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Performance and Comparative Analysis of OFDM, OFDM–CDMA & OFDM–IDMA Systems

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***Abstract* – OFDM-IDMA technology forms the basic platform for the fourth generation mobile communication i.e. 4G when performed perfectly. In this paper we present the simulated results of OFDM system in presence of fading effect and observed the limitation & drawbacks of using it. Then we present OFDM – IDMA system which yields much better results than the previous one. Hence based on the simulated results the paper discusses OFDM – IDMA system advantages along with its usage in complex electromagnetic environment. This system allows very high data rates and also gives proper performance in multi – user environment. Paper concludes by discussing the advantages OFDM-IDMA system in comparison to OFDM-CDMA.**

Keywords – Orthogonal Frequency Division Multiplexing (OFDM); Interleave Division Multiplexing Access (IDMA); Code Division Multiplexing Access (CDMA); multi – user detection.

1. INTRODUCTION

Today as the need for advancement & demand has increased the wireless communication system so as to get high speed, high reliability & high data rate. Therefore, there was a need to go beyond OFDM-CDMA (3G) technology. This was done by integrating the concept of IDMA instead of CDMA in OFDM-CDMA so as to achieve OFDM-IDMA. This idea of a OFDM – IDMA which is a hybrid communications scheme combining OFDM and IDMA has been proposed and studied.

One of the problem is of the orthogonality of the symbols may get destroyed & can cause serious MAI (Multi Address Interference) during differentiating the multiple users. To overcome MAI, MUD (Multi-User Detection) has been used, but it makes the system complex, due to which it becomes very difficult to maintain the orthogonality among the symbols & there is probability that fading will take place [1]. In OFDM – CDMA technology we use the concept of spreading, to spread the codes on the entire bandwidth and also to differentiate among the users. But according to Coding theory it is not a reliable means of spreading the codes, since due to this the system can't get coding gain and the band also increases, this is also an issue related to the OFDM – CDMA system [1]. By using OFDM – IDMA, the users can be differentiated using interleavers, due to which the system will yield better BER performance, good spectrum usability & low complexity at the receiver [1]. The OFDM-IDMA scheme, that employs IDMA instead of CDMA in OFDM-CDMA, inherits many attractive features of OFDM-CDMA, it has a simple treatment to inter-symbol interference (ISI) and effective mitigation of cross-cell interference (CCI) [1].Further, IDMA allows a simple and effective turbo-type iterative multiuser detection (MUD) algorithm applicable to system with having large number of users, which is crucial for system to achieve high throughput.

In OFDM – IDMA system, it is not required to spreading the codes, since the codes are differentiated using interleavers & due to this the whole band spreading of the system can be used for FEC to get higher gain. Simultaneously it also overcomes the difficulties in the earlier OFDM – CDMA system [1].

In both the systems BER is the major performance parameter which lets us know regarding the error in the received signal. It is observed that BER is poor in OFDM – CDMA in comparison to OFDM – IDMA , the poor BER may lead to the symbol fading in the OFMD –CDMA system, and as BER performance is found out to be excellent in OFDM – IDMA and due to the use of Interleavers we get better performance in this system.

Here we also compare the performance of both the systems based on the performance parameters.

2. OFDM SYSTEM

Basic idea of OFDM is that it uses a large number of parallel narrow-band sub-carriers instead of a single wide-band carrier to transport information. The principle of orthogonality must be satisfied among the users so as to keep the system efficient.

Thus OFDM is a digital modulation technique used to split wideband signal to a narrowband signal.

As of now Orthogonal Frequency Division Multiplexing (OFDM) has become the most popular tool & method for digital communication over a wideband bandwidth. Owing to this OFDM is used in all the applications which require high bandwidth like Television system, audio & video broadcasting, higher generations of mobile communications i.e. 3G & 4G. OFDM uses multiple carrier frequencies on which it encodes the digital data for transmission, & since digital data is been used it

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gives higher speed excellent security to the data been processed [6].

The primary advantage of OFDM over single-carrier schemes is its ability to cope with several channel conditions without having complex equalization filters.

