

Timing and Frequency Synchronization for OFDMA/TDD Mode in Downlink of IEEE 802.16-2004 in AWGN Channel

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Abstract— timing and frequency synchronization are the important task in receiver. In this paper, an efficient timing and carrier frequency offset (CFO) estimation method for orthogonal frequency division multiple access/ time division duplexing (OFDMA/TDD) mode in IEEE 802.16-2004 standard (WiMAX) is represented. This method has high performance and jointly estimates timing error and CFO. The performance is evaluated in additive white Gaussian noise (AWGN) channel. This method can be easily used for other OFDM based systems which receiver knows preamble at itself.

Index Terms— timing synchronization, carrier frequency offset estimation, IEEE 802.16, AWGN channel.

I. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) has so applications in broadband communication systems same as wireless metropolitan area network (WiMAX) [1]-[2]. OFDM systems are very sensitive to timing and frequency errors as all the tasks in receiver will be feckless with imperfect synchronization [3]. Thus timing and frequency synchronization in OFDM systems are very important task. Timing error and CFO lead to inter-symbol interference (ISI) and inter-carrier interference (ICI) respectively. There are some methods that we can use them based on qualifications and features of preamble [4]-[6]. There are some methods which do not use preamble and are based on cyclic prefix (CP) [7]-[8]. Synchronization algorithms for orthogonal frequency division multiple access (OFDMA) based systems in downlink are the same as Synchronization algorithms for OFDM based systems. Because in downlink, each receiver should estimate timing offset and CFO related to itself, but in uplink, base station should estimate a vector of CFOs related to all of the active users [9]. Therefore synchronization in uplink is more difficult than downlink definitely. We can't use previous methods in OFDMA mode in WiMAX, because of preamble features. we should modify these methods to WiMAX preamble to use them in downlink transmission. The first symbol of downlink transition is preamble. The preamble of OFDMA mode in WiMAX has size of 2048 in time domain, which makes use of boosted BPSK modulation with specific pseudo-noise (PN) code [1]. Accordingly, there are 114 different preamble signals. Each of them is served at a particular segment of a cell. Each cell is divided to three segments: 0,

1, and 2. The preamble carrier-sets are defined using equation (1) [1]:

$$\text{Preamble carrier set}_n = n + 3k \quad (1)$$

n and k are number of preamble carrier set indexed 0, 1, 2 and a running index 0, 1, ..., 567 respectively. Each segment uses a preamble composed of a carrier set out of the three available carrier set in the following manner [1]:

- Segment 0 uses preamble carrier set 0.
- Segment 1 uses preamble carrier set 1.
- Segment 2 uses preamble carrier set 2.

Therefore each segment eventually modulates each third subcarrier. Fig. 1 depicts the preamble segment 1 [1]. Thus we have 3 blocks (A, B, and C) with length of 682 in time domain that they are not same to each other, but they have good cross correlation. This matter is because of 2048 is not divisible to 3. Blocks A, B, and C begin from 0 to 681, 682 to 1363, and 1366 to 2047 respectively. In [10] some methods are modified for this preamble. In WiMAX, the user situated in a cell is known by IDcell and number of segment and has its own preamble.

We propose a metric method that do timing synchronization and can estimate CFO by knowing preamble in receiver. The proposed method has high performance even in low SNR versus Reddy algorithm [6].

In section II, system model is presented in AWGN channel. In section III, Reddy algorithm is presented. In section IV, the proposed timing metric and its analysis is presented. In section V, simulation results are demonstrated and finally the conclusion is given in section VI.

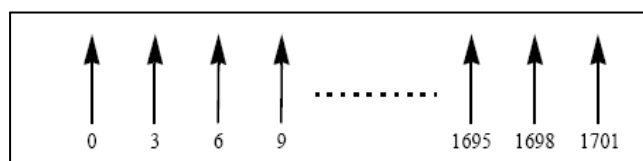


Figure1. Downlink preamble structure [1].

II. SYSTEM MODEL

The transmitted samples in baseband OFDM modulation can be written as:

$$s(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} C_k e^{\frac{j2\pi nk}{N}}; -N_g \leq n \leq N-1 \quad (2)$$

Where N is IFFT length. N_g , C_k , and n are cyclic prefix length, preamble data in subcarrier k , and timing sample index respectively. We concentrate on preamble symbol. n th sample of received signal is given by:

$$r(n) = e^{\frac{j2\pi\epsilon n}{N}} s(n) + v(n); -N_g \leq n \leq N-1 \quad (3)$$

Where ϵ , θ , and $v[n]$ are the carrier frequency offset normalized to the subcarrier spacing, timing offset, and zero mean complex AWGN with variance σ_v^2 respectively.

