

A Fairness Load Balancing Algorithm in HWN Using a Multihoming Strategy

Y. Donoso, C. Lozano-Garzon, M. Camelo, P. Vila

Yezid Donoso

Universidad de los Andes
Bogotá, Colombia, South America
ydonoso@uniandes.edu.co

Carlos Lozano-Garzon

Universidad de los Andes
Bogotá, Colombia, South America
& Universitat de Girona, Girona, Spain.
calozanog@ieee.org

Miguel Camelo, Pere Vila

Universitat de Girona, Girona, Spain.
miguel.camelo@udg.edu, pere.vila@udg.edu

Abstract: Due to the growth of the number of intelligent devices and the broadband requirements, between others technical requirements, of the new applications, suppose a new challenge in planning, maintenance and resource allocation in mobile networks for the telecommunication operators. Service providers must ensure a quality of service for users in a new environment based in Heterogeneous Wireless Networks (HWN). A good way to achieve this goal is to prevent the quantity of services of each mobile users being connected to the same access networks and therefore reducing the possibility of overloading it. This paper presents a load balancing optimization scheme that enables operators to make decisions about re-allocation of each of the services in different access networks, keeping the required Quality of Service (QoS). In this paper, we propose 1) a mathematical model addressed as a fairness resource allocation in order to obtain a global load balancing, and 2) a two-step algorithm based on the anchor-adjustment heuristic to solve it. Our algorithm contribute to unload the network with maximum load while at the same time, the other networks are balanced. As a result, we show that our algorithm finds (near)-optimal solutions while keeps low complexity.

Keywords: Fairness, load balancing, multihoming, quality of service, heterogeneous wireless networks (HWN).

1 Introduction

Nowadays, mobile operators have a great challenge in planning, maintenance and optimization of their complex network infrastructure [2]. Many of these challenges are related to the continuous growth of both mobile subscriptions and mobile traffic; in [3] the Global mobile Suppliers Association estimates that there are around 1.3 billion of broadband mobile subscriptions in the second quarter of 2013, and that the monthly traffic was around 885 Petabyte in 2012 and is expected to reach to 11.2 Exabyte in 2017 [4]. This growing, together with the need of allowing a quality of service that ensures connectivity and mobility to its users, regardless of the access technology, constitute the main topic of our study.

Current infrastructure deployed by the majority of mobile operators is made up by a combination of radio access technologies (RAT). It is possible that during the network operation of the network some of these access channels could be overloaded due to a sudden growth of traffic. Hence it is necessary to perform a good management of the resource allocation, specifically bandwidth in this case, over all the access infrastructures. The final aim is to ensure a balance between the use of network resources and the number of user connections; likewise, operators must allow user mobility between technologies without users perceiving the change [5]. Thus, it is essential for operators to use decision-making algorithms to manage both their network resources and the connection of the services. This decision could be based on the QoS requirements, among other parameters, and it can be seen as a RAT selection process.

Combining the advantage of the existence of user equipment and network protocols to provide connections through multiple interfaces to different kind of networks [10], it would provide network benefits such as ubiquitous access, reliability, load balancing, among others [6]. Specifically, multihoming could separate a flow between multiple points of attachment (simultaneously active or not) of a node, usually by choosing the less loaded connection or according to preferences on the mapping between flows and interfaces. Following the latest idea, we initiated our study about the Always Best Connected (ABC) problem in HWN with an approach based on the possibility that the mobile user could make the decisions about which network it wants to be connected [7]. We designed a Vertical Handover (VHO) Decision Algorithm that allows the user terminal to start a proactive re-allocation of the mobile based on parameters such as: user preferences, QoS requirements, and network conditions. This process has as aim to avoid the over burdening of any interface.

In this paper, we propose an efficient decision-making algorithm to perform a load balancing by re-allocation of connected services among networks by using multihoming as main strategy. However, the decisions are made on the operator side by using both local and global information. The proposed algorithm is based on the anchor-adjustment heuristic proposed by Tversky and Kahneman in [8], which runs in quadratic time proportional to the number of mobiles in the network.

This paper extends the conference paper [1]. The key additions of this journal version are as follows. First, Section 2 describes several works about the use of multihoming in this research scenario. Second, this paper contains an additional explanation of the proposed model in Section 3 and the algorithm designed in Section 4. Finally, this paper contains an additional scenario composed by seven networks and a variable number of mobiles; our obtained results are contrasted with the results of round robin and least connected algorithms, two are the most used load balancing algorithms.

The remainder of this paper is organized as follows. In Section 2 we present the related work on load balancing in cellular networks using multihoming as main strategy. In Section 3 we introduce the mathematical model that encode the objective function to obtain a global load balancing among HWN under QoS constraints. In section 4 the load balancing algorithm based on the anchor-adjustment heuristic is presented. The experimental results about the performance of our proposal compared to round robin and least connected algorithms are shown in Section 5. Finally, concluding remarks and directions for further research are given in Section 6.

2 Related Work

Multihoming and Load Balancing strategies have been topics of several research projects. A mathematical model to load balancing is presented in [9]. This model aims to minimize the load of network by re-allocating services from the more loaded network. Sousa, Pentikousis and Curado present in [10] the architectural goals and system design principles for multihoming, and review

different approaches. In addition, they show in a survey, how multihoming is supported at the different levels of the OSI layers, covering all recent proposals based on a locator/identifier split approach. A mathematical model for heterogeneous network and its performance, considering both multihoming and network coding, is presented in [11]. They propose an optimal resource allocation by deciding which data should be transmitted on which interface and, simultaneously, which coding parameters should be used on the data. They showed that the combination of multihoming and network coding can improve significantly the service rate of Access Points (WiFi) and Base Stations (Cellular System) and reduce the system delay. An alternative technique based on traffic splitting using common radio resource management for Long Term Evolution (LTE) and High-Speed Downlink Packet Access (HSDPA) networks is presented in [12]. They propose a mathematical model to solve the traffic split problem. In their research, they found that to maximize the throughput it is necessary minimize the transmission delay between both networks. Then, the split ratios can be dynamically adjusted according to the channel qualities and the load status of the networks.

