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Performance Analysis of DRA Based OFDM Data Transmission With Respect to Novel High Speed RS Decoding

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Abstract
In this paper, we have analyzed the performance characteristics of OFDM data transmission with regard to a new high speed RS decoding algorithm. The various characteristics identified are mainly speed and accuracy of the transmission irrespective of channel behaviour. We consider two cases viz. data transmission without error control and data transmission with error control. Each of these cases are duly analyzed and it is proven that high speed RS decoding algorithms can actually benefit OFDM data transmission for advanced communication systems only if implemented at the hardware (VLSI) level because of significant processing overhead involved in software based implementation even though the algorithm may have lower computational complexity.
Keywords— RS Decoder, OFDM, MATLAB, Scientific Computing & Simulation, Data Communication

I. INTRODUCTION

The Reed-Solomon codes are found in various applications ranging from digital communications to high speed recording systems. The basic reason for such widespread use of RS codes is its ability to correct burst errors thereby yielding highly error-free systems. Since every particular application has its own performance and time requirements, a large number of techniques exist for high speed decoding of RS codes, each of them being suitable for certain types of systems.

Nevertheless, as the technology progresses and concepts like high definition (HD) broadcast and Internet of Things becomes a reality, we would require highly stable error free systems that can operate at multi-GHz speeds. For such systems we would require very high speed RS decoding capability which is basically the motivation behind growing research in this field.

Orthogonal frequency division multiplexing (OFDM) has become a popular technique for transmission of signals over wireless channels. OFDM has been adopted in several wireless standards such as digital audio broadcasting (DAB), digital video broadcasting (DVB-T), the IEEE 802.11a [1] local area network (LAN) standard and the IEEE 802.16a [2] metropolitan area network (MAN) standard. OFDM is also being pursued for dedicated short-range communications (DSRC) for road side to vehicle communications and as a potential candidate for fourth-generation (4G) mobile wireless systems.

OFDM converts a frequency-selective channel into a parallel collection of frequency flat sub-channels. The subcarriers have the minimum frequency separation required to maintain orthogonality of their corresponding time domain waveforms, yet the signal spectra corresponding to the different subcarriers overlap in frequency. Hence, the available bandwidth is used very efficiently. If knowledge of the channel is available at the transmitter, then the OFDM transmitter can adapt its signaling strategy to match the channel. Due to the fact that OFDM uses a large collection of narrowly spaced sub-channels, these adaptive strategies can approach the ideal water pouring capacity of a frequency-selective channel. In practice this is achieved by using adaptive bit loading techniques, where different sized signal constellations are transmitted on the subcarriers.

OFDM is a block modulation scheme where a block of N information symbols is transmitted in parallel on N subcarriers. The time duration of an OFDM symbol is N times larger than that of a single-carrier system. An OFDM modulator can be implemented as an inverse discrete Fourier transform (IDFT) on a block of N information symbols followed by an analog-to-digital converter (ADC). To mitigate the effects of inter-symbol interference (ISI) caused by channel time spread, each block of N IDFT coefficients is typically preceded by a cyclic prefix (CP) or a guard interval consisting of G samples, such that the length of the CP is at least equal to the channel length. Under this condition, a linear convolution of the transmitted sequence and the channel is converted to a circular convolution. As a result, the effects of the ISI are easily and completely eliminated. Moreover, the approach enables the receiver to use fast signal processing transforms such as a fast Fourier transform (FFT) for OFDM implementation [3]. Similar techniques can be employed in single-carrier systems as well, by preceding each transmitted data block of length *N* by a CP of length *G*, while using frequency-domain equalization at the receiver.

Since the computation of FFT is already involved in OFDM systems, implementing RS encoding and decoding in such systems can be relatively an easy exercise as it involves taking the DFT over a finite Galois Field. This will also increase the accuracy of the system. However, RS encoding and decoding involves a lot of computation time and hence will add to the latency of the system. This gives us the motivation to do research on high speed RS decoding techniques such that the over-all system latency can be minimized.

This work has broadly two parts. One is the analysis of OFDM data transmission when no RS coding is applied. Here the study is mostly focused on assessing various system parameters and how they are going to be affected if extra latency is added to the system by virtue of RS decoding. Second part of the paper deals with OFDM data transmission when RS coding is applied and the resulting system's performance. The RS coding applied here is a new frequency domain decoding algorithm and hence this also serves as an application where the benefit of high speed RS decoding algorithms can be highlighted.

