Switching Antenna Array to Improve Cognitive Radio Performance

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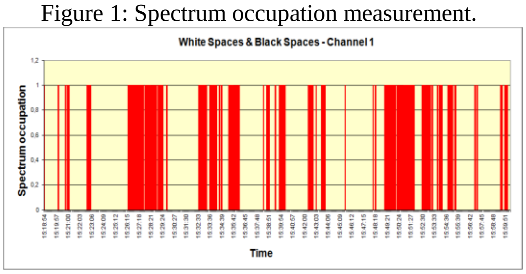
Abstract

The utilization of cognitive radio technology appears as a very useful solution to improve the efficient use of radiofrequencies, although lots of challenging has been detected to get electromagnetic compatibility among primary (licensed) and secondary (no licensed) users. Considering the diversity of primary users in terms of spectrum band applications, station locations, antennas directivities and all kinds of telecommunication services, this paper proposes a concept of switching antenna, coupled to the cognitive radio. This irradiating system can be developed to become an integrated and connected device, which can increase the link signal noise relation in favor of cognitive radio performance. It can be done modifying the antenna beam form, according to the desired receiver and transmitter sector. Dividing the spectrum sensing process also into antenna sectors and using an automatic selection to tune the radio channel, the cognitive link quality can be improved. The performance of this method was simulated by comparing a conventional cognitive radio, using omnidirectional antenna, with another one, applying switching antennas that can select the appropriate beam form. Finally, some advantages conquered when including the switching antennas in cognitive systems are exposed.

I. INTRODUCTION

The currency lack of radio spectrum to make available new telecommunication services is a state of affairs faced by almost all countries. Generally the frequency administrators (regulatory authorities) use the static classical methods to perform the spectrum management, in order to guarantee the appropriate radio compatibility, as commented by George Thomas in [1]. This conventional procedure although still can be considered secure, do not allow the implementation of recent technologies like cognitive radios, in state of the art, that could be a promise alternative to increase the efficiency of spectrum use. In fact, according to many recent articles as mentioned in [2], some frequency bands in the spectrum are largely unoccupied most of the time. The free spectrum holes left in the time and frequency domain, called white spaces, needs to be steadily occupied to provide opportunity services to secondary users. It has to be done in a way that protected the primary users, which have the official licenses, against harmful interference. In order to support this study, some measurements were done in Campinas city, state of Sao Paulo, in Brazil, investigating 15 frequencies (in the band of 450 up to 500 MHz). The results showed that the average of time occupation percentage was about 25%, oscillating among 10% to 51%. There is an example of one of the measurements (a single frequency), recorded in about 40 minutes from 15:18 hours to 16:00 hours (local time), showed in figure 1. In this case the occupation percentage of the frequency was about 32% of the time.

Figure 1: Spectrum occupation measurement.



The white space by a basic definition is a part of the spectrum in frequency and time that is free of radio energy and can be used by secondary stations. But, in fact, if we also consider the spatial sector as an additional dynamic parameter, some improvements can be done to increase the cognitive systems efficiency. Analyzing the location of primary and secondary users, even if some amount of energy is detected in the environment, the changing of the antenna diagram can increase the signal/noise levels. Therefore, the necessary threshold level to make available a white space, to be applied as a secondary link, can be achieved by rotating the antenna diagram. To make it clear, let understand the secondary detector as a system capable to detect a radiofrequency tunnel with a suitable noise level that permits to perform a link, providing a minimum quality level. This detection technique can be highly improved by coupling an

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intelligent antenna system to cognitive radio. Then, this method is explored in this paper.

