

# Multichannel Scheme under Max-Min Fairness Environment for Cognitive Radio Networks

Hans R. Márquez, Cesar Hernández, Ingrid Páez

**Abstract**—This paper develops a multiple channel assignment model, which allows to take advantage of spectrum opportunities in cognitive radio networks in the most efficient way. The developed scheme allows making several assignments of available and frequency adjacent channel, which require a bigger bandwidth, under an equality environment. The hybrid assignment model it is made by two algorithms, one that makes the ranking and selects available frequency channels and the other one in charge of establishing the Max-Min Fairness for not restrict the spectrum opportunities for all the other secondary users, who also claim to make transmissions. Measurements made were done for average bandwidth, average delay, as well as fairness computation for several channel assignments. Reached results were evaluated with experimental spectrum occupational data from captured GSM frequency band. The developed model shows evidence of improvement in spectrum opportunity use and a wider average transmission bandwidth for each secondary user, maintaining equality criteria in channel assignment.

**Keywords**—Bandwidth, fairness, multichannel, secondary users.

## I. INTRODUCTION

**C**OGNITIVE RADIO NETWORKS (CRN) encounter optimization needs for spectrum optimization in wireless networks. This is interpreted as an opportunity for the improvement of the user service level in wireless technologies, creating an opportunity to use the available spectrum and then improving the service level for wireless technology users, making an opportunistic use of available spectrum and therefore improving spectrum efficiency [1], [2]. This opportunistic access in which the secondary user (SU) could make use of the licensed spectrum, until the primary user (PU) requires again that spectrum part which SU is using. In this scenario is necessary that SU moves to another free licensed spectrum; this mobility type is called Spectrum Handoff. This procedure could be defined as a process where the cognitive radio user (SU) changes his operating frequency, when the channel conditions are degraded or when a PU appears, as the first is using a licensed channel [3].

One significant difference of the current paper, when compared with most related work in the literature, is the fact to make multichannel assignments for SU that develop

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applications in real time over a single channel, for those applications which could sustain delays.

Even though, the fact of assigning several channels to a unique SU, could impact in a significant way, equality criteria on a SU interested in using these resources, as all SUs have an interest in transmission. In order to solve the former problem, fairness criteria are implemented to make an equality assignment of available resources among all secondary users in accordance to the application type (real time or best effort)

For the development of these criteria, literature exposes several algorithms, even though one of the most widely used is the *max-min fairness*. This algorithm develops an equality process in recourse assignment. In the same way, it is essential to know which channels are the best to be used by secondary users and these ones make possible Fairness criteria.

The present paper is structured as it follows: In Section II related papers are presented; in Section III, development of the model is described; in Section IV, results are shown and finally in Section V, conclusions are drawn.

## II. RELATED WORK

In [4] it is proposed a protocol called RC-MAC which makes integration without any problem, useful cycle and assignment work for central receptor, yielding a high throughput, without energetic efficiency sacrifice. The way in which they handle a lot of traffic, which could be generated or triggered by one event, this protocol, takes advantage of the data compilation as a subjacent tree at WSN (Wireless Sensor Networks) and in the same way multichannel technique supported by radio frequency devices under IEEE standard 802.15.4. By observing the time in packet processing at low cost sensor nodes, a planning model was designed which guarantees Fairness between origin nodes without throughput sacrificing. Finally, it is demonstrated that throughput and Fairness are improved in a significant way under many loads, under central receptor planning.

In [5] is presented an optimization problem in the radio resource assignment in the cell communication systems, both for tolerant users to delays as for those who demand transmissions in real time. This optimization problem was modeled through functions of the logarithmic and sigmoid utility. Optimization was done under PF criteria in order to make a maximum of utility in these network types, meanwhile user assignment, taking into account, quality for application of service requirements an temporary efficiency.

In research done by [6] a framework is designed for opportunistic administration on multiple wireless channels. With a realistic channel model, any user sub-conduct could be

selected for transmission at any time, even though with different throughputs and system requirements could be selected for transmission at any moment. A selection of best users and transfer rates of an optimization complex problem is done, to a formulation, which is uncoupled and handled. On the other hand, [7] pinpoints its interest in wireless networks multi-rate LAN 802.11, using compulsory distributed coordination function (DCF). It is proposed a criteria modification on PF, which in accordance to researchers, is adequate for mitigation of load problem on LAN networks in wireless LAN with multi-rate, making use of the compulsory DCF option. Proposed Fairness criteria could be applied to general charged networks. Equality criteria proposed for some example scenarios, which confirm the efficiency of proposed criteria for assignment optimized performance.

