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PN Sequence Parameters in DSSS-QPSK Signals by Using Matrix Eigen Vector Decomposition Algorithm (EVD)

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Abstract: *In this project, to ease the computation burden, a fast blindestimation algorithm for the parameters of PN sequence is proposed. At first, the period of PN sequence was estimated using the method based on Reprocessing power spectrum density (RPSD). Then, the staring bit of the PN codes was decided trough the method of segmentation processing and average cross-correlation calculation. Based on the period and the staring bit of PN codes, the estimation of the PN sequence was realized by the Matrix Eigen decomposition (EVD) method.*

Keywords: *DSSS-QPSK; RPSD; Segmentation processing; Average cross correlation; EVD*.

1. Introduction

There are several estimation algorithms of the parameters for PN sequence.it includes LFSR, subspace-based signature waveform estimation technique, neural networks, and matrix eigen vector decomposition(EVD). when these above algorithms are directly applied the problem of large computational complexity occurs. The method based on EVD is usually used with the starting symbol of the PN codes unknowing, but in this paper,we will make use of it after estimation of the starting symbol, which makes the method easier.

Spread spectrum (SS) signals have been used for secure communications, command, and control for several decades. For certain applications, their antijamming capabilities and low probability of intercept justify the price to be paid in increased bandwidth. In direct-sequence spread- spectrum (DS-SS) systems, the information signal is modulated by a pseudo-noise (PN) sequence prior to transmission resulting in a wideband signal resistant to narrowband jamming or multipath.

In multiuser CDMA systems, the PN spreading sequence is typically known to the receiver, where it is used to perform the matched filtering (or “despreading”) operation and recover the transmitted data. In single-user systems, however,there are cases where the receiver may have no knowledge of the transmitter’s PN sequence (e.g., when intercepting an unfriendly transmission in LPI communications). Then, all the related issues of synchronization, multipath equalization, and data detection become more challenging.

Spread spectrum technology has blossomed from a military technology into one of the fundamental building blocks in current and next-generation wireless systems. From cellular to cordless to wireless LAN (WLAN) systems, spectrum is a vital component in the system design process.

Since spread-spectrum is such an integral ingredient, it's vital for designers to have an understanding of how this technology. In this tutorial, we'll take on that task, addressing the basic operating characteristics of a spread-spectrum system. We'll also examine the key differentiators between frequency-hop (FHSS) and direct-sequence spread spectrum (DSSS) implementations.

2. DSSS SYSTEM

2.1 DSSS System Module

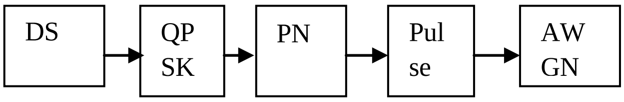


Fig.1 *principle block diagram of DSSS-QPSK system.*

2.2 DSSS-QPSK Signal Module

In the DSSS-QPSK communication system, the complex RF signal module can be expressed as:

$$x(t) = s(t) + n(t) = d(t)c(t)\exp j(2\pi f_0 t + \varphi) + n(t)$$

$$d(t) = \sum_{n=0}^{\infty} d_n p(t - nT_d)$$

Where ,dn represents the symbol value which is modulated with BPSK, dn = an + jbn, and Td is the symbol period;

$$c(t) = \sum_{m=0}^{\infty} c_m p(t - mT_c) \ , \quad c_m \in \{\pm 1\}$$

denotes the PN spreading sequence with length N = Td / Tc , and p (t) denotes a pulse chip with the chip period Tc; fo is the carrier frequency, and φ is the initial phase with a uniform distribution on the interval $(0, 2\pi)$; n(t) represents the additive white Gaussian noise (A WGN) with variance σ^2 and un correlated with the signal.

