Detection of WCDMA uplink signal with combination between sliding match and power spectrum

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Abstract

Aiming at problem of WCDMA uplink signal being difficult to be detected under low SNR, this paper proposes a type of algorithm in which sliding match combines with power spectrum to detect WCDMA signal. Firstly, this algorithm estimates desynchronizing point of signal using Frobenius norm. According to desynchronizing point, a whole cycle of information sequence is intercepted. Correlation of OVSF code sequence is utilized in which residual carrier or DC component of signal would come into being while the received OVSF code sequence completely matches with local OVSF code sequence. Then its power spectrum is calculated and sharp spectral peak would appear in the frequency position of power spectrum. Through detecting amplitude and position of spectral peak, frequencies of OVSF code sequence and residual carrier utilized in WCDMA signal could be accurately estimated. Simulation results show that this algorithm rapidly realizes the estimation on OVSF code sequence and desynchronizing point keeps good detection effect and may effectively overcome the influences of residual frequency offset on it.

Keywords: WCDMA signal, OVSF code sequence, Frobenius norm, sliding match, power spectrum

1 Introduction

In WCDMA [1] System, OVSF code is applied to do spread spectrum on data which belongs to one type of pseudo code sequences. Therefore, detection and estimation of OVSF code sequence are studied according to properties of pseudo code. In spread spectrum communication system, many estimation methods have been proposed at home and abroad nowadays in allusion to do detection and estimation on pseudo code under low SNR including energy detection [2], frequency doubler [3], cyclic spectrum [4], fourth-order cumulant [5], delay multiplication [6], etc. Literature [7] raises a type of method to do tracking on binary carrier modulation signal with residual frequency offset. Literature [8] puts forward a kind of stable symbol period of spread spectrum signal and an algorithm of desynchronizing point blind estimation. However, all of the above-mentioned blind estimation literatures of spread spectrum sequence on record are aimed at general DS system. In terms of blind estimation of WCDMA signal, Literature [9] comes up with signal model of WCDMA physical layer. Literature [10] does channel estimation under the circumstance of OVSF code sequence being known. Literature [11] proposes a WCDMA power control algorithm of low complexity. If estimation and blind estimation could be done on subtle features of WCDMA signal with residual frequency offset under low SNR, this type of weak signal would present great significance on administration and reconnaissance in aspects of civil use, military, software radio, intelligence communication, etc.

Aiming at characteristics like favourable autocorrelation of spreading code OVSF code sequence used by WCDMA signal, this paper utilizes a method in which sliding match combines with power spectrum. This method firstly takes advantage of Frobenius norm to estimate desynchronizing point of the received signal thus intercepting a whole cycle of data after orderly moving it in length of desynchronizing point and then leads it to do sliding match and FFT operation with local OVSF code sequence. When they are completely matched, sharp power spectral peak and sine and cosine signal reflecting residual frequency offset would appear thus rapidly catching and estimating OVSF code sequence. Meanwhile estimated value of residual frequency offset could be acquired, which provides solid foundation for subsequent dispreading processing.

2 Signal Model of WCDMA Uplink

In WCDMA, dedicated physical channels for uplink include DPDCH (Dedicated Physical Data Channel) and DPCCH (Dedicated Physical Control Channel) in which DPDCH is used to support data and DPCCH is used to bear control information. In WCDMA channel, transmission of data takes slot as cell in which Tslot is 0.625ms and each 15 slots form one frame. Each slot of DPCCH is 10 bit. Bit number of each slot of DPDCH has relationship with SF (spreading factor). Expression of sending and receiving model of WCDMA signal is:

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$$y(t)=A\left[d_I(t)c_I(t)s_I(t)-d_Q(t)c_Q(t)s_Q(t)\right]$$
$$h(t)\cos(\omega t)+j*A\left[d_I(t)c_I(t)s_Q(t)+\right. . \quad (1)$$
$$\left.d_Q(t)c_Q(t)s_I(t)\right]h(t)\sin(\omega t)$$

Here A is amplitude of signal. $d_I(t)$ and $d_Q(t)$ are respective input signals of DPDCH and DPCCH. $c_I(t)$ and $c_Q(t)$ are their corresponding OVSF codes. Channelization codes used in each channel differ from each other and are orthogonal independent. $s_I(t)$ and $s_Q(t)$ are respectively real part and imaginary part of complex-scrambled code which are orthogonal independent.

