

Winner-Hopf Interpolation Aided Kalman Filter-Based Channel Estimation for MB-OFDM UWB Systems in Time Varying Dispersive Fading Channel

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Abstract—New channel estimation technique is proposed for multiband orthogonal frequency division multiplexing (MB-OFDM) ultra wideband (UWB) systems in multipath time varying wireless channels. Two-stage approach has been used to achieve this purpose. In first stage, Winner-Hopf filtration has been employed for the interpolation of unknown channel state information (CSI) using comb-type known pilots. In second stage, interpolated channel statistics are then modeled as autoregressive (AR) process and fed into kalman filter. Moreover, in order to suppress intercarrier interference (ICI), an ICI mitigation filter does jointly work with kalman filter. A mathematical framework is given for the realization of our proposed system. Link level simulation (LLS) shows that this new technique shows exact channel tracking and provides better symbol error rate (SER) performance.

I. Introduction

Ultra-wideband (UWB) technology has gained much attention during the last few years as a potential candidate for future wireless short-range data communication. Federal communications commission (FCC) has already allocated the spectrum from 3.1 GHz to 10.6 GHz for UWB applications. Due to its large bandwidth UWB has the promise of high data rates [1].

Due to a number of reasons such as giant financial backup by Intel/TI/many others, similar in nature to IEEE 802.11g/n and spectrum shaping flexibility

for international use, MB-OFDM is considered to be the pioneer implementation approach for UWB technology. In addition, if compared with a single-band impulse radio (IR) (classical UWB); the MB approach optimizes the use of UWB spectrum allocation.

In 2008, ECMA International has already published standard ECMA-368 for high rate ultra wideband PHY and MAC specifications [2]. According to the standard, the MB-OFDM approach divides the UWB spectrum into 14 bands, each with a bandwidth of 528 MHz. The first 12 bands are then grouped into 4 band groups consisting of 3 bands, and last two bands are grouped into a fifth band group. A total of 110 sub-carriers (100 data carriers and 10 guard carriers) are used per band. In addition, 12 pilot subcarriers allow for coherent detection (channel estimation purpose).

The radio channel in mobile radio systems are usually multipath fading channels, which are causing intersymbol interference (ISI) in the received signal. To remove the ISI from the signal many kind of equalizers can be used. However these detectors require knowledge on the channel impulse response (CIR), which can be provided by a separate channel estimator. In this paper, we are going to propose a new channel estimation technique suitable for MB-OFDM system.

In [3], authors shows that comb-type pilot based channel estimation with low pass interpolation

performs the best for OFDM system. Perfect channel estimation [4 and 5] can be used in OFDM systems to improve their performance by allowing coherent demodulation. Robust channel estimation [6] performs nice in rapid dispersive fading channels due to estimator's insensitiveness to channel statistics. But none of these estimators have been evaluated for UWB communications. Low complexity channel estimation [7] can be used in UWB communications but that is for static network and hence mobility is not supported even to some. Study [8] on channel estimation algorithms for MB-OFDM shows that most of the estimators are for the OFDM systems and adopting IEEE 802.11g/n, IEEE 802.15.3a. To the best of our knowledge, no one has worked for channel estimation which makes full use of the specifications of high rate UWB set by [2]. In this article, we have proposed a channel estimation technique that will use Winner-Hopf interpolation [9] to promote Kalman filter to obtain a smooth tracking of channel state information (CSI) for MB-OFDM system. To cope the time varying nature of fading channel and hence to support the

mobility, we have used ICI suppression technique [10] which will jointly work with channel estimation. Moreover, we adopt comb-type pilot [3] to complete kalman filter-based channel estimation.

II. MB-OFDM UWB System Description

According to the outline of high rate ultra wideband PHY and MAC standard [2], our proposed MB-OFDM UWB system architecture is shown in Figure 1. This system diagram is similar to baseband model of a typical OFDM system given in [3] with a modification in receiving part. Motivated by the interference suppression technique proposed in [10], the receiving part incorporates ICI mitigation filter as an additional signal processing block right after the channel estimation block.

