

OFDM PAPR Reduction Using Linear Block Codes with Error Correction in Additive White Gaussian Noise Channel

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Abstract - The past decade has seen many radical changes and achievements in the field of wireless communication. Applications of wireless communication have grown swiftly in the recent past. This rigorous growth leads to more throughputs over wireless channels along with increased reliability. But still the bandwidth demands are endless and increasing day by day. Today we need to constantly work towards achieving reliable wireless communication with high spectral efficiency, low complexity and good error performance results. Orthogonal frequency division multiplexing (OFDM) technique is a promising technique in this regard as it offers high data rate and reliable communications over various fading channels. But the main drawback of OFDM is the high peak to average power ratio (PAPR). In this paper we present the technique to reduce the PAPR using linear block codes with error correction. Simulation results show that the bit error rate (BER) of proposed scheme considerably outperforms the conventional OFDM system.

Keywords - BER, OFDM, PAPR

I. INTRODUCTION

The basic principle of OFDM is to split input data stream into a number of lower rate streams that are transferred simultaneously over a number of subcarriers, the transmission rate is slower in parallel subcarriers, a frequency selective channel seems flat to each subcarrier. At the beginning of all the OFDM symbol, ISI is reduced almost completely by adding a guard interval. However, this interval is filled with a cyclically extended version of the OFDM symbol, instead of using an empty guard time. This method is used to avoid ICI. In MCM, input data stream is distributed into lower rate substreams, these are used to modulate few subcarriers. The individual spectrum of subcarriers do not overlap, because the spacing among these subcarriers is large enough. Therefore the receiver uses a band pass filter tuned to that subcarrier frequency in order to demodulate the signal. Even though the individual frequency spectrum may overlap, the subcarrier spacing is kept at minimum in OFDM, while still preserving the time domain orthogonality between subcarriers. The least subcarrier spacing should be equal to $1/T$, where T is the symbol period. An OFDM symbol in baseband is defined as:

$$x(t) = \sum_{i=-\frac{N}{2}}^{\frac{N}{2}-1} a_{i+\frac{N}{2}} \exp\left(j \frac{2\pi i t}{T}\right) s(t) \quad 0 \leq t \leq T$$

where, $a_{i+N/2}$ denotes the complex symbol modulating the i -th carrier, $s(t)$ is the time window function defined in the interval $[0, T]$, N is the number of subcarriers, and T is the OFDM symbol period. Subcarriers are spaced $\Delta f = 1/T$ apart. The correlation coefficient between the subcarriers may be defined as:

$$\rho_{kn} = \frac{1}{T} \int_0^T \exp\left(j \frac{2\pi k t}{T}\right) \exp\left(-j \frac{2\pi n t}{T}\right) dt$$

As can be seen from (1)

$$\rho_{kn} = \begin{cases} 1, & n = k \\ 0, & n \neq k \end{cases} \quad (1)$$

Therefore, OFDM signal of the form (1) satisfies the condition of mutual orthogonality among subcarriers in the symbol interval. In order to obtain the data modulating the k -th subcarrier OFDM symbol should be down converted with a frequency of k/T , and then integrated over the symbol period [1]. Then above operation may be shown as:

$$\frac{1}{T} \int_0^T \exp\left(-j \frac{2\pi k t}{T}\right) \sum_{i=-N/2}^{N/2-1} a_{i+N/2} \exp\left(j \frac{2\pi i t}{T}\right) dt \quad (2)$$

$$\frac{1}{T} \sum_{i=-N/2}^{N/2-1} a_{i+N/2} \frac{1}{T} \int_0^T \exp\left(-j \frac{2\pi k t}{T}\right) dt \quad (3)$$

Using (2) and (3) together

Resultant signal= $a_{k+N/2}$ considering the sequential transmission of symbols, the baseband signal at the OFDM modulator output can be expressed as:

$$x(t) = \sum_n \sum_{i=-\frac{N}{2}}^{\frac{N}{2}-1} a_{i+\frac{N}{2},n} \exp(j \frac{2\pi i(t-nT)}{T}) s(t-nT)$$

