IJE TRANSACTIONS A: Basics Vol. 33, No. 4, (April 2020) 546-551

International Journal of Engineering

Journal Homepage: www.ije.ir

A Novel Multi-user Detection Approach on Fluctuations of Autocorrelation Estimators in Non-Cooperative Communication

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P A P E R I N F O

Paper history:
Received 26 October 2019
Received in revised form 22 February 2020
Accepted 07 March 2020

Keywords:
Asynchronous Variable Processing Gain
Direct-sequence
Code Division Multiple Access
Length of Spreading Code
Second Order Statistics

A B S T R A C T

Recently, blind multi-user detection has become an important topic in code division multiple access (CDMA) systems. Direct-Sequence Spread Spectrum (DSSS) signals are well-known due to their low probability of detection, and secure communication. In this article, the problem of blind multi-user detection is studied in variable processing gain direct-sequence code division multiple access (VPG DS-CDMA). The method based on the fluctuations of autocorrelation estimators,which previously described in a single and multi-user context, is extended to an asynchronous variable processing gain (VPG) DS/CDMA systems without restrictions on the processing gains in multi-path channel condition. According to the proposed algorithm, not only the presence of the common peaks in the second-order statistic of the received signal is proved, but the relationship between these peaks and the spreading code length is also derived. The simulation results show that the proposed algorithm even in the presence a very low signal-to-noise ratio (SNR) is completely efficient in signal detection. It is remarkable that the minimum description length (MDL) method is used to determine the number of users.

***doi**: 10.5829/ije.2020.33.04a.05*

1. INTRODUCTION

Due to increasing the number of users and sending information at high rates, the ability to assign different data rates and quality of service with optimized utilization of the bandwidth is one of the essential requirements in future wireless systems. Therefore, code division multiple access (CDMA) emerges as a promising technique to meet the above requirements, which is applied in the third generation of cellular telecommunications and employed spread spectrum technique in data transmission [1-3]. To provide a multi-rate system two major approaches are introduced: the usage of multi-code (MC), and variable processing gain (VPG) direct sequence multiple access systems. In both systems, the chip rates of different users are the same, so different users employ the same bandwidth. However, in the first method, according to the data rate of each user, a suitable number of spreading code with the same length is assigned to each user and the data of each user is divided into branches by the number of spreading code then at each branch, the data is multiplied into one code and sent to the channel. The second method is a single-code transmission scheme and to generate different data rates, spreading sequences of different lengths are used. In this way, users with higher rates will be assigned a lesser spectral spreading code and since the chip rate of all users is the same, the data transmission rate increases [4, 5]. In multi-user detection, prior knowledge of parameters such as processing gain, chip rate, number of users, and so on are required on the receiver side. However, in non-cooperative communication system, such as airborne communication surveillance and satellite communication surveillance the receivers have little prior knowledge of the intercepted signals [6-8]. Hence,

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Please cite this article as: F. Samsami Khodadad, F. Nazari , S. Janalizadeh, A Novel Multi-user Detection Approach on Fluctuations of Autocorrelation Estimators in Non-Cooperative Communication, International Journal of Engineering (IJE), IJE TRANSACTIONS A: Basics Vol. 33, No. 4, (April 2020) 546-551

the receiver have to use the blind detection techniques. The number of published approaches [9-13] on the problem of blind estimation, the length of the spreading sequences depending on the importance of the subject are fulfilled. The detection and synchronization of CDMA systems with two active users and Multi-rate CDMA synchronization for more number of active users have been considered by Nzéza et al. [9, 10]. Moreover, a new method for synchronizing a multi-user system based on behavior of the maximum Eigen values of received signal's estimated covariance matrix is presented by Nzéza et al. [11]. Gu et al. [12] investigated the properties of triple correlation function (TCF) of m-sequences. Mirzadeh Sarcheshmeh et al. [13] conducted an study based on expanding subspace algorithm and finite alphabet characteristics used to detect the spread spectrum signals in the blind special restriction on P manner. The block diagram of the proposed method is shown in Figure 1. In this paper, the estimation of the length of the pseudo-random sequences in spread spectrum signals is studied as an important and crucial parameter for information acquisition in blind detection. We consider estimation of the length of spreading code in Asynchronous VPG DS-CDMA systems without restrictions on processing gains. The proposed method in this paper includes autocorrelation function fluctuations to estimate the code length. The remainder of the paper is organized as follows, in section II, mathematical model is presented. Our proposed algorithm is considered in section III. The numerical results confirm our proposal algorithm can be found in section IV. Finally, the conclusion is presented in he section V.

