A New Method of Modulation Recognition of Block Orthogonal Amplitude Modulation

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Abstract —The method of block orthogonal amplitude modulation (QAM) is presented and the demodulation recognition method is studied in this paper. Based on ordinary orthogonal modulation, the basic feature vector is extracted from the received signal cluster sample to estimate the signal parameters of data block for achievement of data block demodulation by using matrix transformation which can reach the recognition of signal modulation. The simulations results show that recognition rate can achieve 90% above under the condition of SNR which is 4 dB and the system is easy to realize, it has wide application prospect in signal recognition.

Index Terms—Block orthogonal amplitude modulation, clustering example, clustering iterative algorithm, basic vector, demodulation recognition

I. Introduction

Modulation identification has been widely used in the military and civil communications such as signal monitoring, signal confirming, interference discrimination, electronic countermeasure, electronic rescue, and the analysis of military threat etc. It is the foundation of software defined radio, cognitive radio and spectrum sensing. As new modulation modes emerge, signal processing becomes increasingly complicated, which affects the effectiveness of modulation identification. To achieve the automatic identification technology is still a challenge research topic [1]-[2].

General orthogonal amplitude modulation is referred to as GOM. Orthogonal amplitude modulation (QAM), including 4QAM, 16QAM, 64QAM, and 256 QAM, has been widely used in fields of all kinds of digital signal transmission, such as digital satellite TV, digital TV, high speed data transmission and other fields because the band utilization rate is very high and the modulation mode is very agile in the digital modulation technology. GOM with the methods of modulation recognition were introduced in many journals [3]. The bock orthogonal amplitude modulations discussed in this paper is introduced few in the literature at present, and the bandwidth efficiency is higher than GOM's, so it has more practical significance for the research of block orthogonal amplitude modulation and modulation recognition method under the condition of limited band resources [4].

For the recognition of GOM signal, the characteristic information needs to be extracted and the signal frame from the transmission signal needs to be reconstructed. Because the dimension of GOM modulation is not high, a few vector is needed, the effect is good and the algorithm of signal reconstruction is simple when classification methods of constellation graph clustering characteristics and particle swarm and subtraction clustering extraction characteristics are used [5], but the signal frame needs 2^N number of vector, and the number of vector increases exponentially, the algorithm of signal reconstruction is complicated relatively for the QAM of N-dimensional bock [6]. A new method for extracting the basic vector is proposed in this paper, the basic vector is composed of N+1 vector for signal QAM of N-dimensional bock. The number of vectors and basic vectors for signal reconstruction is shown in Table I.

TABLE I: NUMBER OF VECTORS AND BASIC VECTORS FOR SIGNAL RECONSTRUCTION

Dimensions	The number of vectors	The numbers of basic vectors
3	8	4
4	16	5
…	…	…
7	128	8
N	2^N	N+1

Table I shows that the number of basic vectors is smaller than the number of vectors when the dimension is larger, so the complexity of calculation is quire simple when the basic vectors are used for signal reconstruction to realize demodulation recognition.

II. Model of Bock Orthogonal Amplitude Modulation

For GOM, it is a way of transmission after two channels of signal orthogonal modulation and stack.

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Compared with GOM, there are N channels of signal which are orthogonal modulated with the same frequency of N for the bock orthogonal modulations of N-dimensional. It is very difficult to describe mathematically for model of bock orthogonal amplitude modulations of N-dimensional with the number of dimension N increases, so it can be described with transfer matrix of multidimensional rotation for bock orthogonal amplitude modulations of N-dimensional in this paper. Modulation parameters including two physical quantities of rotation surface and rotation angle [7].

