

# Co-Simulation of ns-2 and SPHERE for Media Independent Handovers

B.W.M. Kuipers<sup>1</sup>, S. Sargento<sup>2</sup>, J.F. Monserat<sup>3</sup>, J. Cabrejas<sup>3</sup>, P. Chaparro<sup>3</sup>, H.D.C. Pires<sup>2</sup>,  
J.M. Soares<sup>2</sup>, P.M. Neves<sup>2</sup>, M.S. Nunes<sup>1</sup>

<sup>1</sup>INESC-ID/Instituto Superior Técnico/Technical University of Lisbon  
Rua Alves Redol 9,  
1000-029 Lisbon, Portugal.  
martijn.kuipers@inesc-id.pt,  
mario.nunes@inesc-id.pt

<sup>2</sup>IT-Aveiro/Universidade de Aveiro  
Campus Universitário de Santiago,  
3810-193 Aveiro, Portugal.  
susana@au.pt, hugo.dc.pires@ua.pt,  
joao-m-soares@ptinovacao.pt,  
pedro-m-neves@ptinovacao.pt

<sup>3</sup>ITEAM Research Institute,  
Polytechnic University of Valencia,  
Valencia, Spain.  
e-mail: jomondel@iteam.upv.es,  
pedcha1@iteam.upv.es,  
jorcabe@iteam.upv.es

## ABSTRACT

This paper describes a co-simulation implementation of ns-2 and SPHERE. These simulators complement each other by providing support for a group of layers of the OSI communication model. In particular, the SPHERE simulator is responsible for the simulation of lower layers (link layer and physical layer), while the ns-2 simulator provides support for the simulation of the upper layers (network layer, transport layer and application layer). Each simulator has an action plane within the process of co-simulation. The aim of the co-simulation is to simulate heterogeneous handovers between LTE, WiMAX, WiFi and/or UMTS. In order to allow for media independent handovers, our implementation is based on an extension of the base IEEE 802.21 standard provided by NIST. This extension consists on the support of IEEE 802.21 entities on the network side, and on the integration between the IEEE 802.21 framework and the radio access technologies. In the case of LTE integration, this one needed to be provided through the SPHERE framework. From the same simulator, new events such as "link down" and "link up" needed to be implemented. The paper shows how the IEEE 802.21 was successfully used as bases for the integration of the ns-2 and SPHERE simulators. As expected when using co-simulation for different domains, e.g., network and physical layer, the simulation-time is largely dependent on the lowest layer in the stack. This layer usually has the smallest time-resolution and hence will require more processing resources per simulated second.

## Categories and Subject Descriptors

D.4.8 [Performance]: Simulation

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. To copy otherwise, to republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee.  
Simutools 2012, March 19-23, Desenzano del Garda, Italy  
Copyright © 2012 ICST 978-1-936968-47-3  
DOI 10.4108/icst.simutools.2012.247742

## General Terms

Algorithms, Performance, Experimentation, Verification.

## Keywords

Co-Simulation, IEEE 802.21, handovers, ns-2, SPHERE

## 1. INTRODUCTION

With commercial third generation (3G) deployments well on their way, the research community has shifted its attention towards beyond 3G (B3G) and fourth generation (4G) systems. There is a strong research consensus that B3G or 4G systems will be characterized by new Radio Access Technologies (RATs), and their integration and joint management, including current 2G/3G/3.5G cellular networks, Wireless LAN (WLAN), broadcasting systems and any potential new technology like Long Term Evolution (LTE) and IEEE 802.16m. In this context, an important challenge in the path towards 4G heterogeneous wireless systems is to guarantee the interoperability and efficient management of the different RATs with the aim to guarantee the required Quality of Service (QoS) and increase capacity.

The increasing complexity of current and future mobile wireless technologies requires the implementation of adequate platforms to evaluate and optimize their performance. Before considering a prototype or full-scale deployment, the use of simulation platforms is becoming increasingly common within the research community due to its cost/benefit ratio. However, it is important that to conduct meaningful and appropriate studies, such simulation platforms implement accurately the entities and processes under evaluation. The implementation of such advanced simulation tools has become a very challenging task when investigating Common Radio Resource Management (CRRM) techniques since different RATs need to be simultaneously emulated in a single platform. Also, the increasing complexity of mobile and wireless communication systems increases the difficulty of studying the performance of new techniques through analytical models. In fact, analytical studies usually require many simplifications and approximations that limit the accuracy and reliability of the obtained results. Therefore complex simulation tools are preferred EVEREST [1] (considers a GERAN-UMTS-WLAN scenario) and WHYNET [2] (wireless hybrid network

testbed to assess cross-layer interactions in heterogeneous wireless systems, focusing on sensor and mesh networks), are good examples where complex simulations frameworks have been developed.

Projects such as PlanetLab [3] and GENI [4] offer a testbed, but those are focusing on protocols and services, to create the Next Generation Internet. Panlab [5], the European counterpart of PlanetLab, offers a distributed testbed/simulation platform. Rather than developing new models, simulations can be run on existing simulators offered by any of the partners. This does not mean that all the simulators have to be located at the same network domain. Indeed, having some simulators running at a foreign system is possible, in that case the global performance could be degraded because of the additional delay due to network communication.

The approach followed in this framework is similar to the one presented in [20], where the authors interconnect a system level simulator with an OFDM physical layer simulator. The SPHERE simulator is capable of simulating various wireless technologies in the same simulator, taking into account inter system interference.

The aim of the Distributed Infrastructure for Simulations (DINASTI) is to enable a common network and radio simulation platform for heterogeneous wireless systems. The platform provides a framework to allow inter-communication between advanced system level simulators, such as ns-2 [6], ns-3 [7] and SPHERE [8]. The framework allows the use of all these simulators as only one entity, establishing internal communications to maintain every simulator aware about the global simulation process. The implementation uses existing IEEE 802.21 signals to synchronize the simulators.

