Simulation of a heterogeneous handoff algorithm

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Summary
This article shows the design and development of a heterogeneous handoff simulator which let to evaluate the performance of a handoff decision algorithm, which uses a variety of network technologies. It is described the process of specification, design and implementation of this simulator. The proofs to the simulator were made using a handoff decision algorithm, based on relative desirability named ARDE.

Key words:
Vertical handoff, handoff decision algorithm, simulator.

1. Introduction

Due to the success of the Internet, the technological world has characterized for the enormous growth of diverse mobile services. Nowadays the users demand to be connected while they move freely without using any wire. Related with this principle, many studies have been made to integrating a variety of heterogeneous wireless technologies which let users to visualize only one homogeneous wireless network, hiding their differences and making invisible to the user the transitions or handoffs that change the connection point of the mobile terminal from one wireless technology to another one.
Considering that the fourth generation wireless networks (4G) are conformed by a variety of heterogeneous superimposed integrated technologies, it is necessary to have efficient handoff algorithms which decide timely and in the correct way where and when to execute a handoff.
Several vertical handoff decision algorithms have been proposed in the literature; however, the design of handoff decision algorithms is considered as an open problem yet, because that design hasn't been optimized to take correct, on time, trustful, strong decisions [1]. Another inconvenient presented in the literature is the fact that network simulators used to test the decision algorithms are not enough prepared to work on complex heterogeneous sceneries that involve the superimposition of a variety of wireless technologies. The most designs have been adjusted to the limitations of the simulator and they only test the algorithm in very simple scenarios, only considering transitions between two types of technologies, a WLAN(wireless local area network) and a WWAN (wireless wide area network). For this reason, this article propose the design and development of a vertical handoff simulator named VHAND, focused on the execution of handoff decision algorithms in scenarios with different types of wireless technologies. In particular, this simulator was used to evaluate, analyze and improve the performance of the handoff decision algorithm named ARDE (Algorithm of Relative DEsirability) [1].
In diverse investigation articles related with the topic of the vertical handoff [2][3] is presented a variety of handoff algorithms; however, once the algorithm is proposed, the problem about how to validate it arises. There are three types of tools to validate the algorithm: formal methods, laboratory tests and simulation; it was decided to use simulation because of the advantages that offers, compared with the other two options. Some of these advantages are [4]:
- A detailed observation of the system that is being simulated can led a better understanding, and because of this, strategies that improve its operation and efficiency can be suggested.
- The simulation of complex systems can help to understand in a better way the operation of them, to detect the most important variables that interact with the simulation and, consequently, have a better understanding of the interrelations among them.

The problem we face is related with the necessity of testing handoff algorithms in heterogeneous environments using simulation, but, in spite that exist several network simulators that can simulate a vertical handoff [5][6][7], these don't work with a diversity of heterogeneous networks and only consider the superimposition of two different wireless technologies. This causes the algorithms are tested in very simple scenarios [8][9]. Recently, several network simulators, as NS-2 and GloMoSim are working in building scenarios with a big wireless diversity, but, so far, these modules are not available for the people, or are just available in the commercial version of the simulator [10][6]. Another problem is that the user requires learning and understanding a number of commands in a specific language when the user is starting using a simulator, so can be able to construct the scenario to be used to test the handoff algorithm.
The result that is set in this publication is the development of a simulator which uses the superimposition of a variety of wireless technologies that let to observe the process of vertical handoff. The simulator will be designed with a friendly interface to the user, so can use the graphic tools

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to construct the scenarios to be used to test the handoff algorithm.

2. Description of the vertical handoff process.

One of the aspects of mobility in a network of services of personal communication is the handoff which works in the following way: When a mobile user is having a phone call, the mobile station connects to the base station (BS) via a radio link. If the mobile user moves to the coverage are of another BS, the radio link to the old BS is disconnected, and a transparent radio link is established between the new BS and the mobile user to continue the conversation [11]. The vertical handoff (VHO) is carried out between the BSs that are using different types of wireless network interfaces. Generally, the VHO process includes four stages: beginning, decision, execution and evaluation [1].

The reasons why doing the handoff is necessary are established in the beginning stage. A mandatory reason to begin the handoff is because of the degradation of the quality of the factual link; the consequence of this is the loose of the existent connection; another reason, although considered optional, is that a "better" new network appears instead of the existent network. In the decision stage, the mobile device makes the discovery of the networks which can be reached, selects the best choice using some criteria and choose the appropriate moment to change to other network based on certain policies. In the execution stage, it is made physically the commutation of the connection of the mobile node from the actual network to the new network. Finally, in the evaluation stage it is decided how well worked the decision of changing the network and how well the quality of the applications is.

3. Architecture of VHAND simulator

The final product of this investigation was the development of a simulator which lets to design scenarios with a variety of wireless technologies to evaluate handoff decision algorithms named since now VHAND.

VHAND is constituted in six basic modules, which describe common tasks made during the simulation process: 1) design topology, 2) set the path, 3) load initialization parameters, 4) execute simulation, 5) show results and 6) detect reachable networks. This process is shown in figure 1. The five starting modules are available for the user, beginning with the graphic interface. The sixth module runs at the moment the simulation is executed, and works as a support for the decisions algorithm, which corresponds to another module independent of the simulator.

