Performance Improvement of OFDM Communication System in Rayleigh Fading Channel

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Abstract— *OFDM (orthogonal Frequency Division Multiplexing) is considered as a principal element in the development of the 4G of mobile system. The OFDM performance can be improved using the channel coding. The channel coding technique is a class of signal transformations designed to improve communication system performance.*

The work presented in this paper discusses the improvement of OFDM system performance using different channel coding techniques. These coding techniques include Reed Solomon, Convolutional, Concatenated (by combining Reed Solomon with Convolutional), and Interleaved concatenated coding techniques. Besides, a new algorithm produced to choose a good convolutional encoder design with a good distance property for a certain rate and memory registers. The simulation results will be provided for the Rayleigh fading channel model.

Keywords— *OFDM, Rayleigh Fading, Channel Coding, Reed Solomon, Convolutional, Interleaver.*

I. INTRODUCTION

The evolution of the technology of network mobile system requires a several aspects as the needs of increasing rate, the mobile character of terminal and a context congestion of spectrum. The single-carrier modulations that used in the 1st, 2nd and 3rd generation of mobile don't respond optimally to these needs, due to frequency-selective of channels and Multipath can borrow a same signal. The technology of the OFDM is adapted to respond on the posed problems. So it is an essential element in the 4G of mobile. This is because its robustness against multipath fading. [1].The channel coding is used to improve the performance of un-coded OFDM systems. There are many types of coding technique that can be used in OFDM as block code (as Reed Solomon) and convolutional code [2]. The concatenated code is a technique that uses two or more coding techniques to provide a good performance with less complexity [3]. The interleaver can be used with the concatenated code to achieve better improvement in the system performance [4]. The errors that arise in any communication channel can be viewed as 'random errors' that exist in AWGN channel and 'burst errors' that exist in fading channel. The most of coding techniques as Convolutional codes are designed to deal with the random errors, and other coding techniques are designed to deal with the burst errors as Reed Solomon code. So that, the concatenated code that have both types of coding can handle both random and burst errors and provides a good performance [5].

The rest of the paper organized as follow: Section 2 shows the concept of OFDM system. Section 3 shows the fading channel concept. Section 4 shows the concept of different types of channel coding techniques that can be used in OFDM, including Reed Solomon, Convolutional, Concatenated, and interleaved concatenated codes. Section 4 shows the BER performance of uncoded and coded OFDM over the Rayleigh fading channel. Finally Section 5 concludes the paper.

II. OFDM CONCEPT

OFDM is a communication technique that splits the available communication channel into a number of equally spaced frequency bands. A subcarrier carrying a portion of the user information is transmitted in each band. Each subcarrier is orthogonal to each other, allowing overlapping between the bands without interference between them, and also cause saving of bandwidth as referred in Fig. 1 [6]. Each carrier in an OFDM signal has a very narrow bandwidth; so that the resulting symbol rate is low (symbol time is large). This will give the signal a high tolerance to Multipath delay spread, as the delay spread must be very long to cause significant inter-symbol interference (ISI), and in order to totally eliminate ISI, OFDM employs a cyclic prefix which increases the symbol length so that it is much greater than the delay spread of the channel [7].

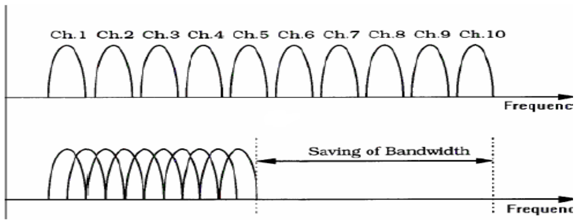

Fig. 1 Saving Bandwidth using OFDM

Fig. 2 below shows the block diagram of an OFDM system [8]. The input data is first passed to the forward error correction (FEC) encoder to improve the system performance by adding redundant bits to the data. Then the coded signal is sent to the modulator where the bits are mapped to symbols, which is represented in in-phase and quadrature (IQ) format. The IFFT is then used for modulating the constellation mapped data onto the orthogonal subcarriers. As the basis functions for an IFFT are N orthogonal sinusoids [8]. S/P and P/S converters used to adjust the format of the data depending on the input of the next block. Finally a cyclic extension is added, and transmits through the channel. And, at the receiver side, all processes will be reversed to retrieve the original data.

