An Adaptive Frequency Domain Equalization to Analyze the Effect of Carrier Frequency Offset on SC-CDMA

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Abstract

In recent days, Broadband wireless accesstechnologies, offering bit rates of tenmegabits per second or more to residential and business subscribers,which are attractive and economical alternatives to broadbandwired access technologies. SC-CDMAtechniques, which employing FDE (Frequency-Domain Equalization) techniquesare appropriate for high data rate transmission over severe time-dispersive channels. However, these techniques may require accurate carrier synchronization and very stable oscillators, especially when employed in the uplink transmission of CDMA (Code Division Multiple Access) based systems with large blocks. Even there is small offset in these carrier frequencysynchronization offers a severe effect on the complete communication system. In this paper we study the impact of carrier frequency offsetson the uplink of SC-CDMA-based Frequency domain equalization system..The earlier proposed CDMA techniques are not able to provide effective carrier frequency synchronization effectively,the recently proposed SC-CDMA with FDE evaluating the linear equalization stillprovides some CFO. To overcome this problem this paper proposes an adaptive FDE for the SC-CDMA system by implementing a DFE(Decision Feedback Equalizer) at the receiver.

Keywords: Single Carrier Code Division Multiple Access, Frequency Domain Equalization,DFE.

1.INTRODUCTION

Fourth Generation of mobile communication systems is to provide users with the capacity to access any service at any time at a reasonable cost and at the required levels of quality .The primary specification for this new access network is that it must provide a throughput of 1 Mbps for mobile users and 1 Gbps for users that are stationary. Other requirements include high spectral efficiency and high capacity and coverage.

Wireless communication has been a very important technology and has emerged rapidly in the market since it provides network mobility, scalability and connectivity to the users.Wireless differs from the wired networks because it can transmit and receive the signal through the propagation medium between a client and access point. The wireless communication, systems suffer from multipath propagation effect such as signal fading, Doppler spread and delay spread. These effects combine to cause smearing together of successive symbols, called Inter Symbol Interference (ISI) distortion, at high speed mobile data transmissions. This problem causes the received signal to be unintelligible as a result of distorted transmitted signal.

1.1 CDMA

Overview OfCDMA

CDMA is a one of the multiple access technique, where several transmitters can send information simultaneously over a single communication channel. This allows several users to share a band of frequencies. To permit this to be achieved without undue interference between the users CDMA employs spread-spectrum technology and a special coding scheme (where each transmitter is assigned a code). Up to now the CDMA adopted with Direct Sequence (DS) has achieved the good performance in third generation mobile communication technologies to achieve much high data rates services. In next generation, wireless access technologies [1], [2], offering bit rates of tens of megabits per second or more to residential and business subscribers, are attractive and economical alternatives to broadband wired access technologies. Thus to access these technologies simultaneously the channel become severely frequency selective [3].

1.2 SC-CDMA

A single carrier (SC) system is a traditional digitaltransmission scheme in which data symbolstransported as a fixed-symbol-rate serial stream of amplitude and/or phase-modulated pulses, which in turn modulate asinusoidal carrier. Single-carrier block transmission with Frequency Domain Equalization (SC-FDE), which enjoys a much simpler transmitter structure and lower PAPR, has received considerable attention. DS-CDMA combinedwith FDE, which is known as Single-Carrier Code Division Multiple Access (SC-CDMA) or cyclic prefix.which can effectively overcome the channel frequency selectivity, significantly improve BER performance for DS-CDMA downlink transmission.

Single Carrier (SC) transmission techniques are mainly adopted as physical (PHY) layer specifications of wireless systems. The SC transmission techniques are very simple and sufficient for narrowband access where transmitted signals suffer from flat fading. However, recent wireless systems desire higher data rate with using broadband channels. The SC transmission techniques are often insufficient for such a broadband access where transmitted signals suffer from Inter-Symbol Interference (ISI) and frequency selective fading. To overcome ISI and frequency selective fading,the SC transmission techniques require some equalization techniques such as Frequency domain equalization.

