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SPECTRUM DECISION MODEL WITH PROPAGATION LOSSES

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ABSTRACT

Spectrum decision selects the proper spectrum bands in order that a new cognitive radio (CR) user can transmit. This paper presents the development and results achieved in a CR technology research, specifically in the spectrum decision stage, where is selected the band(s) most appropriate for transmission, based on the information gathered during the sensing spectrum stage and the requirements of non-licensed users, so that a decision model was applied through multi-criteria selection techniques. Within this were made thirteen measurements at three places in Bogota for a total of thirteen days. With the results was designed a decision model that integrates the propagation losses in the GSM (global system for mobile communications) band in some places of Bogota, Colombia.

Keywords: multicriteria analysis, spectrum decision, radio spectrum, propagation losses, cognitive radio.

1. INTRODUCTION

The cognitive radio is a paradigm of communication that aims to address the spectral underutilization issue [1, 2] since its main purpose is to make efficient use of spectrum allowing opportunistic access [3-5] where secondary or unlicensed users can use licensed bands that are inactive [6, 7]. This work focuses on the decision spectrum stage where the spectral characteristics and requirements of cognitive radio users are identified to choose the best option, there are currently designs for this process that take into account factors such as capacity channel interference, routing, among others[8].

Once all available spectrum bands are characterized, we must select the most appropriate band for the transmission, taking into account the quality of service (QoS) requirements and characteristics of the spectrum. Based on user needs can be determined: the data rate, the error rate, delay, transmission mode and bandwidth for transmission. Then, it can be chosen the set of appropriate spectrum bands, according to the decision rule. In [7], five rules of decision spectrum, focusing on fairness and the cost of communication are presented. However, this method assumes that all channels have similar performance capabilities.

In [8] is proposed an opportunistic frequency channel protocol to search a better channel quality, this decision is based on signal to noise ratio (SNR) of the channel. In order to identify the activity of the primary user, it takes into account in the spectrum decision the number of transfers of spectrum and what happens in a particular spectrum band [9]. In [10, 11] spectrum decision frameworks are proposed considering the application requirements, and in [12]a spectrum decision scheme for wireless mesh networks is applied. The development of this research shows the impact of the propagation loss in the GSM band within a spectrum decision framework in some places of Bogota.

In the next section is presented the methodology used to develop the decision model proposed, which takes into account the channel features such as signal-to-interference-plus-noise-ratio (SINR), the occupancy percentage, the propagation loss and the requirements of secondary users as estimated transmission time, class of service and type of traffic.

In Section 2 analyzes the model designed, then Section 3 shows the results achieved and finally Section 4 contains the conclusions.

2. PROPOSEDMODEL

The model implemented is divided into the following phases: spectrum measurement, modeling the GSM band, requirements modeling and secondary user's selection algorithm development.

2.1 Spectrum measurement

The total measurement campaign was carried out for thirteen days at three places (south, northwest and north) of Bogota. To obtain representative figures in terms of statistical averages, it took 72h in the south and northwest areas. For the north area measurement was performed for a period of 170h, enough time according to the number of samples needed to achieve a desired confidence interval [13, 14]. The measurement setup is shown in Figure-1, the spectrum analyzer and technical specifications of the used devices can be seen in Table-1.

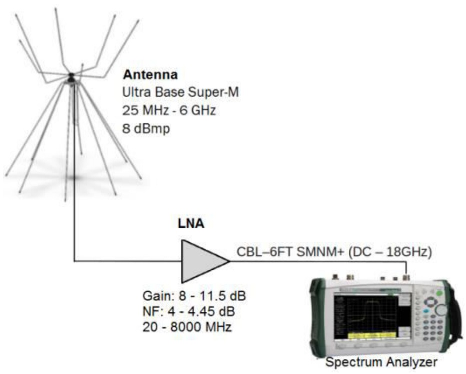

Figure-1. Measurement setup [15].

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Table-1. Measurement equipment specifications [15].

