Description of a Heterogeneous Handoff Algorithm

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Abstract

The aim of this article is to describe the handoff decisions algorithm based on relating desirabilities called ARDE, by calculating a metric of desirability to decide where to make the handoff and by using policies that the same algorithm use to know the appropriate time to run it.

Keywords: *Heterogeneous handoff, handoff decision algorithm, ARDE, mobile technologies.*

1. Introduction

One of the most important features of a mobile network is the ability which allows users to move from one cell to another without losing network connection. The handoff is one aspect of mobility in a network of personal communication services [1] that occurs when a mobile user engages a telephone conversation and his/her mobile station is connected to the base station (BS) via radio link. If the mobile user moves to the coverage area of one new BS, the radio link to the "old" BS is disconnected, and a radio link to the “new” BS is transparently established to the mobile user to continue the conversation.

To perform a handoff is required several seconds, so if a user is making a phone call through a mobile device moves too fast, his/her call will be interrupted. The speed limit for analog systems usually does not exceed 110 km/hr. Some digital systems can operate at speeds exceeding 300 km/hr, which means it can be used in high-speed railways as the Japanese and European [2]. In [3] handoff is classified into Horizontal handoff and Vertical handoff (VHO). A Horizontal handoff is one that takes place between BS using the same type of wireless network interfaces. A Vertical handoff is one that takes place between BS using different types of wireless network interfaces.

Considering the fourth generation wireless networks (4G) are formed by a variety of overlapping integrated heterogeneous technologies, the necessity of having efficient handoff algorithms and handoff decision algorithms to decide at least correctly and timely where and when to execute a handoff , so the development of this work focuses on the Vertical handoff.

Several algorithms of vertical handoff decisions have been proposed in the literature, however , the design of handoff decision algorithms is still considered an open problem due to they have not been optimized yet to make the right, timely, reliable , robust, and secure decisions [4]. In this paper we describe the handoff decision algorithm called ARDE (Algorithm of Relative desirability) as well as the way in which they get their handoff criteria and policies to execute it.

2. Description of the Vertical handoff process

The Vertical handoff (VHO) is performed among BS using different types of wireless network interfaces [3]. Generally, the VHO process includes four phases: initiation, decision, execution and evaluation [5].

In the initial phase the reasons why it is necessary to make the handoff are established. A compelling reason to start the handoff is a degraded link quality, which results in a loss of the current connection. Another reason, although considered optional, is the presence of a new network which is "better" than the current network. In the decision phase, the mobile device performs the discovery of networks within its range, select the best based on criteria and choose the right time to change it based on policies. In the execution phase, the switching is done physically connecting the mobile node of current network to the new network. Finally, the evaluation phase determines how well the decision to switch network worked and how well is the quality of the applications.

3. ARDE description

The main function of the algorithm of handoff decision relative desirabilities (ARDE) is to decide where and when to make the handoff. To decide where to make the handoff, the decision algorithm is based on calculating a measure of desirability using parameters called handoff criteria. To decide when to make the handoff, the decision algorithm is

based on handoff policies that establish rules or conditions to run it at the appropriate time.
Initially, the mobile node is connected to a network (called current network) and continuously performs a discovery of the networks in its range according to its position. For each discovered network its desirability metric is calculated by using handoff criteria of each network and the corresponding weight assigned to each criterion.
Desirability metric for the network *m* at time *t* is defined by the equation (1):

$$D_m(t) = \sum_{i=1}^{n} W_{m,i} \ln(C_{m,i}(t)), where \sum_{i=1}^{n} W_{m,i} = 1 \qquad (1)$$