For orthogonality it is required that the sub-carrier should have spacing of $\Delta f = \frac{k}{T_U}$ Hertz, where T_U seconds is the useful symbol duration and k is a positive integer, where this value is typically equal to 1. Therefore, if we have N sub-carriers, the total pass band bandwidth will be [1] $B \approx N \cdot \Delta f(Hz)$. (1)

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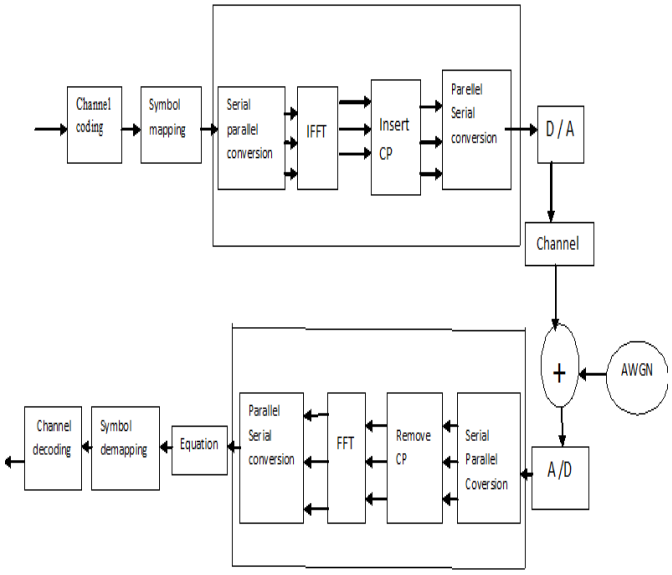

Fig.1: OFDM System [1]

In OFDM, for demodulation of subcarriers we use the concept of guard band. Also, the use of orthogonal subcarriers would allow the subcarriers' to overlap the spectrum, thus increasing the spectral efficiency. As long as orthogonality is maintained, the individual subcarriers' signals can be recovered despite their overlapping spectrums [1].In the above block diagram [1]. Cyclic Prefix (CP) is used so as to avoid the ISI (Inter Symbol Interference). This is done by inserting the CP before the starting of each symbol during transmission. On receiving the symbol at the receiver side this CP is removed & the code is obtained due to this the problem of ISI is avoided. This concept of CP is used exclusively in OFDM technology and it is not used in FDM or any other method. Due to this OFDM is preferred over FDM & method for data transmission with high speed & high data rate.

3. IDMA SYSTEM

The basic concept of IDMA is that it uses the interleaver for different users for the separation of codes. This minimizes the problems of fading and information loss. So IDMA is special form of CDMA in which different interleavers are used for separation. The main advantage of using IDMA is that it protects the signal from fading, which is quite difficult in CDMA system.

Therefore, as IDMA uses interleavers, we get good BER results, also the usability of spectrum is good & the complexity of receiver is less, since no orthogonality is required. So the main function of interleaver is to just separate out the different users in one single channel [1].

The performance of code-division multiple-access (CDMA) systems is mainly limited by multiple access interference (MAI) and Inter Symbol Interference (ISI). Encouraged by the success of turbo codes in additive white Gaussian noise (AWGN) channels. This led to the need for going further to IDMA technology so as to overcome it.

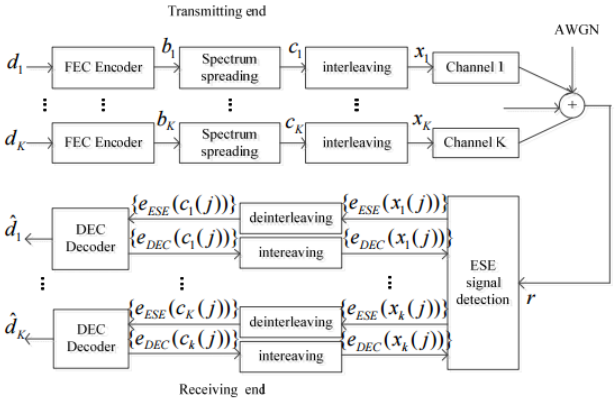

Fig.2: IDMA System [1].

The maximum coding gain can be obtained by combining the coding with the spreading operations with the use of low-rate codes. It is found out that conventional random waveform CDMA (RW-CDMA) system (such as IS-95) is having separate coding & separate operations. On analyzing theoretically when the entire bandwidth expansion is devoted to coding it is possible to achieve the optimum Multiple Access Channel (MAC) [3].

4. OFDM – CDMA SYSTEM

The basic idea of OFDM – CDMA technology is that code is assign to each user & multiple users use the same channel frequency at the same, the codes are differentiated so as to maintain the orthogonality. In most third generation mobile phone systems it is been proposed to use Code Division Multiple Access (CDMA) as their modulation technique [2]. It is a type of spread spectrum technique used for outdoor environment communication that uses neither frequency channels nor time slots. In CDMA, the narrow band signal is getting multiplied by a large bandwidth signal which is a pseudo random noise code.

