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Three Dimensional Concatenated Codes in OFDM Transmission System under a Rayleigh Fading Channel with Carrier Interference

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Abstract

Orthogonal frequency division multiplexing (OFDM) or multicarrier transmission has been shown to be an effective technique to combat multipath fading in wireless Communications. It has been successfully used for HF (High frequency) radio applications and has been chosen as the standard for digital audio broadcasting and digital terrestrial TV broadcasting in Europe and high-speed wireless local areas networks.

This paper describe the concept behind parallel data transmission and the configuration of an OFDM transmitter and receiver system when 8DPSK is used (8ary-Differential phase shift keying) as a modulation technique with the effect of carrier interference. First, the BER (Bit Error Rate) are evaluated for OFDM system in a two typical channels, AWGN channel and Rayleigh fading channel when we used a guard interval of 25% of symbol period compared with the theoretical channel performance for each channel.

Second, the BER are evaluated for OFDM system in a Rayleigh fading channel with the effect of carrier interference for two values of carrier to interference ratio (CIR=15 dB & CIR=20 dB). In this case, some of subcarrier is completely lost by deep fades due to multipath fading and carrier interference. So, Forward Error Correcting (FEC) code is used to improve the performance of the OFDM system with carrier interference. Three techniques are used in this paper, the first technique a Reed Solomon code is used, the second technique a two dimensional concatenated codes is used and the 3rd technique a three dimensional concatenated codes is used which proposed in this paper.

The results of a simulation are obtained by computer MATLAB v.7 language, improved the BER of the OFDM system with carrier interference & prove the robustness of the proposed three dimensional concatenated codes.

الخلاصـــــــة

التعدد ألتقسيمي الترددي المتعامد (OFDM) أو الإرسال متعدد الحاملات هو تقنية فعالة ومؤثرة لمقاومة تأثير المسارات متعددة الخفوت في نظام الاتصالات اللاسلكية (multipath fading in wireless communication) وأثبت نجاحه للتطبيقات الراديوية في قنوات الترددات العالية (HF radio channels) والذي أيضا استخدم كأساس للبث الراديوي والتلفزيوني الرقمي في أوربا وفي شبكات محطات الإذاعة اللاسلكية ذات السرع العالية.

في هذا البحث تمت دراسة إرسال البيانات في نظام التعدد ألتقسيمي الترددي المتعامد بين المرسلة والمستقبلة(OFDM) ولنوع تضمين (8DPSK modulation) بوجود تأثير التداخل بالحاملات. أولا لقد تم حساب نسبة احتمالية خطا البت BER (Bit Error Rate) لنوعين من القنوات. قناة ضوضاء كاو سي (AWGN channel) وقناة خفوت رايلي (Rayleigh fading channels) وباستخدام الفترة الحارسة (guard interval) بطول (25% of symbol period) مع مقارنة النتائج مع النتائج النظرية لكل قناة.

ثانيا تم حساب احتمالية خطأ البت (BER) لتأثير التداخل بالحاملات ولقيمتين بالتداخل (CIR= 15 dB & CIR =20 dB) . في هذه الحالة بعض الحاملات سوف تفقد بصورة كاملة نتيجة الخفوت الكبير للمسارات متعددة الخفوت ونتيجة التداخل بالحاملات.لذلك تم تحسين أداء منظومة (OFDM) بوجود التداخل بالحاملات باستخدام تقنية التصحيح (Forward Error Correcting Code) بأستخدام نوع ترميز (Reed Solomon code) وبأستخدام نوع ثاني ثنائي البعد (Concatenated code) وبأستخدام نوع ثالث مقترح ثلاثي البعد (Three dimensional concatenated code) .

ان النتائج المستحصلة من محاكاة الكومبيوتر باستخدام لغة (MATLAB v.7) تم من خلالها تحسين أحتمالية خطأ البت (BER) لنظام (OFDM) بوجود التداخل بالحاملات وكذلك أثبتت متانة المقترح الجديد (Three dimensional concatenated code)

1. Rayleigh Fading Channel

In atypical wireless communication environment, multiple propagation paths often exist from a transmitter to a receiver due to scattering by different objects. Signal copies following different paths can undergo different attenuation, distortions, delays and phase shifts. Therefore, Constructive and destructive interference can occur at the receiver. When destructive interference occurs, the signal power can be significantly diminished. This phenomenon is called fading. The performance of a system (in terms of probability of error) can be severely degraded by fading. Very often, especially in mobile communications, not only do multiple propagation paths exist, but they are also time-varying. The result is a time-varying fading channel. The total received signal is a vector sum of individually delayed signals, their relative phase angles depending on the frequency and the echo amplitudes and delays. Therefore, since the echo amplitudes and delays are time varying, one observes large variations of the received signal strength at a single frequency as a function of time, or of the strength at a given time as a function of frequency; the latter is termed "selective fading". Another effect of multipath reception is the delay spread of the received signal, consisting of several components that arrive at different time with delay differences exceeding one symbol period T_s, the signal components of the symbol present at the receiver input may be impaired by components of previously sent symbols. This effect is called intersymbol interference (ISI).Further more, time variance of the channel is due to Doppler spread, and is realized by fast fading or slow fading. In the frequency domain, signal distortion due to fast fading increases as the Doppler spread increases, thus causing the channel impulse response to change rapidly within the symbol duration. In a slow fading channel, the Doppler spread is much less than the baseband bandwidth and results primarily in a loss in SNR [1,2,3].

2. Orthogonal Frequency Division Multiplexing (OFDM)

OFDM is a Multi-Carrier Modulation technique in which a high rate bit-stream is split into N parallel bit-stream of lower rate and each of these are modulated using one of N orthogonal sub-carrier [4]. The composite data of all the subcarriers is comparable to the data rate possible using the same basic modulation at a higher data rate with a single carrier in the same channel bandwidth [5]. Increasing symbol duration will result in lower rate parallel subcarriers. This decreases the relative amount of dispersion in time caused by multipath delay spread. So that, the Rayleigh fading channel is looks flat on each carrier [6]. OFDM allows the spectrum of each tone to overlap, and because they are orthogonal, they do not interfere with each other. By allowing the tones to overlap, the overall amount of spectrum required is reduced [3], as shown in **Fig.(1)**.