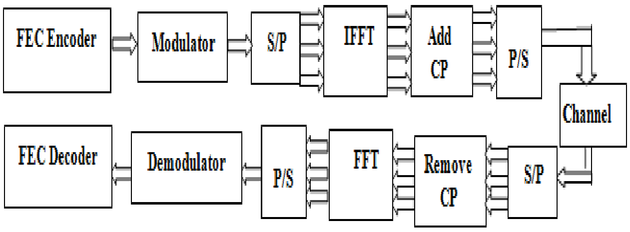

Fig. 2 OFDM General Block Diagram

III. FADING CHANNEL

The fading channel can be expressed by two models, Rayleigh fading channel which contains multiple reflective paths, and there is no line-of-sight signal component, and Rician fading channel that contains a dominant non-fading line-of-sight propagation path [9]. Also, the fading channel can be classified, according to the characteristics of the signal as frequency nonselective (flat) versus frequency selective. A flat fading, if the signal bandwidth is small compared with coherence bandwidth, and in this case, all frequency components of the signal will be affected by the channel in the same manner., so it does not introduce ISI distortion, but the performance degrade due to the loss is SNR whenever the signal is fading. On the other hand, if the signal bandwidth is large compared with coherence bandwidth, the channel is then classified as frequency selective, and different frequency components of the signal will be affected by the channel differently so it has different degrees of fading. So it will introduce ISI distortion [2].

IV. CHANNEL CODING

Channel coding is the transformation of the signal in a certain designed method to enable the transmitted signals to better withstand the effects of various channel impairments such as noise, interference and fading [2].

A. Reed Solomon Code

Reed Solomon (RS) codes are nonbinary cyclic codes with symbols made up of m-bits sequences. The most conventional RS code defined by its parameters as follows [2]:

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

$$d_{min} = n-k+1 \quad (2)$$

Where k: number of data symbols, n: number of code symbols, m: number of bits in each symbol. The RS encoder takes k data symbols and adds 2t redundant symbols to produce n code symbols where each symbol contains m bits [10]. The RS decoder has 2t redundant symbols which are twice the amount of correctable errors t, as for each error, one redundant symbol is used to locate the error and another symbol is used to correct it [2].

RS codes are designed to deal with the burst errors. As RS is a nonbinary code, it works with symbol based arithmetic rather than bit based arithmetic so that it can be configured with long block length (in bits) and large d_{min} with less decoding time, but this increase the complexity [2].

Shortening is performed to improve the performance of the RS code. It done by fixing the rate (k/n) and reduce both the message length (k) and the codeword length (n), so it have the same redundancy and the same error correcting capability as the original code but with less complexity, less decoding time and sometimes less power consumption. It is implemented by appending a certain number of zeros to the information message at the input of the original encoder then discarded these added zeros after the coding procedure [11].

B. Convolutional Code

The convolutional code is designed to deal with the random errors [5]. A general convolutional encoder consists of k shift registers and n modulo-2 adders as shown in Fig 3 [2].

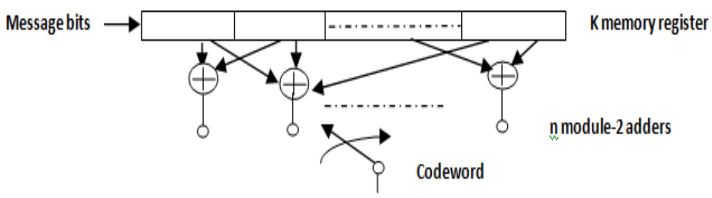

Fig. 3 Convolutional Encoder

The message bits are shifted into the encoder one bit at a time, and the outputs of the n adders are sequentially sampled and transmitted, so that there are n code bits for each message bit and the code rate is 1/n . So, the output sequence is function of both the current input bit and the k-1 previous bits [12].

The convolutional decoder uses the viterbi algorithm that is optimal as it performs maximum likelihood decoding. It reduces the computational load by taking the advantage of the special structure of the code trellis. As the trellis diagram represents the rules of the game as it describes all possible transitions and their corresponding state and finish states, so the error path must follow one of the allowable transitions. So, there are constraints in the encoding process, which cause the decoder to more easily meet good error performance using less E_b/N_o [2].

The choice of connection between the adders and the registers in convolutional encoder provides a certain characteristics to the code. These connections are not chosen arbitrary, it must be chosen to yield good distance properties of the code, and it found by computer search for all possible connection to find the best. [2]

The puncturing technique is used to improve the performance of a convolutional code, it obtained by puncturing or eliminating some outputs of the convolutional encoder. This technique increases the rate of the code and reduces the decoding complexity and time, but it reduces the distance of the code so reduce the error correcting capability of the code [5].

