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Reed Solomon Coding in Orthogonal Frequency Division Multiplexing (OFDM) Communication Systems

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Abstract:

This paper presents a MATLAB simulation that has been developed to investigate Orthogonal Frequency Division Multiplexing (OFDM) communication system using Reed Solomon (RS) Coding process. The efficient encoding and decoding algorithm, and the powerful of error correction capability of Reed Solomon Coding make it one of the most widely used error correction codes algorithm, so we use it with OFDM systems to merge the benefits of multicarrier modulation and Reed Solomon Coding to obtain system that has excellent performance capability in multipath and fading channels. Single-carrier QAM and multicarrier OFDM are compared to demonstrate the strength of OFDM in multipath channels. The bit error rate and the number of error bits are calculated during each test on the system. Two simulations of OFDM are developed with inter modulation QPSK or 16-QAM with Reed Solomon Coding are using to correct errors of transmitted data.

Keywords: Multicarrier OFDM, Reed Solomon Coding, Single-carrier QAM, Multipath and Fading channels.

الترميز بتقنية ريد سلمون في أنظمة الاتصالات المتعامدة التردد بالتقسيم

الخلاصة:

تعرض هذه الورقة المحاكاة باستخدام برنامج MATLAB والتي تم تطويرها لتحقيق نظام الاتصالات المتعامد التردد بالتقسيم (OFDM)باستخدام تقنية الترميز ريد سلمون (RS) . عملية الترميز وفك الترميز الكفوءة والقدرة القوية لمعالجة وتصحيح الخطأ لتقنية ريد سلمون (RS) جعلها واحدة من اكثر التقنيات المستخدمة بصورة واسعة لتصحيح الخطأ , لذلك تم استخدامه مع أنظمة (OFDM) لدمج فوائد التضمين متعدد النواقل (multicarrier modulation) وتقنية الترميز ريد سلمون (RS)

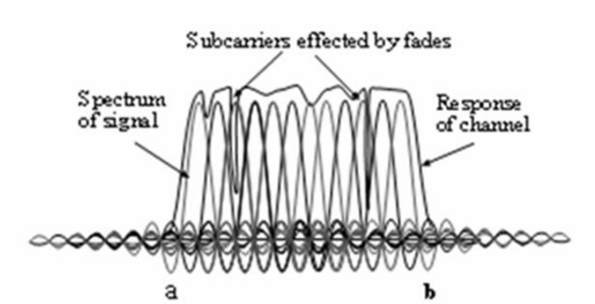
لغرض الحصول على نظام يمتلك قدرة ممتازة الاداء في القنوات متعددة المسار (multipath channels) وقنوات التلاشي (fading channels). ايضا تتم المقارنة بين نظام متعدد النواقل (OFDM) ونظام الناقل الواحد (QAM) لتوضيح قوة نظام متعدد النواقل في القنوات المتعددة المسار(multipath channels) . حيث تم حساب نسبة الخطأ (Bit Error Rate) وعدد الاخطاء (Error Bits) في كل اختبار اجري على النظام . واخيرا تم تطوير محاكاتين لنظام متعدد النواقل (OFDM) احدهما مع التضمين الداخلي باستخدام النظام (QPSK) والاخر مع التضمين الداخلي باستخدام النظام (16-QAM) وتم استخدام تقنية الترميز ريد سلمون (RS) في كلتا المحاكاتين لتصحيح الاخطاء الحاصلة في البيانات المرسلة .

1. Introduction

With the rapid growth of digital communication in recent years, the need for high-speed data transmission has increased. New multicarrier modulation techniques such as Orthogonal Frequency Division Multiplexing are currently being implemented to keep up with the demand for more communication capacity. Multicarrier communication systems “were first conceived and implemented in the 1960s, but it was not spread until the FFT is discovered by Cooly and Tukey at the beginning of the computer resolution [1] , so OFDM became feasible and economical [2- 4]. Two of the fundamental advantages of OFDM are its robustness against channel dispersion and its ease of phase and channel estimation in a time-varying environment [5]. A common problem found in high-speed communication is inter-symbol interference (ISI). ISI occurs when a transmission interferes with itself and the receiver cannot decode the transmission correctly. Because the signal reflects from large objects such as mountains or high buildings, the receiver sees more than one copy of the signal. In communication terminology, this is called multipath. Since the indirect paths take more time to travel to the receiver, the delayed copies of the signal interfere with respect to the direct signal, causing ISI. As communication systems increase their information transfer speed, the time for each transmission necessarily becomes shorter. Since the delay time caused by Multipath remains constant, ISI becomes limited in high-data-rate communication [6]. OFDM avoids this problem by sending many low speed transmissions simultaneously. High data rates can be achieved in OFDM by transmitting a number of orthogonal subcarriers [7]. So OFDM is especially suitable for high-speed communication due to its resistance to ISI. The second problem is fading channel, where the delayed reflected signals added to the main signal and cause either gains in the signal strength or deep fades. For deep fades case, the signal is nearly wiped out. The signal level is very small, therefore; the receiver cannot decide what was there. One of the main reasons of using OFDM is to increase robustness against frequency-selective fading or narrowband interference [8]. OFDM signal offers advantage for the channel that has a frequency selective fading response. As shown in figure (1), when an OFDM signal spectrum is lying against the frequency- selective response of the channel, only two sub-carriers are affected, while the remaining others are not [9]. OFDM has been proved to be an effective technique to combat multipath fading in wireless channels [10]. Besides its implementational flexibility, the low complexity required in transmission and reception as well as the attainable high performance render OFDM a highly attractive candidate for high-data-rate communications over time-varying frequency-selective radio channels [11]. Coding in OFDM systems are able to achieve excellent performance on frequency selective channels because of the combined benefits of multicarrier modulation and coding [12, 13]. Reed Solomon or RS codes are the most well-known and the most widely-used