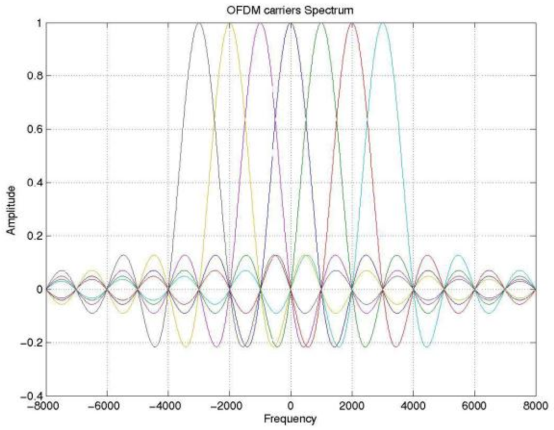

Figure (1) OFDM tones

From a frequency domain perspective, a frequency-selective fade will cause a problematic fading depth on only a few subcarriers. Errors will potentially occur on the few bits associated with those subcarriers but not the others, so that, the net error rate for all subcarriers taken together can still be made acceptable low [5]. By orthogonality of the carriers, we mean that the carrier frequencies satisfy the following requirement [4]:

$$\mathbf{f_i = f_o + \frac{i}{T_s} \qquad i = 0,1,\ldots,N-1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)}$$

where:

f_o: is the carrier frequency,
f_i: is the frequency of the i^{th} subcarrier,
T_s: is the symbol duration of the OFDM signal and
N: is the number of subcarrier.

The above requirement translated to the time domain, means that there must be integer number of cycles of each carrier over the duration T_S. **Figure (2)** shows three tones over a single symbol period, where each tone has an integer number of cycles during the symbol.

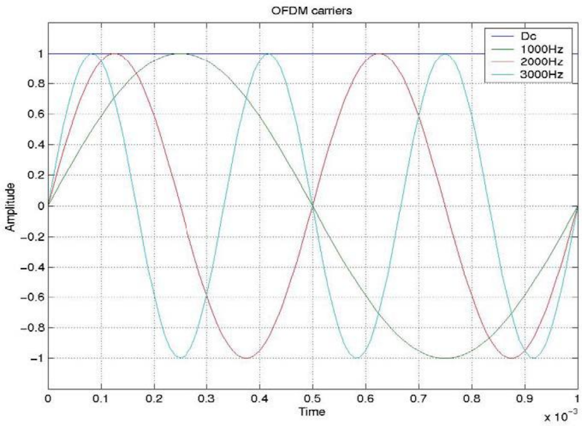

Figure (2) Integer number of sinusoid periods

3. Implementation of OFDM using Fast Fourier Transform (FFT)

The coherent modulation scheme requires a coherent detection; therefore, channel estimation, pilot and equalizer are required, which add extra complexity to the designed system. Binary Differential Phase Shift Keying (DPSK) or (noncoherent PSK) is a modulation scheme in which the input data is differentially encoded, then applied to PSK modulation. The noise performance of DPSK is lower compared with PSK because the phase reference is contaminated by noise in the DPSK schemes. However, the noise perturbation in phase reference is not too great. This gives SNR loss of about 1dB than coherent PSK modulation. In DPSK, the received signal detection can be accomplished without a need for coherent detector. Hence, the noise performance and the SNR loss are not so important factors compared with the receiver complexity (especially in OFDM system) introduced by coherent detection [7]. For this reason, the transmitted data stream is modulated using 8ary-DPSK (8ary-Differential phase shift keying) method which is used in this paper. The transmitted OFDM symbol waveform can be represented as:

$$s(t) = \mathrm{Re}\{\sum_{k=0}^{N-1} d(k)\exp(j2\pi f_k t)\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(2)}$$

where:

$d(k)$: is the modulated data symbol.
f_k: is the subcarrier frequency of k^{th} subcarrier which is equal to($f_c + k\Delta f$).
f_c: is the carrier frequency.
Δf: is the subcarrier spacing (bandwidth) which is equal to ($1/NT_s$).
T_s (symbol duration) = $1/R_s$ and R_s(symbol rate).

Eq.(2) represents the passband OFDM signal, if the equivalent complex baseband notation is used, the complex baseband OFDM signal is written as:

$$s(t) = \sum_{k=0}^{N-1} d(k)\exp(j2\pi k\Delta f t) \quad \text{...} (3)$$

If the signal is sampled at a rate of T_s, then ($t = nT_s$), and for orthogonality ($\Delta f = 1/NT_s = R_s/N$), then eq.(3) can be rewritten as:

$$s(n) = \sum_{k=0}^{N-1} d(k)\exp(j2\pi kn / N) \quad \text{...} (4)$$

Eq.(4) is exactly the Inverse Discrete Fourier transform (IDFT) of the data sequence d(k). So, the transmitter and receiver for OFDM system can be implemented efficiently by using Inverse Fast Fourier Transform (IFFT) techniques. The Inverse Fast Fourier Transform (IFFT) performs the same operations as an IDFT, except that it is much more computationally efficiency, and so is used in all practical systems [3,4,5,6]. **Figure (3)** illustrates the configuration of an OFDM Transceiver system (transmitter and receiver) [3, 4, 5].

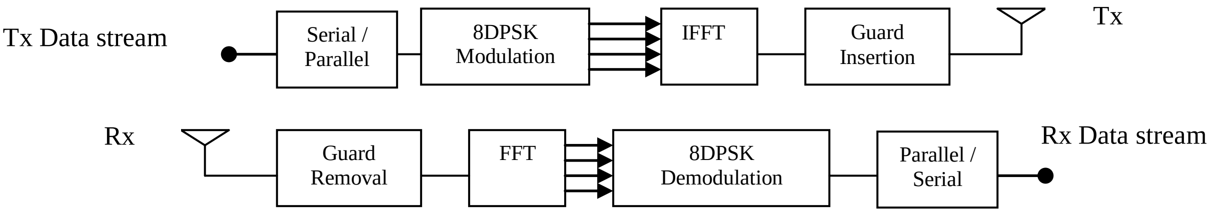

Figure (3) OFDM radio transceiver system (Transmitter and Receiver)

In order to transmit the OFDM signal, the modulated time domain signal mixed up to the required frequency using (IFFT) and Then the OFDM signal is transmitted to the air .The transmitted signal passed through the radio channel which is equivalent to low pass system. At the receiver first, the received signal is contaminated by AWGN. The receiver performs the reverse operation of the transmitter, mixing the RF signal to baseband for processing, then using Fast Fourier Transform (FFT) is used to analyse the signal in the frequency domain. The amplitude and phase of the subcarrier is then picked out in a demodulator and converted back to digital data [6,8].

4. Guard Time and Cyclic Extension

One of the main advantages of OFDM is its immunity to multi-path delay spread that causes Inter-symbol Interference (ISI) in a wireless channels. Since the symbol duration is made larger (by converting a high data rate signal into 'N' low rate signals), the effect of delay spread is reduced by the same factor. Guard Time is introduced inorder to eliminate the ISI almost completely. This is done by making the guard time duration larger than that of the estimated delay spread in the channel. If the guard period is left empty, the orthogonality of the sub-carriers no longer holds, i.e., Inter carrier Interference (ICI) comes into picture. In-order to eliminate both the ISI as well as the ICI, the OFDM symbol is cyclically extended into the guard period. This preserves the orthogonality of the sub-carriers by ensuring that the delayed versions of the OFDM symbol always have an integer number of samples within the FFT interval **[4]**. Thus we can eliminate ISI and ICI by cyclically extending the OFDM symbol into the guard period and making sure that the guard time duration is larger than the delay spread **[6]**, as shown in **Fig.(4)**.

