Performance Analysis of Detection Threshold on OFDM Time Synchronization Using PN Sequences[1]

Yuan Tian
National Key Lab of Communication, UEST of China, Chengdu 610054, China.
tianyuan@uestc.edu.cn

Xia Lei
National Key Lab of Communication, UEST of China, Chengdu 610054, China.
leixia@uestc.edu.cn

Wanbin Tang
National Key Lab of Communication, UEST of China, Chengdu 610054, China.
wbtang@uestc.edu.cn

Shaoqian Li
National Key Lab of Communication, UEST of China, Chengdu 610054, China.
lsq@uestc.edu.cn

Abstract

Many synchronization algorithms for orthogonal frequency division multiplexing (OFDM) systems have been proposed. Among them, the time synchronization algorithm by correlating the training sequence with the local known sequence can obtain good performance with a sharp synchronization peak. Detection threshold is an important and necessary parameter in time synchronization. In this paper, based on this algorithm, we evaluate three different methods of setting threshold and point out one method which performs well when SNR is in large dynamic range. The simulation results are consonant with our theoretic analyses and show that this method is suitable for OFDM systems in multi-path fading channel.

1. Introduction

Among modern communication techniques, orthogonal frequency division multiplexing (OFDM) has become one of the candidate techniques for future mobile communication due to its high data rate transmission capability and its robustness to multi-path delay spread[1][2]. However, OFDM systems are much more sensitive to synchronization errors than single carrier systems[3]. Synchronization is one of the key techniques of OFDM. To estimate the frequency offset, time synchronization must be achieved first. So it is important to estimate the timing offset efficiently.

Many approaches have been proposed on time synchronization for OFDM system. They are taking use of cyclic prefix (CP)[4], scattered pilots[5] or training sequences[6][7]. The main idea of them is to do correlation between the equivalent data, and to get the timing position by the correlation peak. The approaches can be divided into two groups. One is that there are repeated parts in the received data, and the correlation is done between the received data and its delayed parts. The other is to correlate the received data with the local known sequences. The former has lower complexity but worse

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performance, and the latter has better performance but higher complexity. With the development of DSP and FPGA techniques, high complexity algorithms can be realized. The latter group of time synchronization algorithms becomes applicable.

The algorithm in this paper is based on Tufvesson's[6] which is in the latter group using PN sequences. Different methods of setting time synchronization threshold have been proposed before. The method using mean correlation value (method MCV) was proposed in [8], and the method using received data power (method RDP) was proposed in [9]. Both of them are adaptive and different from the method using threshold with fixed value (method FV). But there is no detailed performance analysis in [8] and [9]. We analyze and compare the three methods theoretically. One of the methods is suitable for large dynamic range of SNR. The simulation results are consonant with the theoretic analyses.

Section 2 briefly describes OFDM system model and the time synchronization algorithm we use. Three different methods of setting threshold are introduced in Section 3. Theoretic analyses of the different methods are given in Section 4, and the performance is shown in Section 5 by simulation.

2. System model and time synchronization algorithm

2.1. System model

Figure 1 shows the block diagram of OFDM system. The complex data symbols X_k are modulated onto N subcarriers by taking the N-point inverse fast Fourier transform (IFFT). The modulated data are s_k. In order to avoid Inter-Symbol Interference (ISI), the CP which is longer than the channel impulse response is added. At the receiver, the CP is removed from the received baseband data stream after time synchronization. The data Y_k are retrieved by means of the fast Fourier transform (FFT).

