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Multichannel Allocation Spectrum Model with Fairness Criterion for Cognitive Radio Networks

Cesar Hernández

Universidad Distrital Francisco José de Caldas, Bogotá, Colombia
Universidad Nacional de Colombia, Bogotá, Colombia

Hans Márquez

Universidad Distrital Francisco José de Caldas, Bogotá, Colombia

Luis Pedraza

Universidad Distrital Francisco José de Caldas, Bogotá, Colombia
Universidad Nacional de Colombia, Bogotá, Colombia

Abstract

The inefficient use of the spectrum with the services which each time demand more bandwidth has generated a problem regarding the effective allocation of the spectrum and how to make a better use of it. The present paper develops a model of multiple channel allocation that allow to use in a more efficient way the spectrum opportunities in cognitive radio networks. The developed scheme allows doing the allocation of several contiguous and available frequency channels, to the secondary users that need higher bandwidth, in an environment of Fairness. The developed hybrid model of allocation is conformed by 3 algorithms, one in charge of locating the available frequency channels and gather them in multichannel bands, the second algorithm in charge of ranking these multichannel bands and finally the last algorithm in charge of establishing a fairness criterion to not restrict the spectral opportunities of the other secondary users who wish to transmit. The taken measurements correspond to the average bandwidth, average delay, average throughput and the fairness calculation in the allocation of several channels. The achieved results were evaluated with the experimental spectral occupation data, taken in GMS frequency band. The developed model shows an improvement in the use of spectral opportunities and a higher average transmission bandwidth for each secondary user keeping the fairness criterion in the channel allocation.

Keywords: cognitive radio networks, dynamic spectrum allocation, fairness, multichannel, spectrum opportunity

1. Introduction

The cognitive radio (CR) defined by the International Telecommunication Union (ITU), as “a radio o system that allows and is aware of its surroundings and it can be adjusted dynamically and autonomously with its radio operating parameters”, proposes a solution, the Dynamic Spectrum Access (DSA), making an opportunistic and intelligent use of the frequency spectrum. The aforementioned allows that an unlicensed user, or a cognitive radio user, or a secondary user (SU) can use a channel of an available licensed band, but as soon as a licensed user or a primary user (PU) arrives to take that channel, or if the quality of the taken channel by the SU is degraded, or if the SU interferes with the PU, or if the SU’s mobility causes that it ends outside the coverage area, the SU must release that channel and look for a new available channel (also denominated spectral opportunity, spectral space or blank space) to continue with the transmission, this is called spectral mobility or spectrum Handoff) SH) [1]–[5]. The aforementioned grants to CR the ability to provide a high bandwidth (BW) to SU, through the heterogeneous wireless architectures.

According with the configured SH model, the performance of the CRN can be impacted by factors as: latency, Throughput, signaling, interference, BW, Signal to Interference plus Noise Ratio (SINR), Bit Error Rate (BER), among others [6], [7]. In accordance with current researches [1]–[4], [8]–[12], the SH model, is the key characteristic to activate the continuous transmission of SU data, since this it could reduce the number of channel changes during the SU’s transmission, as well as its latency, minimizing the degradation of the channel [9]. Currently there are several proposes of SH model, however, it is important to analyze that the application of a SH model depends strongly on the network characteristics of the PU [13]–[15].

The current research pretends to develop a model which allows use the SO from the SU, even through a multichannel transmission approach, as always as the SO and SU number allows it. The model stated allows that several frequency channels are assigned to the SUs that require a higher BW for the Real-Time (RT) applications for its transmission. However, the aforestated only will be possible if the number of Sus require the spectral resource is lower than the number of SO. To assess the aforementioned, the model proposed will incorporate a Fairness criterion to assure the balanced allocation of the SO to the SU. The model proposed has been denominated as Multichannel Fairness allocation for Cognitive Radio Networks (MFA-CRN).

It would be appropriate to point out that it is desirable to use multichannel transmissions for applications in RT, as the tolerant transmissions to delays could operate on a single channel. Nevertheless, the fact to assign several channels to a unique Su could affect significantly the fairness criterion in the interested SU in using these resources, since they also attempt to transmit their information. On this point it would be convenient that the proposed MFA-CRN model assures a fair treatment to all SU, in such a way that each one of them has right on the SO, under the same fairness parameters according with the kind of application to perform: RT or Best-Effort (BE).

The MFA-CRN model adapts its operation in accordance with the behavior of the demand and supply of SO in the selected spectral band. In the selected spectral band can occur two kind of scenarios: (1) that the supply of SO is higher than the demand of the SU, and (2) that the supply of the SO is lower than the demand of the SU. The proposed model selects dynamically and intelligently the best SO based on the following decision criteria (DC): availability of probability (AP) of the channel, estimated time of availability (ETA) of the channel, SINR and BW.