III. REDDY ALGORITHM

The Reddy algorithm is one of the most algorithms that the receiver knows the preamble. The Reddy algorithm is presented for timing and frequency synchronization in this section. The modified timing metric is given by [10]:

$$M(d) = \frac{|P(d)|^2}{(R(d))^2} \quad (4)$$

where

$$P(d) = \sum_{n=0}^{L-1} (r(n+d)s(n+N_g))^* (r(n+d+M)s(n+N_g)) \quad (5)$$

and

$$R(d) = \sum_{n=0}^{L-1} |r(n+M+d)|^2 \quad (6)$$

A^* means conjugate A . $L = \lfloor \frac{N}{3} \rfloor$, where $\lfloor B \rfloor$, means floor(B). If $M = L$, correlation between blocks A and B and if $M = 2L + 2$, correlation between blocks A and C will be considered.

IV. PROPOSED ALGORITHM FOR TIMING METRIC

The table 1 shows the cross correlation of the blocks. Cross correlation between blocks A and B is the same as A and C, but cross correlation between blocks B and C is less than others. Autocorrelation for all of the blocks is much stronger than cross correlation definitely. Therefore, by knowing the preamble in receiver, we propose a timing metric that has good performance even in low SNR and use it to estimate the CFO. The proposed timing metric is given by:

$$M(d) = \frac{|P(d)|}{R(d)} \quad (7)$$

Table 1. Cross correlation between three blocks of preamble WiMAX (index=0).

blocks	A and B	A and C	B and C
Cross correlation	163.722	162.987	100.063

where

$$P(d) = \sum_{n=0}^{N-1} r^*(n+d)s(n+N_g) \quad (8)$$

and

$$R(d) = \sum_{n=0}^{N-1} |r(n+d)|^2. \quad (9)$$

The index of maximum of metric shows the start of symbol, we use this index (d_{opt}) to estimate CFO. CFO estimator is given by:

$$\hat{\epsilon} = \frac{-1}{\pi} \angle (P(d_{opt})). \quad (10)$$

$\angle$ means measured angle. In fixed WiMAX, we have CFO because of the change in environment and mismatching between transmitter and receiver oscillators. Thus CFO is smaller than subcarrier spacing. But if the CFO be larger than subcarrier spacing, we compensate the fractional part of CFO by multiplying the received signal by $e^{\frac{-j2\pi\epsilon n}{N}}$. We find the integer part of CFO by regarding to the guard bands in frequency domain: each integer part of CFO causes the frequency shift of OFDM subcarriers as many as subcarrier spacing. Therefore, by knowing the guard bands in frequency domain, we can compensate the integer part of CFO.

In this part, expectation of timing metric is derived. $P(d)$ in AWGN channel is:

$$P(d) = \sum_{i=0}^{N-1} \left[e^{\frac{-j2\pi\epsilon(i+d)}{N}} s^*(i+d) + v^*(i+d) \right] s(i+N_g) \quad (11)$$

At $d = d_{opt}$, d_{opt} means index d at optimum place that is equal N_g , $s(i+d_{opt}) = s(i+N_g)$. $|s(i+d_{opt})|^2$ has a phase $\varphi = -\pi\epsilon$, then $P(d)$ given in (11) can be broken into parts that are inphase and quadrature phase to $|s(i+d_{opt})|^2$, similar to that given in [5]. For moderate values of SNR, the magnitude of the quadrature part is small compared to that of inphase part and can be neglected [5]. Then, upper bound of $|P(d_{opt})|$ is according:

$$|P(d_{opt})| \leq e^{j\varphi} \sum_{k=0}^{N-1} |s(i+d_{opt})|^2 + inphase_{\varphi} \{v^*(i+d_{opt})s(i+N_g)\} \quad (12)$$

And estimate of $R(d)$ is according to [6]:

$$R(d) = \sum_{i=0}^{N-1} |s(i+d)|^2 + |v(i+d)|^2 + 2\text{Re}\{s^*(i+d)v(i+d)\} \quad (13)$$

From *central limit theorem*, both $|P(d_{opt})|$ and $R(d_{opt})$ are Gaussian distributed. Upper bound of expectation of $|P(d_{opt})|$ is according by:

$$E[|P(d_{opt})|] = \mu_{|P(d_{opt})|} \leq \sum_{i=0}^{N-1} |s(i+d_{opt})|^2 = E_s \quad (14)$$

$E[|]$ and E_s , mean expectation and energy of preamble symbol respectively. the energy of blocks are equal to each other approximately. Based on (13), we have:

$$\mu_{R(d_{opt})} = \sum_{i=0}^{N-1} (|s(i+d_{opt})|^2 + \sigma_v^2) = E_s + N\sigma_v^2 \quad (15)$$

From [11], expectation of $\frac{|P(d)|}{R(d)}$ is obtained:

$$\mu_{M(d)} = E\left[\frac{|P(d)|}{R(d)}\right] \approx \frac{\mu_{|P(d)|}}{\mu_{R(d)}} \quad (16)$$

By definition $\frac{E_s}{N\sigma_v^2} \approx \frac{E_b}{L\sigma_v^2}$, (E_b means energy of each block of preamble and $3E_b \approx E_s$) can be seen that by increasing SNR, upper bound of proposed metric ($\mu_{M(d_{opt})}$) goes to one. But for Reddy algorithm, by increasing SNR, goes to $\frac{\sum_{i=0}^{L-1} |s(i)|^4}{E_b^2}$ that in WiMAX preamble is approximately 0.17 and smaller than one.

