A Simplification in Integral Frequency Offset Estimation Based on Joint Detection Algorithm for WiMAX 802.16e

Ahmed Ahmedin[1] Sarah Rashad[2†] Mahmoud Fayez[2†] Marwa Abdel Raouf[1†] Mostafa Sayed[2†]
Hossam Fahmy[2] Ahmed Sultan[1] Mahmoud Hamed[2]

[1]*Nile University { ahmed.ahmedin, marwa.ali, asultan@nileu.edu.eg }*

[2]*Cairo University { sarasalim85@yahoo.com mahmoudfayez@ymail.com mostafasayed_86@yahoo.com hfahmy@arithmetic.stanford.edu mhiis@yahoo.com }*

[†]*These authors contribute equally to this work*

Abstract

Initial downlink synchronization for orthogonal frequency division multiple access (OFDMA) network access involves timing and frequency synchronization. The frequency offset is produced by oscillator drifts and time-varying Doppler shifts. In mobile WiMAX 802.16e carrier frequency offset (CFO) can be divided into: integral carrier frequency offset (ICFO) and fractional carrier frequency offset (FCFO). There are mainly three methods for CFO estimation: data-aided method, blind and semi-blind. This paper is based on the semi-blind method presented in "Joint detection of integral carrier frequency offset and preamble index in OFDMA WiMAX downlink synchronization", IEEE, 2007 , see [2]. We simplify the algorithm presented in that paper by (a) using an adder-subtractor instead of using squares to estimate power and (b) by using a XNOR instead of complex multiplier; thereby reducing hardware gates by a factor of 676. Simulation results show only a slight degradation in performance with a considerable reduction in complexity.

Keywords-frequency synchronization, WiMAX, OFDM.

1. Introduction

In order to demodulate an OFDM signal, the receiver needs to perform two important synchronization tasks. First, optimal timing instants need to be determined. This is referred to as timing synchronization. Second, the receiver must align its carrier frequency as closely as possible with the transmitted carrier frequency. This is referred to as frequency synchronization. Compared to single-carrier systems, the timing-synchronization requirements for OFDM are in fact somehow relaxed, since the OFDM symbol structure naturally accommodates a reasonable degree of synchronization error. On the other hand, frequency synchronization requirements are significantly more stringent, since the orthogonality of the data symbols are reliant on their being individually discernible in the frequency domain [1]. The timing synchronization deals with packet detection, finding the start of the downlink frame and the start of each OFDM symbol. Furthermore, it deals with frequency sampling and timing sampling errors.

In this paper, a simplification for the joint detection of ICFO algorithm is described, reducing its hardware complexity in power calculation and hard decision stages. The organization of this paper is as follows. Through the rest of Section 1, we briefly overview the frequency synchronization constraints in different standards, emphasizing on WiMAX 802.16e and state its frame structure; in Section 2 joint detection of ICFO algorithm is explained stating reasons for applying it; Section 3 presents the proposed hardware simplification; Section 4 presents computer simulation results, and finally, conclusions are drawn in Section 5.

1.1. Frequency synchronization

Although data aided algorithms are most common in previous standards of Wi-Fi and even the 802.16d (fixed WiMAX); it can't be used in 802.16e. All of the existing OFDM systems can operate the detection and correction process easier than mobile WiMAX. In all previous OFDM systems the detection and correction process is done by transmitting unique preamble. As there is only one used preamble the correction of the offset is done by correlating the received preamble with the stored one at the receiver. On the other hand and in order to support multicell operation, the mobile WiMAX standard uses 114 selectable DL preamble sequences. Under unknown fading channels, a proper way for preamble index search is to employ non-coherent methods, i.e, non data aided [6]. Due to the WiMAX frame structure, it is reasonable to take a two-stage approach in which the timing offset and the fractional carrier frequency offset (CFO) is estimated and corrected .Then the ICFO and the preamble index is dealt with. Our paper focuses on ICFO.

1.2. Frequency synchronization constraints

The maximum allowed error is no more than 2% of the subcarrier spacing [3]. The transmit carrier frequency f_{tx}, the receive carrier frequency f_{rx}, and the clock frequency at the base station are derived from the same reference oscillator with accuracy better than $\pm 2\times 10^{-6}$. Another consideration is that substation must finish its frequency synchronization before the end of current symbol. After reaching the required synchronization it must be kept, and if the synchronization is lost again.

