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A NOVEL MULTIUSER INTERFERENCE CANCELLATION METHOD FOR MULTICARRIER DIRECT SEQUENCE CDMA SYSTEM USING MAXIMUM LIKELIHOOD SEQUENTIAL DECODING

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ABSTRACT

It is well known that sequential decoding techniques such as Enhanced Maximum Likelihood sequential decoding (EMLSD) technique can obtain significant performance improvement over conventional decoding techniques in multicarrier direct sequence Code Division Multiple Access (MC-DS-CDMA) systems. Due to its simplicity and usefulness the EMLSD has received significant attention for several years. In this proposed work, three contributions are done for evaluation of the performance of the Multicarrier CDMA receiver. An expression is derived for Bit Error Rate (BER) with arbitrary spreading gain and Signal to Noise Ratio (SNR) requirements. The performance of maximum likelihood decoder under various ordering criteria is then examined based on spreading, path loss and SNR/BER requirement. A set of frequencies is then obtained using a multiuser interference cancellation algorithm. These subcarrier frequencies are very near the optimum in terms of minimizing error rate, thereby increasing the number of users.

Keywords: *EMLSD (Enhanced Maximum Likelihood Sequential Decoding), MUSIC (Multiple Successive Interference Cancellation)*

1 INTRODUCTION

Multicarrier CDMA systems have received considerable attention in recent years due to their bandwidth efficiency, frequency diversity, parallel processing and interference rejection capability in high data rate transmission system. The frequency diversity may be obtained by using an adaptive code as an error correction code across subcarriers [1]. However, when error correction codes are used, the transmitted data must be redundant, resulting in reduction of bandwidth efficiency [1]. The conventional Multicarrier Direct Sequence CDMA system is affected by Inter Symbol Interference (ISI), Multi-path Interference, Multiple Access Interference (MAI) and when the number of users increases the system performance degrades as there is increased complexity in the receiver circuit. The proposed Transceiver with fixed set of transmitting and receiving filters, maximize Signal to Interference Ratio (SIR) to the desired level and the algorithms proposed evaluate the performance of the receiver. Algorithms are developed such that the signals are preserved from Multipath fading, ISI and other interferences that arise due to channel noise [2]. For Multipath fading channels, the transceiver performs very well and at the same time the system complexity reduces as compared to conventional CDMA systems. Multi-Carrier CDMA is a combination of two techniques. First, an OFDM system is used to provide a number of orthogonal carriers, free from ISI. Second, an individual code chip, to provide a spread spectrum system, which modulates each carrier [3]. The main advantage of this method is that when the multiple-access interference becomes a problem, the resulting linear detectors are much simpler to implement, as only a single tap equalizer is required

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for each channel. Rake reception can also be employed to exploit the channel diversity by channel matching in the frequency domain .The data rate of wireless communication systems are limited by time varying characteristics of dispersive fading channel. [4]. To improve the performance with no frequency or time redundancy and to compensate for BER, it is shown that MC-DS-CDMA system with multiuser interference cancellation provides better performance than an MC-DS-CDMA without multiuser interference cancellation in terms of its computational complexity of BER.

Spread spectrum techniques were originally proposed to allow secure communication by spreading the signal over a wide bandwidth, allowing the signal power spectral density to be reduced. This is achieved by transmitting a higher frequency pseudo-noise sequence in place of a single modulated symbol. This signal looks almost like noise and because wideband interference has little effect compared to narrowband interference. The signal can be detected by correlating with the pseudo-noise sequence. In multi-path channels, the multi-path diversity can be exploited by using a channel matched (rake) receiver, giving the optimal performance (for a single user)[5].

By using a number of different pseudo-noise sequences, multiple users can transmit simultaneously using the same bandwidth. In all practical cases, at the receiver, all the user's pseudo-noise sequence will not be orthogonal and therefore the capacity of the system will be limited by this multiple access interference.

A suitable structure of transmit and receive pre-processing matrices ensure that all equivalent sub channels share a common average signal to interference ratio which is further maximized based on channel statistics[6]. For complete suppression of multiple access interference, exponential orthogonal codes or selecting a particular subset of Walsh Hadamard code proves to be the best solution [7].

Multiuser detection for CDMA systems usually relies on some a priori channel estimates, which are obtained either blindly or by using training sequences and the covariance matrix of the received signal that are usually replaced by the sample covariance matrix. Multiuser detection can be obtained by optimizing the worst case performance over two bounded uncertainty sets pertaining to the types of estimation errors [8].

Multicarrier CDMA is a promising protocol in a 2 path frequency selective slow Rayleigh fading channel [9].

The multiple access capability of the system is achieved by means of DS/SS which helps to combat the presence of several paths. DS/SS is also attractive to decrease the multiple access interference [10]. Multicarrier signaling technique has a desirable property of exhibiting a narrow band interference suppression effect, along with robustness to fading by the use of band limited spreading waveforms to prevent self- interference over a frequency selective fading channel[11]

The transmission bandwidth of the system is more efficiently used, the effect of frequency selective multipath interference can be mitigated and frequency/ time diversity is achieved. The multicarrier system is able to outperform the RAKE receiver when the system parameters are selected properly [12]. The Multicarrier system is capable of supporting ubiquitous communications over diverse communication environment without BER performance degradation [13].The survey on the conventional techniques results in achieving desired error free transmission by compromising Bandwidth, number of users and Average Throughput.

