ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645
Indian Journal of Science and Technology, *Vol 10(33), DOI: 10.17485/ijst/2017/v10i33/110001, September 2017*

Multichannel Assignment with Load Balance in Cognitive Radio Networks

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Abstract

Objectives: Based on a load balance perspective, a multichannel assignment model is raised for users whose applications require more than one channel, which achieves a more efficient use of spectral opportunities in cognitive radio networks. The proposed model makes a multiple frequency channel assignment to the secondary users who demand more than one frequency channel, under an equity environment. **Methods**: In order to achieve this, the model integrates the load balance in its assignment process taking into account historical data such as the equity level in the assignment and readjusting its assignment policies; likewise, it consists of a block which is in charge of setting an equity criterion for all users who want to transmit. The measurements made correspond to the average band width, the average delay and the fairness calculation when assigning various channels. **Results**: The obtained results were evaluated with spectral occupation data in the GSM frequency band. The developed model was compared to the MFA-CRN algorithm with no load balance and there´s an evidence of enhancement when assigning a higher average band width of transmission for each secondary user and thus, maintaining the equity criteria in channels assignment. **Improvements**: This work proposes a model of multichannel assignment that integrates a Fairness algorithm and load balance for cognitive radio networks with six evaluation metrics using experimental data of the GSM band.

Keywords: Cognitive Radio Networks, Fairness, Load Balance, Multichannel Assignment

1. Introduction

The use given to the Cognitive Radio Networks (CRN) is due to the needs for passing from a fixed and restricted assignment model of the spectrum to a model that flexibly uses the spectrum aiming to optimize the little resources in the wireless networks. Such flexibility could enhance the service of wireless networks since with an opportunist use of the available spectrum, there would be a better spectral efficiency[1].

These spectral opportunities could be used by Secondary Users (SU) with the restriction that once it is required by a Primary User (PU), the SU must abandon this spectrum piece in order to avoid any interferences to the PU´s transmission. According to this restriction it is

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necessary for the SU to move to another available spectral opportunity. This changing process is denominated spectral handoff[2].

These spectral opportunities have been used through a single channel assignment, however for users with real time applications that require a higher resources use, this type of assignments of one single channel are not the most suitable ones. Considering what´s been described so far, this investigation work aims to develop a model that assigns multiple channels to SE who develops real time applications, and single channel assignments for those SU who execute delay-tolerant applications.

For the purpose of having the opportunity to assign multiple channels and single channels according to the developed application type for each SU, there must be a criterion that guarantees that each SU is being guaranteed with the same available resources assignment opportunities. Aiming to accomplish this equity guaranty, the Fairness criterion implementation is raised, which equally assigns the available resources among all the SUs.

In order to guarantee the fairness during the SU´s transmission time, the load balance was taken into account, making all necessary adjustments to the assignment process so that the best available resources were assigned, enhancing the assignment level during the simulation time.

This load balance was made considering the round robin planning, for which on each quantum (piece of time) there was an assignment tasks generated according to the users demand type. However, this planning had a modification made so it could consider the priorities according to the user demand type. According to this, quantum will not have the same length, but its length will be according to the type of demand (real time or delay-tolerant).

This work is structured as follows, in Section 2, related work is presented, Section 3 describes the model development, Section 4 present the results and finally, Section 5 shows the conclusions.

2. Literature Survey

In[3] describe the importance of cognitive radio as a tool that promotes the efficiency in the existing assignment of the radio spectrum. In the cognitive scope the Cognitive Radio Ad Hoc Networks (CRAHN), the accessibility of routes depends of both, network topology and spectrum´s availability. In order to adapt to this characteristic, a cross layer routing protocol is proposed, which is called Load Balance Ad Hoc Over rhe Distance Vectors demand (LB-AODV). Previous work pays little attention to the networks load condition which allows there to be congestion and performance degradation. In order to fix this problem, the route queue length is used to indicate the load condition of different routes such as the main routing metric. Additionally, a jump limitation is defined in order to limit the average transmission delay. The implementation detailed steps of the routing discovery and local adjustment are described. The results show that, compared to AODV, the proposed protocol provided a better performance in both, the throughput and the average packages delivery in CRAHN.

In[4] analyzes how the charge for using the spectrum is an efficient approach that offers economic incentives to the operators, considering that the load balance produces incentives to avoid SU congestion. This in spite of the complexities such as price fixing, load balance and decision of access to the spectrum by the SU, and the type of applications developed by both, PU and SU. The problem of maximizing the incomes of operators in two market types: The monopoly and the duopoly. For the monopolist market, there is a unique arriving rate for the monopolist channels. The duopoly market is first characterized by a unique arriving balance to two different operators that use different DSA approaches. When two operators are not cooperative, it shows there´s a unique Nash balance for each operator´s income. When they are cooperative, it shows that the optimization of social income can achieve a unique optimal solution. Using Nash´s negotiation framework, there´s also a distribution contract that determines the optimal social income fraction for each operator.

In[5]proposes an access protocol to the Medium Full-Duplex Multichannel for Cognitive radio networks (MFDS-MAC). This model takes advantage of the fact that with Full Duplex (FD) the SU can detect and access the spectrum simultaneously and can use a random dynamic channel selection for the load balance among channels and the standard mechanism for resolving disputes over each available channel. It also develops a mathematical model to analyze the throughput of the MFDC-MAC model. Furthermore, it analyzes the optimized protocol configuration to maximize the network´s performance. This optimization can be done in two stages, the access and transmission parameters optimization in each channel and the optimization of the selection probabilities of user's channels. Such optimization aims to achieve an auto-interference management of the FD transceivers, the overload detection control and the load balance among channels. The results show the impacts of the different protocol parameters and the importance of the throughput parameters optimization.

In[6] considers the problem of assigning resources in the context of the subjacent spectrum in the cognitive radio (CR). In this framework, the Quality of Service (QoS) as a requirement must be satisfied for both PU and SU. It uses admission control algorithms based on elimination among the potency control so that it satisfies the QoS requirements for all admitted SU, as long as it doesn´t cause and excessive interference to the PU.

It also introduces the problem of minimum weight load balance based on weighted bipartite graphs, while combining the potency control and the user elimination. The simulation results show that the algorithm achieves improved results compared to only using potency control algorithms and users elimination.

In[7]the predominant approach in the Dynamic Spectrum Access control (DSA) in order to provide economic incentives to the operators is price fixing, while the load balance provides incentives to avoid congestion for SU. In spite of the complexities, it proposes to resolve the joint problem of load and prices balance to maximize the operator´s income in a monopolist market. In this market, it demonstrates the existence of a unique balance arrival rate of the SU to the monopolist´s channels. Likewise, it proposes a low complexity algorithm that allows the operator to maximize their incomes.

