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Performance analysis of Adaptive Bit-interleaved Coded Modulation in OFDM using Zero Padding Scheme

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Abstract: *OFDM forms the basis for all the 4G wireless technologies which ensures multi carrier modulation. Fading nature of a wireless channel due to constructive/destructive interference degrades the performance of the system. The spectral efficiency and performance gain can be improved by adapting data rate/modulation schemes. We introduce Adaptive Bit-interleaved coded modulation (ABICM) in OFDM using zero padding schemes (ZPS). The paper deal with ABICM-OFDM-ZPS using the expurgated bound provides accurate BER estimates for static fading channels such as indoor wireless systems. Simulation result shows that the proposed ABICM-OFDM-ZPS scheme exhibits better performance gain with reasonable complexity.*

Keywords: *Adaptive Bit Interleaved Coded Modulation, Channel State Information, OFDM, Uncoded Adaptive OFDM, Zero padding*

I. Introduction

For a fixed link margin, the performance of wireless communication system is bad when received power is less than noise power called as deep fade. To overcome this we use multiple links to transmit called diversity. During deep fades, Shannon's capacity can be achieved by adapting the data rate, modulation scheme and power relative to the fade level which is known at the transmitter. The Channel State Information (CSI) is returned to the transmitter via the feedback channel.

First the Uncoded Adaptive OFDM (UAM) proposed by Hayes adapts the transmission power when the channel varies but the drawback is, it increases the peak power of interference. In 1982, to improve the system capacity, Ungerboeck Adaptive Trellis Coded Modulation (ATCM) proposed was proposed, which achieves coding gain in the fading channel under the accurate CSI.

The adaptive modulation in OFDM was proposed by Kalet in 1989, further developed by Chow and Czylwik[1]. The required SNR for the target BER can be reduced by 5 to 15dB. In 1992, Zehavi [2] proposed Bit Interleaved Coded Modulation (BICM) by interleaving bit wise at the encoder output. Soft decision bit metric used as an input to the viterbi decoder in order to reduce the error probability. BICM is more sensitive to prediction errors. In 2001, Ormeci [3] proposed the Adaptive Bit Interleaved Coded Modulation (ABICM) for achieving target BER. Here, the need for parallel branches in Trellis is removed and by employing bit interleaving ABICM is less sensitive to prediction errors.

In conventional ABICM-CP-OFDM, to mitigate the multipath delay spread it allows the cyclic extension (CP) of the transmitted symbols which minimizes Inter Symbol Interference (ISI). The cyclic extension extends the length of the symbol by adding the end of the previous symbol to the start of the next symbol cyclically while maintaining the orthogonality of the waveform. Usually the cyclic extension is chosen as 5 times larger the delay spread. The CP introduces redundancy and correlation into the transmitted signal which produces ripples in the power spectral density (PSD). As a result, the CP decreases the power efficiency of the modulation due to the power spent on the CP.

Alternately, proposed zero padding (ZP) scheme introduces N_G zero padded samples associated to each OFDM block. The length of the OFDM symbol containing ZP is less than the length of OFDM symbol with CP. This results in smaller PSD into band ripple and the larger out of band power. Thus the power back off problem at the transmitter can be avoided.

The rest of the paper is organized as follows. In section 2, a system model for ABICM is introduced. In section 3, the analytical comparison between the ABICM-CP-OFDM and ABICM-OFDM-ZPS scheme is discussed. In section 4, simulation results are discussed. In section 5, concluded the paper.

II. System Model

The system model for ABICM-OFDM-ZPS scheme under investigation is shown in Fig. 1. The data source generates data stream which undergoes convolution coding and bit interleaving. The Adaptive bit and power loading block selects either QPSK/QAM which converts bits into a sequence of QPSK/QAM symbols. The power control block adjusts the constellation power based on certain rules.

The serial to parallel (S/P) block converts the modulation symbol stream into the N parallel streams. Each of N symbols from S/P is carried out by the different subcarrier. Let the symbols are denoted as $\{X_l[K]\}_0^{N-1}$.