Equipment	Specifications	
	Frequency range	**Reference**
Discone Antenna	25 MHz – 6 GHz	Super-M Ultra Base
Wideband cable	DC – 18 GHz	CBL-6FT SMNM+
Low Noise Amplifier	20 MHz – 8 GHz	ZX60-8008E-S+
Spectrum Analyzer	9 kHz – 7.1 GHz	MS2721BAnritsu

The spectrum occupancy was measured in the range from 824MHz to 849MHz. The span for each measurement was less than 60MHz and it was calculated from Equations 1 and 2, since measurement technology has a bandwidth of 200 kHz, in order to ensure an accurate estimate of spectrum occupancy.

$$B_T > f_b \tag{1}$$

$$f_b = \frac{SPAN}{pps-1} \tag{2}$$

where B_T is the channel bandwidth, f_b is the frequency *bin*and *pps* is the number of points per span of the analyzer, which in this case is 551. *Bin*separations lower than frequency bandwidth, guarantee the signal detection [14]. These segments smaller than 100MHz allowed to choose a resolution bandwidth (RBW) less than or equal to the B_T, which was about 100kHz, with sweep times ranging around 52 milliseconds for 13 days of measurement, obtaining 21’600.000 traces.

The measurements were carried out in buildings located at the following places:

- South area with latitude 4.6168 and longitude -74.1303
- Northwest area with latitude 4.6572 and longitude -74.1114
- North area with latitude 4.6865 and longitude -74.0487

The model to find propagation loss was the Okumura - Hata[16, 17] with an adjustment by the method of least squares [18]for the specific area.

$$L(dB) = 86.64 + 26.16 \log f_c - 13.82 \log hte - a(hre) + (45.1 - 6.55 \log hte) \log d \tag{3}$$

where, f_c iscarrier frequency in MHz, *hte* is the height of transmitting antenna in m, *hre* height of receiving antenna in m,*a(hre)* is the correction factor for the effective height of the mobile antenna which is function of the type of service area, and *d* is the distance between transmitter and receiver in km.

2.2 Modeling of the GSM band

With the data collected during the measurement campaign was characterized the band, the values obtained at the frequencies of each channel are averaged, which leads to having an output of 126 channels.

Then it was evaluated whether the channels are occupied or empty considering the decision threshold, which was demarcated with a "1" for busy channel and "0" for free channels, then the SINR of each channel is evaluated according the following Equation 5:

$$SINR = P_E - I - N \tag{5}$$

where *N* is the noise power which is detected when the channels are free, *I*is the interference according to [19], in order to ensure a BER less or equal to 10^{-4}, and P_E is the reception power expected.

$$Ico\text{-}channel = P_c - 9\ dB \tag{6}$$

where P_c is the carrier power that is identified during measurements when the channel is busy.

With a safety margin of3 dB, the Equation 6 is:

$$\text{Ico-channel} = P_c - 12\ \text{dB} \tag{7}$$

For adjacent channel interference:

$$I_{\text{adjacent channel}} = P_c - 3\ \text{dB} \tag{8}$$

Therefore Iis 15 dB.
$P_E$is found with the Equation 9:

$$P_E = P_{BS} - L_p \tag{9}$$

whereP_{BS}, is the transmission power of the base station and L_p are the propagation losses.

Then the occupancy percentage was calculated for each channel during a time of observation via the Equation (10):

$$\text{Occupancy per channel } \% = \frac{N_1}{N_T} * 100\% \tag{10}$$

Where N_T is the total number of samples in a specific channel during the observation time and N_1 is the number of samples with spectral occupancy in a specific channel.

2.3 Algorithm design

The following sections outline the steps taken in order to have the final decision algorithm.

2.4 Modeling requirements of secondary users

For this procedure is considered that secondary users (SU) are characterized bythe type of traffic (data or multimedia), the class of service (real time or best effort) and estimated transmission time.These parameters are modified every second to simulate different SU's needs.

2.5 Algorithm selection

In this section the multi-criteria analysis process to select the best available channel for a SU are described.

- Decision options selection

Decision options having the algorithm is the spectrum measurement range, channels from 824 MHz to 849 MHz with a bandwidth of 200 kHz each, leading to have 126 options.

- Evaluation criteria selection

The initial evaluation criterion is the channel occupancy. This parameter is identified from information gathered and discriminates between a busy or free channel, according to the decision level previously found.

Additionally, it is important to consider that if this criterion gives a result as busy channel then proceeds to discard the channel immediately. The following are the criteria taken into account within the objective function:

- Channel occupancy percentage: in this parameter the number of samples with the spectrum occupancy is identified with respect the total sample.
- SINR: this value can be calculated by the expected signal power and noise power measurements, and the permissible interference level.
- Propagation losses: these losses are found through Equation 3, with data of the environment where measurements were performed.
- Standardization of performance measured.

The technique for the standardization of performance measures was to find the relative error of the parameters from a specific value.

