Research on a Design Algorithm of Dynamic Spectrum Access Criterion

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Abstract. In order to improve the utilization of electromagnetic spectrum, electronic devices can sense the current spectrum occupancy status and use these spectrum resources without disturbing the communication of other authorized users. In the past research, researchers have generally ignored the randomness of the propagation channel and the uncertainty of the location of the authorized user on the spectrum perception. To this end, this paper proposes a dynamic spectral access criterion design algorithm.

1. Introduction

At present, with the rapid development of communication technology, electromagnetic spectrum resources are becoming increasingly tense. Especially in the dense frequency bands of some civilian and military electronic devices, the wireless spectrum is very crowded and many spectrum fragments are formed. With the continuous improvement and maturity of Cognitive Radio technology, it is expected that future mobile system devices and terminals will have certain ability to perceive "spectral holes" and integrate these discontinuous and dynamically changing spectrum fragments. This paper is devoted to researching how to use these spectrum resources occupied by other services, reduce spectrum fragmentation, and implement spectrum access efficiently and dynamically.

2. Spectrum detection method

In the electromagnetic spectrum management, there are three main types of signal detection methods: matched filtering method, energy detection method and cyclic characteristic detection method.

Although matched filtering is a theoretically optimal detection algorithm, it needs to know in advance the signal physical layer such as modulation type, pulse shaping form, packet format, and many parameters of the MAC layer, and it must be timed in the implementation process. Carrier synchronization, even channel equalization, is not suitable for wide spectrum detection in complex environments.

Here, we focus on the research and evaluation of two other methods: energy detection method and cyclostationary feature detection method. The energy detection method achieves the purpose of detecting a signal by determining whether the signal energy is greater than a predetermined threshold. At present, in the engineering implementation, the algorithm is designed by using the delayed autocorrelation structure. The block diagram of the implementation is as follows:
Moving average Comparators

\[ Z^{-\alpha} (\cdot)^{\ast} \]

Moving average

\[ \frac{\overline{C_z}}{Z_a} \]

Threshold, \( \tau \)

\[ \text{Comparators} \]

Figure 1. Signal detection block diagram based on delayed autocorrelation

Wherein, the upper branch is used to calculate the correlation value of the signal and its delay, and the lower branch is used to calculate the modulus of the delayed signal. In this way, the ratio of the calculation results of the two branches will be between 0 and 1. Such double branch processing facilitates setting the normalized threshold on the one hand, so that the threshold setting is not affected by the signal power; To some extent, reduce the impact of bursty glitch spikes on signal detection. The ratio result is greater than the threshold and is judged to have a signal, otherwise it is regarded as noise. The function of the sliding averager in both branches is to filter out the noise and improve the performance of the detection algorithm to some extent. The advantage is that the design is simple, and the signal can be quickly detected under the requirement of satisfying certain detection performance, and is currently used in engineering implementation. The shortcomings are also obvious. First, there is no obvious inhibition on burst noise. Second, the setting of the threshold is affected by many factors such as signal-to-noise ratio.

The design basis of the cyclic feature detection method is the cyclic spectrum. Due to sampling, coding and modulation, the general communication signals are cyclically stable, and the noise does not have this characteristic. Therefore, the cyclic spectrum becomes a powerful tool for signal detection. Compared with the conventional power spectrum analysis method, the spectral correlation function method has the advantages of high resolution and strong anti-interference ability.

The cyclic autocorrelation function of signal \( x(t) \) is:

\[
R_x^\alpha (\tau) = \lim_{T \rightarrow \infty} \frac{1}{T^\alpha} \int \left[ f + \frac{f_\alpha}{2} \right] x^\ast (t + \frac{f_\alpha}{2}) x (t - \frac{f_\alpha}{2}) e^{j2\pi f_\alpha t} dt
\]

(1)

The Fourier transform \( S_x^\alpha (f) = \int \infty_{-\infty} R_x^\alpha (\tau) e^{-j2\pi f \tau} d\tau \) of \( R_x^\alpha (\tau) \) is called SCF. The engineering implementation complexity of the cyclic spectrum itself is relatively high, but considering that in engineering implementation, for example, an FFT-based frequency domain smoothing fast algorithm can be used to reduce the computational complexity; on the other hand, the signal's cyclostationary characteristics are in \( \alpha \) such as \( f = f_\alpha \). The slice and \( \alpha = 0 \) \( f \)-slices are more prominent on the cyclic spectrum slice, so it is completely possible to detect the signal using only a single slice of the cyclic spectrum, which again greatly reduces the amount of computation. Considering that in the actual signal detection, the carrier frequency information of the primary user signal can be considered to be known and the spectral correlation coefficient of the \( \alpha \) slice of \( f = f_\alpha \) is much larger than that of other feature slices, that is, the cyclic stability characteristic of the slice is more Prominent, so detection of a particular primary user signal can be achieved by detecting spectral peaks in the slice. Below is our computer simulation of the \( \alpha \) slice of the MSK signal and the BPSK signal in \( f = f_\alpha \);
3. Dynamic spectrum usage strategy

In order to make full use of the limited wireless spectrum resources and consider the randomness of the propagation channel and the uncertainty of the authorized user location, this paper proposes a dynamic spectrum usage strategy based on the probability model.

Perceived users in deciding whether to use a licensed band, the following two principles must be considered:

a). The current channel quality should meet the local communication requirements for signal to noise ratio;

b). Perceived user communication cannot interfere with normal communication of existing primary users.