3. PERIOD ESTIMATION OF PN SEQUENCE

After demodulating, the signal becomes complex base-band one:

$$x(t) = s(t) + n(t) = d(t)c(t) + n(t) \qquad (2)$$

Period estimation of PN sequence is the necessary condition for the estimation of PN sequence. RPSD is used to realize the period estimation. Firstly, we should calculate the power spectrum of x(t) . Then, use the power spectrum of signal as the input, and calculate the power spectrum of the input. The operation result can be expressed as:

$$\hat{S}(e) = \left| \left[\mathrm{FT} \left| S_x(f) \right| \right] \right|^2 \qquad (3)$$

where, FT[.] is Fourier transform, and $S_x(f)$ represents the power spectral density of the signal. For the received signal x(t) given in equation (2), we can deduce the autocorrelation fnction of x(t) as:

$$\begin{aligned} r_x(t+\tau,t) &= \mathrm{E}\{x(t+\tau)x^*(t)\} \\ &= r_s(t+\tau,t) + r_n(t+\tau,t) + r_{sn}(t+\tau,t) + r_{ns}(t+\tau) \end{aligned} \qquad (4)$$

Where τ is the dither

The last two terms of (4) are approximately zero because of the independency of signal and noise. The source bits are independent with the pseudo noise sequence, so we have:

$$\begin{aligned} r_x(t+\tau,t) &= r_s(t+\tau,t) + r_n(t+\tau,t) \\ &= r_d(t+\tau,t) r_c(t+\tau,t) + r_n(t+\tau,t) \end{aligned} \qquad (5)$$

The source data can be modeled as a binary random sequence and the corresponding autocorrelation function is:

$$r_d(t+\tau,t)=r_d(\tau)=\begin{cases}1-|\tau|/T_d, & 0\le|\tau|\le T_d\\ 0, & |\tau|>T_d\end{cases} \qquad (6)$$

The autocorelationfnction of the PN sequence can be written as:

$$r_c(t+\tau,t)=\begin{cases}1-(N+1)|\tau-kT_c|/T_c, & |\tau-kT_c|\le T_c\\ -1/N, & |\tau-kT_c|>T_c\end{cases} \qquad (7)$$

The spectrum of (6) and (7) can be expressed respectively as:

$$S_d(f)=T_d\left(\frac{\sin\pi fT_d}{\pi fT_d}\right)^2 \qquad (8)$$

$$S_c(f)=\frac{N+1}{N^2}\left(\frac{\sin\pi fT_c}{\pi fT_c}\right)^2\sum_{m=-\infty}^{\infty}\delta\left(f-\frac{m}{NT_c}\right)-\frac{1}{N}\delta(f) \qquad (9)$$

By using the convolution property of Fourier Transform, we can get the power spectrum of s(t), and it is expressed as:

$$\begin{aligned}S_s(f)&=S_d(f)\otimes S_p(f)=T_d\left(\frac{\sin\pi fT_d}{\pi fT_d}\right)^2\otimes\\ &\left\{\frac{N+1}{N^2}\left(\frac{\sin\pi fT_c}{\pi fT_c}\right)^2\sum_{m=-\infty}^{\infty}\delta\left(f-\frac{m}{NT_c}\right)-\frac{1}{N}\delta(f)\right\}\end{aligned} \qquad (10)$$

By the reprocessing of $S_s(f)$, we get the secondary spectum of DSSS-BPSK signal:

$$\begin{aligned}S_s(e)&=\left|DFT\{S_s(f)\}\right|^2\\ &=\left|DFT\left\{\frac{1}{N}\sum_{m=-\infty,m\ne0}^{\infty}Sa^2(\pi m/N)\delta\left(f-\frac{m}{NT_c}\right)\right\}\right|^2\\ &\cong\left|T_c\sum_{k=-\infty}^{\infty}\left(1-\frac{|e-kNT_c|}{T_c}\right)\right|^2,\quad |e-kNT_c|\le T_c, k=0,\pm1,\cdots\end{aligned} \qquad (11)$$

According to (11), the energy of the signal gathers in some more acute Triangle pulse sequence after the reprocessing of power spectrum, and the interval is integer times of PN chip period Tc, but the A WGN n(t) has no the characteristics. $S_s(e)$ loses the phase information after the processing, which is we need. And e in (11) has the dimension of time actually. Thus we can measure the PN period by examining the distance of pulse sequence when these reprocessing power spectrum frequencies are not zeros.

