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New SC-FDMA Scheme Based Spatial Multiplexing with Cyclic Delay Diversity for Uplink LTE

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***Abstract*— Long term evolution (LTE) uses single carrier frequency division multiple access (SC-FDMA) in its uplink transmission. New scheme for SC-FDMA based on circular shifting of the subcarriers is proposed in this paper. The proposed scheme with channel estimation (CH) and frequency domain equalization reduces the problem associated with conventional SC-FDMA concering noise enhancement problem. This new SC-FDMA scheme uses minimum mean square error (MMSE) channel estimation to avoid inter symbol interference (ISI) and uses MMSE frequency domain equalizer (FDE) to avoid inter channel interference (IAI). Simulation results show that the performance of proposed system outperforms that of conventional LTE SC-FDMA.**

***Index Terms*— SC-FDMA, MMSE, channel estimation, frequency domain equalizer.**

I. Introduction

Recently, SC-FDMA systems have found popularity as better candidate for transmission over frequency selective channels [1,2]. Furthermore, these systems have two main advantages over conventional orthogonal frequency division multiplexing (OFDM) systems, namely, low peak average power ratio (PAPR) and lower sensitivity to carrier frequency errors [1].

There are many well-known channel estimators and equalizers that can be used to recover the transmitted signal in SC-FDMA systems. In [3], least mean square (LMS) was used as channel estimator followed by time domain equalizer for localized SC-FDMA (L-SC-FDMA) and distributed SC-FDMA(D- SC-FDMA) with equidistant subcarriers (interleaved SC-FDMA) in pedestrian A-channel. The performances of these two SC-FDMA schemes were compared and showed that L-SC-FDMA system performs better than D- SC-FDMA system in pedestrian A-channel.

Variable step size based LMS channel estimation was presented in [4] for LTE SC-FDMA where the weighting coefficients can be adapted automatically based on channel conditions. Furthermore, phase weighting scheme was used to eliminate signal fluctuations due to noise and decision errors such that an improvement of around 2.5 dB was gained compared with other existing algorithms in terms of LMS.

The impact of the Carrier Frequency Offsets CFOs on the performance of the Discrete Fourier Transform SC-FDMA (DFT-SC-FDMA) and the Discrete Cosine Transform SC-FDMA (DCT-SC-FDMA) systems was investigated in [5]. Based on the Minimum Mean Square Error (MMSE) criterion, a new low-complexity joint equalization and CFOs compensation scheme was proposed. The MMSE weights of the proposed scheme were derived taking into account the MAI and the noise. Furthermore, a hybrid scheme comprising the proposed MMSE scheme and a Parallel Interference Cancellation (PIC) stage was also suggested and investigated to further enhance the performance of interleaved subcarriers mapping systems. The proposed compensation schemes were able to enhance the system performance, even in the presence of the estimation errors [5].

Based on MMSE criterion, efficient frequency domain soft-decision feedback equalization (FDSDFE) scheme for SC-FDMA system was proposed in [6]. The proposed scheme employs residual inter-symbols cancellation (RISIC) algorithm, combining *prior* information to reduce inter-block interference (IBI) and inter-carrier interference (ICI) component caused by the absence of cyclic prefix (CP) in multipath fading channel [6]. Although FD-SDFE turbo equalization scheme improved the bit error rate (BER) performance of SC-FDMA without CP, but the complexity of the system was increased.

In this paper, a new scheme for SC-FDMA based on circular shifting of the subcarriers is proposed for uplink MIMO SC-FDMA. This new SC-FDMA scheme with Spatial Multiplexing and Cyclic Delay Diversity are used to enhance the performance of the system. Minimum mean square error (MMSE) channel estimation is used to avoid inter symbol interference (ISI) as well as MMSE frequency domain equalizer (FDE) is used to avoid inter channel interference (IAI).

The rest of the paper is organized as follows: section II, the system model of the new scheme for uplink SC-FDMA LTE based on Spatial Multiplexing and Cyclic Delay Diversity is introduced. Moreover, channel estimation (CH) and frequency domain equalization are presented in section II for the proposed scheme. In section III, performance evaluation is illustrated using MATLAB program. Finally, Conclusion is presented in section IV.