II. REVIEW OF REED SOLOMON CODES

The Reed – Solomon codes are cyclic codes with symbols made up of *m*-bit sequences, where *m* is any positive integer having a value greater than 2. RS (*n*,*k*) codes on *m*-bit symbols exist for all *n* and *k* for which the following condition is satisfied:

$$0 < k < n < 2^m + 2 \quad \dots (1)$$

Where *k* is the number of data symbols being encoded, and *n* is the total number of code symbols in the encoded block. For most conventional RS (*n*,*k*) codes,

$$(n, k) = (2^m - 1, 2^m - 1 - 2t) \quad \dots (2)$$

Where *t* is the symbol-error correcting capability of the code and $n - k = 2t$ is the number of parity symbols. RS codes achieve the largest possible code minimum distance for any linear code with the same encoder input and output block lengths. The code minimum distance is given by:

$$d = n - k + 1 \quad \dots (3)$$

The RS code generator polynomial can be written as:

$$g(x) = \prod_{i=b}^{b+d-2} \left(x - \alpha^i\right) \quad \dots (4)$$

With the code being defined over GF(*q*), *q* being a prime power and the code length is $n = q - 1$, *b* is any natural number and *α* is a primitive element of GF(*q*). The received vector is represented as a polynomial:

$$R(x) = \sum_{i=0}^{n-1} r_i x^i = C(x) + E(x) \quad \dots (5)$$

Where *C*(*x*) is the codeword and *E*(*x*) is the error vector. The *i*-th error in the error vector *E*(*x*) has a locator given as:

$$Z_i \in \left\{\alpha^0, \alpha^1, \alpha^2, \dots, \alpha^{n-1}\right\} \quad \dots (6)$$

And the error value

$$Y_i \in GF(q)\backslash 0 \quad \dots (7)$$

The error locator polynomial is given as:

$$W(x) = \prod_{i=1}^{t} (x - Z_i) \quad \dots (8)$$

Where $t \le (d - 1) / 2$. The message polynomial of the RS code can be shown to be:

$$M(x) = \sum_{i=0}^{k-1} m_i x^i \quad \dots (9)$$

The component c_i of the codeword *C*(*x*) is computed as:

$$c_i = M\left(\alpha^i\right),\ i \in \left[0, n-1\right] \quad \dots (10)$$

III. OFDM DATA TRANSMISSION WITHOUT RS CODE

We designed a generic OFDM system where data points were processed in block size of 8. The data points were passed through a random channel with noise characteristics modelled by a pseudorandom noise sequence generator. The result is shown in Figure 1.

Here in this figure, 4096 data points were transmitted as OFDM signal through a random channel estimated through a PN sequence. The received data shows the exact characteristics of the transmitted data which is expected if the channel estimation is adequately done. However, this is not possible in reality and one or more errors do creep in the received codeword due to a number of factors like channel variation, high noise, improper operational characteristics of the transmitters or receivers and so on. That is the reason why we need error detection and correction codes in the first place. Furthermore, the random noise channel that has been modelled is random only in the statistical sense and is not truly random which is what is expected in reality. This trivial aspect also has serious repercussions on our communication system design. However, appropriate statistical analysis carried out in MATLAB reveals that the channel that we have created for simulation purposes is quite close to actual random noise channel as far as impulse response of the system is concerned.

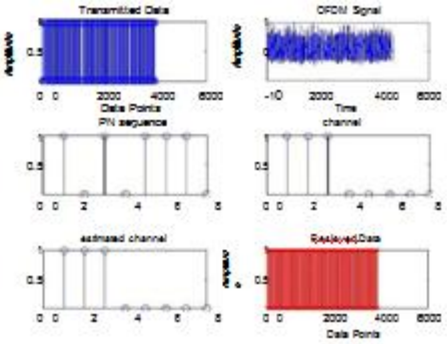

Fig. 1

IV. OFDM DATA TRANSMISSION WITH RS CODE

We included a new RS code block in the code of OFDM system and went on to analyse its characteristics. This time the channel was modelled as AWGN and the data transmission was analysed. The results are shown in Figure 2.

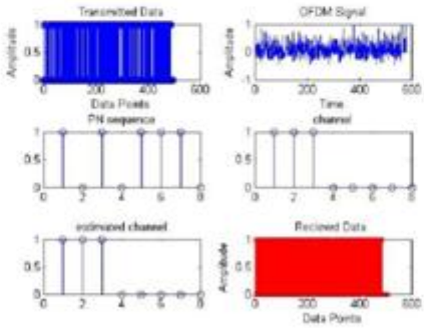

Fig. 2

As can be seen here, errors were injected in the original transmitted data and seen if it is corrected by the RS code module. The received data is free from errors as expected but few key points were noted during the simulation as follows:

1) The simulation time was increased by a margin of 5 seconds
2) Sometimes, few errors were detected but not corrected (happened twice out of 30 simulations carried out with different data points)
3) Channel estimation took longer time than usual

The above three points reveal an interesting aspect with regard to the new RS code block that was implemented in the system and has been discussed in the next section.

V. EFFECT ON OFDM SYSTEM DUE TO RS CODE BLOCK

The effect on the performance of the OFDM system due to RS code block can be understood by the way RS decoding algorithm works here.

Reed – Solomon codes can be decoded in both time and frequency domain. Consequently, a lot of algorithms already exist for efficient decoding in both these domains. However, for our work we have chosen Gao's algorithm as the starting point and we describe it here for the case of $b = 1$ [4].

Step 1: Construct an interpolating polynomial $T(x)$ such that

$$T(\alpha^i) = r_i,\ i \in [0, n-1] \qquad \text{… (11)}$$

Where degree of $T(x) < n$.

