Robust Frame Synchronization Algorithm on the cell edge in the Mobile-WiMax System

Jeong Mi You
Graduate School Electrical and Computer Engineering, Sungkyunkwan University
Telecommunication R&D Center, Samsung Electronics, Korea
Samsung Electronics co., LTD., Dong Suwon P.O.Box 105,
416, Maetan-3dong, Yeongtong-gu, Suwon-si, Gyeonggi-do, Korea
E-mail: jm.you@samsung.com

Abstract: The Mobile-WiMax system is susceptive to inter-cell interference. At the cell edge, particularly, a severe synchronization error may occur due to decreased signal-to-interference ratio. In this paper, therefore, we propose a robust frame synchronization algorithm in inter-cell interference for the Mobile-WiMax system. The proposed algorithm shows a clear peak at the correct frame timing and has low computational complexity.

1. Introduction

In the cellular OFDMA systems with the frequency reuse factor as one, all the same subcarriers are used in every sector of adjacent cells. It will induce very strong inter-cell interference particularly for the mobile station at the cell edge.

In the Mobile-WiMax system, the frame synchronization should detect the correct OFDMA symbol timing fast and accurately to demodulate data symbols which are transmitted after preamble [1]. Several frame synchronization algorithms have been proposed for OFDMA systems [2]-[3]. In [2], repetition property based algorithm is proposed. In [3], conjugate-symmetric based algorithm is introduced, and this algorithm shows better performance than [2] algorithm. [2] has a good correlation property but this is corrupted when a mobile station is at the cell edge. So this algorithm cannot detect the correct frame timing.

Preamble has conjugate-symmetric property in the time domain because it has only real value by BPSK modulation in the frequency domain. This property is maintained though other signals are overlapped. Therefore the [3] have good performance at the cell edge. This algorithm however, has large computational complexity because of unnecessary complex multiplications.

The proposed algorithm also uses the conjugate-symmetric characteristic. But we reduce unnecessary complex multiplication of conjugate-symmetric samples.

This paper is organized as follows. Section 2 introduces the structure of the signal and systems. Section 3 shows the conventional frame synchronization algorithm. Section 4 proposes an improved frame synchronization algorithm. The performance results of the proposed algorithm are presented in Section 5. Finally, we draw some conclusions in Section 6.

2. System model

The structure of the burst frame which we consider is shown in Fig. 1. The preamble is transmitted before data symbols and has roughly three times repetition by allocating pilots by the interval of three subcarriers. The pilots of preamble will be transmitted with BPSK modulation in frequency domain .

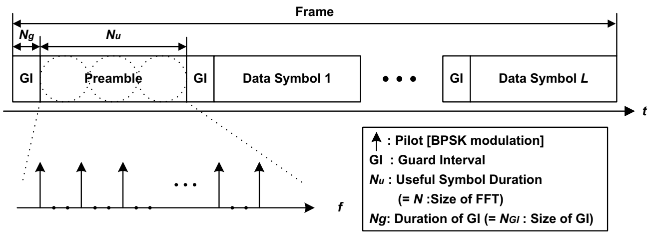


Fig. 1 Structure of frame

The n-th time domain OFDM sample s_n is the signal corresponding to the BPSK modulated pilots a_k in the frequency domain. The relation between the time domain signal s_i at the i-th sample and s_{N-1} at the (N - i)-th sample is the complex conjugate of each other, as shown in Eq. (1)[1]. We can describe the structure of the preamble as shown in Fig. 2.

$$\begin{aligned} s_{N-i} &= \sum_{k=0}^{N-1} a_k \cdot e^{j2\pi \frac{k}{N}\cdot(N-i)} = \sum_{k=0}^{N-1} a_k \cdot e^{-j2\pi \frac{k}{N}\cdot i} \\ &= \left(\sum_{k=0}^{N-1} a_k \cdot e^{j2\pi \frac{k}{N} i} \right)^* = s_i^* \end{aligned} \quad (1)$$

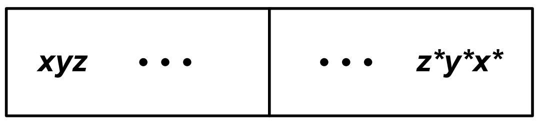
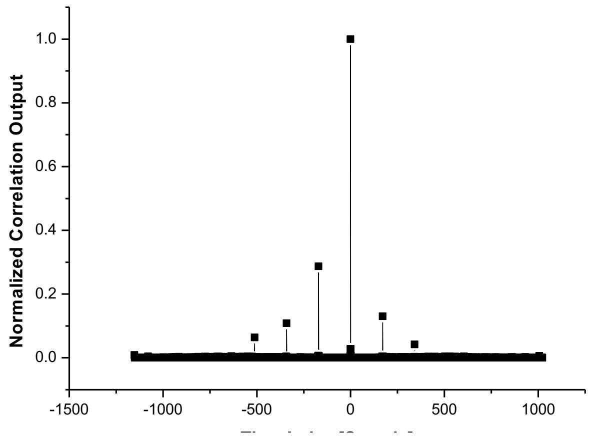