codes having non-binary symbols [14]. Reed Solomon (RS) coding process has the ability to correct random errors, as well as many random bursts of errors, for this reason RS Codes are popular in many practical systems [15].

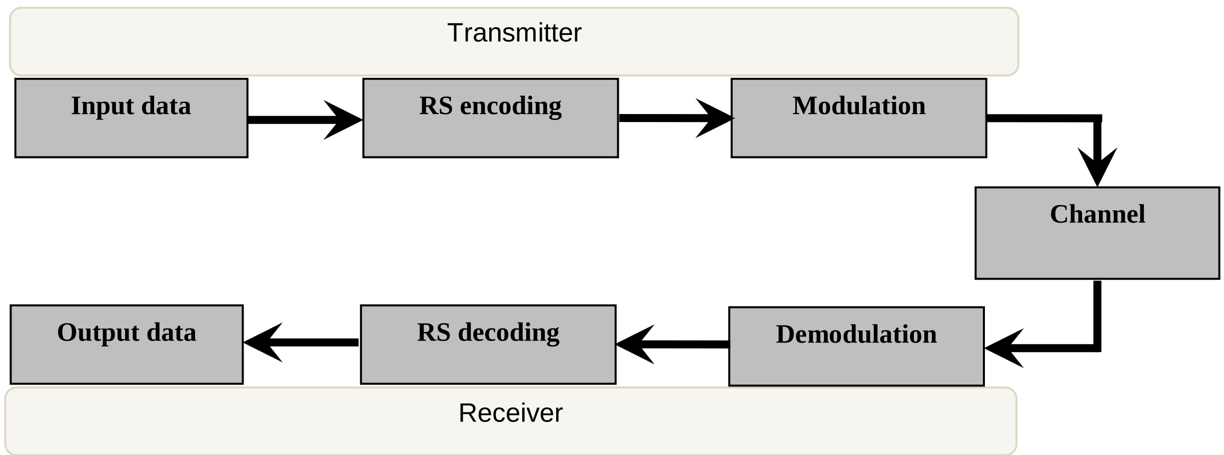
In this work a Matlab simulation program for an OFDM system with RS error correction capability have been developed and implemented. This paper is organized as follows. The description of the system blocks are detailed in section 2. Simulation results are discussed in section 3 and the final section gives conclusions.



Figure(1). Spectrum of OFDM signal against the response of channel.[9]

2. System Description

The block diagram in figure (2) illustrates a general block diagram for the proposed simulation model. In the input data block, the data are converted to a binary representation. We can see that the data pass through RSEncoding. Then, it pass through modulation process. In the modulation block, we can choose the inter-modulation type for OFDM (QPSK or 16-QAM) and compare it with16-QAM. After that, the modulated data will pass through the channel. Then, the received modulated data will pass through demodulation and RS Decoding. Finally, the received data are converted to the original form in the output data block.



