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Performance Analysis of Equal Gain Combining of Cooperative Spectrum Sensing in Cognitive Radio Networks

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ABSTRACT

There is a huge demand for spectrum, but in conventional system, radio spectrum is inefficiently used. To overcome this problem cognitive radio (CR) technology concept came in to existence. Cognitive Radio aims to access the wireless spectrum in an opportunistic manner while the licensed user is not using it. Among most challenging problems in cognitive radio systems is spectrum sensing concepts. This study has been performed based on Energy detection spectrum sensing techniques. Energy detection based spectrum sensing techniques are favourable due to its simplicity and low complexity. This paper investigates energy detection based cooperative spectrum sensing technique over Additive White Gaussian Noise (AWGN) channel. Simulation of the cognitive system is created in MATLAB programming language to implement the scheme and to analyse its simulation performance. The results of the simulation show that the cooperative spectrum sensing and equal gain combining techniques are appropriate for radio frequency sensing networks. The performance of the technique was assessed by the use of the receiver operating characteristics (ROC) curves over AWGN channel.

Keywords– Cognitive Radio Network (CRN), Equal Gain Combining (EGC), Fusion Centre, Matrix Laboratory (MATLAB), Probability of detection, Probability of false alarm and Probability of Missed detection.

I. INTRODUCTION

Modern communication relies heavily on wireless technology. As a multitude of wireless technologies have been developed, and continuously increased capacity is in demand, a severe problem has emerged. The electromagnetic spectrum is a fixed physical quantity, and only a certain part of it is suitable for radio communication. Available electromagnetic spectrum for wireless transmission has become a scarce and highly valuable resource.

A large part of the spectrum is not being effectively utilized, because of the fact that system demand among licensed users varies significantly with time and location. This has spurred the development of a next generation wireless technology commonly referred to as cognitive radio. A device using cognitive radio technology will intelligently determine whether a certain part of the frequency spectrum is idle, or if it is being utilized. If the cognitive radio can successfully determine with a high degree of certainty that a specific part of the spectrum is being idle, it can then transmit on those frequencies without interfering with the licensed owner of the spectrum, thus achieving better spectral resource efficiency. The requirement of no interference is extremely rigid to avoid disturbing licensed users. It is thus key for the development of cognitive radio to invent fast and highly robust ways of determining whether a frequency band is available or being occupied.

For perfect use of the spectrum CR sense the spectrum to locate whether the PU is actually active or even not that's why spectrum sensing is a vital process to get the spectrum holes. There are three main techniques of spectrum sensing: matched filter detection, energy detection, and cyclostationary feature detection.

Out of these, energy detection is very suitable method for its easy implementation and low computational complexity. There is no need any priori information of PU's signal, unlike the other two methods which require full knowledge of signal being transmitted by the primary user.

The decision on the presence of the PU is achieved by gathering individual sensing information from multiple CRs and cooperation among them it is possible to improve the detection performance where all CRs send their sensing information without performing local decisions at local CRs at Fusion Centre (FC) using various soft and hard data fusion schemes. Hard decision fusion schemes are AND rule, OR rule and MAJORITY rule. Soft decision fusion schemes are square law combining (SLC), selection combining (SC), square law selection (SLS), Equal Gain Combining (EGC) and Maximum Ratio Combining (MRC).

Equal gain combining (EGC) is a better alternative regarding receiver combining technique at destination since it does not require estimation of channel fading amplitudes. Therefore, its complexity is reduced. EGC technique has been implemented very recently into cooperative networks to reduce the system complexity.

II. RESEARCH APPROACH

This section provides a summary of the approach chosen to attack the topic, and how the research was structured. The problem at hand is very open as it is presented in the problem description. It is stated that current spectrum sensing techniques suffer from challenges in the low signal to noise range, requires for this to be analysed and suggests that higher order statistics or information theoretic criteria are possible areas to look for a solution to overcome the problem. It is apparent that the problem at hand is wide and challenging. To meet the outlined demands, it is important that the scope is limited to provide a tangible base for a master's thesis. Hence the first step in the research has been to analyse the problem and decide on the correct approach.

The research is split in the following sections:

1. Analysis of the problem at hand to limit the scope.
2. Analysis of a selection of the conventional approaches to identify problems in the low signal to noise region.
3. Proposing a novel spectrum sensing scheme and providing insight through a theoretical analysis and simulations.