In[8] studied the dynamic load balance for deciding the CRN spectrum which dynamically distributes the SU packages through different primary channels. Unlike what´s shown in literature, this work considers two different service classes devolved by the SU, Better Effort services (BE) and Delay Sensitive (DS). Then, an analytic model is proposed for improving the priority problem and analyzing the delay performance for the two services separately. According to the obtained results, two Markov´S Decision Processes are formulated (MDPs) to maximize the average delay in both services, while it guarantees the DS service priority. The simulation results show that the MDP scheme proposed has a significant improvement in the delay´s performance for both DS and BE services.

3. Methodology

In order to develop the multichannel assignment simulation, the model described in Figure 1 was developed.

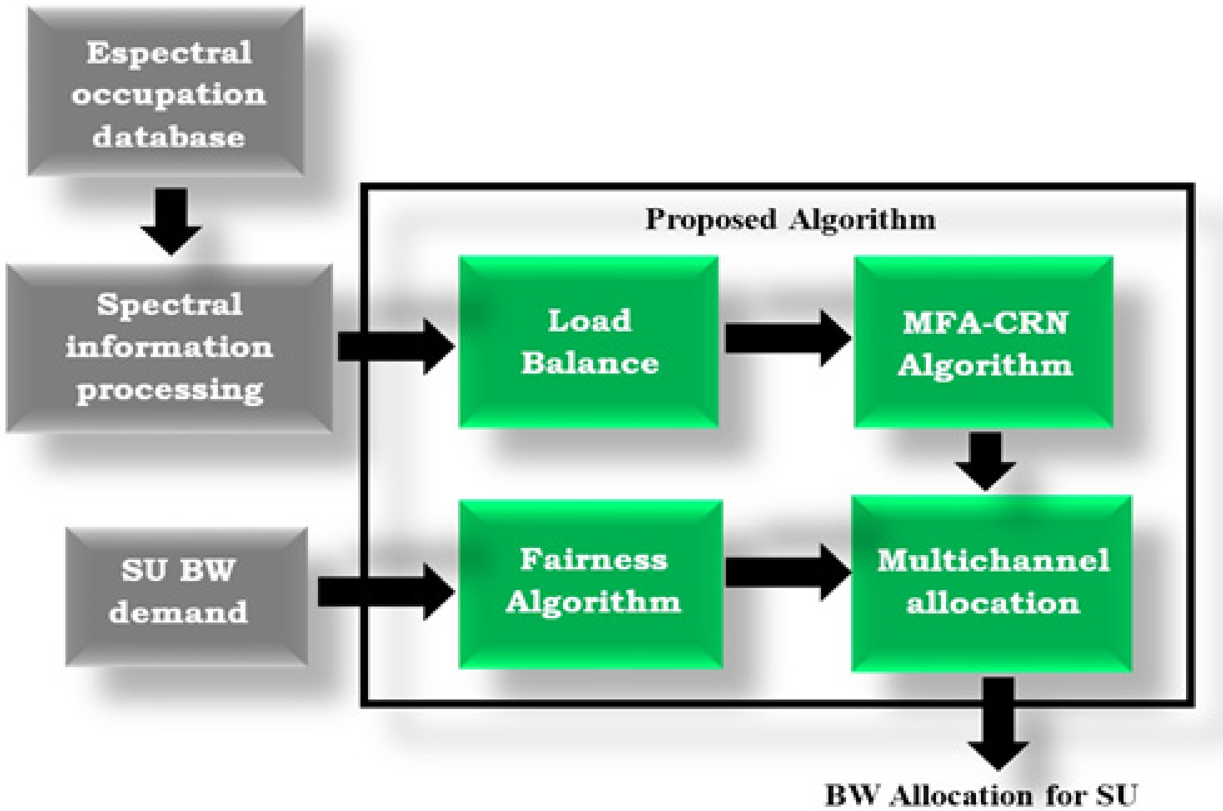

Figure 1. General structured of the proposed model.

3.1 Defining the Simulation Variables

The main task of the model consists on the multiple and unique assignment of channels according to the type of application developed by each SU. For the purpose of revising the model´s behavior, a 10 minutes simulation period was taken, sectioned into time rabbets, each of them with a 0.3 sec duration during which the model was evaluated.

Also, took into account the behavior of the model against different traffic types, meaning scenarios with a high resources demand down to those scenarios with a low resources demand. As an input, there was a data base of the GSM band spectral occupation, which was measured in different time intervals, for the purpose of obtaining high traffic data and low traffic data.

3.2 Choosing the Load Balance Method

This load balance was made considering the round robin planning. The Round Robin Planning provides each task with the same time lapse in terms of CPU execution time. However, this type of planning does not satisfy the real time system requirements since these works under different importance levels. In order to improve this, planning can be made based on combined priorities with Round

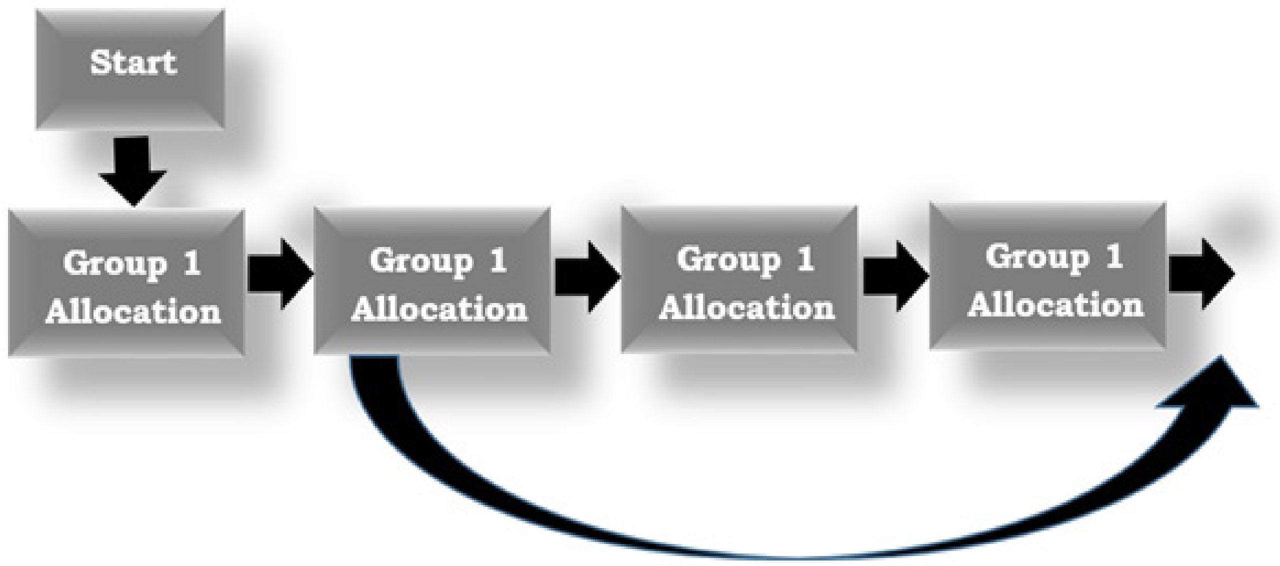

Figure 2. Round robin cycle.

Robin to administrate the quantum (time pieces) but handling the priorities of each task[9,10].