An N-dimensional information vector $\mathbf{S}=[\mathbf{S_1},\mathbf{S_2},\ldots,\mathbf{S_n},\ldots\mathbf{S_N}]$, for M hexadecimal data, $\mathbf{S}_n=\pm\mathbf{d}$, $\pm3\mathbf{d}$, $\ldots$, $\pm(M-1)\mathbf{d}$, $n\in(1,2,\ldots,N)$. A signal vector of bock modulations of N-dimensional $\mathbf{C}=[\mathbf{C_1},\mathbf{C_2},\ldots,\mathbf{C_N}]$ is defined by:

$$\mathbf{C}=\mathbf{SH} \tag{1}$$

where $\mathbf{H}$ is a transfer matrix, which consists of information of consecutive rotations in a multidimensional space, and rotations of the multidimensional space are expressed by a product of the rotation matrix R and the transfer matrix $\mathbf{H}$ to be rotated. The rotation angle in the ith and jth dimensions is defined as θ_{ij}, where $i \prec j$, for $\theta_{ij}=\alpha$, the rotation matrix $\mathbf{R}$ is written by

$$\mathbf{R}=\left[\theta_{ij}=\alpha\right]=\begin{bmatrix}\mathbf{r_{11}} & \mathbf{r_{12}} & \cdots & \mathbf{r_{1N}}\\ \mathbf{r_{21}} & \mathbf{r_{22}} & \cdots & \mathbf{r_{2N}}\\ \vdots & \vdots & \ddots & \vdots\\ \mathbf{r_{N1}} & \mathbf{r_{N2}} & \cdots & \mathbf{r_{NN}}\end{bmatrix} \tag{2}$$

where $r_{ii}=r_{jj}=\cos\alpha, r_{ij}=-r_{ji}=-\sin\alpha$, after continuous rotation by L times, transfer matrix can be expressed as

$$\mathbf{H}=\mathbf{R_L}\mathbf{R_{L-1}}\cdots\ \ldots\mathbf{R_2}\mathbf{R_1}\mathbf{E} \tag{3}$$

where $\mathbf{E}$ is an initial transfer matrix, so the block orthogonal modulation of N-dimensional can be expressed by changing modulation parameter or change the rotation surface and rotation angle.

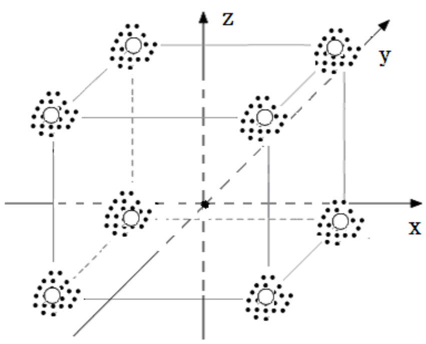


Fig. 1. Constellation of block orthogonal amplitude modulation of 3-dimensional

For block orthogonal modulation of 3-dimensional, let information symbol be binary data, that is M=2, let $S_n=\pm1$. According to the above definition, the constellation diagram can be received as shown in Fig. 1.

In Fig. 1, the signal of transmission and receiving are expressed respectively by white small garden ring and black point.

III. Principle of Demodulation Recognition of Block Orthogonal Amplitude Modulation

In this paper, the block diagram of the principle of demodulation recognition of block orthogonal amplitude modulation is shown in Fig. 2.

The signal of block orthogonal modulation which output form transmitter interference by white gaussian noise in the channel, at the receive end, all receiving signal used to rebuild signal framework of N-dimensional (clustering samples), and then through the basic vector estimation and extraction, one way is to send data demodulation to recover data demodulation, another way is to send matrix conversion in order to realize achieve purpose of modulation mode recognition [8].

Not all the received signals are used to estimate basis vectors in our estimation method. We denote the set of all received signals clustering samples by $\mathbf{Z}$, define the samples which are employed to estimate basis vectors as “clustering target samples”, and the set of clustering target samples by $\mathbf{Z}'$, define an initial vector of the set of received signal as $\mathbf{Z_0}$, and denote other signals by $\boldsymbol{Z_1}$, $\boldsymbol{Z_2}$, …, $\boldsymbol{Z_{M-1}}$, where M is the total number of received signals. Fig.3 shows clustering sample $\mathbf{Z}$ of all the received signals, clustering target samples $\mathbf{Z}'$, initial vector $\mathbf{Z}_0$ and other three basis vectors in the space of three dimensional block orthogonal amplitude modulation.

