*2011 International Conference on Computer Communication and Management*
*Proc .of CSIT vol.5 (2011) © (2011) IACSIT Press, Singapore*

# A New symbol Timing Synchronization Scheme for Multi Band OFDM Ultra Wideband (MB-OFDM UWB) systems

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**Abstract.** A new low complexity correlation based symbol timing synchronization algorithm called (MSTS) is presented for MB-OFDM UWB systems. The proposed algorithm attempts to locate the start of Fast Fourier Transform (FFT) window during frame synchronization (FS) sequence of the received signal. First, a correlation based function is performed between the current received sequence and the base sequence which is known in the receiver. A maximum likelihood metric is defined to identify the peak value of this function. Verifying the gained timing offset and averaging on several symbols is the last step to locate the start of the FFT window. The proposed algorithm shows great improvement in the MSE, synchronization probability and bit error rate metrics compared with those of earlier works.

**Keywords:** MB-OFDM, Synchronization, UWB.

## 1. Introduction

Ultra-Wideband (UWB) technology is the main candidate for short distance (<10 m) and high data rate (55-480 Mbps) communications in Wireless Personal Area Networks (WPAN). Multi band orthogonal frequency division multiplexing (MB-OFDM) based communication scheme is the most noteworthy, among the several proposals for efficient use of the 7.5 GHz bandwidth allocated for UWB technology.

MB-OFDM is the combination of OFDM modulation and data transmission using frequency hopping techniques. In this method, all the available bandwidth (3.1-10.6 GHz) is divided into 14 frequency bands each with 528 MHz of bandwidth. These 14 frequency bands are categorized in 5 groups. Each of the first 4 groups has 3 frequency bands and the fifth group contains only 2 frequency bands. Data is transmitted over different frequency bands using a *Time-Frequency code* (TFC), which causes frequency diversity and multiple access capability [1].

OFDM systems have the advantage of being able to operate as a set of N (number of subcarriers in the system) parrallel links over flat fading channels. However the performance of non-ideal OFDM systems is degraded by imprefections caused by timing offset, improper number of *cyclic prefix* (CP) and frequency offsets. Among all the imperfections, effect of timing offset on the system performance and bit error rate is much more sever.

Synchronization techniques for narrowband OFDM systems utilize maximum correlation between the received signal and timing symbols or CP [2-3]. All such techniques assume that the first received multipath component (MPC) is the strongest one. So, in a channel with dense multipath effects, a delayed stronger component may cause errorneous timing synchronization, which leads to Inter Symbol Interference (ISI) and destroys the orthogonality of OFDM subcarriers and degrades the performance [4].

Several algorithms are proposed for timing synchronization in MB-OFDM systems [5-8]. In [5], the proposed algorithm (FTA). detects the direct path by comparing the difference between two consecutive accumulated energy samples at the receiver against a predetermined threshold. However, the threshold is only determied by the probability of false alarm, while other important error measures such as the missed detection probability is not exploited. Further, the computational complexity is high due to the large amount of multiplications involved in the algorithm. In [6], a *correlation based symbol timing synchronization* (CBTS) has also been reported. The idea is similar to that of [5] and estimates the first significant multipath of the received signal by comparing the difference between two successive correlated MB-OFDM symbols against a predetermined threshold. compared with that of [5], the computional complexity is reduced and performances in terms of both the *mean square error* (MSE) of timing offset and the perfect synchronization probability are improved. These two algorithms [5-6] cannot operate properly at low SNR values due to imperfecttions in auto correlation property of the base sequence and the dense multipath channel enviroments. Combination of the autocorrelation function and restricted and normalized differential cross-correlation (RNDC) with a threshold-based detection is used in [7] to find the timing offset of the OFDM symbol. In [8], the proposed algorithm utilizes a maximum likelihood function to estimate the timing offset. Concentration of this algorithm is on frequency diversity and computational complexity is rather high.

In this paper, a modified symbol timing synchronization (MSTS) algorithm for MB-OFDM UWB systems is proposed, which utilizes time domain sequences to estimate the timing offset. The computational complexity of the proposed algorithm is reduced by simplification in correlation based and maximum likelihood functions. The organization of this paper is as follows: in Section 2, we present the MB-OFDM system model, MB-OFDM signal model and characteristics of an UWB channel. In Section 3, we describe the proposed algorithm for MB-OFDM timing synchronization and Section 4 shows the simulation results of our proposed algorithm and compares that with those reported in [5], and [6]. Important concluding remarks are made in Section 5.