Each quantum executes a task for a defined time interval until all the tasks are executed in a specific quantum, completing this way a Round Robin cycle. When all tasks have executed, a controller that carries the task sequence is reset and the cycle starts once again for executing the respective tasks in each quantum[11].

According to this, there could be said this is a circular cycle as observed in Figure 2.

According to Figure 2, same length quantum's are used, therefore, Round Robin´s cycle could be posed as Equation (1) shows.

$$T_{RR} = \sum_{s=1}^{S} (q_s) \quad (1)$$

Where T_{RR} is Round Robin´s cycle and q_s is each of the quantum that intervene in this cycle.

However, for the purpose of this investigation, there was posed that the quantum's wouldn't have the same length but they would adequate to the priority level by users group, therefore Equation (1) turns into Equation (2).

$$T_{RR} = \sum_{s=1}^{S} K(q_s) \quad (2)$$

Where K represents the quantum´s priority level within Round Robin´s cycle

3.3 Scenario: Load Balance Behavior with Insufficient Resources against Demand

In this scenario, the system allows to satisfy the users demand with applications of both real time and better effort. Taking into account that the load balance process exists, to satisfy the needs of all users the condition described by Equation (3) must be accomplished.

$$K\sum_{i=1}^{n} DQSi \leq \sum_{s} BWs \tag{3}$$

Where DQsi corresponds to the sum of demands of each user group in each quantum of time and K refers to the priority of each user group within the Round Robin cycle.

There must be kept in mind that each quantum represents a group of users who develop better effort or real time applications

3.4 Scenario: Load Balance Behavior with Higher than Demand Resources

In this scenario, the following condition must be considered for the different quantum in the Round Robin planning. It´s known that each quantum develops an assignment process for a group of users according to the demand type (real time or delay-tolerant). Therefore, if for a specific quantum there´s fulfillment of the condition where the offer is lower than the demand, there must be guaranteed that all users will be able to use the network resources, even though they may not obtain all that´s being demanded in terms of resources. Considering this premise, Equation (4) can be inferred.

$$H(n) = \sum_{i=1}^{n} [KQ(n) - C(n)] \tag{4}$$

Where QKn is the quantum with K priority that can transmit but with Cn penalty due to the partial assignment of resources against what was requested because of the limitations of system´s resource.

3.5 Design Model

As mentioned in the methodology section (Section 3), a spectral occupation data base is used, and likewise, different resource demands work as an input variable, which translates into the bandwidth required by each SU, which are processed so they can be interpreted by the rest of the model. Then, there comes the load balance block which is in charge of revising the channels assignment to each of the SU and in case there´s any kind of penalty, it develops some adjustments in the assignment priority based on certain weights given to each group type.

The selection process also considers the equitable assignment for all SU. For this, the model includes the block "Fairness Algorithm" which uses the MFA-CRN algorithm[12], which tries to generate assignment equity in the band width. It could be defined as a set of active S users where the assignment mechanism assigns to each *s* user an R(s) resource so that it fulfills Equation (5).

$$\sum_{s=1}^{S} [R(s)] \leq R_T \tag{5}$$

Where R_T is the total system resource. However, when the resource offer is higher than the demand, Equation (6) must be satisfied instead of Equation (5).

$$\sum_{s=1}^{S} [R(s)] + \frac{\sum_{i=1}^{S} Ni}{S} + R_{CH} \leq R_T \tag{6}$$

Where Ni represents the number of surplus resources, and R_{CH} is a resources reserve.

Due to the load balance imposed in the model, it is important to consider the Fair Queuing[13], which must be used in transmissions with resources restrictions. This algorithm allows to efficiently managing the quantum´s assignment that along with the Round Robin planning as a load balance method, it is possible to make the average assignment of bandwidth for each SU group in different time quantum, so that it´s equally made.

4. Simulation

The bandwidth for each SU was classified according to the type of application developed for each user. However, these bandwidth demands can consist of a single channel or multiple channels. Therefore, for the simulation there were 4 types of demands developed, starting from the one that had a predominant number of users with applications in real time, up to the demand with a balanced number of users with applications in real time against users with delay-tolerant applications, for the purpose of making a performance assessment of the proposed algorithm in this scenarios. The 4 types of demands are shown in Table 1.

The algorithm for each type of demand makes the planning of resources assignment by time quantum. Therefore, a quantum represents the group of users that demand 10 channels, another quantum represent the

Table 1. Types of demand of SU by application type

Demand	Description	Applications users Real Time		Applications users Delay-Tolerant		Users Total
		Amount Demand Channels	**Amount Users**	**Amount Demanded Channels**	**Amount Users**	
DMA	Additional Resources Assignment	10	5	1	20	40
		4	5			
		2	10			

Table 1 Continued

DMB	Additional Resources Assignment	10	10	1	30	65
		4	10			
		2	15			
DMC	Partial Resources Assignment	10	25	1	35	100
		4	15			
		2	25			
DMD	Partial Resources Assignment	10	40	1	25	100
		4	15			
		2	20			

users that demand 4 channels and so on, so that in the simulation there will be 4 quantum's in the Round Robin planning process.

5. Results

The following metrics were considered in the results to measure the model´s behavior against different demand