C. Concatenated Code

A concatenated code is a very useful technique that leads to the construction of very efficient codes [13] that provides large coding gain with less implementation complexity [8]. A big, powerful code with good BER performance can be constructed in an equivalent concatenated form by combining two or more codes of relatively small size and complexity to provide the same performance with less complexity, and decoding is done by combining two or more relatively low complexity decoders instead of a complex decoding of a big code [13].

D. Serial Concatenated Code

In a serial concatenated code, a message block is first encoded by the outer code, then the output encoded by the inner code. The decoding of the concatenated code operates in two stages: first performing the decoding of the inner code and then the decoding of the outer code [13]. Fig 4 represents serial concatenated code.

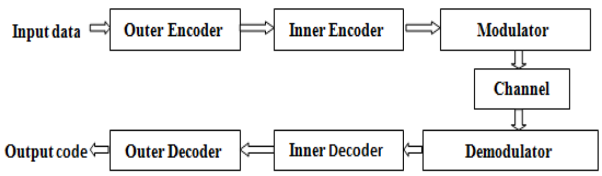

Fig. 4 Serial Concatenated Code

E. Interleaved Concatenated Code

Interleaving is a technique that used against burst errors, as it is designed to convert error patterns that contain long sequences of serial erroneous data into a more random error pattern, so distribute errors among many code vectors, Burst errors are occur in fading channel, and they also occur in concatenated codes, where an inner decoder overloaded with errors can pass a burst of errors to the outer decoder. There are different types of interleavers, which differ according to the way that the data spreading out. The random interleaver spread it in a random fashion, the block interleaver spread it in a form of matrix with a certain number of rows and columns and finally the convolutional interleaver spread the data by shifting it according to a certain construction of number of shift registers [13].

V. The Performance of OFDM System in Rayleigh Fading Channel

The OFDM system parameters used according to IEEE Std 802.16.1a-2013. The modulation technique is QPSK, FFT length equals 1024 and the cyclic prefix (CP) length equals 1/8 of the symbol length [14]. Assuming the channel is in a static case and the channel is a flat as CP length is 1/8*1024 = 128 samples and number of taps in the channel is 10 which is a much less than the CP. The performance of the system is determined by the relation between bit error rate (BER) and bit energy to noise ratio (E_b/N_o). Assume that, the desired quality of transmission is BER = 10^{-4} and the objective is to achieve this BER with the minimum power as possible.

A. The Performance of Uncoded OFDM through Rayleigh Fading Channel

The performance of uncoded OFDM system can be calculated theoretically and practically by the matlab simulation as shown in Fig 5.

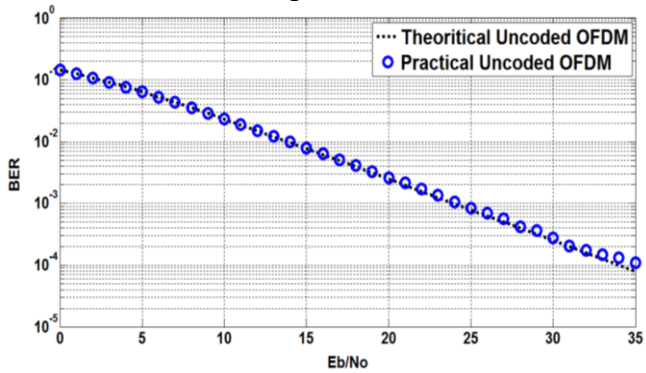

Fig. 5 Theoretical and Practical Uncoded OFDM

From Fig.5, the desired BER which is 10^{-4} achieved in the uncoded OFDM at E_b/N_o = 35 dB. This value is very large to be achieved practically. So, there must use a certain coding technique that reaches the E_b/N_o to a value that can be achieved practically.

B. The Performance of Coded OFDM versus Uncoded OFDM

1) Reed Solomon Coded OFDM

The Reed Solomon code is expected to have a good performance in the fading channel as it designed to treat with the burst errors. The optimum rate for RS codes can be taken from 0.3 to 0.4, as mentioned in [2].