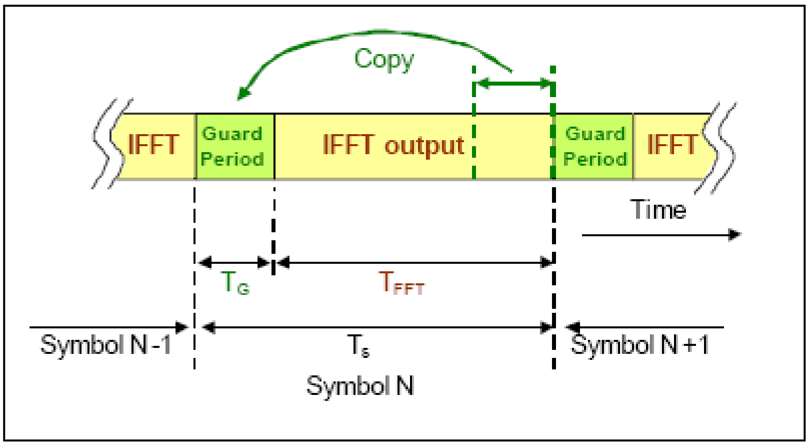

Figure (4) Addition of a guard period to an OFDM signal

After insertion the guard period, the total length of the symbol is

$$\mathbf{T_f = T_G + T_{FFT}} \quad \ldots\ldots \quad \mathbf{(5)}$$

where:

T_f: is the total length of the symbol in samples,
T_G: is the length of the guard period in samples, and
T_{FFT}: is the size of the IFFT used to generate the OFDM signal **[8]**.

In wireless systems, a guard interval of 25% of symbol period is often met and seems to be a good compromise. That is the value taken for DAB (Digital Audio Broadcasting), it allows a maximum distance of about 80 kilometers between transmitters **[6]**. In practice, these samples (guard time T_G) are not enough to make a real OFDM signal. The reason is that there is no over sampling present .To introduce over sampling, a number of zero can be added to the input data vector in the middle and one zero at the beginning (over sampling present) before fed into the N-point IFFT. For 64 point IFFT, the insertion of zeros is shown in the **Fig.(5)** [9].

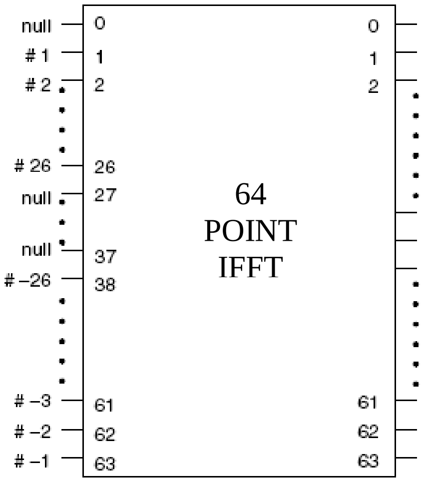

Figure (5) Input and output of IFFT

5. Coding Techniques in OFDM System

For channels with deep fades at some frequencies, the subcarriers at these faded frequencies will experience very high error rates because of low signal-to-noise ratio (SNR) values. The error performance on these weak channels can dominate the overall error rate, thus setting a lower bound on the error performance of OFDM. Therefore, for reasonable error rate performance, it is essential for OFDM systems to have coding. Coded OFDM is known as COFDM [5]. Channel coding is used in digital transmission systems to detect and correct errors which are applied to the signal before transmission, to overcome errors due to lost carriers from noise, fading, multipath, external interference, and other channel impairments [6]. The choice of a suitable channel coding scheme depends on the properties of the channel. While an AWGN channel leads to single errors which are stochastically distributed, radio channels are mainly characterized by a bursty error structure due to fading effects. In any case, the use of a suitable code is always justified, which corrects these burst errors. Furthermore, efficient burst error correction codes can be employed. Among them Reed-Solomon codes (RS codes) play an important role to correct burst error due to multipath fading in OFDM system [10].

5-1 Reed-Solomon Codes

The special subclass of non-binary Bose Chadhuri Hocquenghem (non-binary BCH) codes is called Reed Solomon codes (RS). Reed Solomon code consists of a set of fixed length code words in which the elements of the code words are selected from an alphabet of q symbols denoted by {0,1,2,…,q-1}.Usually, $q=2^k$, so that k information bits are mapped into one of the q symbols. The length of Reed Solomon code word is denoted by n and the number of information symbols encoded into a block of n symbols is denoted by k. The minimum distance of Reed Solomon code is denoted by d_{min}. A systematic (n, k) Reed Solomon code consists of k information symbols and n-k parity check symbols [1]. In a Reed Solomon codes, the symbol sequences are coded instead of bit sequences are coded and that consequently total symbols, consisting of several bits, are corrected in the receiver. Thus, a Reed-Solomon code is capable of correcting burst errors [10].

A t-error-correcting Reed Solomon code with symbols from GF(q) has the following parameters [1, 11].

Block length : $n = q - 1$
Number of parity–check digits : $n - k = 2t$
Minimum distance : $d_{min} = 2t + 1$

Such a code is guaranteed to correct up to t error. A second reason for their importance is the existence of efficient hard decision decoding algorithms, which make it possible to implement relatively long codes in many practical applications where coding is desirable.

A Reed Solomon code is particularly matched to M-ary modulation technique for transmitting the 2^k possible symbols in OFDM system. Specifically, M-ary Differential phase shift keying (M-ary DPSK) signaling is used. Each of the 2^k symbols in the q-ary alphabet is mapped to one of the $M=2^k$ Differential signals. Thus the transmission of a code word is accomplished by transmitting n Differential signals, where each signal is selected from the set of $M=2^k$ possible signals [1], as shown in the **Fig.(6)**.

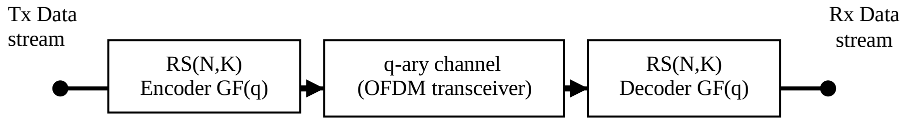

Figure (6) Block diagram of reed solomon code-OFDM scheme

The performance of the hard decision decoder Reed Solomon code may be characterized by the following upper bound on the code word error probability [1,5]:

$$P_e \le \sum_{i=t+1}^{n} C_i^n P_M^i (1 - P_M)^{n-i} \quad \text{.......................................} (6)$$

where:

$$C_i^n = \frac{n!}{i!(n-i)!},$$

t: is the number of errors guaranteed to be corrected by the code and
P_M: is the channel symbol error probability.