To assess the performance level of the algorithms developed a comparative analysis will be made between them and the most relevant SH algorithms of the current literature with MFA: Proportional and Max-Min. Unlike related documents, the benchmarking was validated through a novel simulation tool developed with a trace of real date of spectral occupation taken in the Global System for Mobile communications (GSM) frequency band [16][17], that models the real behavior of the PU [18]. The performance evaluation and validation of the MFA-CRN model was performed in GSM network, taking into account three RT applications: Voice (SU1), Videoconference (SU4) and Streaming (SU10), and one application of BE: Web (SU2), in two different scenarios, Strong Overallocation (DMA) and Strong Suballocation (DMD),with a level of High Traffic (HT), for which were taking into consideration four Evaluation Metrics (EM): Average Bandwidth (ABW), Average Accumulated Delay (AAD), Average Accumulated Throughput (AAT) and Fairness.
The rest of the document is structured as follows. In Section 2 a description of the related work in the current literature is made. In Section3 a brief theoretic substantiation. In Section 4 is described the methodology of the current research. In Section 5 the obtained results in the research are presented. And finally, in Section 6 the conclusions are drawn.

2. Related Work

In [19] is considered that the problem of the maximization of the distributed throughput for Aloha multichannel networks. The authors focus on networks that have a great number of users who transmit over a small number of channels. It is considered initially the maximization of the distributed data, where the user rates are limited by the probability restrictions of total transmission. An algorithm of better response is proposed to answer the problem of maximization of rate, where each user updates his strategy using his condition information channel and in the same way monitoring the channel use. It is considered the scenario where the users are not restricted by the probabilities of transmission. The distributed optimization in the network under uncertainty is mandatory because the probabilities of transmission of other users are unknown. It is proposed a distributed scheme to answer the problem of optimization of throughput under uncertainty, where the users adjust their probability of transmission to maximize their trates, but keeping the desired load in the channels. Thus, algorithms are proposed: sequential and parallel.

In [20] is presented the current problem in cellular communication systems, regarding the problem of optimization in the allocation of radio resources blocks, with users that are tolerant to delay and those who demand real time transmission, which were modeled as function of logarithmic and sigmoid utility. The optimization was carried out under the Proportional criterion with the purpose of maximizing the utility of these type of networks, while the allocation of the resources was carried out taking into account the QoS requirements of the application. In the developed algorithm is explained the way in which this algorithm prioritize the applications in real-time over the applications tolerant to delays, assuring minimum QoS.

Moreover [21] focuses its interest in the study of 802.11 Multirate Wireless LAN networks using the distributed coordination function (DCF). Its objective is triple, first, with the state transition model of multi-dimensional Markov the behavior of the IEEE 802.11 protocol is characterized in the control layer of access to the medium, in which is presented an extension that represents the transmission failures of packages due to channel errors , second, it establishes the conditions of the constituted network by N stations, each station of transmission with its own velocity of bits $R\mathrm{d}(s)$, and package rate λs, it can assume with charge. Finally, it proposes a modification in the Proportional criterion, which according with the researchers is appropriate to mitigate the problem of the charge in the wireless LAN networks with multirate using DCF. The simulation results are presented for some sample scenarios, which confirms the efficiency of the criterion proposed for the allocation of optimized performance.

The paper [22] corresponds to the first part of a series of results in the study of the use of the function of utility of Proportional as a basis for the allocation of resources and the planning in the wireless networks of multiple multichannel velocities. The fundamental properties and the physical - economic interpretation of the optimization of Proportional are presented. It is found that one solution for Proportional in general consists of many allocations of zero during the time in the air, when the difference between the number of users and the number of channels is big. Several algorithms are presented of optimization of Proportional, including an a fast algorithm that allows a parallel implementation. Finally, the use of the utility of Proportional is studied for the allocation of resources in the WI-FI networks on a large scale that consists of many adjacent wireless local area networks.

In the second part of the research [23], as it was described in the afore paragraph the use of the function of utility for Proportional is studied as a basis for the allocation of resources and the programming in wireless networks of multichannel multiple velocities. In this second part of the research is studied the allocation of subcarrier and the programming of the Orthogonal Frequency Multiplexing Modulation (OFDM) in cellular wireless networks. The concept of Doppler W-normalized frequency is introduced to receive the level in which the opportunistic programming can be exploit to achieve the performance increase of the gain of the relation throughput-*Fairness*.

Although the mentioned researches do a rigorous treatment with multichannel models and Fairness criterion, this proposal attempts to determine the impact that these two thematic could have in the allocation of the bandwidth resource in CRN, where they have not been implemented, and to validate the results with real occupancy spectral data, which also it has not been proposed in the state of the art of the literature about CRN.

3. Fairness Criterion

In [24], it is mentioned that the *Fairness* is reached if all the users consume the same average of resources. On another part [25] explains that the *Fairness* is just reached the difference of throughput for the two users is proportional to the difference of average capacity of the channel for the two users. As [26] defines a type of *Fairness* denominated "*Hard Fairness*" in which indicates that system reaches the *Fairness* if all the users have the same data transference rate. As it is observed, the definition and attributes that must be taking into account to reach the *Fairness* criterion are very subjective, whereby it does not exist a consensus about *Fairness*.

The *Fairness* criterion is a special property of the algorithms of allocation of resources; whereby, if a wireless network has insufficient resources to satisfy the demand, this can distribute the resources in a fair way to the network users. Due to the use of this criterion in different knowledge areas such as economy and the networks, among others, its the definition can be subjective, however in its most basic form Fairness can be defined as the equality of resources among users based on a preset agreement. [6], [27].

3.1 Jain's Index

The Fairness criterion can be measured through the Jain's Index which identifies the underused channels as it is described in the Equation (1) [6], [27].

$$J = \frac{(\sum_{i=1}^{n} X_i)^2}{n \sum_{i=1}^{n} {X_i}^2} \tag{1}$$

Where n is the number of users and Xi is the performance of the i-th connection

The related Fairness algorithms in the current literature are described below.

