Channel Estimation in Constant Envelope Orthogonal Frequency-Division Multiplexing

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***Abstract*—Recently, Constant Envelope Orthogonal Frequency-Division Multiplexing (CE-OFDM) has been considered as a promising transmission scheme for next generation mobile communications and radar applications due to its 0 dB peak to average power ratio (PAPR) and its inherent benefits to mobile transmitters and their power amplifiers. However, the issue of channel estimation in CE-OFDM still needs to be addressed. This is crucial, as the performance of the equalizer, the coding and synchronisation in the communications system depends on the quality and accuracy of the channel estimate and channel state information (CSI). A novel channel estimation method needs to be implemented and adapted to CE-OFDM; doing this would add significance to CE-OFDM and enable a direct comparison to currently implemented systems, making it easier to equate conventional modulation techniques to CE-OFDM. Similarly, the effect of imperfect channel state information on the performance of CE-OFDM needs to be addressed. After adaptation and implementation of various proposed novel channel estimation techniques in CE-OFDM, a performance gain comparison and evaluation over fast fading channels can be presented and discussed.**

***Index Terms*—Orthogonal frequency-division multiplexing, OFDM, Constant Envelope, peak-to average power ratio, CE-OFDM, PAPR, Channel Estimation.**

I. Introduction

DUE to the fact that orthogonal frequency-division multiplexing (OFDM) provides multipath delay spread tolerance, immunity to the frequency selective fading channels, high spectral and power efficiency makes it an attractive wireless communications technology, which has become a popular technique in various high-speed wireless data transmission systems [1], [2].

One key weakness of multicarrier signals such as OFDM is the high peak-to-average power ratio (PAPR). Nonlinear distortions caused by the power amplifier are aggravated by high PAPR, which in turn affects the OFDM [3]. These nonlinearities in amplifiers cause both intersymbol interference (ISI) and intercarrier interference (ICI) in the system. A "power backoff" is required to prevent spectral broadening and a performance degradation from intermodulation distortion. Commonly, the power in the transmitted signal is reduced and thus the power amplifier at the transmitter can again function in the linear operating range. However, this power reduction results in inefficient operation of the entire communication system and is an inadequate solution especially for mobile battery-powered systems in which the power amplifier (PA) efficiency is low [4].

Constant Envelope OFDM (CE-OFDM) provides a solution to the high PAPR issue in OFDM. The high PAPR OFDM signal is transformed, by way of phase modulation, to a constant envelope signal, thereby alleviating the need for a power backoff and allowing for the most efficient power amplifier operation possible [5]. The performance and bandwidth of the CE-OFDM system has been studied in [5] and [6]. CE-OFDM has been found to compare favourably to conventional OFDM, over a two-path fading channel in the presence of clipping [7].

An equalization technique, based on cyclic prefix transmission in conjunction with a frequency domain equalizer (FDE), was proposed and studied over various multipath channel models in [5], [6] and [8]. This was shown to work well, however, the channel characteristics were assumed to be known at the receiver. In most communication systems that employ equalizers, the channel state information and characteristics are unknown a priori and generally the channel response is time-variant [4]. Therefore, the performance of an equalizer is dependant on the channel estimate. To gain performance advantages, coherent detection is generally desired but requires reliable estimation of the time-dispersive channel, and knowledge of the channel impulse response is imperative.

A performance evaluation of CE-OFDM in fast fading channels, using various newly developed and adapted practical channel estimation techniques with low complexity and high accuracy, need to be presented. The constraints of performance and complexity of channel estimators work against each other and a trade-off between the two needs to be found.

II. Estimation

Two main types of channel estimation techniques exist, namely the supervised or trained and the unsupervised or blind [9]. In the supervised or trained estimation scheme, a portion of the bandwidth is allocated to training or pilot symbols. By exploiting the frequency correlation and/or the time correlation of the pilot and data symbols, the channel state information (CSI) can be estimated, but the addition of the pilot symbols increases the signalling overhead [10]. The blind technique is implemented by exploiting statistical properties or the deterministic information of the transmitted symbol (e.g. finite alphabet, constant modulus, etc.) [10]. Blind channel estimation and equalization methods are well motivated as they avoid the use of training sequences, they save bandwidth and are capable of tracking channel variations [11]. Blind techniques are considered more attractive due to their self-sufficiency in training, however, they tend to have a higher computational complexity.

