An Adaptive Threshold Decision Algorithm in Non-cooperative Signal Detection

Ziheng Li(✉), Shuo Shi, and Xuemai Gu

Harbin Institute of Technology, Harbin, China
liziheng@stu.hit.edu.cn, {crcss,guxuemai}@hit.edu.cn

Abstract. As the communication environment becomes more and more complex, it becomes more meaningful to detect and capture useful signals accurately. In this paper, we mainly focus on several typical burst signal detection algorithms in wireless communication networks. We analyze the signal energy detection algorithm, preamble detection, and frequency domain detection algorithms, then perform simulations for them. Above these, responding to non-cooperative communications, an adaptive threshold decision algorithm based on projection method is designed. Finally, we come to a conclusion, that each algorithm is suitable for burst signal detection, having its own advantages and disadvantages in different environments. And our decision algorithm is effective.

Keywords: Signal detection · Burst · Energy · Projection

1 Instruction

Now is an era of information technology. With the rapid development of economic globalization, the demand for information transmission and information exchange in various countries is increasing day by day. Communication information technology is developing in an unprecedented situation. Information transmission technology is affecting and changing people's production methods and lifestyles, and has gradually become an important driving force for modern economic development. It has also become a key factor in enhancing the comprehensive strength of countries and improving their competitiveness.

As one of the key technologies in information transmission, signal detection technology has been widely studied by scholars because of its important position. On the one hand, modern communication signals have the characteristics of adaptively adjusting their own parameters according to different communication environments, and thus the signals themselves will have more and more complex and varied forms. On the other hand, under the premise that the signal prior information is known, it will be affected by various factors of space during the transmission process, and frequency offset, attenuation, distortion.

When studying signal detection problems, the burst signal detection under cooperative conditions is relatively simple, and a matched filter is usually used as the detection structure. For non-cooperative correspondents, maybe lack most of the prior information, but burst signals often have two stable characteristics. First, the burst signal has obvious time continuity. Although the duration of the burst is unknown, it

S. Han et al. (Eds.): AICON 2019, LNICST 286, pp. 342–349, 2019.
https://doi.org/10.1007/978-3-030-22968-9_30

will certainly last for a period of time from the beginning to the end, which can be observed. The second characteristic is that most burst signals are band-pass, that is to say, most of the energy of burst signals in the spectrum is concentrated together. Most of detection algorithms utilize these characteristics of burst signals, and then perform corresponding operations according to the subsequent different signal processing requirements.

2 Signal Detection Algorithm

The current common burst signal detection algorithms mainly include time domain detection algorithm, frequency domain detection algorithm and so on. Energy detection algorithm is a more intuitive algorithm of time domain detection algorithm, it determines whether the signal into the receiver by using the energy of the received signal. The result is decided by observation on the sample value of the signal for a certain period of time and the calculation of the energy size. If the value is greater than a certain threshold, the signal will be determined to enter and the receiver notified to start the synchronization process. Preamble detection is based on the pilot sequence of the signal itself, then operate again on the local preamble correlation using the already known fixed signal format, to define the arrival time of the received signal accurately.

In addition, there are other frequency detection algorithms such as power detection, frequency spectrum detection. This paper mainly studies and analyzes several signal detection algorithms in wireless networks based on the Gaussian white noise channel model.

2.1 Energy Detection

The energy detection algorithm usually measures the average energy of a signal over a period of time to determine whether a signal arrives. It does not require prior information of the signal to be detected, also because of its low computational complexity has it become the most commonly used signal detection algorithm in an actual system. Method A directly measures the total energy of the received signal over a period of time and then compares it with the decision threshold to determine the presence of a signal. The principle of the algorithm and the block diagram works as follows formula (1) and Fig. 1:

$$Z(d) = \sum_{k=0}^{L-1} |r(d+k)|^2 \quad (1)$$

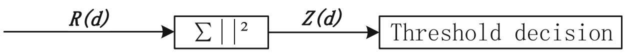

Fig. 1. Flow diagram of method A

Simulate this algorithm, we can get the result as Fig. 2. From this figure, it is obvious to find when useful signal reach.