By exploiting the diversity provided by associated radios, CSS improves the overall detection sensitivity without imposing higher sensitivity requirements on the individual CRs. A network of cooperative cognitive radios, which experience different channel fading conditions from the target, would have a better chance of detecting the primary radio if the individuals' local sensing is jointly combined at a base station.

1. Energy Detector

It is a simple detector which detects the total energy content of the received signal over specified time duration and compares it to the threshold. It has the following components:

1. Band-pass filter – Limits the bandwidth of the received signal to the frequency band of interest.

2. Square Law Device – Squares each term of the received signal.

3. Summation Device – Add all the squared values to compute the energy.

A threshold value is required for comparison of the energy found by the detector. Energy greater than the threshold values indicates the presence of the primary user.

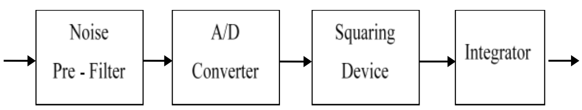

Figure 1 Energy detection based spectrum sensing block diagram

The output of the integrator at any time is the energy of the filter received signal over the time interval T. The noise pre-filter limits the noise bandwidth; the noise at the input to the squaring device has a band-limited, flat spectral density. The output of the integrator is considered as the test statistic to test the two hypotheses H_0 and H_1.

2. Combining Process

Various techniques are known to combine the signals from multiple diversity branches. In Equal Gain Combining, each signal branch is weighted with the same factor, irrespective of the signal amplitude. However, co-phasing of all signal is needed to avoid signal cancellation.

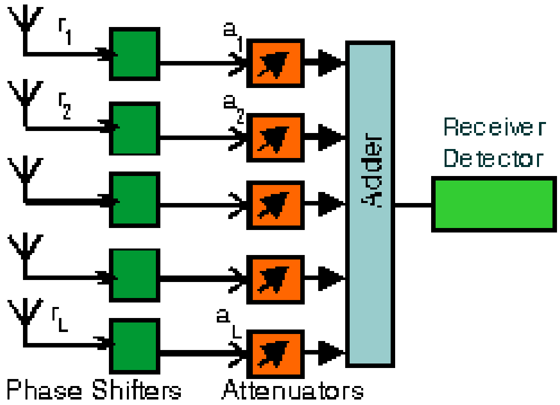

Figure 2 Combining Process: L-branch antenna diversity receiver (L = 5)

The received signal y (t) takes the form:

$$y(t) = h\,s(t) + n(t)$$

where $h = 0$ or 1 under hypotheses H_o or H_1, respectively. As described, the received signal first pre-filtered by an ideal band-pass filter with transfer function.

$$H(f) = \begin{cases} \dfrac{2}{\sqrt{N_{01}}}, & |f - f_c| \le W \\ 0, & |f - f_c| > W \end{cases}$$

To limit the average noise power and normalize the noise variance. The output of this filter is then squared and integrated over a time interval T to finally produce a measure of the energy of the received waveform. The output of the integrator will act as the test statistic to test the two hypotheses H_0 and H_1. According to the sampling theorem, the noise process can be expressed as

$$n(t) = \sum_{i=-\infty}^{\infty} n_i \quad sinc(2Wt - i)$$

where $sinc(x) = \frac{\sin(\pi x)}{\pi x}$ and $n_i = n\left(\frac{i}{2W}\right)$.

One can easily check that $n_i \sim N(0, N_{01}\,W)$, for all value of i.

Over the time interval (0, T), the noise energy can be approximated.

$$\int_0^T n^2(t)\ dt = \frac{1}{2W}\sum_{i=1}^{2u} n_i^2$$

where $u = T\,W$. We assume that T and W are chosen to restrict u to integer values.