Some other research studies about the use of multihoming in the cellular heterogeneous networks are related with the VHO process. In [13], authors present a transport-layer scheme to support VHO between Universal Mobile Telecommunications System (UMTS) and Wireless Local Area Network (WLAN) using Stream Control Transmission Protocol (SCTP). Their method is based in the multihoming capability and the dynamic address reconfiguration extension of SCTP; through it, they obtain a decrease in handover delay and improve throughput performance. The study of Liu, Boukhatem, Martins and Bertin in [14] propose a multihoming approach to implement a seamless VHO for UMTS and WiMAX over integrated and tight coupling architectures. Based on these architectures, authors design a sublayer of OSI layer 2 to be added to the Radio Network Controller (RNC) and Mobile Station (MS); this sublayer implements a dual retransmission queue scheme to enable a soft handover that can eliminate packet losses and reduce handover latency significantly.

Paik et al. [15] also designed a seamless VHO mechanism using multihoming for mobile networks. They implement a multihomed mobile access point, which was tested over heterogeneous networks formed by Wireless Broadband Network (WiBro) and HSDPA access technologies. As a result, they obtained a significant reduction of handover latency by reducing IP connection latency. Authors in [16] also use the seamless handover and multihoming techniques but their aim was to increase the access availability, which is fundamental for QoS and critical services. They propose one method to calculate and distribute network topology information with estimated availability, which allows to predict the overall availability of accessible networks. This is a criteria, among others, used for a handover decision in the IMH 802.21 framework. To test the proposal they used three different access technologies, WLAN, WiMAX and UMTS.

Finally, other researchers have studied the use of multihoming as strategy to make a better distribution of the bandwidth charge. Sungwook and Varshney [17] worked on a dynamic on-line bandwidth reservation algorithm for some multimedia services over cellular networks. This algorithm was designed to control bandwidth according to the priority of traffic services and current network traffic conditions. Later, in [18] they proposed another adaptive on-line algorithm for the multimedia services but it is based on the minimization of the maximum available bandwidth in each cell in order to keep the load balancing. They compared the performance of both proposed schemes with the ABR scheme and the CAC provision scheme, obtaining an appropriate performance balance between contradictory requirements.

In this paper, we propose both a generic mathematical model to load balancing in HWN, which uses as a main objective function the concept of *fairness* over the networks, and a scalable two-step algorithm with low computational complexity that can be implemented by using VHO.

3 A Mathematical Model for Load Balancing

Since the resources are limited, an incorrect allocation could impact both the performance of the network and the satisfaction perception of the users. Therefore, it is necessary to define a mathematical model that encodes the requirements of the user, the environment constraints and the main target: to balance the load among different networks while ensuring the QoS requirements are met. In the following sections, we define the variables, functions and parameters of the mathematical model, and a solution that gives us an optimal distribution of loads across multiple networks under QoS constraints.

3.1 Network Load

Let N , M and S be the sets of n networks, m mobiles and s services that compose a Cellular System, respectively (See Figure 1). Additionally, let $y_{j,k} \in [0, 1]$ be a binary parameter that indicates if the service k of the mobile j is activated or not. We calculate the load of the network i (α_i) as the sum of demanded bandwidth (D_k) of each connected service (k), for each mobile (j) over the total capacity of the network channel (C_i).

$$\alpha_i = \frac{\sum_{j=1}^m \sum_{k=1}^s D_k \cdot x_{i,j}^k \cdot y_{j,k}}{C_i}, \forall i \quad (1)$$

Where $x_{i,j}^k = 1$ if the service k of the mobile j is connected to the network i , or 0 otherwise.

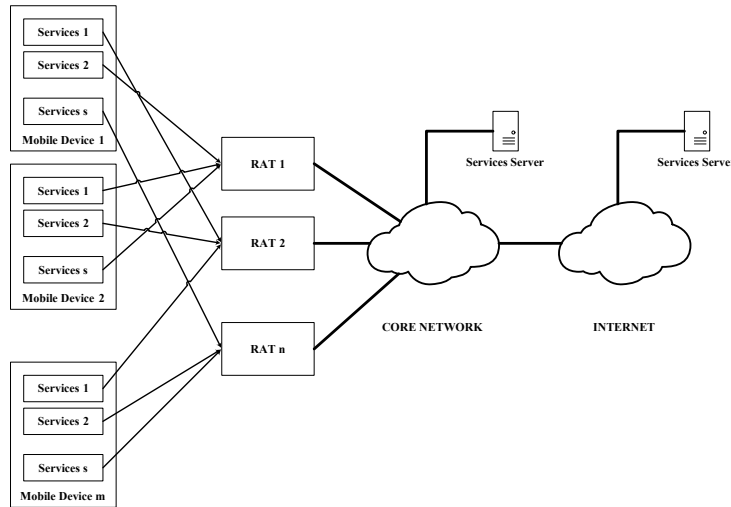


Figure 1: Multihoming Cellular System

3.2 Load Balancing: Jain's Index Functions

Fairness is a concept related with "equality" in the resource allocation widely used in many research fields, including those in Wireless Networks [19]. The Jain's Index function [20] can be formulated to measure the fairness of resource allocation among networks, i.e. it can give us an accurate measurement of how well-distributed is the network load in the Cellular System. This function can be formulated as follows:

$$f_1(\alpha) = \frac{[\sum_{i=1}^n \alpha_i]^2}{n \cdot \sum_{i=1}^n \alpha_i^2}, \alpha_i \geq 0, \forall i \quad (2)$$

$f_1(\alpha)$ is a continuous map in to the real interval $[0,1]$, where a value closer to 0 represent a unbalanced load in the system, whilst a value near to 1 represents a fairer allocation.