2. MATHEMATICAL MODEL

2. 1. System Model Consider an asynchronous VPG-DS/CDMA system and suppose there are G groups of users with various spreading code lengths. The total number of users is N and the number of users in j group names N_j . Then, the transmitted discrete-time signal at the chip rate describes as follows:

$$s(n)=\sum_{j=1}^{G}\sum_{k=-\infty}^{\infty}\sum_{i=1}^{N_j} d_i(k)c_i(n-kP_j) \tag{1}$$

where $d_i(k)$ is data symbols and $c_i(n)$ is i[th] users spreading sequence with the length P_j and there is no.

The signal $s(n)$ is transmitted through a multi path channel with impulse response $h(n)$, hence the received signal at the receiver can be written as follows:

$$y(n)=\sum_{j=1}^{G}\sum_{k=-\infty}^{\infty}\sum_{i=1}^{N_j} d_{i,j}(k)g_{i,j}(n-kP_j-\tau)+w(n) \tag{2}$$

where $g(n)$ is the combination of impulse response of the channel and spreading code of the i[th] user and written as follows:

$$g_i(k)=\sum_{n=0}^{P_i-1} c_i(n)h_i(k-n)=c_i(k)*h_i(k) \tag{3}$$

Where $*$ denotes the convolution operator, and $w(n)$ is samples of the noise.

3. NOVEl PN DETECTIONN APPROACH

In the detection of direct sequence spread spectrum signals, their cyclo-stationary properties can be exploited because the structure of pseudo-noise code is repeated in each period and its mean and variance have periodic structure. According to this fact, the length of the spreading code can be calculated using a second-order statistics estimator.

Using the mean of autocorrelation function of M data observation window, an estimation of the second-order statistics can be obtained as follows:

$$\rho(m)=\hat{E}\left\{\left|R_y(m)\right|^2\right\}=\frac{1}{M}\sum_{n=0}^{M-1}\left|R_y^n(m)\right|^2 \tag{4}$$

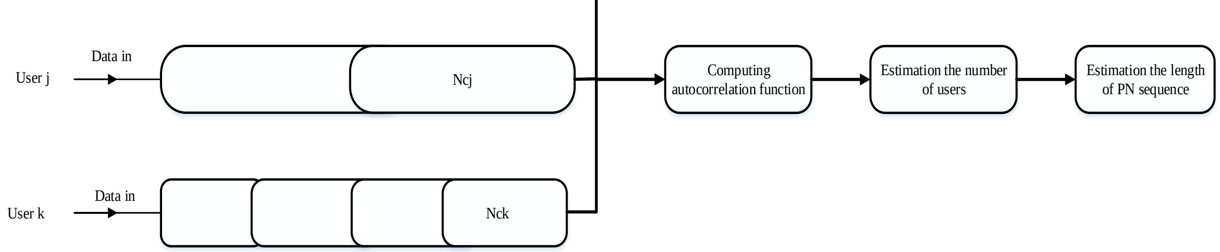

Figure 1. The block diagram of the proposed method

As one can see in Equation (4), the performance of the proposed method is influenced by the length of the data observation window, while no specific algorithm for selecting the optimal window is presented. On the other hand, choosing a suitable window has a major impact on the computational complexity. In addition, choosing the window length, and choosing the appropriate threshold level for signal and noise separation are also important. Burel and Bouder [14] and Bouder et al. [15] were considered the threshold level for separating signal, and noise stated as follows:

$$THR = m_{\rho(m)} + 2\sigma_{\rho(m)} \tag{5}$$

where σ_ρ is the standard deviation, and m_ρ is the average value of $\rho(m)$.