$h(t)=\dfrac{\sin\left[\pi(1-\alpha)t/T\right]+(4\alpha t/T)\cos\left[\pi(1+\alpha)t/T\right]}{(\pi t/T)\left[1-(4\alpha t/T)^2\right]}$ is root-raised cosine filter whose roll-off factor is $\alpha=0.22$; $\sin(\omega t)$ and $\cos(\omega t)$ are modulated carriers; $n(t)$ is white Guassian noise whose mean value is zero and variance is σ_n^2. The above-mentioned OVSF code sequence is used to keep orthogonality among different physical channels of user thus assuring that different operations could be better transmitted.

3 Detection and Estimation of OVSF Code Sequence of WCDMA Signal

3.1 DESYNCHRONIZING POINT ESTIMATION OF OVSF CODE SEQUENCE

Utilize Frobenius norm to do blind estimation on desynchronizing point in which desynchronizing point receiving signal is effectively estimated which provides good security for subsequent detection and estimation of OVSF code. Relevant matrix of real data $r_I(n)=d_I(n)+n_0(n)$ receiving WCDMA signal is:

$$R_{r_I}(\tau)=E\left\{r_I(n)r_I(n+\tau)^H\right\}=\sigma_I^2\sum_{k=1}^{K}\left[d_{Ik}(\tau_k)d_{Ik}{}^H(\tau_k)\right]+\sigma_v^2 I . \quad (2)$$

Among them σ_I^2 is variance of information code, σ_v^2 is variance of noise and H stands for conjugate transpose.

Do eigenvalue decomposition on Formula (2) above and acquire that:

$$R_x(\tau)=\frac{\sigma_b^2 N_c}{T_s}\sum_{k=1}^{K}\left[(T_s-\tau_k)u_k^r u_k^{rH}+\tau_k u_k^l u_k^{lH}\right]+\sigma_v^2 I . \quad (3)$$

In the formula $U=\left[u_1^r u_1^l \ldots u_k^r u_k^l\right]$ is normalized unit matrix. Then eigenvalue of $R_x(\tau)$ is:

$$\begin{cases}\lambda_{2i-1}=\sigma_b^2 N_c/T_s\left(T_s-\tau_i\right)+\sigma_v^2\\ \lambda_{2i}=\sigma_b^2 N_c/T_s\tau_i+\sigma_v^2\end{cases} . \quad (4)$$

Here comes $i=1,2,\cdots,K$. When $i>2K$, $\lambda_i=\sigma_v^2$. Therefore, desynchronizing point $\hat{\tau}_k$ could be estimated based on relatively larger eigenvalue of relevant matrix receiving signal.

Frobenius norm square of relevant matrix actually corresponds to the sum of square of function eigenvalue namely:

$$\left\|R_x(\tau)\right\|_F^2=\sum_{i=1}^{N_c}\lambda_i^2(\tau). \quad (5)$$

$\{\lambda_i, i\geq 3\}$ does not depends on desynchronizing point. It is obvious that $\left\|R_x(\tau)\right\|^2$ reaches the maximum when $(\lambda_{2i-1})^2+(\lambda_{2i})^2$ acquires its maximum value. It is obtained through Formula (4) that:

$$\lambda_{2i-1}+\lambda_{2i}=c . \quad (6)$$

Here c is a constant, which does not depends on desynchronizing point. Therefore:

$$\begin{aligned}(\lambda_{2i-1})^2+(\lambda_{2i})^2&=2(\lambda_{2i-1})^2-2c\lambda_{2i-1}+c^2\\&=(4\lambda_{2i-1}-2c)^2+c^2/2\end{aligned} . \quad (7)$$

Suppose that eigenvalues sort according to descending order. As $\lambda_{2i-1}\geq c/2$, the formula above is always positive value (otherwise $\lambda_{2i}>\lambda_{2i-1}$ in Formula (6)). Therefore, $\left\|R_x(\tau)\right\|_F^2$ is increasing function of λ_{2i-1} meaning that maximizing λ_{2i-1} is just maximizing $\left\|R_x(\tau)\right\|_F^2$.