3.3 Constraints

In this model we need to consider several constraints in order to ensure the adjustment to the real-life networks. Some constraints are related to QoS requirements and others to the service connectivity.

QoS constraints

We consider only two QoS parameters in our modeling: Bandwidth and Signal Strength. However, it is important to remark that the model can be extended by including any other QoS requirements. The bandwidth is a resource that is not unlimited, therefore, it is necessary to ensure that all the services connected to a given network receive the requested bandwidth, otherwise the network must reject the connection. In other words, the service k of the mobile j can be connected to the network i if and only if:

$$D_k \cdot x_{i,j}^k \leq AB_i \quad \forall i \in N, \forall j \in M, \forall k \in S \quad (3)$$

Where AB_i is the available bandwidth of the network i .

The Received Signal Strength Indication (RSSI) is the relative received signal strength in a wireless environment. It measures the power level being received by the antenna, where higher values of the RSSI imply stronger received signals. If this value is below a certain threshold $RSSI_{th}$, we assume that the quality of the communication between the mobile and the base station is very poor. Thus, we can define that the service k of the mobile j can be connected to the network i if and only if:

$$x_{i,j}^k \leq z_{i,j}^k \quad \forall i \in N, \forall j \in M, \forall k \in S \quad (4)$$

Where the parameter $z_{i,j}^k = 1$ if $\frac{RSSI_{i,j}^k}{RSSI_{th}} \geq 1$, or 0 otherwise.

Activated services constraint

This constraint ensures that all activated services of each mobile device j must be connected to some network in N .

$$x_{i,j}^k \leq y_{j,k} \quad \forall i \in N, \forall j \in M, \forall k \in S. \quad (5)$$

Connectivity constraint

Through this constraint we ensure that each service used by the mobile j is connected to only one network.

$$\sum_{i=1}^n x_{i,j}^k = \max_{1 \leq i \leq n} \{z_{i,j}^k \cdot y_{j,k}\} \quad \forall j \in M, \forall k \in S. \quad (6)$$

Summary

A summary of the proposed mathematical model is presented as follows:

Maximize

$$f_1(\alpha) = \frac{[\sum_{i=1}^n \alpha_i]^2}{n \cdot \sum_{i=1}^n \alpha_i^2}, \alpha_i \geq 0 \quad (2)$$

Subject to

$$D_k \cdot x_{i,j}^k \leq AB_i, \quad \forall i \in N, \forall j \in M, \forall k \in S \quad (3)$$

$$x_{i,j}^k \leq z_{i,j}^k, \quad \forall i \in N, \forall j \in M, \forall k \in S \quad (4)$$

$$x_{i,j}^k \leq y_{j,k}, \quad \forall i \in N, \forall j \in M, \forall k \in S \quad (5)$$

$$\sum_{i=1}^n x_{i,j}^k = \max_{1 \leq i \leq n} \{z_{i,j}^k \cdot y_{j,k}\}, \quad \forall j \in M, \forall k \in S \quad (6)$$

$$x_{i,j}^k \in \{0, 1\}, \quad \forall i \in N, \forall j \in M, \forall k \in S \quad (7)$$

4 Proposed Algorithms

The resource allocation problem has been proved to be NP-Complete [21], therefore, an efficient algorithm that solves this problem is not known yet. In addition, our model includes an objective function (see equation 2) that can only be solved by Mixed-Integer Nonlinear Fractional Programming methods [22], which also difficult the possibility of finding an optimal solution even in small problems. Thus, it is necessary to implement heuristics that either solve the problem quickly or find an approximate solution when classic methods fail.

Based on the anchor-adjustment heuristic proposed in [8], we present a two-step algorithm that solves the above mathematical model in quadratic time proportional to the number of mobiles in the network. The proposed algorithm (see Algorithm 1) finds a (near)-optimal load balancing among networks by performing a re-allocation of connected services. Roughly speaking, the first step of the algorithm tries to balance the load of the network by distributing the services from the more loaded network to the one with minimum load. Second step performs an optimization on the result obtained from the first one by using a load distribution method with local information.

Algorithm 1 Two-Step algorithm based on anchor-adjustment heuristic

Require: List of the set of Available Networks $AN_{j,k} = \{t_1, \dots, t_p\}, \forall j \in M, \forall k \in S$ and $p \leq n$

Require: Set of actual connection of mobiles and their services $X = \{x_{1,1}^1, \dots, x_{n,m}^s\}$

Ensure: A (re) allocation of each used service by each connected mobile device.

- 1: Call Anchor algorithm based on a Max-Min strategy at network level (Algorithm 2)
 - 2: Call Adjustment algorithm based on local information (Algorithm 3)
 - 3: **return** A set of connections of mobiles and their services $X = \{x_{1,1}^1, \dots, x_{n,m}^s\}$
-

We assume that for each mobile $j \in M$ and each service $k \in S$ of j , we have access to the set of available networks $AN_{j,k} = \{t_1, \dots, t_p\}, \forall j \in M, \forall k \in S$ and $p \leq n$, which is derived by selecting those networks that meet both requirements the RSSI threshold and the available bandwidth (see constraints 3 and 4). We will see below that the time complexity of this two-step algorithm is bounded by $O(m^2)$, when $m \gg n$ and $m \gg s$.

