Spectrum Occupation Modeling on the 450 MHz Band for Cognitive Radios Aplication

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***Abstract* — Currently the spectrum occupancy has been the major concern for regulatory bodies because there are repressed demands of telecommunications users, especially in large cities due to lack of free frequencies. The cognitive radio technology appears on the scene as a solution to improve the spectrum efficiency by increasing the density of users on radio frequencies. However, there are still open issues to optimize techniques for radio spectrum dynamic access, in order to achieve proficiently the spectral vacancy, called white spaces. In this study measurements were performed on various primary users on the 450 MHz band, which is vastly used, in order to understand the spectrum occupancy models. In the research, the captured signals were demodulated and the audio communication was evaluated in order to identify each sequence considered as a conversation, requiring human interpretation. Within each conversation, bursts of audio (speech of interlocutors) were listed. Besides it the spaces between these bursts and the intervals among conversations were recorded as modeling parameters. The results were statistically analyzed and the study proposes to use this data as a basis for developing an algorithm that aims to improve techniques for access the radio spectrum to enable the powerfully utilization of cognitive radios.**

Index Terms—cognitive radio; spectrum occupation; white space; black space; algorithm

I. Introduction

This paper studied the behavior of primary user communications, in order to understand how they occupied the radio spectrum. The choice of the 450 MHz band is due to the following factors: a) The propagation mechanisms allow to overcome some typical obstacles in urban areas and in rural mountain regions; and b) Besides the favorable propagation characteristics, the frequency range is high enough to provide communications of voice and data with a satisfactory throughput, leaving a remarkable cast of services to be explored.

It is possible to explain the cognitive sensing in several ways and it kind of wisdom can be identified in common activities as in the performance of motorcycle riders. If we appreciate the figure 1, we can see the cognitive itinerary performed by the motorcycle driver. The motorcycle drive passes by some buses and cars, predicting the future action of them, and calculating the necessary speed to be developed to arrive first and safely in positions 1, 2, 3 and 4 The drivers can do it because they use their cognitive sense to estimating the future positions of car and buses. This kind of predicting is possible because the motorcycle drivers are applying what they learned by previous observations on the paths of cars and buses. Sometimes they need to correct or change the decision, but for good drivers it occurs just on few cases. If we suppose the radio spectrum is the street, and the buses and cars are the primary users, the motorcycle riders are perfectly matched with a cognitive radio behavior. Based in this theory, the behavior of telecommunication primary user was explored to be better understood.

A. *Paper organization*

The first part of this study is the spectrum occupancy measurements, described on section II. *Spectrum Occupation Measurements*. The section III. *Selection of Measured Parameters* explains which parameters were chosen to modeling the way primary users demand their communications. Preliminary statistics results permit to propose a basic spectrum occupation modeling, which is presented on section IV. *Spectrum Occupation Modeling* and section V. *White Spaces Prediction Algorithm Bases* proposes how to use the results to improve the dynamic spectrum access, to share the channels between primary and secondary users. Finally, the section VI. *Conclusion* concludes the studies and section VII. *Future Works* proposes future works to get progress in this field.

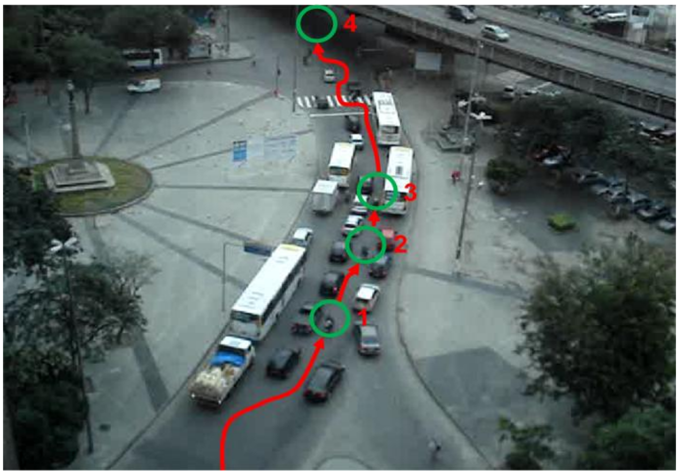

Figure 1. Motorcycle drives cognitive itinerary.