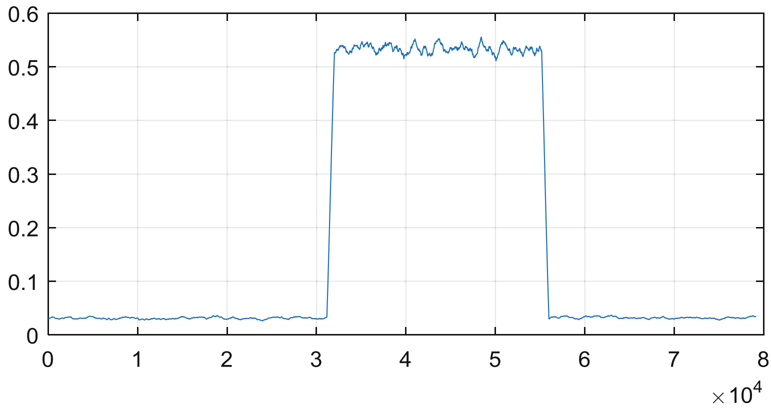

Fig. 2. Simulation result of method A

Method B is an improvement based on method A, which uses the ratio of the signal shift correlation to the energy of the signal itself as a decision statistic, a kind of relative threshold algorithm [1]. This algorithm performs better but has a slightly higher complexity than method A. The principle and block diagram work as follows Fig. 3 and formula (2):

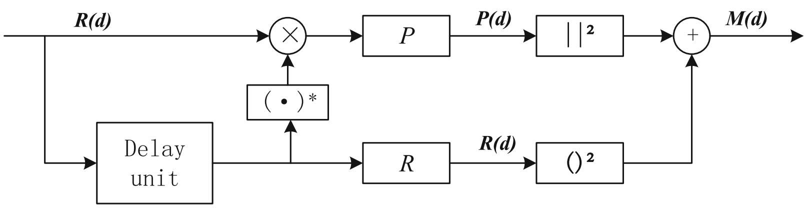

Fig. 3. Flow diagram of method B

$$
\begin{aligned}
\mathrm{P}(d) &= \sum_{m=0}^{L-1} r(d+m)r*(d+m+D) \\
\mathrm{R}(d) &= \sum_{m=0}^{L-1} r(d+m+D)r*(d+m+D) \\
&= \sum_{m=0}^{L-1} |r(d+m+D)|^2 \\
M(d) &= \frac{|P(d)|^2}{|R(d)|^2}
\end{aligned}
\tag{2}
$$

From Fig. 4 we can get when useful signal arrive, statistics decision generate a peak value. And we can get the simulation as Fig. 4.

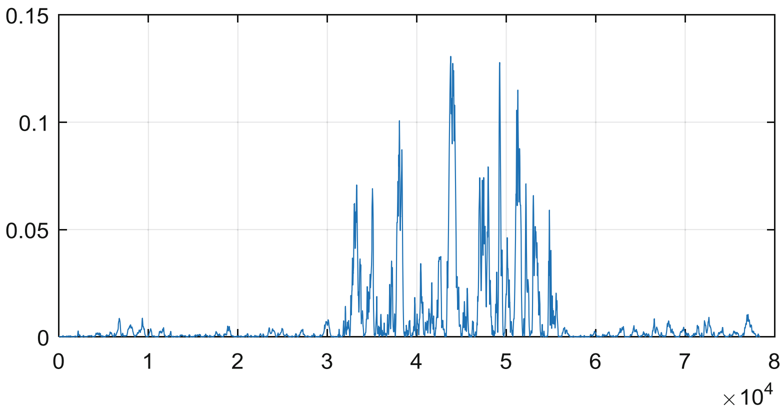

Fig. 4. Result of method B

2.2 Signal Detection Using Preamble

In wireless network communication, the receiving end can detect the communication signal by detecting and capturing the preamble sequence added before the data is effectively transmitted, and can also utilize the preamble sequence to initial capture the bit timing. In a wireless communication system, the power of the received signal is greatly affected by the transmission distance and various fading. Therefore, the signal detection performance has a crucial influence on the overall communication. Because the received signal level is unknown and time-varying, the fixed-threshold signal detection scheme often cannot obtain good detection performance, so that the detection probability decreases or the false alarm probability increases, while the unknown power of interference and interference power changes will affect the detection performance.

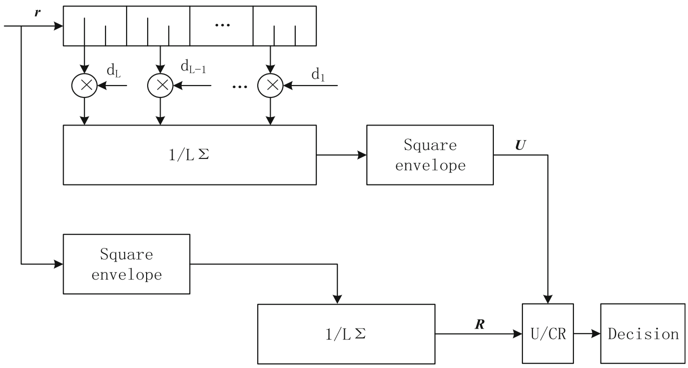

Fig. 5. Flow diagram of preamble detection

These situations are more suitable for using adaptive signal detection algorithm to detect the signal in the preamble to complete the wireless communication network signal detection. The principle block diagram of this algorithm is like this, Fig. 5.