This framework was created to allow the various simulation models developed by the different partners to be simulated together. In this system the physical layer of, amongst others, LTE and HSDPA, are incorporated in a system-level simulation in ns-2. Although other simulators could be added, at the moment the framework allows ns-2 and SPHERE to simulate together, since these are the simulators the different partners were actively working on.

This paper is structured as follows; Section 2 gives an introduction to the used simulators, i.e., ns-2 and SPHERE. The distributed design model, based on IEEE 802.21 is described in Section 3. Section 4 shows the message handling of a handover scenario in co-simulation. Simulation results are shown in Section 5 and conclusions are drawn in Section 6.

## 2. About the Simulators

### 2.1 ns-2

ns-2, with its IEEE 802.11 support, is a widely utilized simulation tool for wireless communications researchers, which has become the de facto standard for the simulation of packet-switched networks. Specifically, more and more published network studies and investigations take ns-2 as their evaluation tool to verify their work. The ns-2 is roughly composed of various traffic models, transport-layer protocols, network-layer protocols, medium access control (MAC) layer protocols, and more. These components enable ns-2 to simulate different types of networks and their topologies. Researchers can benefit from these preliminary tests on their investigation and find out the drawbacks of their new design in the early stage efficiently.

## 2.2 SPHERE

SPHERE (Simulation Platform for Heterogeneous wireless systems) is an ambitious and scalable radio simulation platform for heterogeneous wireless systems developed by the Polytechnic University of Valencia [9]. The platform currently integrates five advanced system level simulators, emulating the GPRS, EDGE, HSDPA, WLAN and LTE Radio Access Technologies (RATs). SPHERE is a unique simulation platform that emulates all five RATs in parallel and at the packet level, which enables an accurate evaluation of the final user perceived QoS through the implementation of novel CRRM and RRM mechanisms. The radio interface specifications of these five technologies have been faithfully implemented in the SPHERE simulation platform, which works with a high time resolution (in the order of some milliseconds) [10][11]. This modeling approach validates the capability of the SPHERE simulation platform to dynamically and precisely evaluate the performance of RRM/CRRM techniques. The platform has been developed following a modular and scalable design, which guarantees an easy adaptation of the platform configuration to specific requirements, and allows the rapid integration of new functionalities.

Figure 1 shows the scenario modeled by the SPHERE platform, which includes the GPRS, EDGE, HSDPA, WLAN and LTE radio interfaces. As shown in Fig. 1, the SPHERE platform does not only model the radio interface of the five technologies but also implements various RAT specific RRM features and a centralized CRRM entity. This entity directly collects specific RAT information (e.g., load, channel quality conditions, etc) and interacts with the RRM entities implemented at each RAT.

The logical structure of the SPHERE simulation platform, which is a discrete-event system level simulator concentrated on the downlink performance, is also shown in Figure 2. This figure depicts the modular design of the platform, presenting its components, as well as their features and interactions.