II. Spectrum Occupation Measurements

The measurements were performed on 450 MHz to 470 MHz frequency band. The mentioned frequency band is explored by communication voice services, for cab groups, aviation support, transportation companies and downstream industry. All users are primary and apply the frequency band to carry out private services. The equipment used to conduct the measurements was the FSH8 - Rohde & Schwarz, connected to a J-Pole antenna. The site was in a building roof, located in the following address: Barao de Paranapanema Street, 146, Bosque - Campinas - Sao Paulo - Brazil (urban environment) Latitude: 22º 54' 33.25" South / Longitude: 47º 02' 43.61" West - Altitude: 667m.

The environment noise level was checked in the building roof and in the street level as showed in figure 2, indicating –120 dBm, considered as a reference. The data collecting period was from 08:00 AM to 18:00 PM hours, in July, 2011, with industrial and commerce activities running on the whole. One representative example of the acquired samples (channel occupation) is presented on figure 3, that correspond to the time segment (about 40 minutes) of an occupied frequency: 457.530 MHz, monitored from 14:19:00 PM to 15:00:20 PM hour. The respective time occupation percentage of frequency was 34.3 %.

Figure 2. Environment noise level.

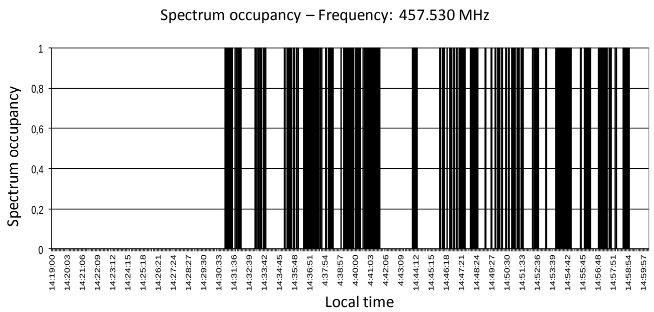

Figure 3. Spectrum occupancy 457.530 MHz / 34.3%.

The criterion to select the channels to be investigated was the frequency monitoring, focus on those that were presenting the major spectrum occupation time. This criterion was selected to check the cognitive radio system robustness when the density of primary and the secondary users are high. It was observed that the channels tested had a relatively low occupation, as can be seen in the graph of figure 4.

The graph in figure 5 shows the channel on frequency 463.550 MHz on two occasions, once at 15:41:01 hours, with spectral space and at 15:41:18 hours with the respective spectrum occupied. For the automation of the results, in this particular case, was considered a threshold level of -100 dBm, above which the channel was considered busy.

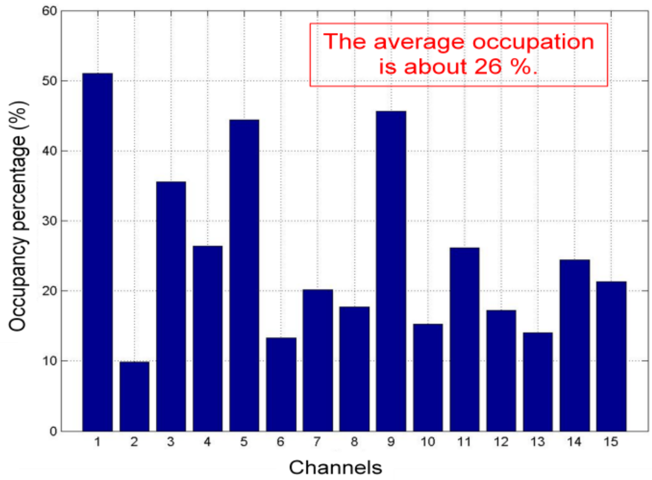

Figure 4. Channels occupation in Campinas.

The spectrum band between 450 to 470 MHz (20 MHz) has 1,600 channels with bandwidth of 12.5 kHz available to users, as standardization of the local telecommunication regulator. Around the measuring point of Campinas, in a radius of 20 km, there are 1,563 authorized (allocated) frequencies. Some mentioned frequencies have irradiation at 100% of the time, which would prevent the use of cognitive radios in these channels in the same region. However, many of the allocated channels (in fact the great majority) have a low occupancy in time domain, so there is a real opportunity to use the spectral spaces for cognitive radios in secondary mode.