where $C_{m,i}(t)$ is the value of the ith handoff criterion for the network m at time t and $W_{m,i}$ is a value between 0 and 1 which represents the weight of the ith handoff criterion for network m.
The desirability is a value representing the degree of preference or acceptance that a network has at a given time. The decision algorithm assigns as the "best network" the one with the highest desirability.
Each criterion has an associated weight representing the preference or priority that the user assigns to a criterion over another. The addition of the same network weights must be one and if one criterion is not relevant to the user, the user can assign zero to its corresponding weight.
Handoff criteria are parameters of different kinds associated with access networks which enable us to measure the desirability of a network. Some of these parameters are: the quality of wireless links, the bandwidth of the network, packet latency, the actual rate of data transfer, the utilization rate of bandwidth and the cost of the connection. The criteria that contributes in a directly proportional way to the desirability are expressed as the natural logarithm of the criterion (eg bandwidth), whereas those which contribute in an inversely proportional way to the desirability are expressed as the natural logarithm of the reciprocal of the criterion (e.g. the cost of connection) [5].
Evaluating the desirability of the current network and the discovered networks continuously we can generate graphs of desirability for each network with regard to time. Desirability changes correspond to changes in the values of the handoff criteria that are dynamic. Figure 1 shows the curves of desirability of the access networks 1 and 2, represented by $D_1(t)$ and $D_2(t)$, and the handoff control parameters used by the decision algorithm ARDE when a handoff from network 1 to network 2 is performed.

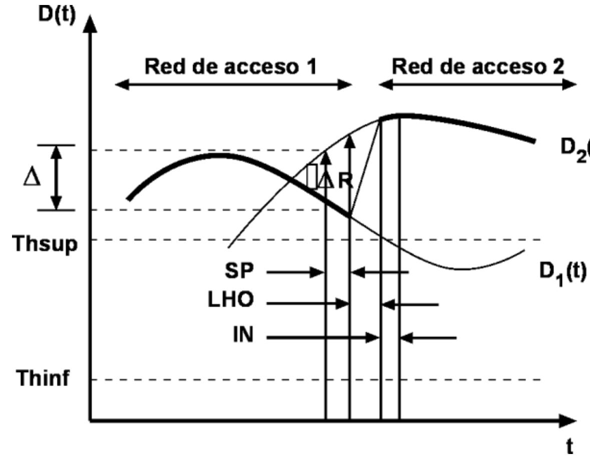

Fig 1. Algorithm control parameters.

The handoff control parameters illustrated in the above figure, are defined as:
• (ΔR) Relative Desirability: desirability difference between the best discovered network and the current network. It indicates how much better is the new network with regard to the current network. Its value is given by the relation $\Delta R(t) = D_{mejor}(t) - D_{actual}(t)$.
• (Δ) desirability hysteresis threshold: It is continuously compared with ΔR to determine whether the new network has the minimum level of desirability to initiate a handoff. So, only if $(\Delta R(t) \geq \Delta)$ the new network becomes the chosen network for handoff .
• (Thsup) higher desirability Threshold: It determines whether the necessity for a handoff is imperative. If the desirability of the current network is maintained above this value, there is no imperative requirement to make the handoff .
• (Thinf) lower desirability threshold: It represents the lower limit of acceptance that a net may have before being disconnected. If the desirability of the current network is less than this value, apps and the user will experience an interruption in their communications. When the desirability of discovered network is less than Thinf it will not be considered for choosing the best network.
• (SP) Stable period: It determines the decision algorithm waiting time before a handoff is executed in order to verify that the new network is stable. The handoff is executed only if the condition $(R(t) \geq \Delta)$ is accomplished during the period of stability.
• (IN) Period of instability: It determines the time after the handoff in which it is evaluated how accurate and timely was the handoff decision.
• (LHO) handoff latency: transition period of the mobile node connectivity from the current network to the new network.
Figure 2 shows graphically the ARDE decision algorithm.