- Weighting of criteria

Weights are assigned considering the three parameters must sum to 100%, as shown in Table-2.

Table-2. Assigning weights to criteria.

Evaluation criteria	w_n	Weight
SINR	w_1	0.4
Propagation losses	w_2	0.4
Occupancy percentage	w_3	0.2

- Order criteria

In this phase the weights of the criteria are combined with performance measures, so we proceed to determine Equations 11, 12 and 13, leading to the objective function to satisfy the requirement of each SU.

$$f_{SINR} = \frac{w_1 * (SINR - SINR_{required})}{SINR_{required}} \tag{11}$$

$$f_{Prop\ Loss} = \frac{w_2 * (Prop\ Loss - Prop\ Loss_{required})}{Prop\ Loss_{required}} \tag{12}$$

$$f_{occupa\ \%} = \frac{w_3 * (occupa\ \% - occupa\ \%_{required})}{occupa\ \%_{required}} \tag{13}$$

- Decision Making:

In Figure-2 a flowchart of operation of the proposed decision model is shown. The implementation was done in the MATLAB software.

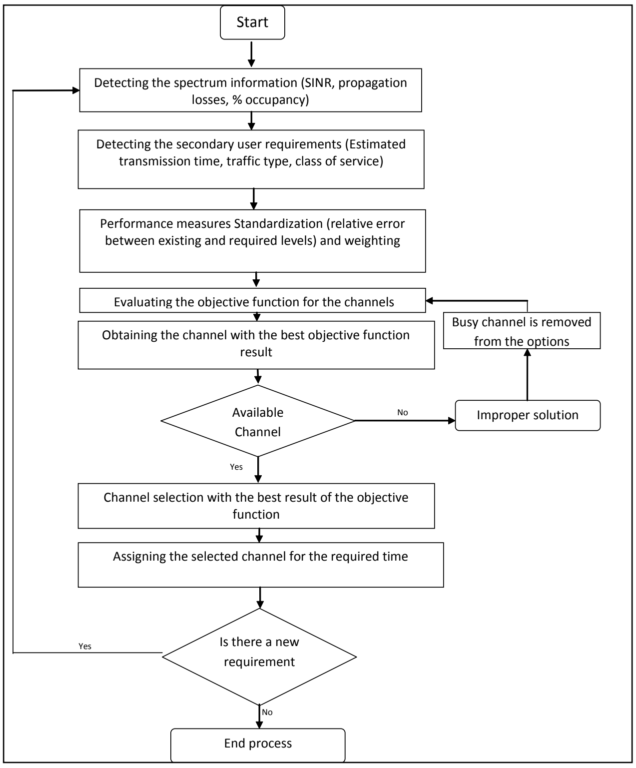

Figure-2. Decision algorithm flowchart.

3. RESULTSAND DISCUSSIONS

Considering that the behavior of the propagation losses is different in each measurement point given the characteristics of the base stations and the geographical environment, then a separate analysis is performed for each location. Figure-3shows the behavior of the signals detected at a point in the south area.

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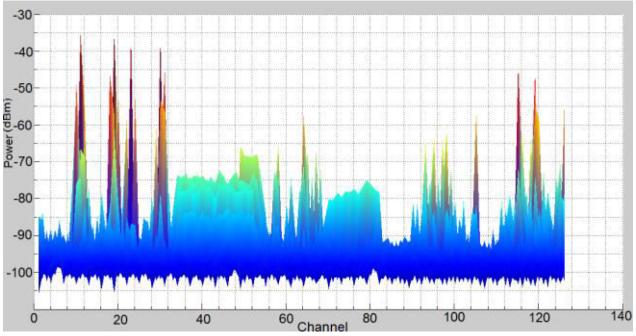
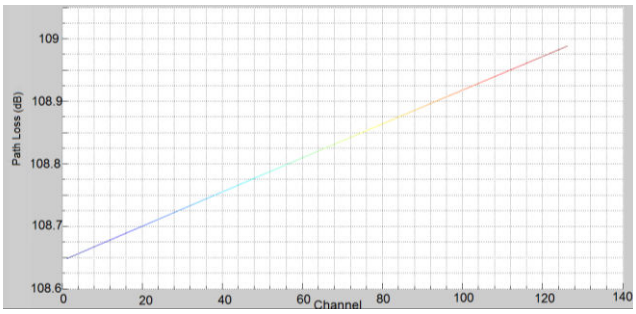


Figure-3. Measurement at a point in the south area.