3.2 Proportional Fairness

The Proportional algorithm aims at taking into consideration the throughput balance among users as the total throughput of all the users. [6], [28].

The formal definition of Proportional is: "*an allocation of the X rate is proportionally equal if and only if for any other allocation, the following inequality remains*" (See Equation (2)) [28].

$$\sum_{s=1}^{S} \frac{y_x - x_x}{x_s} \leq 0 \tag{2}$$

In other words, any change in the allocation must have a change of negative average.

Proportional is an example of a more general concept of Fairness called the utility approach, which is defined as: each S source has one utility function u_x where $u_x(x_s)$ indicates the value of the S source having an x_s rate. Each connection *l* (or a network resource in general) has a cost function g_p where $g_l(f)$ indicates the network cost to support an amount of *f* flow in the connection *l* [29]. Thus, a fairness allocation of utility rates is an allocation that maximizes *H(x),* defined by the Equation (3) [29].

$$H(x) = \sum_{s=1}^{S} u_x(x_x) - \sum_{l=1}^{L} g_l(f_l) \tag{3}$$

With $f_l = \sum_{s=1}^{S} A_{l,x} x_x$ on a set of feasible allocations, where S is the number of sources and $A_{l,i}$ is the traffic fraction of the *i* source which uses the *l* connection.

3.3 Max-Min Fairness

Max-Min Fairness is known as an optimal throughput fairness definition and is used to define the fairness in data networks. If S is defined as a set of active users, it can be stated that the allocation mechanism of resources assigns to each one of the S users a Rs resource, such $\sum_{s\in S} R_s \leq R$, where R is the total resource available of the system [30].

According with the aforementioned a feasible allocation to the users from the S set, is Max-Min Fair, if for each S user, *Rs* cannot be increased without decreasing *Rs'* where *Rs'*≤ *Rs.* [30].

In order to use Max-Min Fairness on a medium of communication with restrictions of sharing capability, *fair queuing* is used. The algorithms that use this kind of criterion require information on the global state of all nodes on the network [30].

4. Methodology

The methodology of this research was structured as follows: first, a study about the state of the art was implemented and it was possible to identify the most relevant aspects for the SH topic in the CRN, as well as its most significant algorithms in the current literature with MFA. Second, based on the analysis of the previous information, a methodology for the performance evaluation of the mobility in mobile networks of CR was designed. Third, a data collection of actual spectrum occupancy in GSM band was carried out in order to analyze the function of that band and PU. Fourth, the data gathered was processed so as to construct databases with organized information about the function of PU and the features of the spectrum resources of the GSM band; a level HT was considered for those databases. Fifth, the DC was established for the selection of the best SO and the historical values of the SO were calculated based on the information of the databases supplementing the aforementioned ones. Sixth, the most relevant algorithms of SH were selected and developed in the current literature with MFA. Seventh, the proposed MFA-CRN model was designed and developed. Eighth, based on analysis of the state of art of SH in CRN, four EM were created with the objective of evaluating the algorithm performance suggested for this research, as well as the ones selected from the current literature and, two scenarios of evaluation DMA and DMD were propounded for four different types of applications: Voice (SU1), Web (SU2), Videoconference (SU4) and Streaming (SU10); with the aforestated information a MFA- CRN benchmarking was implemented with the Max- Min and proportional algorithms because they are the most pertinent in the current literature to carry out an equitable channels allocation. Ninth, based on the previous information, a simulator that allows a quantitative evaluation of the SH algorithms performance with MFA was designed and developed, taking into consideration the PU actual behavior. Tenth, with the results gathered from the simulator, a benchmarking of its performance in each one if the EM was carried out.

4.1 Spectrum information processing

Spectrum occupancy actual data correspond to GSM band of (824MHz-874MHz). To determine the occupancy or availability of each one of the channels of GSM band, a decision threshold was calculated. The value of the decision threshold power was computed based on Equation (4) with a false alarm probability of 1% [16], which was -109 dBm.

$$P_{fa} = \frac{\Gamma\left(m, \frac{\lambda}{2}\right)}{\Gamma(m)} \tag{4}$$

In the first 60 minutes of each subtrace, the average value of the four selected decision criteria (AP, ETA, SINR and BW) was calculated and, in the last 10 minutes, the evaluation and validation of the three selected algorithms (Proportional, Max-Min and MFA-CRN) was completed.

4.2 Decision criterion

With the power matrix and based on a processing of itself, the AP, ETA, SINR and BW matrices are obtained. To calculate the average values of each one of the decision criteria on the first 60 minutes, the following process was carried out. For the magnitude of the AP variable, a standard work cycle of the frequency channel was determined. For the ETA variable, the time in which each channel was continuously available was calculated and the average was based on them. The SINR variable was estimated on the average of the difference between the power of the signal and the average value of the noise floor. Finally, for the BW variable, it was decided to take the bandwidth of every adjacent channel that were available, inasmuch as each GSM channel has a fixed value of bandwidth equal to 200 kHz.