Figure(2)General Simulation block diagram

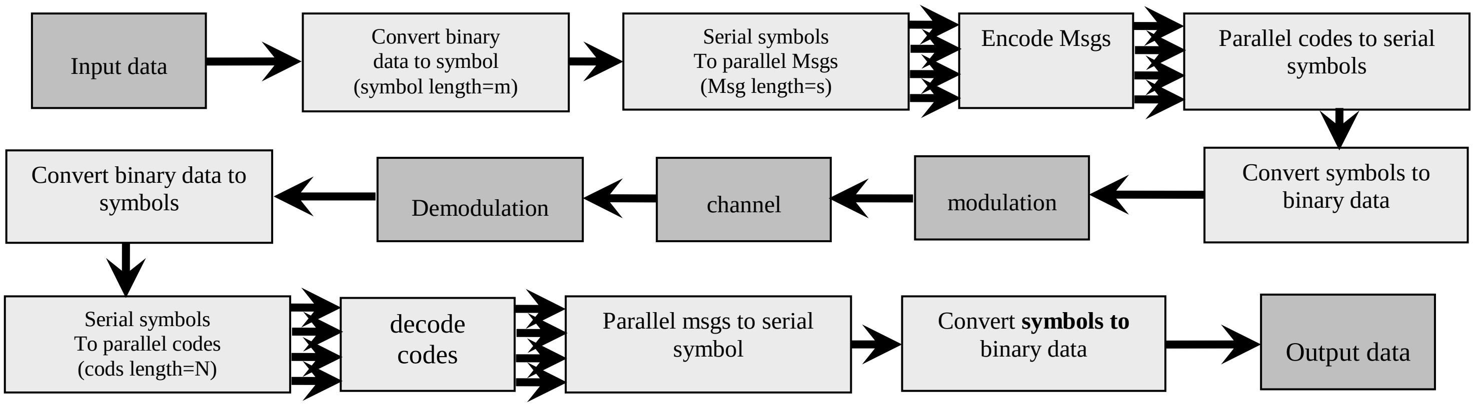
The details of each block are illustrated in the following.

2.1 Input and Output Data Blocks

The input data block can accept three different types of input: binary random data, text, and audio. The output format of this block is binary. So for the text data, the ASCII code of each character is taken and converted to 8-bit binary data string. For the audio data, at first the audio waves are converted to samples, the range level of these samples is between -1and +1. Then, the sample's level is normalized to be a real number between 0 and 255. After that, it is converted to 8 bit-binary data. In the output data block, the same operations of the input data block are applied on the received data but in reverse order, this means the received data are converted back to the original form.

2.2 Reed Solomon Encoding and Decoding Blocks

Figure 3 shows the RS block diagram of the procedure of encoding and decoding data. First in the RS encoder block, the input data is converted to symbols (each m binary data converted to a decimal symbol). This symbols is converted to a number of parallel messages (message length = s) knowing that, before this procedure zeros must be padded to generate an integer number of messages if necessary. Then the data encoded (messages become codes). After that the parallel codes are converted to serial codes.
These codes are passed through a modulator (modulation procedure), channel and demodulator (demodulation process). In the RS decoder block, the procedure that has been applied on the received codes will be opposite to that in the RS encoder block.



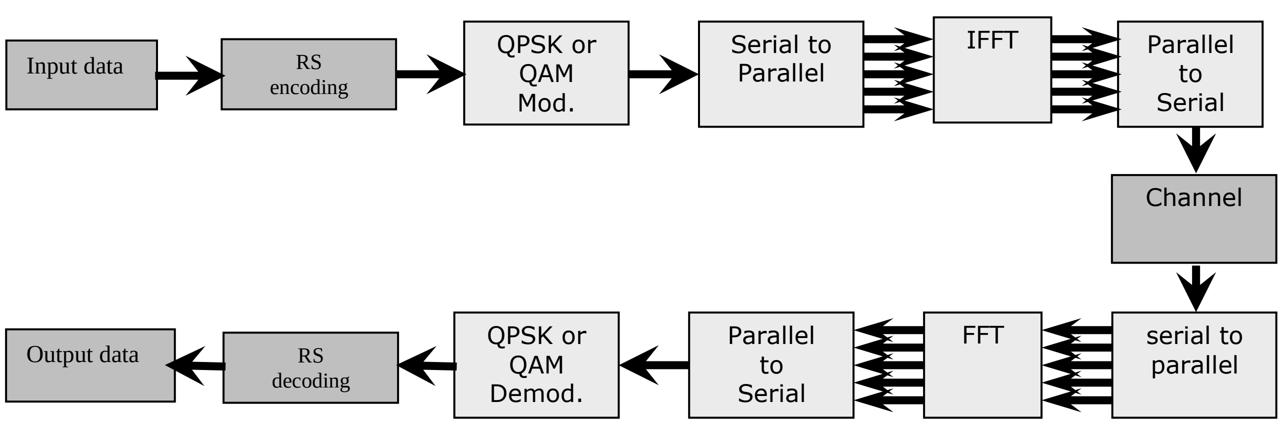
Figure(3)Reed Solomon block diagram

2.3 Modulation and Demodulation Blocks

In the modulation block, the inter-modulation type for OFDM as either QPSK or 16-QAM can be chosen. The operation in the demodulation block will be opposite to that in the modulation block. The construction of the modulation and demodulation blocks for each system will be illustrated in the following paragraphs.