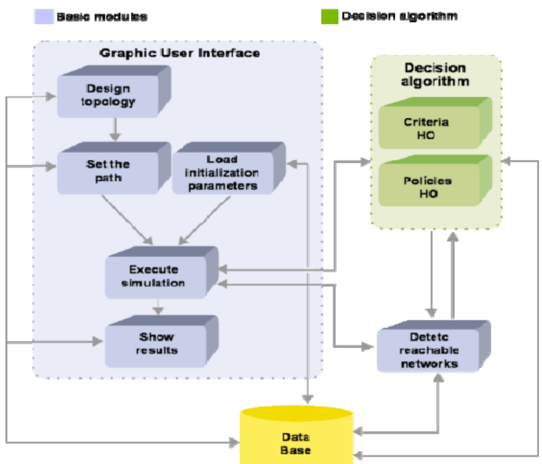

Fig 1. Architecture of VHAND.

Next, it is presented a short description of each one of the modules which form VHAND:

Design Topology. The user draws and defines the characteristics of each cell. A cell represents some of the network technologies used in the simulator, such as GSM, GPRS, UMTS, CDMA 2000, WiMAX 802.11a, 802.11b,802.11g and Bluetooth.

Set the path. It is used to draw the path that the mobile node will follow during the simulation. The path is defined with continuous straight line segments. For each segment are defined some characteristics such as: type of speed (pedestrian or vehicular), speed and type of application (data, multimedia, voice, etc.).

Load initialization parameters. The initialization parameters are a serial set off values which are used to indicate to the decision algorithm what will be the initial information to run the simulation. The parameters used in this module are: the initial charge of the battery of the mobile device, the cost of the connection to each wireless technology and the handoff control parameters. Such parameters are established initially by the system, but they can be modified by the user according to convenience.

Execute simulation. It consists in bringing up the handoff decision algorithm which will be tested. In this case is ARDE. Later, the user watches graphically the way the mobile node moves through the predefined path and how the connection point of the mobile node changes from one cell to another one.

Show results. The function of this module is to display in the screen the results of the simulation to be used for the final user to analyze the decision algorithm.

Detect reachable networks. The objective of this module is to discover in each time unit, the networks that can be reached by the mobile node, according to the node position, and communicates to the decision algorithm the list of reachable networks.

Finally, the decision algorithm is constituted of two modules: "handoff criteria" to calculate the metric of desirability of each reachable network in an instant of time, and "handoff policies" to determine the exact time to produce the handoff.

4. Design of VHAND

This section details the design of VHAND trough each one of the modules. The graphic interface of VHAND is shown in figure 2.

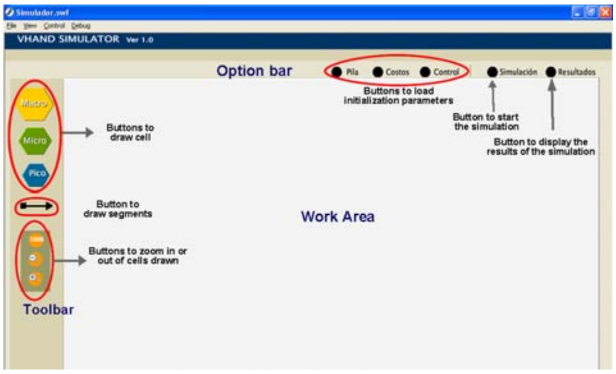

Fig 2. Main interface of VHAND.

4.1 Design topology

In this module, the user designs simulation scenarios drawing the cells. To do this, the interface uses a tool bar, which uses three hexagonal buttons (figure 2) labeled with the word macro, micro and pico, used to draw a macrocell, a microcell and a picocell, respectively. Due to some cells drawn in the work area of the simulator can be of a big size, the simulator uses buttons to zoom in or zoom out the drawn cells, as well as a button to reestablish the zoom level to the default value.

Once the cell has been drawn, this contains predefined values which are obtained from an external XML document named Document of Initializations Values of Cell (DIVC, by its acronym in spanish). The structure of DIVC is shown in figure 3.

The simulator has a contextual menu with the option "Cell data" and "Edit weights", where the user can modify the default information of each cell. If it is necessary to change the cell data, a cell must be selected first, and then, by clicking on that cell with the right button of the mouse, a contextual menu is displayed, where the option "Cell data" is selected. After that, a window is displayed (figure 4) depending of the type of selected cell. The radius of coverage of the cell is assigned by the system having in mind the selected technology and powerfulness, reason why this variable can't be modified by the user.

If the user wants to modify the weight of each handoff criteria, has to do the same steps described in the previous paragraph choosing "Edit weights". Finally, this action displays a window with a list of criteria, which weight can be changed, if it is necessary for the user (figure 5).