The coded and interleaved binary serial input data, $b[i]$ where $i=0, 1, 2, \dots$, shall be divided into groups of two bits and converted into a complex number representing one of the four QPSK constellation

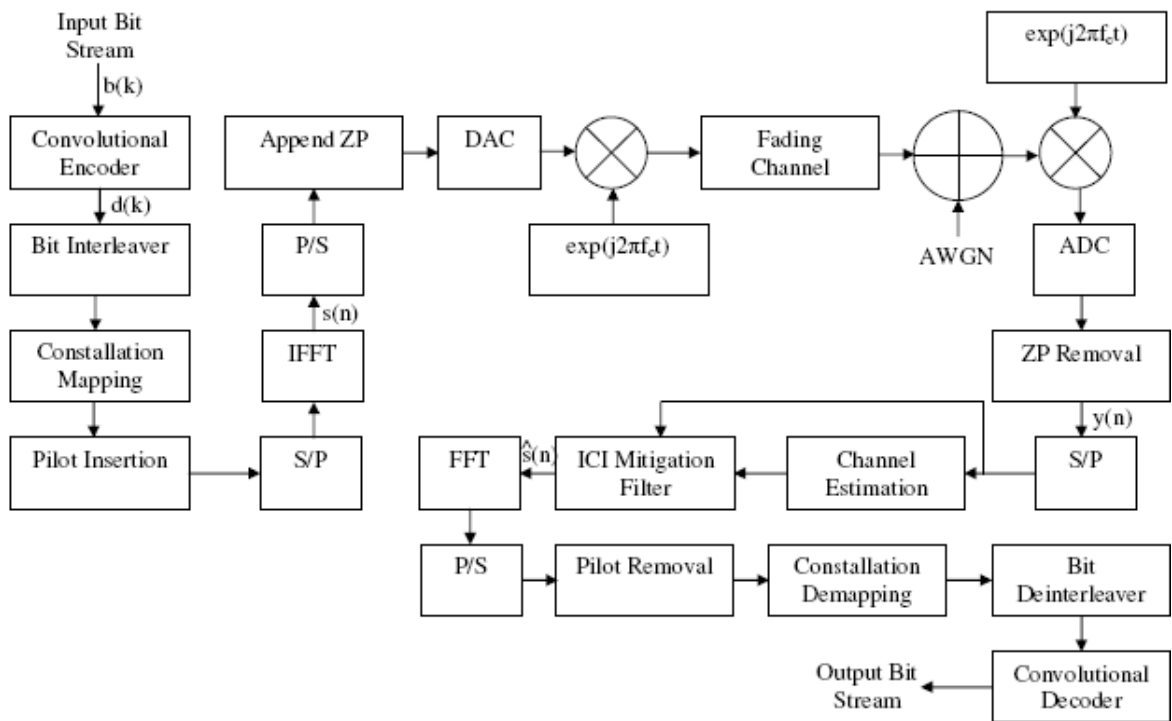


Figure 1: Block diagram of proposed MB-OFDM UWB system.

points (for data rates 200 Mbps and lower). The conversion shall be performed according to the Gray-coded constellation mapping. The output values, $d[k]$ where $k=0, 1, 2, \dots$, are formed by multiplying $(2 \times b[2k]-1) + j(2 \times b[2k+1]-1)$ value by a normalization factor of K_{MOD} , as described in the following equation:

$$d[k] = K_{MOD} \times [(2 \times b[2k]-1) + j(2 \times b[2k+1]-1)] \quad (1)$$

The discrete time signal, $s(n, k)$, shall be created by taking the IFFT of the stream of complex values as follows:

$$s(n, k) = \frac{1}{N_{FFT}} \left[\sum_{l=0}^{N_D} C_{D,n}[l] \exp(j2\pi M_D[l]k / N_{FFT}) + \sum_{l=0}^{N_G} C_{G,n}[l] \exp(j2\pi M_G[l] / N_{FFT}) + \sum_{l=0}^{N_P} C_{P,n}[l] \exp(j2\pi M_P[l] / N_{FFT}) \right] \quad (2)$$

where $k \in [0, N_{FFT}-1]$, N_D is the number of data subcarriers, N_G is the number of guard subcarriers, N_P is the number of pilot subcarriers, and $C_{D,n}[l]$, $C_{G,n}[l]$, $C_{P,n}[l]$ are the complex numbers placed on the l^{th} data, guard and pilot subcarriers of the n^{th} OFDM symbol, respectively.

The transmitted RF signal (signal into the channel) can be written in terms of the complex baseband signal as follows:

$$S_{RF}(t) = \text{Re} \left\{ \sum_{n=0}^{N_{packet}} s_n(t - nT_{SYM}) \exp(j2\pi f_c(q(n))t) \right\} \quad (3)$$

where $\text{Re}(\cdot)$ represents the real part of the signal, T_{SYM} is the symbol length, N_{packet} is the number of symbols in the packet, $f_c(m)$ is the center frequency for m^{th} frequency band, $q(n)$ is a function that maps the n^{th} symbol to the appropriate frequency band

and $s_n(t)$ is the complex baseband signal representation for the n^{th} symbol.

For the sake of simplicity, we ignore RF part of signal and do the analysis at discrete time case. The symbol received at any instant of time is distorted by fading channel and additive white Gaussian noise (AWGN) as:

$$y(n) = \sum_{l=0}^{L-1} h(n, l) d(n, l) + w(n) \quad (4)$$

where L is the number of multipath, $h(n, l)$ is the time varying CIR and $w(n) \sim N(0, \sigma^2)$.