The proposed algorithm is capable to estimate the spreading code length at lower SNR using the autocorrelation function. It is another advantage of the proposed method in comparison to other previous methods . Besides, by choosing an adaptive window, the computational complexity of the proposed algorithm is reduced to a reasonable value with respect to other methods. Also, this algorithm maintains its performance under asynchronous VPG and multipath condition with more users. The proposed method consists of two parts: At the first part, we choose an adaptive window and at the second part, we have to choice an appropriate threshold level for better observation of regular peaks with various code length intervals.

It is remarkable that since the receiver samples the received signal at the chip rate, the symbol period and the code length are the same.

3. 1. Algorithm Procedure The proposed method is as:

1. Choose threshold level (TL) for separating signal and noise level.
2. Choose TC as a counter to decide that a special code length is desired or not.
3. Define a matrix as Δ for managing the information obtained from the processing windows.

Define TC and TL as follows:

$$\begin{aligned} & i \mid \left\{ \sum_i \rho(m) > TL(i) \right\} < TC \\ & TL(i) = TL(i-1) - K_{adpt} TL(i-1) \\ & i \mid \left\{ \sum_i \rho(m) > TL(i) \right\} < TC \\ & TL_{Final} = TL(i) \\ & L(0) = \max(\rho(m)) \end{aligned} \tag{6}$$

Also, Δ is defined as follows:

$$\Delta = \begin{bmatrix} \delta_1 & \delta_2 & \delta_3 & \cdots & \delta_n \\ \delta_1 & \delta_2 - \delta_1 & \delta_3 - \delta_1 & \cdots & \delta_n - \delta_1 \\ \delta_2 & 0 & \delta_3 - \delta_2 & \cdots & \delta_n - \delta_2 \\ \vdots & \vdots & \cdots & \cdots & \vdots \\ \delta_{n-1} & 0 & \cdots & 0 & \delta_n - \delta_{n-1} \\ \delta_n & 0 & 0 & \cdots & 0 \end{bmatrix} \tag{7}$$

where elements of Δ are defined In Equation (8), and describe the distance between two peaks.

$$\begin{cases} \delta_{ij} = \delta_{1j} - \delta_{i1} & i \le j \\ \delta_{ij=0} & i \succ j \end{cases} \tag{8}$$

Define a corresponding matrix P whose elements show the probability of δ_{ij} as a PN code length of a special user. Moreover, the elements of Matrix P are determined based on the amplitude of δ_{ij} and the number of repetition in the analysing windows.

4. SIMULATION RESULTS

In this section, the performance of the proposed algorithm is evaluated to estimate the code length using simulation results. Simulations consist of two parts. At the first, simulations are carried out on assuming processing gains of $P_1 = 31$, $P_2 = 63$ and $P_3 = 127$.The parameters used in the simulation are summarized in Table 1. For sake of simplicity, the number of users is assumed to be equal to 3 and SNR=-5 dB. Furthermore, the general case of uplink is considered. As can be seen in the Figure 2, the distance between successive peaks of the same size represents the length of the code and when the length of the code increases, the processing gain increases, and the probability of correct detection is enhanced, so the corresponding peaks will achieve with a better clarity. P and Δ matrices is demonstrated in Equation (9). It can be seen that the length of the corresponding code with the maximum probability in the matrix p is $P_1 = 31$, $P_2 = 63$ and $P_3 = 127$.