Table 2. Types of analyzed demands

TYPE	Amountofusers
DMA	40
DMB	65
DMC	10
DMD	10

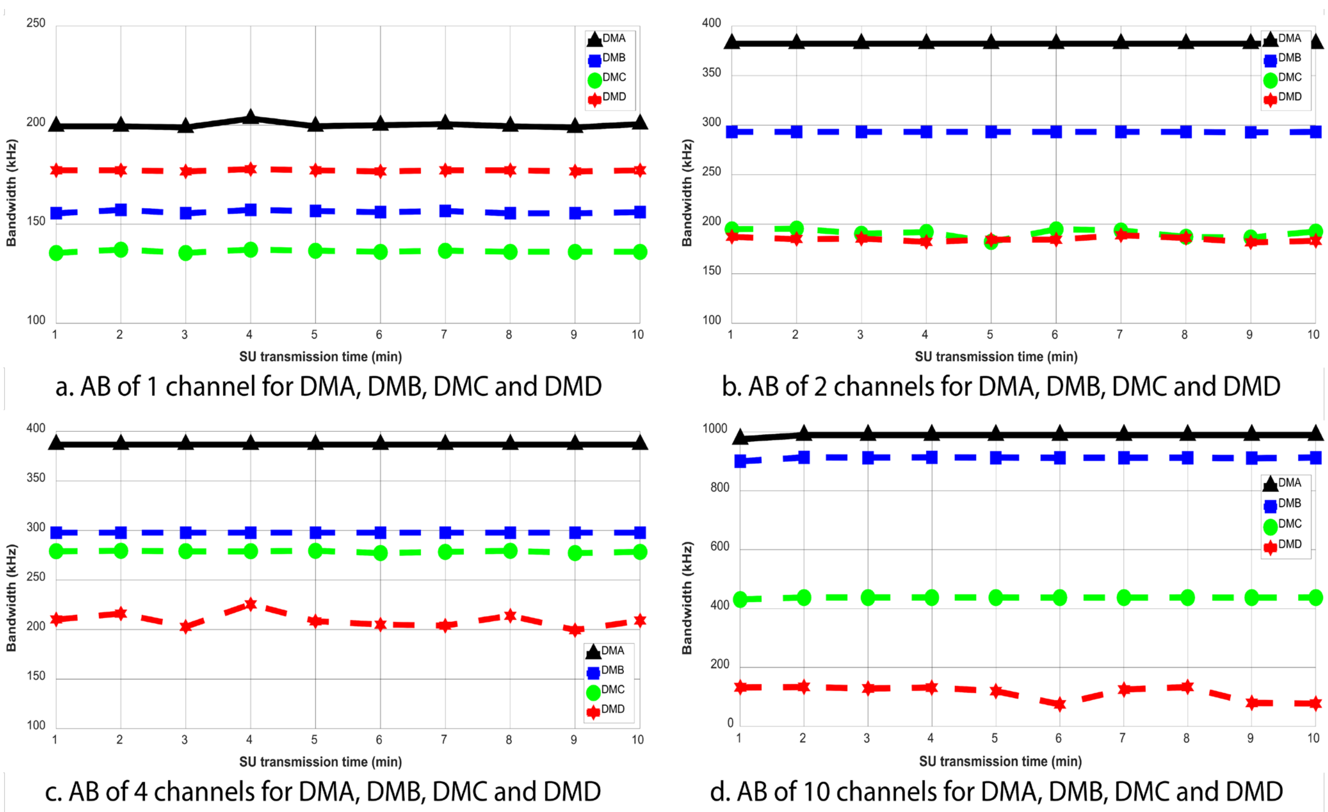

Figure 3. Average bandwidth in high traffic for DMA, DMB, DMC and DMD.

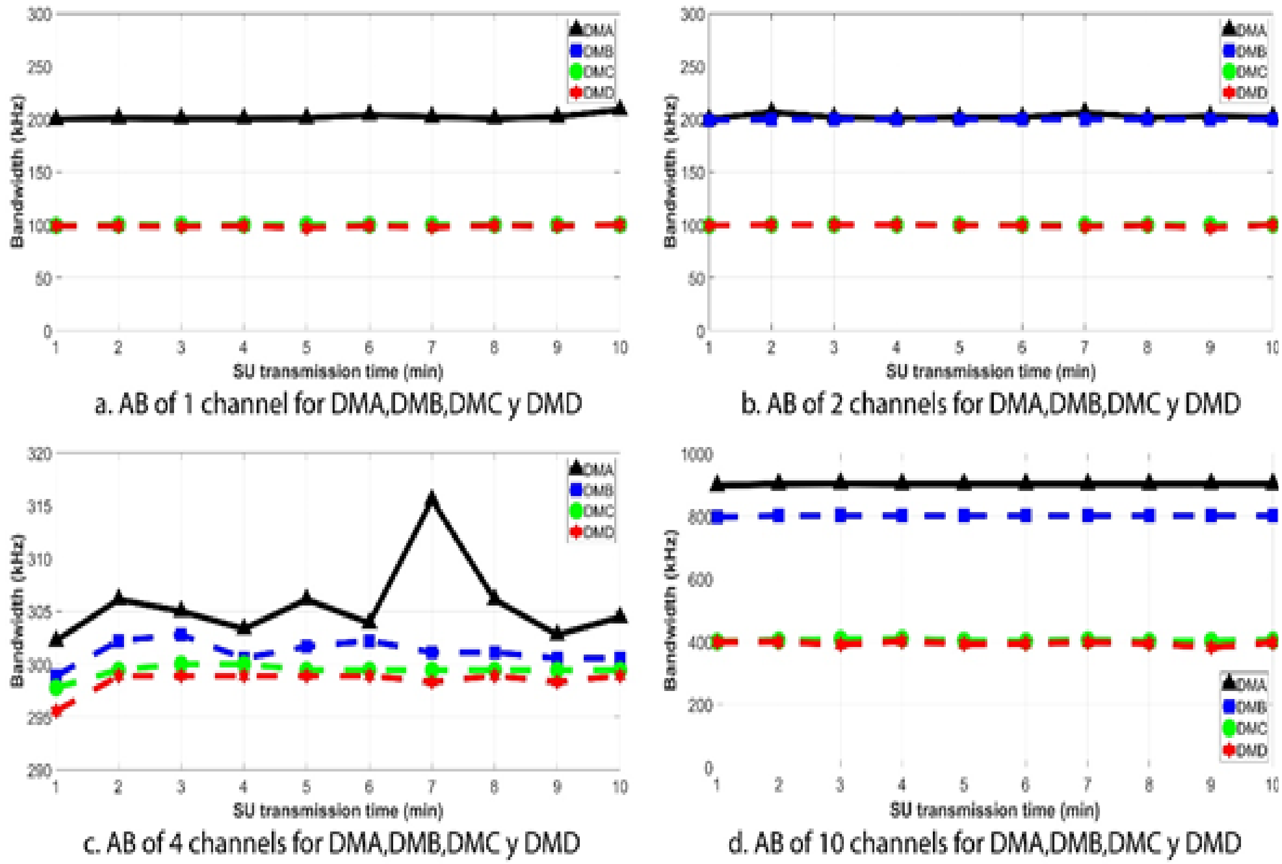

Figure 4. Average bandwidth in high traffic for DMA, DMB, DMC, DMD without load balance.

types in a 10 minutes simulation range:

- Band width.
- Successful Handoffs.
- Unsuccessful Handoffs.
- Average Delay.
- Through put.

Table 2 condenses the information of demands shown in Table 1 for demands used in the simulation:

The obtained results in the simulation are presented in Figures 3 through 12

Figure 3 and 4, it is established that the bandwidth assignment of 2 channels, 4 channels and 10 channels was higher using the load balance method against the results without using load balance. It is also observed that in the assignment of 1 channel it overcomes what was requested in all types of demands from a 25% to a 100% (Figure 3(a)), this same behavior is reflected for 2 channels of DMB and DMA demand, while DMC and DMD assigned approximately what was requested. (Figure 3(b)). In the case of 4 and 10 channels of average bandwidth assigned, it was below what was requested, which concords with the high traffic type. (Figures 3(c) and 3(d)).