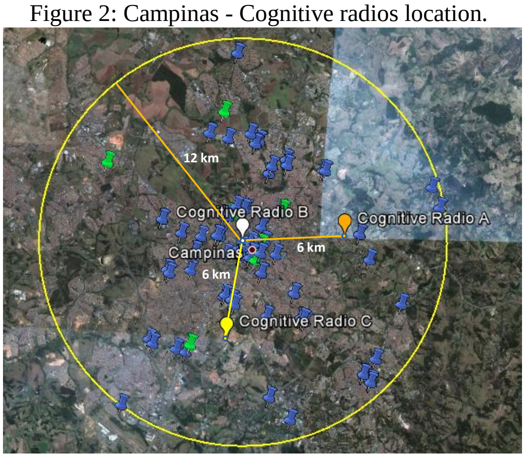
II. PROPOSED TEST SCENARIO

We decided to choose a frequency band out of the most fashioned one to cognitive radio on 700 MHz (television broadcasting), which has a large white space, according with geographical location. This decision is justified because it is considered important to face real environments, in critical situations, where there is a considerable amount of allocated frequencies. This way, the robustness of cognitive technology can be properly checked. Therefore, the selected frequencies band to be studied is from 450 to 500 MHz, in which there are different primary users, exploring many kinds of telecommunications services. In addition, the mentioned frequency range is high enough to provide a relatively high data rate transmission and also the mechanisms of propagation are favorable to overcome obstacles in the cities, unlike the higher bands (above 1 GHz) where buildings represent considerable obstruction to the radio links. The secondary users (cognitive radios) are composing by small links in urban area. Each connection has a maximal distance of 6 km. In each location we propose two links (station A to B and from C to B) both converging to a center station (B)[1] with approximately 90° aperture, between the radio links. It was arbitrated a radius of 12 kilometres in order to define an area to be studied, with the center located on station "B" of cognitive radio. The types of telecommunication services in the environment are mainly data, and voice communications. The selected urban centers were Campinas (state of Sao Paulo), Rio de Janeiro (state of Rio de Janeiro), and Sao Paulo (state of Sao Paulo); all of them are big cities with a large radio spectrum occupation.

III. SYSTEM PERFORMANCE EVALUATION

The first approach was to analyze the performing of cognitive radios in the defined scenarios, using omnidirectional antennas and the second one was to do the same exam with switching antennas (connected to the system) that have the capacity to change the beam form. Both situations are simulated and have the statistical results compared in the three mentioned cities (Campinas, Rio de Janeiro and Sao Paulo). We defined a situation where all frequencies in each region are allocated to primary users and the cognitive radio needs to find the spectral holes in three dimensions: i) frequency, ii) time and iii) space sector, domains. The amount of frequencies, locations, link directions and azimuths came from real stations. The frequency information was obtained from the website of Brazilian national telecommunication agency [3]. One of the regions studied (Campinas city) is presented on figure 2, with the three stations "A", "B" and "C". The reference coordinates of cognitive radios A, B and C, applied as the references to this paper, in the cities of Campinas, Rio de Janeiro and Sao Paulo are available in table 1. It is important to emphasize that in this work we have been omitted details of spectral spaces searching, in time domain, normally executed by cognitive radios, because the focus here is to show the advantages to use switching antennas.

Figure 2: Campinas - Cognitive radios location.



In Campinas area (figure 2) there are 19 directional systems represented in green color and 129 omnidirectional systems (in blue). Many stations are concentrated and located in the same position, with several frequencies allocated, by this reason the figure view seems to have a smaller number of stations, although the allocation amount of channels are significant.

Table 1: Coordinates of the stations.

Cities	Stations	Coordinates	
		Latitude	Longitude
Campinas	A	22°53'56.10" South	47° 0'37.08" West
	B	22°54'11.36" South	47° 4'8.41" West
	C	22°57'21.79" South	47° 4'33.09" West
Rio de Janeiro	A	22°54'16.86" South	43° 7'18.19" West
	B	22°54'26.55" South	43°10'30.23" West
	C	22°57'24.22" South	43°10'33.75" West
São Paulo	A	23°32'44.87" South	46°35'4.61" West
	B	23°32'56.93" South	46°38'19.03" West
	C	23°35'55.66" South	46°38'14.16" West

All primary frequencies allocated in 450 up to 500 MHz were considered as a potential channel to cognitive radio, after the sensing process, in time domain. The figure 3 can provide a brief

[1] Center station located in Campinas city (State of Sao Paulo) connected in two links with an aperture about 90°, represented on figure 2.

