Frequency Channel Estimation for Spectrally Efficient Frequency Division Multiplexing Systems

Waseem Ozan, Paul Anthony Haigh and Izzat Darwazeh
Department of Electronic and Electrical Engineering
University College London, London, UK
Email: {w.ozan, p.haigh i.darwazeh}@ucl.ac.uk

***Abstract*—In spectrally efficient frequency division multiplexing (SEFDM) systems, the subcarrier spacing is compressed, below the orthogonality limit, by a factor (1-α), where α ≤ 1. In such systems, inter-carrier interference (ICI) is generated between the subcarriers due to the lack of orthogonality and the received pilot symbols are affected by ICI, thus preventing the receiver from correctly estimating the channel. Considering the deterministic nature of the induced ICI, in this paper a new SEFDM frequency-domain channel estimation method is proposed that decouples the ICI from the channel. The ICI is first found analytically at the receiver using an FFT. This information is then used to estimate the channel characteristics based on received pilot symbols. We show that for various values of α, the proposed method offers similar performance to time-domain methods, with reduced computational complexity, due to the use of an FFT instead of matrix inversion.**

I. Introduction

Spectrally efficient frequency division multiplexing (SEFDM) offer bandwidth saving by employing non-orthogonal overlapped multicarrier signals, which makes it an attractive technique for future 5G systems [1]. However, by compressing the subcarriers and breaking their orthogonality, the system performance is impacted in many ways. For instance, one artefact of non-orthogonal subcarrier compression is inter-carrier interference (ICI), which requires a more complex receiver to recover the data [2]. In addition, channel estimation becomes more challenging due to combined ICI and multi-path effects. In this work, we present a new method of frequency domain channel estimation in SEFDM using pilots. Employing channel estimation in the frequency domain decreases the computational complexity of the estimation in comparison to time domain channel estimation. In [3], standard frequency domain channel estimation, using SEFDM pilots, was demonstrated to offer acceptable mean square error (MSE) results at low E_b/N_o values, but reaches an error floor at high E_b/N_o values. On the other hand, [3] also demonstrated that time-domain channel estimation offers better MSE performance than the frequency domain equivalent, however, the computational complexity at the cost is exponentially increased with increasing number of subcarriers, since time domain estimation requires matrix inversion operation to perform the deconvolution process needed to estimate the channel, leading to high latency. This is a major impediment in the implementation of SEFDM real time systems. In this work, an FFT is utilized to perform the channel estimation deconvolution process. The computational complexity when using an FFT increases linearly with the number of subcarriers and hence the overall receiver complexity is lower than that when using the matrix inversion method. The key contribution of this work is a new approach to utilizing the deterministic ICI to estimate the received pilot symbols and hence differentiate the ICI from the channel response to improve the overall channel estimation process.

II. Test Setup

Fig. 1 shows a simplified block diagram for the SEFDM system under test. Pilot data information is passed to an (N/α)-point IFFT, where N is the number of subcarriers, to generate an SEFDM pilot symbol. The additional zeros at the end of the IFFT input compress the subcarrier spacing [2], and hence it is possible to ignore the (1-α)N/α zero samples at the output. The SEFDM pilot symbol is transmitted over a fading channel with additive white Gaussian noise (AWGN). The received pilot symbol is passed to an N-point FFT to generate the frequency samples of the received symbol, where the samples have the self-generated ICI in addition to the channel effects. These samples are divided by the transmitted pilot symbols affected only by ICI, which may be analytically calculated at the receiver.

SEFDM pilot symbols consisting of known QAM symbols are inserted at the start of each frame, which consists of multiple SEFDM symbols. This method of pilot insertion is referred to as