When a code word error is made, the corresponding symbol error probability is:

$$P_{es} = \frac{1}{N} \sum_{i=t+1}^{n} i C_i^n P_M^i (1 - P_M)^{n-i} \quad \text{.......................................} (7)$$

Furthermore, if the symbols are converted to binary digits, the bit error probability is:

$$P_{eb} \approx \frac{2^{k-1}}{2^k - 1} P_{es} \quad \text{...} (8)$$

5-2 Concatenated Code

Concatenated codes have been used as a practical mean of achieving long block or constraint lengths to combat errors on very noisy channel. In this method, two codes are used, one is a binary or nonbinary code which is denoted by (C1) and the other is a nonbinary code which is denoted by (C2). The code (C1) is the inner code and is an (n, k) code where n and k are measured in terms of symbols from a q-ary alphabet while the code (C2) is the outer code and is an (N, K) code where N and K are measured in terms of symbols from a q^k-ary alphabet [1,11]. Then an (Nn, Kk) long code can be formed such that each code word is a rectangular array of N columns and n rows in which every row is code vector in (C2) and every column is a code vector in (C1), as shown in **Fig.(7)**. This two-dimensional code is called the direct product (or simply the product) of (C1) and (C2). The Kk symbols in the lower left corner of the array are the information symbols. The symbols in the lower right corner of this array are computed from the parity-check rules for (C2) on rows, and the digits in the upper left corner are computed from the parity-check rules for (C1) on columns. The check symbols in the upper right corner are computed using the parity-check rules for (C1) on columns or parity-check rules for (C2) on rows. It turns out that either way would yield the same (N-k)*(n-k) check symbols [11].

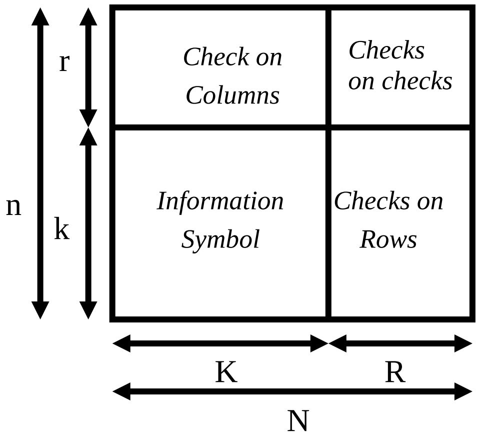

Figure (7) Concatenated code

The information block of q-ary symbols is of length Kk. This block can be broken into K sub blocks of k symbols; each sub block is viewed as an element from a q^k-ary alphabet. A sequence of K such sub blocks can be encoded with an (N, K) code over $GF(q^k)$. Then, each of Nq^k-ary symbols can be reinterpreted as kq-ary symbols and coded with an (n, k) q-ary code. In this way a concatenated code has two distinct levels of coding. So that, we obtain a concatenated block code having a block length of Nn symbols and containing Kk information symbols. Hence, the combination of the encoder, channel and decoder can be thought of as a super-channel with the large input/output alphabet over $GF(q^k)$ [11]. The product of an (N,K) code with error-correcting capability $t_2=[(Dmin-1)/2]$ and an (n,k)code with error-correcting capability $t_1=[(dmin-1)/2]$can correct all patterns of weight $t=[(Dmin * dmin -1)/2]$ or less and all symbol bursts of length up to $b = \max(Nt_1, nt_2)$ [1,11].

The construction of super-code for OFDM transceiver is shown in **Fig.(8)**, where both the inner and outer code is a Reed Solomon code.

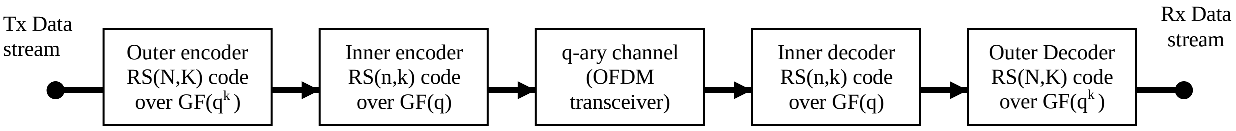

Figure (8) Block diagram of concatenated code-OFDM scheme

5-3 Three Dimensional Concatenated Code

To obtain significant improvement, one needs to increase the length of the code, and hence increasing the complexity of the system. Another disadvantage of using longer codes is the necessity to have large interleavers, resulting not only in increase in complexity but also in large delays. The proposed solution in this paper by using a three dimensional concatenated code, concatenation allows the significant reduction in complexity over single level code that would provide the same overall error rate. The choice of the codes should be governed by a trade off between performance and system complexity. Since Reed Solomon codes are powerful to correct burst error due to multipath delay, hence they are a popular choice for the three dimensional concatenated codes and to reduce the design complexity of a three dimensional concatenated code we used the same Reed Solomon code With short block length (n) and low error correcting capability (t) in each dimension to have long code with a high error correcting capability. The proposed three dimensional concatenated code for an qary channel is obtained by a concatenation outer (N1, K1) Reed Solomon code over $GF(q^{k2})$ in yz-plane with inner (N2,K2) Reed Solomon code over GF(q) in yz-plane & with sub inner (N3,K3) Reed Solomon code over GF(q) in xy-plane where k2 is equal to K3 for simplicity as shown in the **Fig.(9)**.

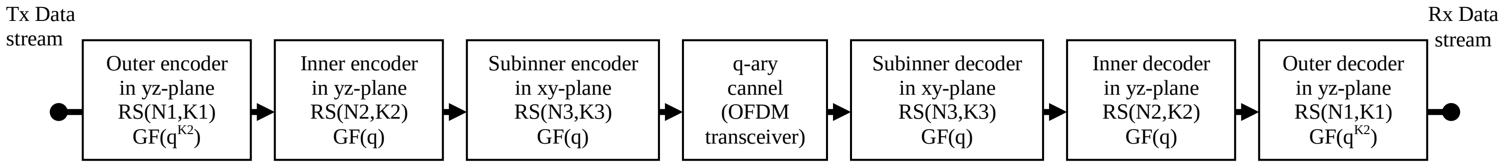

Figure (9) Block diagram of three dimensional concatenated code-OFDM scheme

The procedure of encoding and decoding of proposed three dimensional concatenated codes are listed below.

1. The original data in three dimensional xyz axis-K1*K2*K3 symbols in GF(q) are generated, K1*K2 symbols in each yz-plane for each level K3 in x-axis, as shown in the **Fig.(10)**.