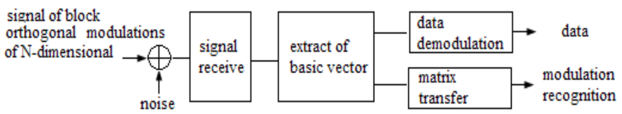


Fig. 2. Block diagram of demodulation recognition principle.

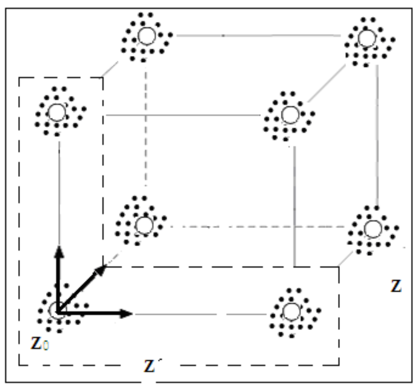


Fig. 3. Map of $\mathbf{Z}$, $\mathbf{Z_0}$, $\mathbf{Z}'$ and other three basic vector.

It is very important to choose clustering target sample $\mathbf{Z}'$, which will affect extraction of the basic vector directly, thus affect signal recognition of block orthogonal amplitude modulation [9]-[10]. We will discuss respectively about selection of cluster target sample $\mathbf{Z}'$, the algorithm of basic vector estimation and principle of modulation recognition is as follow.

Define an angle between initial vector $\mathbf{Z}_0$ and *i*th dimensional vector $\mathbf{Z}_i$ as

$$\theta_i = \arccos\left(\frac{\mathbf{Z}_0 \cdot \mathbf{Z}_i}{\|\mathbf{Z}_0\|\|\mathbf{Z}_i\|}\right) \tag{4}$$

where $\mathbf{Z}_0 \cdot \mathbf{Z}_i$ is an inner product of $\mathbf{Z}_0$ and $\mathbf{Z}_i$, and $\|\mathbf{Z}_0\|, \|\mathbf{Z}_i\|$ is respectively a norm of $\mathbf{Z}_0$ and $\mathbf{Z}_i$.

where we define θ_{ne} and θ_{op}, they can be calculated as

$$\theta_{ne} = \arccos\left(\frac{N-2}{N}\right) \tag{5}$$

$$\theta_{np} = \arccos\left(\frac{N-4}{N}\right) \tag{6}$$

Select the average of θ_{ne} and θ_{op} as an intermediate angle of judgment threshold

$$\theta_t = \frac{\theta_{ne}+\theta_{op}}{2} \tag{7}$$

When θ_i is larger than θ_t, $\mathbf{Z}_i$ is far from $\mathbf{Z}_0$ than adjacent vertices, so $\mathbf{Z}_0$ does not belong to cluster target sample $\mathbf{Z}'$, only if the condition of $\theta_i < \theta_t$ is satisfied. Next, target sample $\mathbf{Z}'$ is clustered into *N*+1 groups, and the center vector of each group is expressed respectively by $c_1, c_2, \cdots, c_{N+1}$, of all *N*+1 the vector which is closest to the initialization vector $\mathbf{Z}_0$ which is called "support vector of basic vector", and denoted by:

$$e_i = c_j - c_p \tag{8}$$

where j=1,2,…,*N*+1, $c_j \neq c_p$, the performance estimated of basic vector depends on which vector is selected as the initialization vector $\mathbf{Z}_0$, in order to improve the estimation performance of basic vector, we use c_p instead of $\mathbf{Z}_0$, and for (4) to (7) we use iterative algorithm to calculate processing [11], steps of algorithm are follows.