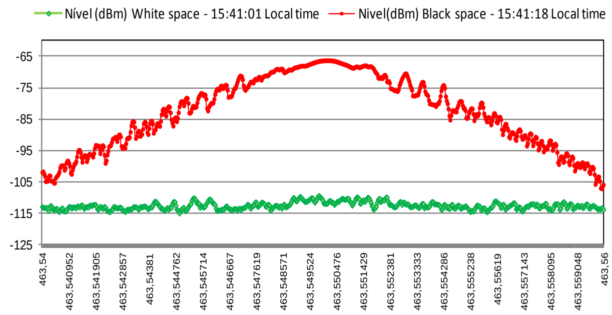

Figure 5. White and Black Space detection.

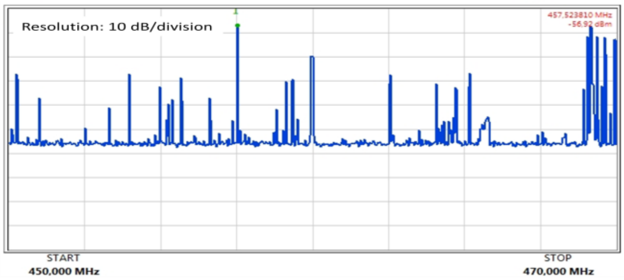

Figure 6. Spectrum monitored view.

III. SELECTION OF MEASURED PARAMETERS

In this channel occupation study it was evaluated how users of voice service communication behave over time, in order to better understand what kind of occupation model is on course. As a remark, it is important to say that the demand for this service is high and currently the used frequency band is considered congested. This fact fully justifies this study that can result in a method to provide safety reuse of channels, allowing increasing the spectrum efficiency use in the regions of interest.

Therefore, to obtain more accurate samples, in the time domain, the frequencies considered with significant spectral occupancy (within the set of samples) had their channel demodulated. These data were recorded for detailed study of the behavior trend of transmissions, analysis of the existing spectral spaces and other parameters. The selected frequencies were demodulated and subsequently loaded into a computer passing through audio processing software, allowing measurement with a milliseconds precision of spectrum time occupancy, spectral vacant spaces, and other parameters as the evaluated sample in figure 7. The audio was assessed in order to identify each sequence considered as a conversation, requiring human interpretation. Within each conversation, audio bursts (speech of users) were registered. The spaces between these bursts were also recorded, as well as the intervals between conversations. These conversations transpire in a half duplex systems which ensure that complete conversations were properly identified. Note that the white spaces and black spaces were classified sequentially from "1" to "n". In this context, Table I presents a legend indicating the measured parameters, which were used for the characterization of conversation, and therefore the spectrum occupancy model applied by primary users of the area.

Table II shows the individual results of the parameters collected, properly organized, aiming to facilitate the processing performed to characterize the speech bursts. The time intervals were recorded in milliseconds.

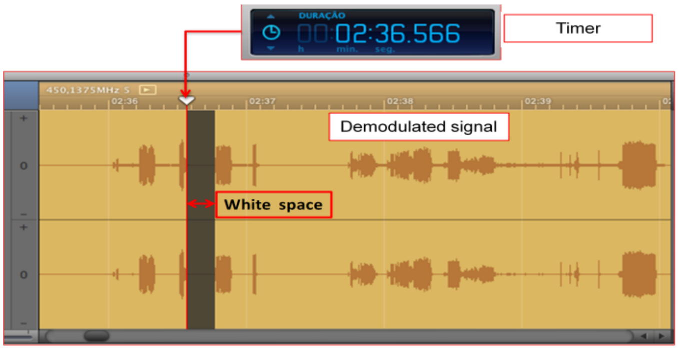

Figure 7. Demodulated signal analysis by software audio.

TABLE I. MEASURED PARAMETERS

QSB(n)	Quantity of Speech Bursts within the conversation.
TBC(n)	Time Between Conversations.
WS(1)	First White Space of the conversation (n).
WS(n)	Last White Space of the conversation (n).
BS(1)	First Black Space of the conversation (n).
BS(n)	Last Black Space of the conversation (n).
n	General accountant of segments QSB, TBC, WS and BS.
Time in milliseconds.	