OFDM system with 2048 subcarriers and 256 samples for CP and AWGN channel is considered. Simulation results demonstrate that this timing metric can achieve more accurate timing offset and CFO estimation than Reddy algorithm. The performance of proposed algorithm is evaluated by computer simulations. Fig. 2 and fig. 3 indicate timing metric with $2\pi\epsilon = 3$ and SNR=0 dB for proposed algorithm and Reddy algorithm respectively. The largest peak is the first of symbol. Can be seen, peak of the first of preamble in proposed algorithm is larger than Reddy algorithm. Table 2 indicates comparison of CFOs estimation between two algorithms with various CFOs in SNR=0 dB. Regarding to table 2, the proposed method has better performance. Figure 4, indicates comparison estimation of CFO ($2\pi\epsilon = 3$) in various SNR between two algorithms by mean square error (MSE) criterion. Based on Figure 4, the proposed algorithm has the better performance.

VI. CONCLUSION

In this paper, we proposed an algorithm for timing metric that can be used for CFO estimation. This algorithm can be used for downlink in OFDM(A) based systems that preamble is known at receiver. We compare the performance of the proposed algorithm with Reddy algorithm. Simulation results indicate that this algorithm has high performance even in low SNR.

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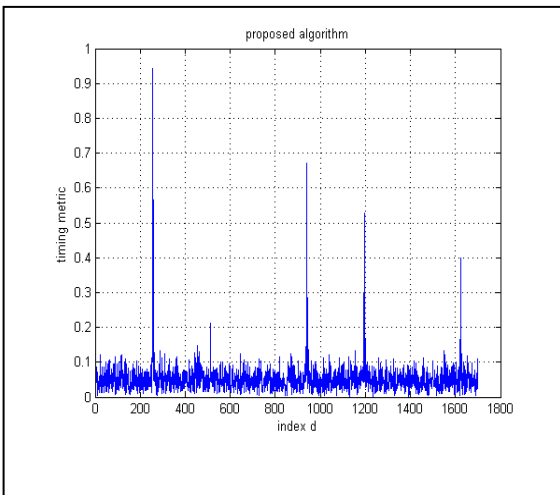


Figure 2. Proposed timing metric.

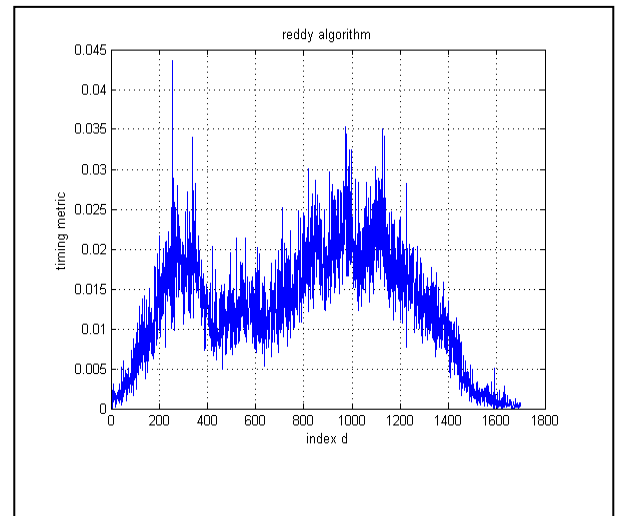
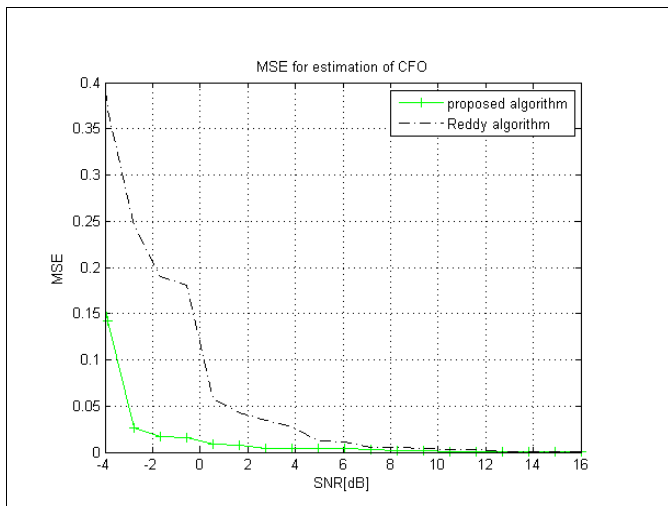


Figure 3. Reddy timing metric with M = 682.

Table 2. Estimated CFO for SNR=0 dB.

$2\pi\epsilon[\text{rad}]$	-3	-2	-1	0	1	2	3	4
Proposed algorithm	-2.965	-1.976	-0.980	0.00	1.00	2.056	2.988	3.962
Reddy algorithm	-2.957	-2.048	-1.158	0.04	1.06	1.875	2.924	3.819

Figure 4. MSE for estimation of CFO with various SNR and $2\pi\epsilon = 3$.

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