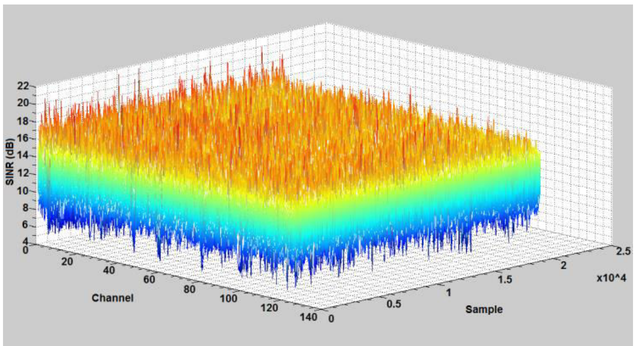
The behavior of Figure-3 shows the underutilization of radio spectrum, it is observed that the number of primary users using the channels is low; an average of 7.31% utilization and by an analysis can be concluded that channels 82 to 89 and 106 to 108 have the best options for a SU with respect to the noise power.

With the same analysis for the northwest area it was obtained that the average utilization is 12.81% and were identified channels 56 to 60 and 116 to 120 as the best option.

Figure-4 shows the characteristics of the propagation losses and SINR at the point of measurement of the south area.



a)



b)

Figure-4. Measurement at a point of south area. a) Propagation losses b) SINR.

Since calculating the propagation losses in one location is affected by the channel frequency having a completely linear behavior. In addition, the SINR has similar transitions in this band channels along the measurements.

Then we proceed to analyze the behavior of signals when measured at various points within the same zone. In this case are five points of measurement in the northwest area (see Figure-5).

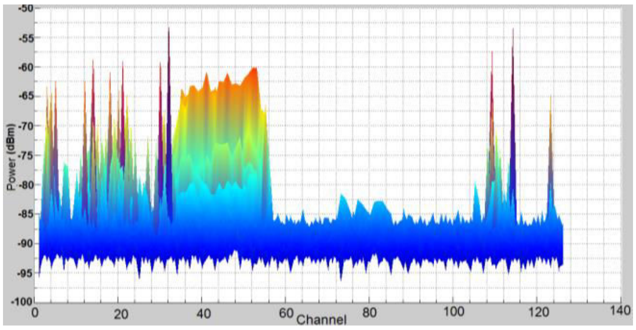
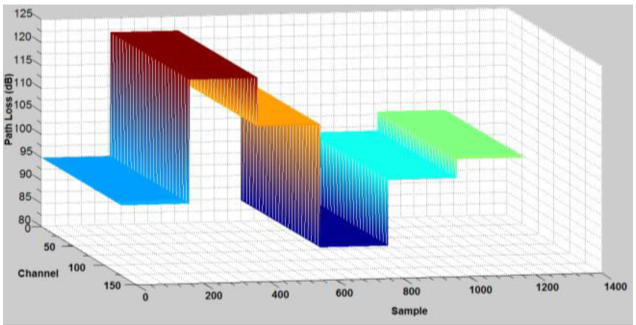


Figure-5. Five points measurement in the northwest area.

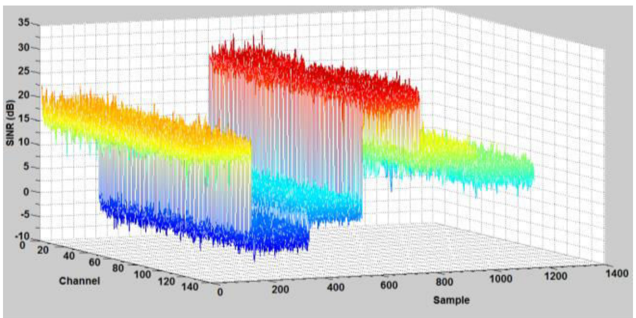
Figure-5 shows the channels 60 to 104 as a suitable option for use by SUs because unoccupied are found most of the time during the measurement.

During the same procedure in the south area, it is concluded that the best channels for use by SUs are from 100 to 110.

In Figure-6 the behavior of the propagation losses and SINR for the five measurement points in northwest area are presented.



a)



b)

Figure-6. Five points measurement in the northwest area. a) Propagation losses b) SINR.

Figure-6 is evidenced inversely proportional behavior between the propagation losses and the SINR, these values change in relation to the distance from the measuring point to the base station for each measurement period.