Adaptive decision threshold C is after the literature derived as formula (3)

$$\begin{aligned} &C = 1 - (P_f')^{1/(L-1)} \\ &P_\rho(\rho|H_0) = (L-1)(1-\rho)^{L-2}, 0 \le \rho \le 1 \\ &P_f' = P(\rho \ge C|H_0) \end{aligned} \tag{3}$$

When the decision value $\frac{U}{CR}$ exceeds the adaptive threshold, it indicates that the received signal is consistent with the local reference preamble sequence, and the system detects the preamble of the signal; on the contrary, when the decision value is less than the threshold, it indicates that the preamble is not detected by the system. The communication signal detection can be completed through this process.

2.3 Power-Law Detection Based on High-Order Spectrum

Frequency domain signal detection algorithm means to transform the signal to the frequency domain, and then calculate the decision statistic to determine the presence of the signal. Frequency-domain decision statistics usually use higher-order statistics [2] or the spectrum obtained by DFT. This algorithm usually has higher computational complexity, but it has still a good detection quality at a lower SNR. These signal detection algorithms are mainly the algorithms based on DFT Power-Law [3, 4], and an optimization called high-order spectrum Power-Law detection algorithm [5]. The decision statistics used in the Power-Law algorithm based on the DFT transform are some transformation of the amplitude spectrum and can be described as the formula (4):

$$Z(n) = \sum_{k=0}^{N-1} X_k^v(n) \tag{4}$$

Where $X_k^v(n)$ represents the k-th amplitude square value of the P-point DFT result of the signal data sequence x(n) at time n, v is a non-negative real number, The data length N used to calculate the decision statistic $Z(n)$ should always be consistent with the number of points P of the DFT, otherwise the energy of the data in the frequency domain cannot be truly reflected. The number of DFT points cannot be too small as well, otherwise the fluctuation between the frequency domain sample points will be great. These conditions will all result in leakage or mistake of decision.

Improvements to this algorithm are based on higher-order Power-Law detectors, using the third-order cumulated spectrum of the signal, also called bispectrum, replaces judgment statistic $X_k^v(n)$, and then the judgment statistic is compared with the threshold. The Fourier transform of each piece of data is recorded as $X^{(i)}(w)$, its bispectrum estimation is shown as formula (5):

$$B_{xx}^{(i)}(\omega_1, \omega_2) = M^2 X^{(i)}(\omega_1) X^{(i)}(\omega_1 + \omega_2) \tag{5}$$

Calculate the decision statistic and we give an example like Fig. 6.

$$Z(n) = \sum_{j=1}^{N} \sum_{i=1}^{K} \left| B_{xx}(\omega_{1j}, \omega_{2i}) \right|^{v}$$

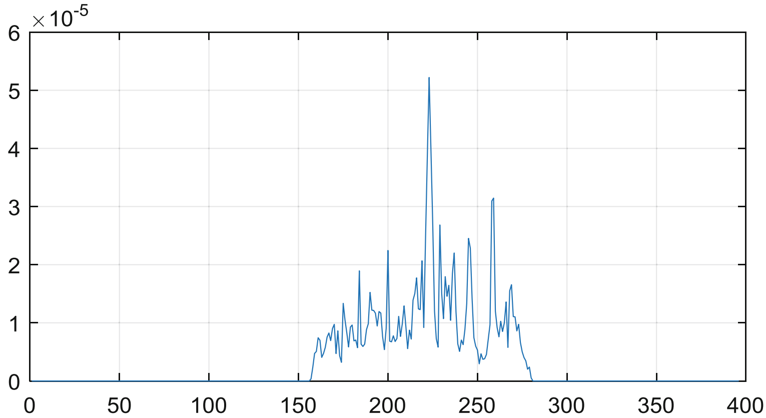

Fig. 6. Simulation result of bispectrality Power-Law detection

3 An Adaptive Threshold Decision Algorithm Based on Projection Method

In the above research on the signal detection algorithm, it is found that the existing threshold decision algorithm has a performance degradation when the signal-to-noise ratio is low, resulting in a false judgment. In many simulation experiments, we found that, when there is a burst signal in a period of time, the magnitude of the decision statistic obtained by various signal detection algorithms shows a bimodal distribution. These conditions are in line with the idea of separating single-peak subclasses by projection method in pattern recognition, so an adaptive threshold decision algorithm based on projection method is designed.