It is known from the definition of Frobenius norm that Frobenius norm of one matrix is equal to arithmetic square root of quadratic sum of all elements in this matrix. Therefore, it is much easier to calculate $\left\|R_x(\tau)\right\|_F^2$ than calculating eigenvalue. Desynchronizing point is estimated to be:

$$\hat{\tau}_k=\arg\max_{\tau}\left(\left\|R_x(\tau)\right\|_F^2\right). \quad (8)$$

3.2 DETECTION AND ESTIMATION OF OVSF CODE SEQUENCE

In WCDMA system, the received baseband signal would keep certain residual frequency offset because of the frequency deviation and Doppler shift among transceivers. On the receiving end, do down-conversion simulation on the received WCDMA signal and then analog-to-digital conversion in which sample rate equals to chip rate namely $f_s = 1/T_c$. Here T_c is the duration of each chip. The received WCDMA signal changes to number with residual frequency offset. Complex sinusoidal signal is presented as:

$$r(i) = A\left(d_I(i) + j*d_Q(i)\right)\exp\left[j\left(2\pi\triangle f\, iT_c + \varphi\right)\right] + n_0(i). \tag{9}$$

Here A stands for amplitude attenuation value of signal. $d_I(i)$ and $d_Q(i)$ are discrete amplitude values of real part and imaginary part of the received WCDMA signal. $\triangle f$ is the size of residual frequency offset. φ is the initial phase. $n_0(i)$ is white Guassian noise whose average value is zero and variance is σ_0^2.

Move the received signal $r(i)$ backward $\hat{\tau}_k$ in order according to the estimated size of desynchronizing point and intercept a whole cycle of WCDMA signal data to be:

$$\begin{aligned} & r_s(k) = A\left(d_I(k) + j*d_Q(k)\right) \\ & \exp\left[j\left(2\pi\triangle f\, kT_c + \varphi\right)\right] + n_0(k)\left(1 \le k \le R\right) \end{aligned}. \tag{10}$$

Here R is the size of OVSF code sequence cycle. When cycle of OVSF code is known, utilize correlator to do correlation operation on $r_s(k)$ and local OVSF code sequence $s'(i+i')$ among which:

$$s'(i) = \sum_{i=1}^{R*R}\left(d_s(i) + j*d_s(i)\right). \tag{11}$$

Both lengths of correlator and the intercepted WCDMA data are R. i' is duration between local OVSF sequence and the intercepted data in the received signal. In order to simplify the analysis, make it to be $A=1$, in which useful signal part is $s_l(k)$ and noise part may be presented as $n_s(k)$ in $x_l(k)$ if output of the l th sliding match is $x_l(k)$.

$$\begin{aligned} x_l(k) &= r_s(k)s'(l*R)^* \\ &= \left(d_I(k) + j*d_Q(k)\right)\exp\left[j\left(2\pi\triangle fkT_c + \varphi\right)\right] \\ &\left(d_{si}(l*R) - j*d_{sq}(l*R)\right) + \\ &n_0(k)\left(d_{si}(l*R) + j*d_{sq}(l*R)\right) \\ &= R_l(k)\exp\left[j\left(2\pi\triangle fk + \varphi\right)\right] + n_l(k) \end{aligned}. \tag{12}$$

Among those $s'(l*R)^*$ stands for conjugation of local OVSF code sequence $s'(l*R)$ and $R_l(i)$ stands for correlation value of the intercepted data after correlation operation. Make that:

$$s_l(k) = R_l(k)\exp\left[j\left(2\pi\triangle fk + \varphi\right)\right], \tag{13}$$

$$n_l(k) = n_0(k)\left(d_{si}(l*R) - j*d_{sq}(l*R)\right). \tag{14}$$

Among them:

$$\begin{aligned} R_l(k) &= \left(d_I(k) + j*d_Q(k)\right)\left(d_{si}(l*R) - j*d_{sq}(l*R)\right) \\ &= d_I(k)*d_s(l*R) + j*\left(d_I(k)*d_{sq}(l*R)\right. \\ &\left.-d_Q(k)*d_{si}(l*R)\right) + d_Q(k)*d_{sq}(l*R) \end{aligned}. \tag{15}$$