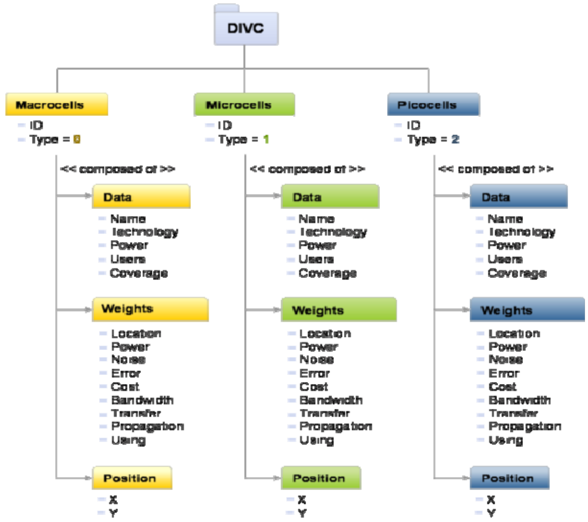

Fig 3. Structure of DIVC.

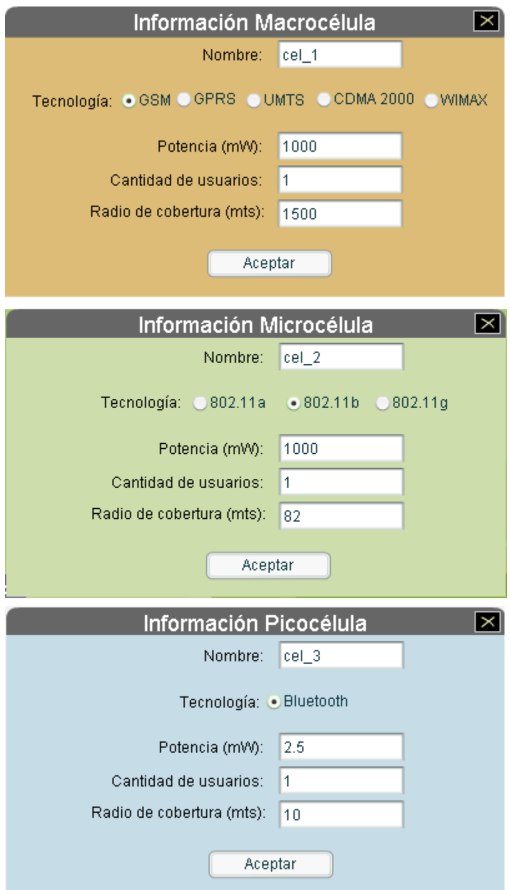

Fig 4. Windows to modify information of the cells.

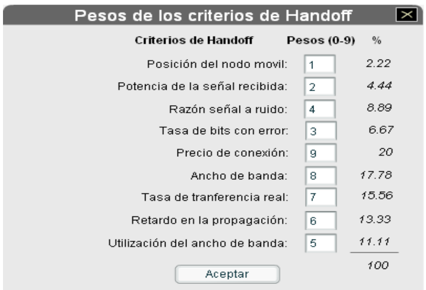

Fig 5. Window to modify the weight assigned to the handoff criteria

4.2 Set the path

In this module, the user draws the path that will be followed by the mobile node at the moment of executing the simulation. The user draws this path with segments of straight line, and the associated information related with each of these segments is loaded.

To draw the segments that will constitute the path to be followed by the mobile node during the simulation, it is used the button with the figure of a row (figure 2).

Once a segment has been drawn, this contains default values, defined in an external XML document named Document of Initialization Values of Segment (DIVS, by acronym in spanish); its structure is shown in figure 6.

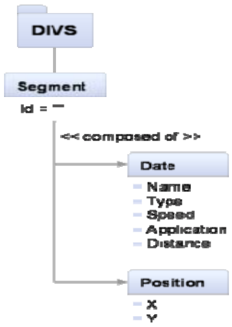

Fig 6. Structure of DIVS.

The simulator has a contextual menu with the option "Path data", where the user can modify the default information of each segment. To do this, select first the vertex of any segment, click with the right button of the mouse and choose the option "Path data". Then the window "Path information" is displayed (figure 7), which lets to modify any data of the segments.

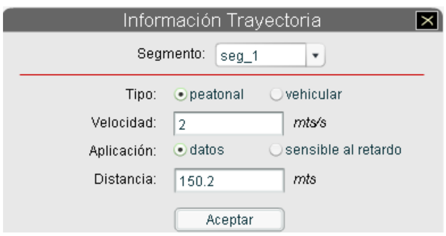

Fig 7. Window to modify the information of a segment.

4.3 Load initialization parameters

In this module, the user enters information related with: the initial load of the battery of the mobile node. The cost of connection of each wireless technology and the value of the handoff control parameters. For this information, the interface has an options bar; the first three options are used: heap, costs and control (figure 2).

To enter the initial loading of the battery of the mobile node, click in the button "Heap" in the options bar. It is displayed the window "Heap information", so the user can enter the correspondent value, which goes from 0 to 100%. There is an external XML document named Document of Initialization Values of Load Parameters (DIVCP, by acronym in spanish), which contains the preloaded values for the connection prices of the technologies involved in the simulator, and for the initial values of the handoff control parameters. The structure of this document is shown in figure 8.