The basic steps of the algorithm are as follows. Obtain the judgment statistic $S(n)$ by the detection algorithm, divide the amplitude N segments by the same length, and calculate the probability density p_i of each segment separately. Look for the number of peaks in the probability distribution. If the probability distribution shows a single peak, then there is only noise during this period. If there are two or more peaks, find the minimum point between every two peaks, as Fig. 7.

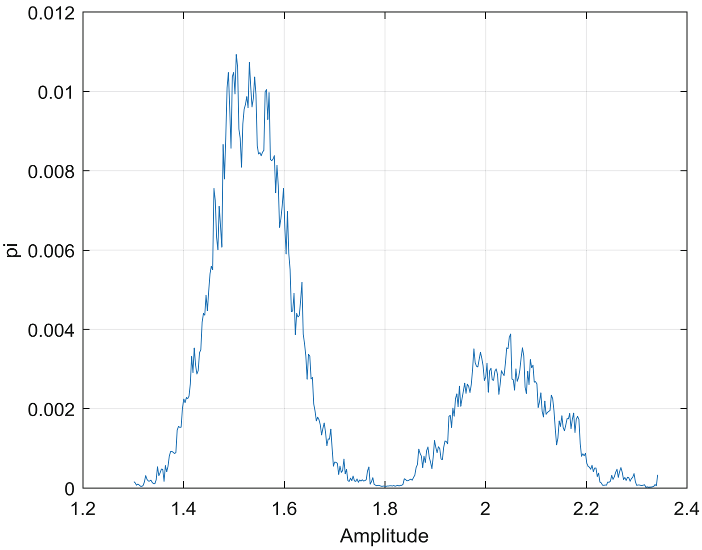

Fig. 7. Probability distribution of statistics

In order to reduce the error, M minimum values are searched as the undetermined data near the valley, and the corresponding sample amplitude point x_i is calculated as the sample classification mean, intra-class dispersion and total intra-class dispersion as formula (6) and (7).

$$m_j^i = \frac{1}{N_j}\sum_{x \in X_j} x, i = 1, 2, \ldots, M; j = 1, 2. \tag{6}$$

$$\begin{matrix} S_j^i = \sum\limits_{x \in X_j} (\mathrm{x} - \mathrm{m}_j^i)^2 \\ S_w^i = \sum S_j^i \end{matrix}, i = 1, 2, \ldots M; j = 1, 2. \tag{7}$$

Since the entire data set only needs to be divided into two categories, the value of j is taken as 2. Subsequent calculation of the minimum value of the dispersion Sw within the total class, as shown in formula (8).

$$S = \min(S_w^i), i = 1, 2, \ldots, M \tag{8}$$

Finally, the magnitude corresponding to the dispersion S in the smallest total class is selected as the adaptive threshold Z calculated by the algorithm, and the threshold decision is performed by using Z.

4 Conclusion

In this paper, we analyze and theoretically simulate several burst signal detection algorithms. Among them, the energy detection algorithm works faster and easier, has a very good detection effect when the channel conditions are good. The preamble sequence-related detection has been widely used in cooperative communication, and due to its correlation, it can still achieve better results when the channel is poor. Compared with the energy detection algorithm, the bispectrality Power-Law detection algorithm has a larger amount of computation and higher computational complexity, takes a while to accumulate data, but at the cost of this, its detection performance is quite excellent. When the channel environment is very bad, the burst signal can still be detected more accurately. For non-cooperative signal detection, our proposed adaptive threshold decision algorithm also achieves good results in simulation, and can improve signal detection performance when the channel environment is degraded, but the real-time performance needs to be improved.

References

1. Chen, H.-H., Sim, H.-K.: Orthogonal decision-feedback detector for asynchronous multiuser CDMA systems. IEEE Trans. Commun. **8**(42), 1963–1972 (2001)
2. Colonnese, S., Sxarano, G.: Transient signal detection using higher order moments. IEEE Trans. Signal Process. **47**(2), 515–520 (1999)
3. Wang, Z., Willett, P.: All-purpose and plug-in power-law detectors for transient signals. IEEE Trans. Signal Process. **49**(11), 2454–2466 (2001)
4. Kirsteins, I.P., Mehta, S.K.: Power-law processors for detection unknown signals in colored noise. In: IEEE Processing ICASSP, vol. 1, pp. 483–486
5. Xiong, S., Wu, Y.: The detection of transient signals based on gabor transform. In: IEEE Processing ICSP, vol. I, pp. 259–262 (2006)
6. Huang, C., Liu, Y., Chen, L.: Time-frequency joint analysis for peak power of microwave burst signal. In: IEEE International Symposium on Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications, Chengdu, pp. 202–205 (2013)