TABLE 1. Simulations Parameters

Modulation	PN seq	Fading Channel	Chip Period
Bpsk	m-sequence	FIR filter	1.5 MHZ

$$\mathbf{P} = \begin{pmatrix} 3.7 & 0 & 0 & 0 & 0 & 52 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 70 & 0 & 0 & 47 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 58 & 0 & 46 & 0 & 0 & 46 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 35 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 10 & 0 & 47 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 23 & 35 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 3 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 23 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 12 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1.1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

$$\Delta = \begin{pmatrix} 5 & 15 & 46 & 68 & 77 & 127 & 131 & 139 & 170 & 194 & 254 & 257 & 263 \\ 5 & 10 & 41 & 63 & 72 & 122 & 126 & 134 & 165 & 189 & 249 & 252 & 258 \\ 15 & 0 & 31 & 53 & 62 & 112 & 116 & 124 & 155 & 179 & 239 & 242 & 248 \\ 46 & 0 & 0 & 22 & 31 & 81 & 85 & 93 & 124 & 148 & 208 & 211 & 217 \\ 68 & 0 & 0 & 0 & 9 & 59 & 63 & 71 & 102 & 126 & 186 & 189 & 195 \\ 77 & 0 & 0 & 0 & 0 & 50 & 54 & 62 & 93 & 117 & 177 & 180 & 186 \\ 127 & 0 & 0 & 0 & 0 & 0 & 4 & 12 & 43 & 67 & 127 & 130 & 136 \\ 131 & 0 & 0 & 0 & 0 & 0 & 0 & 8 & 39 & 63 & 123 & 126 & 132 \\ 139 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 31 & 55 & 115 & 118 & 124 \\ 170 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 24 & 84 & 87 & 93 \\ 194 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 60 & 63 & 69 \\ 254 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 3 & 9 \\ 257 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 6 \\ 263 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix} \quad (9)$$

Figure 3 shows the performance of adaptive windows to estimate PN code length in multipath condition. As one can see, at this stage only two code lengths of 63 and 127 are detectable, and separation of the smaller code with smaller amplitude of the fluctuations is not possible from the available noise. In the next step, by selecting a smaller window, we will search to find smaller code lengths. It can be seen (Figure 4) that at this stage, the shorter code length, 31, is also detectable. At the second part of the simulation, the performance of the proposed algorithm is evaluated to estimate the code length of active users. The spread spectrum system random codes are used and there are not any specific restrictions on the spreading codes. The multi-path channel is also a channel with finite impulse response. At first, we estimate the number of users based on the MDL criterion, which is one of the most practical methods in detecting the number of sources and detect the number of sources by counting

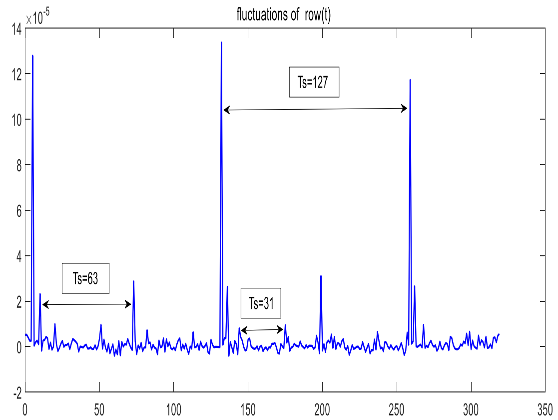

Figure 2. estimation of PN period in 3rate system in AWGN for SNR=-8dB

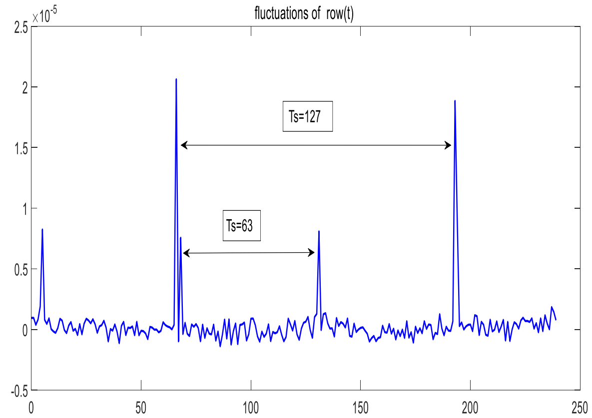

Figure 3. First adaptive analyzing window selection for estimation of PN periode in multipath fading channel