1.3 Carrier Frequency Offset(CFO)

The carrier frequency of the received signal may be different from that of the nominal value of the transmitter carrier frequency effect of a frequency offset between a transmitter and a receiver is the loss of orthogonality between the subcarriers resulting in Inter Carrier Interference (ICI). The characteristics of this ICI are similar to white Gaussian noise and lead to a degradation of the SNR. For both AWGN and fading channels, this degradation increases with the square of the number of subcarriers. In DS-CDMA systems, many detection schemes are proposed to eliminate the MUI. However if these scheme are used for MC-CDMA Systems, their performance deteriorates even in the presence of a small frequency offset. The CFO reduces the Signal to Noise Ratio (SNR), Increases the Bit Error Rate (BER). The CFO cannot be fully removed, and a certain amount of residual CFO still exists, which inevitably degrades system performance.

There are so many approaches proposed to analyze this effect on different communication technologies like OFDM, MC-CDMA, and SC-CDMA respectively. In [4], Orthogonal frequency division multiplexing (OFDM) is proposed which is an attractive modulation scheme used in broadband communication systems. The basic idea of OFDM is that of converting a frequency selective channel into a parallel collection of frequency flat sub-channels. Hence one can easily recover the signal by a one-tap equalizer on each flat sub-channel. Since the different subcarriers signal spectrum can overlap in frequency, the available bandwidth is used very efficiently. But the main problem associated with OFDM technique, it is not applicable to high data rates, but the analysis carried out on CFO is less complex.Recently Single-Carrier Block Transmission (SCBT) has gained a lot of attention in the literature recently [5]. In addition, SCBT uses only one carrier, instead of the many typically used in OFDM, so the peak-to-average transmitted power ratio for SC-modulated signals is smaller.But this conventional CDMA suffers Multipath Interferences (MPIs) and Multiple-Access Interferences (MAIs), which significantly limit the system capacity and data rate. On the other hand, Multicarrier Code Division Multiple Access (MC-CDMA)[9-12] based on combining Orthogonal Frequency Division Multiplexing (OFDM) with CDMA can effectively cope with the frequency-selective fading and exploit the frequency diversity. Unfortunately, the multicarrier system suffers from the High Peak-to-Average Power Ratio (PAPR) problem, which limits performance on practical transmission [7], [8].

When combined SC with frequency domain equalization (SC-FDE) [5], [6], this approach delivers performance similar to OFDM, with essentially the same overall complexity. In recent days it is attaining the more concentration towards high data rate communications due to its simple structure. The study on SC-CDMA,so far, has mostly been constructed based on an optimistic assumption of perfect carrier frequency estimation. Inpractical applications, however, perfect carrier synchronizationis hard to achieve due to noise and other effects. In other words, the Carrier Frequency Offset (CFO) cannot be fully removed and a certain amount of residual CFO still exists, which inevitably degrades system performance. This paper investigates the effects of the residual CFO on the Adaptive FDE-based SC-CDMAsystem. This paper proposes an alternative approach based on Single-Carrier FDE (SC-FDE) methods. It also combines the power considered for transmission of a signal using SC-FDE.
The rest of the paper is organized as follows: section gives the basic communication mode for the single carrier block transmission technique. The proposed adaptive frequency domain equalization combined with SC is illustrated in section III. Section IV gives the performance evaluation o the proposed approach, finally conclusions are provided in section V.

2.MC-CDMA

MC-CDMA transmits multiple modulated subcarriers in parallel [1]. Each occupies only a very narrow bandwidth. Since the channel affects only the amplitude and phase of each subcarrier, equalizing each subcarrier's gain and phase does compensation for frequency selective fading. Generation of the multiple subcarriers is done by performing Inverse Fast Fourier Transform (IFFT) processing at the transmitter on blocks of *M* data symbols; extraction of the subcarriers at the receiver is done by performing the fast Fourier transform (FFT) operation on blocks of *M* received samples. Typically, the FFT block length *M* is at least 4–10 times longer than the maximum impulse response span. One reason for this is to minimize the fraction of overhead due to the insertion of a cyclic prefix at the beginning of each block. The cyclic prefix is a repetition of the last data symbols in a block. Its length in data symbols exceeds the maximum expected delay spread. The cyclic prefix is discarded at the receiver. Its purpose is to:

• Prevent contamination of a block by ISI from the previous block

• Make the received block appear to be periodic with period M

This produces the appearance of circular convolution, which is essential to the proper functioning of the FFT operation.

