LMS Channel Estimation and Time Domain Equalization for SC-FDMA Systems

Ravichandran K.R, Pavitra Pratim Padhi
Applied Electromagnetic Research Group, Department of ECE, Amrita Vishwa Vidyapeetham, Coimbatore, India

Ashmita G, Sangamitra N,
Applied Electromagnetic Research Group, Department of ECE, Amrita Vishwa Vidyapeetham, Coimbatore, India

Sreyas V, Aghil K.R. and Jayakumar M,
Applied Electromagnetic Research Group, Department of ECE, Amrita Vishwa Vidyapeetham, Coimbatore, India

ABSTRACT
SC-FDMA (Single Carrier Frequency Division Multiple Access) has been accepted as an uplink standard in 3GPP Release 8, December 2008. As per the release the frequency domain equalization (FDE) is used to mitigate the distortion effects due to the channel. This type of equalization is complex and requires high power consumption at the receiver. In this paper we propose LMS channel estimation followed by Time Domain Equalization which offers better performance when compared to the standard FDE.

General Terms
Channel Estimation, 3GPP LTE Uplink.

Keywords
SC-FDMA, LMS, QPSK, OFDM

1. INTRODUCTION
Advancement in wireless multimedia and internet services has fuelled intensive research in the field of high speed data transmission. High speed data transmission can be achieved using higher transmission bandwidth which in turn makes the frequency selectivity of the channel more severe and leads to higher inter symbol interference (ISI). Orthogonal frequency domain multiplexing (OFDM) is a multicarrier transmission technique which mitigates ISI. This technique has already been adopted by several wireless networks such as IEEE802.11a [1] and IEEE802.16e[2] and is to be used in the future for 4G mobile communication and high speed wireless LAN. However this modulation technique suffers from several drawbacks which include large peak-to-average power ratio (PAPR), intolerance to amplifier nonlinearities and high sensitivity to carrier frequency offsets [3].To overcome these disadvantages 3rd Generation Partnership Project (3GPP) conducted extensive research and accepted Single Carrier Frequency Division Multiple Access (SC-FDMA) for uplink transmission in its Release 8 in December, 2008 [4][5][6].SC-FDMA combines the SC-FDE with frequency domain multiple access (FDMA).It has similar spectral efficiency, throughput performance and immunity to multipath interference compared to the orthogonal frequency division multiple access (OFDMA) system [7].

This modulation technique has a major advantage of low PAPR which makes it a potential candidate for uplink transmission in cellular systems. The nature of channel as stated above is frequency selective hence dynamic channel estimation (CE) techniques are required to improve the performance and robustness of SC-FDMA systems in wireless communication. Various channel estimation techniques have been proposed and accepted for multicarrier communication systems like OFDM.As SC-FDMA can be also stated as a DFT pre-coded form of OFDM most of the channel estimation techniques used for OFDM are also applicable for SC-FDMA except the use of decision directed estimators in frequency domain on SC-FDMA systems [8][9].However, considering the computational complexity, knowledge of channel statistics and the dynamic approach of adaptive estimators-LMS channel estimation for SC-FDMA systems has been proposed.

In this paper we analyze the performance of SC-FDMA systems using LMS channel estimation technique for Pedestrian-A channel [10].This paper mainly focuses on the system model of SC-FDMA system and the subcarrier mapping techniques by which the proposed channel estimation model is presented. The performance of LMS channel estimation for IFDMA and LFDMA systems are studied and compared using simulations.

2. SYSTEM MODEL
At the transmitter the input bit stream is modulated using any of the baseband modulation formats like QPSK, BPSK,8-PSK, 16-QAM, 64-QAM based on the channel conditions .Then the modulated symbols are grouped into streams of N symbols and N-point FFT is performed. Before assigning the symbols to the M (>N) subcarriers and computing the IFFT, subcarrier mapping is carried out in which the N frequency domain symbols are spread across M subcarriers which is explained in detail in section III. After IFFT processing, parallel to serial conversion is carried out to place the symbols in a time sequence which makes it suitable for transmission over the channel. However before transmission of the symbols through the channel cyclic prefix is added in order to provide guard interval and hence avoid inter-block interference (IBI). Addition of cyclic prefix is the key reason in modeling the

transmission of data symbols through the channel as the circular convolution of the data symbols transmitted and the channel impulse response.