TABLE II. WORKSHEET WITH LOG PARAMETERS

General accountant	TBC(n)	BS/WS	Event duration (ms)	QSB(n)
1	TBC1		49610	
				3
2	1	BS1	4310	
3	1	WS1	1990	
4	1	BS2	12060	
5	1	WS2	1700	
6	1	BS3	5270	
7	TBC2		188770	
		⋮		
497	TBC52		6000	
				2
498	52	BS1	4180	
499	52	WS1	1970	
500	52	BS2	3410	

Still aiming to facilitate the understanding of the parameters measured, the figure 8 clarifies how the conversations were identified and extracted the times of TBC(n), QSB(n), WS(n) and BS(n).

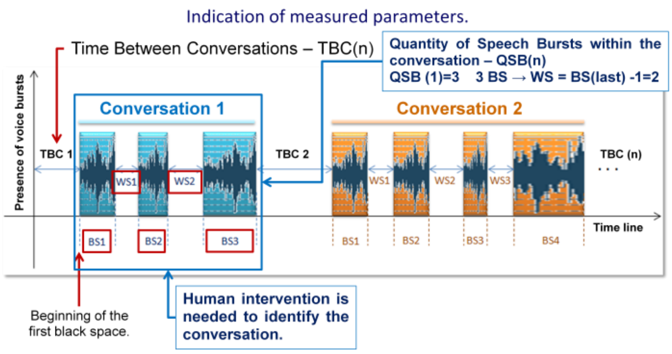

Figure 8. Indication of measured parameters.

IV. SPECTRUM OCCUPATION MODELING

Although the measurement campaign is still in progress, this section presents the first results obtained. The initial perception is that the preliminary results will be consolidated with more data, so the properly statistical studies will be performed.

The quantities of speech bursts of audio - BS(n) in every conversation ranged basically from 1 to 15, with the results presented in chronological order in the figure 9. These data were processed to get the analysis of the same parameter, ordered by size, in the 71 evaluated conversations. The distribution of the speech bursts is arranged in figure 9, where there is higher concentration from two to six among the conversations. The Time Between Conversations – TBC statistics shows interesting results that were processed to verify minimum time, average and values included in 90% of the occurrences. Some of these results can be verified in figure 10. All White Spaces - WS(n) and Black Spaces - BS (n) were recorded. The figure 12 shows the occurrences of BS(n), considering that the series of BS(8) to BS(15) were discarded, due to little representation in the acquired samples up to this moment. This issue will be detailed after the completion of the next measurement campaign. The spectrum occupation model used by primary users began to be identified, as can be seen in figure 13. The model presents an increased occupation time in BS(3) to BS(6) range, being reduced in other BS(n). Similar graphics generated by the studies show that the WS (n) decrease with the QSB sequence. This information will be used in algorithms for identifying white spaces to cognitive radios.

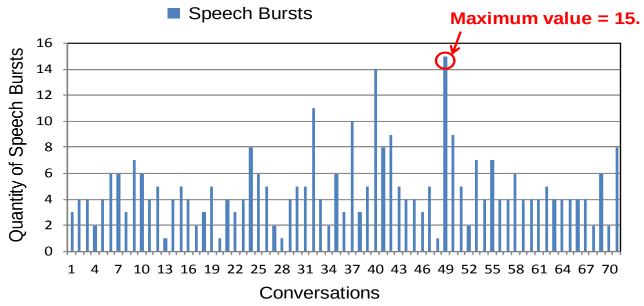

Figure 9. Quantity of Speech Bursts (in order of capture).

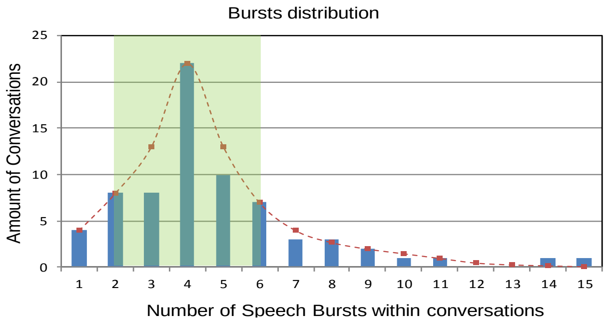

Figure 10. Bursts distribution.