In the case of delay, it is observed that the behavior is a little higher when using load balance (Figure 5), against the delay results without using load balance (Figure 6). This indicates that since in the use of Round Robin´s

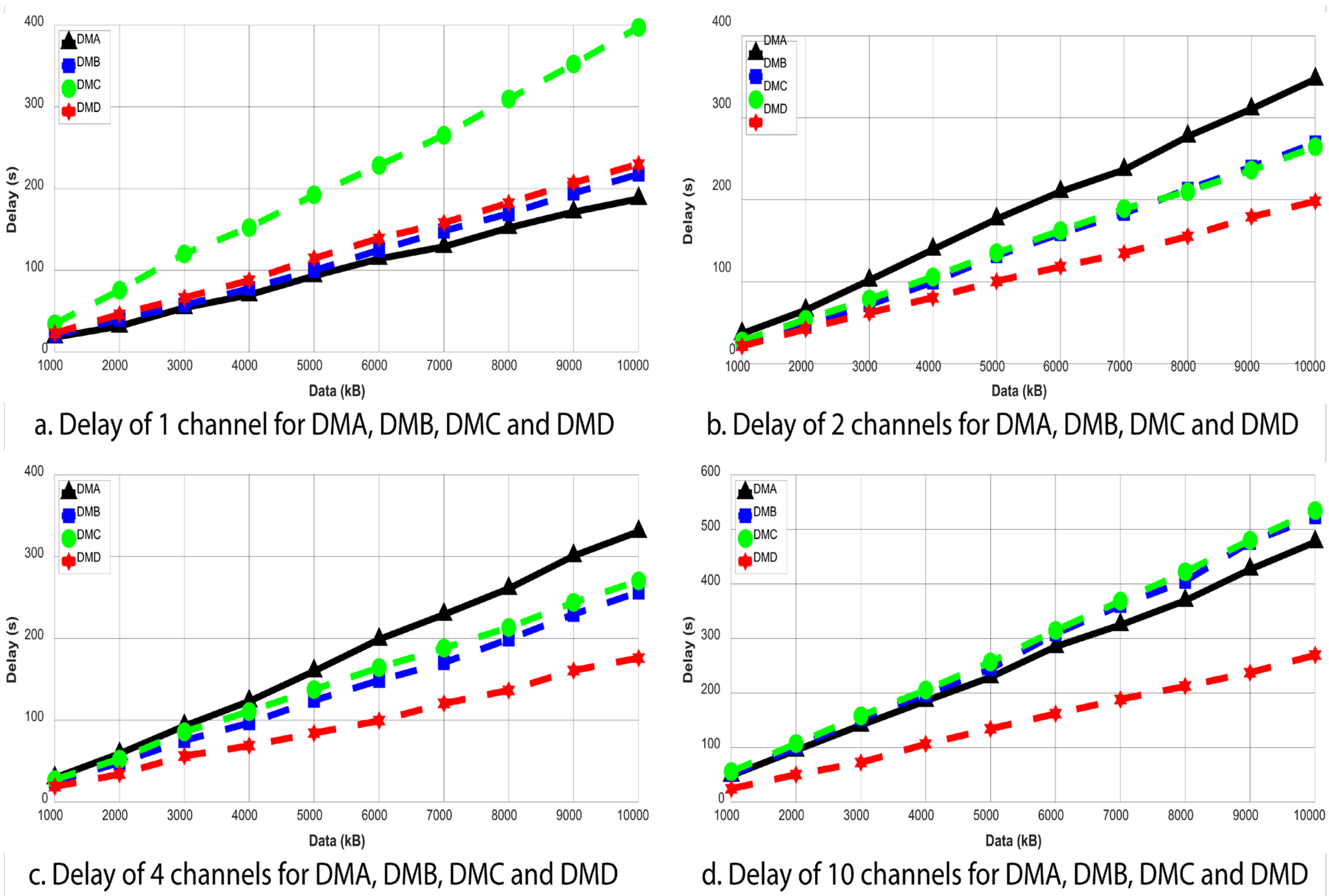

Figure 5. Average delay in high traffic for DMA, DMB, DMC and DMD with load balance.

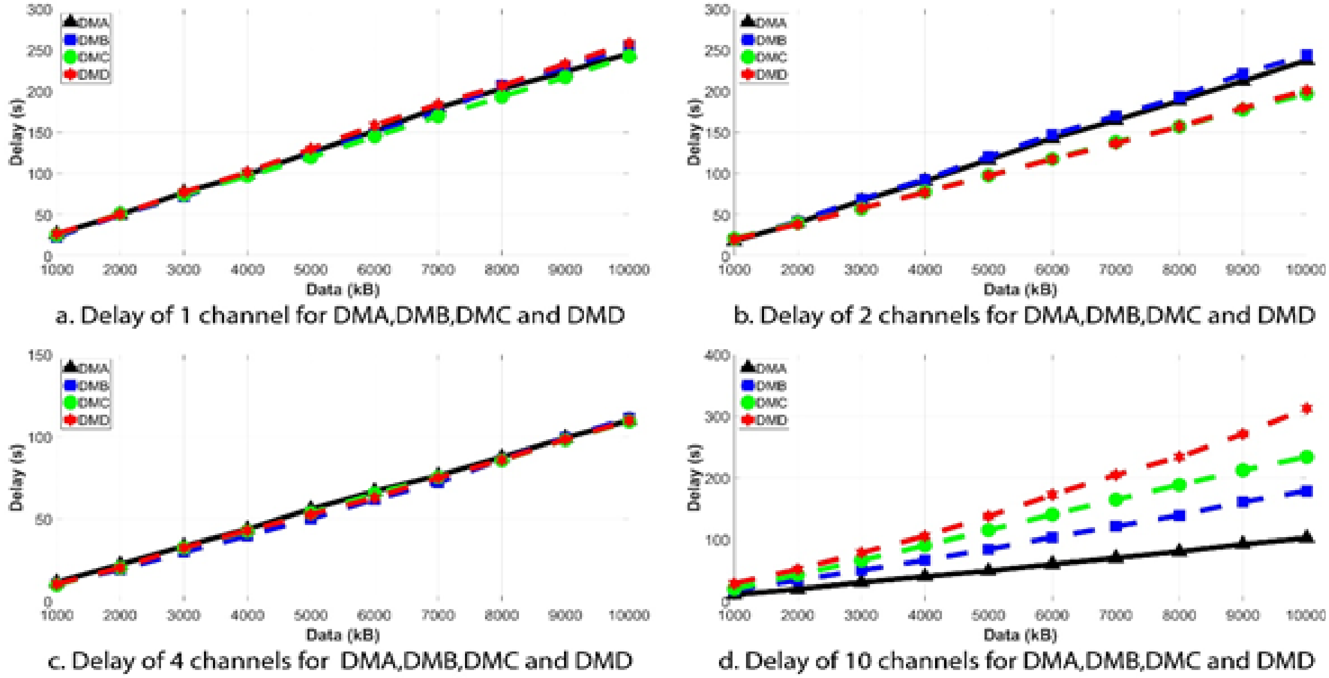

Figure 6. Average delay in high traffic for DMA, DMB, DMC and DMD without load balance.