As OVSF code sequence keeps orthogonality, then:

$$\frac{1}{R}\sum_{k=1}^{R} d_i(k)*d_j(k) = \begin{cases} 1 & \text{i=j} \\ 0 & \text{i} \ne \text{j} \end{cases}. \tag{16}$$

So when the intercepted data and local OVSF code sequence just match well, $R_l(k) = d_I^2(k) + d_Q^2(k)$. Then comes:

$$\begin{aligned} & x_l(k) \\ & = \left(d_I^2(k) + d_Q^2(k)\right)*\exp\left[j\left(2\pi\triangle fk + \varphi\right)\right] + n_l(k) \end{aligned}. \tag{17}$$

It is seen from Formula (17) that only complex signal with residual frequency offset remains in this formula when they match well.

If the way of vector is utilized, output signal calculated through correlation operation could be expressed as:

$$\mathbf{x}_l = \mathbf{s}_l + \mathbf{n}_l. \tag{18}$$

As noise in the received signal conforms to Gaussian distribution whose mean value is zero and variance is σ_0^2, it is known from central-limit theorem that output noises passing correlator also keep Gaussian distribution which are unrelated if length of correlator is large enough. There exists complex sinusoidal random signal of ω_D ($\omega_D = 2\pi\triangle f$) in data vector $\mathbf{x}_l$ whose probability density function can be presented as:

$$\begin{aligned} & p(\mathbf{x}_l - \mathbf{s}_l) \\ & = \frac{1}{\left(\pi l\sigma^2\right)^l}\exp\left[-\frac{1}{l\sigma^2}\left(\mathbf{x}_l - \mathbf{s}_l\right)^H\left(\mathbf{x}_l - \mathbf{s}_l\right)\right] \end{aligned}. \tag{19}$$

In the formula H stands for conjugate dispose, Directly does Fourier transform on observation data $\mathbf{x}_l$ and act square of Fourier transform output value as estimated value $\hat{S}(\omega)=\frac{1}{l}\left|\sum_{n=0}^{l-1}\mathbf{s}_l(i)\exp(-j\omega_D i)\right|^2$ of power spectrum density. In terms of complex sinusoidal signal $\mathbf{s}_l(i)$ with complex white Guassian noise, its maximum likelihood solution $\hat{\omega}_D$ is the corresponding frequency to the maximum value of power spectrum. When the intercepted data in WCDMA signal and local OVSF code sequence just align, maximum value of output amplitude would appear on frequency point $\hat{\omega}_D$ after FFT. Therefore, estimated value $\triangle\hat{f}$ of residual frequency offset would be acquired while intercepting OVSF sequence through Formula $\omega_D = 2\pi l \triangle f T_c$ and according to the maximum value of power spectrum peak.

3.3 ANALYSIA ON COMPUTATIONAL COMPLEXITY

Aiming at the proposed algorithm of OVSF code blind estimation in this paper, multiplication serves as the index to measure complexity. Suppose that length of the received signal is M. Desynchronizing point estimation through F- norm needs 2M times of multiplication. Sliding match and power spectrum calculation mainly include corresponding bit multiplication and FFT transform in which corresponding bit multiplication needs M times of multiplication, FFT transform needs R*Mlb(100M) times of multiplication and module-square on its result needs 2M times of multiplication whose total number is 5M+R*Mlb(100M).

4 Algorithm Flow

Figure 1 shows the structure diagram realizing the above-mentioned algorithm:

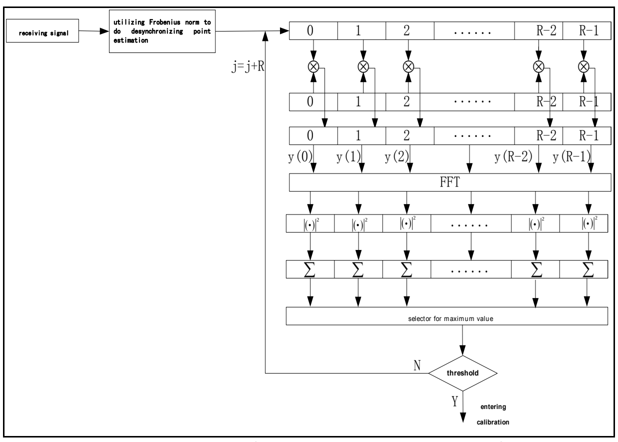


FIGURE 1 Block Diagram of Detection and Estimation of OVSF Code Sequence

This algorithm could be summarized as follows:

(1) After doing down-conversion simulation on the received WCDMA signal, do sampling on it in the rate of chip in which data of real part is chosen to do desynchronizing point estimation utilizing Frobenius norm.