The time equalization typically requires a number of multiplications per symbol that is proportional to the maximum channel impulse response length. MC-CDMA processing requires on the order of $\log_2 M$ multiplications per data symbol, counting both transmitter and receiver operations. Since M is proportional to the maximum expected channel response length, MC-CDMA appears to offer a better performance/complexity trade-off than conventional SC modulation with time domain equalization for large multipath spread [4]

A variation is adaptive SC-FDE, where the signal constellation on each sub channel depends onchannel response at that frequency. It requires feedback from the receiver to the transmitter, and is not commonly employed radio systems due to complexity and channel time variations. Because of the fixed power and bit rate on each sub channel, some of which might be severely faded by frequency-selective channels, non-adaptive SC-FDE must be coded.

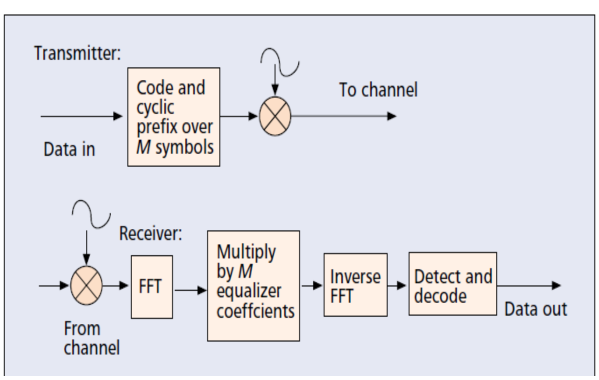

Figure.1.SC-FDE with Linear Equalizer

2.1Single-Carrier Modulation Frequency Domain Adaptive Equalizer

An SC system transmits a single carrier, modulated, for example, with QAM, at a high symbol rate. Frequency domain linear equalization in an SC system is simply the frequency domain analog of what is done by a conventional linear time domain equalizer. For channels with severe delay spread, frequency domain equalization is computationally simpler than corresponding time domain equalization for the same reason MC-CDMA is simpler because equalization is performed on a block of data at a time, and the operations on this block involve an efficient FFT operation and a simple channel inversion operation. Sari et al.[6,7] pointed out that when combined with FFT processing and the use of a cyclic prefix, an SC systemwith FDE (SC-FDE) has essentially the same performance and low complexity as an MC-CDMA system. Also notable is that a frequency domain receiver processing SC modulated data shares a number of common signal processing functions with an MC-CDMA receiver. In fact, as we point out in the next section, SC and MC-CDMA modems can easily be configured to coexist, and significant advantages may be obtained through such coexistence. Figure (1) shows conventional linear equalization, using a transversal filter with *M* tap coefficients, but with filtering done in the frequency domain. The block length M, suitable for Multichannel Multipoint Distribution Service(MMDS) systems with 6 MHz bandwidths, would be chosen in the range of 64–2048 for both MC-CDMA and SC-FDE systems. There are approximately $\log_2 M$ multiplications per symbol, as in MC-CDMA. The use of SC modulation and FDE by processing the FFT of the received signal has several attractive features:

• SC modulation has reduced peak-to-average ratio requirements from MC-CDMA; thereby allowing the use of less costly power amplifiers.Its performance with FDE is similar to that of MC-CDMA, even for very long channel delay spread.

• Frequency domain receiver processing has a similar complexity reduction advantage to that of OFDM: complexity is proportional to log of multipath spread.

• Coding, while desirable, is not necessary for combating frequency selectivity, as it is in non-adaptive MC-CDMA.

• SC modulation is a well-proven technology in many existing wireless and wire applications, and its RF system linearity requirements are well known.