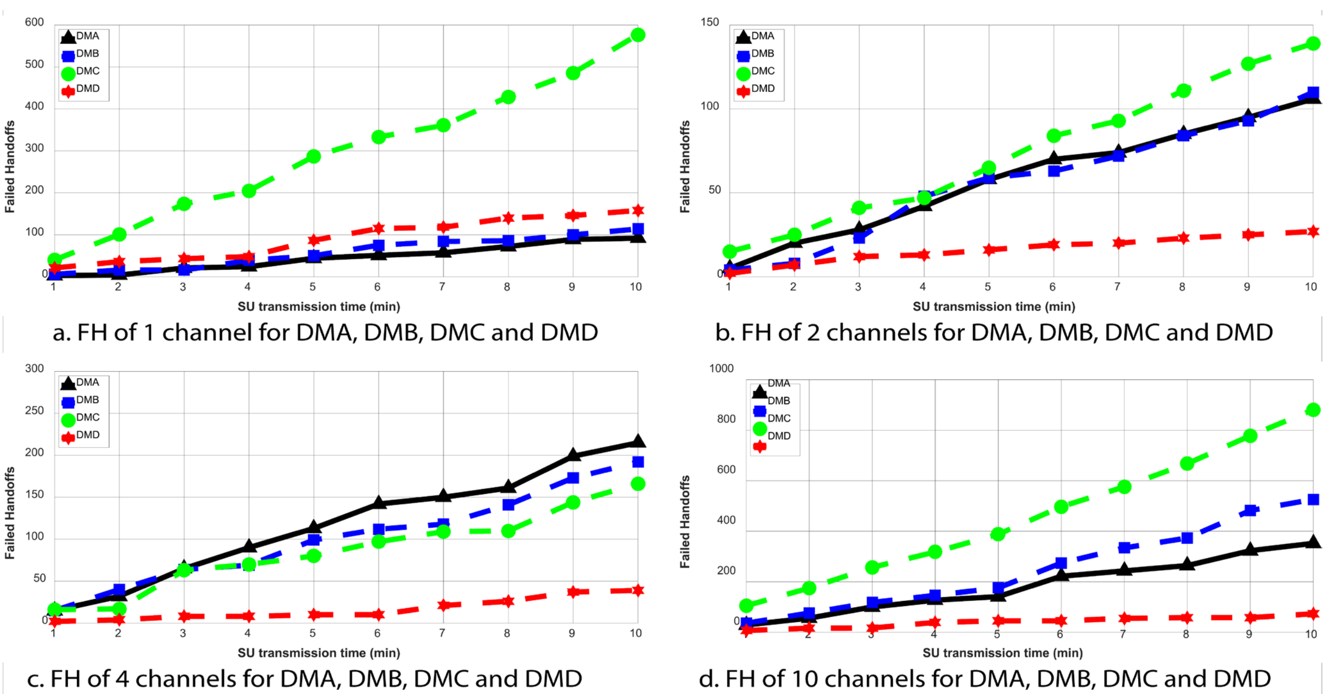

Figure 7. Unsuccessful handoffs in high traffic for DMA, DMB, DMC y DMD with load.

planning each user has to wait their turn to use the available resources, there´s a delay related to this wait.

Figure 7 shows a similar behavior against the results where there´s no use of load balance (Figure 8). Likewise, it is observed in Figure 7 the number of unsuccessful handoffs for DMA in 2 and 4 channels is higher because the algorithm searches for a higher number of channels against what was requested to generate an over assignment.

In the case of handoffs (Figure 9), the same behavior as Unsuccessful Handoff occurs, it is observed that it is higher against what´s shown in Figure 10, in spite of this,

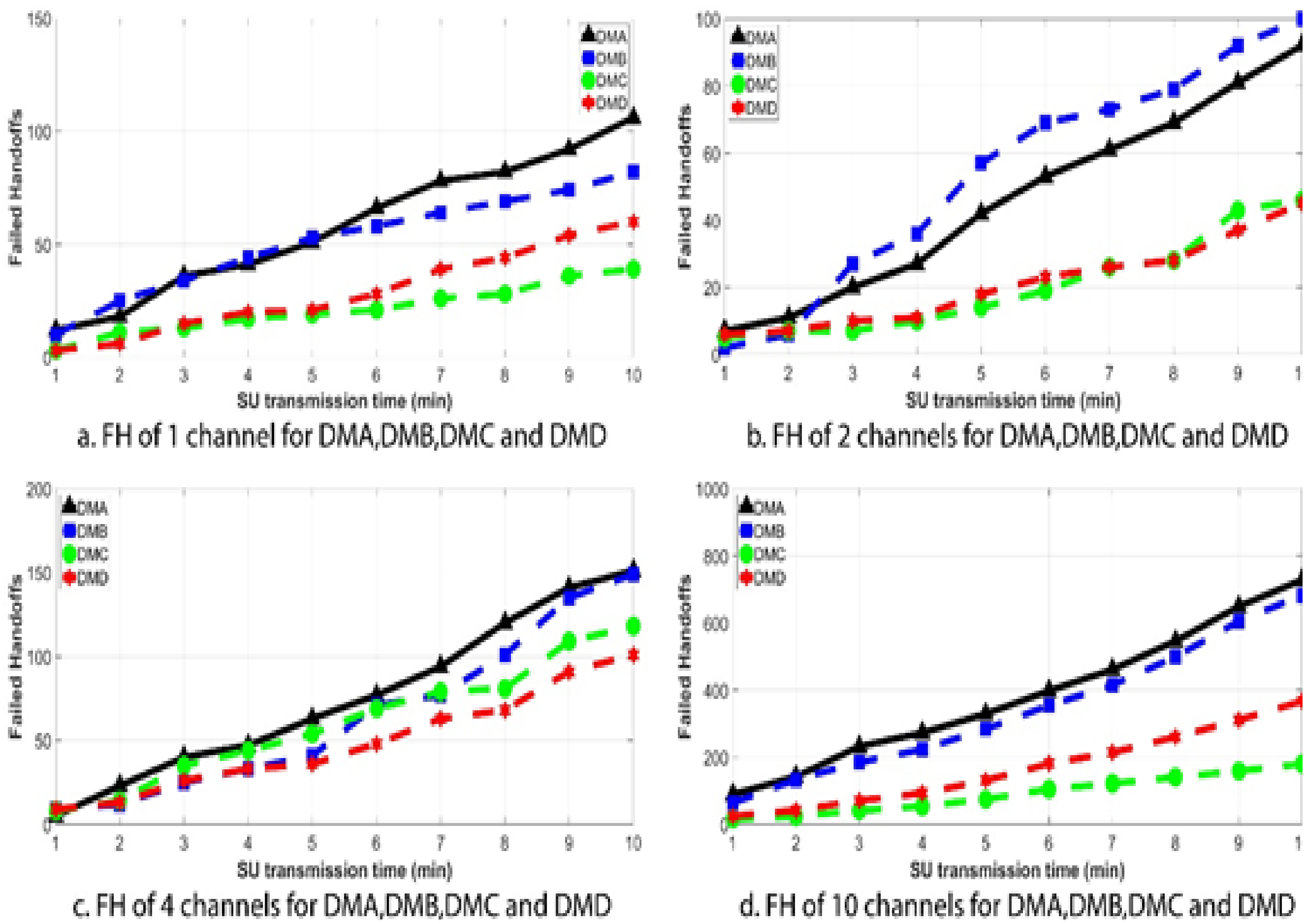

Figure 8. Unsuccessful handoffs in high traffic for DMA, DMB, DMC y DMD without load balance.