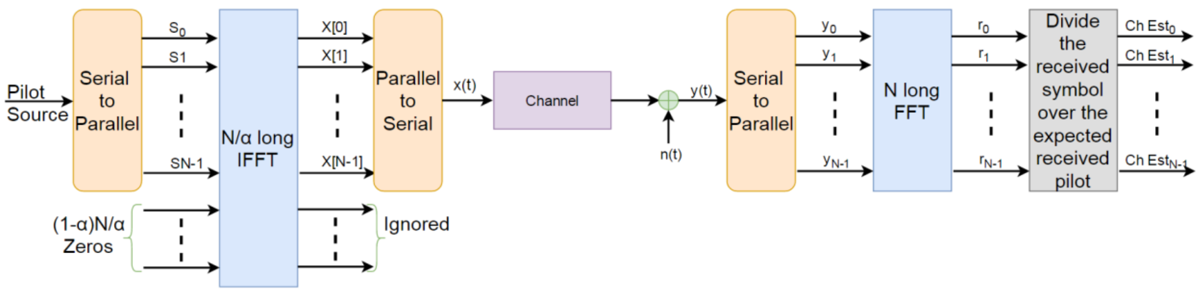

Fig. 1 SEFDM transceiver with channel estimation block

the block pilot method [4]. The pilots have compressed subcarrier spacing, relative to those of an equivalent OFDM symbol of the same duration. compressed subcarrier spacing. In SEFDM systems, the self-interference generated due to the bandwidth compression is deterministic and can be described mathematically by a correlation matrix [5]. The receiver employs the knowledge of such correlation matrix to find the expected SEFDM pilot symbols plus interference analytically, which are clearly different from the transmitted pilots even when no channel is present. Therefore, this process takes into consideration the ICI effects of the SEFDM system and includes these in the predicted pilot information samples. These samples are then used in conjunction with the received pilot symbols, which have been passed through a fading AWGN channel, to estimate the fading channel characteristic in the frequency domain. The received pilot symbols are converted to the frequency domain via an FFT and the resulting symbols are divided by the expected received pilot symbols to find the channel taps in the frequency domain.

III. Key Results

The MSE of the SEFDM system is tested in the presence of fading channel [6] with impulse response h = [0.8765, -0,02279, 0, 0, 0.1315, 0, -0.4032i] using $N = 10$ subcarriers, QPSK and with different values of compression factor $\alpha = 1$, 0.8 and 0.7. Two different SEFDM pilot symbols are used to estimate the channel characteristics. The first symbol is a random SEFDM symbol that is known to both the transmitter and the receiver and the other symbol applies equal inputs to the IFFT (same QAM symbol for all pilot tones). Fig 2(a) and (b) show the MSE curves of the time and frequency channel estimation using a time estimation method similar to that of [7]. Similar results are observed for both the time and frequency channel estimations. The results also show that when the same input is used to modulate all pilot tones, better performance is obtained for both frequency and time domain estimation (Fig. 2b).

In previous SEFDM work where time-domain channel estimation was implemented, the matrix inversion operation required to predict the amplitude and phase of the channel taps in the time-domain, made the complexity prohibitive. Furthermore, in order to utilise the estimated channel taps, a time-domain equalizer is implemented that depends on a matrix inverse to cancel the channel effects before the FFT at the receiver. That means, in addition to the computational complexity of the estimation, similar complexity is added for the time-domain equalizer, which makes achieving a real time system very complex. Hence the improvement demonstrated in this work, by using frequency-domain channel estimation, where both the estimator and equalizer computational complexity increase linearly in with N, whilst maintaining approximately equivalent performance, as is shown in Fig. 2.

IV. Conclusion

A frequency-domain channel estimation method for SEFDM systems is proposed to decrease the receiver complexity. The complexity of time-domain channel estimation

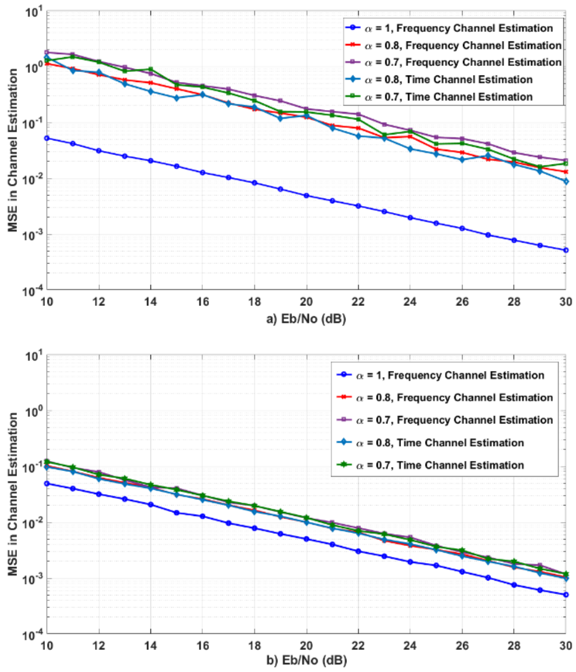

Fig. 2: MSE of time-domain and frequency-domain channel estimation. (a) Random pattern. (b) Same QAM symbol pattern.

increases exponentially with the number of sub carriers, while the proposed channel estimation in frequency-domain increases linearly with the number of subcarriers, offering substantial improvement in computational complexity. allowing implementation of real time systems with no loss in performance.

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