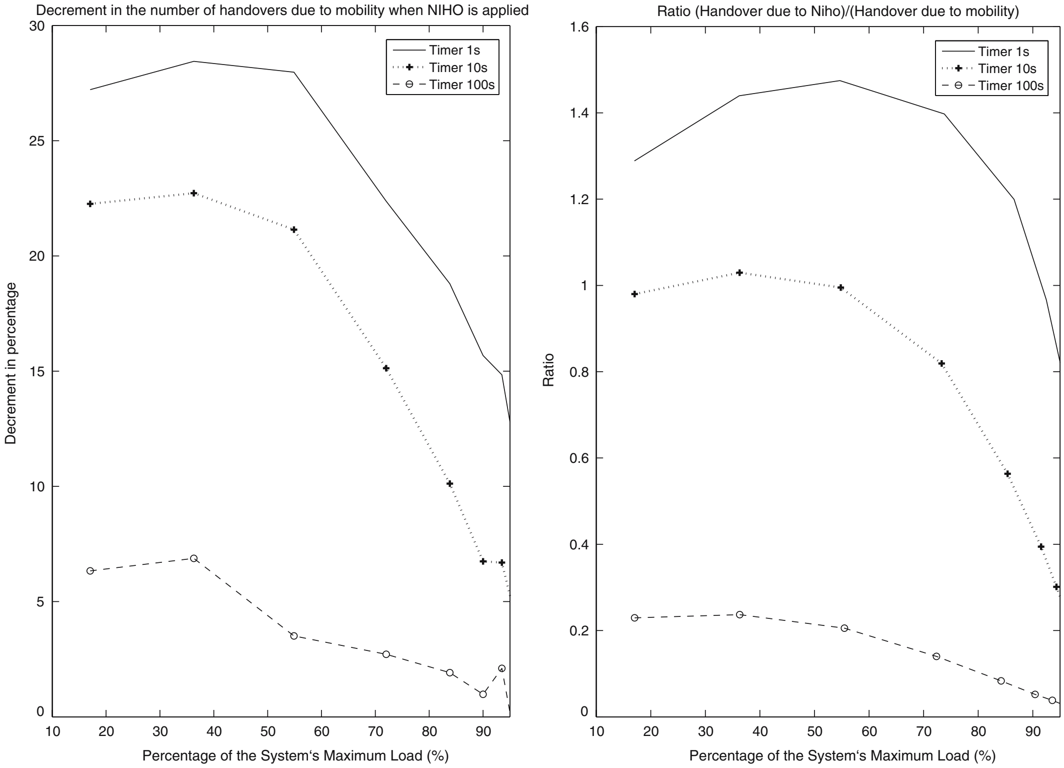


Fig. 9 From *left* to *right*: decrement in the number of handovers (Mobile Initiated) between Miho and Miho + Niho, Ratio between Mobile Initiated Handovers and Network Initiated Handovers in the Miho + Niho case (varying timers)

5 Increased advantage of using NIHO in asymmetrical scenarios

Last section presented simulation results considering evenly distributed mobile nodes over a limited region with different wireless overlapping cells. The mobile nodes are uniformly distributed and are dropped from the network as soon as the terminal is denied connection, either because of rejection during handover or because of rejection at first connection. These are reasonable assumptions when studying the performance of the network focusing on the blocking probability values of the system under evaluation. However, to present the full potential exploitation of the NIHO technology we have to introduce some more specific cases where distribution of the nodes is not uniform. In fact, this is a common situation in some scenarios where physical conditions create concentrations of users (e.g., airports). Another situation with the type of asymmetrical distributions in which NIHO can provide increased benefit is the multi-technology case, where the asymmetry is created by the different characteristics of the technologies.

The new simulation scenario developed considers mobile nodes generated with higher probability in the same region, thus leading to an overload of certain access points. In this new scenario, the overlapping regions allow the network to move terminals around, aiming at redistributing the load and increasing the network capacity. It should be noted that without NIHO technology the network would be overloaded only in some portions and the rejection probability (mainly because of admission control) would increase beyond acceptable values. The necessary condition to avoid this is a good planning of the overlapping area across technologies. If we consider a single wireless technology, this overlapping is strictly related to physical channels availability, whereas in case of heterogeneous wireless technologies the cell overlapping planning can become quite complex. In both cases the overlap percentage should be sufficient to move terminals to another cell while keeping (if not improving) similar link characteristics. This can be implied by the results in the previous section.

To check experimentally that NIHO achieves an increased performance benefit in situations with asymmetrical distribution of nodes, we analyze the following scenario. We have a set of three access points with sufficient overlapping area. Each access point is able to accept at the maximum ten mobile nodes (admission control). To simulate a more challenging environment we let mobile nodes always being generated in the middle access point area. Movement is allowed within the overlapping area, never leading to disconnected terminals. This is a realistic scenario, for instance, in airports where people getting off at the gate switch on their mobile devices while leaving the plane. In such case mobile users generate extra load in the middle access point tending to saturate the system and increasing the rejection rate for people newly connecting to the network. It would be desirable to have intelligence implemented in the network able to react upon a configured threshold and instructing mobile nodes to connect to alternative access points. The scenario provides insightful results on how overlapping should be configured to allow network intelligence to perform NIHO, even across multiple technologies.