4.3 Demand Analysis SU Bandwidth

The BW demand of the SU was quantified based on the number of required channels (channels demand) according to the type of application that each SU is executing. The channel demand establishes the number of channels that SU is requesting. These demands can only be part of one channel (simple) or multiple channels (multi-channel). As part of the analysis for this research, two kinds of demands (Table 1), were drawn up in order to evaluate the suggested algorithm performance under different scenarios.

Table 1. Channels demand per user scenarios

Demand	**Description**	**Users 10 Channels**	**Users 4 Channels**	**Users 2 Channels**	**Users 1 Channel**	**Total Users**
DMA	Strong Overallocation	5	5	10	20	40
DMD	Strong Suballocation	40	15	20	25	100

In demand A (DMA) the offer is higher than the demand, thus, not only a reserve channels for future users could be implemented but also it is possible to carry out a channel allocation for each one of the 40 users. That additional allocation could be for one or more channels per user. En demand D (DMD) the offer is much lower than the demand, in this manner, the reserve channels could not be done and the demanded channels could not be assigned by the users, on the contrary, it is possible that some SU communications should be discontinued.

The four types of SU that are shown in Table 1, which demand 10, 4,2 or 1 channel are determined by means of a transfer rate analysis (Table 2) corresponding to five types of services or applications that a SU uses commonly nowadays and whose demand is increasing. Due to the number of channels that demands those services, four types of users (or applications) were defined and are listed as follows:

- ✓ SU that demand 10 channels (SU10)
- ✓ SU that demand 4 channels (SU4)
- ✓ SU that demand 2 channels (SU2)
- ✓ SU that demand 1 channel (SU1)

Although GSM frequency channels have a fixed BW of 200 kHz, the simulation tool worked with 100 kHz channels to do a more efficient allocation of the spectrum. Based on a 100 kHz BW, the number of channels that was needed was determined so as to comply the users demand according to the type of application that is being used.

Table 2. Channels needed by type of service for 16 QAM consolidated

Aplication / Service			**Recommended Rate (kbps)**	**Channels Required (Channel=100 kHz)**	**Full channels Required**
Voice	Skype	Call	64	0,25	**1**
Web	SMS	SMS	2	0,005	**1**
	Web pages	El Tiempo	856,7	21,418	**2**
Movies Streaming	Netflix		1500	3,75	**4**
Video-Conference	Skype	Group video (5 people)	4000 / 512	10	**10**
Multimedia	Youtube	720p	4000	10	**10**

Source: [31]–[34]

4.4 Performance metric for the Multi-channel Model

The multi-channel allocation algorithm presented in this research uses four metrics to measure the performance of the selected algorithms and the suggested one, both in terms of effective channels allocation to the different users and parameters of OoS in data transmission such as: bandwidth, delay, Throughput and Fairness.

4.5 Proposed model for multi-channel designation design

The Figure 1 depicts mainly in block diagram the Multi-channel Allocation Model with proposed Fairness. The first block named “Spectrum Occupancy Database” entails actual spectrum occupancy data corresponding to the GSM band of (824 MHz- 874 MHz). This block is the input for the “spectrum data processing” which has the task of defining the occupancy or availability of each one of the channels in GSM band, according to the false alarm probability equation. On the other hand, the block called “SU bandwidth demand” contains the data of the quantity of users that demand 10 channels, 4 channels and 1 channel. This block will have four types of demand in order to evaluate the MFA-CRM algorithm facing the Proportional and Max-Min algorithm.

The rectangular area corresponds to the proposed model consisting of three blocks or algorithms: (1) available multi-channel band localization algorithm, (2) multichannel band ranking algorithm and (3) multi-channel allocation with Fairness algorithm (MFA- CRN). The function of the first one is to organize the available channels in multi-channel frequency bands: the second one is responsible of ranking of the multi-channel bands in terms of the selected decision criteria; the function of the third and most important one is to determine how many and which channels are assigned to each SU according to its channel demand request and the available offer.

