International Journal of Innovative Research in Computer Science & Technology (IJIRCST)
ISSN: 2347-5552, Volume-2, Issue-4, July-2014

Complex Number RS Coded OFDM by Unique Word Prefix

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Abstract- **In this paper, we introduced concept of unique word orthogonal frequency division multiplexing (UW-OFDM). In UW-OFDM instead of conventional cyclic prefixes (CPs) we use deterministic sequence, which we called unique word (UW's), as a guard interval. Since Unique word represent known sequence they are advantageously be used for synchronization and channel estimation purposes. The UW's are generated by approximately loding so called redundant subcarrier. We derived optimum complex valued code generator matrices matched to best linear unbiased estimator (BLUE) and to linear minimum mean square error (LMMSE) data estimator. With the help of simulations we highlight the superior bit error ratio (BER) performance of non-systematic coded UW-OFDM compared to systematic coded UW-OFDM and to CP-OFDM in additive white Gaussian noise (AWGN) as well as in frequency selective environments.**

Index Terms: **Cyclic Prefix (CP), Reed-Solomon Coded OFDM, Unique word OFDM (UW-OFDM), Best linear unbiased estimator (BLUE), Linear minimum mean square error (LMMSE)**

I. INTRODUCTION

In the Conventional OFDM signaling systems subsequent symbols are separated by guard intervals which are usually implemented as cyclic prefix (CPs)[1].CPs is used as a guard interval in order to reduced ISI and for cyclicity. In this paper we propose to use known sequence which we call unique word (UW's) instead of cyclic prefix .The technique of UWs has already been investigated in -depth for SC/FDE system[2],where the introduction of unique word in time domain is straightforward since the data symbol are also defined in time domain .In this paper we will show how the unique word can also be introduced in OFDM time domain symbol even though the data QAM (Quadrature Amplitude Modulation)symbols are defined in frequency domain .Fig 1 Compares the Transmit data structure of CP and UW based transmission in time domain[3]Both structures make sure that the linear convolutation of an OFDM symbols with impulse response of dispersive (e.g. multipath) channel appears as a cyclic convolutation at the receiver side .

Nevertheless there are also some fundamental differences CP & UW based transmission The CP is a random sequence whereas the UW is deterministic. Hence, the UW can be optimally designed for particular needs like synchronization and/or channel estimation purposes at the receiver side .In UW-OFDM the guard interval is part of the DFT interval, whereas this is not the case for CP-OFDM which improve the bit error ratio (BER) performance. UW-OFDM has the superior spectral density of the generated waveform than CP-OFDM. If a unique word (UW) is chosen in advance and introduced at the end of each OFDM symbol, cyclicity appears, too. The better way of guard interval is done by using unique word (UW) .This solves the disadvantages of CP having medium BER behavior and bandwidth efficiency. Since unique words represent known sequences, they can advantageously be used for synchronization and channel estimation purposes. Furthermore, the proposed approach introduces a complex number Reed-Solomon (R-S) code structure within the sequence of subcarriers.Viterbhi algorithm is used for coding & decoding.

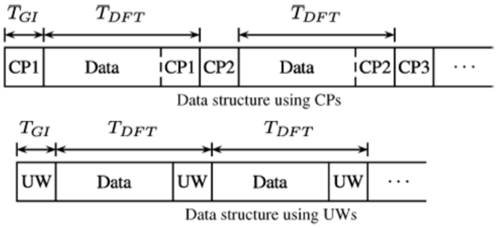

Fig. 1: Transmit data structure using cyclic prefix (CPs) & Unique word (UWs)

II. PROJECT METHODOLOGY

In this project we will design OFDM transmitter and receiver with UW concept using reed Solomon coder and decoder. The block diagram of the system is as given below. The input is random number with 64 0r 128 bits and output is BER graphs