4.1 First Step: Anchor based on a Max-Min strategy at network level

Given the set N of networks and a valid set of connections $X = \{x_{1,1}^1, \dots, x_{n,m}^s\}$, i.e. set of connections that meet the constraints 5 and 6, the algorithm finds the network $i_{max} \in N$ with maximum load $\alpha_{i_{max}}$ and selects a random service k connected to it. Then, k is moved to the available network with minimum load $i_{min} \in N$ that is available for k . In case that there are no alternative networks to connect s , i.e. either there are not more reachable networks to connect the service or all the networks have the same load, the service is not re-allocated. Note that although the Algorithm 2 can obtain an optimal load balancing among networks in most cases, the addition of constraints into the mathematical model may permit that the algorithm can be stuck in local minimum. For example, if all services connected to $i_{max} \in N$ have not alternative networks to move, then the algorithm can not perform a load balancing among any network. The load balancing is obtained by the assignation of each service to the feasible network with the minimum load at that moment.

Algorithm 2 Anchor based on a Max-Min strategy at network level

Require: List of the set of Available Networks $AN_{j,k} = \{t_1, \dots, t_p\}, \forall j \in M, \forall k \in S$ and $p \leq n$

Require: Set of actual connections of mobiles and their services $X = \{x_{1,1}^1, \dots, x_{n,m}^s\}$

Ensure: A (re) allocation of each used service by each connected mobile device.

```

1:  $i_{max} \leftarrow 0, i_{min} \leftarrow 0, l \leftarrow 0;$ 
2: repeat
3:   Compute  $\alpha_i, \forall i \in N;$ 
4:    $i_{max} \leftarrow i \mid i \in N$  and  $\max_i \{\alpha_i\};$ 
5:   Select any  $x_{i,j}^k = 1 \mid i = i_{max};$ 
6:    $i_{min} \leftarrow t \mid t \in AN_{j,k}$  and  $\min_t \{\alpha_t\};$ 
7:   if  $\alpha_{i_{min}} < \alpha_{i_{max}}$  then
8:      $x_{i_{max},j}^k = 0, x_{i_{min},j}^k = 1;$ 
9:   end if
10:   $l = l + 1$ 
11: until  $l = m \cdot s$ 
12: return A set of connections of mobiles and their services  $X = \{x_{1,1}^1, \dots, x_{n,m}^s\}$ 

```

The complexity of the Algorithm 2 is $\Theta(m^2 \cdot s^2)$, where m is the number of mobile devices, and s the number of services. Remark that although the main loop has $\Theta(m \cdot s)$ iterations, step 6 of the algorithm implies to find the services connected to a specific network. This operation takes at most $\Theta(m \cdot s)$ steps, i.e. we need to classify each mobile and its services regarding which network they are connected to.

4.2 Second Step: Adjustment based on local information

Algorithm 4.2 uses the result of the Algorithm 2, and tries to improve the allocation of services by using an iterative process of adjustment. The algorithm iterates on each $j \in M$ and moves each one of its service k to its available network with minimum load. In case that there are no alternative networks to connect the service k , i.e. either there are not more reachable networks to connect the service or all the networks have the same load, the service is not re-allocated.

Observe that Algorithm 3 permits to leave local optimal from Algorithm 2 in a greedy way: in each iteration, the service $k \in S$ of each mobile $j \in M$ is moved to its less loaded available network (local information). However, we can not ensure an optimal solution at the end of Algorithm 3 because in each iteration, the actual load of the networks has been influenced by

both the initial allocation of services (from step 1) and the allocation of services performed before the current iteration.

Algorithm 3 Adjustment based on local information

Require: List of the set of Available Networks $AN_{j,k} = \{t_1, \dots, t_p\}, \forall j \in M, \forall k \in S$ and $p \leq n$

Require: Set of actual connection of mobiles and their services $X = \{x_{1,1}^1, \dots, x_{n,m}^s\}$

Ensure: A (re) allocation of each used service by each connected mobile device.

```

1: for  $1 \leq j \leq m$  do
2:   for  $1 \leq k \leq s$  do
3:      $i_{act} \leftarrow i \mid x_{i,j}^k = 1;$ 
4:      $i_{min} \leftarrow t \mid t \in AN_{j,k}$  and  $\min_t \{\alpha_t\};$ 
5:     if  $\alpha_{i_{min}} < \alpha_{i_{act}}$  then
6:        $x_{i_{act},j}^k = 0, x_{i_{min},j}^k = 1;$ 
7:     end if
8:   end for
9: end for
10: return A set of connections of mobiles and their services  $X = \{x_{1,1}^1, \dots, x_{n,m}^s\}$ 

```

We found that the complexity of the Algorithm 3 is $\Theta(m \cdot s)$, where m is the number of mobile devices, and s the number of services. Note that this algorithm has a linear time complexity with respect to the total number of mobiles. In general, the combination of Algorithm 2 and 3 gives us a time complexity equal to $\Theta(m \cdot s + m^2 \cdot s^2)$. However, since the number of mobiles is usually larger than the number of services and networks, the time complexity of the Algorithm 1 has as upper bound $O(m^2)$.

5 Experimental Results

We propose an experimental environment composed for seven different radio access technologies and a finite number of mobile devices, each one with at most three different network interfaces to supporting data, voice, and video services.