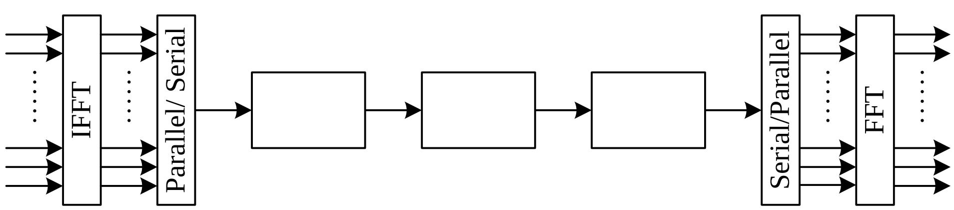


Figure 1. OFDM system

2.2. Time synchronization algorithm

We achieve time synchronization by introducing training sequence in time domain. The training sequence is composed of one or more repeated PN sequences. Tufvesson proposed an approach for OFDM synchronization using PN sequences[6]. This method can provide good performance with a sharp synchronization peak because of the good correlation between the received data and the local known PN sequence. To reduce the complexity, we remodel the synchronization signal

$$\gamma(m) = \sum_{k=0}^{L-1} c^*(k) r(m+k) \tag{1}$$

where $r(m)$ is the sampled received signal, $c(k)$ is the known local PN sequence, L is the length of the PN sequence. The timing position θ is given by the peak of $\left|\gamma(m)\right|^2$.

3. Detection threshold

When system is in acquisition mode, we can not get the timing position by simply searching the max value of $\left|\gamma(m)\right|^2$ directly, because the max value is meaningless when the training sequences are not in the searching window. So detection threshold should be introduced. Threshold is an important parameter in time synchronization and will influence the synchronization performance in a certain extent. Different methods of setting detection threshold have been proposed before.

3.1. Method FV

A simple method is to judge the inequation

$$\left|\gamma(m)\right|^2 > T_{FV} \tag{2}$$

If the inequation (2) is met, it means the correlation value exceeds the threshold. Then the timing position θ is found as $\theta = m$. Here T_{FV} is the threshold with fixed value.

3.2. Method MCV

According to the method in [8], the judging inequation is changed to

$$\left|\gamma(m)\right|^2 > T_{MCV} \cdot R_{MCV}(m) \tag{3}$$

where

$$R_{MCV}(m) = \frac{1}{M}\sum_{a=1}^{M}\left|\gamma(m-a)\right|^2 \tag{4}$$

$R_{MCV}(m)$ is the mean correlation value, and T_{MCV} is the parameter used for setting the threshold.

3.3. Method RDP

Another method was proposed in [9]. The judging inequation is

$$\left|\gamma(m)\right|^2 > T_{RDP} \cdot R_{RDP}(m) \tag{5}$$

where

$$R_{RDP}(m) = \sum_{k=0}^{L-1}\left|r(m+k)\right|^2 \tag{6}$$

T_{RDP} is the parameter used for setting the threshold, $R_{RDP}(m)$ is the power of the received data sequences.

4. Performance analysis

Among the methods above, method FV is the simplest. However, this method is not suitable for multi-path fading channel. The power of the received signal is very small when the channel is in deep fading. Then the probability of missing the training sequence will increase in this case.

The thresholds in method MCV and method RDP are both adaptive and can overcome the disadvantage of method FV. Now we mainly analyze the performance of these two methods.

Let $s(m)$ denotes the transmitted data. In AWGN channel, the received data can be represented as

$$r(m) = s(m) + n(m) \tag{7}$$

where $n(m)$ is white Gaussian noise. The carrier frequency offset is not considered here. Then $|\gamma(m)|^2$ is

$$\begin{aligned} |\gamma(m)|^2 &= \left| \sum_{k=0}^{L-1} c^*(k) r(m+k) \right|^2 \\ &= \left| \sum_{k=0}^{L-1} c^*(k) s(m+k) + n(m+k) \right|^2 \end{aligned} \tag{8}$$