If we define

$$n_i' = \frac{n_i}{\sqrt{N_{01}W}}\ ,$$

Then, the test or decision statistic Y can be written as.

$$Y = \sum_{i=1}^{2u} n_i'^2$$

Y can be viewed as the sum of the squares of $2u$ standard Gaussian variants with zero mean and unit variance. Therefore, Y follows a central chi-square (χ^2) distribution with $2u$ degrees of freedom. The same approach is applied when the signal s(t) is present with the replacement of each n_i by $n_i + s_i$ where

$$s_i = s\left(\frac{i}{2W}\right)$$

The decision statistic Y in this case will have a non-central (χ^2) distribution with 2u degrees of freedom and a non-centrality parameter 2γ. Following the shorthand notations mentioned in the beginning of this section, we can describe the decision statistic as

$$Y \sim \begin{cases} \chi^2_{2u}\ , & H_0 \\ \chi^2_{2u}(2\gamma)\ , & H_1 \end{cases}$$

The probability density function (PDF) of Y can be written as

$$f_y(y) = \begin{cases} \dfrac{1}{2^u\Gamma(u)}\ y^{u-1}e^{\frac{y}{2}}\ , & H_0 \\ \dfrac{1}{2}\left(\dfrac{y}{2\gamma}\right)^{\frac{u-1}{2}} e^{\frac{2\gamma+y}{2}} I_{u-1}\left(\sqrt{2\gamma y}\right)\ , & H_1 \end{cases}$$

where Γ (.) is the gamma function, and $I_V(.)$ is the vth -order modified Bessel function of the first kind.

3. Probability of detection and Probability of false alarm in AWGN channel

An approximate expression for probability of detection for non-fading AWGN channel. In this section, exact closed-form expression for both probability of detection P_d and probability of false alarm P_{fa} are presented. The P_d and P_{fa} can be generally calculated by

$$P_d = \Pr(Y > \lambda\,|H_1)\ ,$$
$$P_{fa} = \Pr(Y > \lambda\,|H_0)\ ,$$

where λ is decision threshold value. Also, P_{fa} can be written in terms of Probability density function (PDF) as:

$$P_{fa} = \int_\lambda^\infty f_y(y)\ dy$$

From this equation, we can write:

$$P_{fa} = \frac{1}{2^u\Gamma(u)}\int_\lambda^\infty (y)^{u-1}e^{-\frac{y}{2}}\ dy$$

Dividing and multiplying the R.H.S. of above equation by $2^{\,u-1}$, we get

$$P_{fa} = \frac{1}{2\Gamma(u)}\int_\lambda^\infty \left(\frac{y}{2}\right)^{u-1} e^{\frac{y}{2}}\ dy$$

substituting $\frac{y}{2} = t\ ,\ \frac{dy}{2} = dt$ and changing the limit of integration to $\left(\frac{\lambda}{2}\ ,\infty\right)$, we get

$$P_{fa} = \frac{1}{2\Gamma(u)}\int_{\lambda/2}^\infty (t)^{u-1}e^{-(t)}\ dt$$

Or,

$$P_{fa} = \frac{\Gamma(u\ ,\lambda/2)}{\Gamma(u)}$$

Now probability of detection can be written by making use of the cumulative distribution function

$$P_d = 1 - F_y(y)$$

The cumulative distribution function (CDF) of Y can be obtained (for an even number of degree of freedom which is $2u$ in our case) as:

$$F_y(y) = 1 - Q_u\left(\sqrt{\lambda}\ ,\sqrt{y}\right)$$

where Q $_u$ (a, b) is the generalized Marcum Q-function. Hence,

$$P_d = 1 - Q_u\left(\sqrt{2\gamma}\ ,\sqrt{y}\right)$$

III. SIMULATION RESULTS

A simulation test bed has been developed in MATLAB to access the performance of cooperative spectrum sensing techniques under AWGN channel. In order to analyse the performance of the system receiver characteristics (ROC) are used.

The results of spectrum sensing that is based on square law (SL) energy detection methods at different probability of detection and false alarm for non-fading AWGN Channel are shown. After the energy detection, apply equal gain combining (EGC) for combining the different sensing outputs. Equal Gain Combining is soft decision combining method.

In this method, the result on different parameters at different values of time bandwidth factor (u) and at different SNR values and also the results on the basis of probability of detection (P_d) and probability of false alarm (P_{fa}) are compared.

1. Probability of detection (P_d) v/s SNR (at different values of P_{fa}).
2. Probability of Missed Detection (P_{md}) v/s Probability of False Alarm (P_{fa}).
3. Probability of Detection (P_d) v/s Probability of False Alarm (P_{fa}) (at different values of SNR).
4. Probability of detection (P_d) v/s SNR (at different values of time bandwidth factor).
5. Equal Gain Combining, Probability of Detection (P_d) v/s Probability of False Alarm (P_{fa}) (at different values of SNR).