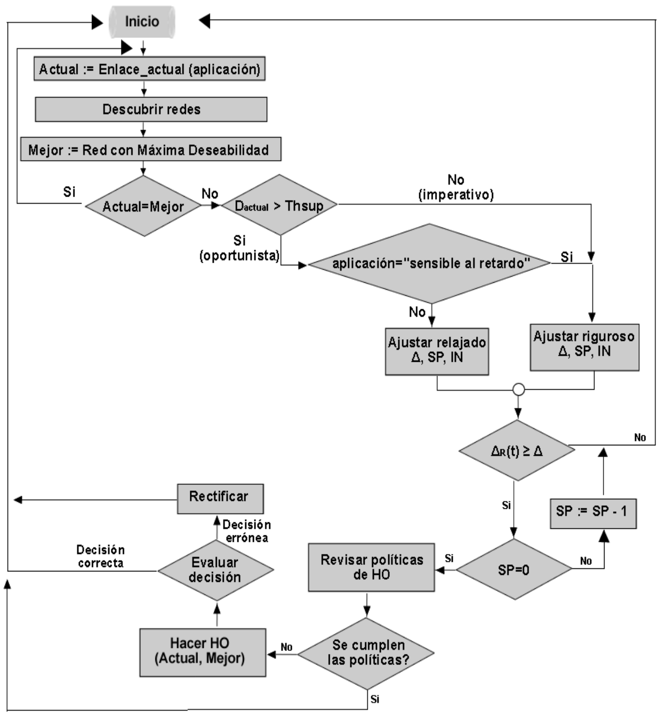

Fig 2 . ARDE flowchart.

4. Calculating handoff criteria

This section describes how to get the value of each of the nine criteria used by ARDE handoff to decide where to make the handoff.

Criterion 1: Distance from the mobile node to the base station

The distance of the mobile node to the base station is obtained for each instant of time as the mobile user moves through the path traced. This position is calculated by taking the distance (in meters) between the mobile node and the base station of the cell. This criterion value changes at every instant of time. If we assign the point (x_1,y_1) to the mobile node's position and the point (x_2,y_2) to the cell base station, the position of the mobile node is obtained with the equation (2). For purposes of calculation it is considered that the base station of each cell is located at the center thereof.

$$d = \sqrt{(y_2 - y_1)^2 + (x_2 - x_1)^2} \qquad (2)$$

Criterion 2: received signal strength (RSS)

The received signal strength (RSS) for the mobile node can be obtained with the equation (3) [6].

$$\frac{P_{out}}{P_{in}} = 10^{\frac{-\gamma(distancia)}{10}} \qquad (3)$$

where:

- P_{out} represents the power of the signal received (in mW).
- P_{in} represents the transmission power of the base station (in mW).
- *distancia* represents the distance (in Km) from the position of the mobile node to the position of the base station is located .
- γ represents the change of power in dB/Km.

The equation (4) is used to calculate the value of RSS:

$$RSS = potencia \quad del \quad punto \quad de \quad acceso * 10^{\frac{-\gamma(distancia)}{10}} \qquad (4)$$

The value of this criterion is obtained for every unit of time. Finally, as the RSS value is expressed in dBm, this value is converted to mW using the equation (5).

$$RSS_{mW} = 10^{\frac{RSS_{dBm}}{10}} \qquad (5)$$

Getting γ:
γ is a factor which represents the change of power, and its possible values are in the range of 0.1 to 1 dB/Km. Given this range of values, we used the central value of this range, i.e. the value of γ is 0.5 dB/km.
Regarding the power of the access point (or base station), this value is provided for each of the cells, which can be:

- For macrocells of 1000 mW to 4000 mW.
- For microcells 100 mW to 1000 mW.
- For picocell , from 0.25 mW to 2.5 mW.

For purposes of calculation, it is required that the given power in mW is expressed in dBm so we use the equation (6) for conversion, which uses a milliwatt (mW) as a reference , that is, 0 equivalent to 1 mW dBm.

$$Potencia_{dBm} = 10 Log \frac{Potencia_{mW}}{1mW} \qquad (6)$$

Finding *distancia*:
The distance value must be obtained for each unit of time. The distance to be calculated is from the mobile node's position to the base station. The calculation of this value is similar to the described value in criterion 1.