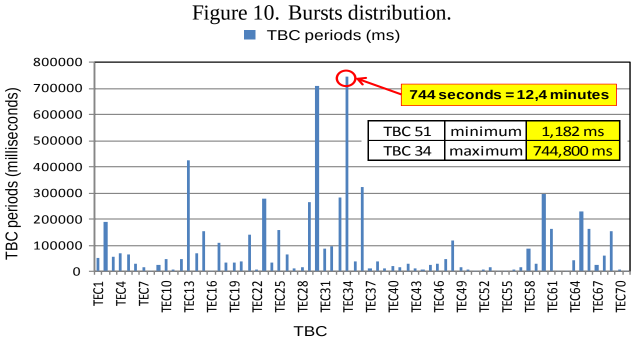

Figure 11. TBC (in order of capture).

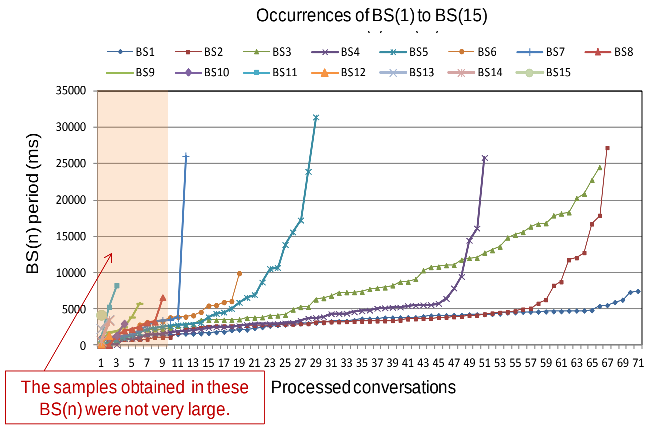

Figure 12. BS(n) occurrences.

The TBC(n) average was detected as 1.5 minutes and 90% of them are include in the period of 4.4 minutes. The WS(n) average was detected as about 2 seconds and 90% of them are included in the period of 3.6 seconds.

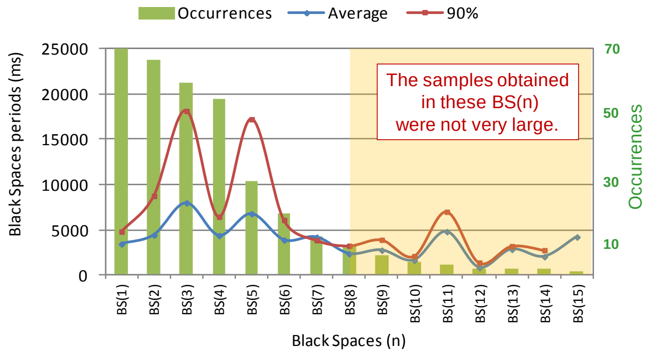

Figure 13. BS(n) occurrences.

V. White Spaces Prediction Algorithm Bases

Useful information was extracted from collected data at the first measurement campaign. The 450 MHz band, in voice communications services was explored in the tests. More data are necessary to propose robust method to predict the white spaces, nevertheless some conclusions show guide lines to be followed.

- The primary user channels need to be monitoring for a minimum period, before the cognitive system start to work. It is necessary to estimate the future White Spaces, according with the recent past statistics.
- The parameters TBC(n) and WS(n) are the conventional *White Space* to cognitive radios. Means that the spectrum is free to be used. The new approach in this study demonstrated that is better to use a TBC(n) – *White Space* than WS(n) when possible, because the statistics show that TBC(n) is higher and will provide freer spectrum time to cognitive radio.
- A good question could be how to identify if the *White Space* detected is a TBC(n) or a WS(n). However, the periods detected in the measurements makes clear that TBC(n) is much bigger than a WS(n), so it is easy to identify both with good accuracy. The figure 14 shows clearly the duration differences in seconds.

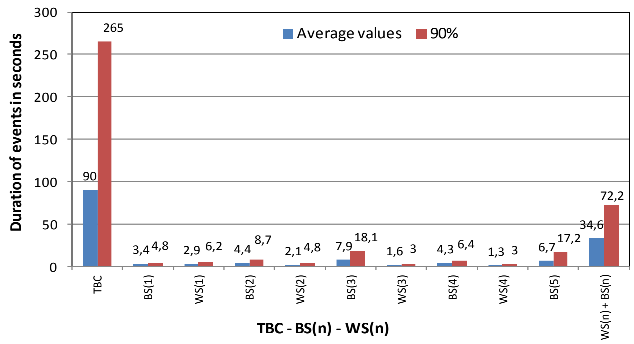

Figure 14. Duration of TBC, WS & BS.