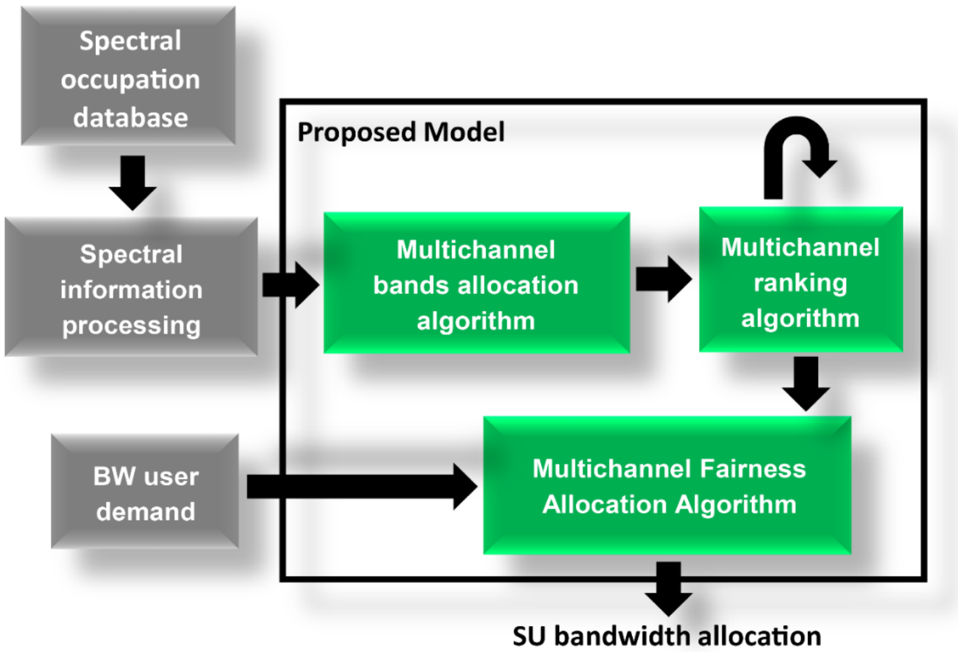

Figure 1. Suggested MFA-CRN algorithm general structure

To validate the MFA-CRN algorithm, a benchmarking with Max-Min and Proportional algorithms was implemented because those algorithms are the most suitable in the current literature to do a channel equitable allocation [6].

MFA-CRN multi-channel equitable allocation algorithm

The MFA-CRN algorithm adapts its procedure according to the behavior of the channel demand and offer in the selected spectrum band. Thus, two possible scenarios were taken into consideration when it was about resources allocation:

- ✓ Scenario 1: spectrum resources higher then de users' demand
- ✓ Scenario 2: spectrum resources lower than the users' demand

Scenario 1: in a system, resources as BW could be used by any user who requires to transmit data, however, the users who employ applications in RT require higher BW. In accordance with the aforementioned statement, it would be more advisable to use multi-channel transmissions for this type of users. Nevertheless, so the system could meet all the users' requirements both in RT applications and BE, the Equation (5) of condition has to be fulfill.

$$\sum_{i=1}^{N} BW_i \leq \sum BWs \tag{5}$$

Where BW_i corresponds to the BW demand by the N users available in the system and BW corresponding to BW of the system.

Taking into account the Equation (5), it is expected that the demand of each user is fulfilled for each time slot during the transmission, as is displayed in Equation (6).

$$\sum_{t=1}^{T} BWt = BWi \tag{6}$$

It is important to highlight that when the condition shown in Equation (6) is fulfilled, the MFA-CRN algorithm checks the excess offer and according to this one, the channel reserve is developed. The channel reserve is done with the purpose of making a portion of channels available for the future users that can be on a near future.

Once the channel reserve is done, the excess channels that are available are enumerated and an equitable distribution of these channels among all the SU is carried out, making an over-assignment in all the SU.

Scenario 2: B in this scenario it is necessary to take into consideration that not all the users demands could be completely fulfilled because the offer is lower than the demand; however, following a Fairness criterion, it must be a warranty that all the users are going to be able to use the network resources, although this process is not developed in the same time slot but in the following slots. Taking into consideration the previous statement, Equation (7) could be deduced.

$$H(x) = \sum_{s=1}^{S} (Ux) - \sum_{l=1}^{L} Cx \tag{7}$$

Where Ux is the transmission probability of the x user in the system, which is assigned with a Cx cost that refers to the possibility of transmission in a later time slot due to the limitations of the resource of the system.

In the process of multi-channel allocation, when the offer of the available spectrum resources is lower than the channels demand of the SU, a special process is required because if a Fairness criterion is expected with all the users when it is about the allocation, it has to ensure that the users are not going to have all the resources they requested, efforts will be made to provide the users with the resources to transmit without any penalties when it is about allocation. To fulfill this objective, the current offer derived from the quantity of available channels in the multi-channel matrix is taken in consideration and based on this statement, an ideal projection of each one of the users' demand is implemented. Once this process is developed, the users are assembled according to the quantity of the resources demand.

Then, the algorithm checks if the current offer fulfills the resources demand of the different users if not, the group of users with higher resources demand is checked and one channel is subtracted from the expected allocation. This process is developed for each one of the users as far as the global demand is equal to the available offer, on the contrary, the algorithm proceeds to the second group with higher resource demand and the same procedure of subtracting a channel per user checking the demand is equal to the offer.

It is possible that all the users get only one channel or even they must be isolated in the process (not to assign any channels). In the case of isolating SU from the process, it is necessary to start with the ones that demand more channels (SU10), leaving last the ones that demand less channels (SU1), this order of penalty was set up to benefit the users of one channel that would have higher probability of transmitting their data and represent the most significant percentage in terms of SU quantity.

5. Results

To evaluate the suggested MFA-CRN algorithm performance, a complete analysis was carried out, it took into account the following parameters: (1) high traffic; (2) two types of demands: strong over-allocation (A) and strong sub-allocation (D); (3) five types of service: voice, web, videoconference, streaming and multimedia that identify four types of users: 10 channels (SU10), 4 channels (SU4), 2 channels (SU2), 1 channel (SU1).

For each metric, a figure made of eight sub-figures was designed, they correspond to four types of SU/Application (SU1, SU2, SU4 and SU10) in two proposed scenarios (DMA and DMD), in each sub-figure, the three algorithms are graphed: Proportional, Max-Min and MFA-CRN (proposed). In each one of the following figures, the same format and color are retained to identify each algorithm.