Criterion 3: Signal to Noise Ratio

The signal to noise ratio represented as SNR or S/N is the ratio of signal power and the noise power present at a particular point in the transmission. For convenience, this ratio is measured in decibels (dB) and it is given by the equation (7):

$$SNR_{dB} = 10Log_{10}\frac{S}{N} \qquad (7)$$

Where S represents the power of the received signal and N represents the noise power.
The equation (7) expresses the amount, in decibels, that the signal exceeds the noise level. A high SNR means a high quality signal. SNR value used will be between 0 and 50 dB [7].

Getting the value of S:
S is calculated using the equation (4), which provides the distance according to the position in which the mobile node is . The value of S is equal to the value of RSS obtained as criterion 2. RSS value expressed in mW is assigned to the variable S, ie S = RSS_{mW}.

Getting the value of N:
To calculate the value of N we perform the following procedure:
Step 1: It is calculated using the equation (4) but using as a distance the maximum coverage of the cell. The obtained RSS value is called RSS_{min} (in dBm).

$$RSS_{min} = potencia\ del\ punto\ de\ acceso * 10^{\frac{-\gamma(Cobertura_{máxima})}{10}}$$

Step 2: We calculate the maximum noise level for the cell assigning to this variable the minimum possible value of the RSS in the cell , i.e. $N0_{max} = RSS_{min}$.

Step 3: We subtract 3 dB to the value of $N0_{max}$ and the new value is assigned to the variable N0, i.e. $N0 = N0_{max}$ - 3dB.

Variable N0 is the average noise level, therefore, according to the decibel formula we have that

$$10Log\frac{2N0}{No} = 10Log2 = 10(0.30) = 3dB$$

where 3dB is the value we use in step 3 and 4.

Step 4: We calculate the minimal noise for the cell, assigning (N0-3) dB to this variable, i.e. $N0_{min}$ = N0 - 3dB

Step 5: The value of $N0_{max}$ and $N0_{min}$ will be the extreme values of noise whenever the mobile node is in this cell. To get the value of the noise N we will generate a random number between the minimum and maximum value of the noise. $N0_{min} \leq N \leq N0_{max}$.

Once the value of N in dBm is obtained, this value is converted to mW, using the equation (8).

$$N_{mW} = 10^{\frac{N_{dBm}}{10}} \qquad (8)$$

Finally, with the obtained value of S and N (both expressed in mW) the SNR value is calculated.

Criterion 4: Bit Error Rate (BER)

The BER is defined as the probability that a bit is received in error, it is a fraction of a bit sequence of messages received with an average error per million bits transmitted, the unit of measure are bits. For example, a value of 10^{-7} means that a bit in transmitted 10^{-7} bits would be wrong. According to [7], it should be noted that the value of SNR affects the rate of bits in error, so that an increase in SNR results in a decrease in the BER. Therefore, the BER value will be dependent on the obtained SNR value and will be randomly generated. The BER will be between 10^{-6} to 10^{-12} bits, as Table 1 shows.

Table 1. Considerated criteria for the value of BER.

SNR	BER
0 dB ≤ SNR ≤ 8 dB	10-6 ≤ BER ≤ 10-7
8 dB < SNR ≤ 10 dB	10-7 < BER ≤ 10-8
10 dB < SNR ≤ 25 dB	10-8 < BER ≤ 10-10
> 25 dB	10-10 < BER ≤ 10-12

Another factor affecting the BER is the interference and in reality this would affect the Wi-Fi and Bluetooth networks because of the use of the same frequency band. However, this work does not consider this situation because we do not have experiments to find a model for the BER where both signals Bluetooth and Wi–Fi are combinated.

Criterion 5: Prices of connection

This criterion refers to the cost that the user has to pay for connecting to a wireless technology. In this paper we consider that prices will be provided by the user for each of the considered wireless technologies which are: Bluetooth , 802.11a , 802.11b , 802.11g , GSM , GPRS , WIMAX , CDMA 2000 and UMTS .