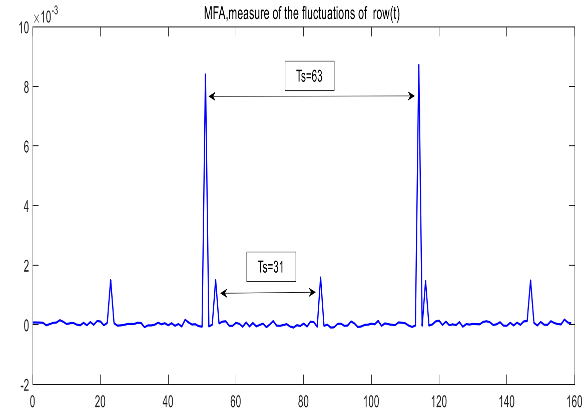

Figure 4. Second adaptive analyzing window selection for estimation of PN periode in multipath fading channel

the smallest eigenvalues of the correlation matrix [16] (Figures 5 and 6). Furthermore, according to P and matrices, we can estimate the processing gains.

Figures 5 and 6 show the estimation of the spreading code in 4-rate systems and 5-rate systems with increasing number of users. It is notable that spreading code is considered as random codes and not necessarily suitable codes.

Figure 7 shows the performance of the proposed algorithm by increasing the rate of the system with 10 users. It is observed that as the number of different code lengths increases, the performance of the method is reduced and for a constant SNR the probability of detection decreases, which is quite obvious, as the number of active users increases as their interference increases.

Finally, we compare the performance of the proposed algorithm with the correntropy and conventional correlation method. From the Figure 8, the performance of the proposed algorithm is clearly better than the mentioned method.