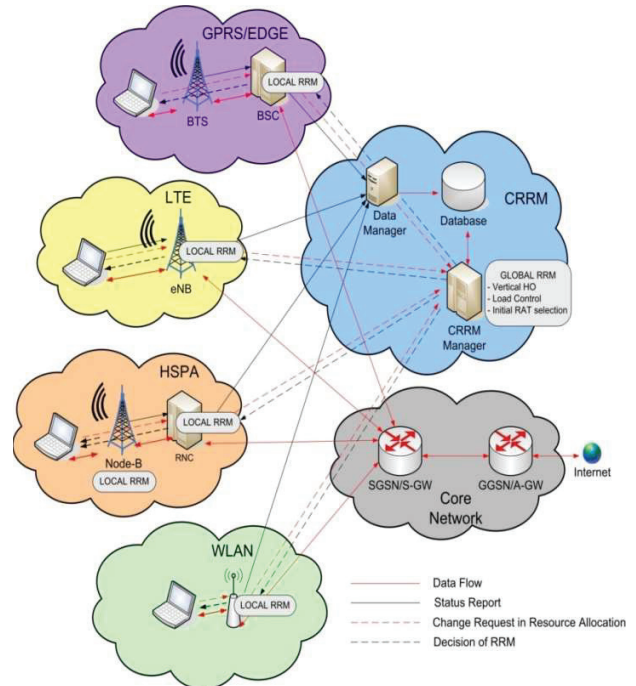


Figure 1 SPHERE Simulation tool

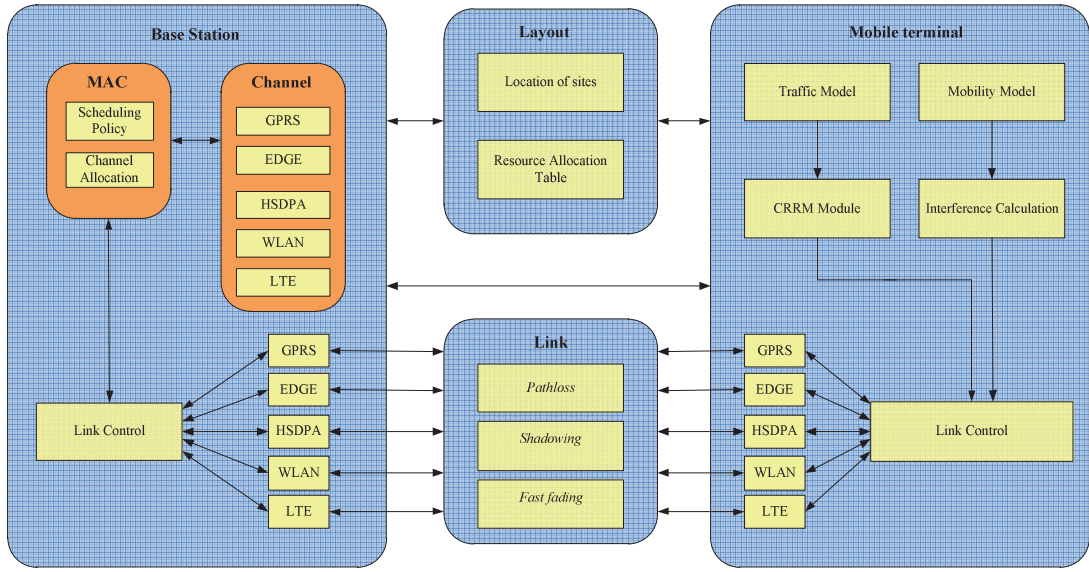


Figure 2 SPHERE Modular design

SPHERE emulates a multimedia traffic environment with email, web and real-time H263 video users. Each traffic type is simulated at the session level, with the session arrival modeled through a Poisson process [12]. The session duration is modeled by Poisson, geometric and exponential distributions for email, web and H.263 users, respectively.

All three RATs implement their own Link Quality Control mechanisms to adapt their error protection and data rates to the existing channel quality conditions. SPHERE models the pathloss by means of the Okumura- Hata COST 231 model, and the shadowing through a lognormal distribution with 6dB standard deviation. The shadowing correlation is implemented using the Gudmundson model with a de-correlation distance of 20 m [13]. To reduce the complexity of system level simulations, the physical layer effects resulting from the probabilistic nature of the radio environment have been included by means of Look-Up Tables (LUTs), extracted from link level simulations and mapping the Packet Error Rate (PER) to the experienced channel quality conditions. Erroneously received data is retransmitted using a selective repeat ARQ protocol for GPRS and EDGE, and a 4-channel Stop-And-Wait protocol for HSDPA and LTE that also includes incremental redundancy.

### 3. Co-Simulation ns-2 – SPHERE through IEEE 802.21

The integration of SPHERE and ns-2 is performed through IEEE 802.21, where the interaction between the lower layers technology-dependent information and the higher layers are performed through the IEEE 802.21 events. Two possible integration platforms can be envisioned, the horizontal integration shown in Figure 3 and the vertical integration shown in Figure 4. In the horizontal integration, each technology dependent platform contains a mobility controller interface that exchanges IEEE 802.21 messages with the mobility controller. In the vertical

integration, there is a single ns-2 instance that interacts and exchanges inform IEEE 802.21 messages with SPHERE.

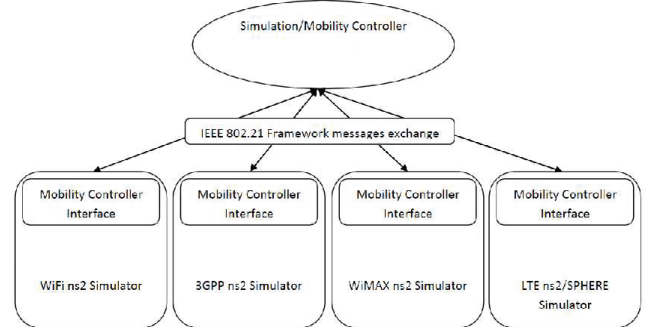


Figure 3 Horizontal Integration of SPHERE and ns-2

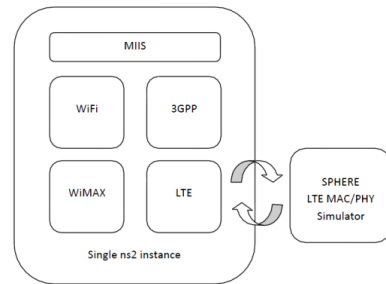


Figure 4 Vertical Integration of SPHERE and ns-2

The handover process is described in four phases: initiation, preparation, execution and completion. In the following, we describe this integration in the several phases with the extended IEEE 802.21 support, through the exchanged IEEE 802.21 messages during the handover procedures.

### 3.1 Initiation Phase

In this phase, there are two different interactions between SPHERE and ns-2, on the Information Query and on the Resource Availability Check. On the Information Query, it is required to get information from the available technologies in SPHERE, which is performed through the following messages: `MIH_Get_Information.request` (SRAN to MIIS/manager) and `MIH_Get_Information.response` (MIIS/manager to SRAN). The Resource Availability Check requires the information of the resources in the several candidate access networks, through the following messages: `MIH_N2N_HO_Query_Resources_Request` (SRAN to CRAN<sub>i</sub>) and `MIH_N2N_HO_Query_Resources_Response` (CRAN<sub>i</sub> to SRAN). In the horizontal implementation, messages from the Resource Availability Check phase, exchanged between the SRAN and each CRAN, are relayed by the manager.

### 3.2 Preparation Phase

In the Preparation Phase it is required to interact with the SPHERE to prepare the access technology resources that will be then committed for the new sessions and users moving to the new network. The messages exchanged are the `MIH_N2N_HO_Commit_Request` (SRAN to manager, then to TRAN) and `MIH_N2N_HO_Commit_Response` (TRAN to manager, then to SRAN). In the horizontal implementation, messages from the Resource Preparation phase, exchanged between the SRAN and TRAN, are relayed by the manager.

### 3.3 Execution Phase

In the Execution phase the handover is performed and there are no 802.21 messages are exchanged. If MIPv6 or FMIPv6 is used for handover implementation, MIPv6 or FMIPv6 messages are exchanged, according to the standard in the ns-2 framework.

### 3.4 Completion Phase

In the Completion Phase it is required to contact SPHERE to perform the Resource Release in the previous access network. For this purpose, the following IEEE 802.21 messages are exchanged: `MIH_N2N_HO_Complete_Request` (TRAN to manager, then to SRAN) and `MIH_N2N_HO_Complete_Response` (SRAN to manager, then to TRAN). In the horizontal implementation, messages from the Resource Preparation phase, exchanged between the SRAN and TRAN, are relayed by the manager.