Table 1: Access Network Bandwidth

Network	EDGE	HSPA	WiMax	HSPA+	WiFi G	WiFi N	LTE
Bandwidth(Mbps)	0.384	14.4	37.0	42.0	54.0	100	100

Table 2: Requested Bandwidth for Service

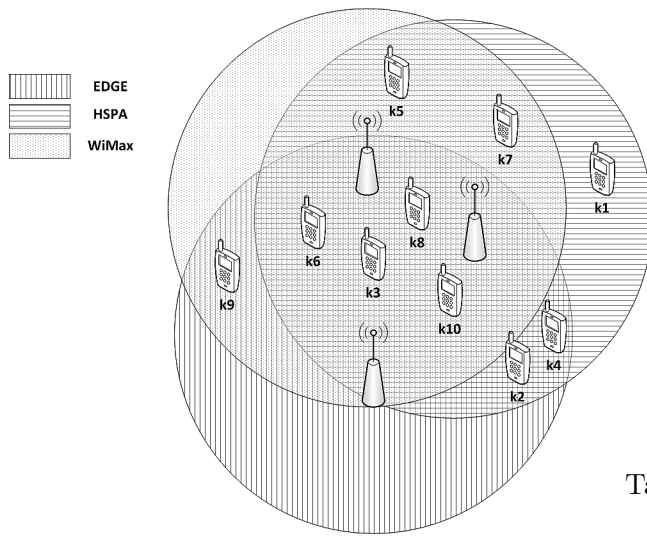
ID	Service	Required Bandwidth (Mbps)
1	Voice	0.012
2	Data	0.028
3	Video	0.128

Tables 1 and 2 show the characteristics of each access network and the minimum required bandwidth to ensure QoS for each service. To verify the efficiency and effectiveness of our algorithm, we compare the solutions found by our algorithm with respect to those obtained by solving the mathematical model and by using both the Round Robin and Least Connected algorithms. The mathematical model was implemented in GAMS [23], and it was solved by using the global optimization solver BONMIN (Basic Open-source NonlinearMixed INteger programming) [24].

Two different scenarios to evaluating the proposed algorithm are presented in the following sub-sections.

5.1 Scenario 1: Three networks and 10 mobiles

The first scenario is composed of three networks (WiMax, EDGE and HSPA) and 10 mobile devices, where each one of them has two activated services: data and voice. Mobiles are randomly distributed among networks and the RSSI threshold is set to 10. Figure 2, and Table 3 show the distribution of mobiles among the networks and the RSSI values of each mobile according to a random distribution. Table 4 (a) presents an initial connection matrix, which is the result of a random selection process on the mobile RSSI matrix, which ensures the required bandwidth of each service.



Mobile	WiMax	EDGE	HSPA
k1	0	3	26
k2	9	27	23
k3	16	19	29
k4	5	15	12
k5	29	4	12
k6	14	17	24
k7	24	8	29
k8	15	14	18
k9	28	15	0
k10	19	21	11

Table 3: RSSI for each mobile in scenario 1

Figure 2: Distribution of mobiles in scenario 1

(a)			(b)			(c)		
Mobile ID	Service 1	Service 2	Mobile ID	Service 1	Service 2	Mobile ID	Service 1	Service 2
k1	HSPA	HSPA	k1	HSPA	HSPA	k1	HSPA	HSPA
k2	HSPA	HSPA	k2	HSPA	HSPA	k2	EDGE	HSPA
k3	EDGE	EDGE	k3	WiMax	WiMax	k3	WiMax	WiMax
k4	HSPA	HSPA	k4	HSPA	HSPA	k4	HSPA	HSPA
k5	HSPA	HSPA	k5	HSPA	HSPA	k5	WiMax	WiMax
k6	EDGE	EDGE	k6	WiMax	WiMax	k6	WiMax	WiMax
k7	HSPA	HSPA	k7	HSPA	HSPA	k7	WiMax	WiMax
k8	EDGE	EDGE	k8	WiMax	WiMax	k8	HSPA	WiMax
k9	EDGE	EDGE	k9	WiMax	WiMax	k9	WiMax	WiMax
k10	EDGE	EDGE	k10	WiMax	WiMax	k10	WiMax	WiMax
Jain's Index = 0.3510			Jain's Index = 0.5586			Jain's Index = 0.6653		

Table 4: Connection of services: (a) Initial, (b) obtained from Algorithm 2, and (c) obtained from Algorithm 3

From the initial connection matrix, the computed Jain's Index (See function (2)) was 0.3510 (See Table 4 (a)). Once we ran the Algorithm 2, this value raised up to 0.5586 (See Table 4 (b)). Finally, by using the connection matrix resulting from Algorithm 2 as input for 3, the Jain's Index increased to 0.6653 (See Table 4 (c)), while the optimal value of such function calculated by BONMIN was 0.7070 in 17 seconds (See Table 5). We emphasize that the solution found by our proposal has only a relative error of 5.9% with respect to the optimal one, and its execution time was less than 1 second.

Mobile ID	Service 1	Service 2
k1	HSPA	HSPA
k2	HSPA	HSPA
k3	WiMax	WiMax
k4	HSPA	HSPA
k5	HSPA	WiMax
k6	WiMax	HSPA
k7	HSPA	HSPA
k8	EDGE	HSPA
k9	WiMax	WiMax
k10	WiMax	WiMax
Jain's Index = 0.7070		

Table 5: Optimal connection of services

5.2 Scenario 2: Seven networks and a variable number of mobiles

In this scenario, we show the behavior of the proposed algorithm when the number of mobiles is increased. The scenario is composed for seven different radio access networks (EDGE, HSPA, WiMax, HSPA+, WiFi G, WiFi N, and LTE), and a set of a distributed randomly mobile devices over those networks, where each one has three activated services and the number of them is increased from 10 to 1000. We also implement both the round Robin (RR) and Least Connected (LC) algorithms [25] to compare their performance with respect to our proposed algorithm. The pseudo-codes of these algorithms are described in Algorithms 4 and 5. It is important to note that our version of RR and LC also include a random selection process when the next network in the list can not be reached by a given mobile.