The decision algorithm implemented is as follow. Besides the timer based control, the algorithm (pseudocode 2) is also triggered when the NIHO LOAD THRESHOLD is crossed (set to five in the simulations). This simple but efficient mechanism shows the effects of the NIHO technique on the previously introduced metrics.

The results are summarized in Table 2. The first column ("λ") indicates the user interarrival frequency used to increase the load in the network following a Poisson law (mean connectivity to the network is fixed to 180 s). The second column, ("NumberUsers") indicates how much in percentage the number of users is increased in the same scenario when NIHO + MIHO is applied compared to pure MIHO only. The third and the fourth columns ("RejectHOProb" and "RejectConnProb") indicate the decrement (in percentage), respectively of the reject probability during handover and the reject probability at connection. The fifth

Table 2 Metrics values for different network loads (lambda)

λ	Number Users	Reject HOProb	Reject ConnProb	Number HO	Load
0.04	9.53%	83.2%	86.78%	14.16%	50.52%
0.06	7.64%	85.57%	85.6%	16.57%	63.9%
0.12	24.9%	64.73%	55.04%	84.8%	84.7%
0.31	30.52%	28.12%	44.8%	14.93%	92%
1	31.15%	9%	21.8%	56.13%	100%

column ("NumberHO") represent the percentage of reduced number of handovers triggered for mobility reasons. Finally the last column ("Load") represents the load of the system for the lambda used.

The results show that the total increment of users, when NIHO is applied, may reach 30%. Probability of rejection during handover and at connection time is reduced, confirming the tendency already presented in the previous section. It is worth to notice how using NIHO + MIHO the number of users is incremented while the probabilities of rejection during a handover and at connection are reduced, showing a clear benefit for operators. We argue these results clearly show the benefit of NIHO techniques, being this kind of scenarios likely to happen in open environments such as airports, shopping malls or public hotspots. Mobile operators have therefore the possibility to better control terminals in the network and potentially increasing the number of users consuming services. That is, the technology opens new business and revenue opportunities for mobile/fixed operators.

6 Conclusions

In this paper we presented an exhaustive analysis on challenges and possibilities of network controlled handovers and their combination with more traditional types of mobility. Starting from current trends both in the research community [15] and standardization bodies [4,14], we derive motivations and scenarios where network controlled handovers apply. Through an extensive simulation study we present insightful results on the advantage of applying such technology in future all IP networks *networks, including some basic recommendations on deployment aspects for improved performance.* We argue future mobile operators, aiming at the delivery of end to end seamless services across heterogeneous wireless/wired access technologies, will benefit from the analysis of this framework. It should be noted that the study focuses on the conceptual analysis of network initiated handovers in IP environments abstracting from technology specific radio resource management mechanisms. As current and future work we are undergoing a thoroughly study on the implementation of network controlled handover in the IEEE 802.21 framework (see [17]).

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Telemaco Melia received his Informatics Engineering degree in 2002 from the Polytechnic of Turin, Italy. He did his master thesis at NL-E in Heidelberg on QoS and VoIP. In June 2002 he joined the Mobile Internet Group of NEC Europe Ltd. in Heidelberg, Germany as Software Engineer. He worked on IPv6 based Mobile Communication within the EU IST Moby Dick Project. He is currently working on mobility architecture issues in the EU IST Daidalos project. His main research areas are IP mobility support across heterogeneous networks and resource optimization control, closely following standardization bodies such as IEEE and IETF. He is author of several publications in international conferences and he is currently employed as Research Staff Member.

Antonio de la Oliva received the Telecommunication Engineering degree from the Universidad Carlos III de Madrid, Madrid, Spain, in 2004. He is currently working towards the Ph.D. degree in the Telematics Department, Universidad Carlos III de Madrid, where he has been working as a Research and Teaching Assistant of Telematic Engineering since 2004. He is currently involved in several European projects such as EU IST Daidalos and EU IST OneLab.

Ignacio Soto received a telecommunication engineering degree in 1993, and a Ph.D. in telecommunications in 2000, both from the University of Vigo, Spain. He was a research and teaching assistant in telematics engineering at the University of Valladolid from 1993 to 1999. In 1999 he joined University Carlos III of Madrid, where he has been an associate professor since 2001. His research activities focus on mobility support in packet networks and heterogeneous wireless access networks.

Pablo Serrano received a MSc degree in Telecommunications from the Universidad Carlos III de Madrid in 2002, and a PhD degree from the same university in 2006. Since 2002 he is a lecturer at the Telematics Department of the same university. His current research interests are performance evaluation and resource allocation ov WLAN networks.

Rui L Aguiar concluded his PhD at the University of Aveiro, Portugal, in 2001. He is currently a professor at the Universidade de Aveiro and a researcher at Instituto de Telecomunicações, where he is leading a group on heterogenous communications. He has published about 200 papers in national and international Journals and conferences in telecommunications systems and networks. He has taken key technical coordination responsabilities in several national and European projects and has been active in the technical committee of several conferences. He is currently the TPC Co-Chair of ISCC'07. His current main interests lie in communication systems, focusing especially in wireless networks evolution.