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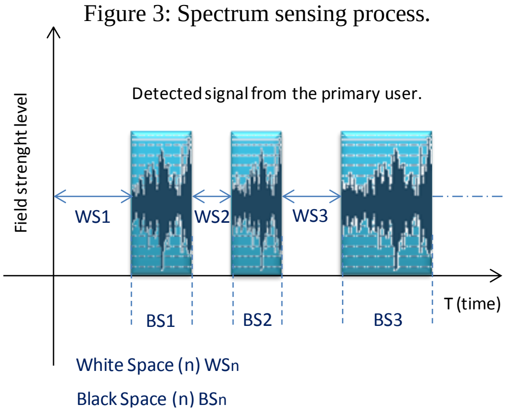
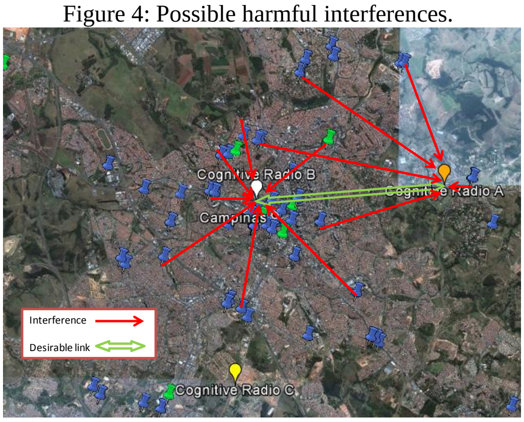
idea about the detection of white spaces, along the time, exploring only one frequency. Now, expanding the understanding about what really happen, we can realize that not only one primary user is emitting energy in the environment. As we describe, in Campinas selected area we have 148 official stations using 114 different allocated frequencies, in the 450 up to 500 MHz spectrum band.

Figure 3: Spectrum sensing process.



Supposing that we have an omnidirectional antenna, when the cognitive radio tries to get a spectrum vacancy in a frequency to maintain a link, for instance from station B to A, lots of primary users in the area can generate a harmful interference, as the basic representation in figure 4. Of course, in statistic terms, probably not all radios will be in the same frequency, but as mentioned, the amount of allocated channels increases the harmful interference risks.

Figure 4: Possible harmful interferences.



In order to reinforce this thesis we can appreciate the figure 5, area of Rio de Janeiro, where the higher concentration of radio stations can be detected visually. If we apply, in Rio de Janeiro scenario (with 574 stations), a directional antenna with 90^{o} half power angle, pointed from station B to A, it permits illuminate just 154 primary users and isolate about 420 users, or 73% of the total number of allocated channels, minimizing the harmful interference probabilities, as we can see in the simulation presented on figure 6. This information, although is clearly logic, is also very general. However, when accessing the official registrations, in the telecommunication agency data bank, the information available about, frequencies, types of antennas and numbers of stations, in each mentioned region and the selected areas, permits to form a better mathematical model of electromagnetic spectrum occupation density. Going deeper to understand the scenario presented, it is suggested to observe the table 2, *Official stations and frequencies allocated*, which reflects in numbers the perception of high frequency density, generated by the figures.

Figure 5: Potential primary jammers concentration.

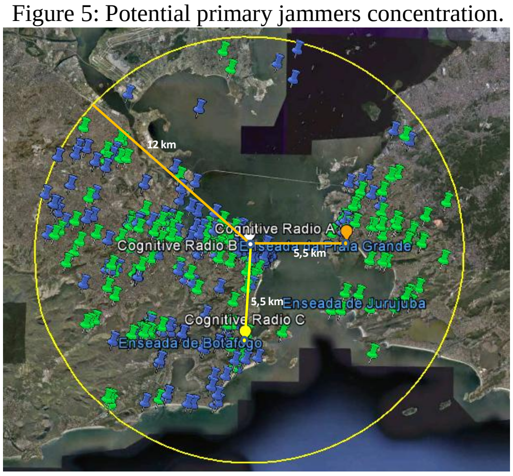


Figure 6: Directional antenna sector (in yellow).