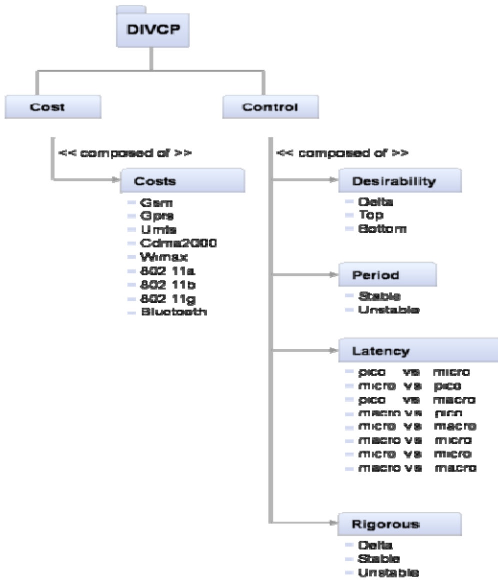

Fig 8. Structure of DIVCP.

If the user doesn't want to use the preloaded values can use the buttons "Costs" and "Control" in the options bar. To enter the cost of connection of each wireless technology, click in the button "Costs" in the options bar of the simulator. The function of this buttons to display the window "Costs of connection", which contains the wireless technologies so the user can enter the cost to connect to each one of them. The assigned value to the cost of connection to each network is a scale from 0 to 25. It was decided to use a scale instead of a particular measuring unit, due to the Internet suppliers charge the time in some cases, mainly because of the amount of transmitted data, etc.

To enter the value of the handoff control parameters, the simulator has a “Control” button in the options bar. The function of this button is to display the window “Control parameters”, which contains a list of control parameters (figure 9).
Related with the measurement unit of the handoff control parameters, the values of the desirability hysteresis threshold and the desirability thresholds are numerical values without measurement unit, while the values of the variables SP, IN and LHO are expressed in seconds (fig 9).

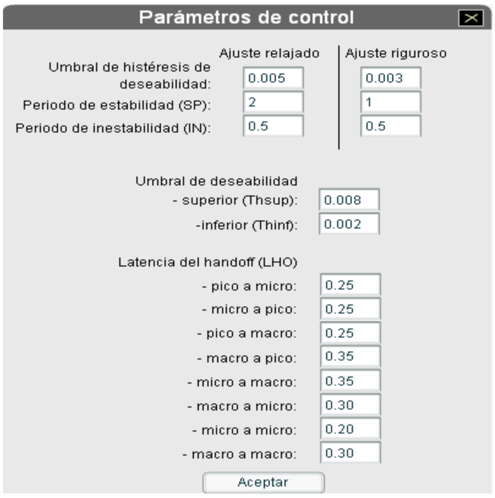

Fig 9. Window to enter the values of handoff control parameters.

The values assigned to the desirability hysteresis threshold and the threshold desirability in the DIVCP, were obtained after doing a series of tests to the algorithm to observe the desirability results given for each one of the simulated networks. The values assigned to the handoff latencies were considered inferior to one second, so the HO can’t be visible to the user.

4.4 Execute simulation

The objective of this module is to show in the *work area* of the simulator the movement of the mobile node through the defined course. As the mobile node moves in each time unit, this module communicates with the module Detection of Reachable Networks and the Handoff Decision Algorithm. To start the execution of the simulation it is enough to click in the Simulation button, located in the options bar on the main interface (figure 2).

4.5 Show Results

The purpose of this module is to show the results obtained in the end of the simulation, to make the analysis of the decision algorithms easy. To this, the simulator shows the following information for each time unit:

- For each discovered network: Name of the network, value of each handoff criteria, weight of each criteria and desirability of the network.
- Name of the actual network and the best network.
- In case of executing a handoff: previous network where the mobile node was connected, network to the mobile node will connect to do the handoff and type of handoff done (opportunist or imperative)
- In case of starting the preparation of the handoff but not execute it completely, it will be shown the reason why was not executed.
- To see the results of the simulation it is enough with clicking in the button *Resultados* (Results), located in the options bar in the main interface (figure 2). This action displays the window *Información de Resultados* (Results Information) with the results of the simulation.

4.6 Detect Reachable Networks

This module begins by executing the simulation and it has the purpose of discovering in each time unit the networks the mobile network can reach, depending on the position it is. Finally, the module provides to the Decision Algorithm the list of detected networks.

5. Tests and Results

To test the simulator and analyze the development of the ARDE algorithm it was decided to build two test scenarios: one of them to test correct decisions and the other one to test opportune decisions. ARDE takes a correct decision when is able to connect to mobile node to the best network. On the other hand, ARDE takes an opportune decision when it verifies the execution of the required conditions and policies, at the moment of running the handoff.

5.1 Scenario A: Test of correct decisions.

For this scenario we used a macrocell (named gprs), 2 microcells (named 11 g1 and 11 b1) and 1 picocell (named bt 1). Their characteristics are described in the table 1. The weight that was assigned to each handoff criteria and each cell is shown on table 2. The path defined for the mobile node is formed by 3 segments of straight line, and their characteristics are described in the table 3.
The percentage of initial load of the mobile node battery is 100%. The value of the handoff parameters used in this proof is described in the table 4.

Table 1. Cell data which constitute the network

Name	Technology	Power (mW)	Users	Covering (mts)	Cost
gprs	GPRS	1000	30	1500.0	25
11 g1	802.11g	500	5	45.5	15
11 b1	802.11b	1000	1	82.0	12
bt 1	Bluetooth	2.5	1	10.0	5

Table 2. Weight assigned to the handoff criteria of each cell.