1.3. Frame stucture

The DL-subframe starts with a preamble. A preamble is one OFDMA symbol that contains known data. It is mainly used for synchronization in a mobile station (MS) receiver to correct the errors generated due to time and/or frequency shifts. Upon entering the network or upon a need to handover, the MS has to identify the preamble index of the BS segment that it will communicate with. Being only one OFDMA symbol, using the preamble for frequency synchronization is hard as there are no repeated data within one symbol to compare with. The preamble has a guard band and a zero DC subcarrier in the frequency domain and it has a cyclic prefix in the time domain as all other OFDMA symbols. The number of guard band subcarriers is 86 on the left side and the same on the right side. The remaining preamble subcarriers (1024 - 2×86 = 852) are indexed from 0 to 851 and are divided into three groups 0, 1, and 2. Each group contains the indexes (n + 3×k), where n is the group number and k is a running index from 0 to 283. A preamble uses one group of these three and sets the other two groups to zero. That makes the preamble has the form in figure 1. Preamble symbols are binary phase shift keying (BPSK) modulated. The used group

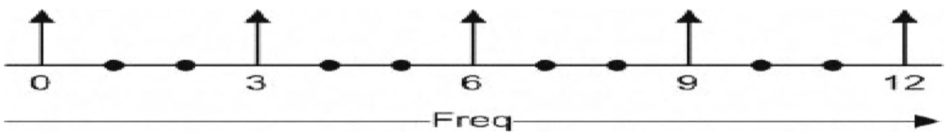

FIGURE 1. An example for the preamble structure

of subcarriers corresponds to the segment number. Each mobile WiMAX cell may be served by three different MAC layers differentiated by their segment number. Then the combination of the segment number and the cell ID defines the bit sequence that will be used to modulate the preamble subcarriers and the locations of these subcarriers. Since there are 3 segments, each having 32 preambles, that makes 96 possible preambles to be transmitted by the base station. The standard adds 18 more sequences with repeated combinations of the segment number and the cell ID. That makes a total of 114 possible preambles. The segment number and the cell ID are not given from the base station to the mobile stations by any messages. This makes one of the synchronization tasks of the MS receiver is to discover which preamble is transmitted and hence determine the segment number and the cell ID through cell search.

2. ICFO estimation based on joint detection

We consider here the joint detection of integral CFO and preamble index, under the assumption OFDM symbol boundaries and fine frequency offset have been acquired to reasonable accuracy. Based on an optimization formulation, a number of detection methods are driven of different complexity and optimization methods. The methods exploit the quasi-orthogonality among the OFDMA WiMAX preamble sequences as well as the organization of the nonzero subcarriers in the preambles [2]. This algorithm detect the integer frequency offset in range [-9:9 frequency offset pins] by correlation in frequency domain between the received preamble -that is one of the 114 preambles- and the 114 preambles stored in the receiver. The max correlation indicates the most probable preamble sent, then we can use it to calculate the integer frequency offset. If the spacing of the nonzero subcarriers in the preamble is much smaller than the coherence bandwidth of the channel, then the channel responses at neighboring preamble subcarriers are approximately equal,

$$\text{i.e., } H(k+3) = H(k) + \Delta H(k), \tag{1}$$

where $|\Delta H(k)| \ll |H(k)|$ and k is index for nonzero preamble subcarriers.

$$\begin{aligned} \Re e\{Q(k)Q^*(k-3)\} &= \Re e\{H(k)\, P_j(k+n)\, H^*(k-3)\, P_j^*(k+n-3)\} && (2)\\ &\approx |H(k)|^2\, D_j(k+n), && (3) \end{aligned}$$

where

- *Q(k):* is the received preamble in the frequency domain.
- $P_j(k)$*:* the transmitted preamble of index (j) in the frequency .
- $D_j(k) = P_j(k) \times P_j(k-3)$*:* preamble (j) multiplied by a shifted version of 3 subcarriers apart.
- *n:* is the integral frequency offset normalized to the subcarrier spacing.
- $\Re e$*:* is real part of the signal.
- $\Im$*:* is imaginary part of the signal.

The latter means that multiplying each active subcarrier by the conjugate of its predecessor will cancel the channel-added phase and then receieved preamble is correlated with the preamble patterns shifted by the expected values of the integral carrier frequency offset and select the maximum correlation as follows:

$$M_n^{n,j} = \sum_{k=0}^{N_p-1} D_j(k+n)\, \Re e\{Q(k)\, Q^*(k-3)\}, \tag{4}$$

where $\Re e\{Q(k)\, Q^*(k-3)\}$ is called the differential signal and N_p is the OFDM symbol without left and right guard-bands. The estimated integral CFO -carrier frequency offset- and preamble index are given by:

$$(\hat{n}, \hat{j}) = \arg\max_{n,j} M_{n,j}^n. \tag{5}$$

This method, however, requires large number of multipliers. A simplification is stated in [2] which makes hard decision on $\Re e\{Q(k)\, Q^*(k-3)\}$ then measures the Hamming distance with the sequence $D_j(k+n)$ instead of the correlation. We can call this simplification the hard decision approach. For the received preamble, the channel's effect is eliminated with each active subcarrier multiplied with its predecessor's conjugate. Then three power windows are taken in the middle of preamble symbol to determine the place of the active subcarriers. In addition, each window is shifted one subcarrier from the other two. Choosing the window that gives maximum power accumulation indicates the indices of active subcarriers, as well as, the "apparent" segment of the received preamble. This "apparent" segment is that the indexes of the active subcarriers may be changed by means of coarse frequency offset. Thus, each "apparent" segment has a set of possible shifts, see table 1. The focus here is on the hard decision approach which finds the Hamming distance between the received with and the 114 stored ones. The smallest distance represents most likely preamble; hence, finding the possible coarse shift and the preamble index. For further

TABLE 1. Possible shifts for each segment within a group

Group No	For segment 0	For segment 1	For segment 2
group 0	[-9, -6, ..., 9]	[-7, -4, ...,8]	[-8, -5, ...,7]
group 1	[-8, -5 ,..., 7]	[-9, -6, ...,9]	[-7, -4,...8]
group 2	[-7, -4, ...,8]	[-8, -5, ..., 7]	[-9, -6, ...,9]

understanding of the theoretical and mathematical concepts behind the joint detection algorithm refer to [2].

3. Proposed simplifications of the hard decision approach in joint algorithm

We took the hard decision approach a step further in simplification. That's to say, in the original algorithm, the elimination of the channel-added phase is through multiplying each sample by the conjugate of its predecessor, taking the real part, then making hard decision. To implement this, 870 complex multipliers can be used where (a + jb) complex number is implemented in 13 bit for real and imaginary parts to decrease quantization error. Considering the simplest multiplier: the carry save multiplier which consists of about 13 × 13 full adders. Inside of it, each full adder is about 4 XOR gates [7]. Instead, we propose the using of Xnor gates that is equivalent to $\Re e\{Q(k)\ Q^*(k-3)\}$, refer to equation 3. Thereby, reducing hardware gates by a factor of 676. Furthermore, we propose another simplification for the power calculation stage. To Reduce hardware complexity, the following is proposed: since calculating power for (a + jb) is equal to: $(a^2 + b^2)$. The whole point of calculating power here is to find window with maximum accumulation. Instead, of using 13-bit multiplier -squaring real and imaginary part-, the accumulation is changed into = $|a| + |b|$. No need for multipliers nor squares as seen in figure 3. For 13-bit complex number, accumulation is done on the most 12 significant bits with acceptable hardware performance, see next section.