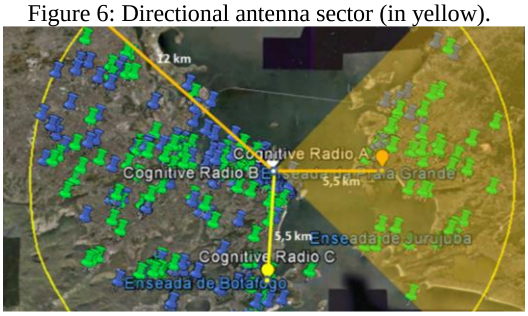


Table 2: Official stations and frequencies allocated.

Region (radius = 12 km)	Stations	Diferent frequencies	Type of spectrum occupancy
Campinas	148	114	High occupancy
Rio de Janeiro	574	439	Very high occupancy
São Paulo	1317	748	Extremely high occupancy

Without further comments we can understand that in the proposed scenarios, for static communication system, the use of directive radiant systems can assist isolation from unwanted radiofrequency and improves the signal/noise relation of the desired link. However, if any change occurs in one of the system station positions, it will be necessary to modifying the radiating systems or at least to redirect it, which will require human intervention to mechanical adjustments in the equipments set. It is a great motivation for the development of switching antenna, main focus

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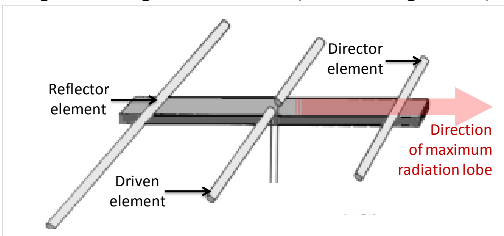
of this study. The use of switching antennas will eliminate the mentioned human intervention.

IV. PROPOSAL OF SWITCHING ANTENNA

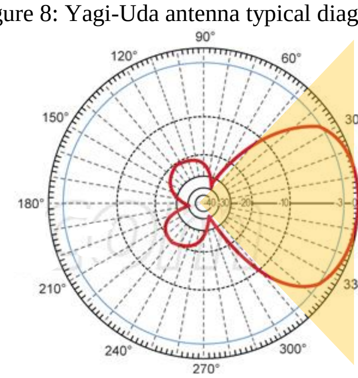
Understanding the philosophy of cognitive radio operation, it is obvious that the system must have a minimum autonomy and intelligence enough to evaluate the spectral environment in the surround, to permit: i) to check the white spaces availability, ii) to record the positions of other cognitive radios, and iii) to select the channels that show, statistically higher probabilities to be free to provide opportunistic use of the frequencies, among other items. Deal with real situations, such as of the scenarios presented in the previous section, it is clear that a cognitive system that can adjust the antenna radiation diagram, according to direction of the link, will provide greater versatility for communications, which also will be translate into an operational advantage. The switching antenna proposed is based on Yagi-Uda irradiating system. This type of antenna is a directional apparatus, composed by a simple construction array, like the illustration in the figure 7.

Figure 7: Yagi-Uda antenna (basic configuration).



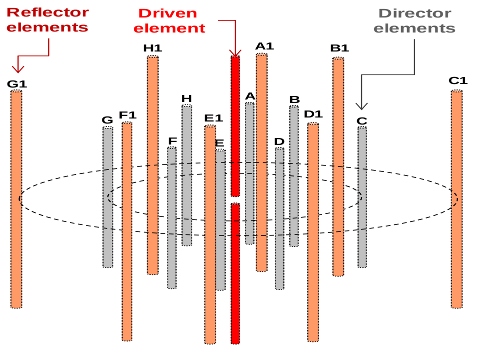
The antenna can be mounted using a basic configuration, with three elements; a driven, reflector and director. The antenna feed is done by connection of the coaxial cable at the center dipole, the driven element. A basic configuration like this provides a radiating diagram as the one indicate in the figure 8, which has better performance than a single dipole. Actually there are many variations of Yagi-Uda antennas, especially the configuration that increases the numbers of directors, which provide a higher, gain.

Figure 8: Yagi-Uda antenna typical diagram.