### 3.5 IEEE 802.21 Extensions to ns-2

In this section we briefly describe the additions and modifications made to the existing IEEE 802.21 NIST add-on for the ns-2 simulator [15][16] to perform the handovers between different technologies, Wi-Fi, WiMAX, UMTS and LTE [17].

The base NIST add-on provides an implementation of the IEEE 802.21 (draft 3) framework, defining two main entities: MIHF and MIH User (MIHU). The MIHF is implemented as an *Agent* and handles the list of local MIHUs, their registration and the communication with the remote MIHFs; additionally, it has the list of the local link layer interfaces to get their status and control their behavior through the MIH standardized interfaces. The MIHU is also implemented as an *Agent* that needs to register itself

with the MIHF in order to receive events from local and remote interfaces. The MIHUs are entities that make use of the MIHF functionalities in order to enhance user performance by optimizing handovers. Since there are an infinite number of implementations depending on the user preference or network policies, the implementation provides an abstract class *MIHUser* that can be easily extended.

One of the major drawbacks of the 802.21 NIST add-on is the lack of support for the 802.21 entities on the network side, specifically the MIHU. Therefore, there was only local communication with the MIHUs, missing the communication between MIHUs on the network and on the MN. To overcome this limitation and able the communication between all the network entities, either local or remote, a MIHU was specified and implemented on the network side (PoAs)[17].

Another important weakness was the inexistent support for one of the most critical services provided by 802.21 – MIIS. Furthermore, the MICS and MIES services, were still missing critical functionalities and primitives to be fully supported. This limitation was solved by adding new primitives for the MICS and MIES services, and implementing, from scratch, the MIIS service and the related primitives. All the primitives of IEEE 802.21 were then implemented [17].

Further, the NIST implementation also lacks integration between the IEEE 802.21 framework and the RATs, in particular for the UMTS case (this problem is further increased in the LTE case, as it is not supported in ns-2). Even though the NIST add-on provides support for the UMTS technology model, developed within EURANE [18], this implementation was in its early stages. Therefore, an intensive study of UMTS model was made and modifications were implemented to overcome the limitations raised by the integration with the MIH framework. One of the changes made to the UMTS model was on the MAC layer level. When creating any element, the ns-2 calls its base MAC class, which is common to all elements, and after that the specific MAC for each technology is called. In the UMTS case, when the specific MAC class was called, it changed the unique MAC address given by the base MAC class, and all UMTS elements were given the same MAC address. However, for an entity to send a MIH message, it is necessary to know its base MAC address (to get the interface IP address). To provide unique MAC address values into UMTS elements, it was necessary to modify the MAC layer and add an extra variable to store the original values of the MAC addresses. With this change, the MAC address variable of UMTS elements keeps its value, which is necessary for the UMTS structure to work; moreover, it is possible to consult its original base MAC address and distinguish each entity [17]. These extensions are available in [19].

Regarding LTE integration via SPHERE in ns-2, the MAC layer of the ns-2's IEEE 802.11 implementation was used. In the configuration of the IEEE 802.11 MAC layer a new flag (LTEBS\_) was introduced that allows distinguishing from an 802.11 or an LTE MAC layer. The link and physical layers simulation is handed over to SPHERE, as seen in Figure 5. To do this, in the case that the LTEBS\_ flag is active, the send and receive methods transfer the incoming packets to a socket created to communicate with SPHERE. As shown in Figure 7, the simulation in ns-2 side then holds while the packets are processed by SPHERE. When the processed packets are received back in ns-2 the simulation proceeds. This is done for the downlink connection (from BS to MN), and for the uplink connection, the

BS behaves as an 802.11 AP. Since IEEE 802.21 was already integrated with IEEE 802.11 and able to perform HO with the remaining RATs, there was no need to specifically integrate LTE at this level.

### 3.6 IEEE 802.21 Extensions to SPHERE

The architecture of co-simulation couples two different simulation tools: SPHERE and ns-2. Depending on the design, simulators complement each other by providing support for a group of layers of the OSI communication model. In particular, the SPHERE simulator is responsible for the simulation of lower layers (link layer and physical layer), while the ns-2 simulator provides support for the simulation of the upper layers (network layer, transport layer and application layer). The SPHERE simulator needs to synchronize its internal clock with the caller (ns-2). The drawback of this method is that most of the time only one of the simulators is active, such that not a big gain in simulation-time is obtained. However, the simplicity of this approach outweighs the benefits of a reduced simulation time for our demands.

Figure 5 shows how the network layer is the layer where the exchange of information was made. Gray arrows depict the flow of information. Thus, each simulator will have an action plane within the process of co-simulation.

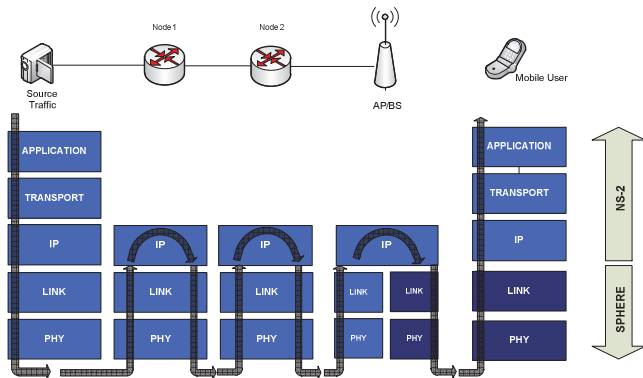


Figure 5 Co-simulation scenario

Both simulators communicate using sockets, which provides the advantage that the simulators could be running separately on two different computers connected through any network, LAN or WLAN. To achieve this, we have modified the structure of the *SimpleLink* module of ns-2 simulator. Such modification consists in the inclusion of a block between *queue\_* and *link\_* blocks called *sk\_module* (see Figure 6). The *sk\_module* integrates a client-server module that provides the ability to communicate with a remote entity and pass information related to the simulation packets.