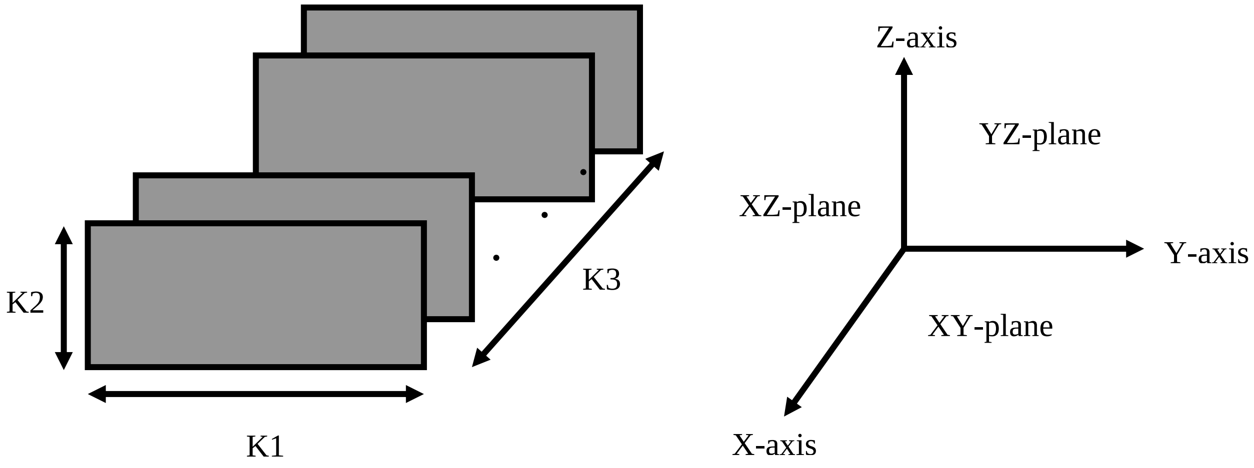

Figure (10) Original data in a three dimension xyz

2. The outer codeword (N1,K1) Reed Solomon code over $GF(q^{K2})$ encode the original data in each yz-plane for each level K3 in x-axis (each column in yz-plane is one symbol for the outer (N1,K1)Reed Solomon code i.e. one symbol in outer code is a number in $GF(q^{K2})$ contain K2 symbols and each symbol is a number in GF(q), the parity block is the last R1 columns in each yz-plane) as shown in the **Fig.(11)**.

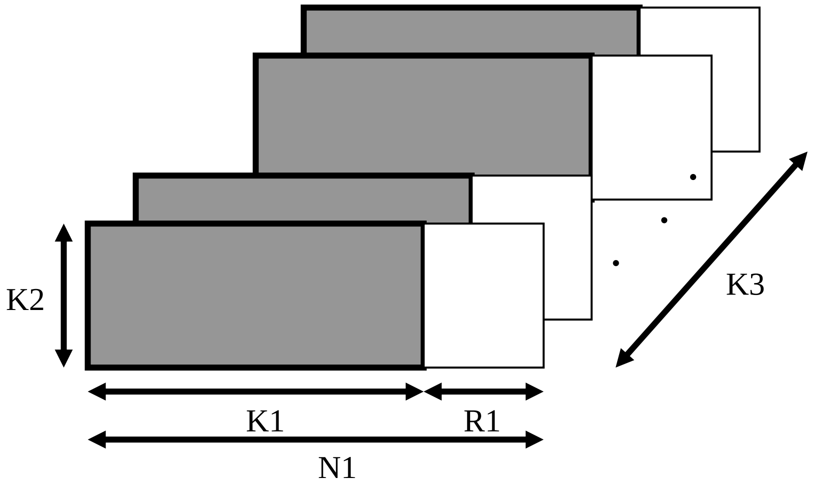

Figure (11) Data after outer encoder

3. Inner code word-N1 copies of (N2,K2) Reed Solomon code over GF(q) encode the data in each yz-plane for each level K3 in x-axis. (Each column in yz-plane is one code word for the inner (N2,K2) Reed Solomon code. The parity block is the first R2 rows in each yz-plane), as shown in the **Fig.(12)**.

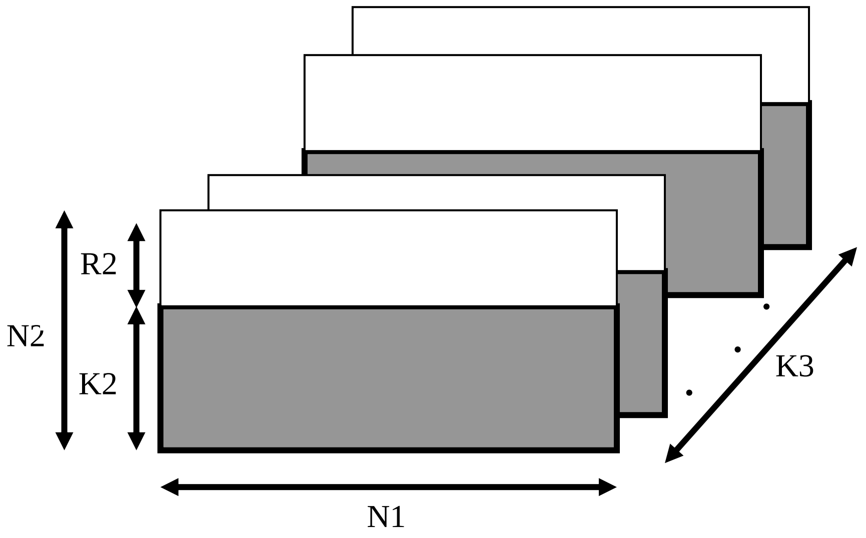

Figure (12) Data after Inner encoder

4. The sub inner code word-N1 copies of (N3,K3) Reed Solomon code over GF(q) encode the data symbol in each xy-plane for each level N2 in z-axis, (each column in a 3rd dimensional i.e. in xy- plane is one code word for (N3,K3) sub inner code, parity block is the last R3 columns in each xy plane), as shown in the **Fig.(13)**.

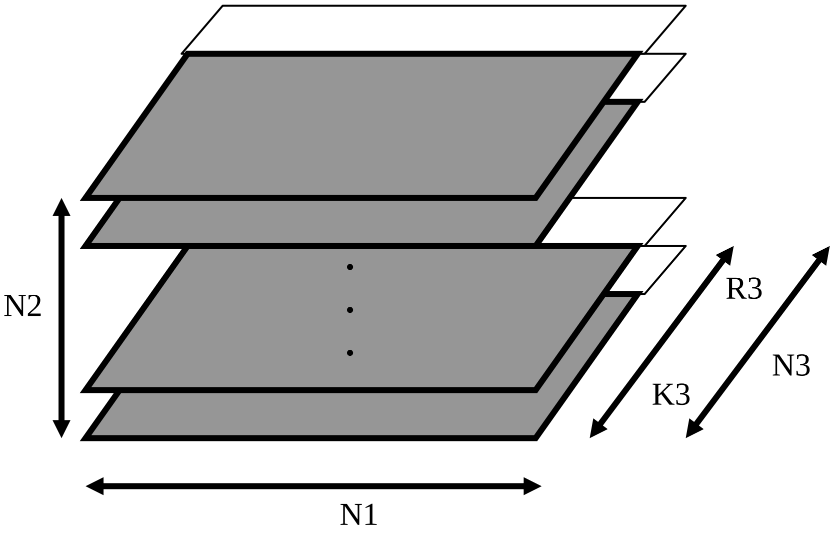

Figure (13) Data after sub inner encoder

The sub inner encoder is generating one column at a time in xy-plane. Here the sub inner code word are stored by columns until the entire three dimensional concatenated code word is assembled in xyz-plane, it is then read into the channel by rows in xy-plane.