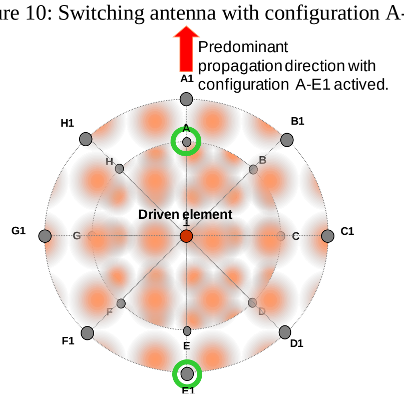
Based on the need to obtain a directive diagram irradiation with a reasonable relation front-back and enough gain in the desired direction and still allow the rotation of the radiated beam, in the horizontal plane, the arrangement shown in figure 9 was designed. In the center of the array there is a driven element, like in the reference antenna. Going outside of the center, there are eight elements (named as A, B, … up to H – in gray color), smaller than the driven element, displayed in a circle to act as the directors elements. There is other external circle formation with more eight elements, bigger than the driven element (named A_1, B_1, … up to H_1 – in orange color) to act as the reflectors. In fact, this arrangement is the combination of eight Yagi-Uda antennas, sharing in parallel way all the elements of the array. This kind of interaction causes a strong interface with the electromagnetic fields and modifies the irradiation diagram. In order to solve this question, it is essential that only the appropriate elements of the array be combined with the driven, and the other elements need to become "invisible" to the electromagnetic waves.

Figure 9: Aspect of antenna switching antenna.



Then, the antenna was mounted, as the diagram shows in figure 10, which is a top view of the arrangement. In order to make the irradiation aligned to the direction indicated by the red arrow, only the elements **E1** (reflector) and **A** (director), marked with green circle, must be activated. The others elements, as mentioned above, have to be transparent to electromagnetic fields.

Figure 10: Switching antenna with configuration A-E1.



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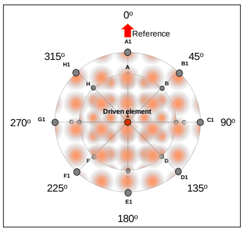
If we want to change the position of the lobe radiation, rotating it in order to have the maximum power aligned in the direction from the center of the antenna to **B1** route (45^o), we have to disable the components **A** and **E1** and activate the elements **F1** and **B**. Thus, following the same reasoning, to rotate the antenna radiation diagram, and locate the maim lobe into desired direction, it is necessary to active only the elements indicated in each line of table 3.

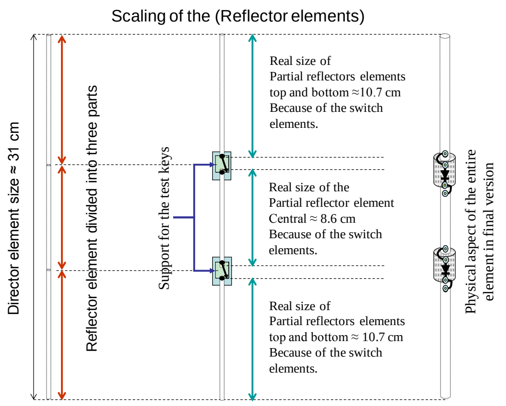
Table 3: Direction of main lobe and active elements.

Angle of maximum power (degrees)	Active elements	
0	E1	A
45	F1	B
90	G1	C
135	H1	D
180	A1	E
225	B1	F
270	C1	G
315	D1	H



The procedure to switch the antenna diagram is defined by the activation of the right elements and deactivation of the others. However, since the elements are mechanically fixed, the following method is applied to maintain the disabled components as transparent as possible in the operational frequencies. The reflectors and directors elements were mounted, dividing the designed dimension in three parts. This was done in order that when these elements are disabled they do not tune the frequencies of operation and become, as previously mentioned, "invisible" to the electromagnetic waves. In the prototype the define dimensions to reflector elements are the values indicated in the figure 11. In the spaces between the partial elements were installed supports with keys. These keys are tuned on when the elements are activated, otherwise the keys must be turned off. The final version of the prototype will have PIN diodes[2] that will be activated by electronic circuits.