# 2. MB-OFDM System Model

## 2.1. MB-OFDM Signal Model

Synchronization in MB-OFDM systems is data-aided [1]. In standard preamble structure, the first 21 packet synchronization (PS) sequences are used for packet detection, AGC stabilization, coarse timing and frequency synchronization. The next 3 frame synchronization (FS) sequences are meant for a fine timing and frequency synchronization. These sequences are followed by 6 channel estimation (CE) sequences as shown in Fig. 1. Depending on the time-frequency code, a particular preamble pattern is selected. The PS and FS sequences have the same magnitude but opposite polarity.

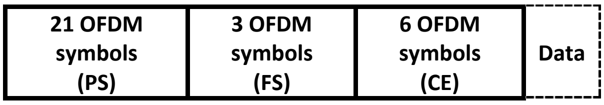


Figure 1. Frame Format in MB-OFDM Systems [1].

Consider $S_{s,n}(k)$ as k[th] sample of n[th] transmitted OFDM symbol, which is given by

$$S_{s,n}(k) = S_c(n) \times S_b(k). \tag{1}$$

In Eq. (1), $S_b(k)$ is the k[th] sample of the n[th] symbol in the time domain and $S_c(n)$ is the spreading code for the n[th] symbol and $k = 1,2,...,M$ and $n = 1,2,...,P$, which M is the number of samples in one OFDM symbol and P is the total number of transmitted symbols in $PS$, $FS$ and $CE$ sequences. MB-OFDM symbols prepared by suffixing 32 null samples called zero padded ($M_{ZP}$) and 5 null guard samples called ($M_g$) to FFT (IFFT) output sequences of length 128 (M) samples according to the frame format [10]. The total length of $M+M_{zp}+M_g$ samples of one MB-OFDM symbol is denoted by $M_T$.

## 2.2. UWB Channel Model

IEEE802.15.3 channel modelling sub-committee has specified 4 different channel models (CM1-CM4) depending on transmission distances based on a modified saleh-valenzuela (S-V) model [9]. UWB channel model is a cluster based model, where individual ray shows independent fading characteristics. An UWB channel not only shows frequency dependence of instantaneous channel transfer functions, but also the variations of averaged transfer function caused by different attenuations of different frequency component of an UWB signal [11].

Impulse response model of an UWB channel can be represented as

$$h(t) = \sum_{l=0}^{L} \sum_{k=0}^{K} a_{k,l} \ \exp(j\varphi_{k,l}) \ \delta(t - T_l - \tau_{k,l}). \tag{2}$$

In Eq. (2), $\{a_{k,l}\}$ and $\{\varphi_{k,l}\}$ are weighting coefficients and tap phases of the k[th] component in l[th] cluster, respectively, and $h(t)$ represents small scale fading amplitude. Delay of k[th] MPC toward arrival time of l[th] cluster, $\{T_l\}$, is shown with $\{\tau_{k,l}\}$. We also define n(t) as a zero mean additive white Gaussian noise (AWGN) with variance $\sigma_n^2$. The received signal with timing offset equal to $\theta$ could be described as following

$$r(k) = \sum_{i=0}^{L-1} S_s(k-\theta).h(i) + n(k). \tag{3}$$

# 3. Proposed MSTS Algorithm

The main objective in the symbol timing synchronization is to find the timing offset of the received symbol. To attain this goal, it is assumed that the receiver can detect the OFDM symbol and there is no received noise-only packet. In the first stage a cross-correlation based function is defined to calculte the correlation between the received signal with timing offset and base sequence as given below

$$F(\theta) = \sum_{k=0}^{M-1} r(k+\theta).S_b(k). \tag{4}$$

In the above equation $\theta$ represents the timing offset of the current OFDM symbol and * denotes the complex conjugate operation. Maximum value of cross correlation function can be found by a maximum likelihood based metric, which is given by

$$\lambda(\theta) = \left|\mathrm{Re}(F(\theta)) \times \mathrm{Im}(F(\theta))\right|. \tag{5}$$

As the timing offset decreases the value of $\lambda(\theta)$ in Eq. (5) increases. We define $S_N$ as the index of the received m[th] sample sequence and $\omega(S_N)$ as the time instant of the first sample for that sequence. Inserting $S_N$ and $\omega(S_N)$ in Eq. (5) the maximum likelihood metric can be written as

$$\lambda(\omega(S_N)) = \left|\mathrm{Re}(F(\omega(S_N))) \times \mathrm{Im}(F(\omega(S_N)))\right|. \tag{6}$$