Then convert the spectra to time domain by taking the Inverse Discrete Fourier Transform (IDFT) results as $\{x_l[n]\}$ from n=0 to N-1 i.e., IFFT block converts each symbol vector into N-point IFFT. To maintain the orthogonality between the transmitted signals add the guard time (zero padding) as an extension to the OFDM symbol.

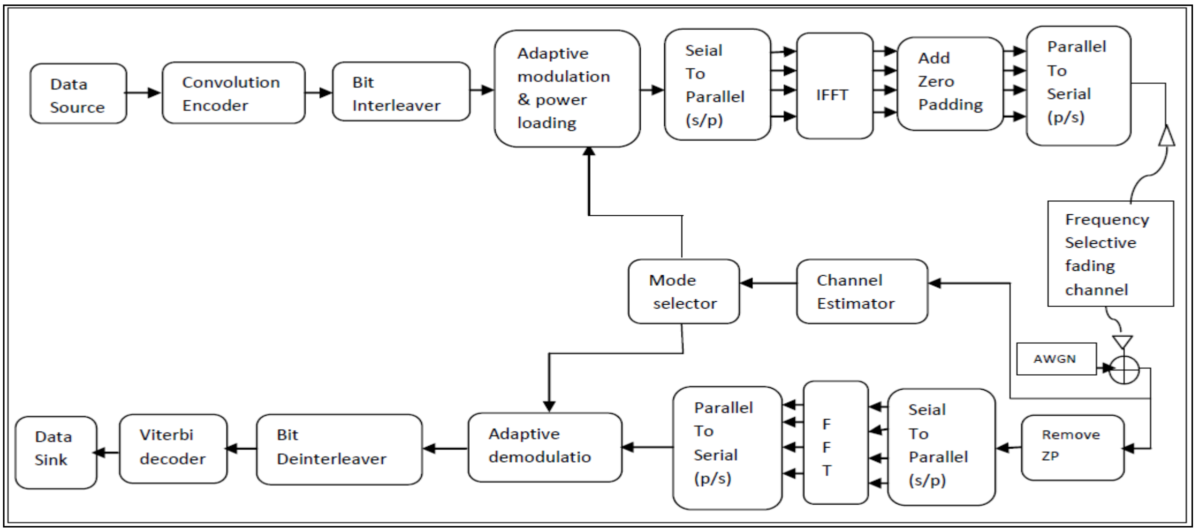


Fig. 1. System model of ABICM with ZP-OFDM

Consider the frequency selective Rayleigh fading channel. The received signal for the lth subcarrier of the nth OFDM symbol is

$$Y(n,l) = H(n,l)X(n,l) + W(n,l) \quad (1)$$

Where denotes $H(n,l)$ channel impulse response, $X(n,l)$ denotes the transmitted signal and $W(n,l)$ denotes complex additive white Gaussian noise with zero mean and variance σ_n^2.

The only difference with CP-OFDM is that the CP is replaced by trailing zeros that are padded at each precoded block where the detailed description is given in next section.

By allowing low complexity, FFT based implementation at the receiver, where an overlap-add method is used. The proposed ABICM-OFDM-ZPS scheme presents good performances even in the deep frequency notches.

III. Comparison of CP-OFDM and ZP-OFDM schemes

3.1 CP-OFDM:

The guard interval is inserted between two consecutive OFDM symbols to mitigate ISI effect. It can be inserted in two different ways. The conventional method is the cyclic extension of the OFDM symbol by copying the last samples into its front, typically 25% of the cycle taken from the end and added to the front. This allows the demodulator to capture the symbol period up to the length of a cyclic extension. The length of CP is considered longer than the delay of the multipath channel.

If the length of CP is shorter than the maximum delay, then the tail part of an OFDM symbol affects the head part of the next symbol, as a result ISI occur. If the length of CP is greater than the maximum delay, then it maintains the orthogonality among all subcarriers as follows.

$$\frac{1}{Tsub}\int_0^{Tsub} e^{j2\pi f_k(t-t_0)} e^{-j2\pi f_k(t-t_0)} dt = 0, k \neq i \quad (2)$$

The linear convolution of the channel impulse response and the transmitted signal in (1) can be treated as cyclic convolution relatively to the length N. Let T_{CP} is the length of the CP and T_{sym} is the symbol duration without guard period. Then T_{tot} is the length of OFDM symbol with CP.