Let $|c(k)| = 1$. If the PN sequences are m sequences, we can get

$$E\left\{ |\gamma(m)|^2 \right\} = \begin{cases} \sigma_s^2 + L\sigma_n^2 & m \neq \theta \\ L^2\sigma_s^2 + L\sigma_n^2 & m = \theta \end{cases} \tag{9}$$

where $\sigma_s^2 = E\left\{ |s(m)|^2 \right\}$ is the transmitted signal power and $\sigma_n^2 = E\left\{ |n(m)|^2 \right\}$ is the noise power. $m = \theta$ means the timing is correct and $m \neq \theta$ means the timing is wrong. From (9), it can be found that the mean correlation peak is

$$E\left\{ R_{peak} \right\} = L^2\sigma_s^2 + L\sigma_n^2 \tag{10}$$

and the mean threshold in method MCV is (not including T_{MCV})

$$E\left\{ R_{MCV} \right\} = \sigma_s^2 + L\sigma_n^2 \tag{11}$$

From (11) we can find that R_{MCV} is mainly affected by the noise power. The threshold in method RDP is the power of the received data, and its mean value can be expressed as (not including T_{RDP})

$$E\left\{ R_{RDP} \right\} = L\sigma_s^2 + L\sigma_n^2 \tag{12}$$

The effect from noise in method RDP is much smaller.

Figure 2 shows the mean value of thresholds at different SNR. σ_s^2 is set to be 1. As SNR increases, R_{MCV} falls more quickly than R_{RDP}. In this case, larger T_{MCV} is needed for avoiding the increase of wrong detection probability in method MCV.

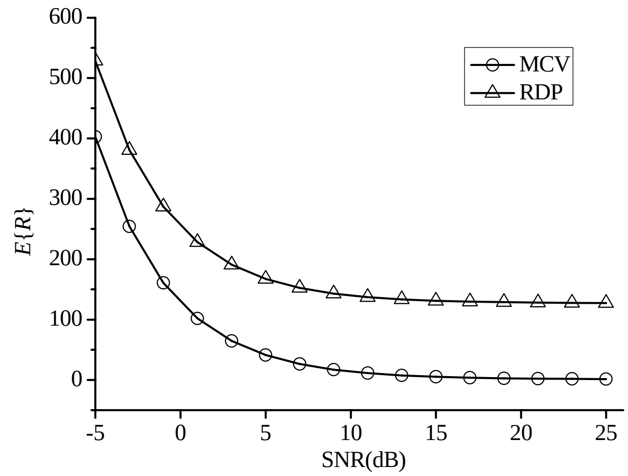


Figure 2. The mean value of threshold in AWGN channel, L=127, $\sigma_s^2 = 1$

Figure 3 shows the ratio between correlation peak and thresholds. We can find that, as SNR decreases, the ratio falls rapidly in method MCV. That is, for method MCV, a proper T_{MCV} value for high SNR will cause large missing probability at low SNR. So different T_{MCV} is needed at different SNR in method MCV. It does not fit for large dynamic range of SNR. From figure 2 and figure 3 we can see that method RDP is much better.

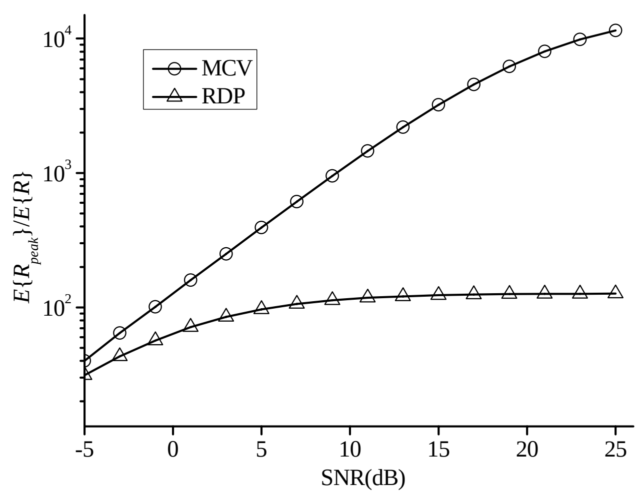


Figure 3. The ratio between correlation peak and threshold in AWGN channel, L=127

5. Simulation

Figure 4 shows the detection performance of three methods with single period PN sequence in 3-tap Rayleigh fading channel. We here consider the timing is correct when it is on the taps. The delay between the taps is 4 samples. The first tap is the strongest one and others attenuate 4dB one by one. The length of each PN sequence is L=127. The simulation was run 10000 times for each SNR value.