An important issue when designing co-simulation systems is to establish synchronization between the simulators to control the total simulation run [14]. The method used in our work makes the primary simulator stop its execution while the other simulation runs, and vice versa, i.e. there will always be a simulator in stand-by and another running. Figure 7 shows the flow chart in the co-simulation platform.

## 4. Co-Simulations

In this section we describe an 802.21 compliant seamless handover procedure between LTE and WiMAX. The integration with UMTS and Wi-Fi are similar, with significant differences on the resources activation part. The handover process is described in four phases: initiation, preparation, execution and completion.

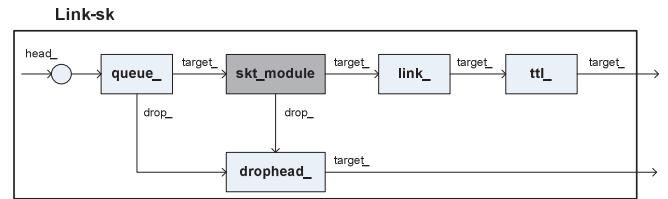


Figure 6 New link module in ns-2

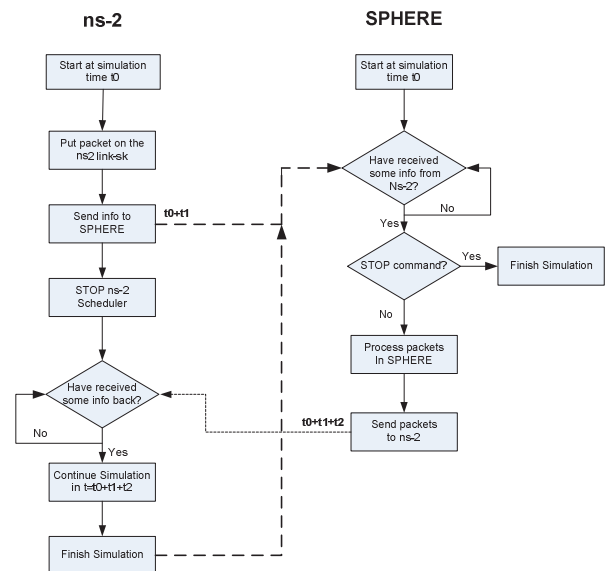


Figure 7 Synchronization between ns-2 and SPHERE

### 4.1 Handover Initiation

In the beginning, the LTE MIHU on the network side, in this case the LTE PoS, configures the MN LTE interface with a set of predefined QoS thresholds using the *MIH\_Link\_Configure\_Thresholds* command (Figure 8; step 1). Consequently, the MN LTE interface periodically sends measurement reports to the registered MIHUs using the *MIH\_Link\_Parameters\_Report* event, keeping them informed about the channel quality (Figure 8; step 2). As soon as the LTE link conditions start degrading and the negotiated QoS parameters cannot be satisfied, the MN LTE interface triggers the *MIH\_Link\_Going\_Down* event towards the LTE MIHUs (Figure 8; step 3). With the measurement reports received from the MN, the LTE PoS is able to trigger the handover preparation phase before the LTE link is disconnected.

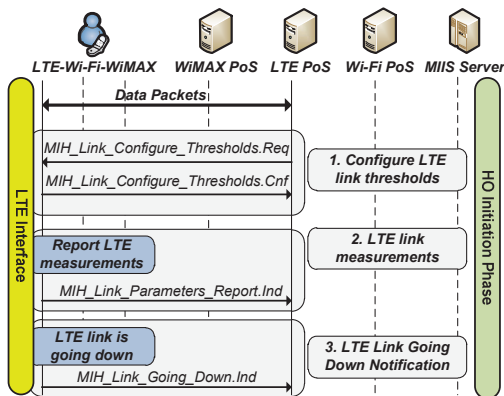


Figure 8 HO Initiation Phase

## 4.2 Handover Preparation

The handover preparation phase is triggered when the registered LTE MIHUs receive the *MIH\_Link\_Going\_Down* event from the LTE interface in the MN. Thereafter the MN has to discover the candidate RATs in its geographical area by sending a *MIH\_Get\_Information* message to the MIIS server (Figure 9; step 4) – *MIIS Query* phase. The MIIS server indicates that a WiMAX network is available. Hence, the MN will check for the available resources in the WiMAX network using the *MIH\_MN\_HO\_Candidate\_Query* and *MIH\_N2N\_Query\_Resources* messages (Figure 9; step 5) – *Candidate RAT (CRAT)* phase. To conclude the handover preparation phase, resources in the WiMAX link must be reserved – *Target RAT (TRAT)* phase. The reservation request is transported up to the WiMAX PoS through the *MIH\_MN\_HO\_Commit* and *MIH\_N2N\_HO\_Commit* messages (Figure 9; step 6), which will trigger the Dynamic Service Addition (DSA) WiMAX MAC management messages – *DSA-Req/Resp/Ack*.