Manuscript received July 22, 2014

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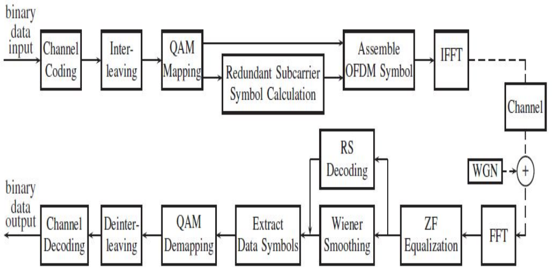

Fig. 2: Block diagram of UW OFDM

Input is binary data which is given to channel coding block for encoding channels. It will send to QAM modulator for modulating or mapping signal through interleaving block. Reed soloman encoding is done on QAM output signal. Unique word Symbols are inserted, IFFT is apply on than signal, which is pass trough channel where white Gaussian noise is added, we apply FFT on that and remove UW symbols, after this exactly opposite process takes place as transmitter side.

A. *Steps for Methodology*

Channel coding/decoding

To avoid this domination by the weakest subcarriers, forward error correction coding is essential. By using coding across the subcarriers, error of weak subcarriers can be corrected up to a certain limit that depends on the code and the channel. A powerful coding means that the performance of an OFDM link is determined by the average received power, rather than by the power of weakest subcarrier. At the receiver the encoded data is recovered by decoding which is exact reverse of encoding.

Interleaving/Deinterleaving

The interleaving is applied to randomize the occurrence of bit errors prior to decoding. At the transmitter, the coded bits are permuted in a certain way, which makes sure that adjacent bits are separated by several bits after interleaving. At the receiver the reverse permutation is performed before decoding. A commonly used interleaving scheme is block interleaver, where input bits are written in a matrix column by column and read out row by row. Instead of block interleaver, it is also possible to use a convolution interleaver.

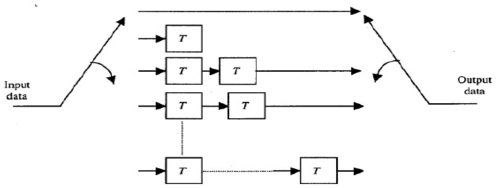

Fig. 3: Convolution interleaver

This interleaver cyclically writes each input symbol or bit into one of k shift registers that introduces a delay of 0 to k-1 symbol duration. The shift registers are read out cyclically to produce the interleaved symbols

QAM mapping/Demapping

Quadrature amplitude modulation (QAM) is the most popular type of modulation in combination with OFDM. Especially rectangular constellation are easy to implement as they can be split in to independent pulse amplitude modulated (PAM) components for both the in-phase and the quadrature part. Noise immunity is better in case of QAM because signal vectors differ not only in phase but also in amplitude Fig.4 is constellations of QPSK,16 QAM .In the receiver, the incoming QAM symbols have to be demapped.

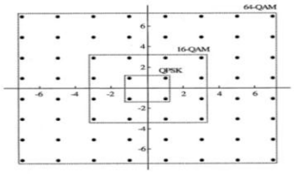

Fig. 4: QPSK, 16 QAM & 64 QAM Constellation

FFT/IFFT

IFFT modulates a block of input QAM values on to a number of subcarriers. In the receiver, the subcarriers are demodulated by an FFT, which performs the reverse operation of an IFFT. In fact, the IFFT can be made using an FFT by conjugating input and output of the FFT and dividing the output by the FFT size. This makes it possible to use the same hardware for both the transmitter and the receiver. Of course, this saving in complexity is only possible when the modem does not have to transmit and receive simultaneously, which is the case for the standard. In practice, this transform can be implemented very efficiently by the IFFT because, IFFT drastically reduces the amount of calculations by exploiting the regularity of the operation in the IDFT.

Equalization

When the signal is passed through the channel, distortion is introduced in the terms of amplitude and delay creating problem of ISI. This distortion can be compensated with the help of equalizers. Zero Forcing Equalizer refers to a form of linear equalization algorithm used in communication systems which inverts the frequency response of the channel. The Zero-Forcing Equalizer applies the inverse of the channel to the received signal, to restore the signal before the channel. It has many useful applications. The name Zero Forcing corresponds to bringing down the intersymbol interference (ISI) to zero in a noise free case. This will be useful when ISI is significant compared to Noise.