Step 1: define the initial vector $\mathbf{Z}_0$ as a received signal vector whose amplitude is maximum and define other signal vectors by $\mathbf{Z}_1, \mathbf{Z}_2, \ldots, \mathbf{Z}_M$;

Step 2: For i= 1, 2,…, *M*-1, calculate θ_i by Equation (4);

Step 3: Select clustering target samples from received signals to satisfy inequality $\theta_i < \theta_t$ and the set of them is defined as $\mathbf{Z}'$;

Step 4: Cluster Z′ into *N* + 1 groups using modified *k*-means algorithm and define the center of each cluster as c_i (*i*=1,2,…, *N*+1);

Step 5: Select the pivot vector c_p from c_i, which is the closest one to $\mathbf{Z}_0$;

Step 6: Estimate the basis vectors e_i from (8);

Step 7: $c_p \rightarrow \mathbf{Z}_0$;

Step 8: Iterate Step 2 $\rightarrow$ Step 7 α times.

Ultimately we have extracted basic vector which is meet the requirements.

According to relationship of the conjugate transformation matrix and basic vector $\hat{\mathrm{H}} = [\mathbf{e_1 e_2} \cdots \mathbf{e_n}]^{\mathrm{T}}$ and $\mathbf{C} = \mathbf{SH}$ we can estimate the data vector of *N*-dimensional, so as to realize modulation recognition of block orthogonal amplitude modulation of *N*-dimensional signal.

IV. Theory Analysis of Modulation Recognition Performance of Block Orthogonal Amplitude Modulation

The performance of modulation recognition of block orthogonal amplitude modulation of *N*-dimensional can be denoted by high and low of recognition rate.

Let transmission vector of block modulation signal of *N*-dimensional be

$$\mathbf{T} = [\mathbf{T_1}, \mathbf{T_2}, \ldots \mathbf{T_n} \ldots, \mathbf{T_N}] \tag{9}$$

where $\mathbf{T}_n = m\mathbf{d} = \pm\mathbf{d}, \pm 3\mathbf{d}, \ldots, \pm(M-1)\mathbf{d}, n \in (1, 2, \ldots, N)$. And let vector of noise be $\mathbf{N} = [\mathbf{N_1}, \mathbf{N_2}, \ldots, \mathbf{N_n}]$, the vector of receiving signal be $\mathbf{Y} = [\mathbf{Y_1}, \mathbf{Y_2}, \ldots, \mathbf{Y_n}]$, then the total vector of receiving signal is:

$$\mathbf{Y} = \mathbf{T} + \mathbf{N} \tag{10}$$

At the receiving side, for block orthogonal modulation of 3-dimensional, the signal recognition rate *p* depends on projection $\mathbf{Y1}$ which is vector $\mathbf{Y}$ of receive signal projection on extraction basic vector (set $\mathbf{Z1}$), as shown in Fig. 4:

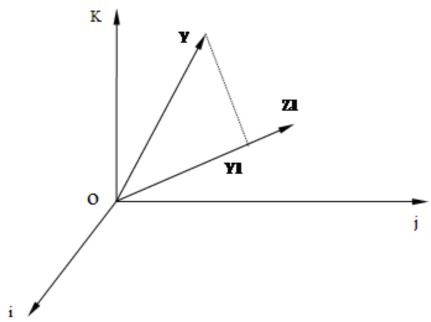


Fig. 4. Relationship map of $\mathbf{Y}$, $\mathbf{Z1}$ and $\mathbf{Y1}$

When block modulation signal of *N*-dimensional $T_1 = md$ is send, theoretically, recognition rate is the probability of y_1 between $(m-1)d$ and $(m+1)d$ [12-13] as:

$$p = proble[(m-1)d < y_1 < (m+1)d] \tag{11}$$

Definition: the range between $(m-1)d$ and $(m+1)d$ expressed by *L*, consider of the influence on received signal and extraction basic vector from noise, signal recognition rate should depends on projection component y_{lx} which received signal projection on basic vector axis of no error after converted by rotational matrix $\mathbf{R}$ [14] as shown in Fig. 5.

