An Unique Codeword for Coded OFDM

Puja Wankhede[1], Archana[2]
Assistant professor, Electronics department
K.C.College of Engineering Management studies & Research Mumbai University, Thane, India
[1]wankhedepuja@gmail.com, [2]archana3008@gmail.com

***Abstract*— COFDM is a special case of multicarrier transmission, where a single DataStream is transmitted over number of lower rate subcarrier. In case of coded OFDM the information in the lost carrier can be recovered provided enough forward error correction is sent. Main reason to use COFDM is to increase the robustness against frequency selective fading or narrowband interference. Some of the most popular applications of coded OFDM (COFDM) include: several high frequency military systems, high speed modem, and digital mobile communication, high density recording, ADSL, VDSL, DAB and HDTV. In this method a novel transmit signal structure and an adjusted and optimized receiver for OFDM is proposed. Instead of the conventional cyclic prefix use of a deterministic sequence, called as unique word (UW), as guard interval. 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 (RS-) code structure within the sequence of subcarriers. This allows for RS-decoding or to apply a highly efficient Wiener smoother succeeding a zero forcing stage at the receiver**

Keywords—COFDM, RS-code, Wiener Filter, Zero forcing equalizer.

I. Introduction

For narrow bandwidth transmissions if the null in the frequency response occurs at the transmission frequency then the entire signal can be lost. This can be partly overcome in two ways. By transmitting a wide bandwidth signal or spread spectrum as CDMA, any dips in the spectrum only result in a small loss of signal power, rather than a complete loss. Another method is to split the transmission up into many small bandwidth carriers, as is done in a COFDM/OFDM transmission. The basic principle of OFDM is to split high-rate data stream in to number of lower rate streams that are transmitted simultaneously over a number of subcarriers. In OFDM system design, a number of parameters are up for consideration, such as: number of subcarriers, guard time, symbol duration, subcarrier spacing, modulation type per subcarrier, type of forward error correction coding. Choice of parameters is influenced by system requirement such as: available bandwidth, required bit rate, tolerable delay spread, Doppler values. Intersymbol interference is eliminated almost completely by introducing a guard time in every OFDM symbol. There are many challenges while designing OFDM system, like intersymbol interference (ISI), intercarrier interference (ICI), carrier frequency offset (CFO), multiple access interference (MAI), high peak to average power ratio (PAPR). If these issues are not recovered then result in performance degradation. So it is necessary to recover these issues.

Coded OFDM, or COFDM, is a term used for a system in which the error control coding and OFDM modulation processes work closely together. An important step in a COFDM system is to interleave and Code the bits prior to the IFFT. This step serves the purpose of taking adjacent bits in the source data and spreading them out across multiple subcarriers. One or more subcarriers may be lost or impaired due to a frequency null, and this loss would cause the contiguous stream of bit errors. Such a burst of errors would typically be hard to correct. The interleaving at the transmitter spreads out the contiguous bits such that the bit errors become spaced far apart in time. This spacing makes it easier for the decoder to correct the errors. Another important step in a COFDM system is to use channel information from the equalizer to determine the reliability of the received bits. The values of the equalizer response are used to infer the strength of the received subcarriers. COFDM systems are able to achieve excellent performance on frequency selective channels because of the combined benefits of multicarrier modulation and coding.

A. *COFDM with cyclic prefix [1]*

Fig. 1. Shows the block diagram of Coded-OFDM modem, where the upper path is the transmitter chain and the lower path corresponds to receiver chain. In the center IFFT, which modulates a block input of QAM values on to a number of subcarriers? In the receiver, subcarriers are demodulated by FFT, which performs the reverse operation of an IFFT. These two operations are almost identical. 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. Binary input data is encoded by forward error correction code. The encoded data is then interleaved and mapped on to QAM values. The output of the FFT contains Ns QAM values, which are mapped onto binary values and decoded to produce binary output data.