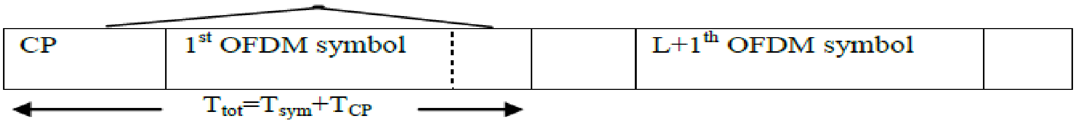


Fig. 2. CP-OFDM scheme

The CP is discarded at the receiver end to avoid inter block interference (IBI). Each truncated block is fast Fourier transform (FFT) processed corresponding to each subcarrier. Flat fades are removed by dividing each sub channel's output with the channel transfer function at the corresponding subcarrier.
Finally, the CP leads to a decrease of the spectral efficiency of the modulation, since that interval is not effectively used for data transmission.

3.2 ZP-OFDM:
So replace the nonzero CP by zero padding (ZP) i.e., by adding zero symbols after the IFFT - precoded symbols. If the number of appended zero symbols equals the CP length, then ZP-OFDM and CP-OFDM transmissions have the same spectral efficiency. Compared to CP-OFDM, ZP-OFDM guarantees symbol recovery.

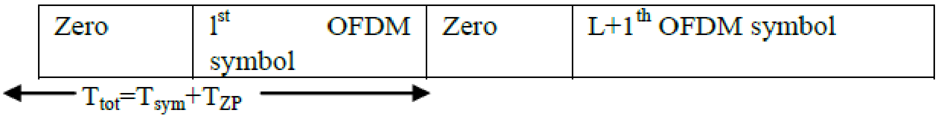


Fig. 3. ZP-OFDM scheme

The zero padded ZP-OFDM system internally incorporates a precoding operation which uniformly spreads the spectrum with the source symbols. ZP-OFDM scheme employs an overlap and- add method at the receiver. The BER performance of conventional CP-OFDM schemes decreases with $\tau_{\max}$ due to the increased power spent on the CP. The BER performance of conventional ZP-OFDM schemes improved with $\tau_{\max}$.

The ZP is filled with zeros, the total length of an OFDM symbol containing ZP is shorter than that of an OFDM symbol containing CP. So, length of a rectangular window for transmission is also shorter, so that the corresponding sinc-type spectrum may be wider. This implies that CP-OFDM, allows more power to be used for transmission with the peak transmission power fixed.

IV. Analysis of ABICM with ZP-OFDM

In ABICM system, the first step is to interleave and code the bits prior to the IFFT. This step serves the purpose of taking adjacent bits in the source data and spreading them across multiple subcarriers. One or more subcarriers may be lost or impaired due to a frequency null, and this loss would cause a continuous stream of bit errors. Such burst of errors would be hard to correct. The interleaving at the transmitter spreads out the contiguous bits such that the bit errors become spaced far apart in time. This spacing makes it easier for the decoder to correct the errors.

The second step in an ABICM system is to use channel information in order to determine the reliability of the received bits. If the channel fade level is known at the transmitter, then Shannon capacity is achieved by adapting the transmit power, data rate, and coding scheme relative to this fade level [4].

The performance of ABICM was evaluated using the CSI estimated at the receiver and fed back to the transmitter. Due to rapid fading variation, this CSI becomes outdated, and fading prediction is necessary to maintain reliable performance [6],[7]. By using long range fading predictor (LRP) [9] for an OFDM system, one can evaluate the CSI.