R-S Decoding/Wiener Smoothing

Either the Wiener smoother or algebraic RS decoder is applied to the OFDM symbol, depending on the specific receiver concept. A class of nonbinary codes that does reach the above bound are the *reed- Solomon* codes. These codes have great power and utility, and are today found in many applications from compact disc players to deep-space applications. Reed-Solomon codes are nonbinary cyclic codes with symbols made up of m-bit sequences, where m is any positive integer having a value greater than 2.*R-S (n, k)* codes on m-bit symbols exist for all n and k for which $0 < k < n < 2m + 2$ where k is the number of data symbols being encoded, and n is the total number of code symbols in the encoded block. For the most conventional *R-S* (n, k) code,(n, k) = ($2m - 1$, $2m - 1 - 2t$) where t is the symbol-error correcting capability of the code, and $n – k = 2t$ is the number of parity symbols. An extended R-S code can be made up with $n = 2m$ or $n = 2m + 1$, but not any further.

The introduction of UWs in time domain leads to another fundamental and beneficial signal property: A UW in time domain generates a word of a complex number RS (Reed Solomon)-code in the OFDM frequency domain symbol vector. Therefore, the UW could be exploited for algebraic error correction or (more appropriately) for erasure correction for highly attenuated subcarriers. However, as it turns out, algebraic RS decoding leads to solving a very ill-conditioned system of equations and thus cannot achieve a reasonable solution, as soon as even only little noise is present in the system. Another interpretation of the introduction of UWs in time domain is that it leads to correlations along the subcarriers. Therefore, a receiver based on a Bayesian estimation is obvious, too. A receiver based on a Bayesian estimation will in fact significantly improve the BER behavior by exploiting the covariance matrix of the subcarrier symbols.

Unique Word Generation

In this project we are applying the concept of UW to Systematic coded OFDM & Non systematic coded OFDM. We are also using two types of equalizer

1) Best linear unbiased estimator (BLUE)
2) Linear minimum mean square error (LMMSE)

Systematic Coded UW-OFDM

Unique Word Generation

In our concept described in [3] , we suggested to generate UW-OFDM symbols by appropriately loading so-called redundant subcarriers. The minimization of the energy contribution of the redundant subcarriers turned out to be a challenge. We solved the problem by generating a zero UW in a first step, and by adding the desired UW in a separate second step. We showed that this approach generates OFDM symbols with much less redundant energy [4] than a single step or direct UW generation approach as e.g., described in [9]. In addition, we optimized the positions of the redundant subcarriers to further reduce their energy contribution. Several other attempts of applying UWs in OFDM systems can be found in the literature, e.g., in [11] and [12]. In all those approaches the guard interval and thus the UW is not part of the DFT-interval. Therefore, and in contrast to our UW-OFDM concept, no coding is introduced by these schemes. Our systematic complex number RS coded UW-OFDM concept is presented in [3].

We generate an OFDM symbol with a zero UW in a first step, and we determine the final transmit symbol by adding the desired UW in time domain in a second step. As in conventional OFDM, the QAM data symbols (denoted by the vector) and the zero subcarriers (at the band edges and at DC) are specified as part of the frequency domain vector , but here in addition the zero word is specified in time domain as part of the vector . Denotes the length DFT matrix with elements The system of equations with the introduced features can, e.g., be fulfilled by spending a set of redundant subcarriers. We let the redundant subcarrier symbols form the vector with; we further introduce a permutation matrix, and form an OFDM symbol (containing zero subcarriers) in frequency domain by

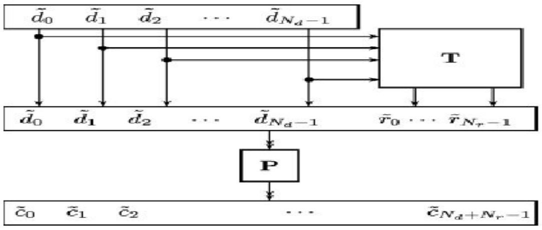

Fig. 5: Codeword generation for the systematic codes
It is described by G.