2.3.1 OFDM Block

The block diagram in figure (4) shows the OFDM configuration. In all types of modulation the input binary data (0,1) is converted to polar form (-1,1). Inter-modulation type (QPSK or 16-QAM) is chosen as described before. The input data are converted from serial to parallel (chunks) where chunks length = number of carrier. In our simulation program 32 carriers are used, FFT size =128. Also a number of zeros are padded in between, so that chunk length will be compatible with FFT size. After the channel, the operation in the demodulation block will be opposite to that in the modulation block. In our simulation program the BER in percentage is computed.



Figure(4)OFDM detailed block diagram

2.3.2 16- QAM Block

The block diagram in figure (5) shows the 16-QAM configuration. The input binary data are converted from binary form to polar form. Then the polar form data are converted to four levels data form (-1, 1,-3, 3). After that, the data are converted into two types, in phase (I) and quadrature phase (Q). The in phase data are multiplied by *cosine* and quadrature are multiplied by *sine*. Both of them are summed together and then are transmitted .The previous procedures are reversed in blocks followed channel block, the received data are changed (may increases or decreases) because channel's effects, so using make decision between (-1,1,-3,3) will be accomplished. Then the BER will be calculated.

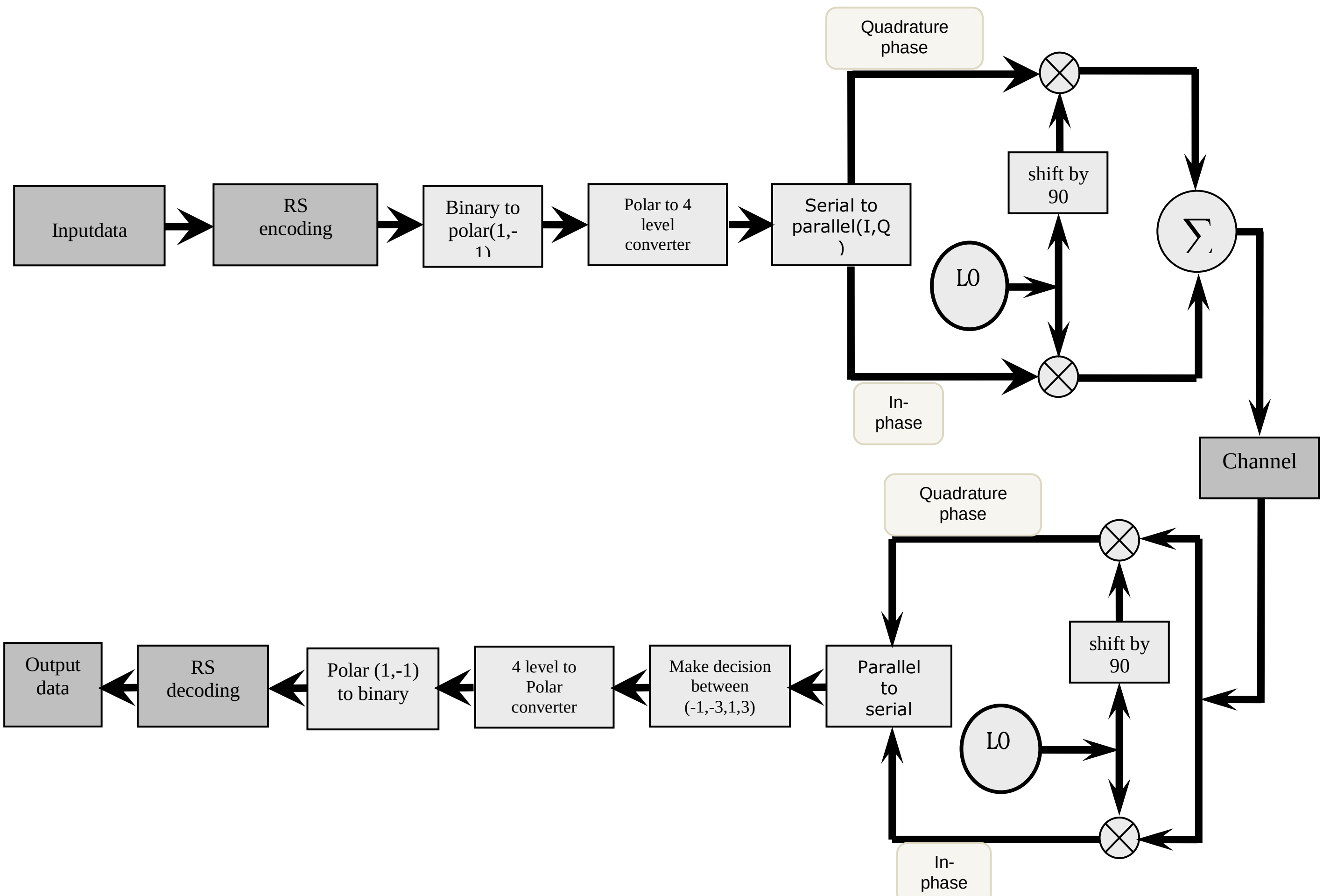
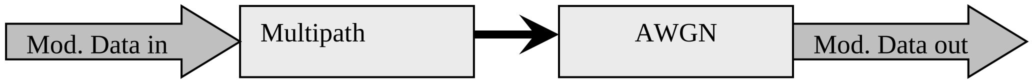