In [8] the research corresponds to the first part of a series of results in the utility function (UF) use from PF, as a basis for resources assignment and planning of wireless networks of multiple multichannel speeds. In the same way characteristics for optimum PF solutions are found, useful for PF algorithm construction. It is found that one PF solution in general consists in many assignments of zero on airtime, when the difference between the number of users and number of channels is considerably big.

In the second part of the research [9], described in the former paragraph, it is studied in utility function use for PF as a basis for resource assignment and programming for wireless networks at multiple multichannel speeds. In the second research part, the sub-carrier assignment is studied and also the programming of OFDM (Orthogonal Frequency Division Multiplexing) at cell wireless networks concept of Doppler frequency W-standardized to detect the degree in which opportunistic programming could be exploited, to reach an increase in performance of gain for throughput-Fairness ratio.

### III. METHODOLOGY

Suggested model scheme is presented in Fig. 1.

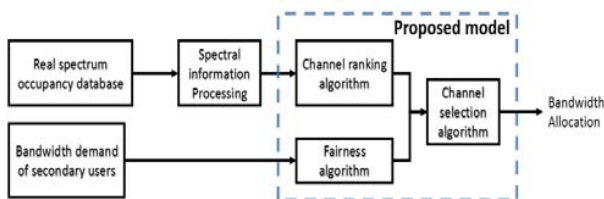


Fig. 1 General structure of the proposed model

#### A. Selecting the Multichannel Parameters for Simulation

In the model, the design was presented as a scheme with multiple channel demand by secondary users, making variations in simulations, from two channels up to a maximum of 10 channels. It is noticed that channels that are assigned in a simulation should be adjacent.

Taking into account former conditions, multichannel assignment is done in accordance with the demands on resource for required wideband by secondary user.

At a probable scenario in which secondary user demand

exceeds actual system resources, available resources are supplied.

#### B. Defining Simulation Time and Spectrum Data Occupation

The model performs resource assignment in accordance with the current time slots for simulation. It is observed that each slot has a duration of 0.3 sec and the total simulation time is about 10 minutes.

The model has a database input, a data matrix with spectrum occupation data for GSM frequency bands, making an important differentiation of traffic measured at different time intervals. Such differentiation refers to information volume and occupation shown for each one of the channels, showing high traffic data and low traffic data. This variation allows making an evaluation in two different scenarios, each one of them with its own characteristics.

**Scenario 1. System Resources Bigger Than User Demand:** In a system, resources like those that bandwidth could be used by users who require transmit application in real time. In accordance with this, it would be preferable for this type of users the use of multi-channels transmitters; however, in order to satisfy system demands for all users, both in real time applications as well as those of best effort, it is necessary to fulfill condition (1):

$$\sum_{i=1}^N BW_i \leq \sum BW_s \quad (1)$$

where,  $BW_i$  corresponds to bandwidth demand of each user for  $N$  available users in the system.

Taking into account (1), is hoped that the demand of each user is satisfied for each time slot, which transmission is used, as shown in (2):

$$\sum_{t=1}^T BW_t = BW_i \quad (2)$$

**Scenario 2. System Resources Lower Than User Demand:** Under this scenario should be taken into consideration that not all user demands are going to be satisfied completely; however, under an equality criteria, it should be guaranteed that all users could make use of network resources, even though they are not going to be made on the same time slot, but in successive slots. Taking into account the former premise is possible to infer that (3):

$$H(x) = \sum_{s=1}^S (Ux) - \sum_{l=1}^L Cx \quad (3)$$

where,  $Ux$  is the transmission probability for user  $X$  of system and to which it is assigned a cost  $Cx$ , which refers to the possibility of continuing the transmission in one posterior time slot, due to resource limitations for systems resource.

#### C. Design Model

The proposed model was developed taking as input variable, real spectrum occupation data and in the same way demands for bandwidth for secondary users.

During the reading process for spectrum occupation data, they went through a block of spectrum information in order to

adequate data, to be in position to make a ranking analysis for channels

It is important to illustrate that channel ranking is done by means of using VIKOR algorithm with the purpose of determining the best channels for Signal to Noise ratio and availability average. Additionally, in this part of the process, ordering the best available channels will be made in an ascending way.