Step 2: Compute the partial GCD by solving the congruence such that

$$W(x)T(x) \equiv P(x)[mod(x^n - 1)] \qquad \text{… (12)}$$

Where degree of $P(x) < (n+k)/2$

The above step can be done by applying the extended

Euclidean algorithm to $x^n – 1$ and $T(x)$ and we can obtain unique pair of polynomials $P(x)$ and $W(x)$.

Step 3: Compute the message polynomial as

$$M(x) = \frac{P(x)}{W(x)} \qquad \text{… (13)}$$

From the algorithm above, it is quite clear that for N blocks of data that is to be transmitted over N sub-carriers, each data block must be RS encoded and then decoded. We have used a single RS code block which required the N blocks of data to be fed serially to the RS code block and that led to extra computation time as mentioned in point 1 in the previous section. The second point can be understood from the fact that FFT performed on information symbols for demodulation can be regarded as essentially the same process of DFT computation required in RS code block over finite field. The solution to this problem evidently is to have parallel RS code blocks for parallel N data blocks and to have adaptive RS code blocks for variable data sizes.

VI. PERFORMANCE OF THE RS CODE BLOCK

The performance of the RS code block is critical for over-all performance of any communication system. As evident from the analysis carried out in the previous sections, we are faced with the problem of greater latency of including additional RS code block in the OFDM system on one hand and more system area and other operational issues owing to use of N parallel RS code blocks for N information blocks. Naturally under such circumstances, we need to look closely at the individual RS code block performance in the context of the operation of the communication system.

The graph of bit error probability v/s channel symbol error probability is shown for 32-ary orthogonal signaling and n = 31, t error correcting RS coding. For different values of t, the corresponding graphs have been shown below.

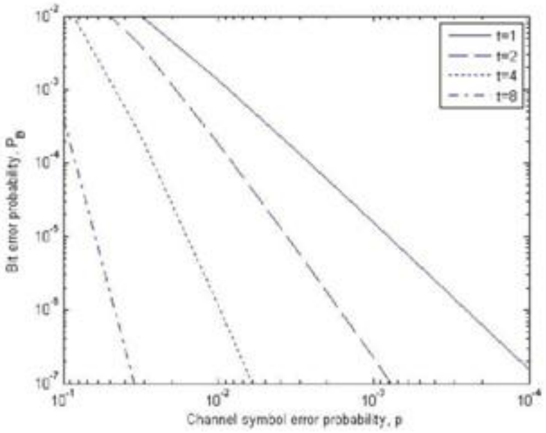

Fig. 3

Next figure shows the graph of bit error probability versus Eb/NO performance of several n = 31, t-error correcting Reed-Solomon coding systems with 32-ary MFSK modulation over an AWGN channel.

From these curves it can be clearly seen that the RS code block performs quite according to the accepted standards and is suitable for implementation in any digital communication systems.

In Figure 5, The RS decoder performance as a function of symbol size is plotted to understand the actual computational benefit of the new algorithm with variable size of the information symbols. As can be seen, the RS decoder performs as expected as the symbol size increases. However, this means that the only way one can reduce the latency of the over-all system by resorting to system level design approach and using appropriate VLSI architectures to speed up the computation.

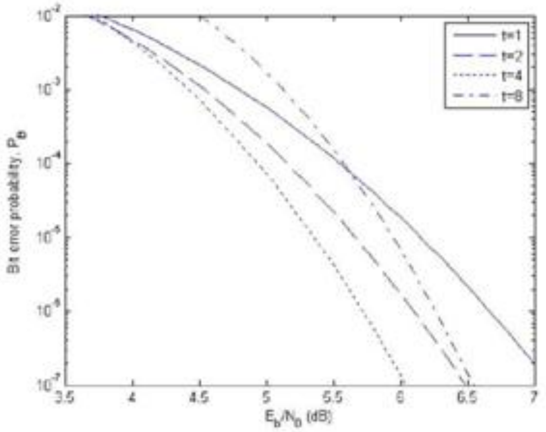

Fig. 4

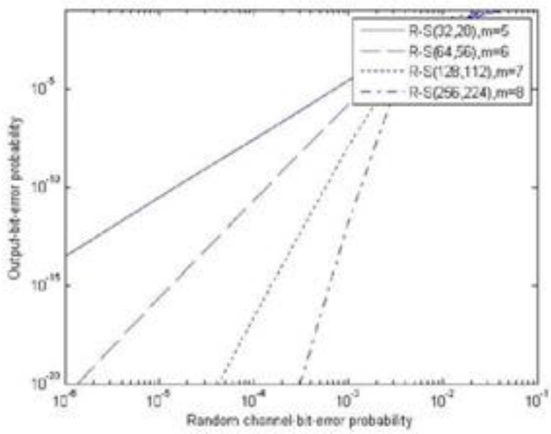

Fig. 5

This also shows that software based RS decoding can in fact add to the latency of the system and hence only proper VLSI approach can give us significant performance benefit even though the algorithm of RS decoding is computationally feasible.

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