At the receiver side, the cyclic prefix is removed and N time domain samples are extracted after carrying out N pt IFFT on the isolated N frequency domain samples obtained after subcarrier de-mapping the M frequency domain equalized received samples of each source signal. The N time domain symbols will be useful in determining the input bit stream after the baseband demodulation and detection phase.

3. SUBCARRIER MAPPING SCHEMES IN SC-FDMA

As mentioned in section II, the N modulated frequency domain samples are spread across M subcarriers. This assignment of symbols to the subcarriers can be carried out in two ways: localized subcarrier mapping and distributed subcarrier mapping. Hence the respective subcarrier mapping modes of SC-FDMA are known as localized FDMA (LFDMA) and Distributed FDMA (DFDMA) respectively. In case of LFDMA, the modulated frequency domain symbols are allocated to N adjacent subcarriers and in DFDMA, the symbols are equally spaced. The rest M-N subcarriers are assigned zero amplitude. When the input signal is represented by $\{x_n$: n=0, 1, N-1$\}$ and m=N.q+n ($0 \le q \le Q-1$, $0 \le n \le N-1$).Here Q is equal to M/N. The time domain representation of a LFDMA signal:

$$y_m = y_{n.Q+q} = \begin{cases} \frac{1}{Q} x_{(m)\bmod N} & q = 0 \\ \frac{1}{Q}.(1-e^{j2\pi\frac{q}{Q}}).\frac{1}{N}\sum_{p=0}^{N-1}\frac{x_p}{1-e^{j2\pi\left\{\frac{(n-p)}{N}+\frac{q}{QN}\right\}}} & q \neq 0 \end{cases} \quad (1)$$

Interleaved FDMA is a special case of DFDMA in which the symbols assigned to subcarriers which are spaced at equal distances of a spreading factor Q (=M/N) from each other.

4. PROPOSED MODEL

In our model we propose time domain estimation and equalization of the received signal using LMS algorithm as shown in Figure.1. This technique is adaptive and involves less complexity hence is considered better than the conventional equalization techniques used to retrieve data from received SC-FDMA symbols. In the current conventional method the channel is estimated by the reference symbols (CAZAC sequence) and hence after the subcarrier de-mapping frequency domain equalization is carried out. In this model, an adaptive channel estimator and equalizer compensate for the unknown time varying multipath channel. The adaptive estimator uses a specific algorithm to constantly update its parameters as more information is received about the channel. The algorithm should be able to efficiently track the channel variations at low complexity. Least Mean Square (LMS) algorithm is a robust algorithm which aims at minimization of the mean square error between the desired output signal and the actual input signal and requires only 2N+1 operations per iteration. If n denotes the sequence of iterations, LMS can be computed iteratively by

$$\begin{aligned} \hat{d}_k &= w_N^T(n) y_N(n) \\ e_k(n) &= x_k(n) - \hat{d}_k(n) \\ w_N(n+1) &= w_N(n) - \alpha e_k^*(n) y_N(n) \end{aligned} \quad (2)$$

Where, N denotes the number of delay stages in the estimator, α is the step size which controls the convergence is the convergence rate, w_N is the weights of the adaptive filter, e_k is the prediction error and y_N is the input signal.