Figure (5) 16-QAM block diagram

2.3.3 Channel Block

In the proposed simulation program, multipath channel with Additive White Gaussian Noise (AWGN) is used. Knowing that, the channel can be turned ON or turned OFF. Also, the SNR of different values for testing the system in different situation are applied. The block diagram in figure (6) shows the channel configurations.



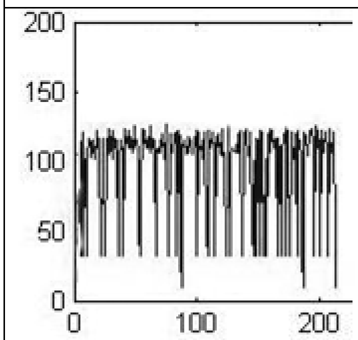
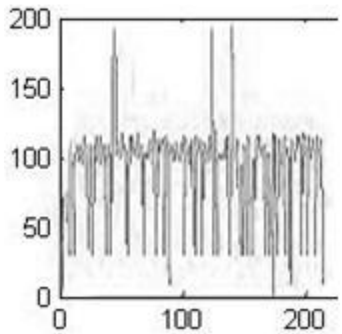
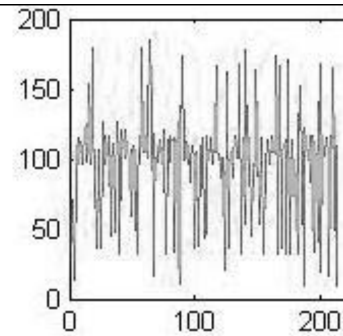
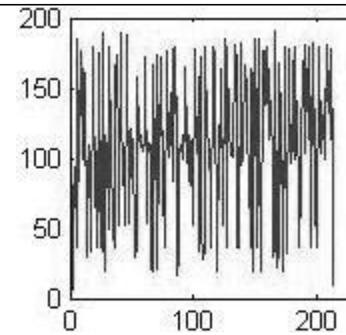
Figure(6) Channel block diagram

3. Simulation Results

The OFDM with QPSK inter modulation system and OFDM with 16-QAM inter modulation system versus 16-QAM system with different input data types and different channel types are extensively tested. The bit error rate and the number of error bits during each test are calculated. In some tests, we used Reed Solomon Coding with the systems to correct errors and reduce the bit error rate as demonstrated in table bellow :-

Table(1) Simulation results

Type of input data	**Channel**		**(7,3) Reed Solomon coding**	**OFDM with QPSK inter-modulation**		**OFDM with 16-QAM Inter-modulation**		**16-QAM**	
	Multipath channel	**AWGN channel**		**BER %**	**Bit errors**	**BER %**	**Bit errors**	**BER %**	**Bit errors**
Random binary data(2^{14} bit)	**ON**	OFF	OFF	0	0	9.63	1577	22.1	3615
	ON	**ON**	OFF	1	164	14	2301	23.6	3859
Text	**ON**	**ON**	OFF	0.993	17	12.7	217	22.4	383
	ON	**ON**	**ON**	0	0	9.75	167	20.1	344
Audio	**ON**	**ON**	OFF	1.07	1812	12.3	20807	20.2	34316
	ON	**ON**	**ON**	0.00707	12	8.77	14877	19.8	33659

The Original Data	**OFDM with QPSK** **inter-modulation transmission** **BER = 0.993%** **Bit Errors = 17**	**OFDM with 16-QAM** **Inter-modulation transmission** **BER = 12.7%** **Bit Errors = 217**	**16-QAM transmission** **BER = 22.4%** **Bit Errors = 383**
OFDM is a combination of modulation and multiplexing. Multiplexing generally refers to independent signals, those produced by different sources. So it is a question of how to share the spectrum with these users.	OGDM is a comcination#ofmodulatinn and mu_tiplexing. Multiplexinggenerally senmrs to Independentsignals, those pbnduce_ bydifferent sïurces.So it is c questionof h/w_to share the spectrum with these usgrs.	KFD`is`p` czlb_na´ij^$jV$ m•`ulat-_o0Q~d mylyepm`<in2j Mum´iuley¹z§_v Unerally reburs!h•!_ i®dipenTend $gi&nals,0tdose `q¦odeVe`_¢y% `iVfufe~¨ so6²cfs-`Sj¤y5Pis a`re artiz® •¦$hor t« rh a1Y q_Y` zpect2um!g)t¨_thfsf _t3¥b2n	O_E^$¹rT ±d£__bYm!´yo^ $¯V$½/_tl1´io.$_®d 4½tl 4ip¼5xyn'_$ _tltip¬5xin__§ U®_q¥¬<x$±¥feu²T´o_ _indup¥nTun 44²_g_!¬2_$´xob U$´±®_yc_ 4²¹$´yffeµ©®$$¶_ dq¦_r^$£__¹t$¹r_±d° ´¥r¤yo _$__$¨•&_´• ²_aq©d´he$Nr µg¤q ´m$¶Y4h$´hur_ dµ²_q²]
 Original symbol data	 received symbol data	 received symbol data	 received symbol data