The received message with an errors is first decoded in sub inner(N3,K3) Reed Solomon code in xy-plane for each level N2 in (z-axis) to remove the last R3 redundancy columns, then the data decoded in inner (N2,K2) Reed Solomon code in yz-plane for each level K3 in (x-axis) to remove the first R2 redundancy rows, finally the data decoded in outer(N1,K1) Reed Solomon code in yz-plane for each level K3 in (x-axis) to remove the last R1 redundancy column to obtain the received data.

6. Performance by Computer Simulation

This section calculates BER in OFDM system when used a Modulation Schemes 8DPSK with carrier interference under multipath delay channel for three different coding techniques (Reed Solomon code, Concatenated code and proposed three dimensional concatenated codes) by using MATLAB v.7 computer simulation software. The following parameters are used in program [3, 4, 11].

Number of subcarriers = 52.

Number of parallel channel = IFFT length = FFT length = 64.

Channel Spacing is 20 MHz is used for 64 point IFFT.

Symbol Rate = S_r = 312.5 (ksymbol / sec) = Carrier Spacing (F_c) (= 20 MHz/64).

Symbol time = $T_s = 1/S_r = 3.2$ μsec.

Guard time = $T_G = T_s/4 = 800$ nsec.

OFDM block length = $T_f = T_G + T_{FFT} = 4$ μsec.

Rate in OFDM = $1/T_f = 250$ (ksymbol/sec).

Modulation Schemes = 8DPSK.

Number of modulation level = 3 bits for 8DPSK.

The bit error rate (BER) is calculated by XOR'ing the information signal at the transmitter with the finally received signal and then dividing it with the number of Transmitted bits. For all simulation, the BER are obtained after long simulation time which is plotted against the SNR (Eb/N0) dB values.

6-1 Performance of 8 DPSK in OFDM system under AWGN channel

The BER performance of 8DPSK modulation in OFDM system under AWGN channel is shown in **Fig.(14)** which is compared with theoretical results for 8DPSK in OFDM system. In this simulation, we achieved 52 subcarrier transmission by using an OFDM technique based on 64 point IFFT circuit with a guard time interval equal to ¼ symbol time after insertion 11 zeros in the middle of data and one zero at the beginning to present over sampling as shown later in **Fig.(5)** to obtain real OFDM simulation, there was a 0.9691 dB shift form the theoretical value when using guard time. The shift from theoretical value was caused by the cutting off of the guard interval power from the received signal which is calculated as follows.

$$\textbf{Shifted value (dB)} = -10\log_{10}(\text{FFT\_length} / (\text{FFT\_length}+\text{guard\_length})) \quad \dots\dots (9)$$

$$= -\log_{10}(\,64 / (\,64 + 16\,)\,) = +\,0.9691\ \text{dB}$$

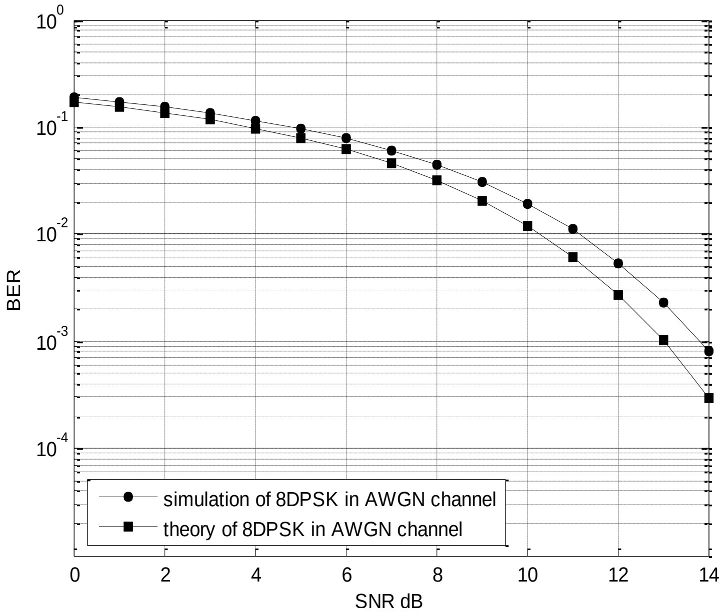

Figure (14) Performance of 8DPSK modulation in OFDM system under AWGN channel with guard time equal to ¼ symbol time

6-2 Performance of 8DPSK in OFDM System under a Rayleigh Fading Channel with and without Carrier Interference

Figure(15) show the BER performance of 8DPSK in OFDM system with and without carrier interference for two values of carrier to interference ratio (CIR=15dB and CIR=20dB) which is compared with the theoretical value of a Rayleigh fading channel which has a

Doppler shift of 150 Hz, that is mean a fading period equal to 6.667 msec. In this simulation, we achieved 52 subcarrier transmission by using an OFDM technique based on 64 point IFFT circuit with a guard time interval equal to ¼ symbol time after insertion 11 zeros in the middle of data and one zero at the beginning to present over sampling as shown in the **Fig.(5)** to obtain a real OFDM simulation. In this case, the Nominal Bandwidth is equal to 16.25 MHz (=312.5 kHz ∗□ 52) and there was a +0.9691dB shift from the theoretical value. The shift of the value was caused by the cutting off of the guard interval power form the received signal as was calculated in eq.(9). Two systems are simulated.

1. Without carrier to interference effect, the error performance of the separate subcarriers can be considered independently as long as the subcarriers remain orthogonal and there is no inter carrier interference. We notice that the BER decreases when we increase the SNR, which is normal because the signal becomes stronger than the noise and multipath fading.
2. A fundamental measure of the capability of a digital modulation scheme is its BER (Bit Error Rate) in the presence of carrier to interference ratio effect. For two values (CIR=15 dB and CIR=20dB). The BER is a function of the ratio of the desired signal level to the noise and interference levels, increasing as the ratio increases. i.e. more degradation occurs and the system is unable to reconstruct the original signal, and eventually become unstable. Form the simulation result of (CIR=15dB), the performance dose not improved after SNR=20dB. i.e. BER is equal to $5*10^{-2}$ (no more than 5 in 100 bits are received in error) unchanged even that the SNR dB is increased while for (CIR=20dB), the performance dose not improved after SNR= 26 dB. i.e. BER is equal to $18*10^{-3}$ (no more than 18 in 1000 bits are received in error) unchanged even that the SNR dB is increased.