Fig. 2 shows convolution interleaver. This interleaver cyclically writes each input symbol or bit into one of k shift

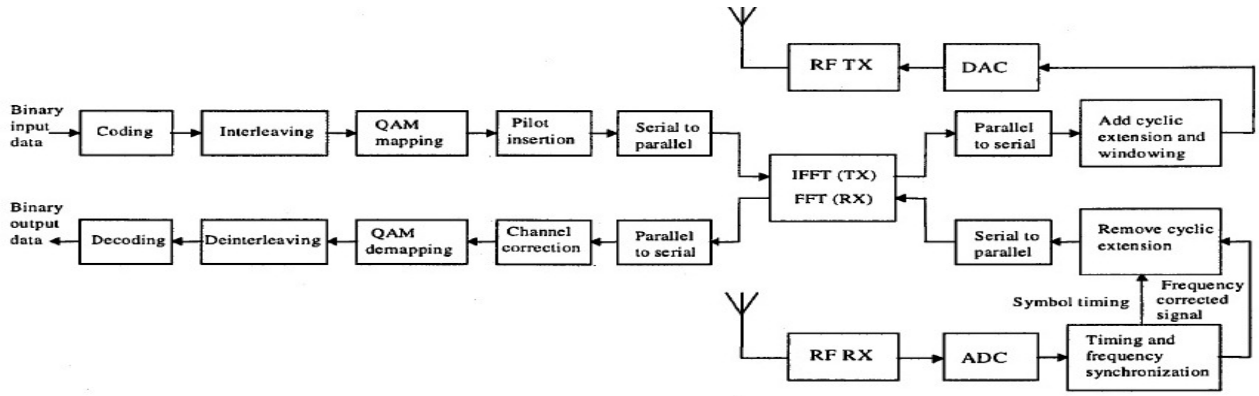

Fig. 1. Fig. 1 Block Diagram of coded OFDM with cyclic prefix.

registers that introduces a delay of 0 to k-1 symbol duration. The shift registers are read out cyclically to produce the interleaved symbols. With the use of interleaver robustness against burst error can be increased, so reducing probability of error.

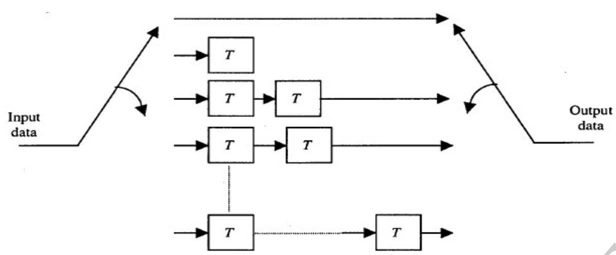

Fig. 2. convolution interleaver.

B. *Structure of cyclic prefix and unique word*

Fig. 3 compares the transmit data structure of CP- and UW-based transmission in time domain[2]. Both structures make sure that linear convolution of an OFDM symbol with the impulse response of a dispersive (e.g. multipath) channel appears as a cyclic convolution at the receiver side. Nevertheless, there are also some fundamental differences between CP and

UW-based transmission:

1)The UW is part of the DFT (discrete Fourier transform) interval, whereas the CP is not. Due to that and in contrast to previous attempts of applying UW to OFDM[3],our UW-OFDM approach achieves an almost identical bandwidth efficiency as conventional CP-OFDM.

2)The CP is random, whereas the UW is a known deterministic sequence. Therefore the UW can advantageously be utilized for synchronization and channel estimation purposes.

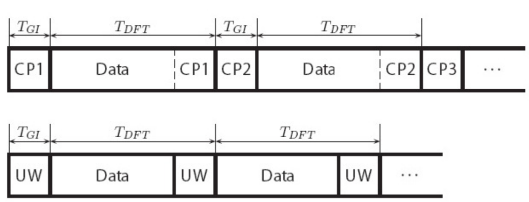

Fig. 3. Figure 3: Transmit data structure using CPs (above) or UWs (below).