Algorithm 4 Round Robin Algorithm

Require: List of the set of Available Networks $AN_{j,k} = \{t_1, \dots, t_p\}, \forall j \in M, \forall k \in S$ and $p \leq n$

Require: Set of actual connection of mobiles and their services $X = \{x_{1,1}^1, \dots, x_{n,m}^s\}$

Ensure: A (re) allocation of each used service by each connected mobile device.

```

1:  $i_{new} \leftarrow -1$ ;
2: for  $1 \leq j \leq m$  do
3:   for  $1 \leq k \leq s$  do
4:      $i_{act} \leftarrow i \mid x_{i,j}^k = 1$ ;
5:      $i_{new} \leftarrow (i_{new} + 1) \bmod (n - 1) + 1$ ;
6:     if  $t_{i_{new}} \in AN_{j,k}$  then
7:        $x_{i_{act},j}^k = 0, x_{i_{new},j}^k = 1$ ;
8:     else
9:        $i \leftarrow$  Select a random network index from  $AN_{j,k}$ ;
10:       $x_{i_{act},j}^k = 0, x_{i,j}^k = 1$ ;
11:    end if
12:  end for
13: end for
14: return A set of connections of mobiles and their services  $X = \{x_{1,1}^1, \dots, x_{n,m}^s\}$ 

```

Algorithm 5 Least Connected Algorithm

Require: List of the set of Available Networks $AN_{j,k} = \{t_1, \dots, t_p\}, \forall j \in M, \forall k \in S$ and $p \leq n$

Require: Set of actual connection of mobiles and their services $X = \{x_{1,1}^1, \dots, x_{n,m}^s\}$

Ensure: A (re) allocation of each used service by each connected mobile device.

```

1:  $i_{new} \leftarrow -1;$ 
2: for  $1 \leq j \leq m$  do
3:   for  $1 \leq k \leq s$  do
4:      $i_{act} \leftarrow i \mid x_{i,j}^k = 1;$ 
5:      $i_{new} \leftarrow$  Network with less number of connections;
6:     if  $t_{i_{new}} \in AN_{j,k}$  then
7:        $x_{i_{act},j}^k = 0, x_{i_{new},j}^k = 1;$ 
8:     else
9:        $i \leftarrow$  Select a random network index from  $AN_{j,k};$ 
10:       $x_{i_{act},j}^k = 0, x_{i,j}^k = 1;$ 
11:    end if
12:  end for
13: end for
14: return A set of connections of mobiles and their services  $X = \{x_{1,1}^1, \dots, x_{n,m}^s\}$ 

```

# Mobiles	Optimal	Without Vertical HandOver	Relative Error	Proposed Algorithm	Relative Error
10	0.852	0.231	0.729	0.717	0.158
30	0.890	0.173	0.806	0.890	0.000
50	0.991	0.179	0.819	0.767	0.226
70	0.999	0.174	0.826	0.769	0.230
100	0.955	0.176	0.816	0.882	0.076
200	1.000	0.176	0.824	0.784	0.216
300	1.000	0.172	0.828	0.841	0.159
400	1.000	0.170	0.830	0.878	0.122
500	0.945	0.169	0.821	0.939	0.006
600	0.975	0.171	0.825	0.973	0.002
700	0.991	0.172	0.826	0.990	0.001
800	0.998	0.172	0.828	0.997	0.001
900	1.000	0.173	0.827	0.999	0.001
1000	1.000	0.173	0.827	0.998	0.002

Table 6: Computed Jain’s Index: Optimal, Without Vertical HandOver and using the proposed algorithm

# Mobiles	Round Robin	Relative Error	Least Connected	Relative Error
10	0.162	0.810	0.174	0.796
30	0.198	0.778	0.248	0.721
50	0.216	0.782	0.256	0.742
70	0.244	0.756	0.307	0.693
100	0.490	0.487	0.338	0.646
200	0.500	0.500	0.409	0.531
300	0.659	0.341	0.515	0.485
400	0.624	0.376	0.589	0.411
500	0.682	0.278	0.646	0.316
600	0.709	0.273	0.686	0.296
700	0.783	0.210	0.712	0.282
800	0.815	0.183	0.758	0.240
900	0.829	0.171	0.781	0.219
1000	0.860	0.140	0.737	0.203