A simplified expurgated bound on pair wise error probability, which employs $\hat{H}$ and χm, is defined as

$$\bar{f}_{ex}(d,\mu,\chi,\hat{H}) = \bar{f}_{ex}(d,\mu,\chi^{i_0},\hat{H}^{i_0}) \triangleq \frac{1}{2\pi j}\int_{\epsilon-j\infty}^{\epsilon+j\infty} [\varphi_{ex}^{i_0}(s)]^{d}\frac{ds}{s} \tag{2}$$

For a rate k_c/n_c convolutional encoder with the free Hamming distance d_{free}, the union bound on the BER is

$$P_b \leq \frac{1}{k_c} \sum_{d=d_{free}}^{\infty} W_I(d) \widetilde{f_{ex}}\left(d, \mu, \chi_m, \widehat{H}\right) \tag{3}$$

The average symbol energy that satisfies the BER constraint is

$$E_{\widehat{H}}(m) = \arg \min_{E_m} \left\{ \frac{1}{k_c} \sum_{d=d_{free}}^{\infty} W_I(d) \widetilde{f_{ex}}\left(d, \mu, \chi_m, \widehat{H}\right) \leq BER_{tg} \right\} \tag{4}$$

Where BER_{tg} is the target BER, the predicted channel coefficient $\hat{H}$ and χ_m is the constellation vector. Equation (4) is used to compute the thresholds for adaptive modulation. Such that the assumption is, the bit-loading algorithm selects the symbol energy and the constellation to maintain the same performance for all symbols.

V. Simulation Results

By considering the $BER_t = 10^{-5}$, the receiver tracks continuously the post processing SNR, and the M-QAM order is computed based on the SNR thresholds. Consider the set of different constellation sizes are {0, 4, 8, 16, 64, 128}. Spectrally efficient adaptive MQAM technique, at low BER's this adaptive coded modulation exhibits a 3-dB gain using a four state code, a 3.6-dB gain using an eight-state code, and comes within 6 dB of the Shannon capacity limit of the fading channel with adaptive transmission using a 128-state code. These coding gains are obtained both in Rayleigh fading and in lognormal shadowing.

Total bandwidth	1.3 MHz
Subcarrier spacing	10.94KHZ
Carrier frequency	2.5GHZ
Number of sucarriers	120
IFFT size	128
Doppler frequency	200HZ w.r.t. prediction ranges 0.4λ and 0.1λ
Channel fading	Rayleigh independent frequency flat and selective fading