Figure(7)OFDM with QPSK inter-modulation and OFDM with 16-QAM inter-modulation vs. 16-QAM for text data

<table>
<tr>
<th>The Original Data</th>
<th>OFDM with QPSK
inter-modulationtransmission
BER = 0 %
Bit Errors = 0</th>
<th>OFDM with 16-QAM
Inter-modulationtransmission
BER = 9.75%
Bit Errors = 167</th>
<th>16-QAM transmission
BER = 20.1%
Bit Errors = 344</th>
</tr>
<tr>
<td>OFDM is a combination of
modulation and multiplexing.
Multiplexing generally refers to
independent signals, those
produced by different sources. So it
is a question of how to share the
spectrum with these users.</td>
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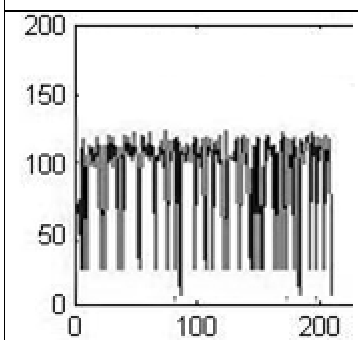
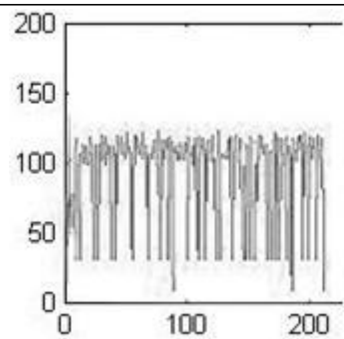
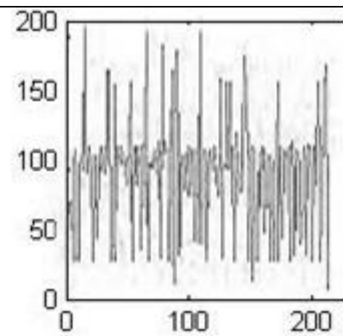
<td>
Original symbol data</td>
<td>
received symbol data</td>
<td>
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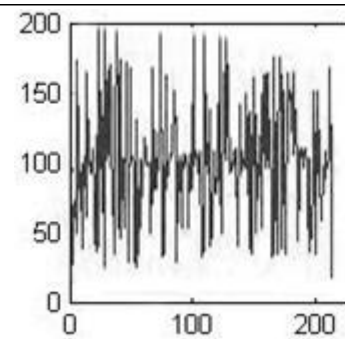
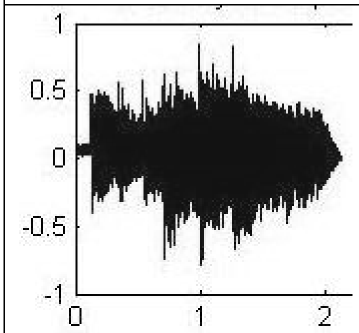
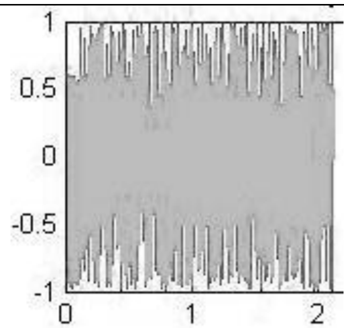
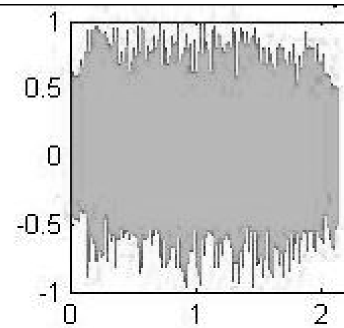
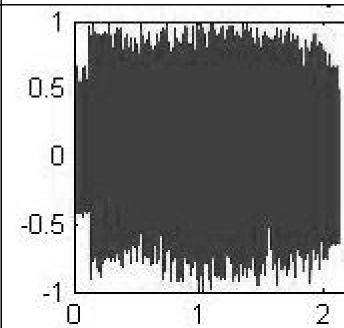
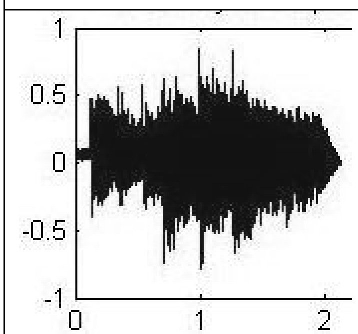
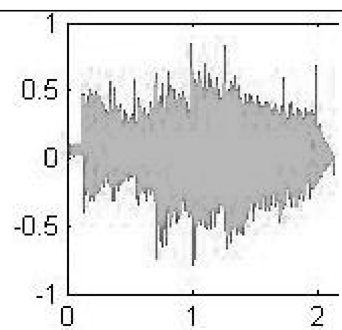
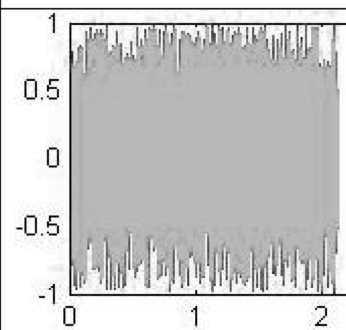
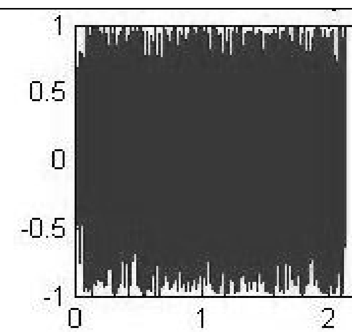
<td>
received symbol data</td>
</tr>
</table>