A cyclic prefix is appended to each block of M symbols, exactly as in MC-CDMA. As an additional function, the cyclic prefix can be combined with a training sequence forequalizer adaptation.

For either MC-CDMA or SC-CDMA with FDE broadband wireless systems operating in severe outdoor multipath environments, typical values of *M* could be

256–1024, and typical values of *P* could be 64 or 128. Overlap-save or overlap-add signal processing techniques could also be used to avoid the extra overhead of the cyclic prefix.

An inverse FFT returns the equalized signal to the time domain prior to the detection of data symbols. Adaptation of the FDE equalizer's transfer function can be done with Least Mean Square (LMS), root least square (RLS), or Least Squares Minimization (LS) techniques, analogous to adaptation of time domain equalizers [8, 9].

KNOWN CHANNELS

Data is transmitted in blocks of *M* data symbols $\{a_k\}$ at a symbol rate of 1/*T* per second. Each block is preceded by a cyclic prefix. We consider a single-carrier frequency domain DFE that processes blocks of *MI* received samples $\{r_m\}$ at a time, using a *MI*- point FFT, where *I* is the number of receiver input samples per data symbol, and *M* is the number of data symbols per FFT block. The choice of *I*>1 gives a fractionally-spaced equalizer whose performance is relatively insensitive to sampling phase; good performance can also be obtained for *I*=1 sample per symbol with an optimal sampling phase derived from a symbol timing subsystem.

The data symbols are assumed to be normalizeduncorrelated complex random variables derived from a discrete alphabet such as QPSK or 16QAM, with zero mean, and unit variance. The forward filter has *MI* complex frequency-domain coefficients $\{W_l\}$. After the inverse FFT operation, its time domain output is sampled once per symbol interval. There are *B* complex feedback coefficients $\{f_k^*\}$, $k\in FB$, where *FB* is a set of non-zero indices that correspond to the delays (in symbol periods) of the *B* feedback coefficients.

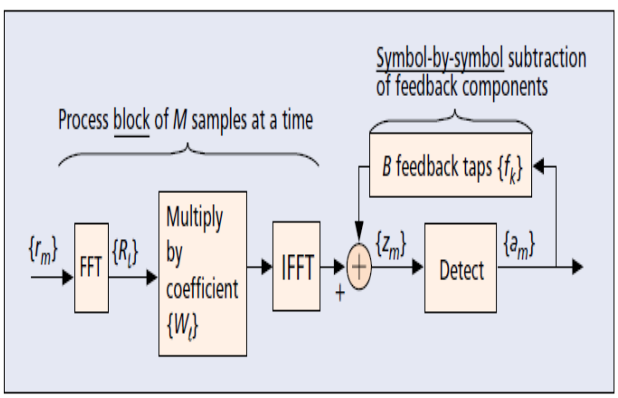

Figure 2: SC-FDE with Decision Feedback Equalizer

For example, the indices *FB* could correspond to the relative estimated delays of the largest channel impulse response echoes; for example, *B*=1 and *FB* has just one non-zero index – the relative delay of the largest echo. For Linear Equalization (FD-LE) *B*=0, and *FB* is a null set.

With this notation, the m_{th} time domain output sample, obtained by decimating the sampled forward filter output

$$Z_m = \frac{1}{MI}\sum_{l=0}^{MI-1} W_l R_l \exp(j\frac{2\pi}{M}lm) - \sum_{k\varepsilon F_B} f_k^* a_{m-k}, ...(1)$$

where $m = 0,1,2....(M-1)$

and where $R_l = \sum_{m=0}^{MI-1} r_m \exp(-j\frac{2\pi}{M}lm)$ ....(2)

Where $l = 0,1,2....(MI-1)$

is the FFT of the received *MI*-sample sequence $\{r_m\}$. Complex conjugates are denoted by asterisks. The error at the m_{th} sample is

$$e_m = z_m - a_m.......(3)$$

and the mean squared error $E(|e_m|^2)$) is to be minimized with respect to the$\{w_l\}$ and$\{f_k\}$.