Determination of Starting Symbol

Assuming that synchronous start bit is Tx the received base-band signal with noises can be written as

$$s=\{d(1)c(T_x)+n(T_x)\}\oplus\cdots\oplus\{d(N)c(T_d)+n(T_d)\} \qquad (12)$$

Where d(1),d(2)….d(N) are information symbols, N is the number of the information symbols, c(.) is a full PN sequence, n(.) represents the Gauss white noise with zero mean.

Assuming the period of PN chip Tc is known, we can divide the received signal into segments with length of each segment L = Td /Tc. If noise is free, when subsection start point is the same as that of the data modulation, each segment is a fll PN sequence, and the segments are the same or inverse for each other, there is maximal cross-correlation between these segments. AWGN is independent with each other and its correlation value is very small. So it can't affect the estimation result. We can calculate the maximum cross-correlation value under the condition of different segmentation to estimate the start point of the modulation sequence.

Supposing the sample rate is 1, the length of data is L = Tx + (N -I)Tc so the number of segments is m = N -I. When the starting time is the k-th sample sequence, the segments can be expressed by: point in PN sequence ,the segments can be expressed by:

$$\vec{D} = \left(\vec{D}_1, \vec{D}_2, \cdots, \vec{D}_m\right)^T = \begin{pmatrix} d_{11} & \cdots & d_{1T_c} \\ \vdots & \ddots & \vdots \\ d_{m1} & \cdots & d_{mT_c} \end{pmatrix} \tag{12}$$

where, the elements of each row represent the vectors with the number of Tc in a segment, the number of rows m means dividing m segments. We can obtain the auto-correlation matrix:

$$\vec{R}_k = \mathrm{E}\left\{\vec{D}_i \vec{D}_j\right\} = \begin{pmatrix} r_{11} & \cdots & r_{1m} \\ \cdots & \cdots & \cdots \\ r_{m1} & \cdots & r_{mm} \end{pmatrix} \tag{13}$$

where, r_{ij} is the cross-correlation between the i-th segment and the j-thsegment.Calculate the sum nk of the absolute value of all elements in matrix $\vec{R}_k$.Change the value k fom 1 to Tc, fnd the k corresponding to the maximum value nk .Then k can be considered as the synchronous starting minute Tx.

Estimation of PN Sequence

We use the method of Eigen Vector decomposition to estimate the PN Sequence.

Eigen Vectors:

Eigenvectors and eigenvalues are numbers and vectors associated to square matrices, and together they provide the eigen-decomposition of amatrix which analyzes the structure of this matrix. Even though the eigen-decomposition does not exist for all square matrices, it has a particularly simple expression for a class of matrices often used in multivariate analysis such as correlation, covariance, or cross-product matrices. The eigen-decomposition of this type ofmatrices is important in statistics because it is used to find the maximum (or minimum) of functions involving these matrices. For example, principal component analysis is obtained from the eigen-decomposition of a covariance matrix and gives the least square estimate of the original data matrix.