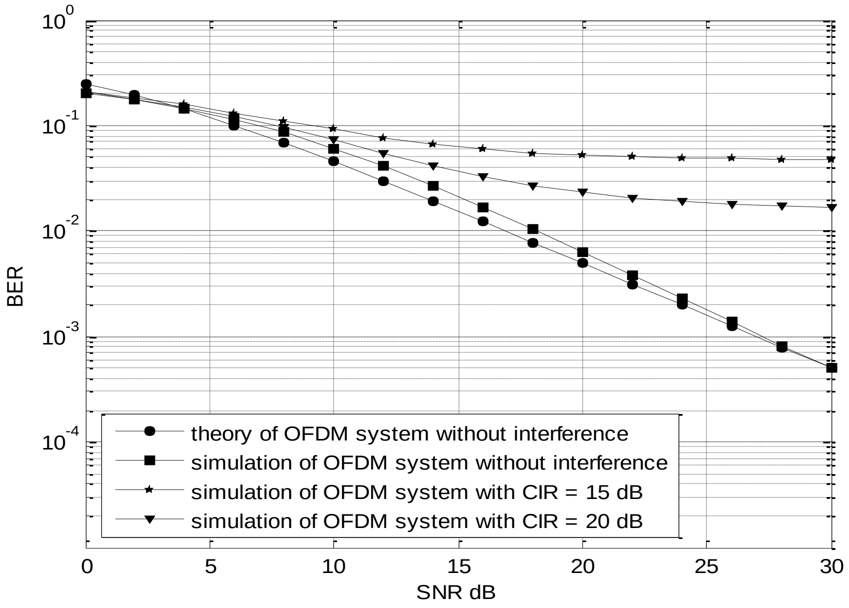

Figure (15) Performance of 8DPSK modulation in OFDM system under a Rayleigh fading channel has a Doppler freq = 150 Hz with and without carrier interference

6-3 Performance of Forward Error Correcting Techniques in OFDM System under a Rayleigh Fading Channel without Carrier Interference

Figure (16) show the BER performance of 8DPSK in OFDM system in a Rayleigh fading channel which has a Doppler shift of 150 Hz with three different techniques of FEC code are used (Reed Solomon (7, 5) code with a single error correcting capability t = 1, two dimensional concatenated code where both the inner and outer is a Reed Solomon (7, 5) code and proposed three dimensional concatenated code where each code is a Reed Solomon (7, 5). From the simulation result, the proposed three dimensional concatenated code has been the best performance. i.e. lower BER for all values of SNRdB achieved in this technique compared with the other two techniques. While the two dimensional concatenated code has a lower performance and finally a Reed Solomon code is clearly the worst. The error rate improvement achieved through the use of coding is often called the coding gain. The coding gain in dB is the reduction of the SNR needed to achieve the same detected/decoded error rate as the uncoded raw error rate.

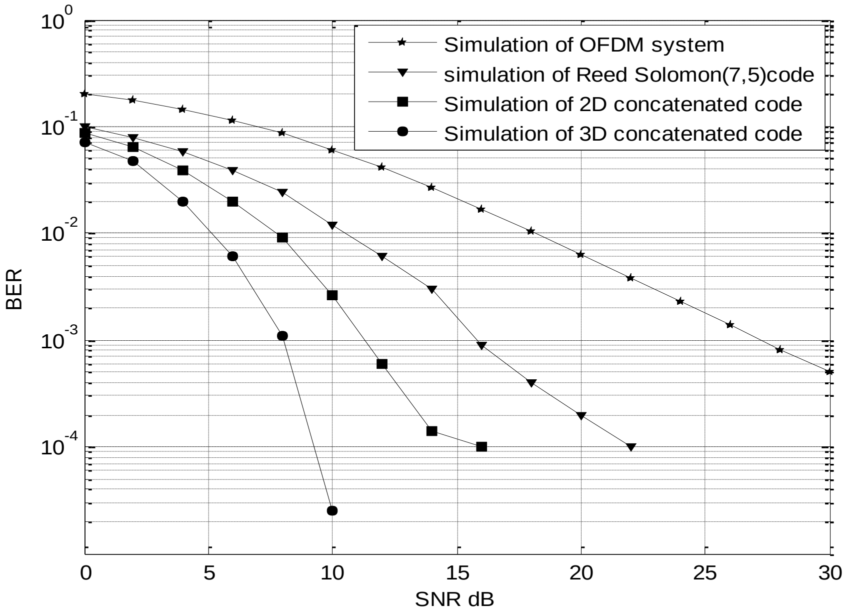

Figure (16) Performance of FEC techniques in OFDM system under a Rayleigh fading channel with Doppler freq = 150Hz

The performance gains due to three previous FEC techniques are very impressive. **Table (1)** gives a coding gain for (Reed Solomon code, two dimensional concatenated code and proposed three dimensional concatenated code). The increase in coding gain may be attributed to the increase in the minimum hamming distance and hence increase the error correcting capability.

Table (1) Coding gain in dB

BER	RS(7,5)	2D concatenated code	3D concatenated code
10^{-2}	7	10	13
10^{-3}	11.5	16	19.5
$5*10^{-4}$	12.5	17.5	21.5

6-4 Performance of Forward Error Correcting Techniques in OFDM System under a Rayleigh Fading Channel with Carrier Interference

In order to reduce the effect of greater distortion of symbols of high carrier to interference ratio we apply forward error correcting (FEC) coding across several OFDM symbols to reduce the probability of error. Here the errors caused by symbols of high carrier to interference ratio value are corrected by the surrounding symbols.

Figures (17) and **(18)** show the BER performance of 8DPSK modulation in OFDM system with two values of carrier to interference ratio (CIR=15dB and CIR=20dB) respectively under a Rayleigh fading channel which has a Doppler shift of 150 Hz.