Both statements hold for OFDM as well as for SC/FDE systems. However, in OFDM different to SC/FDE the introduction of UWs in time domain leads to another fundamental and beneficial signal property[4][5]:

- A UW in time domain generates a word of a complex number RS-code or of a specific coset to such a code in frequency domain, i.e. along the subcarriers. Therefore, the UW could be exploited for error correction or (more appropriate) for erasure correction for highly attenuated subcarriers.
- Another interpretation of this fact which we prefer here is an introduction of correlations along the subcarriers. These correlations can advantageously be used as a-priory knowledge at the receiver to significantly improve the BER (bit error ratio) behaviour in frequency selective environments

II. MODELLING AND ANALYSIS

In conventional method cyclic prefix has been used as guard interval. As per the proposed method unique word is used as guard interval. Fig. 5 shows simulation analysis block diagram in which two types of decoding methods are shown [6].

- Generation of UW In OFDM Symbols: A UW in time domain generates a word of a complex number RS (Reed Solomon)-code in the OFDM frequency domain symbol vector. An OFDM symbol based on this UW-OFDM approach can be interpreted as a systematic code in the frequency domain generated by the code generator matrix.

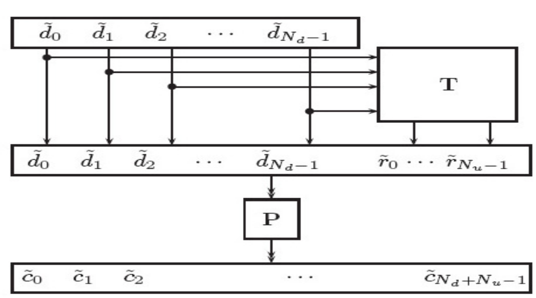

Fig. 4. Code word generator.

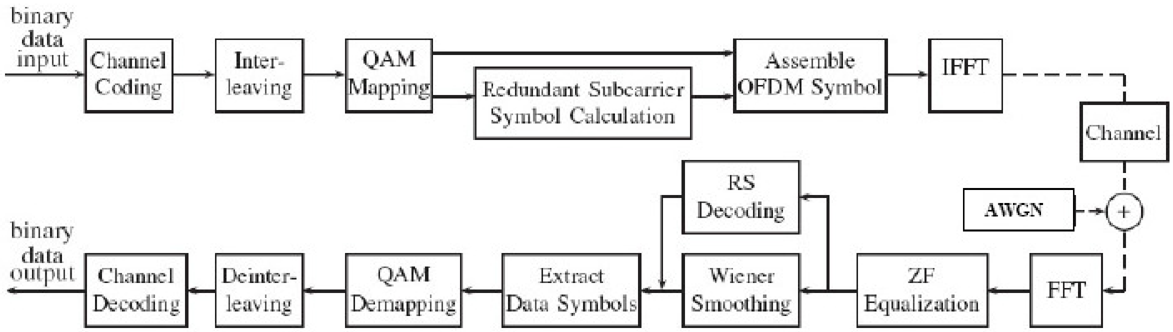

Fig. 5. Figure 4: Block diagram for simulation analysis.

- Algebraic RS Decoding based UW-OFDM Receiver: In case of algebraic RS decoding, we apply the same principle as at the transmitter side to generate the redundant subcarriers.
- LMMSE UW-OFDM Receiver: In the Bayesian approach, we exploit the fact that the redundant subcarrier symbols have been calculated out of the data symbols, and thus are correlated with the data symbols and among each other. Because of that we propose to apply an LMMSE Wiener smoother on received signal after zero forcing steps, which results in the noise reduced estimate.