(2) Orderly move the received WCDMA data backward desynchronizing-point data and intercept part of data in the length of a whole cycle of OVSF code sequence.

(3) Do sliding match calculation on the intercepted data and local OVSF code sequence. Each time choose R point from local OVSF code sequence to do its multiplication with the intercepted data.

(4) Do R point FFT calculation on the result of correlation operation, choose square of its module and orderly move local OVSF code sequence backward R chips namely $j = j + R$.

(5) Compare the maximum value with threshold value, which are chosen by maximum selector. If it surpasses the presupposed threshold value, the intercepted OVSF code sequence successfully match with local OVSF code sequence. Detect OVSF code sequence of WCDMA signal. Through detecting the position of maximum peak, OVSF code sequence used at transmitting end would be estimated.

5 Simulation Results

Experiment one: Utilize algorithm in this paper to do simulation experiment on OVSF code sequence of WCDMA signal in which SNR is -5dB, length of OVSF code SF is 256 and chip rate is 3.84Mchips/s. Apply RRC filter whose roll-off factor is $\alpha = 0.22$. Delay point of receiving signal is 66 in which eight times of sampling is done on the received signal and F- norm is used to do desynchronizing point estimation on it as shown in the following Figure 2:

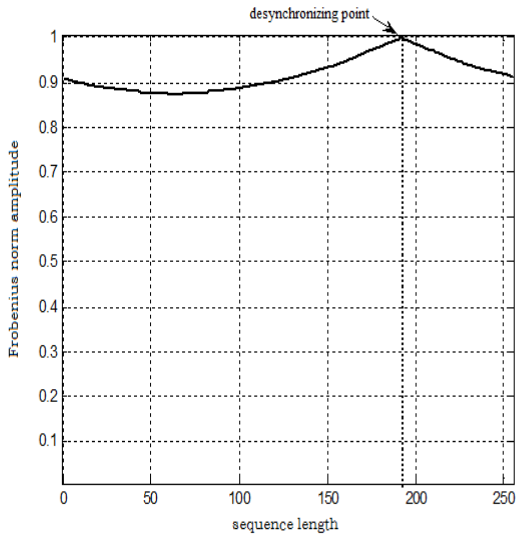


FIGURE 2 Blind Estimation of Desynchronizing Point

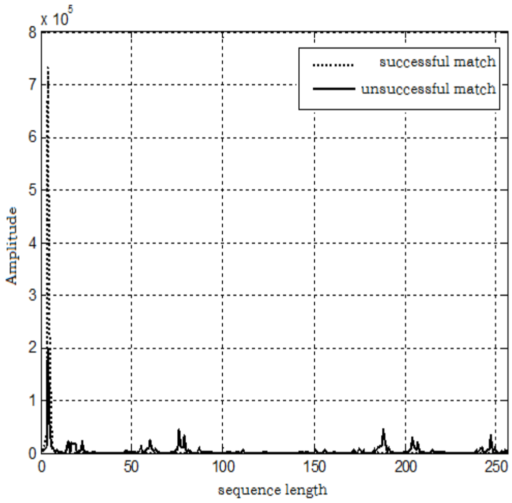
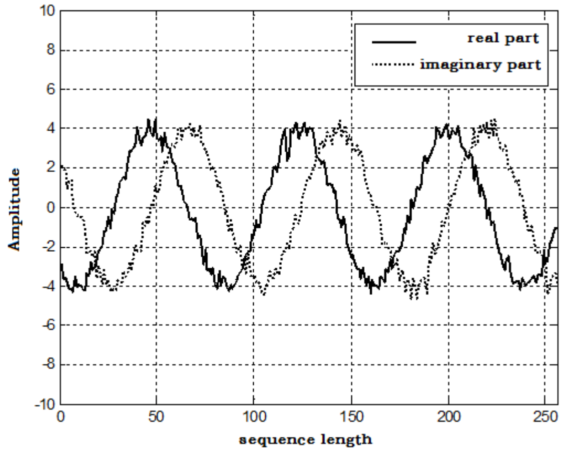