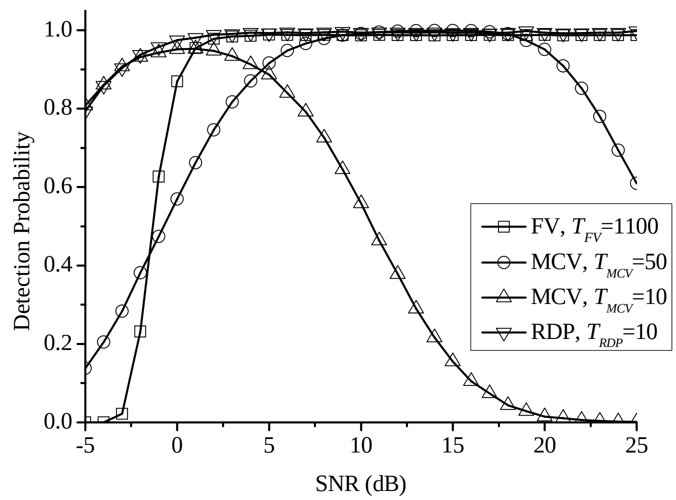


Figure 4. Detection performance in 3-tap Rayleigh fading channel, L=127

From Figure 4, we can see that method FV can not get good performance at very low SNR in multi-path fading channel. Method MCV needs different threshold parameter T_{MCV} at different SNR. When T_{MCV}=50, method MCV performs well at SNR=9~19dB. As SNR decreases, the missing probability increases with the increasing threshold, so a smaller T_{MCV} is needed. When T_{MCV}=10, method MCV performs well at SNR=0dB. As SNR increases, the wrong detection probability increases with the decreasing threshold, so a larger T_{MCV} is needed. Method RDP performs well with a fixed value of T_{RDP}=10 at different SNR.

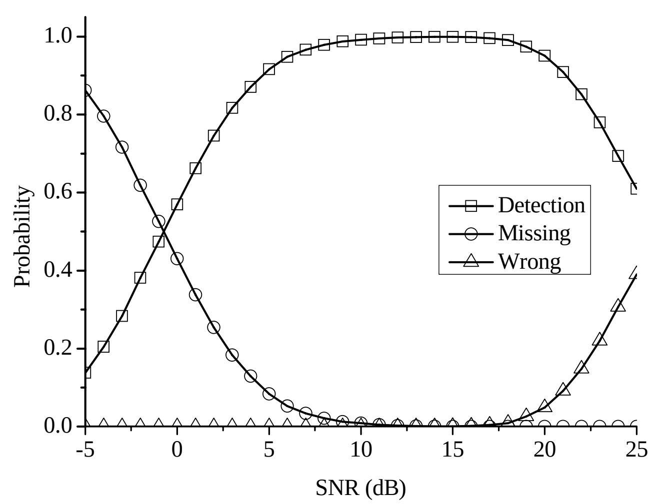


Figure 5. Synchronization probability of method MCV in 3-tap Rayleigh fading channel, L=127, T_{MCV}=50

Figure 5 shows the synchronization probability of method MCV when T_{MCV}=50. The simulation parameters are same to those of Figure 4. This figure accords with the analyses above.

6. Conclusion

In this paper, based on the time synchronization algorithm by using PN sequences, we evaluate three methods of setting detection threshold. With theoretical analyses and simulations, we can find that detection threshold is an important parameter and will influence the synchronization performance greatly. The method using fixed threshold (method FV) performs badly at low SNR in multi-path fading channel. Though the method using mean correlation value (method MCV) is adaptive, different threshold parameter T_{MCV} is needed at different SNR. This method is not applicable for unfixed or unknown SNR. The method which is taking use of received data power (method RDP) can get good performance in large dynamic range of SNR with fixed synchronization parameter T_{RDP} in multi-path Rayleigh fading channel.