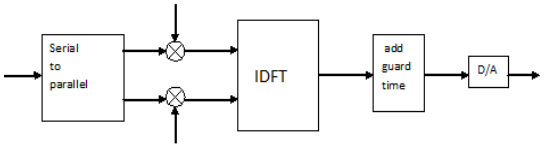

Fig.3: Block Diagram of OFDM – CDMA system transmitter [5]

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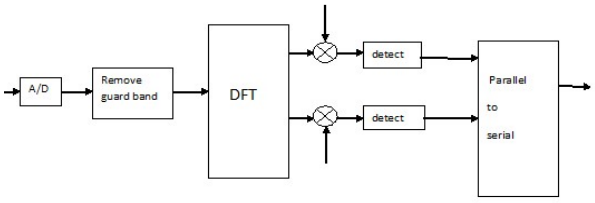

Fig.4: Block Diagram of OFDM – CDMA system receiver [5]

The key point in this concept is that, code is assign to each users multiple users use the same channel frequency at the same time, so there is a need to differentiate those codes; for which it is required to have the codes to be orthogonal, but they were having following two problem associated with it viz. MAI (Multi-User Detection) & on observing the use of only OFDM system for wireless communication, there are some drawbacks found out which limits the use of OFDM. So to overcome it many proposals were proposed which said that OFDM should be combined with CDMA so as to obtained better results for wireless communication with satisfying all the properties & by taking the care that there should not be any disadvantage should be encountered. With OFDM – CDMA many modulated subcarriers are used over which multiple data symbols are transmitted. OFDM – CDMA gives good spectral properties, where OFDM technique resolve the frequency selectivity in multipath fading channels [5].

In this system we use Walsh Hadamard code for orthogonal spreading of codes [5].

5. OFDM – IDMA SYSTEM

OFDM-IDMA combines most of the advantage of both OFDM and IDMA, The key advantage of OFDM-IDMA is that MUD can be realized efficiently with complexity is significantly lower than that of other alternatives.

In wireless communication the major sources of impairments were observed to as Multiple-access interference (MAI) and inter-symbol interference (ISI). The solution to this was Multi-User Detection (MUD) & also time-domain equalization were found out very costly. So there was a need to overcome all this drawbacks & to develop a optimum solution for wireless communication, & it was found out that by using the combination of OFDM & IDMA these two interferences can be overcome & the fading problem can be resolved. Due to this Orthogonal Frequency-Division Multiplexing Interleave-Division Multiple-Access (OFDM-IDMA) Scheme was introduced [4].

The structure of the OFDM-IDMA system is as shown above, it is supposed that dk is the output of the k^{th} user, dk is sent to the FEC and RA encoders and output the (ICCSEE 2013). sequence k c, k c is interleaved by interleaver and mapped to the sequence [1].

In case of OFDM – IDMA we can use any of the FEC encoding method, preferably low rate coding technique must be used, since it gives robust in frequency domain [4] as it is required here.

In the receiving end, OFDM signal is demodulated before iterative multi-users detection, we assume that the max delay of multi-path channels is smaller than cyclic prefix (CP), if CP and OFDM demodulation are removed, the received signal is [1] :

$$r(j) = \sum Hk(j)xk(j) + Z(j) \quad (2)$$

kZ(j) is the transformation of complex Gauss white noise, i.e. Z (j) = FFT((z) j) ; {Hk(j)}is the fading coefficient of j^{th} carrier. For the OFDM-IDMA system, the fading factor {Hk(j)} of OFDM sub-carrier is the same for the different j [1].

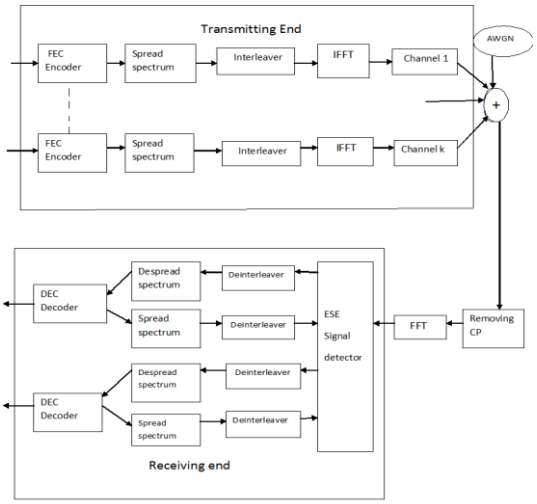

Fig.5: Block Diagram of OFDM – IDMA system [1].