Time varying frequency response of channel at time instant n is defined as

$$H(n, k) = \frac{1}{\sqrt{N}} \sum_{l=0}^{L-1} h(n, l) \exp(-j2\pi kl / N) \quad (5)$$

In fact, the modulated symbol has a contribution not only from the desired symbol but also from the other transmitted symbols which constitutes interference called intercarrier interference (ICI) apart from additive noise. Hence, $y(n)$ can be written as [10]:

$$y(n, k) = d(n, k) H(n, k) + \sum_{m=0, m \neq k}^{N-1} ICI(m, k) + w(n, k) \quad (6)$$

III. Channel Estimation

A. Channel Model

Considering the channel is Gaussian wide sense stationary uncorrelated scattering (GWSSUS) with uniformly distributed angle of arrival, we use modified Jake's model. Then we have the following correlation equation for the channel gain $H(n, k)$ [11]:

$$R_{HH} = E \{ H(m, k) H^*(n, l) \} = J_0(2\pi f_d(m-n)T_{SYM}) \frac{1 - j2\pi(l-k)\tau_t / T_{SYM}}{1 + 4\pi^2(l-k)^2 \tau_t^2 / T_{SYM}^2} \quad (7)$$

where f_d is the maximum Doppler frequency, τ_r the maximum delay spread of the multipath channel and $J_0(\cdot)$ is the zeroth-order Bessel function of the first kind.

B. Interpolation using Winner-Hopf filtration

We have performed interpolation to get the channel state information (CSI) in intermediate time-instants/subcarriers using known position of comb-type pilots. The use of sample collection of the random process values and its derivatives in the interpolation nodes is more effective than using samples collections of random process values [9].

Let the realization of the random process $h(n, k)$ is defined on the interval $n \in n_0 + N$ while the interpolation nodes are defined at the moment of n_0 and N . In this interval we will interpolate the value of realization $h(n_0 + \Delta n)$ where $0 \leq \Delta n \leq N$ using sample collection $h(n_0), h(n_0 + N)$ or the sample collection $h(n_0), h'(n_0), h(n_0 + N), h'(n_0 + N)$ and sample collection $h(n_0), h'(n_0), h''(n_0), h(n_0 + N), h'(n_0 + N), h''(n_0 + N)$ as well. Then the correlation matrix R will be computed from $R(\Delta n) = \sigma^2 \rho(\Delta n)$ [9] where $\rho(\Delta n)$ is the normalized correlation function and hence

$$R = \sigma^2 \begin{vmatrix} 1 & \rho''(0) & \rho(N) & \rho''(N) \\ \rho''(0) & \rho^{(4)}(0) & \rho''(N) & \rho^{(4)}(N) \\ \rho(N) & \rho''(N) & 1 & \rho''(0) \\ \rho''(N) & \rho^{(4)}(N) & \rho''(0) & \rho^{(4)}(0) \end{vmatrix} \quad \text{--- (8)}$$

C. Kalman Filtering and ICI suppression

In this stage, the interpolated channel, obtained from (7) and (8) (replacing R matrix from equation 8 into equation 7), will be further modeled as an autoregressive (AR) process. Since channel is

already interpolated, a simple first order AR process is sufficient as:

$$H(n) = \phi_1 H(n-1) + w(n) \quad \text{--- (9)}$$

where ϕ_1 is the parameter of AR model used.

Accordingly, kalman filter equations can be written as below [12]:

Initial conditions are:

$$\begin{aligned} \hat{H}(0) &= E\{H(n)\} = 0; \text{ and} \\ p(1) &\geq \{\sigma_w^2 \text{ and } \sigma_v^2\} \\ \text{--- (10)} \end{aligned}$$

$$\text{Kalman gain: } k(n) = \frac{p(n)}{p(n) + \sigma_v^2} \quad \text{--- (11)}$$

Current estimate:

$$\hat{H}_{curr}(n) = \hat{H}(n) + k(n)[H(n) - \hat{H}(n)] \quad \text{--- (12)}$$

Predicted estimate;

$$\hat{H}(n+1) = \phi_1 \{\hat{H}_{curr}(n)\} \quad \text{--- (13)}$$

where σ_w^2 , σ_v^2 , $p(n)$, $H(n)$, $\hat{H}(n)$ and $\hat{H}_{curr}(n)$ are noise variance, error variance, error covariance, known channel (pilot), interpolated channel and kalman estimate of current channel respectively.