Interpretation as a Systematic Complex Valued Reed–Solomon Code with $G = P[\frac{I}{T}]\varepsilon\mathbb{C}^{(Nd+Nr)\times Nd}$ (1)

We can interpret

$$\tilde{c} = P\begin{bmatrix}\tilde{d}\\ \tilde{r}\end{bmatrix} = P\begin{bmatrix}I\\ T\end{bmatrix}d = G\tilde{d} \quad (2)$$

$\tilde{c} \in \mathbb{C}^{(Nd+Nr)\times 1}$ As a codeword of a systematic complex number Reed–Solomon code with the code generator matrix G. As already mentioned above an RS code with minimum Hamming distance dmin may be defined as the set of codeword’s, which all show a block of dmin-1 consecutive zeros in their spectral transform w.r.t. a Fourier transform defined in the (elsewhere usually finite) field from which the code symbols are taken; cf. [6]. Here, simply time and frequency domains are interchanged and the field is the set of complex numbers. Fig 5 illustrates the generation codeword.

$$\tilde{c} = [\tilde{c}_0, \tilde{c}_{1,\ldots,}\, \tilde{c}N_d + N_{r-1}]^T \quad (3)$$

Optimum Linear Data Estimators

Best linear unbiased estimator (BLUE)

One way to look for an optimum data estimator is to assume the data vector to be deterministic but unknown, and to search for unbiased estimators. In order for the estimator to be unbiased we require

$$\mathrm{E}[\hat{\tilde{d}}] = \mathrm{E}[\mathrm{E}\tilde{y}\,] = \mathrm{EE}[\widetilde{H}\mathrm{G}\tilde{d} + \check{v}\,] = \mathrm{E}\widetilde{H}\mathrm{G}\tilde{d} = \tilde{d} \quad (4)$$

Consequently, the unbiased constraint takes on the form

$$E\widetilde{H}\mathrm{G} = \mathrm{I}\,. \quad (5)$$

It is equivalent to the zero forcing (ZF) criterions for linear equalizers. The optimum solution which is commonly known as the best linear unbiased estimator, and which is equivalent to the optimum linear ZF equalizer, is found by applying the Gauss–Markov theorem, to the linear model in (14). The solution is given with the noise covariance matrix

$$C_{\tilde{v}\tilde{v}} = E[\tilde{v}\,\tilde{v}^H] = N\sigma_n^2 I \quad (6)$$

So,

$$\mathrm{E}_{\mathrm{BLUE}=}\left(G^H\widetilde{H}^H C_{\tilde{v}\tilde{v}}^{-1}\widetilde{H}G\right)^{-1}G^H\widetilde{H}^H C_{\tilde{v}\tilde{v}}^{-1} \quad (7)$$

Linear minimum mean square error (LMMSE)

The most common linear data estimator is the LMMSE estimator which belongs to the class of the Bayesian estimators. In the Bayesian approach the data vector is assumed to be the realization of a random vector instead of being deterministic but unknown as assumed above. By applying the Bayesian Gauss- Markov theorem , where we now assume to be the realization of a random vector, the LMMSE equalizer follows to

$$E_{LMMSE}=\left(G^H\widetilde{H}^H\widetilde{H}G + \frac{N\sigma_n^2}{\sigma_d^2}I\right)^{-1} G^H\widetilde{H}^H \qquad [8]$$

The covariance matrix of the error $\tilde{e} = \tilde{d}\text{-}\hat{\tilde{d}}$

Immediately follows to

$$C_{\tilde{e}\tilde{e}=} N\sigma_n^2\left(G^H\widetilde{H}^H\widetilde{H}G\right)^{-1} \qquad [9]$$

$For\ \sigma_n^2 = 0$ the LMMSE equalizer and the BLUE are identical.