Due to the modified S-V channel model, the first arriving path may not be the strongest one. As a result, using only the conventional cross-correlation function will locate a delayed multipath component with stronger amplitude as the first one and hence will cause misdetection. To correctly estimate the position of the first arriving path, we take the moving average of $\lambda(\omega(S_N))$ over a window of size $N_c$ where most of the channel energy is concentrated. In other words

$$\lambda'(\omega(S_N)) = \sum_{w=0}^{N_C-1} \lambda(\omega(S_N)+w). \tag{7}$$

This could be substituted by the following recursive equation as given below,

$$\lambda'(\omega(S_N)+1) = \lambda'(\omega(S_N)) + \lambda(\omega(S_N)+N_C) - \lambda(\omega(S_N)). \tag{8}$$

In the above equation, $N_c$ is considered as the maximum delay spread of the multipath channel. Eq.(7) should be calculated for all samples in one OFDM symbol. The exact symbol boundary ($\omega^o(S_N)$) could be found by the following equation

$$\omega^o(S_N) = \arg\max_{\omega}\left\{\lambda'(\omega(S_N)), \lambda'(\omega(S_N)+1), \ldots, \lambda'(\omega(S_N)+M-1)\right\}. \tag{9}$$

If the calculated value of $\omega^o(S_N)$ in Eq. (9), stands in the range of added zero prefix ($M_{ZP}$), all the subcarriers would experience the same phase shift that could be removed in the receiver. If the value stands out of this range, ISI occurs and subcarriers try different phase shifts that degrade the system performance. Since transmission channel varies in time, timing offset of each symbol is different from others. To find the exact timing offset, we average the calculated timing offset for $N_R$ symbols. Detailed flowchart of the proposed algorithm (MSTS) is shown in Fig. 2. If the estimated value stands in the ISI free zone (sample index $1 \to M_{ZP}$), synchronization is done. If the estimated value stands in the sample index $M_{ZP}+1 \to M_T$, wrong synchronization is performed and the false alarm probability ($P_F$) increases.

# 4. Simulation Results

In simulation of the proposed algorithm (MSTS), it is assumed that the receiver can detect the symbol, there is no noise-only packet and there are no other imperfections except timing offset. The channel model CM1 (0-4 meter line of sight and 5 nanosecond delay spread) and CM2 (0-4 meter non line of sight and 8 nanosecond delay spread) are used. It is also assumed that the first pattern of time-frequency code (TFC1) is used in data transmission and frequency synchronization is ideal. Also $N_C$ and $N_R$ are considered to be 20 and 10, respectively. The performance of the system is evaluated by the MSE of timing offset, probability of synchronization ( $P_{sync}$ ) and bit error rate (BER). Numerical results for the MSE and $P_{sync}$ metrics are listed in Table 1 and 2, respectively. As shown in table 1, in the MSE metric, a great improvement is achieved in all SNR values especially in low values both in CM1 and CM2 channel model compared with those of the CBTS and FTA. Table 2 indicates that in $P_{sync}$ metric and high SNR values, the performance is the same as that of the CBTS algorithm in CM1 channel. In low SNR values and both CM1 and CM2 channel model and High SNR values and CM1 channel model, performance is improved compared with that of the CBTS. In all SNR values and both channel models, performance of the proposed algorithm is better than that of the FTA.

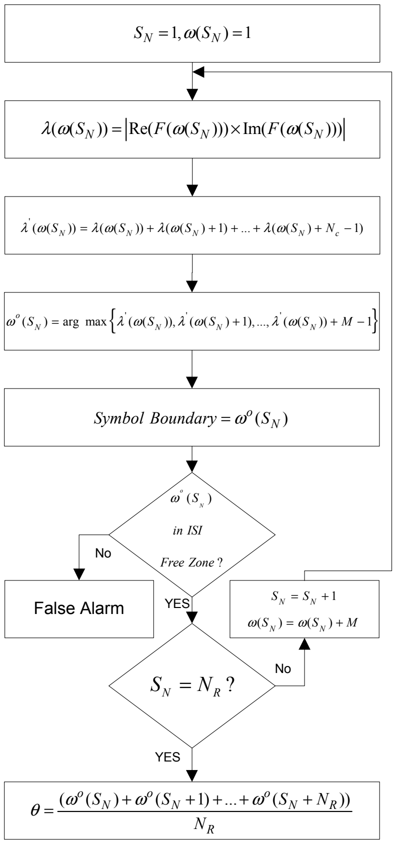


Figure 2. The proposed MSTS synchronization algorithm.