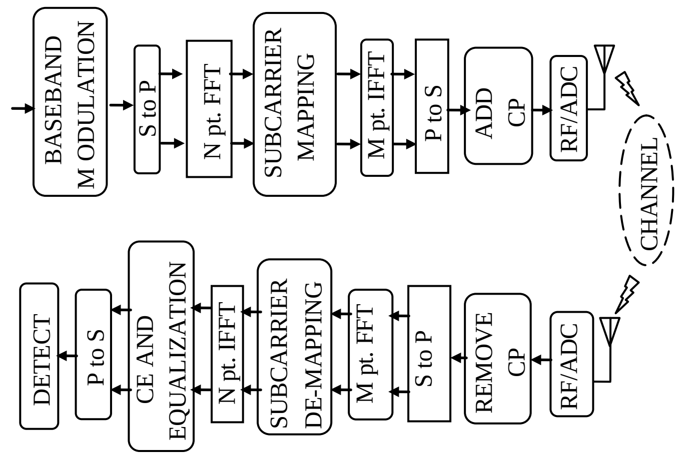

Figure 1: Proposed Model

5. CHANNEL MODEL

The transmitted SC-FDMA signal undergoes multipath propagation and scattering along the channel it passes through, this wide-sense stationary uncorrelated scattering (WSSUS) channel can be mathematically represented for k streams from the transmitter as follows:

$$w(\tau, t) = \sum_{j=0}^{k-1} w_j(t)\,\delta(\tau - \tau_j) + n(t) \quad (3)$$

In equation (3), t denotes the time instant, w_j (t) is the jth complex channel weighting coefficient and τ represents the path delay parameter and n (t) represents the AWGN noise is added to the transmitted signal. The power delay profile also called the multipath intensity profile is the average power intensity of a multipath delay and is calculated empirically. The channel model considered here for multipath channel is ITU Pedestrian-A channel with channel delay profiles as stated below in Table 1.

Table 1: Pedestrian A Channel Power Delay Profile

Delay (nsec)	Power in dB
0	0
110	-9.7
190	-19.2
410	-22.8

6. SIMULATION RESULTS

The primary objective of this section is to numerically compare the performance of proposed SC-FDMA system integrated with a LMS channel estimator and time domain equalizer with the existing SC-FDMA system using FDE for Pedestrian-A channel [10]. Symbol error Rates (SER) of the SC-FDMA system using both interleaved and localized mapping schemes is analyzed in this section. Various channel estimation techniques like least squares estimation, minimum mean squared estimation have been proposed for SC-FDMA systems [9]. However all of the methods show a minimum error rate of 10^{-3} at SNR of 20 dB using FDLMMSE algorithm. The SER comparison of ZF and MMSE algorithms in frequency domain equalized SCFDMA systems also state a minimum error rate of 10^{-4} at SNR of 24 dB [11].LMS channel estimation shows a considerable improved performance in case of LFDMA systems using frequency domain equalization at the SNR of 10 dB and above. In case of IFDMA a SER of 10^{-2} is observed at 20dB.However it is clearly observed from the SER curves in Figure 3 and Figure 4 that the proposed LMS time domain estimation and equalization technique outperforms the conventional FDE technique in both mapping techniques by at least 3-5 dB.

In the proposed model, the channel estimation is computed for the transmitted data after the subcarrier de-mapping is done, as shown in Figure 1, the LMS algorithm adapts itself based on total number of symbols transmitted through the channel when a specific signal to noise ratio is maintained during the transmission of the signal. Hence received signal is equalized for distortion caused by the channel. In case of frequency domain equalization however the received symbols are used to estimate the channel coefficients prior to subcarrier de-mapping for each input block of transmitted symbols and hence estimation is carried out with help of a longer sequence of input data leading to more complexity in the system. Thus when the system is simulated based on the parameters tabulated in Table 2 in MATLAB R2009a environment (System processor: Intel® Core ™ 2 Duo CPU T6400 @ 2GHz)it takes 9.702 seconds approximately in the case of the proposed model whereas 25.84072 seconds in case of the conventional model for executing 1000 iterations at a particular SNR using the training sequences.

Table 2: Simulation Parameters

Simulation Channel	Pedestrian A
System Bandwidth	5 MHz
Modulation type	QPSK
Input Block Size	16
FFT size	16
IFFT size	512
Subcarrier mapping	IFDMA LFDMA
Cyclic prefix	20 samples
Number of iterations	1000
LMS step size	0.01
Equalization	Zero forcing