Fig. 2 Structure of the preamble

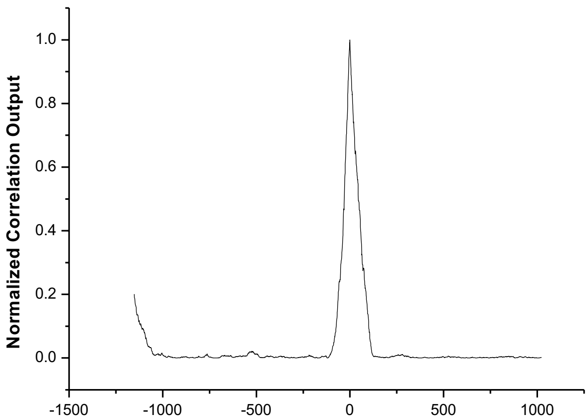
3. Conventional synchronization algorithm

The conventional conjugate-symmetric property based algorithm is performed by complex multiplication between two samples which has the characteristic of Eq. (1) [3]. The start point of frame is detected by searching the sample position n which has the maximum peak value at the output of the Eq. (2).

$$C_n = \left| \sum_{i=1}^{N/2-1} r_{n+i} \cdot r_{n+N-i} \right| \tag{2}$$



(a) Correlation property of the conjugate-symmetric based algorithm



(b) Correlation property of the cyclic-prefix based algorithm

Fig. 3 Normalized correlation outputs

But this shows unwanted peaks as shown in Fig. 2-(a). To eliminate these peaks, conventional algorithm uses cyclic-prefix based correlation output as shown in Fig. 2-(b). cyclic-prefix based algorithm correlates the current sample and N-delayed sample as Eq. (3) [4].

$$G_n = \left| \sum_{i=0}^{N_g-1} r_{n+i}^{*} \cdot r_{n+N+i} \right| \tag{3}$$

The conventional algorithm is performed by multiplying the conjugate-symmetric property based correlation outputs and cyclic-prefix based outputs [3]. In Fig. 4, there is only one peak in the correlation output by this combined algorithm.

The starting point of frame is estimated by searching the sample position of the maximum peak value at the output of the multiplication as Eq. (4).

$$\hat{e} = \underset{n}{Max}\left[C_n \cdot G_n\right] \tag{4}$$

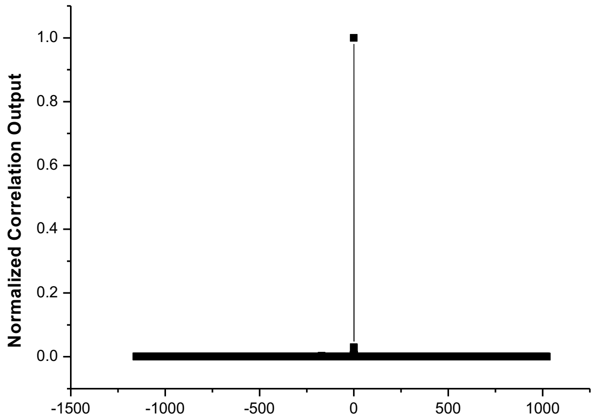


Fig. 4 Output of combined conjugate-symmetric bsed algorithm

4. Proposed synchronization algorithm

The conventional algorithm has large computational complexity of (N/2-1) when we consider complex multiplication between conjugate-symmetric samples only. Preamble has conjugate-symmetric characteristic and three times repetition characteristic in the time domain. That's the reason that conjugate-symmetric property has unwanted peaks. When we consider two characteristics at the same time, the structure of the preamble in Fig. 2 is modified as in Fig. 7, where complex multiplications of the conventional conjugate-symmetric property algorithm divided into three pairs of (③, ④), (②, ⑤), and (①, ⑥). Note that the correlation pattern (③, ④) appears in (①, ②), (②, ③), (④, ⑤), and (⑤, ⑥) pairs which are adjacent each other. Pattern (②, ⑤) appears in (①, ④) and (③, ⑥) pairs which are spaced in two blocks. These similar patterns make many correlation peaks as shown in Fig. 3-(a).