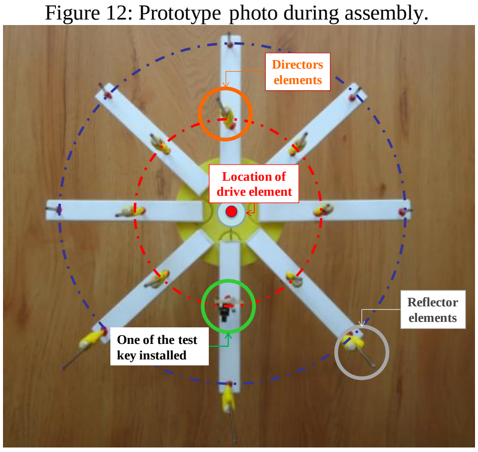
Figure 11: Dimensions of the reflector elements.



[2] PIN Switching Diodes are passivated epitaxial silicon devices. PIN Switching Diodes are designed to provide two impedance states, one approaching an open circuit (reverse bias), and a short circuit (forward bias).

A similar procedure was done to dimension the director elements. The central frequency to operation was choosen as 475 MHz, in the center of the interest band. A photo of the prototype during the montage phase is available in figure 12.

Figure 12: Prototype photo during assembly.



Because the facilities found in the arrangement radiating designed, it was possible to evaluate the radiation pattern diagram of Yagi-Uda and also some variations such as those described below: i) activation of Yagi-Uda (e.g. **E1** – **A**) and activate at the same time **D1** and **F1** elements. As a result, the diagram became more direct, with increased gain level. ii) inserting a new key in the reflector with a resistor, in order to block the signal in the same element direction. As a result we create a null in the pattern diagram. The antenna prototype was tested in the anechoic chamber of the research and development center – CPqD, in Brazil. Some of the results are exposed in the figures 13 - switching antenna with all directors and reflectors elements deactivated (note that it not affect the omnidirectional diagram) and figure 14 - switching antenna with **E1** and **A** elements activated (classical configuration of Yagi-Uda) and in the same time **D1** and **F1** activated, providing an increasing of gain and front – back relation.

Figure 13: Diagram - Directors and reflectors deactivated.

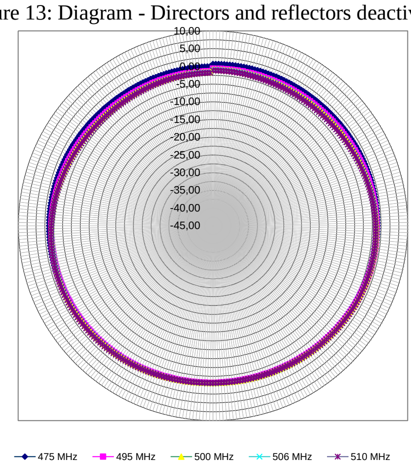


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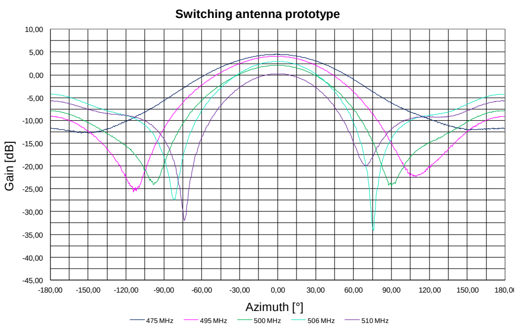
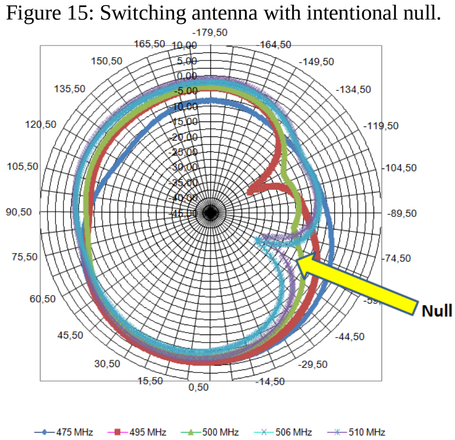
Figure 14: Results with configuration (E1–A) plus (F1–D1).