The above mentioned OFDM – IDMA System can be implemented mathematically by using following steps:

Let dk be the data stream of user-k, which is given as [1]:

$$d_k = [d_k(1), \ldots, d_k(i), \ldots d_k(I)] \quad (3)$$

Where, I is the length of information code.

This data stream is encoded by a forward error correction (FEC) code which gives output [1]:

$$b_k = [b_k(1), \ldots, b_k(l), \ldots, b_k(L)] \quad (4)$$

generating a chip sequence ck

$$c_k = [c_k(1), \ldots, c_k(j), \ldots c_k(J)] \quad (5)$$

Then ck is permutated by a user-specific inter-leaver-k. After symbol mapping, the symbol sequence

$$xk = [xk(1), \ldots, xk(j), \ldots, xk(j)]^T \quad (6)$$

is produced, where J is the frame length [11].

Then these symbols are modulated onto different subcarriers by IFFT. [11].

If we consider the QPSK signalling method, then x_k is given as

$$xk(j) = x_k^{\mathrm{Re}}(j) + ix_k^{\mathrm{Im}}(j) \quad (7)$$

The iterative detection process for OFDM-IDMA is carried out as follows:

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(i) Initialization: Set

$$E(xk(j)) = 0, Cov(xk(j)) = jI, \forall k, j \quad (8)$$

where I is a 2 × 2 identity matrix.

(ii) Main operations: The iterative process indulges two processes viz .step 1: ESE part & step 2: DEC part [11].

In the receiving end, OFDM signal is demodulated before iterative multi-users detection. The problems of multiple access and encoding limits can be figured out by ESE and DECs, the output of ESE and DECs is LLRs about{ $x_k(j)$ },that is we usually called extra information [1]:

$$e(x_k(j)) \equiv \log\left(\frac{(P_r x_k(j) = +1)}{(P_r x_k(j) = -1)}\right) \quad (9)$$

The extra information totally does one Turbo iterative receiving process from chip to chip, and after M time's iteration, DECs of K users will respectively output k relevant code sequence *k* [1]

We suppose that cyclic prefix (CP) is larger than the max delay of multi-path channels, if CP and OFDM demodulation are removed, the received signal is :

$$r(j) = \sum Hk(j)xk(j) + Z(j) \quad (10)$$

Z(j) is the transformation of complex Gauss white noise, i.e; $Z(j) = FFT(z(j))$ {Hk(j)}is the fading coefficient of j^{th} carrier. For the OFDM-IDMA system, the fading factor {Hk(j)} of OFDM sub-carrier is the same for the different j [1].

Step 1: ESE Part **:**We concentrate on detection of xk(j) with user k and rewrite above equation as [11]

$$rr(jj) = Hkk(jj)xxkk(jj) + \zeta kk(jj) \quad (11)$$

Where $\zeta kk(jj) = \Sigma Hmm(j)xm(j) + z(j)mm \neq kk$ (12)

In order to detect xk(j), we generate [11]

Where $\zeta\zeta kk\sim(jj) = Hk_*(j)\zeta kk(j)$ (13)

By the central limit theorem, $\zeta\zeta kk\sim(jj)$ can be approximated as a Gaussian variable. This approximation is used by ESE to generate LLR for xk (j) [11]. We have

$$e_{(ESE)}(x_k{}^{Re}(j)) = \frac{(2\,|H_k(j)\,|^2\,(r_k{}^{Re}(j)) - E(\zeta_k{}^{(\sim Re)}(j)))}{(Var(\zeta_k{}^{(\sim Re)}(j)))} \quad (14)$$

Mean and Variance of the received signal can be estimated as follows [11]

$$E(\zeta_k(j)) = E[r(j)] - H_k(j)E[x_k(j)] \quad (15)$$

$$Cov(\zeta_k(j)) = Cov(r(j)) - R_k(j)Cov(x_k(j)R_k{}^T(j)) \quad (16)$$

Step 2: DEC Part: The DECs carry out APP decoding using the output of the ESE as the input. Outputs of the DEC-k are the extrinsic LLRs for {xkRe(j)} and {xkIm(j)}. We use the extrinsic information to update the mean and variance of each chip [11].