Table 7: Computed Jain’s Index: Round Robin and Least Connected Algorithms

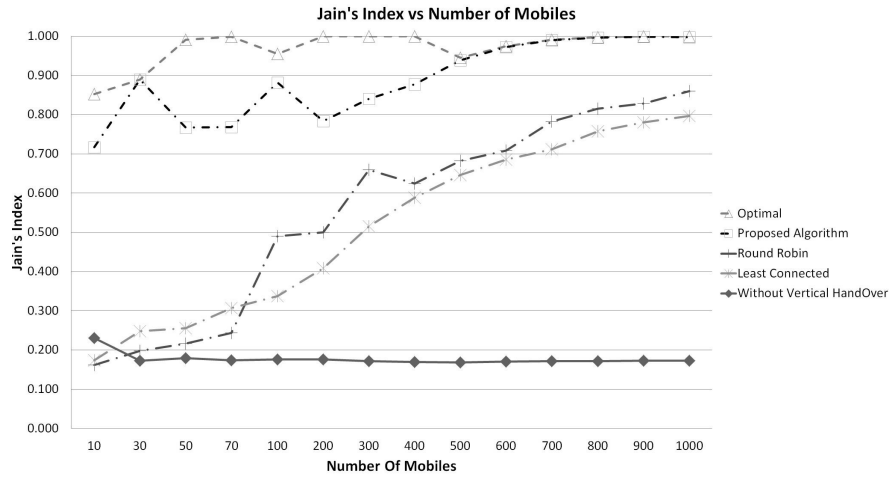


Figure 3: Effectiveness of the proposed algorithm

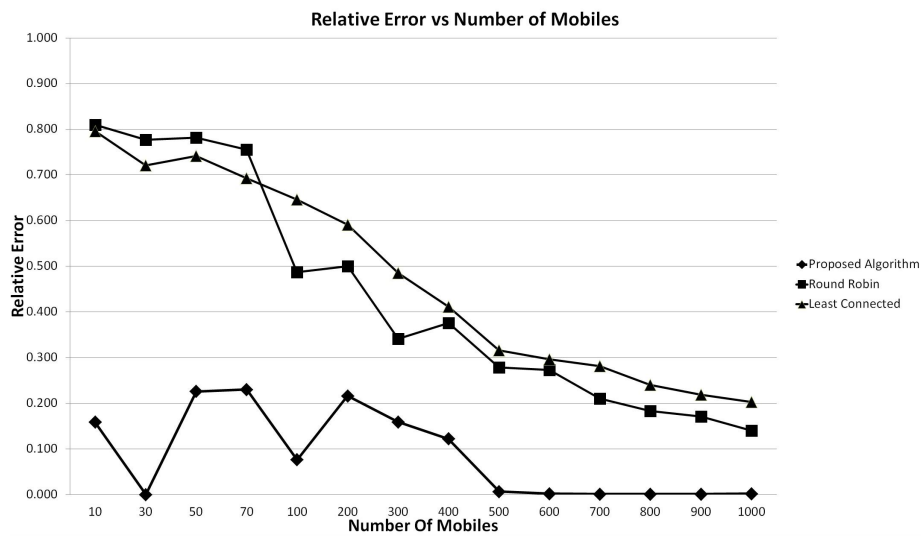


Figure 4: Relative error of the proposed algorithm

Table 8: Final network load and the computed Jain's Index for the instances of 30, 500 and 1000 mobiles

Network	Number of Mobiles								
	30			500			1000		
	PA	RR	LC	PA	RR	LC	PA	RR	LC
HSPA	2.14%	5.22%	11.31%	24.83%	96.08%	99.89%	48.89%	93.81%	99.11%
HSPA+	1.52%	1.90%	1.78%	23.80%	32.72%	41.53%	48.25%	76.98%	70.10%
WIMAX	1.74%	3.07%	2.53%	24.22%	39.37%	67.36%	47.89%	90.36%	99.63%
LTE	1.35%	0.70%	0.50%	23.89%	14.57%	6.01%	48.16%	29.38%	19.41%
EDGE	3.23%	68.75%	48.96%	43.75%	45.83%	94.79%	54.08%	54.17%	98.96%
WiFi N	1.36%	0.99%	0.70%	24.18%	12.46%	5.36%	48.26%	29.07%	14.02%
WiFi G	1.35%	0.74%	0.61%	24.18%	27.11%	28.72%	48.01%	55.69%	99.27%
Jain-s Index	89.05%	19.84%	24.84%	93.94%	68.23%	64.61%	99.82%	86.01%	79.73%

Tables 6 and 7 show the computed Jain's Index and the relative error of the solutions found by Round Robin (RR), Least Connected (LC) and the proposed (PA) algorithms. It is important to remark that for the instances between 100 and 1000 mobile devices, we relaxed the variable $x_{i,j}^k$ to accept real values between 0 and 1 in order to obtain a lower bound for those instances by nonlinear programming. As you can see in Figure 3 our proposed algorithm obtains a near optimal solutions when the number of mobiles is increased. Compared to RR and LC, we can see in Table 8 that our algorithm converge to the optimal values obtaining a fairness load balancing. The results obtained shows that the convergence of RR and LC to the optimal values of Jain's Index is due to the networks being loaded up to 100% instead of a fairness load balancing in fact.

It is appropriate to note that without vertical handover, the Jain's Index of the networks was low, and therefore the initial network load is unbalanced. Once we executed our algorithm, we observed that the resulting resource allocation had given us solutions with relative error less than 23% in the first instances. However, when the size problem increases, our algorithm presents a better convergence towards the optimal solution. Figure 4 shows how the relative error converges to zero when the number of mobiles is increased.

6 Conclusions and Future Work

In this paper, we have presented a load balancing optimization model using multihoming approach in heterogeneous wireless networks. In this approach, we have worked with different wireless access networks like HSDPA, HSPA+, Edge, WiMax, WiFi and LTE. Furthermore, in this paper we designed and implemented a Vertical Handover (VHO) Algorithm following the Always Best Connected scheme. It allows to give a solution, in a proactive way, for re-allocation of services when a new access network is available. It is also best to provide the required resources. Our proposed algorithm gives a solution to global optimality.

The resource allocation problem has been proved to be NP-Complete and we have proposed an algorithm that calculates the best load balancing solution in heterogeneous wireless networks using a multihoming approach in polynomial time $O(m^2)$.

The mathematical optimization model was computed by using the solver called BON-MIN (Basic Open-Source Nonlinear Mixed Integer Programming) and their results were compared with our proposed algorithm. Simulation results showed that without vertical handover, the initial value of the Jain's Index was very low, which means that the initial load balancing of the network was poor. However, the proposed algorithm solved the load balancing optimization model with nearly the same values as the ones given by the optimal solution obtained with the BONMIN solver.

Finally, when the number of mobiles was increased, the results obtained by our algorithm were very close to the optimal ones from the mathematical optimization model.

In further studies, we will consider researching the applicability of Evolutionary Algorithms for a multi-objective load-balancing scheme. In the technical scheme, we are going to work to implement this algorithm like a functional protocol.