Channel selection should not only cover ranking but also, take into consideration that channel assignment should be done in an equality way for all secondary users.

Because of the proposed model, it is used the Max-Min Fairness algorithm, which is recognized as a definition of optimum throughput equity and it defines equality in data networks. It is defined S as set of active users, where it could be stated that resources assignment mechanism, assign to each one of s users, a resource  $R_s$ , such that (4):

$$\sum_{s \in S} R_s \leq R \tag{4}$$

where, R is the total system available resource [10].

The *Fair Queueing* algorithm was applied in order to make use of Max-Min Fairness on a communication medium with restrictions to share the bandwidth available.

The *Fair queueing* is fundamental in the proposed model, as in high traffic scenario, it will be presented occasions where the amount of available bandwidth will be lower than bandwidth demand by secondary users. Because of that, fairness algorithm for the proposed model makes a measurement for channel assignment percentage and in the event of not being able to satisfy demands for all users in 100%, the following time slot makes a weighted average for each channel, as it is shown in (5):

$$x = \frac{\sum_{i=1}^n x_i w_i}{\sum_{i=1}^n w_i} \tag{5}$$

where,  $x_i$  represents the channel percentage of assignment for elapsed time slots and  $w_i$  represents the weight assigned to each one of channels, in accordance to assignments done.

Starting from this, weighting per channel is possible to adjust the model to make an equality assignment of bandwidth for all secondary users.

With fairness model and channel ranking algorithm, it is possible then to select channels for the respective assignment.

#### IV. RESULTS

Accumulated average bandwidth measurements were made for both high and low traffic, making variations on channel assignment from 2 up to 10 channels during a 10 minute period. Additionally, transmission delay was reviewed, both in high traffic scenario, as well as in low one, making variations from 2 channels up to 10. Results are shown in Figs. 2-5:

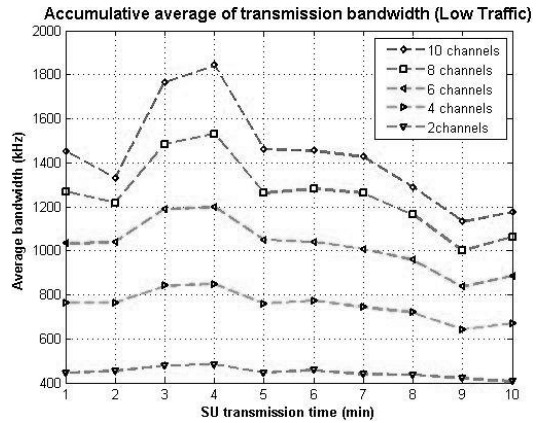


Fig. 2 Average bandwidth for transmission in low traffic for 2, 4, 6, 8 and 10 channels

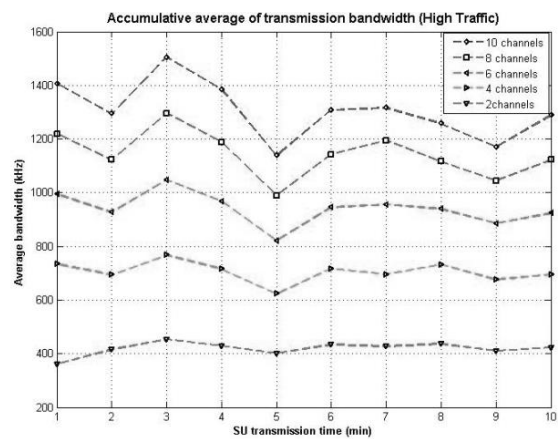


Fig. 3 Average bandwidth for transmission in high traffic for 2, 4, 6, 8 and 10 channels

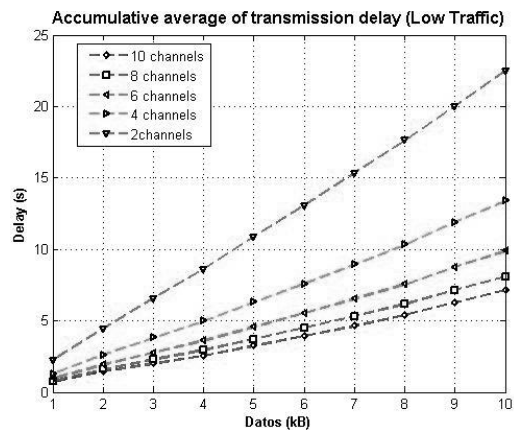


Fig. 4 Average delay in transmission in low traffic for 2, 4, 6, 8 and 10 channels

The average transmission delay when assigning channels is 10. It is 3.32 times lower than when the allocation is 2 channels in high traffic scenario, as shown in Fig. 4. Similarly, it is observed that the delay to 10.8 and 6 channels is quite a similar behavior, while channels 2 and 4 are a significant

increase.