1. Probability of detection (P_d) v/s SNR (at different values of P_{fa})

In the first result, we have calculated the Probability of detection (P_d) v/s SNR (at different values of Probability of false alarm P_{fa}=0.01, 0.05, 0.1 and 0.15), as shown in figure 5. In this plot, X axis represents different SNR values and Y axis represents Probability of detection. At P_{fa}=0.15, probability of detection (P_d) is high which means the performance of AWGN channel is good at P_{fa}=0.15. From the figure it is clear that as the value of probability of false alarm (P_{fa}) increases, probability of detection also increases (P_d) with respect to the signal to noise ratio values (SNR).

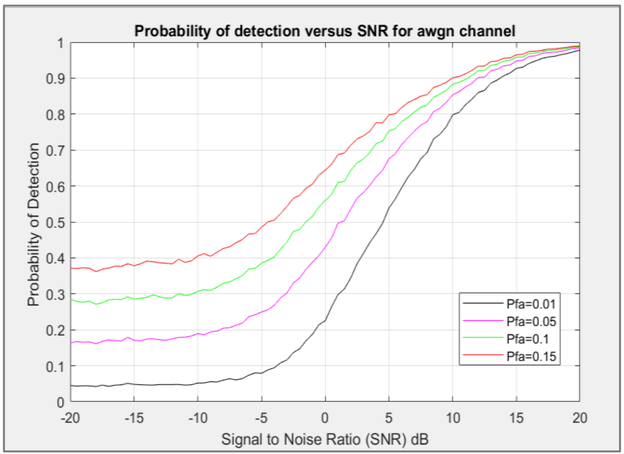

Figure 3 Probability of detection v/s SNR for AWGN channel

Probability of detection (P_d) v/s SNR for AWGN channel				
SNR	**P_{fa} =0.01**	**P_{fa} = 0.05**	**P_{fa} =0.1**	**P_{fa} =0.15**
-20	0.045	0.1634	0.2855	0.3712
-15	0.0484	0.1704	0.2854	0.3782
-10	0.052	0.1895	0.3069	0.4056
-5	0.0791	0.2498	0.3857	0.4855
0	0.2255	0.4299	0.5597	0.6442
5	0.5389	0.6756	0.7532	0.7977
10	0.7977	0.8533	0.8831	0.901
15	0.9271	0.9474	0.9584	0.9647
20	0.9781	0.9844	0.9871	0.989

Table 1 Probability of detection (P_d) v/s SNR for AWGN channel

2. Probability of missed detection (P_{md}) v/s Probability of false alarm (P_{fa})

The below figure shows that the probability of missed detection v/s Probability of false alarm in AWGN environment. The performance is shown at different SNR values. In this plot, X axis represents the probability of false alarm and Y axis represents the probability of missed detection. For comparison, the results of proposed method are generated at different SNR values (5dB, 10dB and 15 dB).

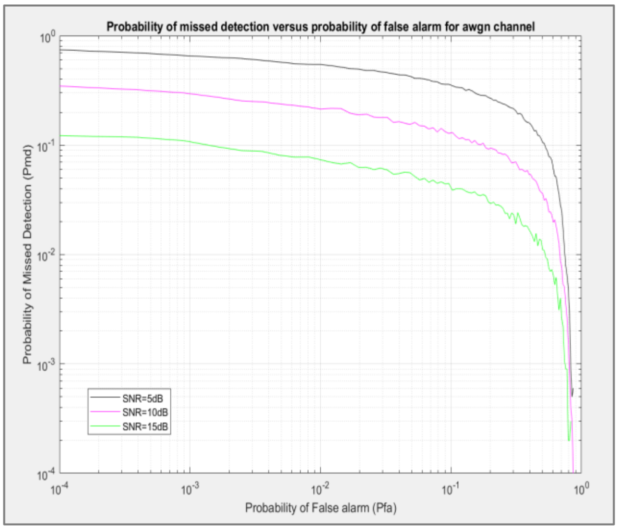

Figure 4 Probability of Missed Detection (P_{md}) v/s Probability of False Alarm (P_{fa})

Table 2 is the tabular representation of the Probability of missed detection (P_{md}) v/s probability of false alarm (P_{fa}) at different SNR values (5, 10 and 15dB). Table 2 shows as the SNR increases values of P_{fa} increases proportionally. Means that higher values of SNR show the lower values of probability of false alarm rate.