a. The Performance of RS Codes Depends on the Redundancy and the Codeword Length

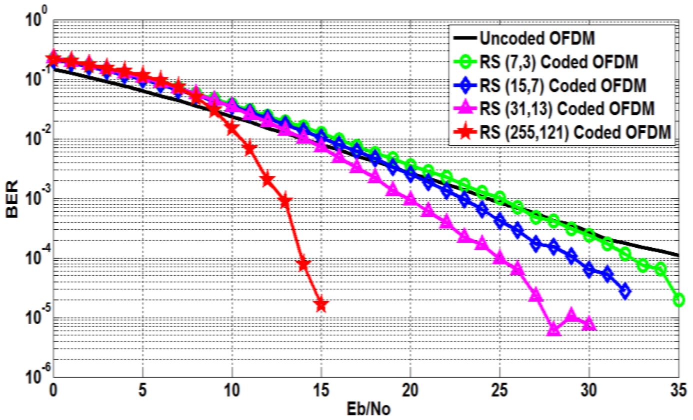

Fig. 6 Different Lengths RS Codes through Fading Channel

Fig.6 shows RS codes with the optimum rate, but with different codeword length and redundancy. It appears that, as the codeword length increases the error correcting capability increases, so RS (255,121) provides the best of them.

Also, there is a crossover between the uncoded and coded performance curves which means that the benefits of coding in performance appear at reasonable values of E_b/N_o. As Coding techniques, that means adding redundancy, cause high transmitting rate and less energy per bit. So, at low power values that cause lower power per bit, there are more errors out of the demodulator that can reach and exceed code correcting capability of the code, so cause poor performance.. And the target from any communication system is not only to transmit at a lower power but with achieving lower BER. Using a powerful coding techniques ,as concatenated codes, cause the crossover occur at earlier point or provide improved performance at lower values of E_b/N_o [2].

b. Shortened Reed Solomon Coded OFDM

From Fig 7, the shortened RS code, which have approximately the same rate as the original code, will result approximately the same bit error performance, it provides the desired BER at power level that save approximately 0.5 dB than the original code, besides reducing the complexity and decoding time.

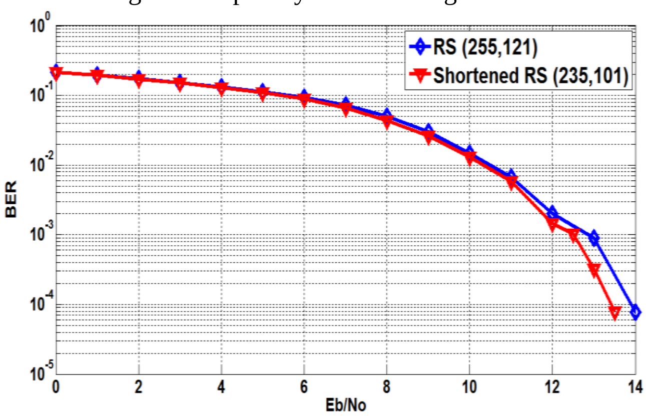

Fig. 7 Shortened RS Coded System

2) Convolutional Coded OFDM through Rayleigh Fading Channel

a. A New Algorithm to Create a Good Convolutional Code

This algorithm can be used to select the best connection for the convolutional encoder to achieve the large distance that represents a measure to the error correcting capability of the code. This algorithm start its work by selecting the required rate 1/n and constraint length K, then testing the all possible connection of the encoder to find the best connection that has a large free distance. From the matlab simulation of this algorithm, to create a good convolutional code, by selecting rate = 1/n = 1/2 and constraint length = K=3, the convolutional encoder design with maximum free distance will have the best connection as shows:

good_conv_code =

'n'	'k'	'max dfree'	'best connection vector'
[2]	[3]	[5]	[5 7]
[2]	[3]	[5]	[7 5]

So, there are many choices of the encoder circuit connections that have a maximum distance. Fig 11 shows the flowchart that illustrates the simulation process of choosing the good distance convolutional encoder design.

b. The Performance of Convolutional Codes with Different Parameters

Here, the convolutional coded system is simulated for rate 1/2 and different constraint lengths (K). From Fig.8, the convolutional code with large constraint length provides a better performance, but the main observation is that the convolutional codes with different K provide the desired BER at high power level. So, the performance of the convolutional codes is a very bad in the fading channel, as it designed to deal with the random errors. So, the convolutional code must be used with an interleaver that used to randomize the burst errors and cause the convolutional code is able to be used in the fading channel.