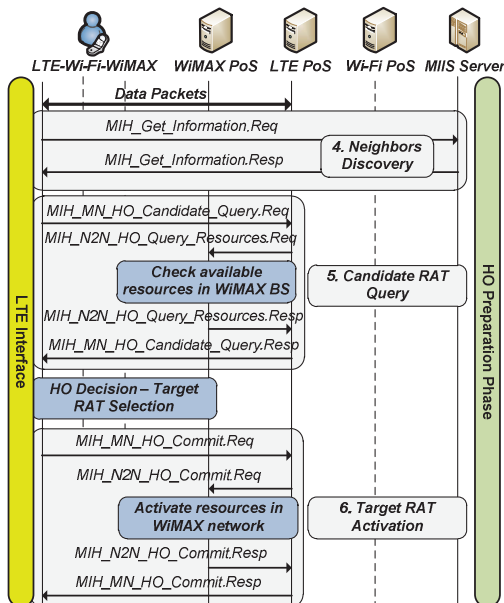


Figure 9 HO Preparation Phase

## 4.3 Handover Execution

During the handover execution phase, the physical handover is performed from the serving access network (LTE) to the target access network (WiMAX). Generally, an authentication handshake is first performed between the MN and the target network. Afterwards, an association request message is sent from the MN to the network, and an association reply is sent backwards.

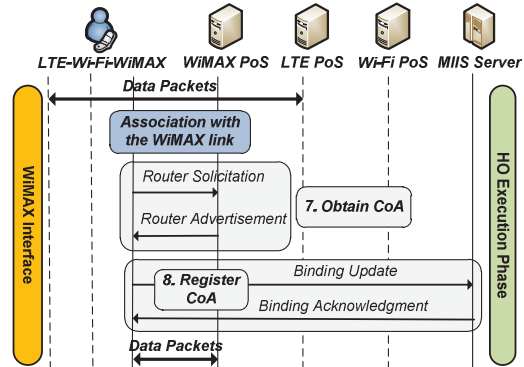


Figure 10 HO Execution Phase

After the physical handover, the WiMAX interface obtains a Care-of-Address (CoA) via the WiMAX PoS (Figure 10; step 7) using the *Router Solicitation* and *Router Advertisement* messages from MIP. After acquiring a valid CoA, the MN registers it in the MIP Home Agent (HA) (collocated with the MIIS server) using the *Binding Update* and *Binding Acknowledgment* messages (Figure 10; step 8). As a result, an IP-in-IP tunnel is configured between the MIP HA and the MN to transfer the downlink data packets.

## 4.4 Handover Completion

To finalize the handover process, the resources in the previous radio access technology (LTE) are released through the usage of the *MIH\_MN\_HO\_Complete* and *MIH\_N2N\_HO\_Complete* messages (Figure 11; step 9).

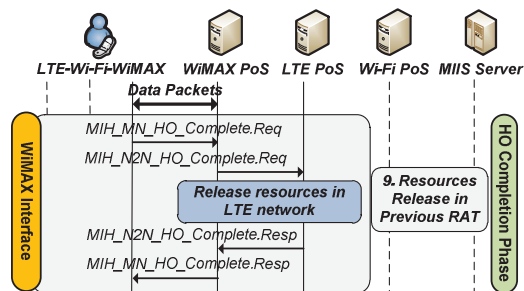


Figure 11 HO Completion Phase

Note that the ns-2 simulator, by default, does not provide make-before-break handover mechanisms, but rather break-before-make. Therefore, any handover performed would result in associated packet loss during the handover execution phase. The wireless access technologies involved in our scenario are UMTS and LTE, as illustrated in Figure 12. A second similar scenario simulates a handover from UMTS to WiFi for comparison purposes.

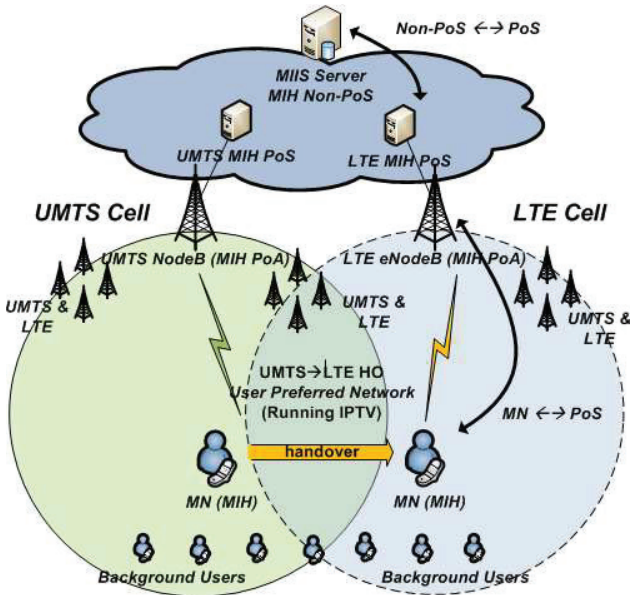


Figure 12 Simulation scenario with UMTS and LTE

IEEE 802.21 entities were integrated in the multimode MN, as well as on the access network and on the core network. The IEEE 802.21 MIIS server was installed on the core network side, whereas the MIH PoS was installed on each one of the RATs gateways. Finally, the MIH PoA functionality was installed on the RATs base stations. The handover shown in the scenarios is a network-initiated handover, as it is triggered on the network side.

The Handover Preparation phase, as one of the most critical phases of the mobility process, is thoroughly evaluated, depicting each one of its internal steps: 1) MIIS Query, 2) Candidate Radio Access Technology (CRAT) Query and 3) Target Radio Access Technology (TRAT) Commit.

Additionally, in order to provide a complete evaluation of the mobility procedure, the handover execution and completion steps are also evaluated. Moreover, QoS measurements were also made, specifically for the packets delay and loss.

The simulation scenario integrates several background users, distributed across the RATs, each one generating Constant Bit Rate (CBR) data flows of 512 Kb/s. The MN is generating an ongoing CBR data flow between of 1 Mb/s.