Handoff criteria	Weight assigned to the cell			
	gprs	11 g1	11 b1	bt 1
Distance from the mobile node to the base station	1	1	1	1
Power of the received signal	2	2	2	2
Signal rate to noise	6	6	6	6
Rate of bits with error	5	5	5	5
Cost of the connection to the accessed technology	9	9	9	9
Bandwidth of the network	8	8	8	8
Rate of real transference	7	7	7	7
Latency	4	4	4	4
Use of the bandwidth	3	3	3	3

Table 3. Segments that conform the path of the mobile node.

Name of the segment	Type of speed	Speed	Type of application	Distance
Seg_5	Peatonal	2 m/seg	Data	91.302 m
Seg_6	Vehicular	100 Km/hr	Sensible to delay	0.784 Km
Seg_7	Vehicular	20 Km/hr	Sensible to delay	0.975 Km

Table 4. Value of the control parameters

Control Parameters	Value
Δ relaxed	0.005
SP relaxed	3
IN relaxed	1
Δ rigorous	0.003
SP rigorous	1
IN rigorous	1
Thsup	0.008
Thinf	0.002
LHO	0.25 *

* Except in LHO from macrocells to microcells where it was used 0.20 segundos

5.2 Results for the scenario A

According to the scenario designed for this test, there were identified three **critical moments**, which are of interest for the analysis of ARDE. A critical moment is a period of time when a mobile node can reach two or more cells (figure 10).

As it can be observed in the figure 10, in the three critical moments the macrocell gprs is always present. However, for each critical moment is involved a microcell (11 g1), a picocell (bt 1) and another microcell (11 b1) respectively.

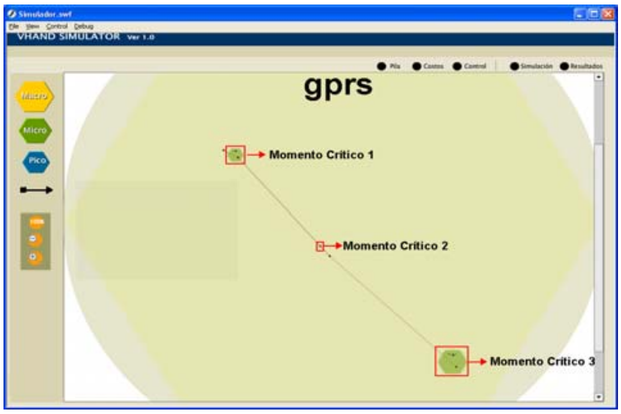

Fig 10. Critical moments detected for the scenario A.

The total time of the simulation for this scenario was 254 seconds. During this time, the mobile node could reach the following networks.

- The network grps, during all the time the simulation lasted.
- The network 11 g1, from the time 16 to the time 48 (critical moment 1).
- The network bt 1, in the time 73 (critical moment 2).
- The network 11 b1, from the time 233 to the end of the simulation (critical moment 3).

The algorithm calculated during the complete simulation, the desirability of the detected networks. The figure 11 shows the desirability of the networks gprs, 11 g1 and bt 1 from t=0 to t=76.

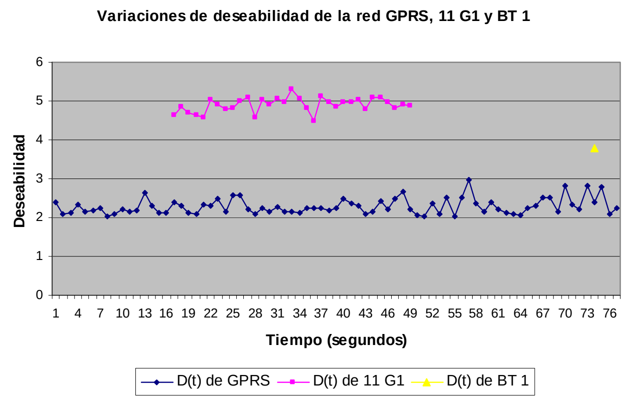

Fig 11. Variations of desirability in the network gprs, 11 g1 y bt 1.

As can be observed in the figure 10, initially the mobile node connects to the network gprs, due to it is the only one which can be reachable. From this moment, gprs becomes in the actual network. This article describes what happened in the critical moments one and two.

Critical moment 1: It occurs when the mobile node can reach the networks gprs and 11 g1, taking place from t=16 to t=48.

In t=16, the network 11 g1 has a desirability of 4.6333, and the network gprs has a desirability of 2.3958. then, from t=16, 11 g1 becomes in the best network because it has more desirability than the actual network. From this moment, the algorithm waits a stabilization period to test that the desirability of the new network (11 g1) keeps more desirability than the actual network. For this critical moment, the stabilization period was 3 seconds.

In t=19, the stabilization period ends, concluding that, from t=19 to t=19, the desirability of the network 11 g1 *was always greater* than the desirability of the network gprs (figure 12). Consequently, the decision algorithm decides to execute in that instant of time (t=19) the handoff, so the mobile node connects to the best network (11 g1).

In t=20, 11 g1 becomes in the actual network. As it can be observed in figure 11, once the mobile has connected to the network 11 g1, this one always mantains the greater desirability compared with gprs.