III.SPHERE DECODING FOR UW-OFDM

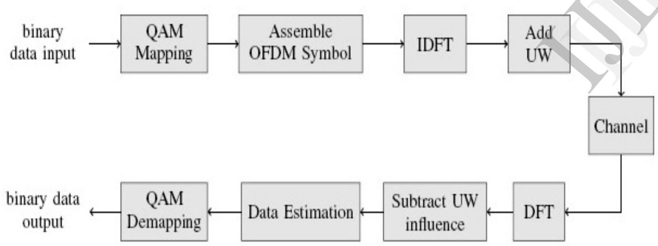

Fig. 6. Block diagram of the transceiver system used for simulation for sphere decoding.

The recently presented UW-OFDM signaling scheme uses certain subcarriers in frequency domain for redundant symbols instead of data, in order to generate a zero word in the DFT interval in time domain. These redundant symbols depend on the data loaded on the other carriers and thus introduce correlation. The resulting linear system model enables sophisticated detectors for data recovery. As the best known maximum likelihood detector for this case, we applied the Sphere Decoding (SD) algorithm to a single antenna UW-OFDM system and evaluated its bit error performance in AWGN. Compared to linear receivers, the SD is able to take the correlations on the redundant subcarriers optimally into account and shows an enormous gain. Fig. 6 shows simulation block for OFDM with sphere decoding method. Simulation is done for different modes of redundant subcarriers and BER performance is mapped and compared to previous methods.

IV.SIMULATION RESULT

Novel UW-OFDM approach with the classical CP-OFDM concept is compared. The IEEE 802.11a WLAN standard serves as reference system. The zero subcarriers are chosen as in order to clearly demonstrate the effect of our UW-OFDM approach with the derived LMMSE receiver; the following discussions are based on results obtained for the displayed channel snapshot.

- Performance Metric: BER (Probability of error)
- Simulation result: Graph of BER vs. SNR.
- Considering ideal synchronization and estimation.

Table I shows all parameters and their values for different decoding techniques i.e. RS-decoding, LMMSE receiver, sphere decoding.

TABLE I. SIMULATION SET UP FOR CYCLIC PREFIX, UW WITH RS DECODING AND WIENER SMOOTHING.

Parameter	CP-OFDM	UW-OFDM RS and wiener decoding
Modulation scheme	64 QAM	64 QAM
Coding rates	1/2,3/4	1/2,3/4
FFT size (N)	64	64
Data subcarriers	48	36
Additional subcarriers	4 pilots	16 redundant
DFT period	3.2μs	3.2μs
Guard duration	0.8 μs	0.8 μs
Total symbol duration	4 μs	4 μs
Carrier spacing	312.5 KHz	312.5 KHz
Bandwidth	16.25 MHz	16.25 MHz
Max. Bandwidth	16.56 MHz	16.56 MHz
Sample rate	20 MHz	20 MHz
Constraint length	7	7
Code generator	[171 133]	[171 133]
No. of data and redundant subcarriers N_d (Nr)	48(16), 32(32) For sphere decoding	
Unique Word xu	0(Nu*1)	

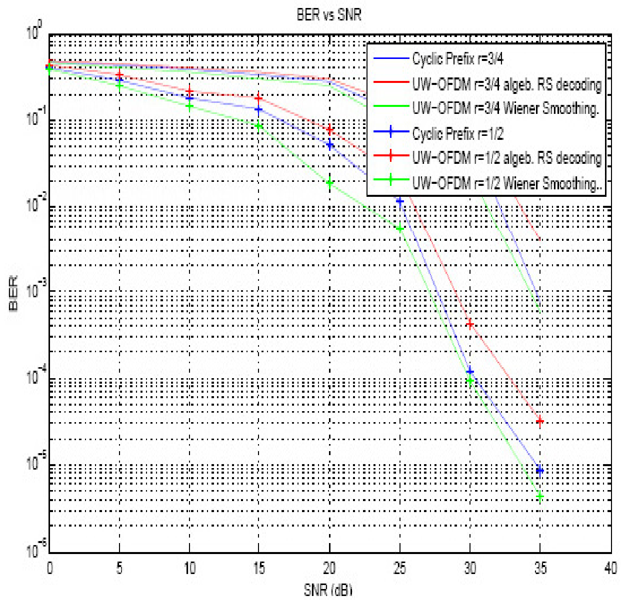

Fig. 7. comparison of coded OFDM by unique word prefix by RS decoding and wiener smoothing with cyclic prefix.