II. SYSTEM MODEL

In SC-FDMA, each subcarrier contains information of all transmitted symbols. The New proposed scheme for SC-FDMA is based on circular shifting of the subcarriers as shown in Fig. 1. Fig.2 shows simplified block diagram of the proposed scheme for SC-FDMA LTE based on Spatial Multiplexing and Cyclic Delay Diversity.

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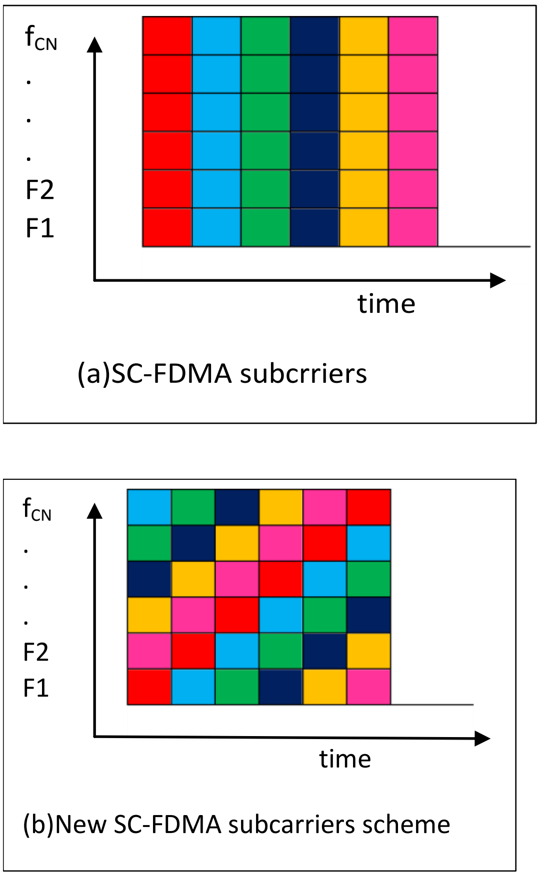

Fig.1Conventional and new proposed SC-FDMA subcarriers schemes.

In Fig. 2, the input bit stream is encoded using rate (1/2) convolutional encoder then the encoded vector is modulated using QPSK modulation. The modulated symbols with pilots perform N- point discrete Fourier transform (DFT).

After DFT, the kth frequency domain samples can be expressed as:

$$S_k = \sum_{n=0}^{N-1} x_n \, e^{-j\frac{2\pi}{N}nk} \qquad (1)$$

Where x_n is the nth symbol. The frequency domain samples are mapped and shift to the right using the proposed SC-FDMA in Fig. 1(b). The mapped-shifted frequency domain samples are transformed back to time domain by an M-points (M>N) inverse DFT (IDFT). The resulting time domain sequence is spatial multiplexing and can be written as:

$$d_{NT,m} = \frac{1}{M} \sum_{v=1}^{M-1} X_{NT,v} \, e^{\frac{j2\pi}{M}mv}, \quad NT = 1,2,..,4 \qquad (2)$$

Where, $X_{NT,v}$ is the *v* th sample at *NT* th antenna. Cyclic delay diversity δ_Q (Q = 1and 2), is applied to the second and forth transmitted antennas [7] as shown in Fig. 1. A cyclic prefix of length greater than or equal to channel impulse response length is appended at the end of each block. The transmitted signal for each antenna will pass through a 3-paths frequency selective Rayleigh fading channel with additive white Gaussian noise (AWGN). The channel is modeled using Jake's model [8], where its discrete impulse response is defined as:

$$h_n = \sum_{l=1}^{L} h_l \, sinc\{ \frac{\tau_l}{T_s} - n \} \qquad (3)$$

Where, T_s is the input sample period to the channel, τ_l is the set of path delays, *L* is the total number of propagation paths, and h_l is the *l* th path gain.