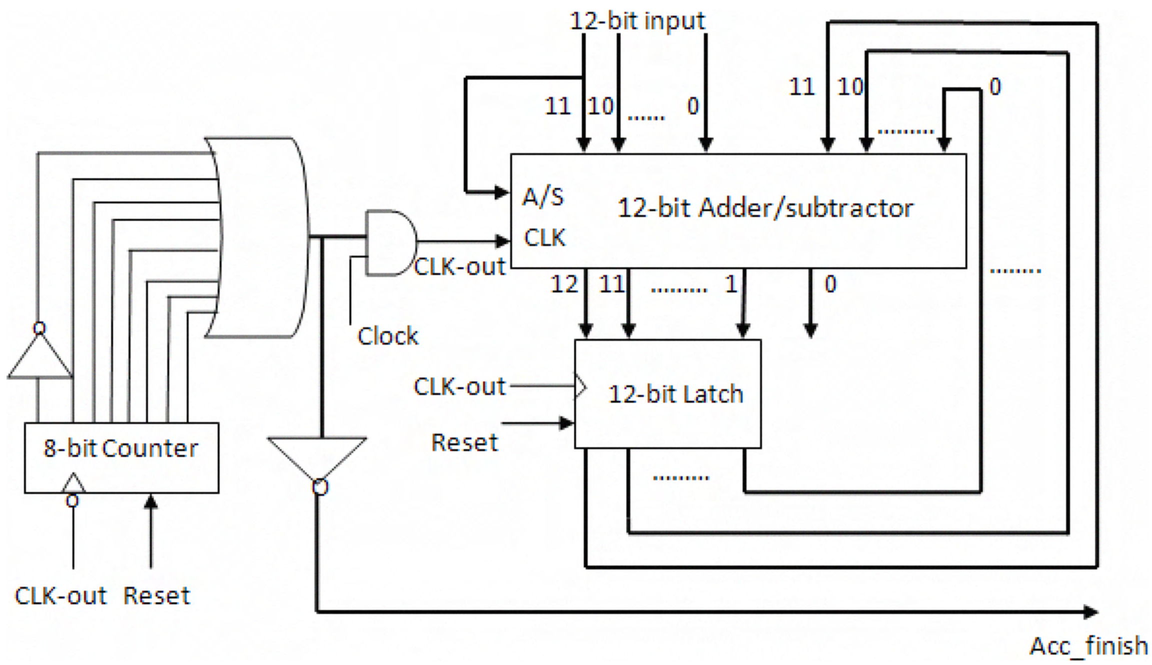

FIGURE 2. 12- bit accumulator

4. Simulation results

Illustrated in table 2 the parameters used, from [3]: There is a minor degradation in performance between the original design and the proposed approach as seen from figure 3. This

TABLE 2. WiMAX OFDM parameters

Symbol	Description	Relation	Used WiMAX value
B	Nominal bandwidth	B = $1/T_s$	10 MHz
L	Number of subcarriers	Size of IFFT/FFT	1024
G	Guard fraction	%of L for CP	1/4
F_s	sampling frequency	1 / T_s	11.2 MHz
T_s	Sample time	1/sampling frequency	89.2 *nano* sec
N_g	Guard band	N_g = GL	256
T_g	Guard time	$T_g = T_s N_g$	22.8 μ sec
T	OFDM symbol time	T = T_s(L+N_g)	114.2 μ sec
B_{sc}	Subcarrier spacing	B_{sc} = B / L	10.94 KHz.

degradation is in trade-off with the reduction in hardware complexity, still performance is acceptable. This figure, using the ITU-channel model profile-4, FFT (fast fourrier transform) output is fixed at 12-bit, also addition is fixed at 12-bit and window size of power calculation is 30 contiguous samples. Searching for a better performance, we can increase the length of window used for power calculation. Also an interleaved power window can be used to enhance the performance against narrow band interference.

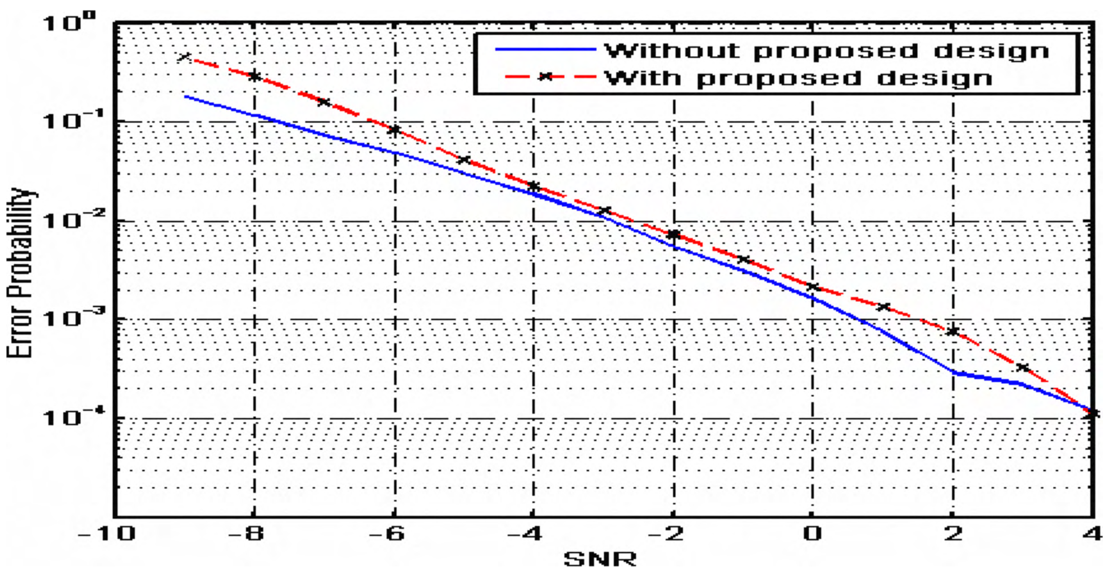

FIGURE 3. Effect of proposed design

5. Conclusion

This paper is based on the semi-blind the joint detection downlink synchronization algorithm for mobile WiMAX (802.16e). Two hardware simplification approaches are discussed to estimate the ICFO and make a cell search i.e. get the preamble number using less hardware. Finally, the results have been verified using MATLAB simulations.

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