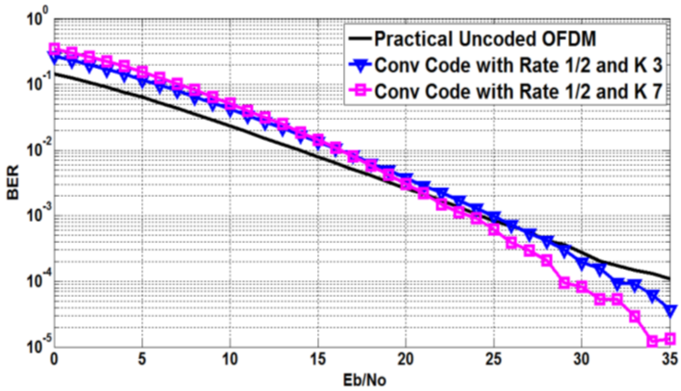

Fig. 8 Convolutional Coded OFDM

c. The Interleaved Convolutional Coded OFDM system

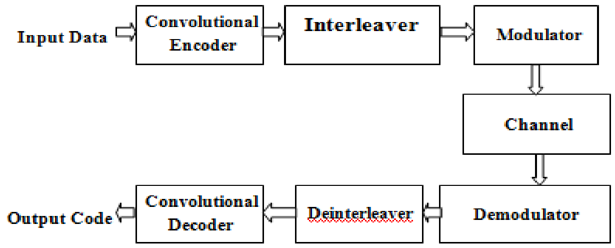

Fig. 9 Interleaved Convolutional Coded OFDM System

Fig. 9 shows the block of interleaved convolutional code. As the interleaver used to randomize burst errors out from the channel so it must be placed before the convolutional decoder at receiver so it placed after encoder at transmitter.

Fig.10 shows the performance of convolutional code with rate 1/2 and constraint length 7, with the block interleaver. And the block interleaver is the preferred interleaver type to be used as it gives the ability to flexible change the interleaved locations between the adjacent bits depending on the expected burst error length of the fading channel. And the interleaved convolutional coded system provides the required BER at E_b/N_o approximately equals 12.5 dB, with a coding gain 22.5 dB than the uncoded case which is a good coding gain.