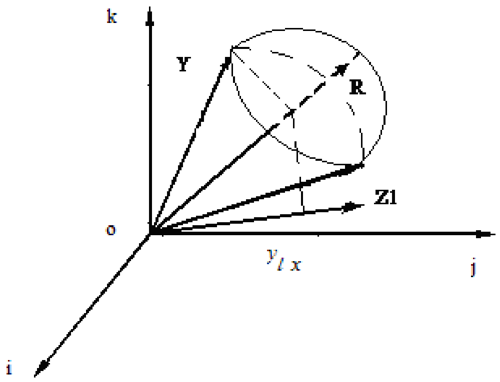


Fig. 5. Relationship map of $\mathbf{Y}$, $\mathbf{R}$ and $\mathbf{Z1}$

The projection weight as:

$$\begin{aligned} y_{1X} &= R(T+N)\cdot(1,0,\cdots,0) \\ &= (RT+RN)\cdot(1,0,\cdots,0) \\ &= f(\theta)+n_1 \end{aligned} \tag{12}$$

where $f(\theta)=RZ\cdot(1,0,\cdots,0)$, $\theta=(\cdots,\theta_{ij},\cdots)$, n_1 Let noise is a white Gaussian noise which one dimensional mean is 0, variance is σ^2 , so theoretically ,when send block modulation signal $T_1 = md$, the ideal recognition rate is:

$$p=\int_L \frac{1}{\sqrt{2\pi}\sigma}\exp\{-\frac{[y_{1X}-f(\theta)]^2}{2\sigma^2}\}dy_{1X} \tag{13}$$

V. Results of Simulation and Performance Analysis

We use the algorithm proposed in this paper to recognize block orthogonal modulation signal and use MATLAB for simulation. The simulation parameters and conditions are: carrier frequency f_c = 150 kHz, sampling rate f_S = 1200 kHz, symbol rate R_B = 12.5 KB/s. The coefficient of ASK modulation is chose as 0.8. 2048 samples are used for single sample identification. The modulation signals use random sequence.1000 times runs are taken. The noise is the white gaussian noise channel of ideal additive, the signal-to-noise ratio (SNR) is 5 ~ 10 dB.

Compare the basic vector algorithm with using all receiving signal vector to modulation recognition, the simulation results of relationship between amount of time needed to identification and numbers of dimension are shown in Table II.

Table II shows that compared with basic vector algorithm, using all receiving signal vector to modulation recognition, amount of time need to identification becomes less relatively with the increase of dimension numbers, so the algorithm proposed in this paper makes computational complexity of block modulation demodulation and recognition reduce greatly.

TABLE II: COMPARISON OF CALCULATION COMPLEXITY SIMULATION

Computing time (second)	Numbers of dimension 3	4	5	6	7	8
Using original vector	0.1	0.20	11.11	47.22	166.67	861.11
Using basic vector	0.01	0.21	5.55	19.44	80.55	394.44

For block orthogonal amplitude modulation of N-dimension, Table I shows that: the frame of reconstruction signal sample needs 2^N vectors at receiving side, therefore we take the number of receiving clustering sample as: $M = 80\times 2^N$, when N is taken 3, 4, 5, 6, 7 respectively, the number of clustering sample M is 640, 1280, 2560, 5120, 10240 respectively under the condition of SNR which is 5 dB, 10 db respectively, the simulation results of relation between recognition rate and iterations λ is shown in Fig. 6.

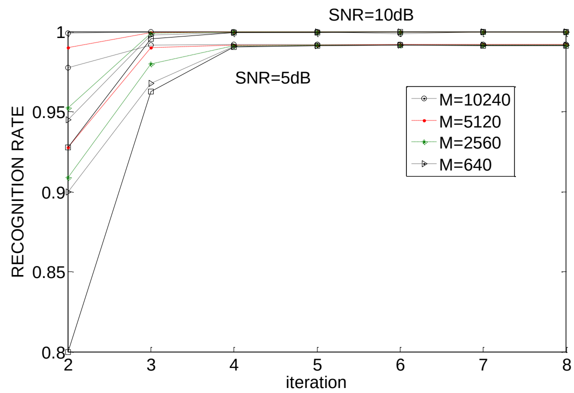
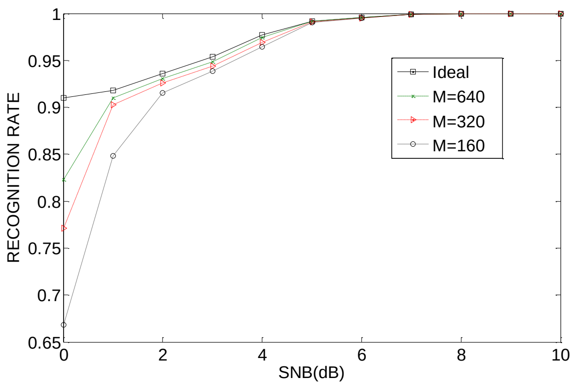