In t=49, the mobile node can't reach the network 11 g1, so connects to the network gprs once again, because this is the only network available, becoming gprs in the actual network.

Critical moment two: It occurs when the mobile node can reach the networks gprs and bt 1, taking place in t=73. In this time the desirabilityof the network bt 1 is 3.7943 and the desirability of the network gprs is 2.3886. This becomes the network bt 1 in the best network. However, as in t=74 the mobile node can reach the best network, this remains connected to the network gprs.

In this moment, the mobile network has a speed of 100 km/hr, because it is located in the segment "seg_6", so when passing by the picocell, it is expected not to execute a handoff to this picocell, in case the picocell is detected by the mobile node, because the speed wouldn't let the mobile node to stay a significative time in it.

Conclusion of the results for scenario A: The decisions taken by ARDE in this test were correct, since the execution of the handoff was always made to the best network, which presented a bigger value of desirability.

5.3 Scenario B: Test of opportune decisions.

For this scenario we used two macrocells (gprs, and cdma 2000), 4 microcells (11 g1, 11 b1, 11 b2 and 11 g2) and three picocells (bt 1, bt 2 and bt 3). Their characteristics are described in the table 5. For this test, ach cell had a weight of 5 in each one of the handoff criteria.

The defined path for the mobile node is constituted by 6 segments of straight line, and its characteristics are described in the table 6. The percentage of initial load of the battery for the mobile node is 80%. About the values of the handoff parameters, it was used 0.25 seconds for the handoff latencies from one cell to another one. The values of the remaining handoff parameters are described in the table 7.

Table 5. Data of cells that conform the network topology

Name	Technology	Power	Users	Coverage	Cost
gprs	GPRS	1000 mW	30	1500.0 mts	10
cdma 2000	CDMA 2000	1000 mW	10	1500.0 mts	10
11 g1	802.11g	500 mW	5	45.5 mts	10
11 b1	802.11b	1000 mW	1	82.0 mts	10
11 b2	802.11b	1000 mW	10	82.0 mts	10
11 g2	802.11g	200 mW	5	18.2 mts	10
bt 1	Bluetooth	2.5 mW	1	10.0 mts	10
bt 2	Bluetooth	2.5 mW	1	10.0 mts	10
bt 3	Bluetooth	2.5 mW	1	10.0 mts	10

Table 6. Data of the segments that conform the path of the mobile node.

Name	Technology	Power	Users	Coverage	Cost
gprs	GPRS	1000 mW	30	1500.0 mts	10
cdma 2000	CDMA 2000	1000 mW	10	1500.0 mts	10
11 g1	802.11g	500 mW	5	45.5 mts	10
11 b1	802.11b	1000 mW	1	82.0 mts	10
11 b2	802.11b	1000 mW	10	82.0 mts	10
11 g2	802.11g	200 mW	5	18.2 mts	10
bt 1	Bluetooth	2.5 mW	1	10.0 mts	10
bt 2	Bluetooth	2.5 mW	1	10.0 mts	10
bt 3	Bluetooth	2.5 mW	1	10.0 mts	10

Tabla 7. Value of the control parameters.

Control Parameters	Value
Δ relaxed	0.05
SP relaxed	2
IN relaxed	1
Δ rigorous	0.003
SP rigorous	1
IN rigorous	1
Thsup	1.8
Thinf	0.002

5.4 Results for the scenario B.

According to the scenario designed for this test, there were identified 9 critical moments (figure 12).

However, after analyzing the results, it was determined that the most critical moments were the 1, 2, 4 ans 5, since in these ones could be analyzed ARDE in a complete way. Due to the objetive of this test is to evaluate if ARDE executes a handoff appropriately, the analysis of the results was focused in extracting datas involved with the process named Determination of Handoff Execution (DEH, by acronym in spanish).

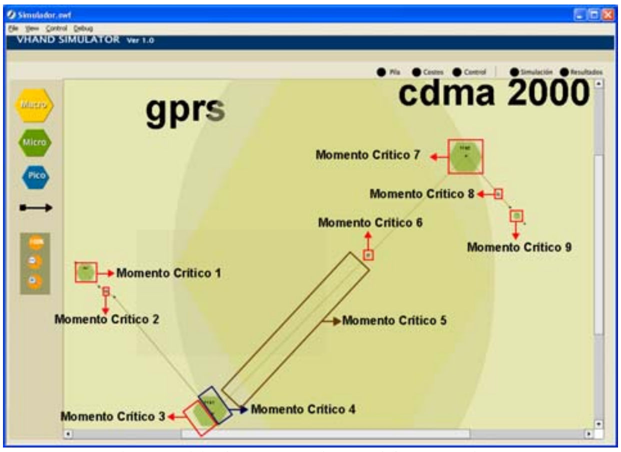

Fig 12 Critical moments detected for scenario B.