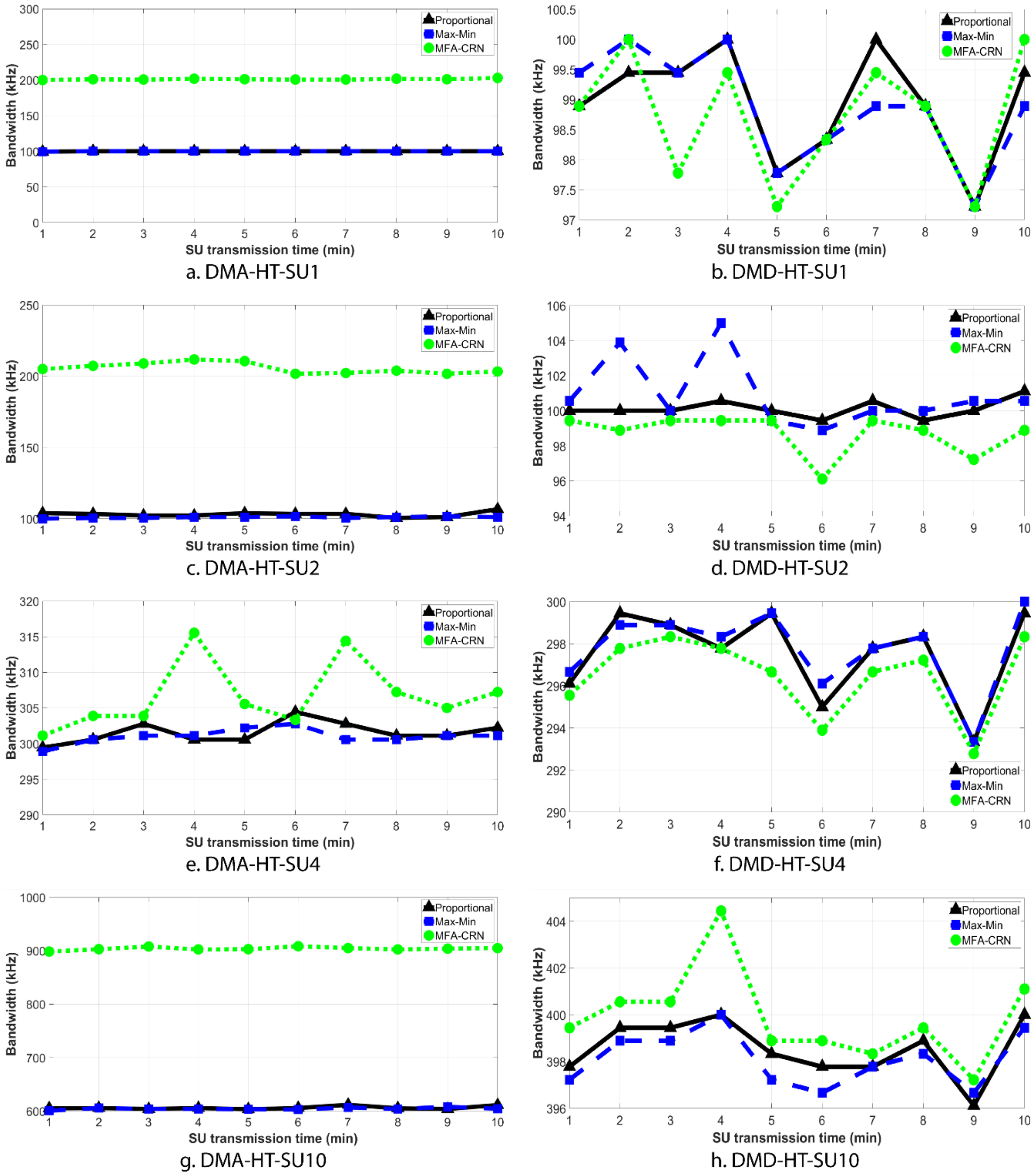

Figure 2. ABW for each type of application with DMA and DMD

The Figure 2 depicts the ABW, Figure 3 describes the AAD and, Figure 4 represents the AAT that is presented in each SH algorithm during a ten minutes transmission in a GSM network with two different types of demand (DMA, DMD) in HT, for each type of application: SU1, SU2, SU4 and SU10, respectively.