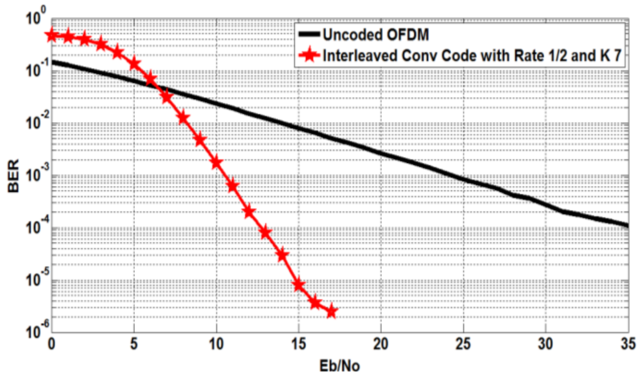

Fig. 8 The Interleaved Convolutional Coded OFDM

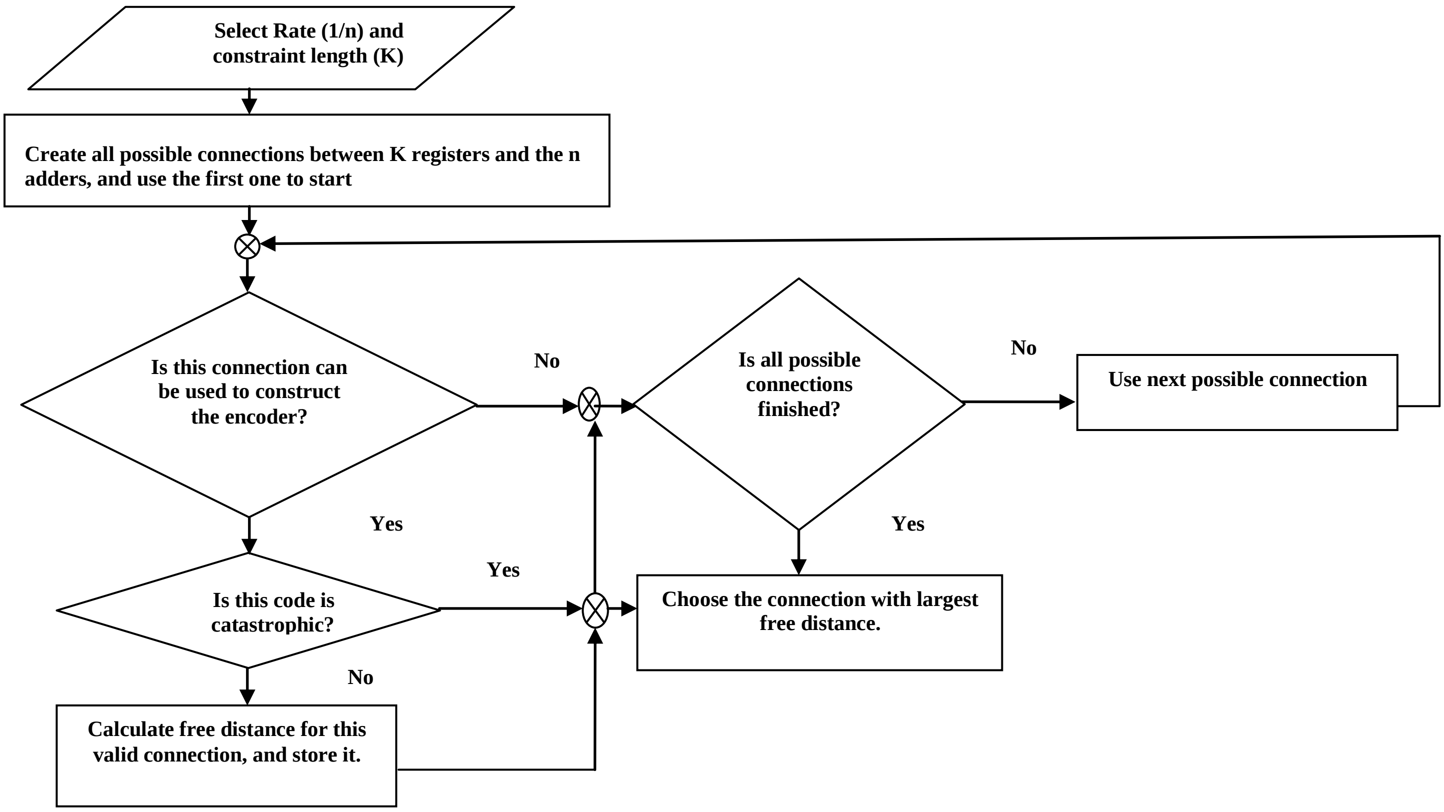

Fig. 11 An Algorithm to Select Convolutional Code with Large Distance

d. Punctured Convolutional Coded System Performance

Fig.12 examines the performance of the punctured convolutional code with different rates. It appears that, for the punctured convolutional code with rate 2/3, the rate increases but the performance degrades. For the other curves, as the rate approximately remain constant its error correcting capability still fixed and its performance as the case of the original convolutional code, and its benefit is to save some decoding time and complexity by saving or removing only a small number of bits that out from the encoder. So, the punctured convolutional code adjusted to make a balance between its advantage and disadvantage, to have the same performance with less complexity. Finally, this technique can be adjusted according to the application requirements.

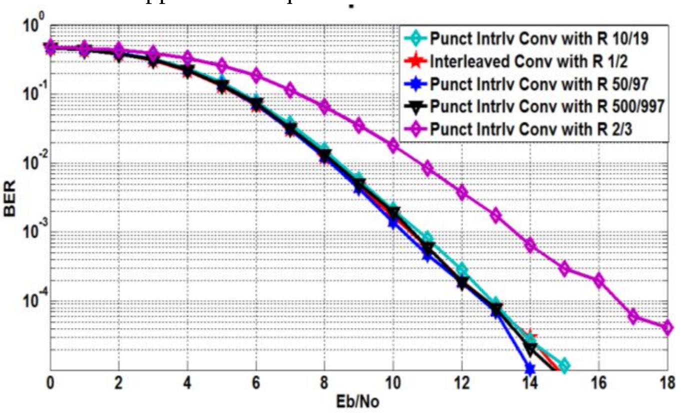

Fig. 9 Punctured Convolutional Coded OFDM

3) Concatenated Coded OFDM through Rayleigh Fading Channel

Firstly, the Reed Solomon code concatenated with the convolutional code without interleaver. Fig. 13 shows that, the performance of these concatenations not provides the expected good performance and this is due the bad performance of convolutional code in fading channel. So, the concatenation must be between the RS code and the interleaved convolutional code must to result a better required performance.

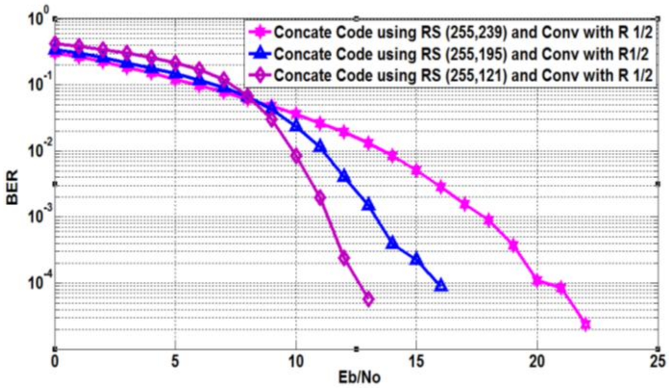

Fig. 103 Concatenated Coded OFDM System Performance

a. Interleaved Concatenated Code

Fig.14 shows the block of the used interleaved concatenated coded system.

