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Analysis of Timing Synchronization with CE for UWBSystem under Fading Channels

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ABSTRACT: In this paper, the BER (bit error rate) of Ultra Wide Band (UWB) block transmission system is analyzed under different multipath channel conditions. The effect of timing error in UWB transmission system is observed with existing least mean square (LMS) channel estimation scheme. A new channel estimation scheme with timing synchronization is proposed here which can reduce the BER to very high extent in case of multipath transmission of OFDM or single carrier block transmission with frequency domain equalization (SC-FDE) UWB systems. This scheme is based on channel impulse response (CIR) of the coarse timing error (CTE) to fine tune the timing position and frequency domain equalization coefficients. This joint scheme also reduces preamble overhead by performing timing synchronization along with the channel estimation and gives less BER with respect to a certain timing error which is again analysed here.

KEYWORDS: OFDM, UWB, SC-FDE, BER, coarse timing error, timing synchronization, channel estimation.

I. INTRODUCTION

In this article two types of block transmission techniques has been proposed for high rate Ultra wideband (UWB) communication system: orthogonal frequency division multiplexing (OFDM) [1] and single carrier with frequency domain equalization (SC-FDE) [2], which are compared to impulse based UWB communication system in terms of energy collection and equalization complexity in multipath UWB channels. SC-FDE is less robust to timing error although it has low PAPR (peak to average power ratio) and is less sensitive to carrier frequency offset compared to OFDM. [3].Because of very high data rate and more dispersive channel for the UWB system, the timing synchronization becomes more challenging than the conventional wideband systems. The preamble assisted synchronization is more preferable for OFDM in the traditional wideband systems [4]–[7]. Minnet. al. [6] have designed a timing synchronization method with frequency offset which has improved training patterns and a robust timing metric function that has a very sharp trajectory. The training symbol contains L identical component swith possible sign inversions and the CIR (channel impulse response) estimated from one identical component is used for fine timing adjustment. Large size FFT (Fast Fourier Transform) cannot be implemented in UWB system due to cost and complexity constraints. The CP (cyclic prefix) must be short in length corresponding to the small FFT size to maintain a reasonable overhead. A highly dispersive channel is also longer than CP in some cases, which causes IBI (inter-block interference).

II. RELATED WORK

It is well known that Chang proposed the original OFDM principles in 1966, and successfully achieved a patent in January of 1970. OFDM is a technique for transmitting data in parallel by using a large number of modulated subcarriers. These sub-carriers divide the available bandwidth and are sufficiently separated in frequency so that they are orthogonal. The Orthogonality of the carriers means that each carrier has an integer number of cycles over a symbol period.Cyclic prefix (CP) or cyclic extension was first introduced by Peled and Ruiz in 1980 for OFDM systems. In their scheme, conventional null guard interval is substituted by cyclic extension for fully-loaded OFDM modulation.



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As a result, the Orthogonality among the subcarriers was guaranteed. With the trade-off of the transmitting energy efficiency, this new scheme can result in a phenomenal ISI (Inter Symbol Interference) reduction. Hence it has been adopted by the current IEEE standards. The proposed scheme saves preamble overhead by performing joint synchronization and channel estimation, and outperforms existing timing acquisition methods in the literature in dense multipath UWB channels. In addition, the impact of timing error on channel estimation and the performance of SCFDE UWB systems are analyzed, and the bit-error-rate (BER) degradation with respect to a certain timing error for AWGN, Rayleigh and Rician fading channels are derived.

III. SYSTEM MODEL

This system model adopts cyclic prefixed single carrier block transmission with frequency domain equalization over UWB channel, the synchronization technique developed is directly applied to an OFDM system. The *p*th transmitted block comprises of digitally modulated symbols xp, $(0 \le k \le N - 1)$, where *N* is the block length. To make the system IBI free, a cyclic prefix of length Ng is used as in an OFDM system. The symbol spaced CIR is denoted by h = [h0, h1, ..., hL], where *L* is the maximum delay in the channel. The UWB channel is assumed to be constant over the data blocks. If the maximum channel delay is shorter than the length of CP (L < Ng), there is no IBI in data demodulation with perfect timing. The task of synchronization in cyclic prefixed block transmission systems can be achieved in the IBI-free region of the CP ([-Ng + L, 0]) [5]. As long as the FFT window starts within the IBI-free region, data demodulation can be carried out perfectly. Otherwise timing error will cause performance degradation to a system.

IV. CE SCHEME WITH TIMING SYNCHRONIZATION

Timing within the IBI-free region causes no extra interference to the detection. But, in UWB system, the IBI-free interval is given as a short CP which is very small or nearly zero, depending on channel realizations. So, it is required to locate the first significant arrival path of the transmitted signal block, which is defined as the exact timing point in the following.