Table 1. Timing offset MSE of the proposed algorithm and its comparision with FTA[5] and CBTS[6].

| MSE | | | | | | |
|---|---|---|---|---|---|---|
| SNR | CM1 | | | CM2 | | |
| | MSTS | CBTS | FTA | MSTS | CBTS | FTA |
| noiseless | 0.25 | 0.32 | 0.32 | 4 | 5.8 | 4.2 |
| 17 dB | 0.28 | 0.49 | 0.36 | 5.5 | 8 | 9 |
| 10 dB | 0.31 | >>10 | >>10 | 6.2 | >40 | >40 |
| 0 dB | 7 | >>10 | >>10 | 23 | >40 | >40 |

Table 2. Synchronization probability ($P_{sync}$) of the proposed algorithm and its comparison with FTA[5] and CBTS[6].

| $P_{sync}$ | | | | | | |
|---|---|---|---|---|---|---|
| SNR | CM1 | | | CM2 | | |
| | MSTS | CBTS | FTA | MSTS | CBTS | FTA |
| noiseless | 95% | 95% | 85% | 94% | 86% | 55% |
| 17 dB | 94% | 94% | 81% | 92% | 80% | 49% |
| 10 dB | 89% | 78% | 71% | 81% | 40% | 25% |

| | | | | | | |
|---|---|---|---|---|---|---|
| 0 dB | 63% | 41% | 34% | 43% | 32% | 10% |

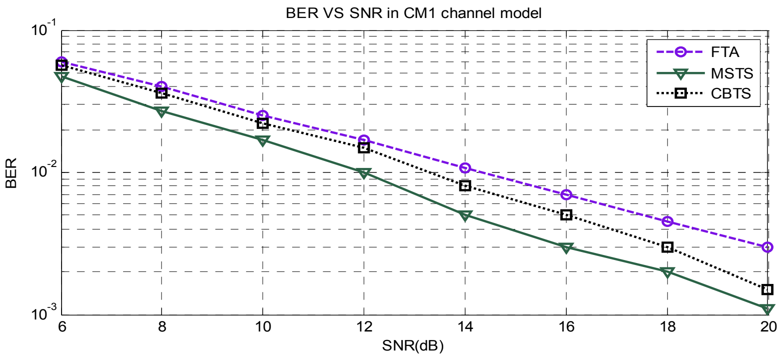


Figure 3. Bit error rate of proposed algorithm and its comparision with FTA[5] and CBTS[5] in CM1 channel model.

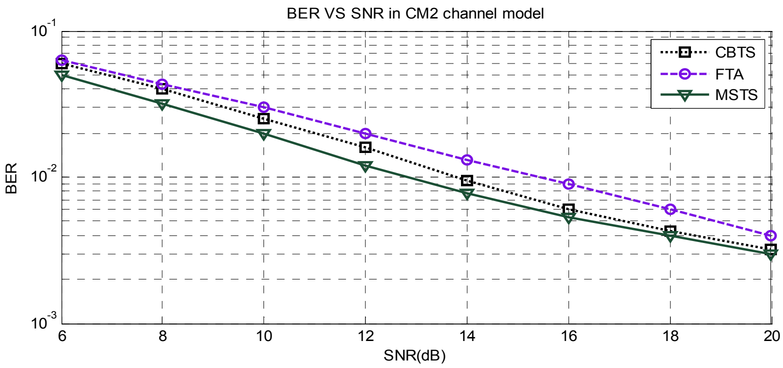


Figure 4. Bit error rate of proposed algorithm and its comparision with FTA[5] and CBTS[5] in CM2 channel model.

# 5. Conclusions

In this paper, a new symbol timing synchronization algorithm proposed for MB-OFDM UWB systems. In the proposed algorithm, computational complexity is reduced and no threshold is required in the synchronization process. Numerical results show significant improvement in the timing offset MSE, probability of synchronization ($P_{sync}$) and bit error rate metrics in comparision with FTA and CBTS algorithms.

# 6. Acknowledgements

This research is partially funded by the Iranian Institute of information and Communication Technology (the former ITRC).

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