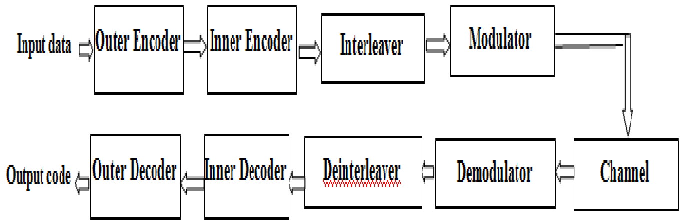

Fig. 11 Construction of Interleaved Concatenated Code

Fig. 15 shows the performance of the interleaved concatenated system that uses a different RS and Block interleaved convolutional codes. The interleaved concatenated code that uses RS (255,239) and RS (255,121) reaches the desired BER at approximately 8.5 dB and the concatenated code that uses RS (255,195) achieves the desired BER at approximately 7.5 dB. So, this concatenation method provides a good performance. Also from the figure, the code with larger redundancy or lower rate, require a more power to reach its good behavior and the code that approximately have an optimum rate provide the better performance.

Fig.16 shows the performance of the concatenated coded system with and without the interleaver. It appears that the interleaver provides a coding gain of approximately 7 dB than the case without the interleaver.

Finally the idea of this concatenation can be concluded as follow, the concatenated code uses two different codes, the first code is RS code with lower redundancy so less complexity as RS (255,239) or RS (255,195) and the second is the convolutional with rate 1/2 which also simple due to Viterbi method, to provide a stronger code that can achieve a good BER at lower power level.

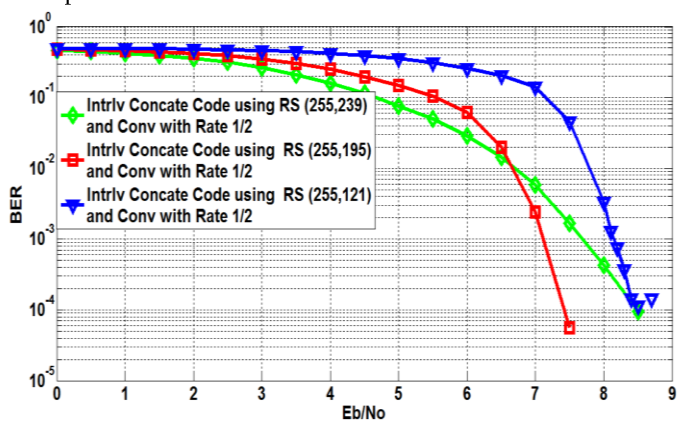

Fig. 12 Interleaved Concatenated Coded OFDM System

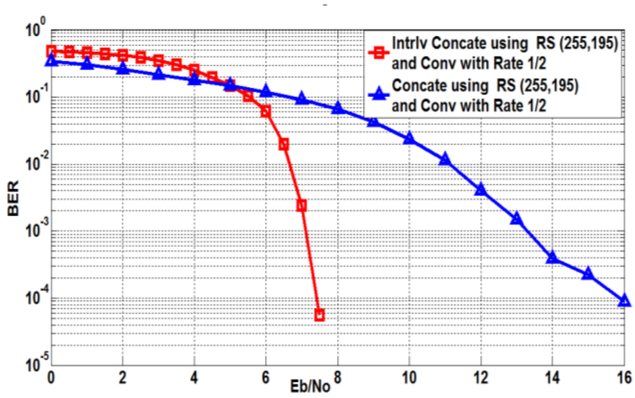

Fig. 136 Concatenated Coded System with and without Interleaver

a. The Concatenated Coded System with Less Decoding Complexity and Time

The concatenated coded system can use the shortened RS code and the punctured convolutional code, to reduce the complexity and decoding time, which provide approximately the same performance as show in Fig.17. it also show that the concatenated code that use soft decision convolutional code will save approximately 1 dB than the case that use the hard decision, with extra few computational due to the special structure of the used trellis.