In order to be properly demodulated, the communication must satisfy a certain signal and noise interference power ratio. Assume that the SINR thresholds of the primary user receiver and the perceived user receiver are $\eta_p$ and $\eta_s$, respectively.

In order to assess whether the channel quality at the location where the user is currently located is satisfied with normal communication requirements, it is calculated:

$$\text{SINR}_s = P_{sr} - N_{0S} - I_p$$

(2)

Where $P_{sr}$ is the received signal power, $P_{sr} = P_{st} - D_{rs}$; $N_{0S}$ is a constant related to the receiver bandwidth; $I_p$ is the interference caused by the authorized primary user transmitter, which can be obtained by the field strength obtained during signal detection. The $\text{SINR}_s$ is compared with the known threshold $\eta_s$. When the result is greater than the threshold, the interference caused by the primary user to transmit the signal to the current location-aware user terminal is authorized, and can be considered to be within the range allowed by the normal communication of the system.

In order to assess whether the perceived user’s communication interferes with the normal communication of the existing primary user, it is calculated:

$$\text{SINR}_p = P_{pr} - N_{0P} - I_s$$

(3)

Where $P_{pr}$ is the useful signal power for the primary user; $N_{0P}$ is the constant associated with the bandwidth of the primary user receiver; $I_s$ is the interference that the perceived user communication causes to the primary user.
Compare $SINR_p$ with threshold $\eta_p$ to ensure that interference to authorized primary users is within the range allowed by normal communication. $SINR_p \geq \eta_p$ is required. That is, considering a certain threshold probability $\beta$, it is required to:

$$P[I_s < I_{th}] \leq \beta$$

In the formula, $I_{th} = P_{pr} - N_{op} - \eta_p$; $I_s = P_{SR} - D_{SP}$

It can be seen that the calculation of the interference power needs to obtain the path loss $D_{SP}$ of the perceived user to the primary user receiver, and,

$$P[D_{SP} < P_{SR} - P_{pr} + N_{op} + \eta_p] = P[D_{SP} < D_T] \leq \beta$$

Due to the uncertainty of the location of the primary user receiver and the randomness of the transmission channel, we now calculate the probability density distribution of $D_{SP}$. The value of the path loss $D_{SP}$ is related to the transmission distance $l$ and the measurement model $u$. The value of $D_{SP}$ generally increases with the increase of the distance $l$. Under the same transmission distance, the randomness of the transmission environment leads to the measurement of the path loss $\hat{D}_{SP}$. There is a big difference, and the joint probability distribution is:

$$f(D_{SP}) = f(l, u) = f(u|l)f(l)$$

Then there is:

$$P[D_{SP} < D_T] = \int_0^{\hat{D}_T} \int_l^{\infty} f(u|l)f(l)dldu$$

The distribution of the transmission distance $l$ is related to the location of the perceived user and the authorized primary user receiver, and its distribution is difficult to express with a well-defined model. Suppose the path loss obtained by a certain measurement model at a fixed transmission distance $l_1$:

$$D_{SP} = \hat{D}_{SP} + X_\sigma$$

Where $\hat{D}_{SP}$ is a value related to $l_1$; $X_\sigma$ is a Gaussian distribution random variable with a mean of 0, and its variance is $\sigma$. So you can get:

$$f(u) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(u-\hat{D}_{SP})^2}{2\sigma^2}}$$

$$P[D_{SP} < D_T] = \int_0^{\hat{D}_T} \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(u-\hat{D}_{SP})^2}{2\sigma^2}} du$$

4. Performance simulation

In formula (10), the measured value $\hat{D}_{SP}$ and the variance $\sigma$ can be obtained according to the actual layout environment. The table is used to judge whether the current spectrum is available. This paper mainly simulates the performance of the spectrum detection algorithm.
In the Gaussian white noise environment, the detection performance of BPSK signal with bandwidth of 1MHz and 64QAM signal with bandwidth of 7MHz is evaluated by 2000 independent Monte Carlo simulation using energy detection method and cyclic feature detection method respectively to ensure false alarm probability. The detection threshold is set under conditions of not higher than 0.01. Figure 3 shows the variation of the detection probability of the two algorithms with the signal-to-noise ratio:

![Detection probability with signal to noise ratio curve](image)

(a) Energy detection method  
(b) Cyclic feature detection

Figure 3. Detection probability with signal to noise ratio curve

It can be seen from the simulation that the cycle characteristic detection method can achieve a detection probability of 90% under the condition that the signal-to-noise ratio is not less than 2dB, which is obviously superior to the energy detection method.

The calculations of the two algorithms are evaluated as follows: the signal length is set to 2048 samples, the FFT points are 2048, and the sliding window width of the energy detection method and the frequency domain smoothing window width in the calculation of the spectral spectrum are both set to 32. The energy detection method requires about 143,393 cycles, while the cyclic feature detection method requires about 153,671 cycles.

By evaluating the performance and computational complexity of the above two algorithms, we conclude that the computational complexity of the cyclic feature detection method is only slightly higher than that of the energy detection method, and the performance is significantly better than the energy detection method.

5. Conclusion

In order to solve the increasingly tight spectrum resources and improve spectrum utilization, this paper proposes a design algorithm for dynamic spectrum access criteria. First, in order to find spectrum holes, different spectrum detection algorithms are analyzed and compared. On this basis, the randomness of the propagation channel and the uncertainty of the location of the authorized user are studied to influence the spectrum perception. A dynamic spectrum usage strategy based on the probability model is proposed.

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