At the receiver, after removal of the CP the received signals at the NR receive antenna can be expressed as [9]:

$$r = H\,d + n \qquad (4)$$

Where:

$$r = [r_1 r_2]^T \qquad (5)$$

$$d = [d_1\ d_2\ d_3\ d_4]^T \qquad (6)$$

$$n = [n_1\ n_2\ ]^T \qquad (7)$$

$$H_{NR,NT} = \begin{bmatrix} H_{11}\ H_{21} \\ H_{12} H_{22} \\ H_{13} H_{23} \\ H_{14} H_{42} \end{bmatrix} \qquad (8)$$

In this work, NT=4, transmit antenna and NR=2 receiving antenna are considered, where, *d* is a vector representing the transmitted block from NT th transmit antenna. The noise vector *n* represents the noise at NR th antenna. $H_{NR,NT}$ is a matrix describing the multipath fading channel between the transmitter and receiver.

The received vector *r* is multiplexed and applied to DFT. The output of the DFT is de-mapped and circularly left shifts to restore the original distribution of the subcarriers, then the received pilots are extracted in order to be used for channel estimation. Minimum mean square error (MMSE) channel estimation is used to avoid inter symbol interference (ISI) where it is represented by [10]:

$$H_{MMSE} = R_{HH}\,[R_{HH} + \frac{\beta}{snr}\,I]^{-1}\,H_{LS} \qquad (9)$$

$$D_{est\_MMSE} = R_{DFT\_MAP}\ .H_{MMSE} \qquad (10)$$

Where, R_{HH} is the auto covariance matrix of $H_{NR,NT}$, H_{LS} is the least square estimator based on transmitted and the extracted received pilots, β is a constant depending on signal constellation and snr is the signal-to-noise ratio[10]. D_{est_MMSE} is the estimated data output of MMSE estimator, R_{DFT_MAP} is the DFT and demapped received vector without pilots.

MMSE frequency domain equalizer (FDE) is now applied to D_{est_MMSE} to avoid inter channel interference (IAI), where its weight is represented by [11]:

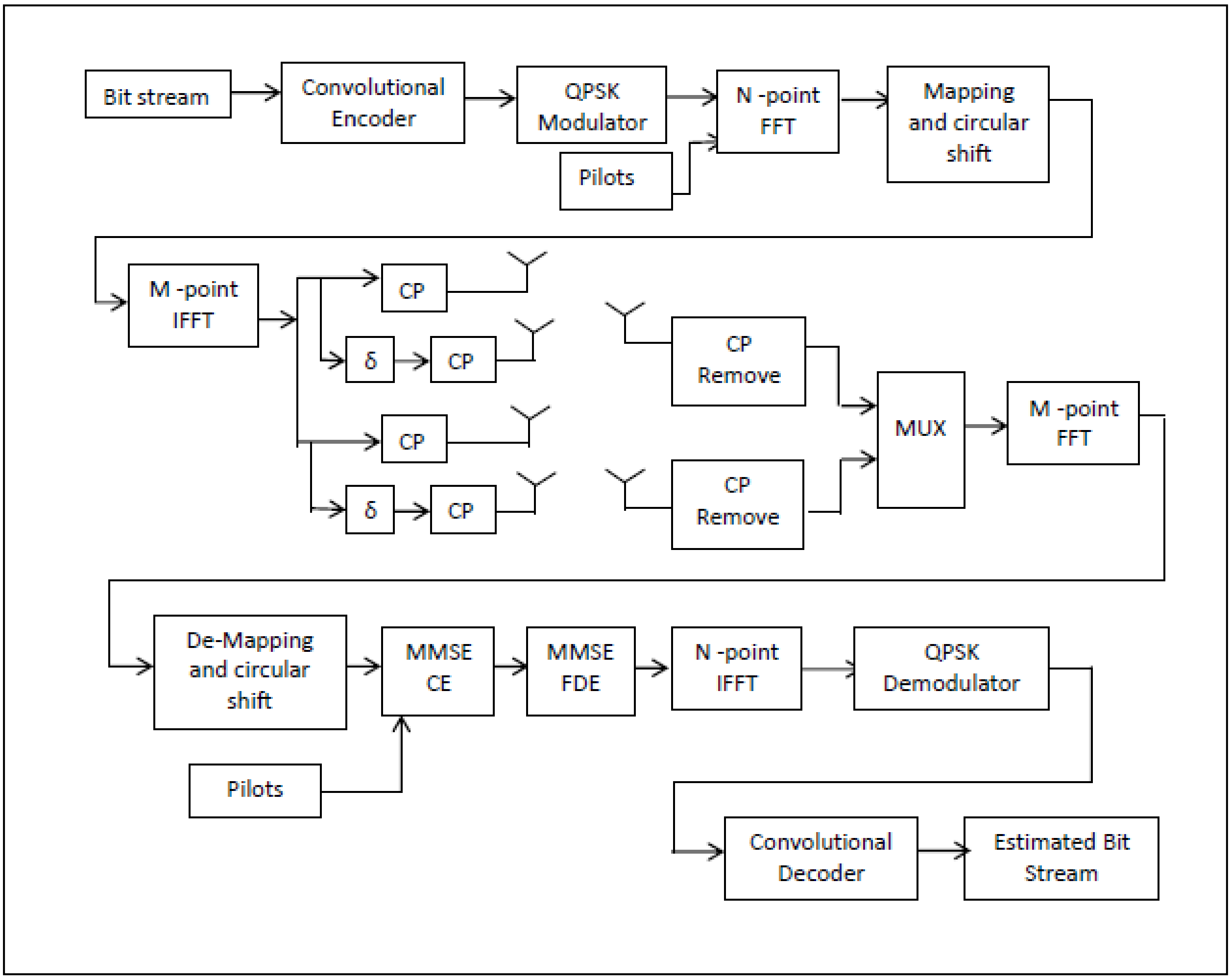

Fig. 2 simplified block diagram of the proposed scheme for SC-FDMA LTE

$$W_{MMSE} = \frac{H^{*}_{NR,NT}(N_c)}{\sum_{nr=1}^{NR}[|H_{nr}|]^2 + (\frac{E_s}{N_o})^{-1}} \quad (11)$$

Where E_s represents the average received signal energy per symbol, $N_o$represents AWGN power spectrum density and * is the complex conjugate. The output vector from MMSE-FDE is given by:

$$Y = \sum_{NR} W_{MMSE}\ D_{est\_MMSE} \quad (12)$$

Y is applied to N-point IDFT, QPSK demodulated and finally decoded using rate (1/2) convolutional decoder [8].

III. PERFORMANCE EVALUATION

The performances of the new scheme for uplink SC-FDMA LTE based on Spatial Multiplexing and Cyclic Delay Diversity under fast fading environment with channel estimation and equalization methods are evaluated using MATLAB simulation program as shown in Fig. 3, and Fig. 4. Table 1, list the simulation parameters that are used in this work.

Table .1 Simulation Parameters

System Bandwidth	5 MHz
FFT Size	16
IFFT size	512
Subcarrier spacing	9.765kHz (5 MHz/512)
Data block size	32
Number of transmitted bits	10000
Type of modulation	QPSK
Convolutional Encoder	Rate =1/2, poly2trellis(7,[171 133])
Channel model	Rayleigh fading channel (Jake’s model)
Doppler Frequency	500 Hz
Channel estimator	MMSE- CE
Channel equalization	MMSE-FDE