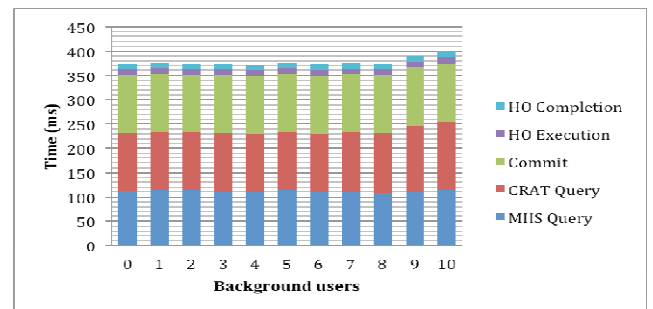


Figure 14 UMTS to WiFi Preparation, Execution and Completion phases

As illustrated in Figure 14, the HO preparation phase takes approximately 360 milliseconds (ms). The handover preparation time is distributed in three internal steps of the handover preparation phase: 100 ms for MIIS Query (blue), 140 ms for CRAT Query (red) and 120 ms for TRAT Commit (green). These values are easily explained due to the one-way delay of the WiFi and the wired links. The one-way delay of the wired part of the network is approximately 5 – 10 ms for the handover presented in this paper, whereas the one-way delay on the wireless link depends on the radio access technology. For the Wi-Fi link, the one-way delay is approximately 50 ms, and for the LTE we have a one-way delay of approximately 40 ms. The time interval spent on

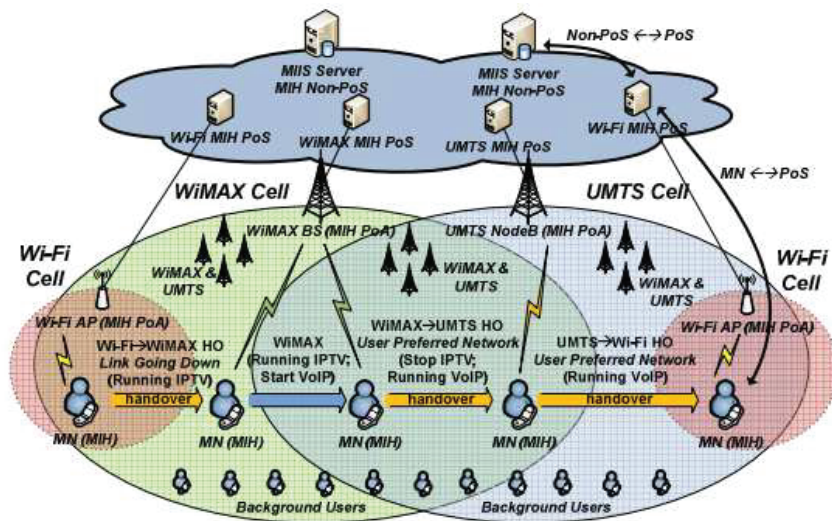


Figure 13 Simulation scenario with UMTS and LTE

each internal step of this phase can be explained if we sum up all the one-way delays in the wireless and wired links. For example, the 110 ms spent by MIIS Query internal step are due to the MIH\_Get\_Information.Req message sent from the MN to the MIIS server (uplink Wi-Fi uplink wireless hop and wired hop) and the MIH\_Get\_Information.Resp message sent from the MIIS server to the MN (downlink wired hop and WiFi downlink hop), as illustrated in Figure 9.

Summing the one-way delays associated with the wired and the wireless links (uplink and downlink) we obtain approximately 100 ms. The values measured for the CRAT Query and TRAT Commit internal steps have a similar justification. The handover execution phase, illustrated in Figure 14, shows that the handover execution (purple) and completion (light blue) times are approximately constant (10 ms) when the number of background users increases.

From Figure 15, we can see that the handover preparation time is around 350 ms. Comparing to the results obtained for the UMTS to WiFi handover, the preparation phase is approximately 25 ms faster, which is reflected by the difference in the one-way delay of the two RATs, as given before. In this case, the 100 ms spent by MIIS Query internal step are due to the MIH\_Get\_Information.Req message sent from the MN to the MIIS server (uplink LTE uplink (that uses the WiFi uplink channel) wireless hop and wired hop) and the MIH\_Get\_Information.Resp message sent from the MIIS server to the MN (downlink wired hop and LTE downlink hop). With respect to the handover execution and completion times, also illustrated in Figure 15, they take around 10 ms to complete, and are always constant.

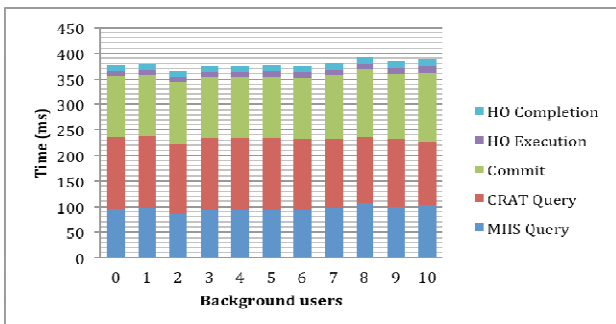


Figure 15 UMTS to LTE Preparation, Execution and Completion phases

On the previous subsection we have described the time spent on the handover preparation and execution phases. In this subsection we will provide important results related with QoS measurements, specifically, packet delay and loss.

Figure 16 presents the packet delay and packet loss for the two handover scenarios considered.

The packet delay for the UMTS to WiFi handover is approximately 59 ms. In comparison, the 29 ms of packet delay during the UMTS to LTE handover reflect the difference in the one-way delay of the two access technologies. Finally, we can observe that while the wireless links are not saturated, we achieved a seamless handover, with zero packet loss.