Non Systematic Coded UW-OFDM

The codeword is described by

$$\widetilde{c} = \breve{G}\,\tilde{d} \qquad [10]$$

Where

$$G= A\,P \begin{bmatrix} I \\ T \end{bmatrix} \qquad [11]$$

Where A is nonsingular matrix

The estimators in systematic can also be used for non-systematic coded UW-OFDM only we have to substitute G by $\breve{G}$.

Transceiver Cost Function for the BLUE:-

The linear data estimators in systematic can also be used for non-systematic coded UW-OFDM.

$$J_{BLUE} =\frac{\sigma_d^2}{cN_d}\, t_r\{\breve{G}^H\breve{G}\}\, t_r\,\{(\breve{G}^H\breve{G})^{-1}\} \qquad [12]$$

Transceiver Cost Function for the LMMSE is

$$J_{LMMSE,\ min} = \frac{\sigma_d^2\,Nd}{c+1}\ I \qquad [13]$$

III. RESULT AND DISCUSSION

In this work we introduces a novel OFDM signaling concept where the guard interval are built by unique words instead of cyclic prefix .This Proposed approach introduces a complex number of Reed-Solomon code structure within the sequence of subcarrier As an important conclusion we can state that besides the possibility to use the UW for synchronization and channel estimation purposes .Figure. 6 shows the comparison between CP OFDM and UW approach for systematic & nonsystematic systems. Systematic coded UW-OFDM performs slightly worse compared to CP-OFDM .But Non Systemic coded UW-OFDM outperforms CP OFDM & Systemic coded OFDM (with LMMSE data estimator) respectively. We consider this as a remarkable performance of Non Systemic coded UW-OFDM. Figure 7 compares the bit error rate performance of Systematic coded UW-OFDM for BLUE & LMMSE estimator. For systematic coded UW-OFDM, LMMSE estimator performs slightly better than BLUE. For Non Systematic coded OFDM both BLUE and LMMSE estimator performs identical

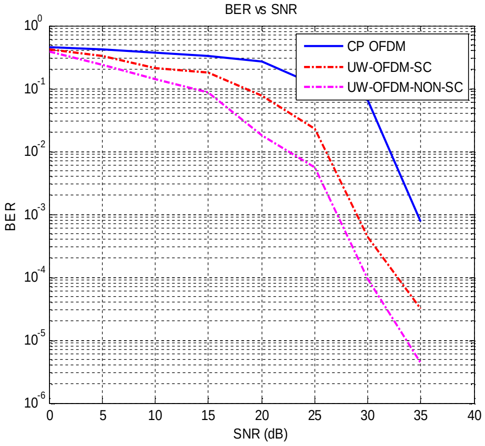

Fig. 6: BER comparison between CP-OFDM,UW-OFDM SC & UW-OFDMNONSC

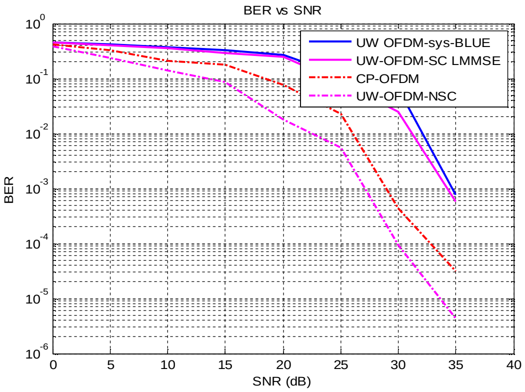

Fig.7: BER comparison between UW-OFDM, BLUE&LMMSE

IV. CONCLUSION

In this work we introduces the concept of UW-OFDM where unique word is used as a guard interval instead of cyclic prefix. The proposed approach introduces a complex number Reed –Solomon code structure within the sequence of subcarrier. An important conclusion we can state here that Unique word give better channel estimation and Synchronization. We also conclude that Non systematic coded UW-OFDM has better bit error rate performance than CP-OFDM and systematic coded UW-OFDM.

ACKNOWLEDGMENT

I would like to thank my guide Mr...Manoj M. Dongre for his valuable guidance and suggestions while writing the paper.

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