- Knowing more about the kind of WS(n), BS(n) and TBC (n), allows the cognitive radio algorithm to rank the available channels, according with the future white space prediction. So when the channels (frequencies) are choosing to start broadcasting, the system performance will be improved.
- Using the same approach of the previous item, if there is a collision between cognitive radio and primary user, again applying the proposed channels ranked the interference generate from cognitive radio will be minimized.
- As an item of sophistication, after the identification of a "TBC", as time elapsed, it is still possible to classify the TBC and ranking it, according with the probability of getting a White Space in the following time slots. This further enhances and the algorithm and reduces the probability of collisions between primary and secondary users.
- The figure 15 shows four stages in a TBC state ("1", "2", "3" and "4") and they presents the decreasing probability to have a white space in the following time slot.

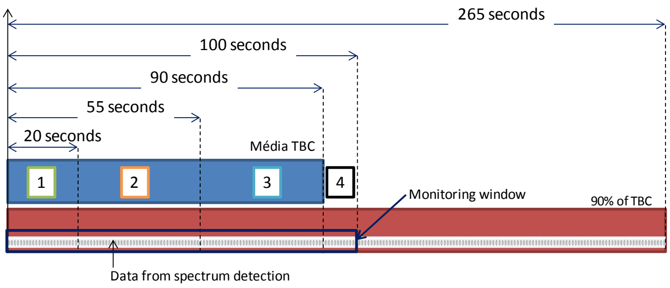

Figure 15. White spaces prediction algorithm.

VI. CONCLUSION

The currently radio spectrum offers many opportunities for the implementation of cognitive radio systems. The primary user's channels that were investigated showed poor spectrum occupancy in time domain.

However, the selected channels used to collect data were those that have high spectrum occupancy. It was decided in order to test the algorithms in critical conditions and make possible to verify the performance of cognitive radios and the interference generated in the primary users.

It is more efficient to use the TBC(n) than WS(n), when it is possible, although both are conventional White Spaces. Using the proposed techniques it is possible to change channels selected to secondary users (cognitive system) before the occurrence of collisions, switching the frequencies according to the ranking. Perform measurements in the 450 to 470 MHz frequency band (voice services, preferably half-duplex) to model primary users can be a good opportunity to improve the radio cognitive studies.

The white spaces prediction algorithms for cognitive radios can be enhanced by applying the techniques proposed in section VI. *White Spaces Prediction Algorithm Bases*, implementing a ranking process to classify the channels to be chosen on the basis of identification of TBC(n), WS(n) and BS(n), as shown in figure 16.

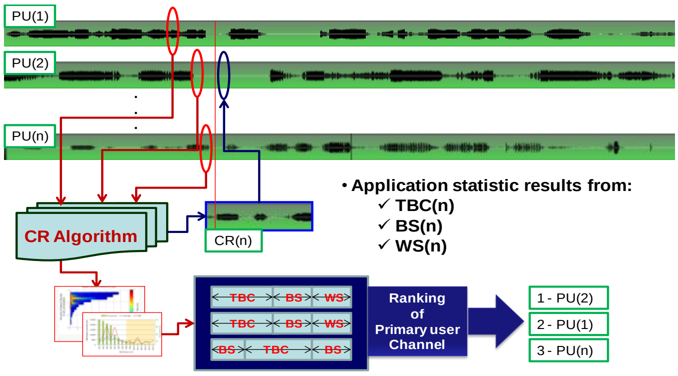

Figure 16. White spaces prediction algorithm.

VII. FUTURE WORKS

As future work, the following items are proposed for continued research and development the planned predicting white spaces method.

a) Complete the new battery of spectrum occupancy measurements in other regions, increasing the database propagation to provide greater diversity of information and consolidate the proposed models.

b) Investigate in detail the statistics of periods and events of TBC(n), QSB, WS(n) and SB(n) to improve the technique of ranking the channels available for use of cognitive radios.

c) Simulate the performance of cognitive radios and interference generation into primary users, by the application of the proposed method.

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