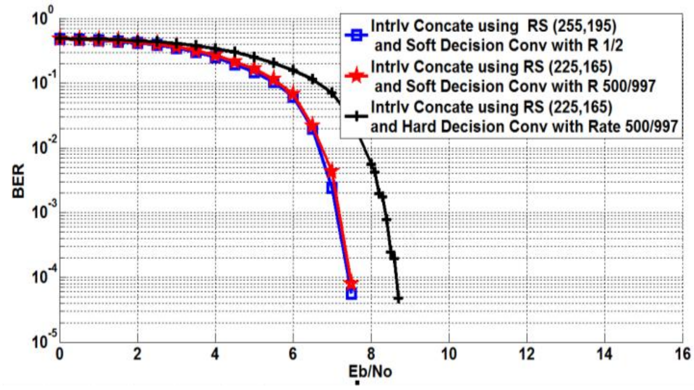

Fig. 147 Concatenated Coded OFDM with Shortened RS and Punctured Convolutional Codes

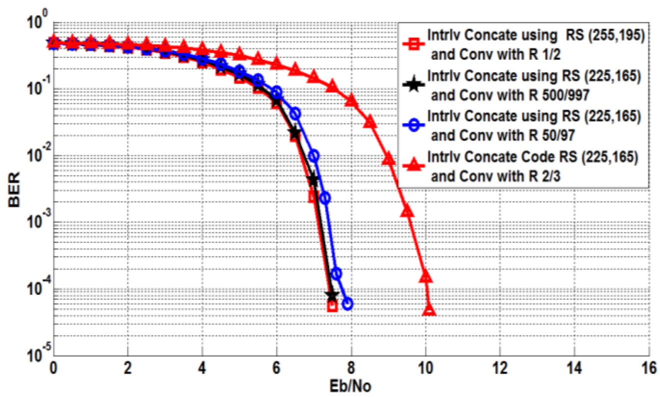

Fig. 1815 Concatenated Coded System with Different Rate Convolutional

Also, the concatenated coded system can use the punctured convolutional code to increase the code rate by using a punctured convolutional code with a high rate and it depends on the requirements of the application as shown in Fig.18.And it will degrade the performance as it reduce its distance, but it reduce the bandwidth consumption so that the used rate depends on the application and the available resources.

e. The Performance of Coded OFDM with the effect of the motion in the system

The performance of the multipath channel can be affected by many factors. One of the most important factors is the Doppler frequency that represents the resultant shift in the frequency due to the motion between the transmitter and the receiver. The doppler frequency can be expressed as:[8]

$$f_d = v * f_c / c \qquad (3)$$

Where, f_d is the maximum Doppler frequency, v is the vehicular speed and fc is the carrier frequency. According to 4G standard, fc can be taken to be 3 GHz or 5 GHz, to cause f_d to 222 Hz or 333 Hz, in case of the speed is 80 km/hr. In this section of the paper, the performance of the concatenated coded OFDM system will be tested in case of the motion between transmitter and receiver exists.Fig.19 shows that the concatenated code achieves a large coding gain and improve the performance of system in case of static or moving objects.

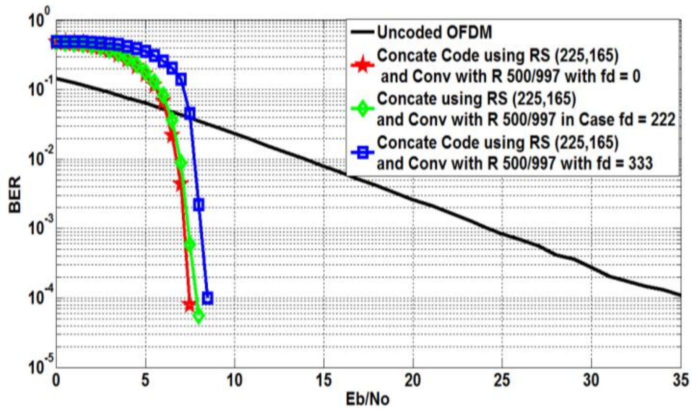

Fig. 19 Concatenated Coded OFDM in Case of Motion

VI. CONCLUSION

This paper represented the performance of uncoded versus coded OFDM system over Rayleigh fading channel. That discusses the effect of different channel coding techniques in the performance of OFDM system. It shows that, RS code is a good in dealing with the burst errors that exist in the fading channel. But the convolutional code cannot deal with this type of errors. So, the interleaved convolutional code used in the fading channel. It also discusses the ability of interleaved concatenated codes to provide a more improvement in the system performance in case of static or moving objects. and its ability to use the shortened and punctured techniques to respond to various systems demands so provide the better performance with the available resources with less decoding complexity and time. Also, the soft decision not produces a more computational in convolutional code, but it can be replaced by the hard decision to reduce complexity by wasting 1 dB in the power level. It also introduced a new algorithm to choose a good convolutional encoder design with certain rate and memory registers.

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