Figure(8)OFDM with QPSK inter-modulation and OFDM with 16-QAM inter-modulation vs. 16-QAM using Reed Solomon Coding for text data

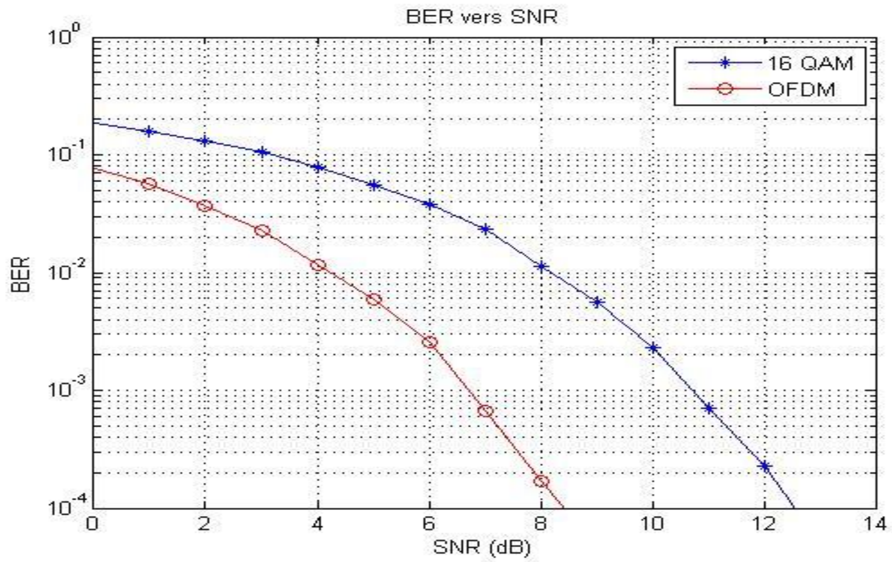
The Original Audio	OFDM with QPSK inter-modulation transmission BER = 1.07 % Bit Errors = 1812	OFDM with 16-QAM Inter-modulation transmission BER = 12.3 % Bit Errors = 20807	16-QAM transmission BER = 20.2% Bit Errors = 34316
			

Figure(9)OFDM with QPSK inter-modulation and OFDM with 16-QAM inter-modulation vs. 16-QAM for audio data