7. References

[1] J.A.C. Bingham, "Multicarrier modulation for data transmission: an idea whose time has come", IEEE Communications Magazine, volume 28, issue 5, May 1990, pp. 5-14.

[2] J. Chuang, N. Sollenberger, "Beyond 3G: wideband wireless data access based on OFDM and dynamic packet assignment", IEEE Communications Magazine, July 2000, pp. 78-87.

[3] T. Pollet, M. Moeneclaey, "Synchronizability of OFDM signals", IEEE GLOBECOM '95, volume 3, Nov. 1995, pp. 13-17.

[4] J.-J. Van de Beek, M. Sandell, P.O. Brjesson, "ML estimation of timing and frequency offset in OFDM systems", IEEE Transactions on Signal Processing, volume 45, July 1997, pp. 1800-1805.

[5] Yong-Jung Kim, Dong-Seong Han, Ki-Bum Kim, "A new fast symbol timing recovery algorithm for OFDM systems", IEEE Transactions on Consumer Electronics, volume 44, issue 3, Aug. 1998, pp. 1134-1141.

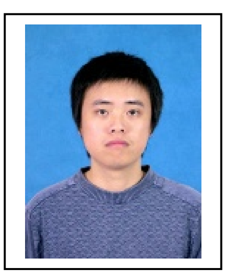
[6] F. Tufvesson, O. Edfors, M. Faulkner, "Time and frequency synchronization for OFDM using PN-sequence preambles", IEEE 50th Vehicular Technology Conference, volume 4, 19-22 Sept. 1999, pp. 2203-2207.

[7] N. Mochizuki, Y. Matsumoto, M. Mizoguchi, T. Onizawa, M. Umehira, "A high performance frequency and timing synchronization technique for OFDM", IEEE GLOBECOM '98, The Bridge to Global Integration, volume 6, 8-12 Nov. 1998, pp. 3443-3448.

[8] Chunlin Yan, Jiayi Fang, Youxi Tang, Shaoqian Li, "OFDM synchronization using PN sequence and its performance", 14th IEEE Proceedings on PIMRC 2003, volume 1, 7-10 Sept. 2003, pp. 936-939.

[9] A.N. Mody, G.L. Stuber, "Synchronization for MIMO OFDM systems", IEEE GLOBECOM '01, volume 1, 25-29 Nov. 2001, pp. 509-513.

Authors



Yuan Tian received the B.S. degree from Nanjing University, China, in 2000, and the M.S. degree from University of Electronic Science and Technology of China (UESTC) in 2006, respectively. He is currently pursuing the Ph.D. degree at UESTC. His research interests are OFDM and synchronization technologies in wireless communication.

Xia Lei received the Ph.D. degree from University of Electronic Science and Technology of China (UESTC) in 2005. She is currently an Associate Professor in UESTC. Her research interests are next generation of mobile communication, MIMO and OFDM technologies.

Wanbin Tang received the B.S. degree and the M.S. degree from University of Electronic Science and Technology of China (UESTC) in 1993 and 1998, respectively. He is currently an Associate Professor in UESTC. His research interests are MIMO and adaptive signal processing technology in wireless communication.

Shaoqian Li received the B.S. degree in communication technology from Xidian University, Xi'an, China, in 1982, and the M.S. degree in Information and Communication Systems from University of Electronic Science and Technology of China (UESTC), Chengdu, China, in 1984, respectively.

Since July 1984, he has been a faculty member with Institute of Communication and Information Engineering, UESTC, China, where he is a professor since 1997, and Ph.D. supervisor, since 2000. He is also the director of National Key Lab of Communication in UESTC and a member. He is the leader of Mobile Broadband Communications (MBC) Experts Team, Ministry of Information Industry of China, for evaluation of strategy and technologies of MBC. His research includes mobile communication systems (3G and Beyond 3G), wireless communications (CDMA, OFDM, Ultra-Wideband, and MIMO etc.), integrated circuits in wireless communications, and radio resource managements techniques.