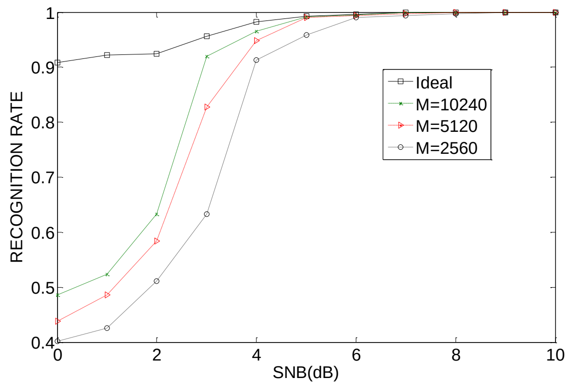
Fig. 6. Relationship map between recognition rate and the numbers of iterations λ.

From Fig. 4 we know that:

- The higher of dimension N, the lower of recognition rate is, when the SNR is 5 db, iterations λ less than 4 times. This is because the number of iterations is not enough, estimation of basic vector is not accuracy, low recognition rate relatively, and the recognition rate is lower with the dimension N higher. But the recognition rate achieves 98% above when the iteration λ equals to 4 times, and the error of basic vector estimation and extract is very small and stability when the iteration λ is more than 4 times, therefore, the recognition rate maintains equal approximately and more than 98% when N were taken 3, 4, 5, 6, 7 respectively.
- The higher of dimension N, the lower the recognition rate is, the situation similarly as receiving SNR is 5dB, when SNR is 10 dB, iterations λ less than 4 times, but the recognition rate can achieve 99% above when the iteration λ equals to 3 times, and the recognition maintains equal approximately and about equal to 1 when the iteration λ more than 4 times, such as N were taken 3, 4, 5, 6, 7 respectively.



(a) *N*=3



(b) *N*=7

Fig. 7. Relationship between recognition rate and the input SNR.

When the dimension N were taken 3 and 7 respectively ,the relationship between recognition rate of block orthogonal modulation N- dimension signal and the input SNR is shown as Fig. 7.

We know that:

- When dimension N = 3, the recognition rate is higher than it was when dimension N = 7, under the condition of the same as receiving clustering sample number M, iterations λ and SNR.
- The recognition rate can reach more than 90% when SNR greater than 4 dB, the recognition rate can reach above 95% when N = 3; and the recognition rate has been very approximation corresponding theoretical value and close to 100% for N = 3, SNR=5dB or for N = 7, SNR=6dB. Visible, the performance is very good to this identification method proposed in this paper.

VI. Conclusion

The method of block orthogonal amplitude modulation was put forward and the recognition method of modulation demodulation was researched in this paper. Based on general orthogonal amplitude modulation, select cluster target sample from the received signal vector sequence and use clustering iterative algorithm to extract the basic vector, can realize modulation recognition of block orthogonal amplitude modulation of high dimensional. The recognition performance of block orthogonal amplitude modulation depend on the numbers of dimension N , the numbers of receiving clustering sample M, iterations λ and input SNR, etc . With the increase of the number of received signal vector, the recognition rate rises greatly, and gradually close to the ideal condition by clustering iteration, the recognition rate can achieve 90% above when SNR is 4 dB and the recognition rate can reach nearly 100% when SNR is 6 dB, at the same time calculation complexity is greatly reduced compared with using all receiving signal vector to recognition.

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