$$E(x_k(j)) = \tanh\left(e_{(DEC)}(x_k{}^{Re}(j)/2)\right) + i\tanh\left(e_{(DEC)}(x_k{}^{Im}(j)/2)\right) \quad (17)$$

$$Cov(x_k(j)) \begin{cases} = 1 - (E(x_k{}^{Re}(j)))^2 & 0 \\ = 0 & 1 - (E(x_k{}^{Im}(j)))^2 \end{cases} \quad (18)$$

6. PERFORMANCE PARAMETER 'BER' (BIT ERROR RATE)

In digital transmission system, the BER is the percentage of bits that have errors relative to total numbers of bits received in transmission, usually expressed as ten to the negative power

BER is an indication of how often a data unit has to be retransmitted due to error. BER is measured by BERT (Bit Error Rate Testers).

Mathematically BER is represented as :

BER = No. of Error / Total No. of Bits

BER occurs due to noise & change in propagation pattern.

It uses the concept of Cyclic Prefix (CP) in order to extend the length of symbol waveform by adding a guard period to start of each symbol which reduces ISI & ICI.

Following are the factors affecting BER:

- Interference
- High Transmission Power
- Low Bandwidth.

Here, we have considered the parameter BER so as to analyze all the above mentioned system & to find out that which of the amongst gives the optimum results.

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7. COMPARISON OF OFDM – IDMA & OFDM – CDMA

TABLE I: Comparison of OFDM – CDMA & OFDM – IDMA Systems.

Sr. No.	Parameters	OFDM–DMA	OFDM– DMA
1	BER	Substantially higher than OFDM – CDMA.[7]	Lower than OFDM – IDMA.
2	MUD problems[1]	Can be overcome without any system complexity.	Can be avoided but makes the system complex, and system become unreliable.
3	ISI & ICI[1] problems	They are avoided by the use of Interleaver.	They can occur in the system, causing fading & information loss.
4	Quality of Service[2]	Much higher than OFDM – CDMA	Lower than OFDM – IDMA.
5	Throughput	Better in this system(By using Superposition coding technique[4])	Low compared to OFDM - IDMA

8. RESULT, ANALYSIS AND DISCUSSION

We have implemented the Transmitter & Receiver block diagram of OFDM system, & for this we have taken a bit length of 8 bits to give as an input to the transmitter of the OFDM system & we successfully received the same transmitted signals at the receiver end as shown below.

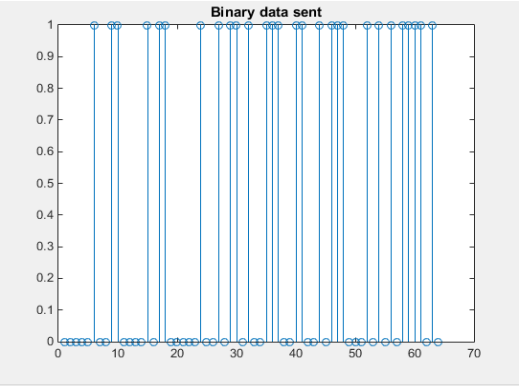

Fig.6: Input to the Transmitter of OFDM System

Here we can clearly make out that both the figures are identical, which indicates that the input given to the system is properly received at the receiving end without any ISI, ICI, or fading or information loss, the obtained results are in absence of fading.

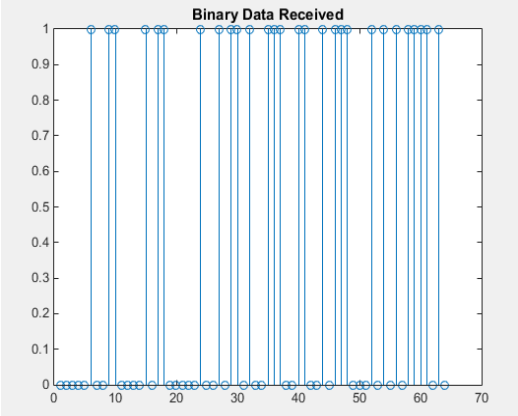

Fig.7: Output to the Receiver of OFDM System

Now when we introduce noise in the above system, it is observed that the accuracy of system is been reduced, which we can make out from the BER curve of OFDM, as shown below.