Unique Word is generated within FFT interval at transmitter side and at receiver side data symbols are extracted. Fig. 7 shows BER performance of coded OFDM with cyclic prefix by RS-decoding and wiener smoothing. There are 4 to 5dB gain in SNR with cyclic prefix than RS-decoding method for code rate 1/2 and 7 to 8dB SNR gain for outer code rate 3/4, because here zero unique word is used so it can correct up to Nu symbols. There is 3dB SNR gain with Wiener smoothing than cyclic prefix for outer code rate 1/2 and 3 to 4dB SNR gain for outer code rate 3/4, because introduction of UWs in time domain is that it leads to correlations along the subcarriers. So cyclic prefix method have better BER performance than RS-decoding method but wiener smoothing have better BER performance than cyclic prefix method. SNR gain increases with increase in outer code rate.

BER performance of wiener smoothing and sphere decoding for external code rate1/2 and 3/4is shown in Fig. 8. There is 2dB SNR gain in sphere decoding than wiener smoothing in case of 1/2 code rate and 3dB gain in case of 3/4 code rate. Because Compared to linear receivers, the SD is able to take the correlations on the redundant subcarriers optimally into account and shows an enormous gain. So sphere decoding has better BER performance than wiener smoothing as well as SNR gain increases with increase in outer code rate.

If BER performance of sphere decoding method with 16 redundant subcarriers and 32 redundant subcarriers are compared as shown in fig. 9, then it is seen that increase in number of redundant subcarrier achieves almost same BER performance. The same result is seen for outer code rate 1/2 as well as 3/4. Due to the reason that bandwidth is depend on data and redundant subcarrier Length, sphere decoding method for unique word OFDM is bandwidth efficient method.

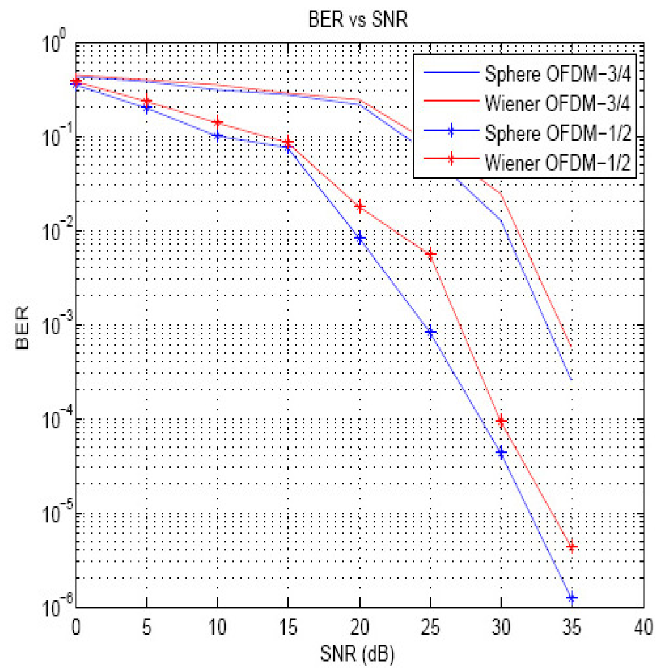

Fig. 8. comparison of coded OFDM by unique word prefix by sphere decoding and wiener smoothing.