The received complex samples $\{r_m\}$, sampled at rate *I/T*, are expressed as

$$r_m = \sum_{k=0}^{M-1} a_k h(mT/I-kT) + n(mT/I)....(4)$$

Where $m = 0,1,2....(MI-1)$

where*h*(*t*) is the channel's impulse response (including transmit filtering), and {*n*(*mT/I*)} are samples of additive noise, assumed to be uncorrelated, have zero mean, and variance σ^2. Because of the presence of the cyclic prefix, the data symbols {*ak*} can be assumed to be periodic (*ak*=*ak*±*LM*, for any integer *L*), as can the impulse response samples ({*h*(*mT/I*)=*h*((*m/I*±*LM*)*T*)).

Decision Feedback Equalization (DFE) gives better performance for frequency-selective radio channels than linear equalization [3]. In conventional DFE equalizers, symbol-by-symbol data symbol decisions are made, filtered, and immediately fed back to remove their interference effect from subsequently detected symbols. Because of the delay inherent in the block FFT signal processing, this immediate filtered decision feedback cannot be done in a frequency domain Equalizer, which uses frequency domain filtering of the fed-back signal. A hybrid time-frequency domain DFE approach, which avoids the above mentioned feedback delay problem, would be to use frequency domain filtering only for the forward filter part of the DFE, and conventional transversal filtering for the feedback part. The transversal feedback filter is relatively simple in any case, since it performs multiplications only on data symbols, and it could be made as short or long as required for adequate performance. Figure 2 illustrates such a hybrid time-frequency domain DFE topology. Once per block, the M FFT output coefficients,$\{R_l\}$, are multiplied by the complex-valued M forward equalizer coefficients $\{W_l\}$(which compensate for the frequency selective channel's variations of amplitude and phase with frequency). An IFFT is applied to the M weight-equalized complex-valued samples, and the resulting time-domain sequence is passed to a data symbol decision device or, in the case of a DFE, the estimated ISI due to previously detected symbols is computed using B feedback taps $\{f_k\}$, and subtracted off, symbol by symbol. FDE can also be combined with spatial processing to provide interference suppression and diversity [9]. The performance evaluation of the proposed approach is illustrated in next section.

3.PERFORMANCE EVALUATION

The performance of the proposed approach is illustrated in this section. It also gives the comparative analysis of the proposed approach with the previously proposed FDE approach. For this we use the Walsh–Hadamard codes for orthogonal spreading and a long PN code. Unless otherwise specified, the block size Nis setto 64. The channel is assumed to be a quasistatic frequency selective fading channel. For illustration, a 16-path (L = 16)channel with a uniform power delay profile (PDP) is adopted, which is the same as the channel used in [11]. A CP with theminimum length (i.e., Ng= 16) is inserted in front of eachblock. It is also assumed that the receiver has perfect timing synchronization and channel estimation.

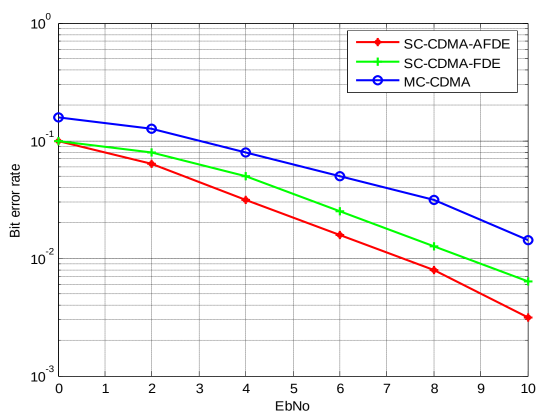

Figure.3 BER Analysis for Various Approaches

The above figure(3) represents the Bit error rate versus Signal to noise ratio plot. From the above figure it is clear that the performance of the proposed method for is efficient. It also denotes that with an increase in SNR value there is a nominal decrease in the BER. It also shows that the decrement of average BER for proposed method is efficient compared to the previous approaches.