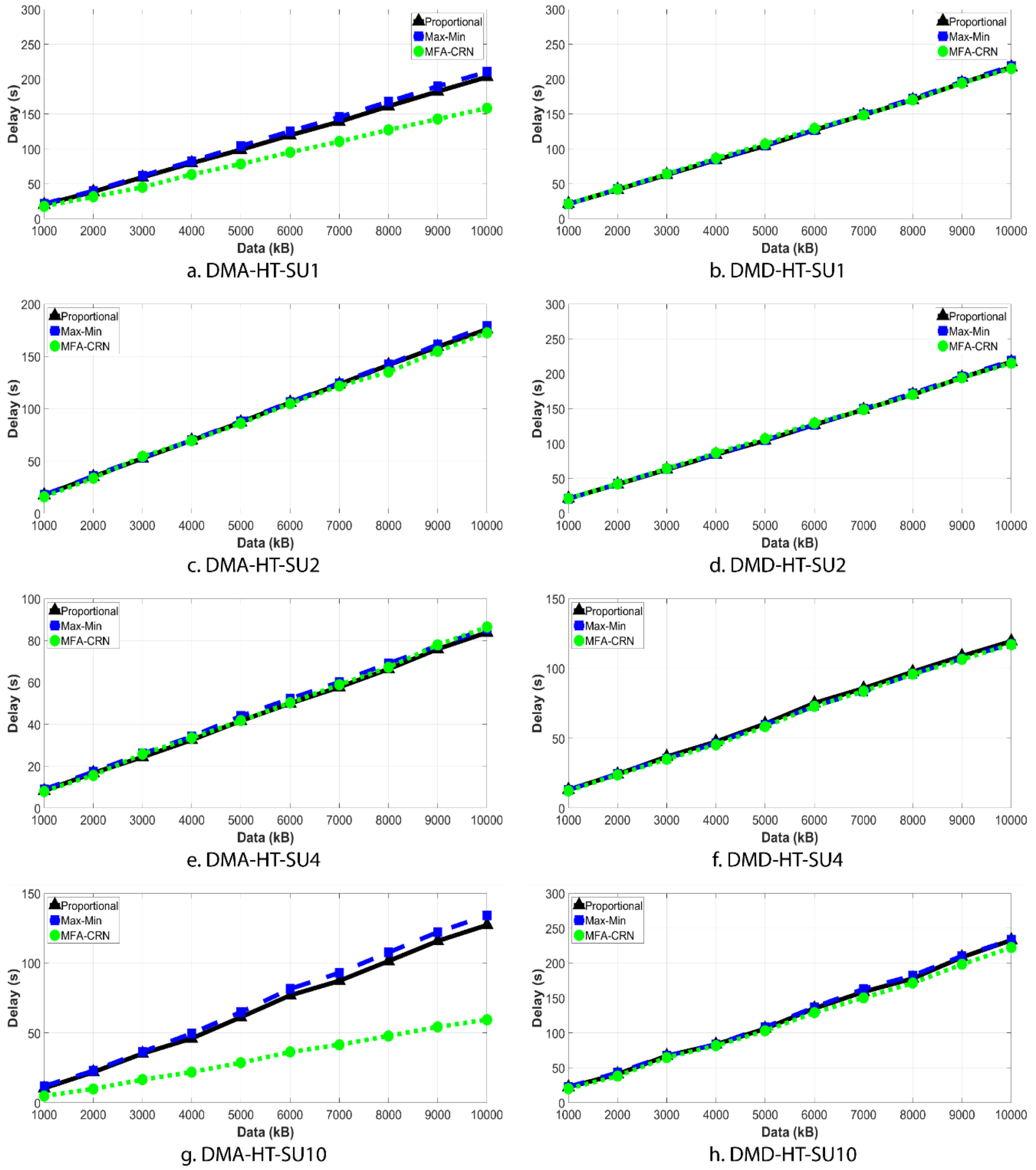

Figure 3. AAD for each type of application with DMA and DMD

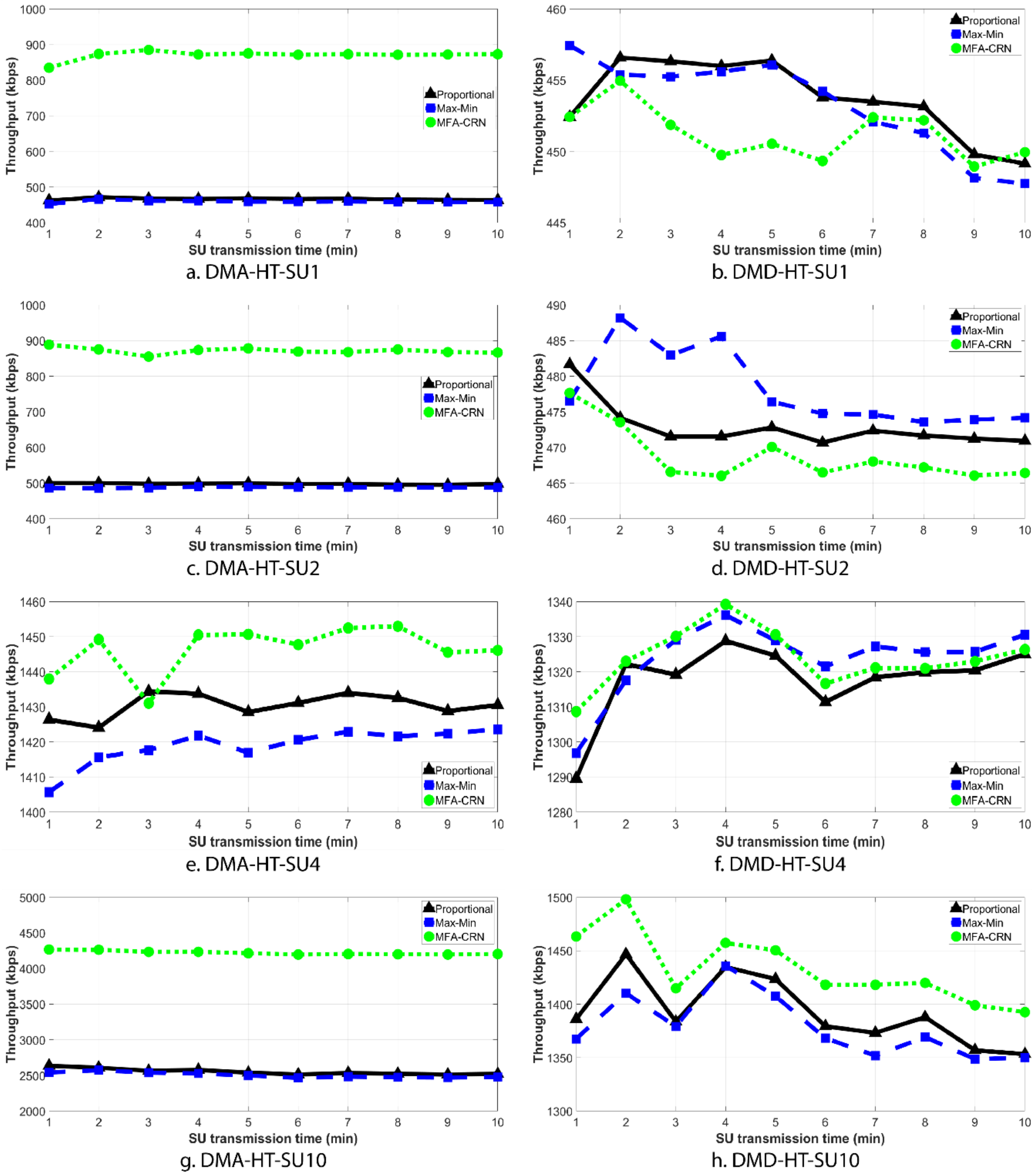

Figure 4. AAT for each application with DMA and DMD

Analyzing the performance of multi-channel hybrid algorithm of SH, MFA-CRN together with the most relevant selected from the current literature including: Proportional and Max-Min the following case is observed. Regarding to ABW, it could be seen that MFA-CRN has the best performance in all the types of service with a wide margin. Concerning AAD, it is observed that MFA-CRN has the best performance in all the types of service with a wide margin. With respect to Fairness, it has the best performance in the DMA scenario with a significant margin; while in DMS scenario, although it is not the best, its deviation rate is in fact zero.

The Figure 5 depicts the Fairness level that is represented in each SH algorithm during a 10 minutes transmission in a GMS network, with two types of demand (DMA, DMD), in HT.

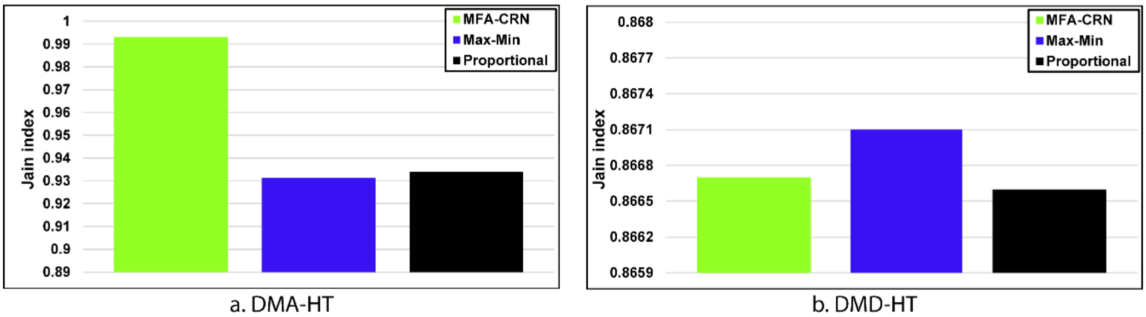

Figure 5. Fairness for DMA and DMD

5.1 Benchmarking

From Table 3 to Table 5 the comparative percentages of the performance of each algorithm per EM, per type of SU and per Fairness are presented. It is seen here that MFA-CRN algorithm has the best performance with an 8,2% margin regarding the second one.

Table 3. Benchmarking per EM for GMS network per type of SU

Stage	SU1			SU2			SU4			SU10		
	MFA	Max-Min	Prop.	MFA	Max-Min	Prop.	MFA	Max-Min	Prop.	MFA	Max-Min	Prop.