(P_{md}) v/s (P_{fa}) for AWGN Channel			
P_{fa}	**SNR=5dB**	**SNR=10dB**	**SNR=15dB**
0.0001	0.745	0.3576	0.1344
0.001	0.6616	0.2912	0.1046
0.01	0.5044	0.2126	0.0662
0.1	0.2932	0.1076	0.041
1	0.0002	0.0002	0.0002

Table 2 Probability of False Alarm rate (P_{fa}) of AWGN channel at different SNR

3. Probability of detection (P_d) v/s Probability of false alarm (P_{fa})

The below the figure 7 shows the probability of detection (P_d) v/s Probability of false alarm (P_{fa}) at different SNR values, where X axis represents the probability of detection and Y axis represents that probability of false alarm. For comparison, the results of proposed method are generated at different SNR values (12dB, 14dB, 18dB and 20 dB). For better understanding of this plot, we have compared the result in the table below.

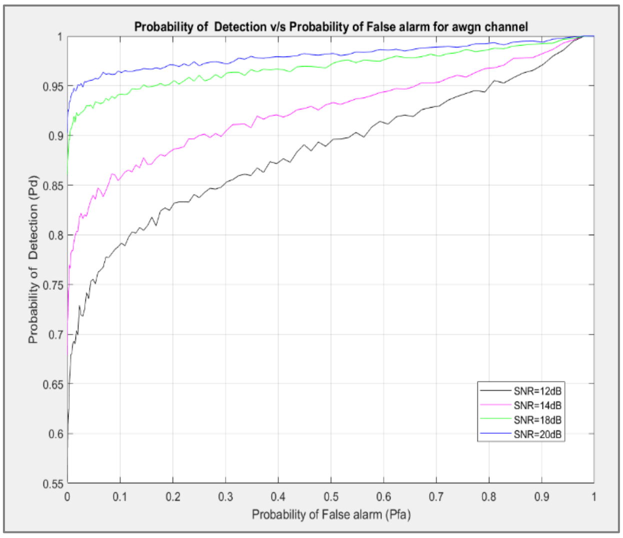

Figure 5 Probability of detection (P_d) and Probability of False Alarm(P_{fa})

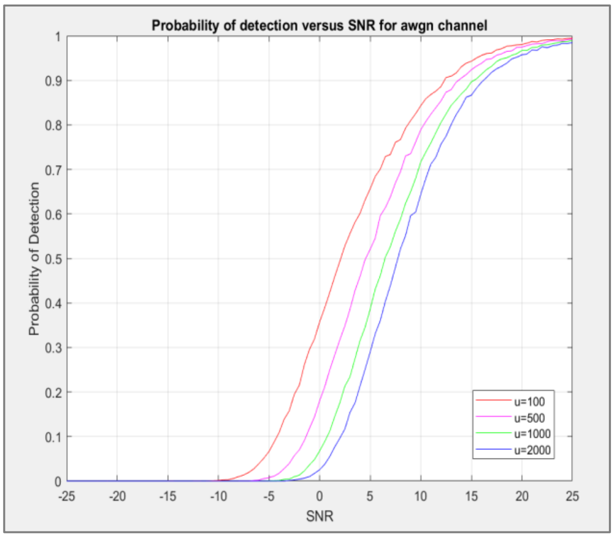

Figure 6 Probability of detection v/s SNR at different u

Probability of False Alarm	Probability of Detection			
	SNR 12dB	SNR 14dB	SNR 16dB	SNR 18dB
0.1	0.78	0.85	0.94	0.96
0.2	0.82	0.88	0.95	0.97
0.3	0.85	0.91	0.96	0.97
0.4	0.87	0.92	0.97	0.98
0.5	0.89	0.93	0.97	0.98
0.6	0.91	0.94	0.97	0.98
0.7	0.93	0.96	0.98	0.98
0.8	0.95	0.97	0.98	0.99
0.9	0.97	0.98	0.99	0.99

Table 3 Probability of False Alarm (P_{fa}) of AWGN channel at different SNR

From the figure it is clear that as the value of SNR increases, we get the highest probability of detection.