Acknowledgments

The authors acknowledge to the Administrative Department of Science, Technology and Innovation (COLCIENCIAS) for the financial support to Carlos Lozano-Garzon through the 528 - 2011 National Call for Doctoral Studies in Colombia, and to the Comissionat d'Universitats i Recerca (CUR), which is part of the Departament de innovacion, universitats i empreses (DIUE) of the Generalitat de Catalunya, the ROGER project (TEC 2012-32336) of the Spanish Government, the CSI project (SGR-1202) of the Generalitat de Catalunya, and the European Social Fund through the financial support given in the grant FI-DGR 2011 to Miguel Camelo.

Bibliography

- [1] Donoso Y., Lozano-Garzon C., Camelo M., Vila P.(2014); A Multihoming Load Balancing Algorithm for a Fairness Resource Allocation in Heterogeneous Wireless Networks, International Conference on Computers, Communications & Control, Romania, Oradea, Baile Felix, May 6-10, 2014, *Abstracts of ICCCC 2014*, ISSN 1844-4334, 4: 43.
- [2] Donoso Y. (2008); *Network Design for IP Convergence*, Auerbach Pubn, ISBN 978-1420067507.
- [3] Global Mobile Suppliers Association, *GSM/3G Stats. Fast Facts*, Global Mobile Suppliers Association, available at <http://www.gsacom.com/news/statistics.php4>.
- [4] CISCO (2013); *Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2012-2017*, Cisco, San Jose, CA, USA.
- [5] Kumar S., Anand S.(2011); A novel scalable software platform on android for efficient QoS on android mobile terminals based on multiple radio access technologies, *Wireless Telecommunications Symposium (WTS)*, New York City, 1-6.
- [6] Ernst T., Montavont N., Wakikawa R., Ng C., Kuladinithe K. (2008); Motivations and Scenarios for Using Multiple Interfaces and Global Addresses, Draft IETF Monami6 Working Group, 2008.
- [7] Lozano-Garzon C., Ortiz-Gonzalez N., Donoso Y.(2013); Mobile Network A Proactive VHD Algorithm in Heterogeneous Wireless Networks for Critical Services, *International Journal of Computers Communications & Control*, ISSN 1841-9844, 8(3): 425-431.
- [8] Tversky A., Kahneman D. (1974); Judgment under Uncertainty: Heuristics and Biases, *Science*, ISSN 0036-8075, 185: 1124-1131.
- [9] Donoso Y., Fabregat R.(2007); *Multi-Objective Optimization in Computer Networks Using Metaheuristics*, Auerbach Pubn, ISBN 978-0-8493-8084-6.
- [10] Sousa B.M., Pentikousis K., Curado M.(2008); *Multihoming Management for Future Networks*, Mobile Network Application, ISSN 1383-469X, 16(4):505-517.
- [11] Capela N., Sargento S. (2012); Optimizing Network Performance with Multihoming and Network Coding, *Globecom Workshops, 2012 IEEE*, 210-215.
- [12] Ruiming Y., Yongyu C., Jia S., Dacheng Y. (2012); Traffic Split Scheme Based on Common Radio Resource Management in an Integrated LTE and HSDPA Networks, *Vehicular Technology Conference (VTC Fall), 2012 IEEE*, 1-5.

- [13] Li M., Yu F., Leung, V.C.M., Randhawa T. (2004); A New Method to Support UMTS/WLAN Vertical Handover using SCT, *IEEE Wireless Communications*, 11(4):44-51.
- [14] Liu B., Boukhatem N., Martins P., Bertin, P. (2010); Multihoming At Layer-2 For Inter-RAT Handover, *2010 IEEE 21st International Symposium on Personal Indoor and Mobile Radio Communications (PIMRC)*, 1173-1178.
- [15] Paik E.K., Heo S.Y., Kim H., Jin J.S., Lee S.C., Lee S.H. (2008); Seamless Vertical Handover Using Multihomed Mobile Access Point, *2008 IEEE Global Communications Conference*, 1-4.
- [16] Folstad E.L., Helvik B.E. (2009); Managing availability in wireless inter domain access, *International Conference on Ultra Modern Telecommunications & Workshops*, 1-6.
- [17] Sungwook K., Varshney, P.K. (2002); An Adaptive Bandwidth Reservation Algorithm for QoS Sensitive Multimedia Cellular Networks, *2002 IEEE 56th Vehicular Technology Conference*, 3:1475-1479.
- [18] Sungwook K., Varshney, P.K. (2003); Adaptive Load Balancing with Preemption for Multimedia Cellular Networks, *2003 IEEE Wireless Communications and Networking (WCNC)*, 3: 1680-1684.
- [19] Shi H., Prasad V., Onur E., Niemegeers I. (2013); Fairness in Wireless Networks:Issues, Measures and Challenges, *IEEE Communications Surveys & Tutorials*, ISSN 1553-877X, 5-24.
- [20] Jain R., Chiu D.M., Hawe W.R., *A Quantitative Measure Of Fairness And Discrimination For Resource Allocation In Shared Computer Systems*, DEC Research Report TR-301, 1984.
- [21] Bayrak A. E., *Optimization algorithms for resource allocation problem ff air tasking order preparation*, Master Thesis, Middle East Technical University, available at etd.lib.metu.edu.tr/upload/12612325/index.pdf.
- [22] Mond. B, Craven B. D. (1975); Non-Linear fractional programming, *Bulletin of the Australian Mathematical Society*, 12(3) : 391-397.
- [23] GAMS Development Corporation, *The General Algebraic Modeling System (GAMS)*, Retrieved November 2013, from <http://www.gams.com/>.
- [24] Computational Infrastructure for Operations Research, *BONMIN and BONMINH Solvers*, available at <http://www.gams.com/dd/docs/solvers/coin.pdf>.
- [25] Teo Y. M., Ayani R. (2001); Comparison of Load Balancing Strategies on Cluster-based Web Servers, *Simulation*, 77(5-6): 185-195, 2001.