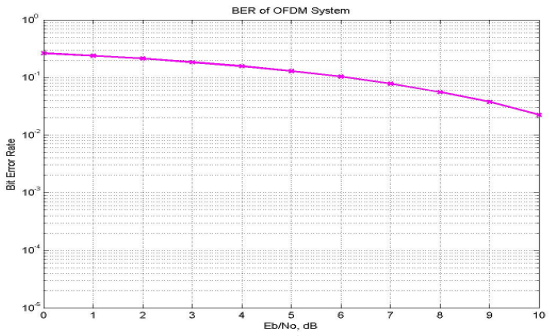

Fig.8: BER Response for OFDM System

This satisfies the above discussed theory regarding the use of OFDM alone for the wireless communication process.

Therefore, when the combination of OFDM – CDMA is implemented even in presence of noise the fading effect should be reduced as compared to the OFDM system, the curve is as shown.

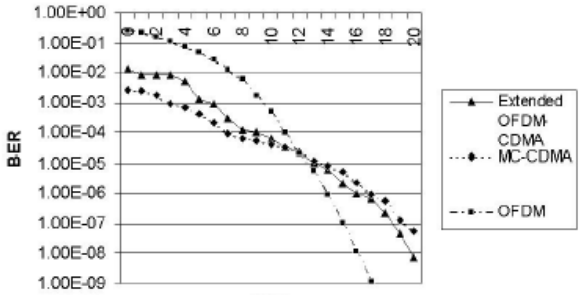

Fig.9: BER Response for OFDM – CDMA System [5]

Lastly, we have implemented the combination of OFDM – IDMA which gives the much better result than the above two techniques with higher accuracy, this can be analyzed from the following BER curve.

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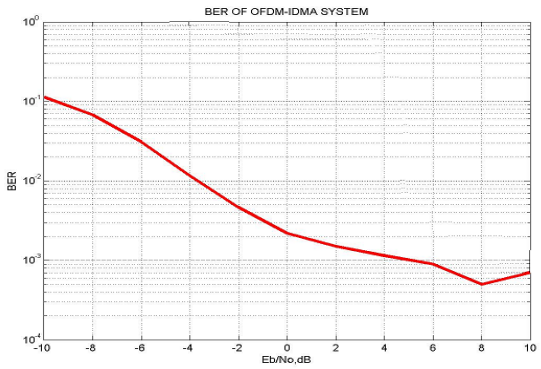

Fig.10: BER Response for OFDM – IDMA System

The following table gives the different BER values of all the three systems, at different SNR intervals in dB. Using the below table we can finally compare the BER values of all the above three mentioned systems, so as to know that which performs the best amongst the all. As the SNR increases, the BER should go on decreasing, which is observed in all the cases, but in case of OFDM – IDMA it is the least, this indicates that, it is the optimum technique as compare to others to give best BER ratio, & also the most suitable for future wireless communication technology.

TABLE II: Comparative Analysis of OFDM, OFDM—CDMA & OFDM – IDMA Systems

BER / SNR (in dB)	OFDM SYSTEM	OFDM – CDMA SYSTEM	OFDM – IDMA SYSTEM
0	0.2645	0.08	**0.0022**
2	0.2132	0.019	**0.0015**
4	0.1575	0.018	**0.00115**
6	0.1035	0.0012	**0.0009**
8	0.05573	0.0091	**0.0005**
10	0.02252	0.00083	**0.0007**

9. ADVANTAGES

- Effectively deals with ISI quasi Static Rayleigh.
- Decreases ISI & ICI to a major extent.
- The output obtained is very high (By using turbo MUD algorithm).
- Since, Interleaver is used; there is no need of spectrum spreading.
- Effective migration of cross cell-Interference.

10. CONCLUSION

On the basis of above analysis we can reach to a conclusion that, in future wireless technologies OFDM-IDMA will play a vital role in enhancing the performance to a larger extent so as to provide access to more number of users simultaneously with lower complexity.

Also from the analysis of table II, it is clear that BER (Bit Error Rate) is found to be substantially more in OFDM – IDMA system than any other discussed. So to Improve BER we switch to OFDM-IDMA from OFDM – CDMA System.

Along with this, OFDM – IDMA will enhance the usage & application range to a greater extent & owing to this, OFDM – IDMA forms the basic platform for 4G technology which is much better than OFDM – CDMA which forms the basic foundation of 3G technology, also as far as data rate & speed is concern, OFDM – IDMA is found out to be the best.

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