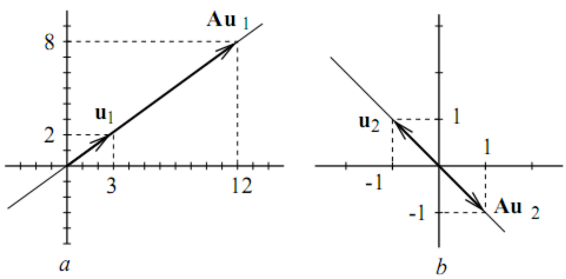


Fig 5. *Two Eigen vectors of a matrix*

We can divide the received signal into segments with each segment including L = Td /Tc points fom the starting symbol Tx and every segment becomes an eigen decomposition vector. Those vectors can compose matrix:

$$X = \left[x(1) \quad x(2) \quad \cdots \quad x(N)\right] \tag{14}$$

where, $\{x(k)\}_{k=1,2\cdots N}$ is the data vector, and the dimension is L, L = Td / Tc, which is the point number of every PN period, and N is the number of the segments. We can get the auto-correlation matrix is $R = \mathrm{E}\{xx^{\mathrm{H}}\}$

Actually, we cannot get the precise values of the auto-correlation matrix when the data is limited, and the approximate expression is:

$$\hat{R} = \frac{1}{N}\sum_{k=1}^{N} x_k x_k^H = \mathrm{E}\{XX^H\} \tag{15}$$

$\hat{R}$ is more approaching the ideal auto-correlation matrix when N is larger. The eigen decomposition result of $\hat{R}$ is:

$$\hat{R} = \bar{U}_s \Lambda_s \bar{U}_s^H + \bar{U}_n \Lambda_n \bar{U}_n^H = \sigma_n^2 \rho \frac{T_s}{T_c} \overline{w}\overline{w}^H + \sigma_n^2 I \tag{16}$$

Where $\Lambda_s = \lambda_1$, $\Lambda_n = diag\left(\sigma_n^2 \quad \sigma_n^2 \quad \cdots \quad \sigma_n^2\right)$, ıe dimension of Λ_n is L-1. The row of Us and Un are made of eigen vectors whose maximum eigenvalue are $\hat{\lambda}_1$ and σ_n^2 correspondingly. I is the identity matrix of Lx L, and $\lambda_1 > \sigma_n^2$.

The maximum eigen vector of $\hat{R}$ includes the full information of a set of PN sequence, so we can restore the PN sequence according to main eigen vector $\vec{v}$:

$$\hat{c} = \pm\,\mathrm{sgn}\left(\vec{v}\right) \tag{17}$$

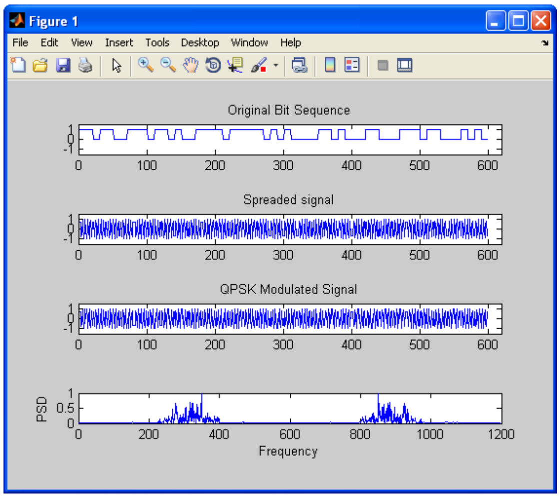
Where sgn(.) is sign function.

Simulation Analysis

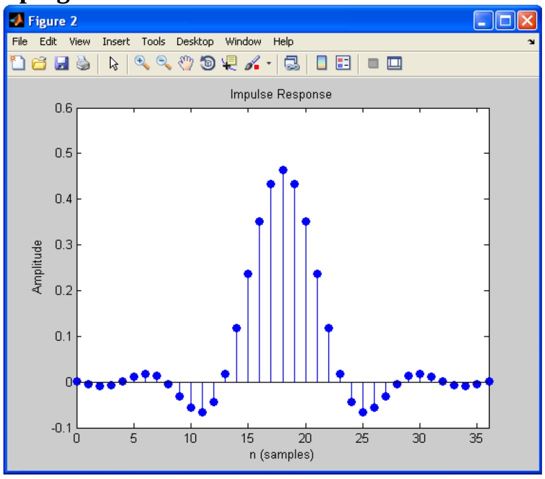
Initialize parameters and estimate PN Sequence.N=60 (Total PN Seq length), Td =100 (Symbol rate),Tc = 10 (Chip rate)Perform QPSK Modulation technique.Pass the modulated signal through a raised cosine or rectangular pulse shaping filter to reduce ISI.