Criterion 6: Bandwidth (BW)

Bandwidth (BW) is defined as the amount of information that can flow through a network connection over a period of time. In digital systems, the basic unit of bandwidth is bits per second (bps).
The bandwidth of each technology is represented in Kbps and it is described in Table 2 [7] [8] [9].

Table 2. Bandwidth of wireless access technologies.

Technology	Bandwidth	Bandwidth
Bluetooth	721 Kbps	721 Kbps
802.11 a	54 Mbps	55,296 Kbps
802.11 b	11 Mbps	11,264 Kbps
802.11 g	54 Mbps	55,296 Kbps
GSM	9.6 Kbps	9.6 Kbps
GPRS	171 Kbps	171 Kbps
WIMAX	15 Mbps	15,360 Kbps
CDMA 2000	2 Mbps	2,048 Kbps
UMTS	2 Mbps	2,048 Kbps

Criterion 7: Actual transfer rate

The actual transfer rate TTR, which is periodically calculated because it depends on the number of users that are connected to the network at any given time. To do this we use the equation (9).

$$Tasa\_de\_transferencia\_real = \frac{Ancho\_de\_banda\_total}{Cantidad\_de\_usuarios} \quad (9)$$

In relation to the number of users, we will take in consideration the value provided by the user to enter the number of connected users to each cell.
In relation to Bluetooth technology, to get the TTR, we divide 721 Kbps by the number of connected users to the picocell.
Relative to 802.11 technology, to 802.11a standard the value considerated as *Ancho_de_banda_total* depends on the distance between the mobile node and the access point. The same situation was considered for the standard 802.11g and 802.11b. These distances are shown in Tables 3 and 4 [8].
In relation to GSM technology, to obtain the *Ancho_de_banda_total* value, we consider the distance between the mobile node and the base station. This value is described in Table 5.
Regarding to GPRS technology we consider for the total bandwidth, the described values in Table 6 according to the distance between the mobile node and the base station and the velocity of the mobile node.
In relation to WiMAX technology we consider for the total bandwidth the described values in Table 7 according to the distance between the mobile node and the base station [10].
Regarding the CDMA 2000 and UMTS technology we consider the distance where the mobile node is located and the speed in which it travels. The used values are described in Table 8 [11].

Table 3. Total bandwidth of an *802.11a* and *802.11g* access points.

Distance (meters) 802.11 a	Distance (meters) 802.11g	Total bandwidth
0 < d ≤ 13	0 < d ≤ 27	55,296 Kbps
13 < d ≤ 15	27 < d ≤ 29	49,152 Kbps
15 < d ≤ 19	29 < d ≤ 30	36,864 Kbps
19 < d ≤ 26	30 < d ≤ 42	24,576 Kbps
26 < d ≤ 33	42 < d ≤ 54	18,432 Kbps
33 < d ≤ 39	54 < d ≤ 64	12,288 Kbps
39< d ≤ 45	64< d ≤ 76	9,216 Kbps
45 < d ≤ 50	76 < d ≤ 91	6,144 Kbps

Table 4. Total bandwidth of 802.11b access point.

Distance (meters)	Total bandwidth
0 < d ≤ 48	11,264 Kbps
48 < d ≤ 67	5,632 Kbps
67 < d ≤ 82	2,048 Kbps

Table 5. Total bandwidth of GSM technology.

Distance (meters)	Total bandwidth
0 < d ≤ 200	9.6 Kbps
200 < d ≤ 1000	4.8 Kbps
1000 < d ≤ 6000	2.4 Kbps

Table 6. Total bandwidth of GPRS technology.

	Speed range		
Distance (meters)	Stationary 0 < v ≤ 1 m/seg	Low mobility 1 m/seg < v ≤ 30 km/hr	High mobility 30 km/hr < v ≤ 200 km/hr
0 < d ≤ 200	171 Kbps	50 Kbps	9.6 Kbps
200 < d ≤ 1000	50 kbps	9.6 Kbps	4.8 Kbps
1000 < d ≤ 6000	9.6 kbps	4.8 Kbps	2.4 Kbps

Table 7. Total bandwidth of WIMAX technology.