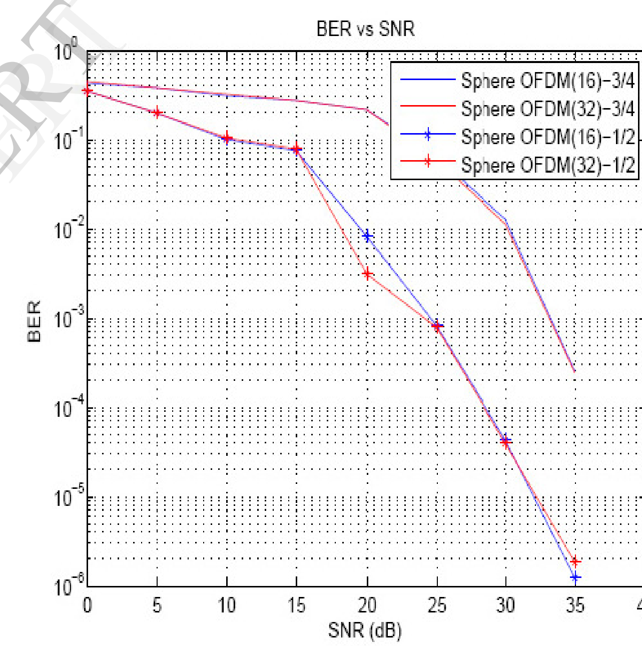

Fig. 9. comparison of coded OFDM by unique word prefix with sphere decoding for different redundant subcarriers.

V. CONCLUSION

In this work introducing an OFDM signaling concept, where the guard intervals are built by unique words instead of cyclic prefixes. The proposed approach introduces a complex number Reed-Solomon code structure within the sequence of subcarriers. As an important conclusion we can state, that besides the possibility to use the UW for synchronization and channel estimation purposes, this approach additionally allows to apply a highly efficient LMMSE Wiener smoother, which significantly reduces the noise on the subcarriers, especially on highly attenuated subcarriers. Simulation results illustrate that this approach outperforms classical CP-OFDM. Furthermore, our approach of introducing UWs provides these benefits over conventional CP-OFDM while still keeping almost the same bandwidth efficiency. A huge gain in performance of the Sphere Decoder is verified, as it takes the correlations on the redundant subcarriers optimally into account. However, it can be seen that decreasing the redundant energy by spending more redundant subcarriers, which improved the BER behavior for linear data estimators, is not worthwhile for the Sphere Decoder. The use of more subcarriers for redundant symbols does not yield a better bit error performance for the Sphere Decoder. It can be concluded, that for the Sphere Decoder based system it is optimal to choose the minimum number of redundant subcarriers. Thus, the Sphere Decoder shows its best performance at maximum bandwidth efficiency.

REFERENCES

[1] R. Prasad R. van Nee. OFDM for Wireless Multimedia Communications. Artech House Publishers, Boston, 2000

[2] J.B. Huber M. Huemer, C. Hofbauer. The potential of unique words in ofdm. In the Proceedings of the 15th International OFDM-Workshop (InOWo 10), Hamburg, Germany, pages 140 – 144

[3] J. Ro L. Jingyi, P. Joo. The effect of filling unique words to guard interval for ofdm. Document IEEE C802.16a-02/87, IEEE 802.16 Broadband Wireless Access Working Group.

[4] Huber J.B Hofbauer C., Huemer M. Coded ofdm by unique word prefix. Communication Systems (ICCS), 2010 IEEE International Conference, pages 426–430.

[5] De Man H. Van Meerbergen G., Moonen M. Reed-solomon codes implementing a coded single-carrier with cyclic prefix scheme. Communications, IEEE Transactions, 57:1031 – 1038, April 2009.

[6] Springer A. Koppler A. Maurer L. Huemer M. Weigel R. Witschnig H., Mayer T. A different look on cyclic prefix for sc/fde. Personal, 2002. The 13th IEEE International Symposium, 2:824 – 828, Sept. 2002.

[7] Alexander Onic and Mario Huemer. Sphere decoding for unique word ofdm. IEEE Communications Society subject matter experts for publication in the IEEE Globecom.