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A Novel OFDM Timing Synchronization Algorithm Based on Stochastic Approximation and ML Algorithm

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Abstract: ML algorithm has low computational complexity but its timing estimation is not good. In order to improve the problem, combination of stochastic approximation and ML algorithm is proposed. Using ML algorithm as timing coarse estimation and stochastic approximation algorithm as timing fine estimation, the simulation results show that the proposed algorithm can realize more accurate symbol timing than ML algorithm.

Key words: ML algorithm, stochastic approximation, timing synchronization, OFDM, timing offset

INTRODUCTION

OFDM (orthogonal frequency division Multiplexing) system which has advantages of high spectrum efficiency and good anti multipath fading performance (Latif and Gohar, 2008) obtains more and more attention. OFDM technology is applied in wireless (Al-Kebsi, 2008), such as DVB and personal area networks (Ramesh and Vaidehi, 2006). The wireless communication system coupled with MIMO-OFDM is regarded as a good idea (Zhaogan *et al*., 2007). OFDM is also commonly adopted in broadband wireless communications (Elahmar *et al*., 2007; Arioua *et al*., 2012; Yi *et al*., 2011) and in wireless underwater communication (Abdellaoui *et al*., 2006). Recently, people try to apply OFDM system in power line carrier.

To an OFDM system, the time when OFDM symbol arrives is unknown and it is more sensitive to timing estimation error than single carrier system. So, the problem of OFDM timing synchronization needs to be solved urgently.

Now, there are many methods to solve the Synchronization problem for OFDM system (Schmidl and Cox, 1997; Minn *et al*., 2000; Ye *et al*., 2007; Van de Beek *et al*., 1997; Chandranath and Vikram, 2002; Bolcskei, 2001; Salari *et al*., 2008), some based on pilot or special training sequence have good synchronization performance but they occupy system bandwidth resources (Schmidl and Cox, 1997; Minn *et al*., 2000; Ye *et al*., 2007; Yi *et al*., 2010); some are non data-aided which do not need neither pilot nor special training sequence and can save system bandwidth resources (Van de Beek *et al*., 1997; Chandranath and Vikram, 2002; Salari *et al*., 2008). The classical algorithm of this type is maximum likelihood estimation algorithm-ML algorithm (Van de Beek *et al*., 1997) which has low computational complexity, but its timing estimation error is larger. To solve the problem, a novel algorithm which combines stochastic approximation with ML algorithm is proposed.

OFDM SYSTEM MODEL

The baseband OFDM data symbol can be expressed as:

$$s(n) = \frac{1}{N}\sum_{k=0}^{N-1} x(k) e^{j2\pi k \frac{n}{N}} \quad (1)$$

where, N is the number of subcarriers. The transmitted OFDM signal sequence {s(n)} is modulated by means of IFFT (inverse fast Fourier transform). There is L cyclic prefix before N IFFT samples, so, the length of the transmitted OFDM is N+L.

In an OFDM system, the complex discrete time signal r(n) in the receiver can be described as:

$$r(n) = s(n-T) e^{j\frac{2\pi n\varepsilon}{N}} + w(n) \quad (2)$$

where, T is the channel delay and w(n) is the additive white Gaussian noise.

THE TRADITION ML ALGORITHM

Cyclic prefix is the copy of the last L symbols of OFDM. The correlation between them is used for synchronization estimation in ML algorithm. The

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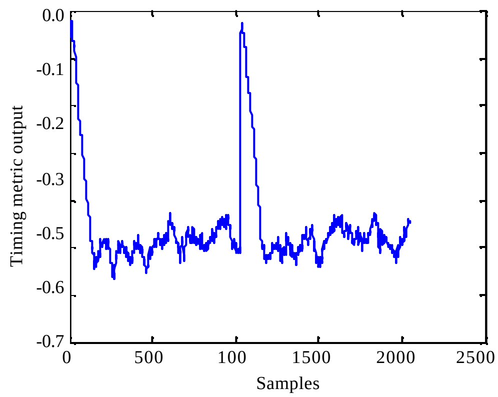

Fig. 1: The curve of timing metric of ML algorithm

formulations for synchronization estimation in ML algorithm are as follows (Van de Beek *et al*., 1997):

$$\hat{\theta}_{ML} = \arg\max(|\lambda(\theta)| - \rho\varphi(\theta)) \quad (3)$$

$$\hat{\varepsilon}_{ML} = -\frac{1}{2\pi}\angle\lambda(\hat{\theta}_{ML}) \quad (4)$$

$$\lambda(\theta) = \sum_{k=\theta}^{\theta+L-1} r(k)r^*(k+N) \quad (5)$$

$$\varphi(\theta) = \frac{1}{2}\sum_{k=\theta}^{\theta+L-1}(|r(k)|^2 + |r(k+N)|^2) \quad (6)$$

$$\rho = \frac{SNR}{SNR+1} \quad (7)$$

SNR is the ratio of signal-to-noise in Eq. 7.