FIGURE 3 Power Spectrums of Different Matching Stages

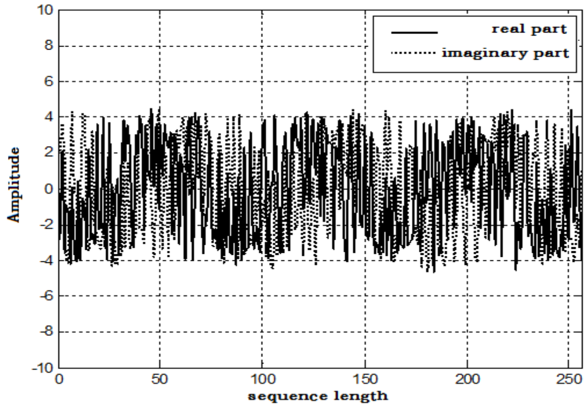
Figure 2 is the simulation diagram in which desynchronizing point is estimated on the basis of Frobenius norm. It is seen from Figure 2 that F- norm amplitude reaches the maximum in the position of desynchronizing point. Through the position of maximum amplitude value, number of desynchronizing point of WCDMA signal could be estimated to be 192, which is 256-66+2 thus being well prepared for subsequent detection and estimation of OVSF code.

Figure 3 is power spectrum diagram to determine whether matching is successful when length of OVSF code is 256. It is seen from Fig.3 that sharp power spectral peak would appear in power spectrum when correlation matching is successful between the intercepted WCDMA signal and local OVSF code sequence. While during sliding match processes of other positions meaning that matching is unsuccessful, power spectral peak is relatively lower. OVSF code sequence utilized at transmitting end would be estimated through detecting the position of sharp power spectral peak.

Figure 4 are simulation diagrams of relevant waveforms of successful matching and unsuccessful matching. Because of influences of residual frequency offset, related complex sine and cosine signal would be acquired as presented in Figure 4(a) at the time intercepted WCDMA data and local OVSF code sequence successfully match. However, related complex sine and cosine signal would not be acquired as seen in Figure 4(b) if they do not match well. Therefore according to whether phenomenon of relevant waveforms comes into being, it would be determined that whether intercepted WCDMA data successfully matches with local OVSF code sequence. Also size of relevant residual frequency offset value $\triangle \hat{f}$ could be estimated.



(a) Relevant Waveforms of Successful Matching



(b) Relevant Waveforms of Unsuccessful Matching

FIGURE 4 Relevant Waveforms of Each Matching Stage

Experiment two: The following one is performance curve simulation experiment of detection and estimation on OVSF code.

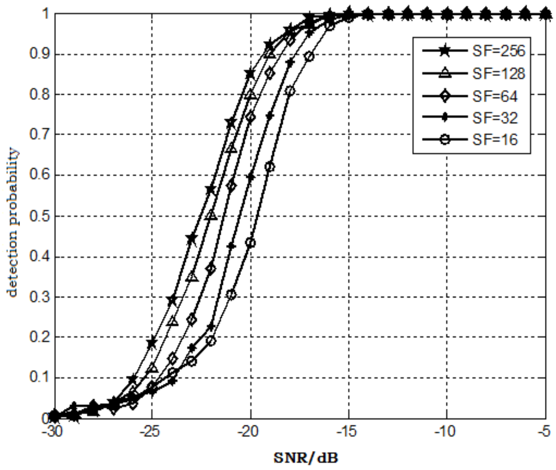


FIGURE 5 Influences of OVSF Code Sequences with Different Lengths on Desynchronizing Point Estimation

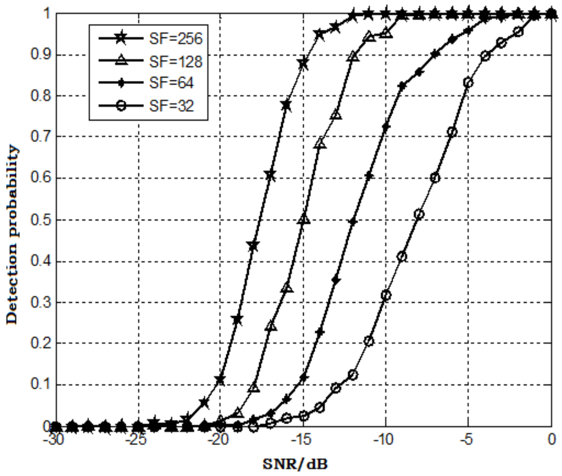


Figure 6 Influences of Different Lengths of OVSF Code Sequences on Detection Performances