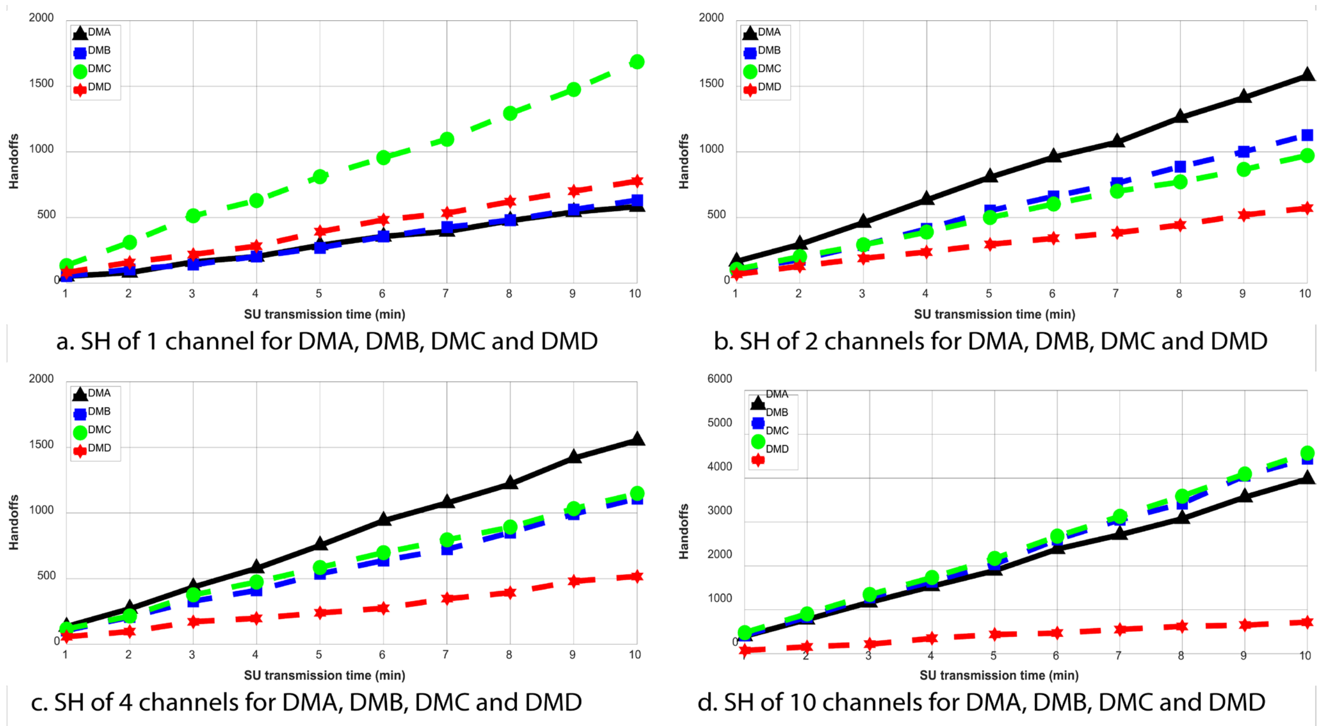

Figure 9. Handoffs in high traffic for DMA, DMB, DMC and DMD with load balance.

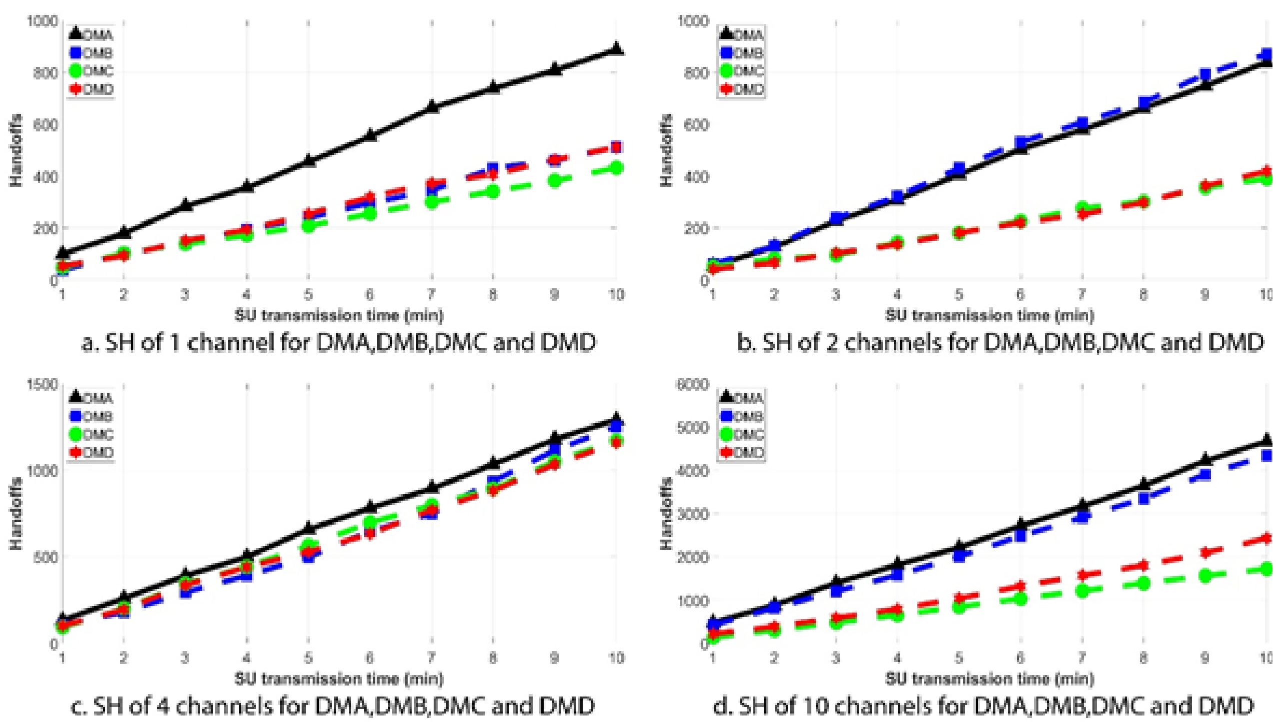

Figure 10. Handoffs in high traffic for DMA, DMB, DMC and DMD without load balance.