After the characterization of the GSM band, the response of the decision algorithm was evaluated for a set of test users that require a secondary channel for transmission, getting the following response in Figure-7.

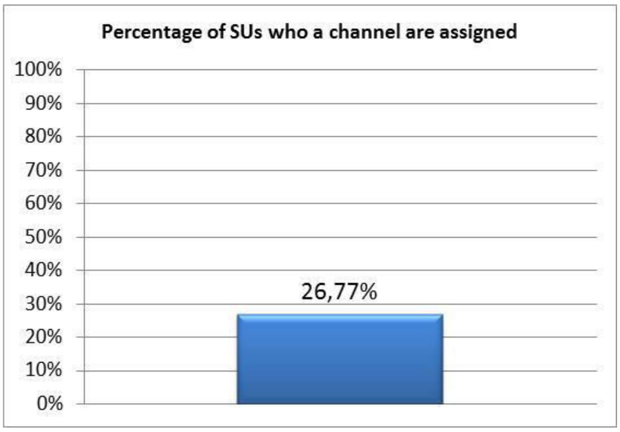


Figure-7. Probability of success in channel allocation for SUs.

In Figure-8 the type of traffic of SUs was about the same between data and multimedia, therefore are assigned a 12.98% of channels for data traffic and 13.79% of channels for multimedia traffic.

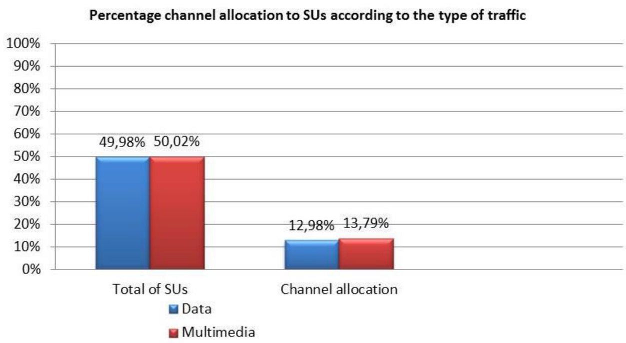


Figure-8. Channel allocation depending on the type of traffic.

In Figure-9 channel allocation to the SUs is presented according to the transmission time required.

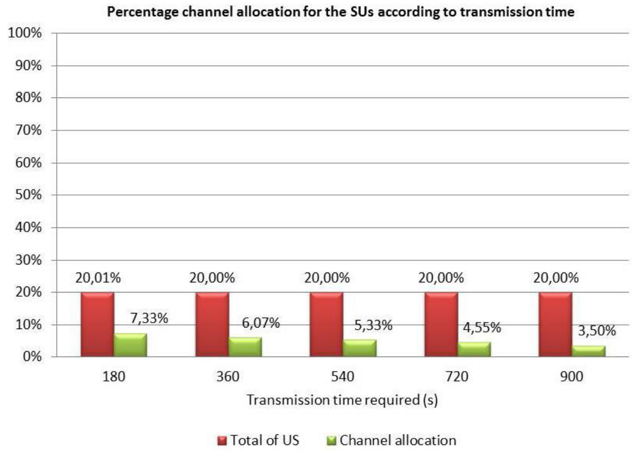


Figure-9. Channel allocation depending on the transmission time.

In Figure-9, it can establish that it is more likely the assignment of a channel for SUswho require a short transmission time.

4. CONCLUSIONS

By consolidating the results of the measurement campaign, underutilization of the radio spectrum was observed; the percentage of primary users making use of this resource is less than 15%, a fact that supports the need for the implementation of a scheme of dynamic spectrum access to provide service to unlicensed users, which would optimize the use of the spectrum.

Propagation losses are calculated by adjusting to the Okumura-Hata model, which allowed the inclusion of specific values for the geography characterization in the decision model.

The GSM band is characterized in terms of the state of occupation (with channels identified as free or busy), the SINR of each channel, the occupancy percentage found during the observation time, and propagation losses, with these features the selection process was fed through the multicriteria analysis of weighted sum and the best transmission channel available for each SU, which is selected taking into account the parameters of QoS: type of traffic, class of service and transmission time required.

Finally, successfully it developed a spectrum decision model for cognitive radio which includes propagation losses in the GSM band and increases about 26% the use of radio spectrum, which should be accompanied by an effort in fixed spectrum allocation policies, in order to make more efficient the use of spectrum and to provide services to the growing number of wireless services demanded by modern society.

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