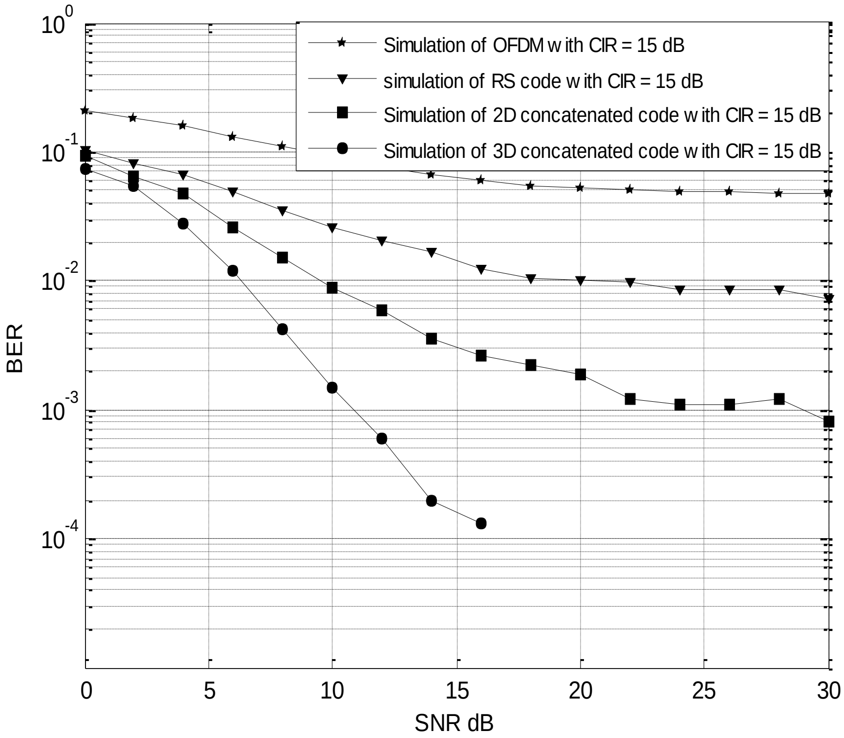

Figure (17) Performance of FEC techniques in OFDM system under a Rayleigh fading channel with carrier to interference = 15 dB

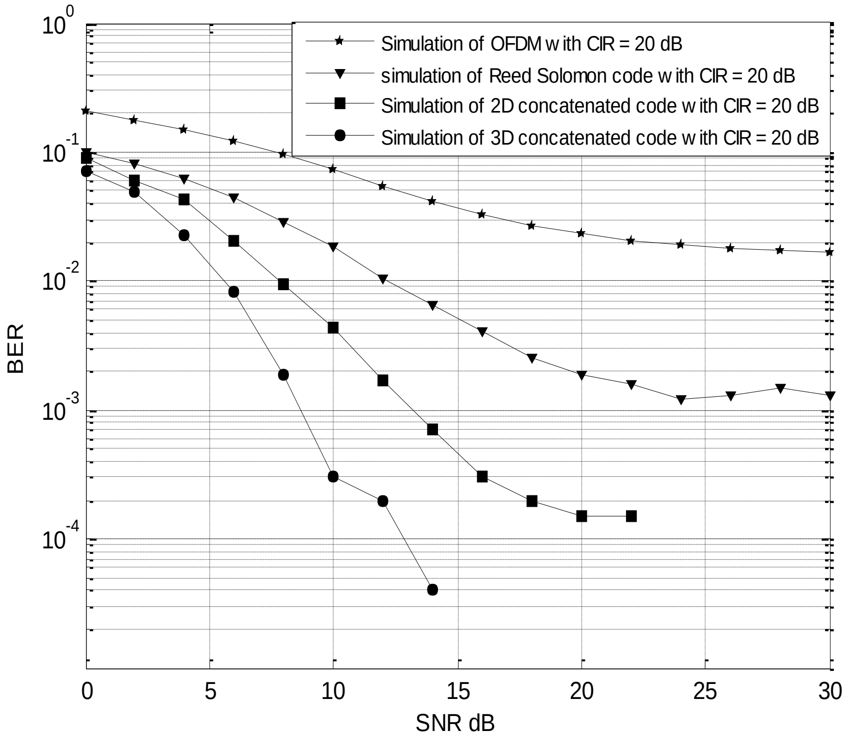

Figure (18) Performance of FEC techniques in OFDM system under a Rayleigh fading channel with carrier to interference = 20 dB

Three techniques of FEC code are used (Reed Solomon (7, 5) code with single error correcting capability t = 1, two dimensional concatenated code where both the inner and outer is a Reed Solomon (7,5) code and a proposed three dimensional concatenated code where each code is a Reed Solomon (7,5) code). The advantages of three dimensional concatenation code begin to be seen with carrier to interference, the degradation is minimal compared to the OFDM system with carrier to interference because the corrected of the effected carriers of the OFDM system can correctly recover the original data. Hence, the three dimensional concatenation code produces a stronger code and results in better BER performance. It is seen that a vast improvement in performance is achieved with three dimensional concatenation code. i.e. the proposed technique has the best performance; while two dimensional concatenated code has lower performance and a Reed Solomon code is clearly the worst. We notice that the BER decreases when we increase the SNRdB in a three dimensional concatenation code, which is normal because the three dimensional concatenation code becomes stronger (more resistance) for the noise, multipath fading and carrier interference. While, Reed Solomon code and two dimensional concatenated code does not improved the BER after SNR = 22 dB even that SNR is increased.

To compare between three techniques and for a digital communication OFDM system which is designed to operate at a SNR =14 dB effected by CIR = 15 dB. The Reed Solomon (7,5) code we has a BER = $166*10^{-4}$ .i.e. no more than 166 in 10000 bits is received in error. While a two dimensional concatenated code has a BER = $36*10^{-4}$ .i.e. no more than 36 in

10000 bits is received in error and the proposed three dimensional concatenated code has a BER = $2*10^{-4}$ .i.e. no more than 2 in 10000 bits received in error as shown in **Fig.(17)**.

While, to compare between three techniques and for a digital communication OFDM system which is designed to operate at a SNR =14 dB effected by CIR = 20 dB. The Reed Solomon (7,5) code has a BER = $660*10^{-5}$ .i.e. no more than 660 in 100000 bits is received in error. While a two dimensional concatenated code has a BER = $70*10^{-5}$ .i.e. no more than 70 in 100000 bits is received in error and the proposed three dimensional concatenated code has a BER = $4*10^{-5}$. i.e. no more than 4 in 100000 bits is received in error as shown in **Fig.(18)**.

7. Conclusions

This paper describes the concept behind of parallel data transmission and the configuration of an OFDM transmitter and receiver. We explained how we configured the OFDM transmitter and receiver by using computer simulation. OFDM system uses orthogonal subcarrier. It achieves high spectral efficiency, saving in bandwidth, and allows separating the subcarrier without causing any interference with each other. Fast Fourier Transform (FTT) is used to modulate and demodulate OFDM system to establish the orthogonality in subcarrier and reduces the complexity needed by the conventional multicarrier modulation system. Guard time with cyclic extension is inserted for each OFDM symbol to eliminate ISI completely and reduces ICI. In OFDM simulation, for AWGN channel and Rayleigh fading channel, the insertion of guard time of 25% of symbol period caused 0.9691 dB shift from theoretical value. Three techniques of FEC code are used (Reed Solomon code, two dimensional concatenated code and proposed three dimensional concatenated code) to improve the BER of the OFDM system with carrier interference. The proposed three dimensional concatenated code is inherently more resistance to carrier interference under multipath fading in OFDM system than Reed Solomon code and two dimensional concatenated code for all values of SNRdB.

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