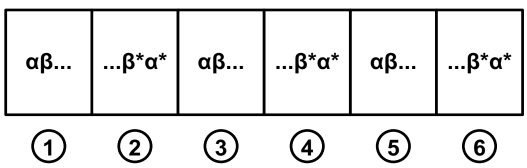
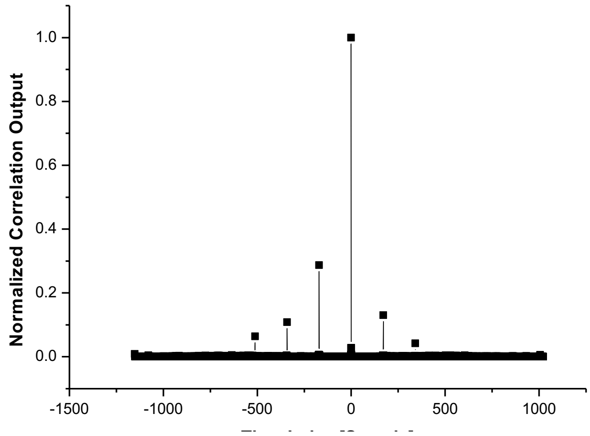
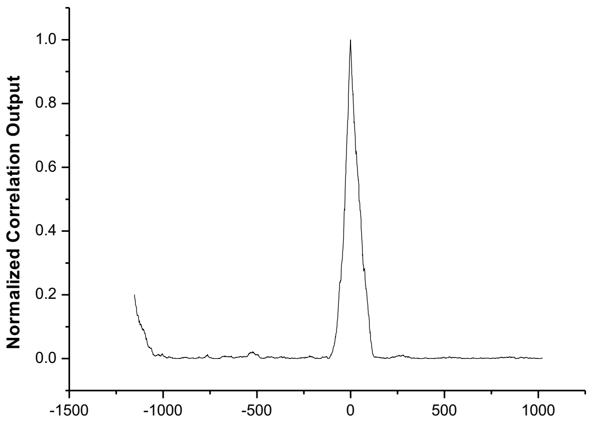


Fig. 5 Modified structure of the preamble

A modified algorithm takes the pair of (①, ⑥) to eliminate these redundant complex multiplications. But this algorithm also has unwanted peak caused by cyclic-prefix as shown in Fig. 6-(a). So the proposed algorithm also combines modified conjugate-symmetric based algorithm and cyclic-prefix based to eliminate these peaks as the conventional conjugate-symmetric based algorithm. Output of the proposed algorithm is shown in Fig. 6-(b).



(a) Modified conjugate-symmetric based algorithm



(b) Proposed algorithm

Fig. 6 Outputs of conjugate-symmetric based algorithms

The modified conjugate-symmetric based algorithm is performed as in Eq. (5) and the proposed algorithm multiplies the correlation outputs of the modified conjugate-symmetric based and cyclic-prefix based algorithm. The starting point of the frame is estimated by searching the sample position of the maximum peak value at the output of the multiplication as in Eq. (6).

$$P_n = \left| \sum_{i=1}^{N/6-1} r_{n+i} \cdot r_{n+N-i} \right| \tag{5}$$

$$\hat{e} = \underset{n}{Max}\left[P_n \cdot G_n \right] \tag{6}$$

Computational complexity of the proposed algorithm is about 1/3 of the conventional one.

4. Simulation Results

In this section, we provide simulation results for the performance of the proposed frame synchronization algorithm in the multi-path fading channels based on ITU channel model vehicular-A [5]. In this paper, SNR is based on the ratio of noise power and the signal power of data subcarrier symbol.

Fig. 7 and 8 are RMSE performance and outage probability in a single cell, respectively. Fig. 7 shows that the proposed algorithm has similar RMSE as the conventional algorithm. Both the proposed algorithm and the conventional algorithm show about 3 samples RMSE over 5 dB. Fig. 8 shows that the conventional algorithm and the proposed algorithm have a similar performance. They show perfect synchronization performance over 0 dB.

Fig. 9 and 10 are RMSE performance and outage probability in multi cell environment, respectively. In this environment, we assumed 2 situations. First, mobile station is on equidistance from three base stations which transmit signals at the same power. Second, object of frame synchronization is detection of the signal which has the strongest power.

Conventional and proposed conjugate-symmetric based algorithms show much better performance than algorithm [2] in this environment. In Fig. 9, [2] shows about 75 samples RMSE over 10 dB which shows large performance degradation compared with the performance in single cell. But both conventional and proposed conjugate-symmetric based algorithms show about 3 samples RMSE in multi cell like the single cell.