Distance (meters)	Total bandwidth	Total bandwidth
0 < d ≤ 200	15 Mbps	15,360 Kbps
200 < d ≤ 1000	12 Mbps	12,288 Kbps
1000 < d ≤ 6000	2 Mbps	2,048 Kbps

Table 8. Total bandwidth of CDMA 2000 and UMTS .

	Speed range		
Distance (meters)	Stationary 0 < v ≤ 1 m/seg	Low mobility 1 m/seg < v ≤ 30 km/hr	High mobility 30 km/hr < v ≤ 200 km/hr
0 < d ≤ 200	2,048 Kbps	384 Kbps	144 Kbps
200 < d ≤ 1000	384 kbps	144 Kbps	64 Kbps
1000 < d ≤ 6000	144 kbps	64 Kbps	9.6 Kbps

Criterion 8: Latency or delay

The latency, sometimes called propagation delay is the time that a packet use to travel from origin to destination station. Latency is measured in seconds or fractions of a second.
In this paper we consider the latency is affected only by the type of application that runs the mobile node. If the application is a data application, we consider the propagation delay will be greater than 0 ms or even 1000 ms. If the application is a multimedia application we considered that the propagation delay will be greater than 0 ms or even 500 ms. These values are obtained ramdomly within the mentioned ranges above depending on the type of application.

Criterion 9: Bandwidth Utilization

The bandwidth utilization is the percentage of traffic that the network is managing at a given time. Its value is between 0 and 100%. A bandwidth utilization of 0% means that the bandwidth is fully free and 100% means you are taking up all the bandwidth.
The bandwidth utilization depends on the type of application. This use is related to the propagation delay. The value of using a bandwidth varies according to the number of connected users to the network, the type and number of applications that the user is running. In our case, we consider that for each line segment in which the user scrolls it only execute an app, which may be data or delay sensitive.
In this paper we consider that the user only runs an app and the number of connected users provides a 50% traffic and the remaining 50% depends on the type of app.
Then, to obtain the utilization of the bandwidth we used the equation (10).

$$U = \left(\frac{Número\_de\_usuarios\_conectados}{Número\_máximo\_de\_usuarios} * 0.5\right) + (Tipo\_de\_aplicación * 0.5) \quad (10)$$

Where *Tipo_de_aplicación* is equal to one when the app is sensitive to delay and is 0.5 when the application is a data application.
The user provides the *Número_de_usuarios_conectados* value when inputting the characteristics of each cell and *Número_máximo_de_usuarios* is a fixed value that depends on the cell type (7 for picocells, 15 for microcells and 50 for macrocells).

5. Policies for handoff execution

Once the decision algorithm finds a network with a better desirability regarding the current network, it starts preparing to execute a handoff. However, to decide a handoff, the decision algorithm verifies a set of policies that prevent the realization of frequent and unnecessary (oscillating) handoffs. The handoff policy we use are:
• If the estimated time of visit (VD) to the new cell is less than or equal to the required minimum visit time (MRVD where MRVD = SP + LHO + IN), ie (VD ≤ MRVD), then the handoff is unnecessary because oscillating handoffs can occur.
• If the battery of the mobile node is critical (between 25% and 30%) and the destination network requires more energy than the current network, then avoid making the handoff.
• If none of the above policies are accomplished, then execute the handoff from the source network to the destination network.

6. Conclusions

Currently, the international scientific community is developing a series of vertical handoff decision algorithms, however, not everyone considers correct and timely decisions as ARDE does, which are of great importance since they reflect a reality about the Vertical handoff process in its behavior.
This paper presented a description of a vertical handoff algorithm, which as a following step will be tested in a *vhand* simulator to evaluate its performance. This simulator is ready to test decision algorithms with complex heterogeneous scenarios which involve the overlaying of a variety of wireless technologies. In addition it has a friendly interface for users, so that they can apply graphs tools to construct scenarios in which the ARDE algorithm will be tested.

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