Table.1. Simulation parameters

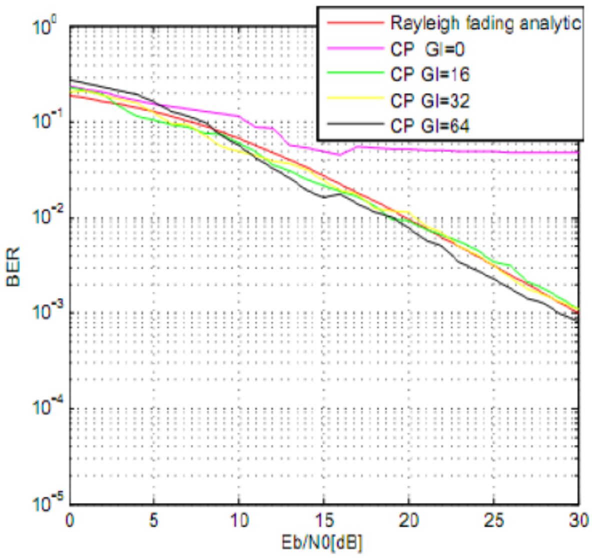


Fig.4. BER performance of CP-OFDM scheme

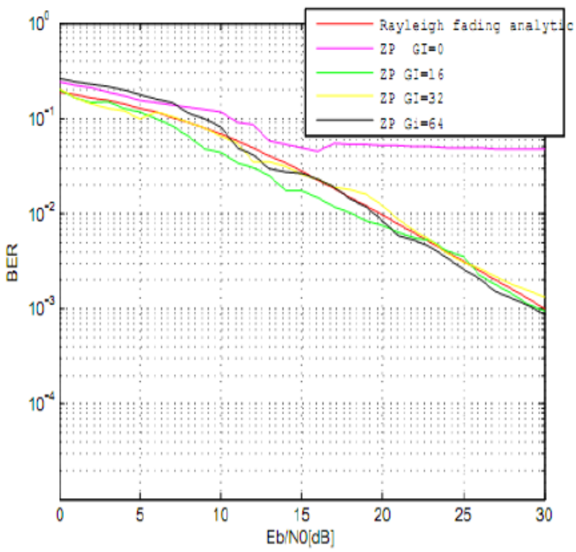
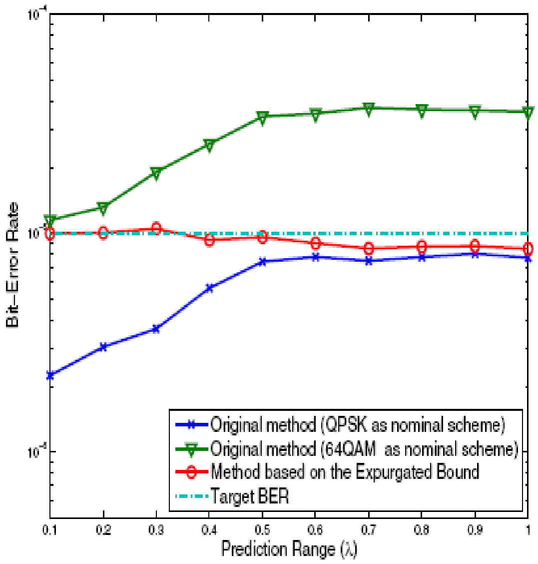


Fig. 5. BER performance of ZP-OFDM scheme



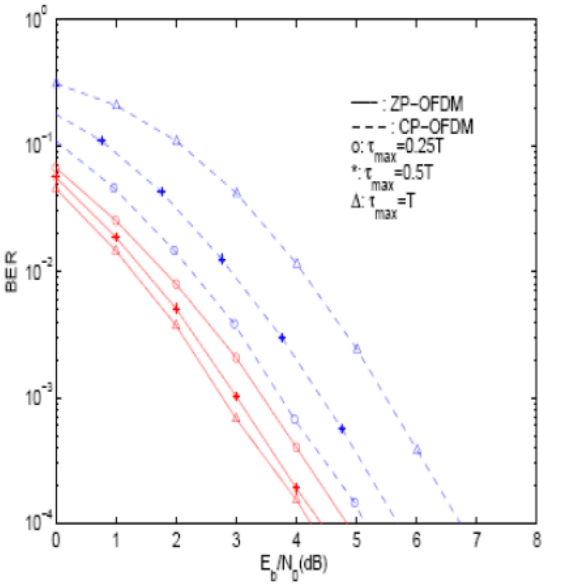


Fig.5. BER of ABICM with ZP-OFDM **Fig..6.** BER performance of ABICM-ZP-OFDM w.r.t. $\tau_{\max}$

Fig.4. & fig.5. gives difference between BER performance analysis between CP-OFDM and ZP-OFDM. Fig.6. depicts the BER performances ZP-OFDM schemes improve slightly with $\tau_{\max}$. It shows that a larger value of $\tau_{\max}$ means a more time-dispersive channel, and, consequently, a higher diversity effect inherent to the ZP-OFDM signals. Fig.7. shows the simulated BER vs. prediction range for the ABICM scheme.

The spectral efficiency of ABICM is better by using long range prediction method. Here, the spectral efficiency of ABICM degrades slowly and saturates at 0.9 bps/Hz for long prediction ranges [15]. ABICM is less sensitive to prediction errors but, it relies on fading prediction to maintain its performance.

VI. Conclusion

ABICM-ZP-OFDM provides higher coding gain, better protection against prediction errors by spreading the bits associated with the poor channel predictions. ZP-OFDM is a good alternative to conventional OFDM schemes, especially for channels with a very long impulse response.

The ZP-OFDM in ABICM (where the duration of the channel impulse response is not a small fraction of the duration of the OFDM block) approach is adopted by multiband-OFDM (MB-OFDM) in an Ultra Wide-band (UWB) system or for the DSL.

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