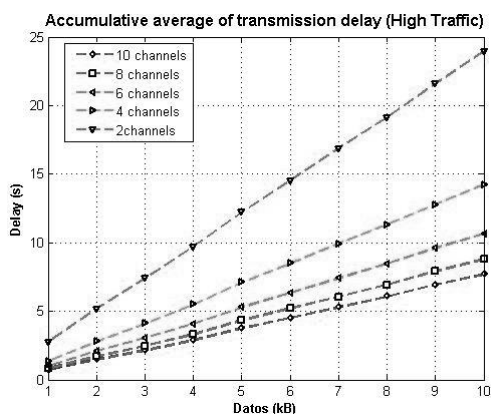


Fig. 5 Average delay in transmission in high traffic for 2, 4, 6, 8 and 10 channels

TABLE I  
DATA AVERAGE BANDWIDTH ALLOCATED TO HIGH TRAFFIC AND LOW TRAFFIC

Average bandwidth (Low Traffic)		Average bandwidth (High Traffic)	
10 channels	2 channels	10 channels	2 channels
Bandwidth (KHz)	Bandwidth (KHz)	Bandwidth (KHz)	Bandwidth (KHz)
1451.832461	446.3541667	1406.28272	360.5128205
1328.947368	451.5789474	1293.96985	415.6565657
1763.934426	478.8043478	1504.81283	452.9411765
1841.304348	483.6956522	1384.53608	428.3505155
1461.979167	445.8333333	1138.30846	401.5075377
1453.763441	456.1497326	1308.80829	433.1606218
1426.17801	437.6963351	1315.73604	428
1288.383838	435.3535354	1258.11518	437.1727749
1131.794872	420.5128205	1169.80198	410.8910891
1174.619289	405.5	1288.83249	422.3350254

In Table I, it is observed that average bandwidth for 10 low traffic channels increment is 9.43%, against the same 10 channels in a high traffic scenario. This is consistent, due to the fact that the number of available channels, is going to be lower in a high traffic scenario against a low traffic one with a greater number of available channels.

In the same way, for 2 channel events in low traffic, the increment in average bandwidth will be about 6.76% against the same 10 channels in a high traffic scenario.

It is observed in Table II that during the period of transmission time for 10 users with 4-channel assignment, that the model tried in each slot time to assign the four channels per user, equivalent to 100%. However, those users who registered lower percentages like 75%, 50% and 25% were assigned 3, 2 and 1 channels respectively by the model. It is interesting to notice that the model measures assignment results for each time slot per user and tries to compensate this inequality at the following slot. In this way, at the end of time slot 10, the average of assignments for each user was around 67%, which it is interpreted in from 4 channels to be assigned per user; model could assign only 2.7 channels.

TABLE II  
PERCENTAGE OF ALLOCATION OF FOUR CHANNELS TO 10 USERS IN A HIGH TRAFFIC SCENARIO OVER A PERIOD OF 10 MIN

min	user 1 (%)	user 2 (%)	user 3 (%)	user 4 (%)	user 5 (%)	user 6 (%)	user 7 (%)	user 8 (%)	user 9 (%)	user 10 (%)
1	100	75	100	100	100	75	50	25	25	25
2	50	50	25	25	50	75	75	100	100	100
3	25	25	100	50	50	50	50	100	100	100
4	75	25	25	100	100	25	100	25	50	50
5	100	100	50	50	25	100	25	75	50	25
6	25	25	100	75	100	25	100	25	75	100
7	75	100	50	50	25	75	25	100	75	75
8	75	100	75	100	100	75	100	100	25	25
9	100	50	100	25	100	75	100	75	100	100
10	25	75	25	100	25	100	50	50	75	100
Avg	65	62.5	65	67.5	67.5	67.5	67.5	67.5	67.5	70