The DEH is executed when the best network is different to the actual network. Such process evaluates the following conditions:

- Determine if the handoff is imperative or opportunist. If the desirability of the actual network is greater than the superior desirability threshold Thsup, the handoff is opportunist. In a contrary case, the handoff is imperative.
- Determine the type of change to apply to the handoff control parameters (**Δ, SP and IN**). If the type of handoff is imperative or the application is sensible to delay, then the type of change to apply to the control parameters is rigorous. In a contrary case is relaxed.
- Determine if it is required to wait for a period of stability or not. If the relative desirability (**Δ_R**) is greater or equal to **Δ**, then the algorithm must wait for a period of stability (PS) before checking the handoff policies. In case that **Δ_R** is NOT greater or equal than **Δ** the handoff is not carried out.
- Determine if the period of stability ended. If the period of stability ends, verify the next point. In other case, there is no reason to execute the handoff.
- Determine if the policies to execute the handoff are accomplished. Verify the handoff policies to determine if the handoff is executed or not. The total time of the simulation for this scenario was 196 seconds. During this time, the mobile node could reach the following networks:
- The network gprs, since t=0 to t=132.
- The network 11 g1, since t=2 to t=5.
- The network bt 1, since t=24 to t=33.
- The network 11 b1, since t=78 to t=84.
- The network cdma 2000, since t=81 to the end of the simulation.
- The network 11 b2, since t=128 to t=133.
- The network 11 g2, since t=160 to t=177.

The networks bt 2 and bt 3 weren't reachable by the mobile node.

As it is observed in figure 12, initially, the mobile node connects to the network gprs, since this is the only network available. From this moment gprs becomes in the actual network. In this article it is described what happened in the critical moments one, four and five:

<u>Critical moment one</u>: It occurs when the mobile node can reach the networks gprs y 11 g1. This takes place from t=2 to t=5. The mobile node is located in the first straight line segment seg_12. Since in t=2 exists a better network, different to the actual network, ARDE starts the process DEH.

The table 8 contains the information required by the DEH, corresponding to the period of stability (PS) which has to wait the algorithm to take an appropriate decision. In this case, PS is equal to one second because it was previously determined by ARDE.

According to the data specified in the table 8, the DEH's conclusions are described in the table 9.

Table 8. Values required to decide if the handoff is executed in t=3.

	Time	
	2	**3**
Actual network	gprs	gprs
Best network	11 g1	11 g1
$D_{actual}(t)$	2.1947	2.5087
$D_{mejor}(t)$	3.9936	4.4771
Thsup	1.8	1.8
Application	Sensible to delay	Sensible to delay
Δ	0.003	0.003
SP	1	0
Δ_R	1.7989	1.9684
DV		4.13
MRVD		1.75
Load of the battery		79%

<u>Critical moment four:</u> It occurs when the mobile node can reach the networks gprs, 11 b1 and cdma 2000, taking place from t= 81 to t=84. The mobile node is located in the third straight line segment seg_14, but in t= 82 it changes to the segment seg_15.

When this critical moment begins, the actual network 11 b1 maintains as the best network and continues like that until t= 84. Therefore, since the best network is equal to the actual network, there is no necessary to begin a handoff process.

Table 9. Conclusions of DEH: handoff from gprs at 11 g1.

Time	Condition to evaluate	Conclusion	Reason
T=2	A. Determine if the handoff is imperative or opportunist	The type of the handoff is **oportunist**.	***Dactual(t)*** is greater or equal to ***thsup***. (2.1947 > 1.8)
	B. Determine the type of set to apply to the handoff control parameters (Δ,	The type of set is **rigorous**. According to table 8, SP is 1, Δ is	Due to the application is sensible to the delay.

	SP e IN).	0.003 and IN is 1 when the set is **rigorous.**	
	C. Determine if a period of stability is required or not	If it is required to wait for a period of stability.	$\Delta_R > \Delta$ (1.7989 > 0.003).
	D. Determine if the period of stability has ended	It hasn't finished yet. PS decrements in one	PS is 1
	E. Determine if the policies to execute the handoff are accomplished	Not apply	PS hasn't ended the period of stability
T=3	A. Determine if the handoff is imperative or opportunist	The type of the handoff is **oportunist**.	***Dactual(t)*** is greater or equal to ***thsup***. (2.5087 > 1.8)
	B. Determine the type of set to apply to the handoff control parameters (Δ, SP e IN).	E The type of set is **rigorous**. According to table 8, SP is 1, Δ is 0.003 and IN is 1 when the set is **rigorous.**	Due to the application is sensible to the delay.
	C. Determine if a period of stability is required or not	If it is required to wait for a period of stability.	$\Delta_R > \Delta$ (1.9684> 0.003).
	D. Determine if the period of stability has ended	The period of stability has ended	SP is 0.
	E. Determine if the policies to execute the handoff are accomplished	Policy 1 is not accomplished.	Because the DV > MRVD (4.13 > 1.75)
		Policy 2 is not accomplished.	Because the load of the battery is not between 25% y 30%
		Apply policy 3. The handoff is applied from the network gprs to the network 11 g1.	Because policies 1 and 2 were not accomplished.

Critical moment five: It occurs when the mobile node can reach the networks gprs and cdma 2000, taking place from t= 85 to t=127. The mobile node is located in the fourth straight line segment seg_15.

As in the previous critical moment, 11 b1 was the actual network, but it stops covering the mobile node in t=85. Then, the algorithm connects the node to the best network between the two reachable ones. Since cdma 2000 has a greater desirability (2.4382) than gprs (1.9890) the node connects to cdma 2000.