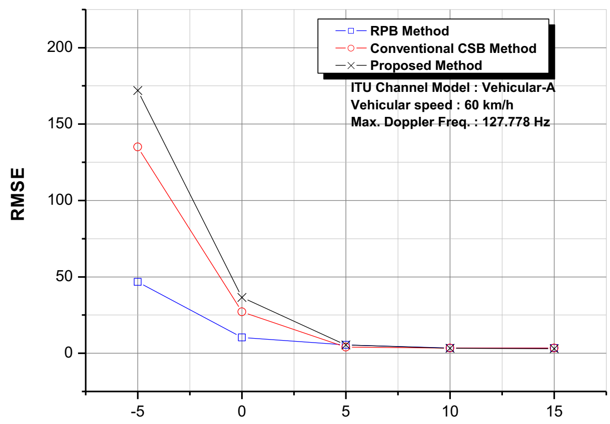


Fig. 7 RMSE performance in single cell

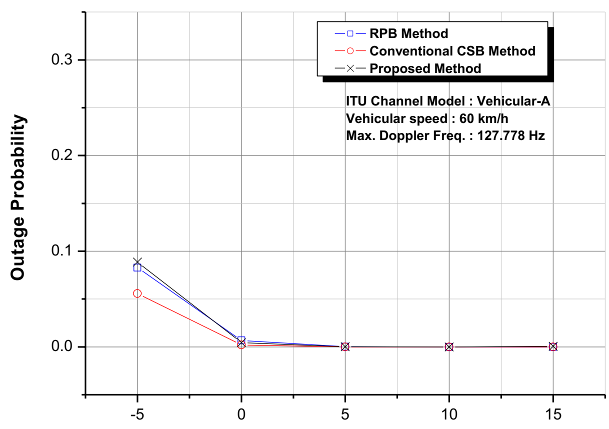


Fig. 8 Outage probability in single cell

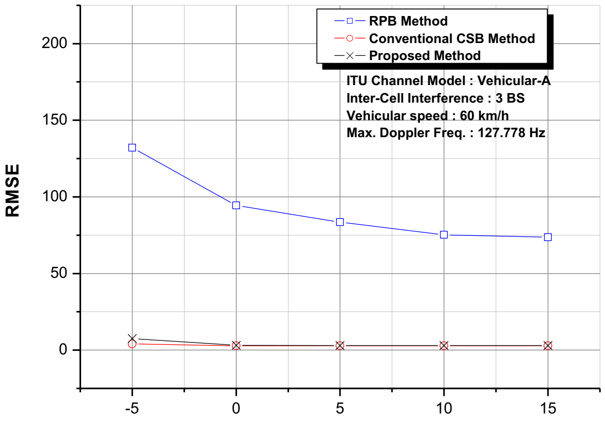


Fig. 9 RMSE performance in multi cell

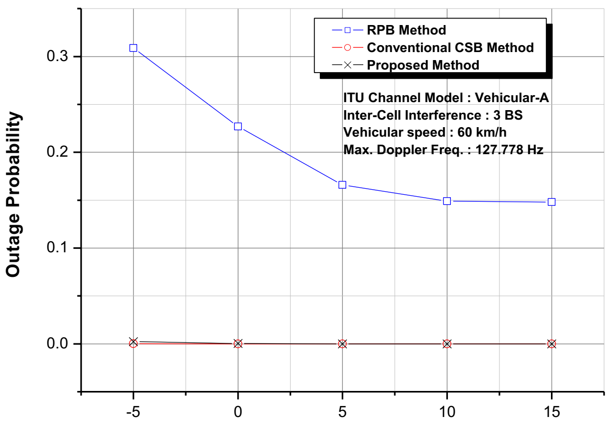


Fig. 10 Outage probability in multi cell

5. Conclusion

In this paper, we have presented a robust frame synchronization algorithm on inter-cell interference. The proposed algorithm utilizes the same conjugate-symmetric based algorithm as the conventional frame synchronization algorithm, but we have reduced the redundant complex multiplications of the conventional algorithm. Simulation results show that the proposed algorithm with low complexity has almost the same performance as the conventional algorithm.

References

[1] H. Kobayashi, K. Mori, and T. Nagaosa, "Proposal of Symbol Timing and Carrier Frequency Synchronization Methods for Burst Mode OFDM Signal," IEICE Trans. Commun., Vol. E86-B, pp. 238-246, January 2003.

[2] D. Lee and K. Cheun, "Coarse Symbol Synchronization Algorithms for OFDM Systems in Multipath Channels," IEEE Commun. Letters, VOL. 6, NO. 10, October 2002.

[3] J. S. Um, S. B. Im, S. S. Kim, and H. J. Choi, "A Robust Timing Synchronization Algorithm for OFDM Systems over Multipath Rayleigh Fading Channels," ITC-CSCC Proceedings, pp. 483-484, July 2005.

[4] Timothy M. Schmidl and Donald C. Cox, "Robust Frequency and Timing Synchronization for OFDM," IEEE Tran. on Commun., VOL. 45, No. 12, December 1997.

[5] M. Ibnkahla, Signal Processing for Mobile Communications Handbook,CRC Press, pp. 2-25 – 2-26, 2005.