III. Broad Design Approach for Proposed Channel Estimator

The frequency domain equalizer and other subsystems of CE-OFDM situated at the receiver, require the channel state information or knowledge of the channel, as is the case in many conventional OFDM systems. A novel channel estimator for CE-OFDM needs to be proposed to improve the entire communications system, produce significant results and create improvements on the existing knowledge of CE-OFDM systems.

The performance of numerous different estimator techniques for CE-OFDM needs to be studied and compared. Channel estimator techniques such as pilot or training sequence aided estimators need to be compared with totally blind, semi-blind and other variations implementing adaptive blind algorithms, to produce performance evaluations of feasible estimation schemes. Trade-offs need to be found and from the knowledge gained by altering and applying estimation schemes to CE-OFDM, a new channel estimator can be proposed, which would show an improvement compared to other methods of obtaining and estimating the channel information and characteristics. This estimation technique is not necessarily only applicable to CE-OFDM but could, with modifications, be applied to conventional OFDM and provide a contribution to all universal OFDM modulation systems.

The channel estimation can be done with pilot-symbol aided or with blind techniques. A mixture of the two, referred to as a semi-blind method, is also possible in which occasional training data is transmitted to improve convergence and to better track channel variations. If training or pilot based methods are implemented, a training signal that has uniformly distributed power, a flat power spectrum over the frequency domain as well as a constant envelope in the time domain is required. This problem of finding a low PAPR training sequence does not need to be considered in a blind estimation technique, since no training or pilot sequences are required. Additionally, pilot signals consume a part of the bandwidth, reducing the data throughput [11]. When channel estimation methods are analyzed and compared, the effects of the amplifier's non-linearities on the channel estimation need to be taken into account when considering CE-OFDM.

The system performance of the proposed channel estimation algorithm would be analyzed in terms of the mean square error (MSE) which should be very close to the Cramer-Rao bound (CRB). The Cramer-Rao lower bound would be derived for performance evaluation and would show the efficiency of the particular algorithm. The system and the proposed algorithms need to be tested under diverse signaling conditions involving various SNR levels in stationary and fading channels that also exhibit abrupt changes. The algorithm should be able to be applied to arbitrary signal constellations and there should be no performance degradation when the constellation size increases.

The channel estimation algorithm would offer a trade-off between performance and complexity. It would guarantee channel identifiability regardless of channel zero locations. Various channel models would be applied to thoroughly test and simulate the estimation scheme. The compared systems and the proposed estimation algorithm would be examined in terms of their channel estimation and tracking capabilities.

IV. Conclusion

Constant envelope OFDM (CE-OFDM) transforms the OFDM signal with phase modulation to a signal designed for efficient power amplification with a reduced PAPR. Hence, CE-OFDM is driven by the desire to use efficient Class C power amplifiers. Other PAPR mitigation techniques based on signal transformations have a lower-peak-to average power ratio but the PAPR is still relatively high compared to single carrier modulation. However, the advantage of the phase modulation transformation of CE-OFDM is that its resulting signal has the lowest achievable peak-to-average power ratio of 0 dB [6].

One of the research questions that remain is the evaluation of CE-OFDM with a newly proposed channel estimation technique. To maximize the performance advantage of OFDM systems, coherent detection is desired, and in this case, a reliable estimation of the time-dispersive channel is required and the need for an accurate and simple to implement channel estimator is crucial. The proposed channel estimation technique would possess attractive features not only for CE-OFDM but also for conventional OFDM.

Due to the fact that a newly proposed channel estimator would be less computational complex, simple to implement, flexible and show an improvement in overall system performance and channel estimation accuracy, it would hold high application potential for CE-OFDM, existing OFDM standards and future generation multi-carrier systems. Further research will provide insight into next generation digital communication systems that require power efficiency, high data rates and robustness in harsh channel conditions.

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Alexander Merensky received his undergraduate degree in 2009 from the University of Pretoria and is presently studying towards his Master of Science degree in Electronic Engineering at the same institution. His research interests include OFDM, MIMO, modulation, estimation, equalization and coding for mobile communication systems.