In t=91, the desirability of the actual network cdma 2000 is less than the desirability of the gprs network, so the preparation of a handoff starts. However, since the desirability of the actual network increments in the next time unit, there is no necessary to execute the handoff because the actual network keeps the greater desirability.

Conclusion of the results for the scenario B: The decisions taken by ARDE are opportune. When the handoff is executed, it has been verified the accomplishments of the conditions and policies described in this section.

In other hand, it was verified that the handoff is executed until the period of stability has ended. During this period it was proved that the desirability of the best netwok was greater than the desirability of the actual network, with the objective of avoiding handoff shoots to unstable networks.

6. Conclusions

Nowadays, the international scientific community is developing a series of vertical handoff decision algorithms. However, there are no appropriate tools to test them. Some of these tools are limited to homogeneous networks, and other ones to the use of two networks of different technologies. Related to this, some of them are expensive and difficult to use, because the interfaces are not friendly to the user and it is required than the user learn a programming language to carry out the simulation.

For this reason, it was decided to develop the simulator VHAND, which characteristics are:

- **Ease of use**. One of the main inconvenient of the simulators is its lack of usability. The design of VHAND was made having in mind to offer a friendly tool.

  So it was created a graphic interface constituted by elements which are familiar to the user (windows, buttons, mouse events, etc). Such interface lets to draw easily the scenarios of tests, using the mouse and its events: right click, "drag and drop", double clicks, etc.

  On the other hand, the process of creation of the tests scenarios was divided in stages (of assistant kind) in a logical way for the user, so it is easier to use.

  Creating a tool with the functionality said before was not trivial, since it required a wide knowledge in Math, Trigonometry and Physics to solve challenges, such as the simulation of the speed or to follow the mobile node through the path, the calculation of the distances between the base station and the position of the mobile node, the length of each segment in the path, the scale of the figures, among others.
- **Offers a modular design that makes its maintenance and extensibility to new algorithms easier**. For the design of the simulator, the tool was divided in modules,

with the objective of making some actions independents of its operation. Therefore, its architecture offers the necessary flexibility to implement the simulator in future versions, testing other handoff algorithms.

- **It is portable tool that is not limited to a specific database manager**. Thanks to the use of XML, the default data of the simulation are loaded from a plane text, which can be read in any platform and does not require a database manager.
- **It is a tool independent of the platform**. The application is a SWF file, compatible with any browser, becoming it in multiplatform. The application doesn't depend on the operative system, but the browser works with flash player.
- **It is a Web application with very few hardware and software requirements**. This characteristic makes the simulator accessible from any geographical point where Internet is available. Furthermore, it only requires a browser and the flash plug-in to see it. It doesn't require a high speed link; it can be used with a dial up connection because the size of the application is less to 200 Kb.

References

[1] González Horta, Francisco Alejandro. *Algoritmo sensible al contexto para la toma de decisiones correctas y oportunas en el proceso de handoff vertical*. Propuesta de tesis doctoral: ITESM Campus Morelos, México, Mayo, 2006.

[2] Zhu F. and McNair J. Artículo: *Optimization for vertical handoff decision algorithms*. WCNC 2004, IEEE Comm. Society, 2004.

[3] Zhang W.; Jahenert J.; Dolzer K. Artículo: *Design and evaluation of a handover decision strategy for 4th generation mobile networks*. 2005.

[4] Pegden, C. Dennis; Robert E. Shanon; Randall P. Sadowski. *Introduction to simulation using SIMAN*. McGraw-Hill International Editions, 1990.

[5] The Network Simulator - ns-2. Consultado el 30 de mayo de 2006 en http://nsnam.isi.edu/nsnam/index.php/User_Information

[6] Yañez-Mingot, Pablo Serrano. *Breve resumen de herramientas de simulación*. Universidad Carlos de Madrid. 26 de octubre de 2004. Consultado el 10 de marzo de 2006 en http://www.it.uc3m.es/pablo/simuladores/

[7] OPNET: Making Networks and Applications Perform. Consultado el 30 de enero de 2006 en http://www.opnet.com/

[8] Laila Daniel; Markku Kojo. *Adapting TCP for vertical handoff in wireless networks*. Consultado el 9 de mayo de 2006 en http://www.cs.helsinki.fi/u/kraatika/Courses/NodesSem05-6/Laila-060317.pdf#search=%22Adapting%20TCP%20for%20vertical%20handoff%20in%20wireless%20networks.%20%22

[9] Richard Rouil and Nada Golmie. IEEE 802.21 Media Independent Handover. Consultado el 9 de mayo de 2006 en http://www.ieee802.org/21/doctree/2006-03_meeting_docs/21-06-0524-00-0000-802_16_Parameter_Effects_on_Handover_Performance.ppt#256,1,Diapositiva 1

[10] National Institute of Standards and Technology. Seamless and Secure Mobility. Consultado el 9 de mayo de 2006 en http://w3.antd.nist.gov/seamlessandsecure.shtml

[11] Yi-Bing Lin; Imrich Chlamtac. *Wireless and Mobile Network Architectures*. John Wiley & Sons, Inc. 2001.

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