OFDM system with 1024 subcarriers and 128 cyclic prefix is modulated by QPSK. The curve of the timing metric of ML algorithm under AWGN channel is shown in Fig. 1.

Figure 1 shows that the curve of timing metric function in ML algorithm is not a peak pulse, so, timing estimation here is not precise.

PROPOSED METHOD

The timing estimation error of ML algorithm is larger, so ML algorithm is suitable for the timing coarse estimation. A novel OFDM timing estimation algorithm which combines ML algorithm with the algorithm proposed by Chandranath and Vikram (2002) is presented. The new algorithm uses ML algorithm as the timing coarse estimation and the method proposed by Chandranath and Vikram (2002) as the timing fine estimation.

Actually, the synchronization problem is the stochastic optimization problem described as Eq. 8 proposed by Chandranath and Vikram (2002).

$$\max E[|P_m(\theta)|] \quad (8)$$

where, θ is an unknown parameter, $[p_m(\theta)]$ which is independent random variable sequence about θ, is defined as follows:

$$p_m(\theta) = \frac{1}{L}\sum_{L=0}^{L-1} r(k+\theta+m(N+L)) \times$$

$$r^*(k+\theta+(m+1)(N+L)-L) \quad (9)$$

where, * represents conjugate.

The steps of the proposed algorithm are as follows:

- Using ML algorithm as OFDM timing coarse synchronization and Eq. 3-7 are used here. Suppose $\Phi = |\lambda(\theta)| - \rho\varphi(\theta)$, compare with the given threshold. When Φ is larger than the given threshold, the OFDM timing fine synchronization namely stochastic approximation algorithm is used
- According to the characteristic of the independent uniform distribution random variable and the current $\hat{\theta}m$, generate a new $\hat{\theta}'m$. Then calculate the value of:

  $$C_m(\hat{\theta}'m, \hat{\theta}m) = |P_m(\hat{\theta}'m)| - |P_m(\hat{\theta}m)|$$

  If $C_m > 0$, then $\hat{\theta}m+1 = \hat{\theta}'m$ else $\hat{\theta}'m+1 = \hat{\theta}m$

  Save the updating $\hat{\theta}^*_m$ every time.

- When the value of Φ is less than the given threshold, stop to calculate $C_m(\hat{\theta}'_m, \hat{\theta}_m)$ and the last updating is the channel delay.

SIMULATION RESULTS

To simulate the traditional ML algorithm and the novel algorithm proposed in this article. The data symbols are modulated by means of QPSK. The number of subcarriers is 1024 and the length of the cycle prefix is 128. The simulation results are shown in Fig. 2 and 3.

We can see that the algorithm proposed in this article has good performance of timing synchronization estimation than the traditional ML algorithm from Fig. 2 and 3.

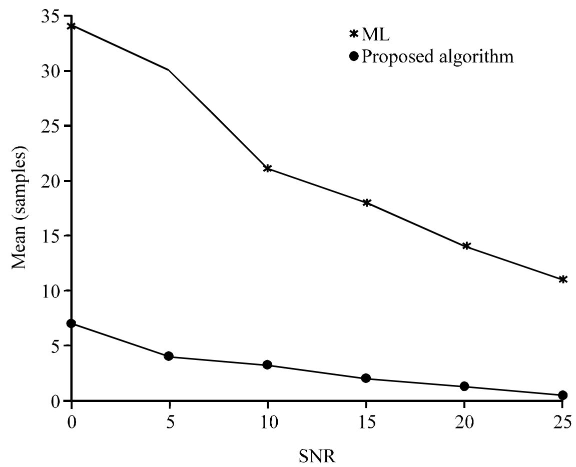

Fig. 2: Mean of timing estimation of the two algorithms

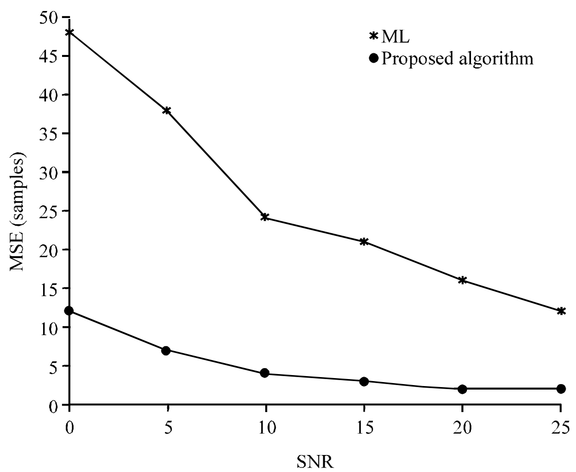

Fig. 3: MSE of timing estimation of the two algorithms

CONCLUSIONS

The novel OFDM synchronization algorithm presented in this article combines stochastic approximation with ML algorithm and it can estimate timing synchronization accurately than ML algorithm.

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