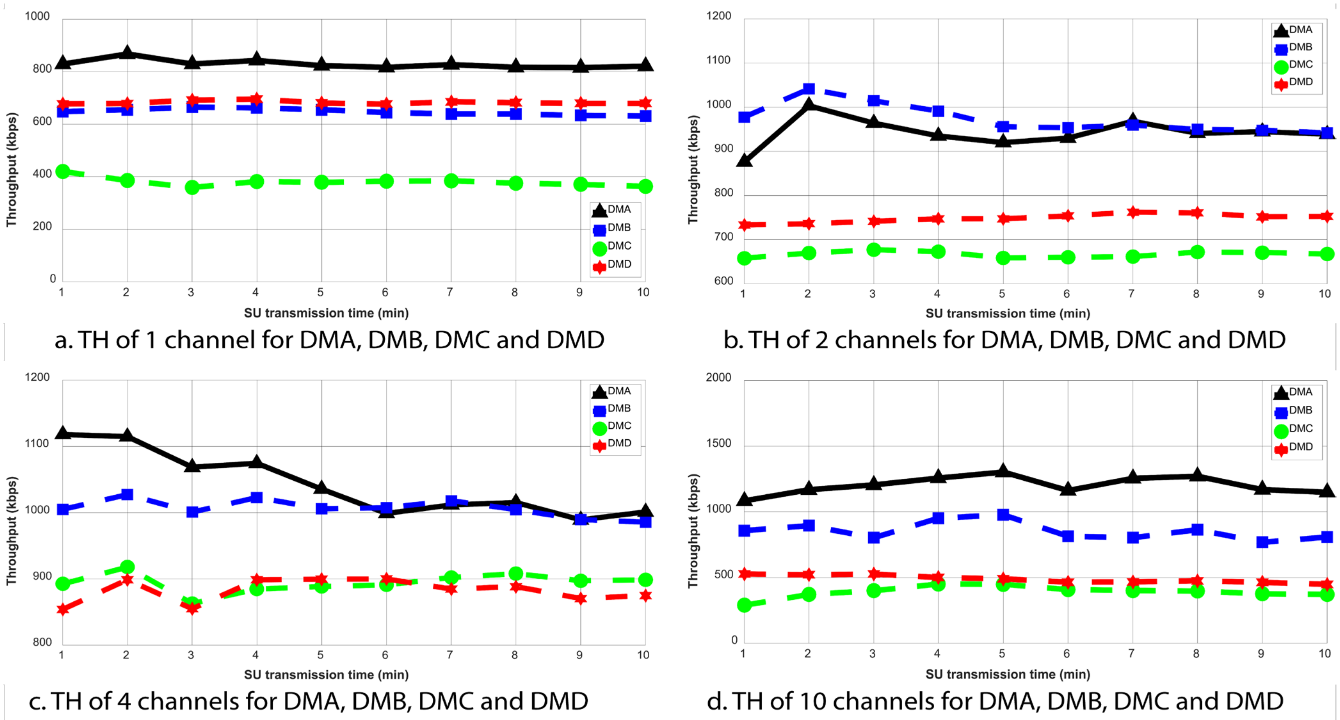

Figure 11. Throughput in high traffic for DMA, DMB, DMC and DMD with load balance.

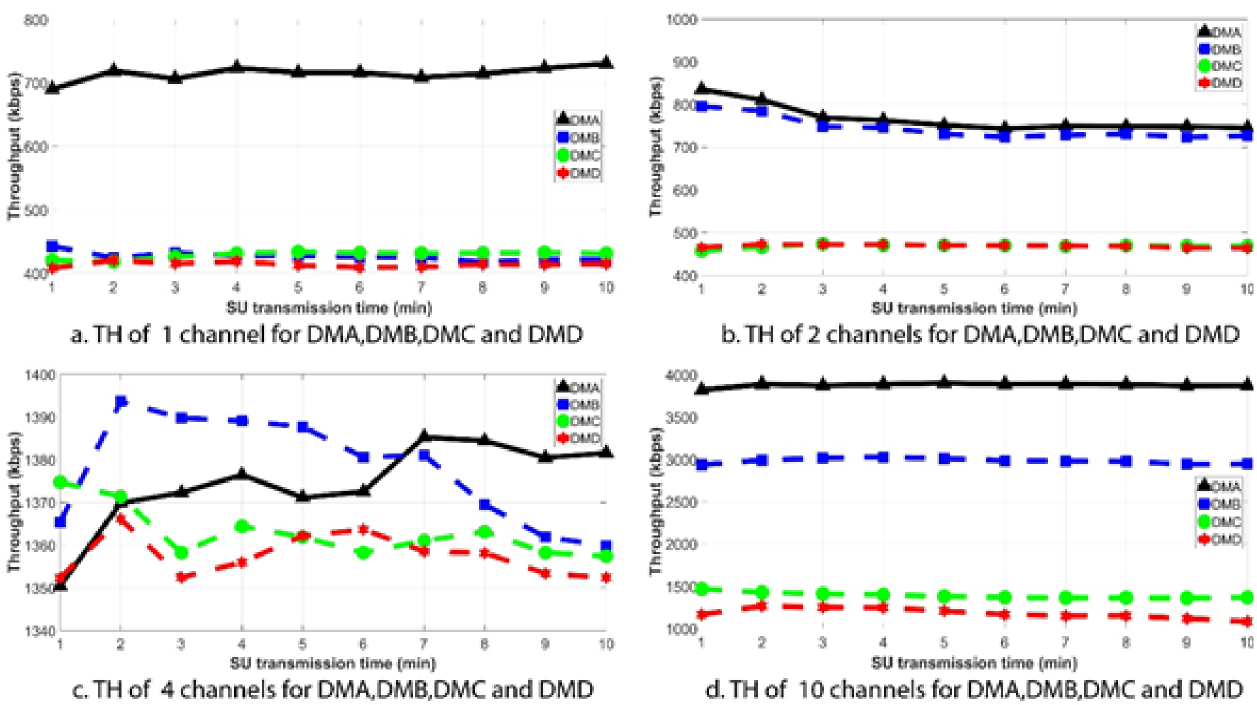

Figure 12. Throughput in high traffic for DMA, DMB, DMC and DMD without load balance.

it was the one with the best bandwidth for each type of demand and user (View Figure 3).

It is observed that the throughput perceived for the simulation with model using load balance is higher against the model that doesn´t use load balance Figures 11 and 12. There can be said then, that in spite of each group not making a continuous transmission during the simulation, but in their defined time quantum, it achieves to explode the additional resources assignment function to each group of users, transmitting more information than if it had been done by competing with all groups of users.

6. Conclusions

Although with Round Robin´s planning as a load balance method, the groups of users are not continually transmitting but in their assigned quantum, it is observed that even though, the average assignment of bandwidth in cases of 1 and 2 channels was positively affected, getting sometimes to be a higher assignment against what was requested. In the case of 4 and 10 channels, there could not be a total resources assignment, but it was able to make a partial assignment according to availability

It is observed that the throughput is positively affected in the model that uses the load balance, which supposes that it is better to assign resources by time quantum, since it allows the algorithm to make an over assignment of resources to a certain group of users even if it is in high traffic environment. This wouldn´t be possible if all groups of users were continually competing for resources continually.

In spite of the amount of handoffs, metrics such as average bandwidth, average throughput and average delay, are never negatively impacted against this increase.

7. Acknowledgements

The authors wish to thank Colciencias and Universidad Distrital Francisco José de Caldas, for the supporting and funding during the course of this research project.

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