ABW	100	85,53	85,53	100	74,67	75,43	100	98,07	98,16	100	84,96	85,28
AAD	100	89,78	90,79	100	92,45	93,78	100	97,2	96,66	100	74,94	76,73
AAT	100	85,65	85,51	100	76,96	77,49	100	97,85	97,87	100	81,52	82,41
Score	100	86,99	87,28	100	81,36	82,23	100	97,71	97,56	100	80,47	81,47

Table 4. Benchmarking per type of SU for GMS network

Aplication	MFA-CRN	Max-Min	Proportional
ANS SU1	100	89,08	90,51
ANS SU2	100	88,77	90,35
ANS SU4	100	98,06	97,07
ANS SU10	100	87,46	89,25
Score	100	90,84	91,8

Table 5. Benchmarking of Fairness for GMS network

Stage	MFA-CRN	Max-Min	Proportional
ANS DMA	100	93,72	93,86
ANS DMD	99,94	99,84	100
Score	99,97	96,78	96,93

6. Conclusions

According to the results obtained by means of the simulations made for all the metrics and evaluation scenarios, the MFA-CRN multi-channel spectrum allocation of spectrum handoff model is a comparatively simple technique with a processing cost relatively low that provides and efficient and effective process of selection of frequency channels, with a low delay level and a high Throughput level. The aforementioned improves and strengthens the spectrum handoff strategies performance in the cognitive radio networks.

In general, the MFA-CRN model has a better comparative performance and it achieves a higher bandwidth and Throughput level with a lower delay level, without diminishing its Fairness level, making it an excellent tool for a multi-channel spectrum allocation with Fairness criterion.

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