The signal used in the simulation meets the following conditions: the sampling frequency is 100.8 MHz; the information symbols rate is 100k bits/s; the PN codes rate is 6.3 M bits/s; the frequency offset is 1 kHz; the phase offset is $\pi/3$; the timimg error is 0.7 (symbol period); SNR ϵ [-15,0] dB; the whole process is under the AWGN channel.

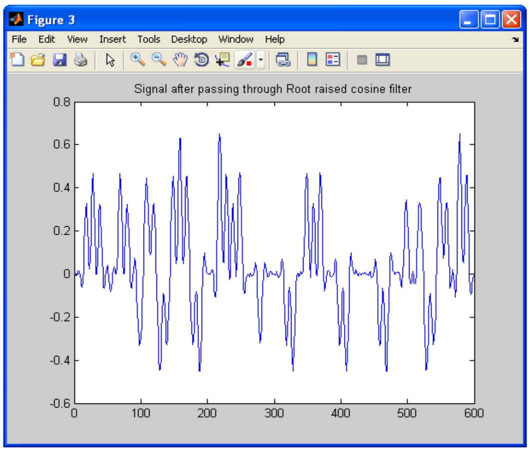
QPSK Modulation Signal with Power Spectrum:



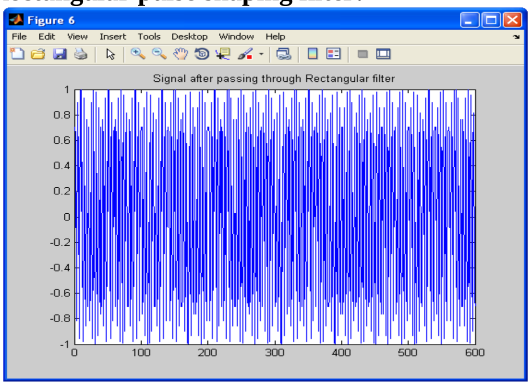
Impulse Response of Pulse Shaping Filter:



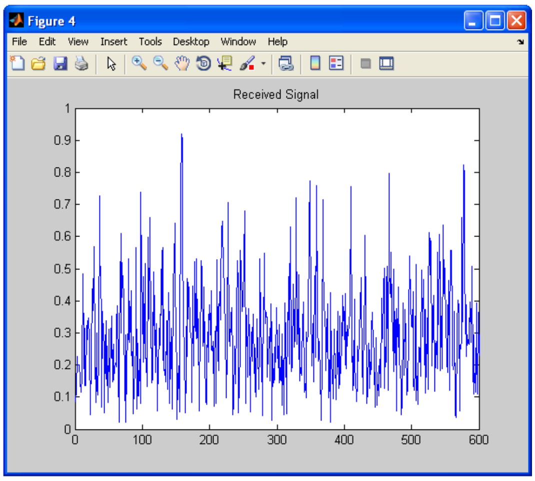
Signal after Passing through Root Raised Cosine Filter:



Signal after passing through Rectangular pulse shaping filter:

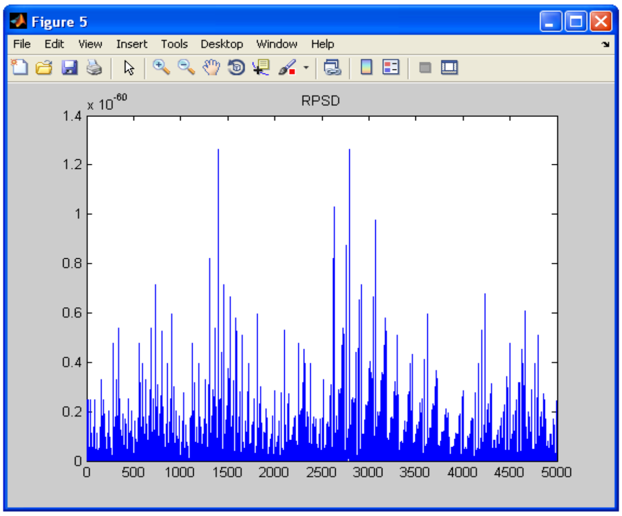


Received Signal:



Simulation of Period Estimation:

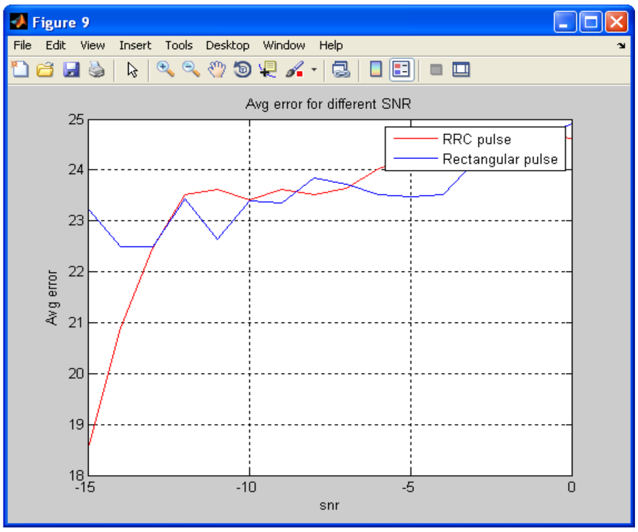
Calculate power spectrum of source signal and also PN Sequence.Total power spectrum is obtained by convolving the obtained above two spectrumsSecondary spectrum is calculated by taking fast fourier transform (fft) of the total spectrum signal.



Simulation of Estimation of Starting Minute:

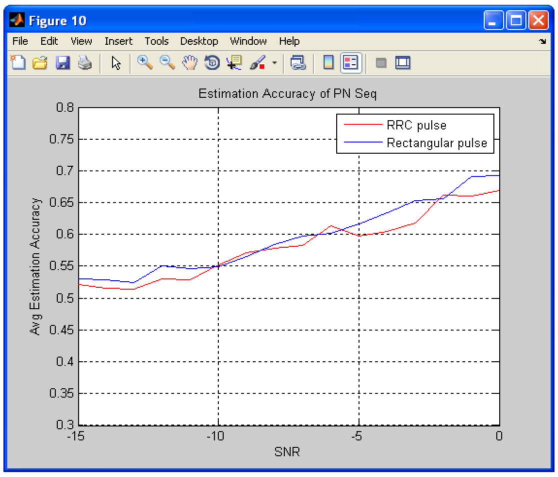
Assuming starting position of PN Sequence to be 120.New length of data is calculated and no of segments is estimated.The data is divided into segments of length Tc and arranged in a matrix.Cross correlation is estimated between different segments.

Absolute sum of all the cross correlation elements is calculated to estimate the starting symbol. Averageerror is calculated by taking the mean of all the starting symbols for different values of SNR



Simulation of Estimation of PN Sequence

The received signal is first divided into segments from the starting point.The segments are each classified to be a eigen matrix Transpose is performed to get the Eigen vectors Auto correlation matrix is then obtained from these eigenvectors.Eigen vector decomposition / Singular value decomposition is done on the autocorrelation matrix.Principal Eigen vector is found by taking the max.From the principal eigen vector the corresponding received data is extracted.The received data is then decoded to get the PN Sequence.This sequence is compared with the original PN Sequence to estimate the average precision error.



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