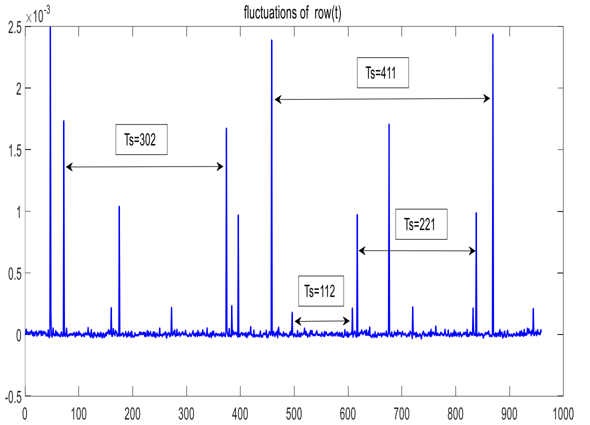

Figure 5. estimation of PN period in 4rate system in AWGN for SNR=-5dB

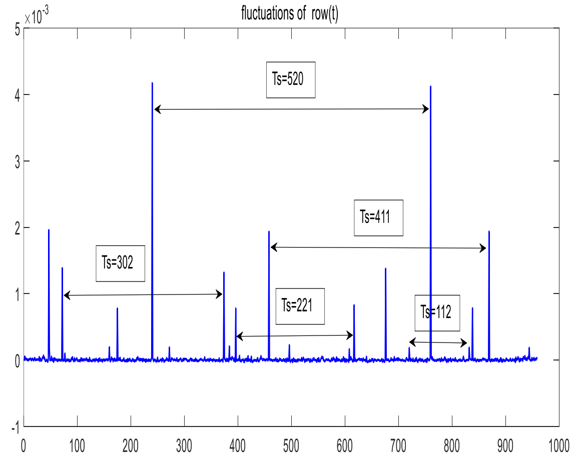

Figure 6. estimation of PN period in 5rate system in AWGN for SNR=-5dB

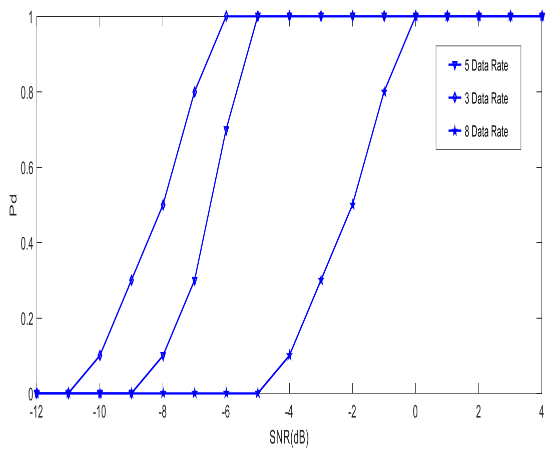

Figure 7. Detection probability of PN period versus different values of SNR for different rate of system

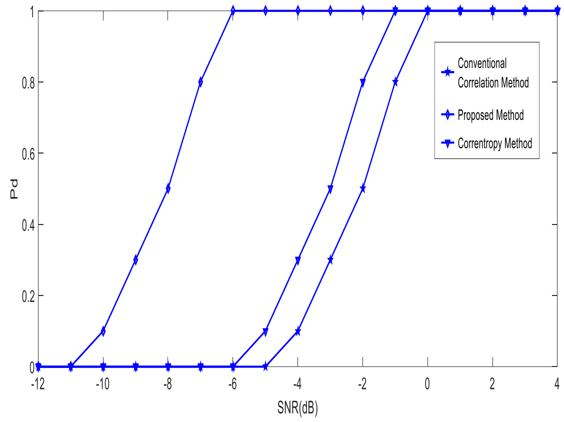

Figure 8. Comparison of detection probability of PN period between the correlation method and the proposed algorithm

5.CONCLUSION

In the context of blind detection of spread spectrum data, estimation the period of spreading sequences is inevitable. Hence, a novel algorithm for estimation the period of the PN sequence based on observation of the peaks of second-order statistic fluctuation in a VPG DS-CDMA system is presented in this article. One of the crucial problems in the proposed method is to select a suitable processing window for accurate detection of the peaks. Therefore, using the adaptive algorithm, we had an optimal choice for the length and number of processing windows. This selection causes that the proposed method be appropriate for variable processing gain scenario.

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Persian Abstract

چکیده

اخیرا، آشکارسازی کور چندکاربره به یکی از موضوعات مهم در سیستم‌های دسترسی چندگانه با تقسیم کد مبدل گشته است. سیگنال های طیف گسترده‌ی دنباله مستقیم به دلیل احتمال کم آشکارسازی و برقراری ارتباطی مطمئن، شناخته شده هستند. در این مقاله، مسئله‌ی آشکارسازی کور چندکاربره در سیستم‌های دسترسی چندگانه با تقسیم کد با بهره‌ی پردازشی متغیر، مورد بررسی قرار گرفته است. الگوریتم مبتنی بر نوسانات تخمین‌گر خودهمبستگی که در قالب سیستم‌های تک کاربره و چندکاربره مورد بررسی قرار گرفته است، به یک سیستم دسترسی چندگانه با تقسیم کد غیر همزمان با بهره‌ی پردازشی متغیر در کانال چند مسیره، گسترش یافته است که هیچگونه محدودیتی بر بهره‌ی پردازشی اعمال نگردیده است. مطابق با این الگوریتم جدید، علاوه بر حضور پیک‌های متداول در ممان آماری مرتبه‌ی دوم سیگنال دریافتی، رابطه‌ی میان این پیک‌ها و طول دنباله‌ی گسترش دهنده نیز اثبات می‌گردد. نتایج شبیه سازی، کارایی الگوریتم ارائه شده را در آشکارسازی سیگنال، حتی با نسبت سیگنال به نویز بسیار پایین نشان می‌دهد. لازم به ذکر است که برای تعیین تعداد کاربران نیز از روش MDL استفاده شده است.