Where, $a_{i+N/2,n}$ represents the data modulating the i -th carrier of the n -th OFDM symbol. The n -th OFDM symbol is transmitted in the time interval $[nT, nT+T]$. Assuming that the windowing function $s(t)$ is nonzero only in $[0,T]$ interval, if N samples are taken from $x(t)$ at time instants $\{nT+kT/N, k=0 \dots N-1\}$, the result will be [1]:

$$y[k] = x(nT + \frac{kT}{N}) = \sum_n \sum_{i=-\frac{N}{2}}^{\frac{N}{2}-1} a_{i+\frac{N}{2},n} \exp(j \frac{2\pi i(nT + kT/N - nT)}{T}) s(nT + kT/N - nT)$$

$$= \sum_{i=-\frac{N}{2}}^{\frac{N}{2}-1} a_{i+\frac{N}{2},n} \exp(j \frac{2\pi i k}{N}) s(\frac{kT}{N}) \quad 0 \leq k \leq N - 1 \quad (4)$$

It can be seen from (4) that, N samples reserved from n -th OFDM symbol at a rate of N/T can be achieved by taking N -point inverse Discrete Fourier Transform (IDFT) of the input data $a_{k,n}, k=0 \dots N-1$, weighted by the window function $s(t)$ at the sampling time instants.

But the major disadvantage of OFDM is the high peak to average power ratio. Our objective is to develop a technique to reduce the PAPR using linear block codes. We will use linear block codes for reducing PAPR and try and evaluate the resultant system performance with and without error correction capability of linear block codes, on additive white Gaussian noise channel.

II. GENERAL OFDM SYSTEM

Fig. 1 and 2 shows a general OFDM system. The transmitter first converts the input data from a serial stream to parallel sets. Each set of data contains one information bit for each carrier frequency. Then, parallel data are modulated to the orthogonal carrier frequencies. The IFFT (Inverse Fast Fourier Transform) converts the parallel data into time domain waveforms. Finally, these waveforms are combined to create a single time domain signal for transmission.

The receiver basically performs the inverse of the transmitter by first separating the data into parallel streams. Then, the FFT (Fast Fourier Transform) converts these parallel data streams into frequency domain data. The data are now available in modulated form on the orthogonal carriers. Demodulation down-converts this information back to the baseband. Finally, this parallel data are converted back into a serial stream to recover the original signal. OFDM faces several challenges. The key challenges are ISI due to multipath-use guard interval, large peak to average ratio due to non-linearity of amplifier; phase noise problems of oscillator, need frequency offset correction in the receiver. Inter-symbol interference (ISI) is eliminated almost completely by introducing a guard time in every OFDM symbol. Large peak-to-average power ratio (PAPR) which distorts the signal if the transmitter contains nonlinear components such as power amplifiers (PAs). The nonlinear effects on the transmitted OFDM symbols are spectral spreading, inter modulation and changing the signal constellation. In other words, the nonlinear distortion causes both in-band and out-of-band interference to signals. Therefore the PAs requires a back off which is approximately equal to the PAPR for distortion-less transmission. This decreases the efficiency for amplifiers. Therefore, reducing the PAPR is of practical interest.

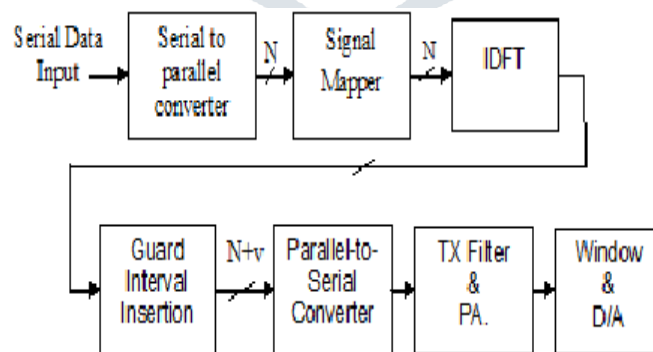


Fig. 1 Block Diagram of an OFDM Transmitter.