AVERAGE PERCENTAGE OF ALLOCATION OF 4 CHANNELS

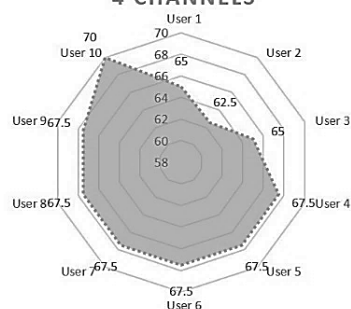


Fig. 6 Average Equitable distribution of 4 channels for 10 users

Fig. 6 represents equity level in the assignment of 4 channels for 10 users who were competing for resources. It is observed that in the majority of users, the same percentage of assignment was about 67.5%, meanwhile in some cases; it was a percentage of 62.5% (lowest assignment) and 70% for the cases where most channels were assigned. Of 10 users, 6 of them have an assignment percentage of 67.5%.

V.CONCLUSIONS

It is observed that not always these requirements are fulfilled, due to factors that limited quantity of resources at the system, so transmits should be developed in subsequent time slots.

The use of multichannel transmission for secondary users, allows handling of wider bandwidth and lower delays in transmission. For 10 channel transmission it is observed that the peak for maximum bandwidth goes up to 1800 kHz and reaches a minimum of 1000 kHz. Meanwhile if there only are transmissions in two channels, in average, transmissions are between 400 kHz and 500 kHz for low traffic scenery. Even though multichannel transmission it is quite effective to get a wider bandwidth in transmissions, it should be taken into account equality for all users who are competing for resources, because of that, it should exist a balance between equity and multichannel transmission.

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## REFERENCES

- [1] Y. Cao, V. O. Li y Z. Cao, «Scheduling Delay-Sensitive and Best-Effort Traffics in Wireless Networks,» *Communications*, vol. 3, pp. 2208-2212, 2003.
- [2] C. Chih-Yung, L.-L. Hung, C.-T. Chang, T.-L. Wang y T.-C. Wang, «A Cognitive Radio MAC Protocol for Exploiting Bandwidth Utilization in Wireless Networks,» de *Wireless Communications and Mobile Computing Conference (IWCMC)*, 2013.
- [3] Akyildiz, W.-Y. Lee, M. Vuran Y. S. Mohanty, «NeXt generation/dynamic spectrum access/cognitive radio wireless networks: A survey,» *Elsevier*, pp. 2127-2159, 2006.
- [4] P. Huang, C. Wang y L. Xiao, «RC-MAC: A Receiver-Centric MAC Protocol,» *IEEE Transactions on Computers*, vol. 64, n° 4, pp. 1149-1161, Abril 2015.
- [5] M. Ghorbanzadeh, A. Abdelhadi y C. Clancy, «A Utility Proportional Fairness Radio Resource Block Allocation in Cellular Networks,» de *2015 International Conference on Computing, Networking and Communications, Communication QoS and System Modeling Symposium*, 2015.
- [6] Y. Liu y E. Knightly, «Opportunistic Fair Scheduling over Multiple Wireless Channels,» *IEEE Computer and Communications*, vol. 2, pp. 1106-1115, 2003.
- [7] M. Laddomada, F. Mesiti, M. Mondin y F. Daneshgaran, «On the Throughput Performance of Multirate IEEE 802.11 Networks with Variable-Loaded Stations: Analysis, Modeling, and a Novel Proportional Fairness Criterion,» *Wireless Communications, IEEE Transactions*, vol. 9, n° 5, pp. 1594-1607, 2010.
- [8] S. C. Liew Y Y. Jun, «Proportional Fairness in Multi-Channel Multi-Rate Wireless Networks-Part I: The Case of Deterministic Channels with Application to AP Association Problem in Large-Scale WLAN,» *IEEE Transactions on Wireless Communications*, vol. 7, n° 9, pp. 3446-3456, 2008.
- [9] Y. J. Zhang y S. C. Liew, «Proportional Fairness in Multi-Channel Multi-Rate Wireless Networks-Part II: The Case of Time-Varying Channels with Application to OFDM Systems,» *Wireless Communications, IEEE Transactions*, vol. 7, n° 9, pp. 3457-3467, 2008.
- [10] W. Li y P. Yi, *Resource allocation in next generation wireless networks*, Nova Publishers, 2006.

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