Fig - 1: The preamble structure; A',B': cyclic prefix

A. Preamble Structure and Coarse Timing

As in dense multipath channels, coarse timing falls far away from the exact timing due to the large channel dispersion, the coarse timing obtained by evaluating a metric function may not provide sufficient accuracy. So estimated channel information is used for fine tuning the timing position. A new preamble structure is designed to obtain the periodical property for acquisition and cyclic structure for accurate CE whose result will be used in the subsequent timing adjustment and frequency domain equalization. As shown in Fig. 2, in addition to the CP, a cyclic suffix is padded after the preamble body. In the proposed preamble shown in Fig. 1, A and B represent the first half and the second half of one block generated by

$$P_t(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} P_t(k) e^{j2\pi nk / N} \quad 0 \le k \le N-1$$

where (k) is a random ±1 sequence in frequency domain (FD), referred to as FD pilot block, which results in flat amplitude in FD for good CE performance. The [A B] structure can be repeated *M*times and finally a prefix and a suffix are added to have [B'A B ... BA']. The length of the prefix and suffix denoted by *Nx*needs to be larger than the



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maximum coarse timing error, and *Nx*should be larger than the channel length *L*to avoid IBI. By repeating [A B] we can achieve noise averaging for more accurate CE, and the adjacent [A B] blocks serve as cyclic extension. Thus the synchronization and CE overhead is 2Nx+N, smaller than the preamble pattern proposed in [1] where the overhead is 2(N+Ng). Following the conventional auto-correlation based metric function; we define our timing metric function as

$$M(d) = \frac{2|C(d)|}{R(d)} = \frac{2|\sum_{t=0}^{2N_x + (M-1)N-1} r_{d+t}^* r^d + N + i|}{\sum_{i=0}^{2N_x + (M-1)N-1} (|r_{d+i}|^2 + |r_{d+N+i}|^2)}$$

and coarse timing is established by finding the maximum of (2) as given by $\theta c = \max dM(d)$. Note the range of d to look for the maximal can be defined as $[\theta s, \theta s + Q]$, where θs is the point where the metric function first exceeds the preset threshold and Q can be set as N. To reduce the computation complexity at the implementation stage, the metric can be implemented in an iterative manner similar to [4] as

$$C(d+1) = C(d) - r_d^* r_{d+N} + r_{d+2N_x+(M-1)N}^* r_{d+2N_x+MN}$$

And
$$R(d+1) = R(d) - |r_d|^2 - |r_{d+N}|^2 + |r_{d+2N_x+(M-1)N}|^2 + |r_{d+2N_x+MN}|^2$$

B. Channel Estimation and Timing Adjustment

In this step, CE is carried out using the same preamble after the initial acquisition and the estimation accuracy is not affected by the timing error. Consider the low complexity least square (LS) channel estimation. If M = 1, the frequency domain CE is given by $H'(k) = P_r(k)/P_t(k)$, where $P_r(k)$ and $P_t(k)$ denote the received and transmitted frequency domain training symbol at the *k*th sub-channel respectively. The estimation can be improved by employing the repetitive [A B] structure to reduce the noise effect. In addition, the cyclic structure given by B' and A' provides IBI-free CE as long as the coarse timing error $|\varepsilon c| < Nx$. The estimated channel is given by $H'_k = H_k e^{j2\pi\varepsilon_c k/N} + W_k$



Fig - 2: Block diagram of timing synchronizer for UWB system

The block diagram of the entire timing synchronizer for SC-FDE UWB systems is shown in Fig. 2. When the timing metric module detects the coarse timing point, it passes the received signal to the subsequent modules. The LS estimator estimates FD channel response H'_k based on the coarse FFT window, and then the coarse timing error is estimated by the CTE estimator based on the coarse CE result. Finally the CTE estimation is used to adjust the FFT window position and the FDE channel coefficients.



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V. SIMULATION RESULTS

At first, the effect of timing error on SC-FDE system with MMSE equalization is simulated and compared with the theoretical result. Fig. 4 and 5 show the BER performance in AWGN and Rayleigh fading channel with various positive timing errors, from which we can observe the similarities between the analytical result and the simulation.





The set of curves in fig-3 representing BER1 refers to the bit error rate in AWGN channel without timing synchronization and without channel estimation. It shows almost all bits are erred if there is a little timing error and for no timing error BER comes 50%. When the channel estimation is applied to the receiver of the UWB system, then the BER reduces which is represented as BER2. When both channel estimation and timing synchronization is applied then the BER reduces drastically and this is represented as BER3 in this figure.



Fig - 4: BER performance in Rayleigh fading channel



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This set of curves in fig-4 shows the BER performance over Rayleigh fading channel. BER1 represents bit error rate of the system when both timing synchronization and channel estimation are disabled, which is similar to that in AWGN channel. BER2 shows the performance under CE enabled and BER3 gives the performance when both CE ant timing synchronization are enabled.



Fig - 5: BER performance in Rician fading channel

This set of curves in the above figure shows the BER performance over Rician fading channel. BER1 represents bit error rate of the system when both timing synchronization and channel estimation are disabled, which is similar to that in AWGN and Rayleigh fading channels. BER2 shows the performance under CE enabled and BER3 gives the performance when both CE and timing synchronization are enabled.

VI. CONCLUSION AND FUTURE WORK

This scheme of combined timing synchronization with channel estimation can reduce the BER of the system very efficiently in case of AWGN channel. But in case of Rayleigh fading and Rician fading channels, it gives better performance only when the timing errors are less than 8 units. Further the BER with respect to the timing error increases exponentially. We can now work for reducing the BER for these two types of fading channels as well as we can make analysis of other types of fading channels for indoor and outdoor propagation models. In this scheme we have implemented QPSK, which may also be replaced by some other modulation scheme to increase the performance of the system under fading channels.

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