Before the final demodulation ICI suppression filter produces its output according to the following equation [10]:

$$\hat{s}(n) = p(n)w(n) \hat{H}_{curr}(n) p^H(n) + p(n)w(n) \quad \text{--- (14)}$$

IV. Simulation and Results

Computer simulation has been performed to evaluate the system performances and we used MATLAB as simulation software. Frequency hopped (FH) point to point communication has been simulated using three frequency bands, where the first symbol is transmitted on a centre frequency of 3432 MHz, the second symbol is transmitted on a centre frequency of 3960 MHz, the third symbol is transmitted on a centre frequency of 4488 MHz, the fourth symbol is transmitted on a center frequency of 3432 MHz, and so on. The energy of pilot symbols is taken two times that of data symbols. All other

related parameters are selected according to specifications in [2]. Simulation results have been found from the average of 1000 realizations.

Now let us evaluate the system in terms of its performances under a time varying nature of multipath environment having a normalized Doppler spread ($f_d T$) of 10%. Figure 2 shows channel tracking performance where horizontal axis is limited to 100 samples for the ease of visual inspection. As seen from the figure, estimated channel gain does almost agree the true channel gain. Figure 3 shows the symbol error rate (SER) performance. SER performance of our proposed system is compared with that of low pass interpolated LS and MMSE based channel estimation. The performance of LS estimation is very poor compared to that of our proposed technique and MMSE. It shows that at high signal to noise ratio (SNR), SER performance is almost similar to that of MMSE. At very low SNR, MMSE estimation gives good performance. But within a range of moderate SNRs, our system outperforms MMSE estimation by 3 dB more or less.

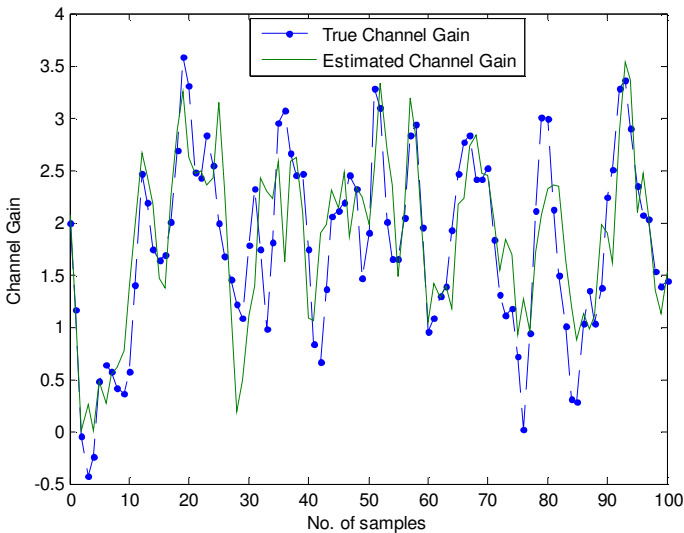


Figure 2: Channel tracking performance

V. Conclusion

The estimation technique in this study can be efficiently used to estimate the channel in MB-OFDM UWB systems. Interpolation of higher order

derivatives provides a pre-stage tracking of dispersive fading channel. And then the joint work

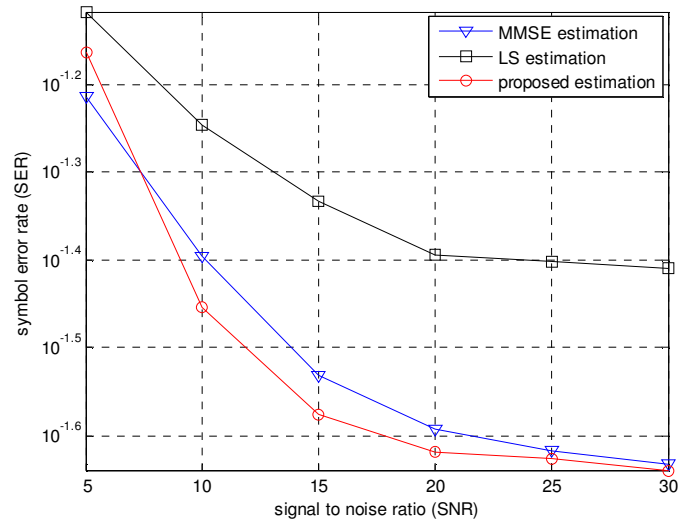


Figure 3: Symbol error rate vs. SNR (in dB)

of channel estimation and ICI suppression filter can successfully estimate the channel along with ICI elimination. Since this estimator can track the time varying nature of multipath channel, it can support mobility of high rate UWB nodes. In addition to support the mobility, even when compared with low pass interpolation based MMSE estimation, it improves the SNR performance by 3 dB in the range of moderate SNRs.

In future, the performance of this proposed technique will be investigated employing rotational coordination as in [12]. Finding out a number of receiver specifications [1] such as receiver sensitivity, clear channel assessment (CCA) performance, link quality indicator is also a part of our future works.

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