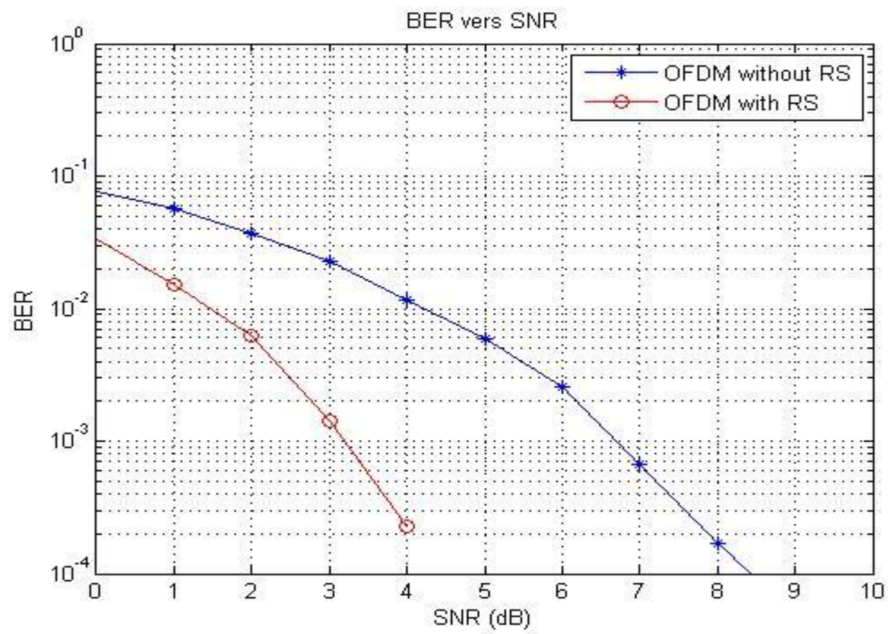
The Original Audio	OFDM with QPSK inter-modulation transmission BER = 0.00707 % Bit Errors = 12	OFDM with 16-QAM Inter-modulation transmission BER = 8.77 % Bit Errors = 14877	16-QAM transmission BER = 19.8% Bit Errors = 33659
			

Figure(10)OFDM with QPSK inter-modulation and OFDM with 16-QAM inter-modulation vs. 16-QAM
using Reed Solomon Coding for audio data

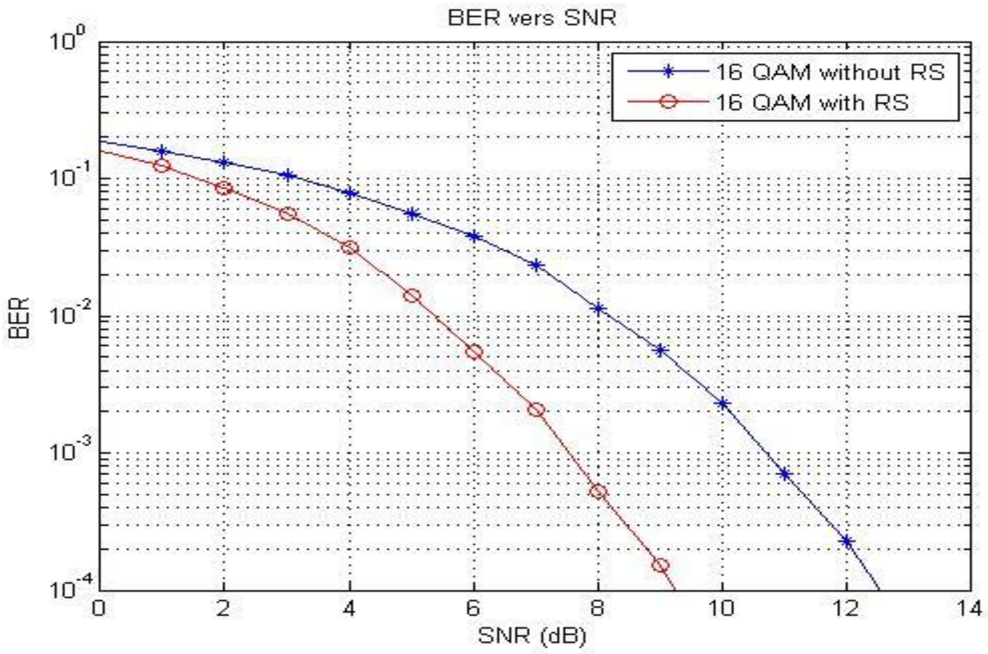
The following figures are the BER versus SNR for OFDM and 16 QAM systems without and with RS coding .Data sent is 100000 bit random binary data . Channel used is AWGN only.



Figure(11)BER vers SNR for OFDM and 16 QAM systems in AWGN channel



Figure(12)BER vers SNR for OFDM with and without RS in AWGN channel



Figure(13)BER vers SNR for 16 QAM with and without RS in AWGN channel

4. Conclusions

From the results ,we conclude that OFDM has superior performance over single-carrier 16-QAM in fading channel and AWGN channel as demonstrated by the BER rates .With the Reed Solomon Coding , we can see that the OFDM system will have a higher performance over fading and AWGN channels .We found that OFDM with inter-modulation QPSK is better than OFDM with inter-modulation 16-QAM as demonstrated by bit error rates (BER) , where the BER of OFDM with inter-modulation QPSK is very low and with coding almost approaches to zero . future research may be based on this paper. These extensions may include channel estimation, cyclic prefix, channel phase shift detection and correction, peak to average power ratio considerations and DSP implementation.

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