4. Probability of detection (P_d) v/s SNR (at different values of time bandwidth, u)

The below the figure 8 shows the probability of detection (P_d) v/s signal to noise ratio (SNR) at different time bandwidth (u) values under AWGN channel, where X axis represents the signal to noise ratio and Y axis represents the probability of detection. For comparison, the results of proposed method are generated at different time bandwidth values (100, 500, 1000 and 2000).

P_d vs SNR				
SNR	Probability of Detection			
	(u=100)	(u=500)	(u=1000)	(u=2000)
-25	0	0	0	0
-20	0	0	0	0
-15	0	0	0	0
-10	0.0013	0	0	0
-5	0.0662	0.0076	0.0005	0
0	0.357	0.1797	0.0673	0.0251
5	0.6563	0.5206	0.3858	0.2898
10	0.8431	0.789	0.7167	0.6439
15	0.9428	0.9237	0.8965	0.8665
20	0.9808	0.9748	0.9672	0.9574
25	0.9946	0.9928	0.9903	0.9851

Table 4 Probability of detection (P_d) v/s SNR at different time bandwidth

From the figure it is clear that probability of detection decreases when time bandwidth factor, u increases.

5. Equal Gain Combining

Performance of this decision fusion method is evaluated at different SNR values. To validate the proposed cooperative spectrum sensing scheme, a Monte-Carlo simulation was carried out to analyse the ROC characteristics, probability of detection under the following conditions: number of secondary users (SUs) = 10, Number of samples = 10000, the SNRs at which performance is evaluated are 12dB, 14dB, 18dB, 20dB. In the plot, X axis represents the probability of detection and Y axis represents that probability of false alarm. From the figure it is clear that as the value of SNR increases, we get the highest probability of detection.

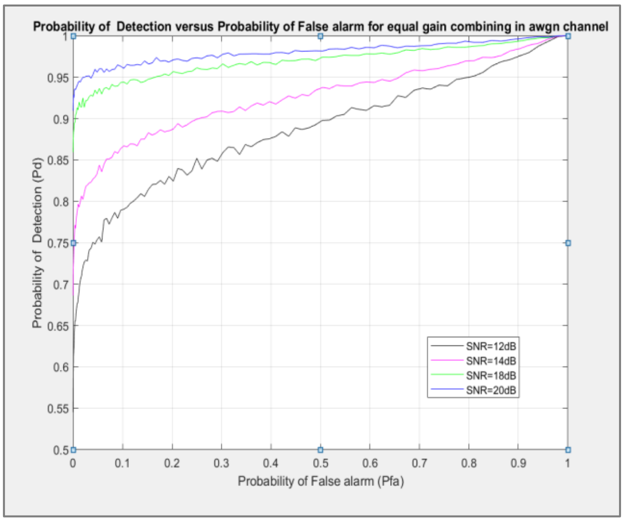

Figure 7 Probability of detection v/s Probability of false alarm for EGC

Probability of False Alarm	Probability of Detection			
	SNR 12dB	SNR 14dB	SNR 16dB	SNR 18dB
0.1	0.78	0.85	0.94	0.96
0.2	0.82	0.88	0.95	0.97
0.3	0.85	0.91	0.96	0.97
0.4	0.87	0.92	0.97	0.98
0.5	0.89	0.93	0.97	0.98
0.6	0.91	0.94	0.97	0.98
0.7	0.93	0.96	0.98	0.98
0.8	0.95	0.97	0.98	0.99
0.9	0.97	0.98	0.99	0.99

Table 5 Probability of detection (P_d) at different Probability of False Alarm rate (P_{fa})

IV. CONCLUSION

In this paper, we proposed Energy detection based spectrum sensing over AWGN channel. Cooperative spectrum sensing is not applicable in all the applications, but where it is applicable, considerable improvements in system performance can be gained. Energy detection is the most popular signal detection method due to its simple circuit in practical implementation. The principle of energy detector is finding the energy of the received signal and compares that with the threshold. The EGC method does not need any channel condition information of CR users compared with other schemes, such as maximal ratio combination (MRC).

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