The serial input data stream is distributed into frames of N_f bits. These N_f bits are arranged into N groups, where N is the number of subcarriers. The number of bits in each of the N groups determines the constellation size for that particular subcarrier. For example, if all the subcarriers are modulated by QPSK then each of the groups consists of 2 bits, if 16-QAM modulation is used each group holds 4 bits. This scheme is called as fixed loading. However, this is not the only way of distributing input bits among

the subchannels. N_f bits could be distributed among subcarriers according to the channel states. Therefore, one of the subcarriers can be modulated with 16-QAM whereas another one can be modulated with 32-QAM, etc. The former subcarrier consists of 4 bits and the latter subcarrier resides of 5 bits. This scheme is named as adaptive loading. OFDM can be considered as N independent QAM channels, each having a different QAM constellation but each operating at the same symbol rate $1/T$. After signal mapping, N complex points are obtained. These multiple points are passed over an IDFT block. Cyclic prefix of length v is added to the IDFT output in order to combat with ICI and ISI. After Parallel-to-Serial conversion, windowing function is applied. The output is fed into a Digital-to-Analog converter efficient at a frequency of N/T . Finally transfer filter is applied in order to deliver necessary spectrum shaping before power enlargement.

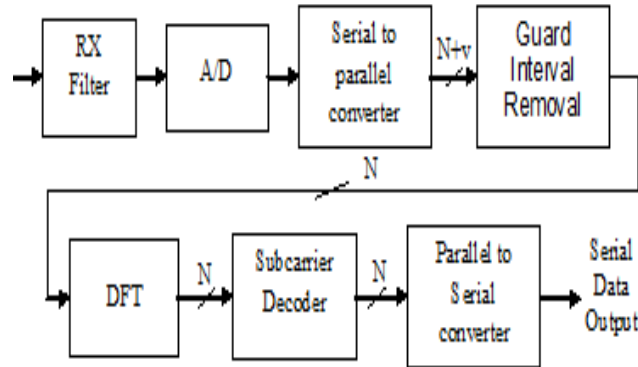


Fig. 2 Block Diagram of an OFDM Receiver.

The receiver implements inverse processes of the transmitter. Received signal is delivered through a receive filter and an Analog-to-Digital converter operating at a frequency of N/T . After these down converting and sampling processes, cyclic prefix is detached from the signal and a DFT operation is achieved on the resultant complex points in order to demodulate the subcarriers. Subcarrier decoder translates obtained complex points to the corresponding bit stream.

Due to the major disadvantage of OFDM which is the high peak to average power ratio, our objective is to develop a technique to reduce the PAPR using linear block codes with error detection and correction capabilities. Linear Block Codes perform up to mark in case error detection and correction problems. If we can use this capability of error detection and correction of the linear block codes in an OFDM environment then we can control PAPR and thus get higher throughput along with a reliable and less error prone wireless communication. Also we can compare the performance of the linear block codes with and without error detection and error correction capability and accordingly deduce the results.

III. PROPOSED OFDM SYSTEM

The OFDM transmitter used in our result simulations is shown in fig.3. The probability that, the PAPR of the OFDM signal exceeds a certain threshold λ is given by:

$$\Pr\{PAPR > \lambda\} = 1 - (1 - e^{-\lambda})^N$$

The probability that, the lowest PAPR λ_1 exceeds a certain threshold λ is given by:

$$\Pr\{\lambda_1 > \lambda\} = \Pr\{PAPR > \lambda\}$$

To generate the sequences that would result in lower PAPR, linear block coding is used at the start of the OFDM system as shown in figure 3.3. The Linear Block Coder transform the serial data before it is mapped to the orthogonal channels. Different sequences are generated by encoding the raw data bits at the beginning of the system. This transformation leads to a lower PAPR value as illustrated in the above equations. The linear block code transforms k data bits to n serial data bits. These n serial data bits consist of enough redundancy to lower the PAPR value as compared to the one generated with raw k data bits. The OFDM receiver used in our result simulations is shown in fig. 4. It is similar to the one described earlier, the only difference being the use of a linear block coder at the end of the receiver system.

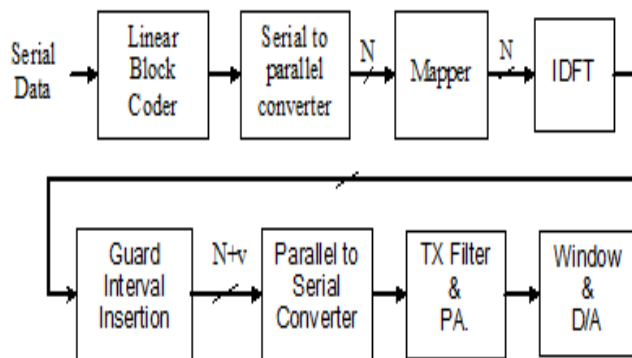


Fig. 3 New OFDM Transmitter.