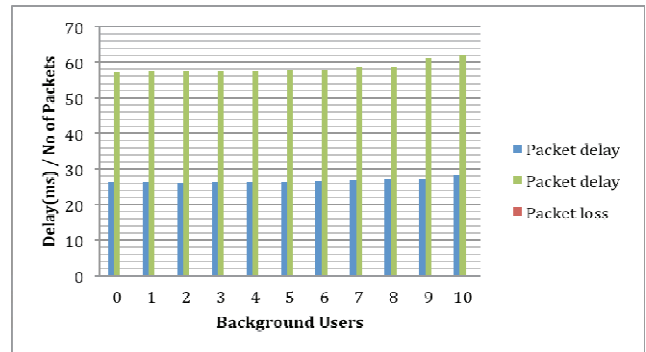


Figure 16 Packet delay for the UMTS to WiFi (blue) and UMTS to LTE (green) handovers and packet loss for both scenarios

## 5. Conclusions

As expected when using co-simulation for different domains, e.g., network and physical layer, the simulation-time is largely dependent on the lowest layer in the stack. This layer usually has the smallest time-resolution and hence will require more processing resources per simulated second.

In this paper, the integration of the SPHERE and ns-2 platforms to simulate heterogeneous handovers has been described. Ns-2 is a platform largely utilized by the international scientist community. SPHERE is a scalable system-level simulator that implements five different RATs in parallel, GPRS, EDGE, HSDPA, WLAN and LTE. The combination of them has allowed performing studies about handover processes based on the 802.21 standard over new emergent technologies such as LTE or 802.16m. Both simulators complement each other giving as a result a more robust and complete simulation tool. Finally, the different stages of handover from LTE technology to WIMAX have been presented.

## 6. ACKNOWLEDGMENTS

This work has been partly funded by the Euro-NF Network of Excellence, through the Specific Joint Developments and Experiments project DINASTI. This work was also partially supported by FCT (INESC-ID multi-annual funding) through the PIDDAC program fund. Part of this work was performed jointly with PT Inovação.

## 7. REFERENCES

- [1] R. Ferrus, A. Gelonch, F. Casadevall, X. Reves, and N. Nafisi, "EVEREST testbed: QoS management evaluation in B3G networks," in Testbeds and Research Infrastructures for the Development of Networks and Communities, 2006. TRIDENTCOM 2006. 2nd International Conference on, Barcelona, Spain, 2006, pp. 6-31.
- [2] M. Takai et al., "Scalable testbed for next-generation wireless networking technologies," in Testbeds and Research Infrastructures for the Development of Networks and Communities, 2005. Tridentcom 2005. First International Conference on, Trento, Italy, 23-25 Feb 2006, pp. 162-171.
- [3] E. Jaffe and J. Albrecht, "PlanetLab - P2P testing in the wild," in Peer-to-Peer Computing, 2009. P2P '09. IEEE

- Ninth International Conference on, Seattle, WA, Sept. 2009, pp. 83-84.
- [4] N. Bencomo, P. Grace, C. Flores, D. Hughes, and G. Blair, "Genie," in Software Engineering, 2008. ICSE '08. ACM/IEEE 30th International Conference on, Leipzig, Germany, 10-18 May 2008, pp. 811-814.
- [5] A. Gavras, H. Bruggemann, and D. Witaszek, "Pan European Laboratory for next generation networks and services," in Testbeds and Research Infrastructures for the Development of Networks and Communities, 2006. TRIDENTCOM 2006. 2nd International Conference on, Barcelona, Spain, March 1-3, 2006, pp. 6-41.
- [6] K. Fall and K. Varadhan, "The ns-manual," University of California, Berkeley, CA, VINT Project 2002.
- [7] ns3 Project. (2010, February) ns-3 Reference Manual. pdf.
- [8] J. Gózalvez et al., "SPHERE - A Simulation platform for Heterogeneous Wireless Systems," in Testbeds and Research Infrastructures for the Development of Networks and Communities, 2007. Tridentcom 2007. 3rd International Conference on, Orlando, FL, 2007, pp. 1-10.
- [9] J. Gózalvez et al., "SPHERE- A Simulation Platform for Heterogeneous Wireless Systems," in proceedings of the 3rd International Conference on Testbeds and Research Infrastructures for the Development of Networks and Communities (TridentCom), pp. 1-10, Orlando, 2007.
- [10] 3GPP specifications, <http://www.3gpp.org/specifications>
- [11] IEEE Standards, <http://ieeexplore.ieee.org/xpl/standards.jsp>
- [12] UMTS 30.03 v3.2.0 TR 101 112 "Selection procedures for the choice of radio transmission technologies of the UMTS", ETSI, April 1998
- [13] M. Gudmundson, "Correlation Model for Shadow Fading in Mobile Radio Systems," IET Electronic Letters, vol. 27, no. 23, pp. 2145-2146, 1991.
- [14] Fummi et al., "A timing-accurate modeling and simulation environment for networked embedded systems," in proceedings of the 40th Annual Design Automation Conference, Anaheim, 2003.
- [15] S. McCanne and S. Floyd. ns Network Simulator.
- [16] The National Institute of Standards and Technology (NIST), Mobility Package – <http://w3.antd.nist.gov/seamlessandsecure/download.html>
- [17] Pedro Neves, João Soares, Susana Sargento, "Media Independent Handovers: LAN, MAN and WAN Scenarios", 5th IEEE Broadband Wireless Access Workshop, IEEE Global Telecommunications Conference (IEEE GLOBECOM 2009), Honolulu, Hawaii (USA), November 2009.
- [18] Enhanced UMTS Radio Access Network Extensions (EURANE) for ns-2 – <http://eurane.ti-wmc.nl/eurane/>
- [19] IT-Av Media Independent Mobility and QoS Support package for ns-2 – [http://www.av.it.pt/ssargento/802\\_21\\_web/main.html](http://www.av.it.pt/ssargento/802_21_web/main.html).
- [20] G. Yeung, et al, "Detailed OFDM Modeling in Network Simulation of Mobile Ad Hoc Networks", 18<sup>th</sup> Workshop in Parallel and Distributed Simulation", May 2004.