Figure 5 shows performance curves of desynchronizing point estimation of different lengths of OVSF code sequences under different types of SNR. It is seen from Figure 5 that probability of detection on desynchronizing point increases with the enlarging of OVSF code length under the same SNR, in which detection probability would present corresponding improvement with increasing of SNR under any type of OVSF code length.

Figure 6 presents simulation curves of performance detection on OVSF code sequences of different lengths under different types of SNR. It is expressed in Fig.6 that capability of detection on different lengths of OVSF code sequences increases with the improving of SNR. Meanwhile probability of detection on OVSF code sequence also enlarges with the elongation of OVSF code under the same SNR.

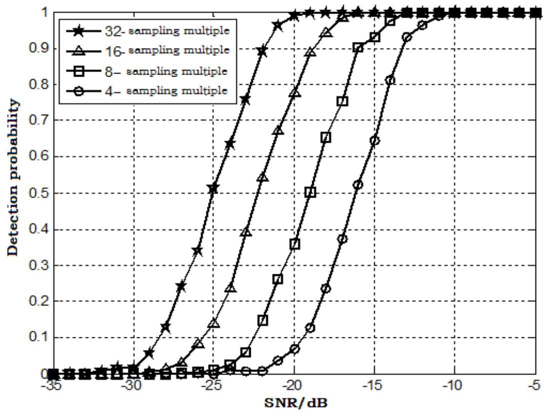


FIGURE 7 Influences of Different Sampling Numbers on Detection Performances

Figure 7 shows the influences on detection probability of OVSF code sequence under the condition of OVSF code length being 128 and under different sampling multiples of 4, 8, 16 and 32. It is known from Figure 7 that detection probability gradually raises with the increasing of sampling multiple under the same SNR. Under the same detection probability, SNR reduces about 3dB when sampling multiple changes from 8 to 16.

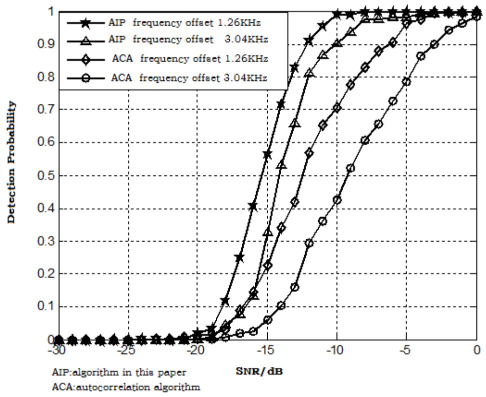


FIGURE 8 Influences of Residual Frequency Offset on Detection Performances

Figure 8 shows the influences of residual frequency offset on detection probability under different types of SNR. It is known from Figure 8 that related loss of matching operation increases and detection probability gradually decreases with the enlargement of residual frequency offset. Under the same type of condition, compare the methods of autocorrelation algorithm to detect OVSF code sequence. Frequency offset keeps relatively higher influences on performance detection utilizing autocorrelation algorithm. In addition it is presented in the figure that algorithm in this paper is better in performance detection than autocorrelation algorithm.

6 Conclusions

Under low SNR, what should be firstly determined are blind synchronization and spreading code of receiving signal namely blind estimation of OVSF code sequence so that detection on WCDMA signal would be realized. Through analysing relevant matrix structure of F- norm and OVSF code sequence in WCDMA signal, this paper firstly acquires desynchronizing point of WCDMA signal according to F- norm estimation and secondly does sliding match and power spectrum calculation. As OVSF code sequence keeps good orthogonal independence, sharp power spectrum peak would be acquired when the intercepted data matches well with local OVSF code sequence. Through size of spectral peak and position of it, OVSF code sequence used at transmitting end could be detected and estimated thus realizing estimation on different operations in WCDMA uplink signal. Simulation results present that this algorithm keeps favourable detection and estimation effects, which could be better when OVSF code sequence is longer.

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