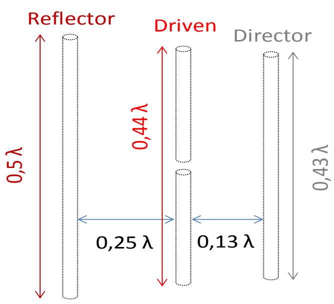
In figure 15 we show the antenna with reflector element activated with resistors between the partial reflectors (instead of a short circuit). The result is a null in the direction of the reflector element. It can be useful to cognitive radio in some conditions when it is receiving no desired signals in some directions. With this new resource, this signal can be blocked.

Figure 15: Switching antenna with intentional null.



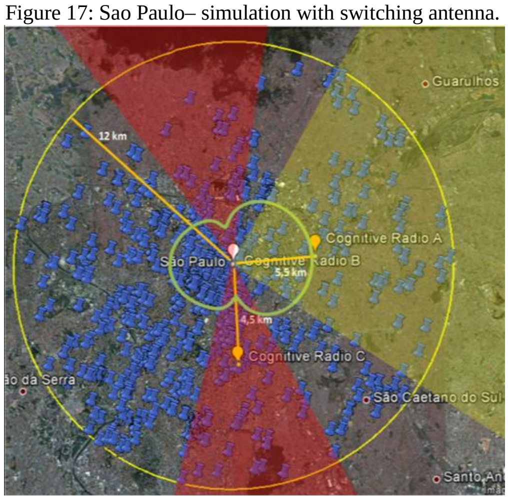
During testing it was found that the original dimensions of the antenna, in the classic model (figure 16), does not match exactly in the desired frequency band tuning, probably due to interaction with other elements of the proposed arrangement, so some changes, based in empirical measurements have been implemented to enhance the tuning in the desired range.

Figure 16: Standard dimensions of Yagi-Uda antenna.



Finally, in order to reinforce the advantages of using the proposed antenna integrated in cognitive radio systems, is shown in Figure 17, the area of Sao Paulo, quoted in the previous section, where we can note a high number of primary users, and in this context, applying one of the diagrams measured with the prototype antenna. The yellow area will have a higher gain compared to other sectors and areas in red have an additional null. Depending on the situation, during the spectrum sensing, cognitive radio can run test combinations to get the best suited for antenna elements or the insertion of resistors that generate null, improving the signal/noise relation for the opportunistic links.

Figure 17: Sao Paulo– simulation with switching antenna.



V. COMMENTS

The proposed antenna will be tested in real situation, probably in a big centre city. As we could see, there are lots of primary users in big centers, but the spectrum occupation percentage is really low, in most cases. It is a great opportunity to cognitive radios that needs to face during the sensing process lots of potential harmful interferences, which can be minimized with the switching antennas.

As an opportunity we can classify the spectrum occupation density, based on the research performed in the database of telecommunication stations of Brazil, according to the following table 4.

Table 4: Occupancy density (Stations/square kilometers).

Region	Area expressed in square kilometers	Occupancy density (Stations/square kilometers)	Type of spectrum occupancy
Campinas	452,39	0,327151827	High occupancy
Rio de Janeiro	452,39	1,268818574	Very high occupancy
São Paulo	452,39	2,911209167	Extremely high occupancy

VI. FUTURE WORK

a) Refine the design of the antenna, including the spacing between elements, improving the project (length) of reflectors, directors and feeder elements, and to investigate the better thickness of them, seeking an operation tuned in the range of desired frequencies;

b) Detailed evaluation of the possible combinations in the activation processes of the antenna elements and to study the response obtained in the pattern irradiation diagrams;
c) Construction of the antenna in an industrial technique, selecting the best materials for manufacturing it; and
d) Development of algorithm for automated use of the antenna together with the process of the spectrum sensing, to improve the detection of white spaces.

VII. CONCLUSION

The present study shows the viability of using a switching antenna integrated with cognitive radio systems. Laboratory tests in the anechoic chamber were promising, although the correct sizing of the elements and dimensioning of resistors values, that provide the null in the diagram pattern, need improvements. The antenna will continue to be studied to obtain the important upgrades in both the constructive and in the development of an algorithm to make possible the integration in the process of spectrum sensing.

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