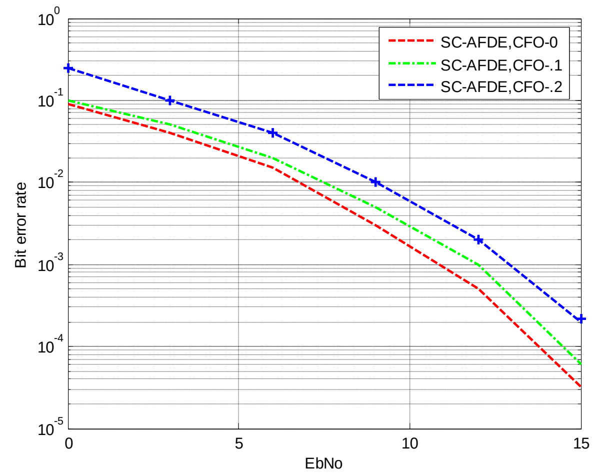

Figure.4 BER Analysis at Various CFO's

The above figure(4) represents the performance of the SC--FDE for various carrier frequency offsets. With increase in the CFO the average BER is increased. The proposed approach is tested for various CFO's(0, 0.1, 0.2), and observed that for a particular CFO with increase in the SNR the average is will be decreased.

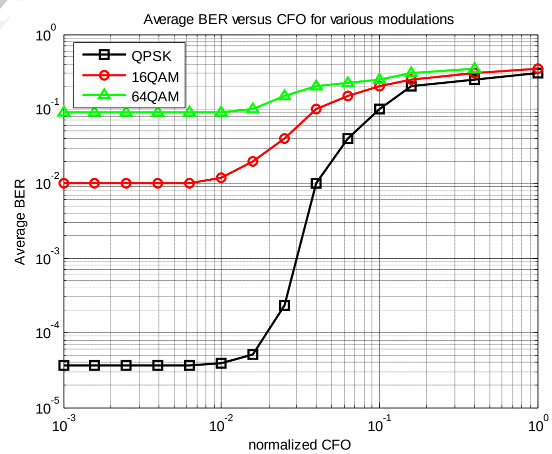

Figure.5 BER Analysis for Various Modulation Schemes

The above Figure(5) gives the comparative analysis of the proposed approach for various modulations. It shows that for a particular modulation technique with decrement in the CFO the average BER is decreasing gradually, it is also observed that the increment is high for the modulation which is having less data rate.

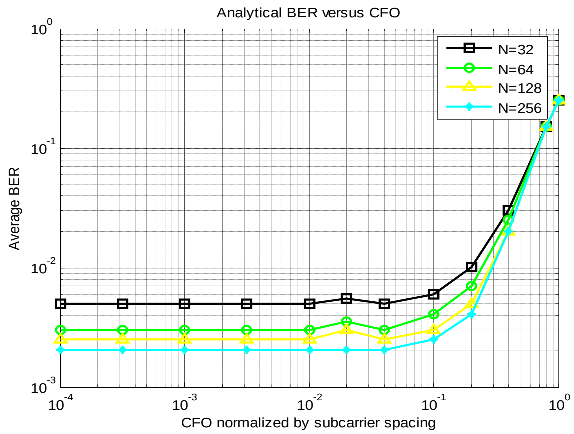

Figure.6 BER analysis for various block sizes

The above figure shows the carrier frequency versus average BER for various block sizes (N=32, N=64, N=128, N=256). From the figure it is observed that as the CFO increases the average BER is increasing gradually. It also varying with block sizes of data considered at transmitter. The conclusions are illustrated in next section.

4. CONCLUSIONS

In this paper we study the impact of carrier frequency offsets on the uplink of SC-CDMA systems based on Frequency domain equalization. The earlier proposed CDMA techniques are not able to provide effective carrier frequency synchronization effectively, the recently proposed SC-CDMA with FDE evaluating the linear equalization still provides some CFO. This approach includes the new concept of Decision feedback equalizer to further reduce the impact of carrier frequency effect on SC-CDMA system. This also considered the power amplifier requirements to analyze the impact of CFO on the system. The results discussed in above section also declares that the proposed approach is efficient compared to previous approaches.

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