The linear block decoder is used to recover the data encoded firstly at the transmitter side. It works in a reverse manner by transforming n encoded data bits to k message bits, thereby removing any added redundancy from the final serial data output.

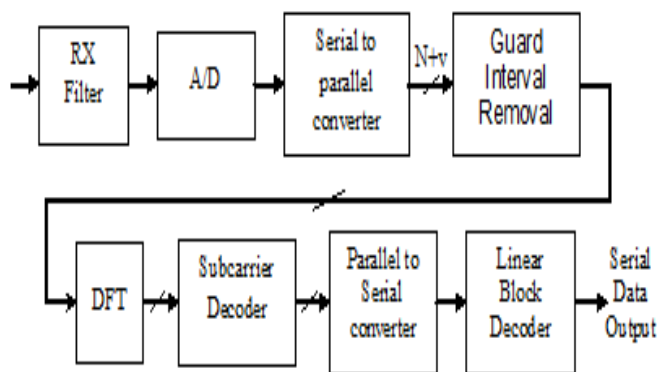


Fig. 4 New OFDM Receiver

IV. SIMULATION RESULTS

TABLE. 1 lists the required OFDM system specifications used while simulation. Fig. 5 illustrates the bit error rate (BER) performance of an OFDM system combined with a (4, 7) Linear Block Codes (LBCs). BER performance is measured over Additive white Gaussian noise channel.

Table. 1 OFDM System Specifications.

Parameter	Value
FFT size	64
Number of subcarriers	52
Subcarrier spacing	312.5 kHz
FFT Sampling frequency	20 MHz
Used subcarrier index	{-26 to -1, +1 to +26}
Cyclic prefix duration	0.8 us
Data symbol duration	3.2 us
Total Symbol duration	4 us

Similarly, from fig. 5, we can see that there is significant improvement in the BER performance with LBCs, both with and without error correction on AWGN channel. The system using LBCs with error correction outperforms the system using LBCs without error correction. The former system is superior by about 2.5 dB at BER of 10^{-3} and by about 2.8 dB at BER of 10^{-5} .

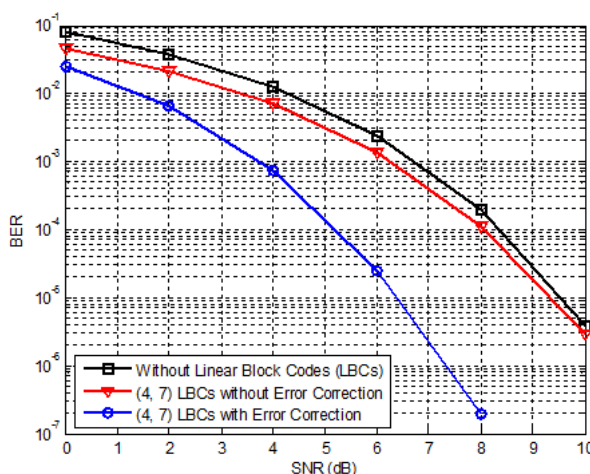


Fig. 5 BER performance of an OFDM system with (4, 7) LBCs over AWGN.

V. CONCLUSION

In this paper we presented a technique to reduce the PAPR of an OFDM system using linear block codes with error correction on AWGN channel. Here we gave an overview of an OFDM system and discussed how an orthogonal frequency division multiplexing (OFDM) system offers high data rate and reliable communications over fading channels. We also discussed about the advantages and disadvantages of an OFDM system. The major disadvantage of OFDM is the high peak to average power ratio. To

mitigate the effect of PAPR or rather somewhat reduce PAPR to certain mean value we used linear block codes. Linear Block Codes perform up to mark in case error detection and correction problems. If we can use this capability of error detection and correction of the linear block codes in an OFDM system then we can achieve higher throughput along with a reliable and less error prone communication. We discussed the OFDM transmitter and OFDM receiver system model that we have used in our simulations. We evaluated the resultant system performance with and without error correction capability of linear block codes, on additive white Gaussian noise channel. As expected, when we can compared the performance of the linear block codes with and without error detection and error correction capability, we found that BER decreased and thus we can say that PAPR also reduced by the use of linear block codes.

There are various techniques to reduce PAPR cum BER and we are using linear block coding technique since it helps to do the same in more effective way. But if we combine some techniques which are advantageous compared to others, there is a scope of even more reduction of PAPR on which we need to research more.

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