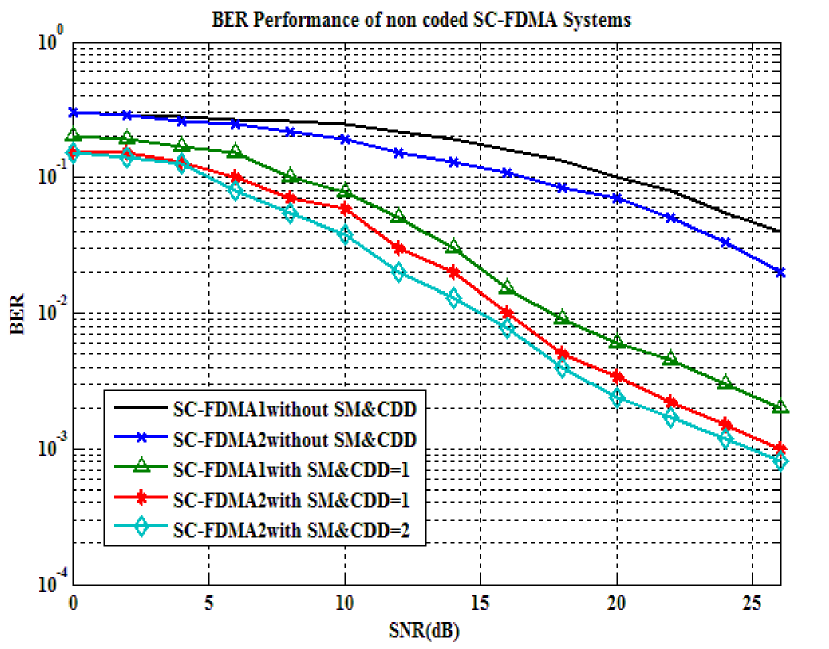

Fig. 3 BER performance of non-coded System without channel estimation

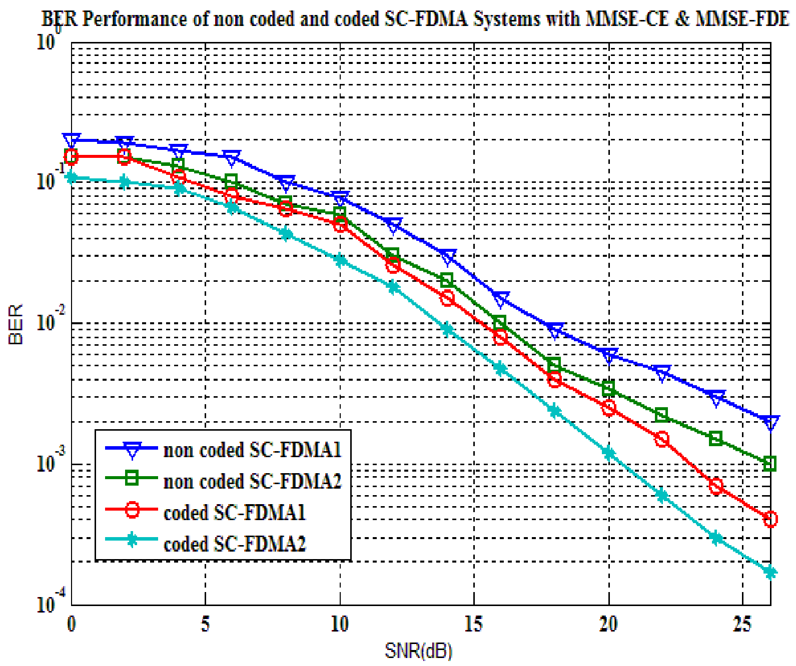

Fig. 4 BER performance of coded and non-coded System with channel estimation and

In this work, conventional SC-FDMA will be denoted in figures as SC-FDMA1 while the proposed SC-FDMA will be denoted as SC-FDMA2.

Fig. 3 shows non-coded SC-FDMA with and without SM and CDD, and only MMSE-FDE is used. The SC-FDMA2 system performance has 2 dB gain at BER= 10^{-2} with SM and CDD, δ=1 compared with SC-FDMA1. Moreover, SC-FDMA2 with CDD where δ=2 performs better than δ=1 by 1 dB at BER=2e-3.

A coded system and non-coded system using MMSE channel estimation and MMSE-FDE are shown in Fig. 4. Assuming SM and CDD, δ=1 are applied to SC-FDMA1 and SC-FDMA2. It can be noticed that the SC-FDMA2 outperforms SC-FDMA1 by 2 dB at BER = 1e-3 for coded system.

IV. CONCLUSION

In this paper, a new scheme for SC-FDMA based on circular shifting of the subcarriers has been proposed for uplink SC-FDMA LTE. Based on MMSE channel estimation and MMSE-FDE, the proposed system of SC-FDMA performs better than conventional SC-FDMA for both coded and non-coded systems as shown in simulation results. Although the complexity of the system is large by applying both MMSE channel estimation and MMSE-FDE but it is clear that the proposed system provides good performance in fast multipath fading channel with high Doppler frequency.

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