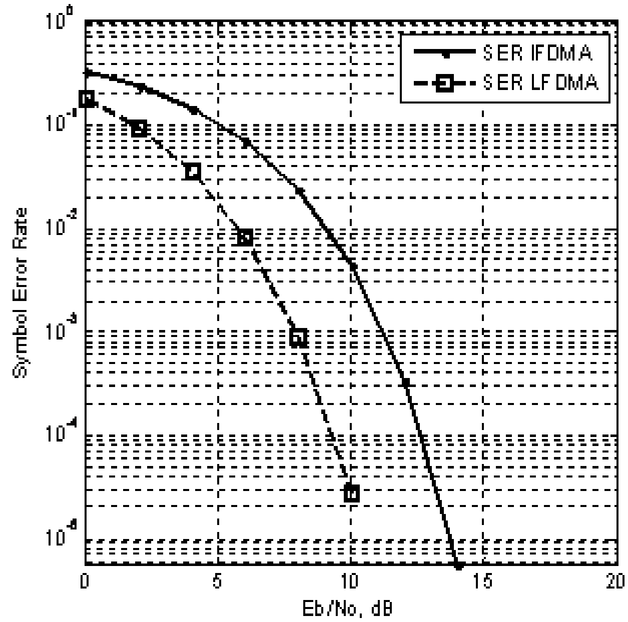

Figure 2: Symbol error probability curve for SC-FDMA symbols using actual channel coefficients and FDE

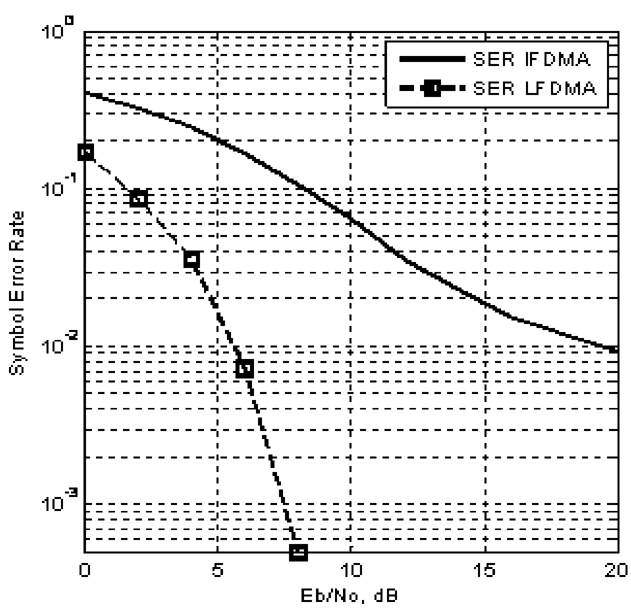

Figure 3: Symbol error probability curve for SC-FDMA symbols using LMS channel estimation and FDE

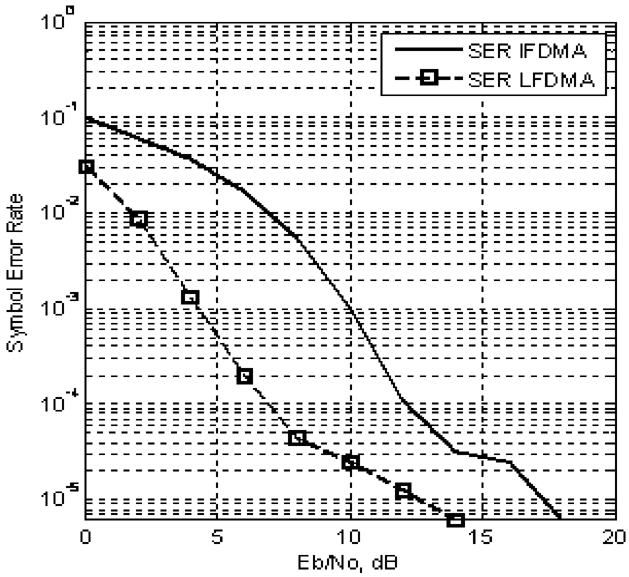

Figure 4: Symbol error probability curve for SC-FDMA symbols using LMS channel estimation and TDE.

7. CONCLUSION

The channel estimation and equalization is a very important process that ensures effective signal decoding and detection. Thus efficient and low complexity algorithms with high level of performances are preferred. The proposed model of LMS channel estimation followed by time domain equalization provides better performance than the existing methods. Further improvements to the proposed system can be made by introduction of various improved adaptive algorithms for estimation and equalization.

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