2 SYSTEM MODEL

Consider Orthogonal Frequency Division Multiplexing of 'M' signals given by,

$$Y(t) = \sum_{i=1}^{M} a_i(t)\cos[2\pi f_i t + \phi_i(t)] \quad (1)$$

Where $a_i(t)$ and $\phi_i(t)$ represent amplitude and phase modulation of i^{th} carrier signal respectively f_i is the i^{th} carrier frequency.

The received signal is of the form

$$y(t) = \mathrm{Re}\left\{\sum_{i=1}^{M} s_i(t)\exp[j2\pi f_i t]\right\} \quad (2)$$

$s_i(t)$ represents symbol vector of the received signal

On definition, the complex envelope of $Y(t)$ is

$$y(t) = \sum_{i=1}^{M} \tilde{y}(t)\exp(2\pi f_0 t) \quad (3)$$

f_0 is the desired carrier frequency

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Where, for the moment f_0 remains arbitrary

The complex envelope of is $\tilde{y}(t)$ is expressed as

$$\tilde{y}(t) = \sum_{i=1}^{M} a_i(t)\exp[j\phi_i(t)]\exp[j2\pi(f_i - f_0)t] \quad (4)$$

The direct and quadrature components of FDM signals are given by

$$y_d(t) = \sum_{i=1}^{M} a_i(t)\cos[2\pi(f_i - f_0)t + \phi_i(t)] \quad (5)$$

and

$$y_q(t) = \sum_{i=1}^{M} a_i(t)\sin[2\pi(f_i - f_0)t + \phi_i(t)] \quad (6)$$

Assume FDM signal with four carriers, suppose that the signal of interest is $x_2(t)$ and that the simulation is being performed in order to examine multiuser interference and intermodulation distortion, since signal of interest is $x_2(t)$,let $f_0 = f_2$ so that $x_2(t)$ is translated to f=0 when the complex envelope of the composite signal $y(t)$ is formed. With $f_0 = f_2$, the complex envelope of $y(t)$ is

$$\tilde{y}(t) = \sum_{i=1}^{4} x_i(t)\exp[j2\pi(f_i - f_2)t] \quad (7)$$

3 RECEIVER MODEL

Let y_m be the allocation (frequency allocation) to be determined for a total of 'm' symbols out of 'M'signals, and n_{ij} be the number of codes of active carrier 'j' of signal 'i'.Then the optimal allocation of Bandwidth for the allocation function R_i for all 'm' symbols over all active carrier 'j' can be obtained as

$$\text{Maximize} \sum_{i=1}^{m} R_i(T_j) \quad (8)$$

T_j is the allocated bandwidth for 'm' symbols and 'j' active carriers over 'M'signals in the range $0 \le t \le T_b$, where T_b is the bit interval

Subjected to

$$\sum_{i=1}^{M} n_{ij} R_i \le T_j max \quad (9)$$

$$0 \le R_i \le T_j max$$

where $T_j max$ is the maximum bandwidth available.

3.1 Multiuser Interference Cancellation Algorithm:

The decoding procedure involves

(a). Make equation (8) solvable in polynomial time.

(b). Approximate original allocation function R_i.

(c). Completely linearize the objective function and split the flow in parallel sub flows, each corresponding to a linear segment of allocation function.

(d). For a subcarrier k of total carriers i ,the allocation is constrained through the allocation function levels T_j^k as

$$t_j^k \le T_j^k - T_j^{k-1} \quad (10)$$

where t_j^k is utilization efficiency of sub carrier

(e). Subflow allocation variables are determined based on estimation.

(f). Estimation of received signal is expressed as

$$\sum_{i=1}^{p} A_i e^{j\omega n_i} + W(n) \quad (11)$$

K-active users for a particular time period;

i- being active carrier for 'M' signals;

$W(n)$-additive noise

It is assumed that amplitude A_i is complex

$$A_i = |A_i| e^{j\phi_i} Ai \quad (12)$$

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With ϕ_i being uncorrelated random variable that are uniformly distributed over the interval

[-π,π].

(g). Calculating the power spectrum of $y(t)$, a set of 'p' impulses of area $2\pi|A_i|$ at frequency ω_i for i=1,2,..........K in addition with power spectrum of additive noise $w(n)$.

3.2 Analytical determination of BER:

With the selection of suitable carrier, considering a symbol s_l is transmitted, an error is made if

$$pr\{error/s_l\} = \iint 1/2\pi\sigma^2 . \exp\left(-\left\{(n_x - s_x)^2/2\sigma_n^2 - (n_y - s_y)^2/2\sigma_n^2\right\}\right) d_{nx} d_{ny} \quad (13)$$

$$(\tilde{s}_x + n_x, \tilde{s}_y + n_y) \in d_l$$

Inference from decision region implies that the following condition

$$pr\{error/s_l\} \langle \int_{-\infty}^{0} f_{nx}(n_x \div \tilde{s}_x, \sigma_n) dx . \int_{-\infty}^{\infty} f_{ny}(n_y \div \tilde{s}_y, \sigma_n) dy \quad (14)$$

is a metric that decides probability of Error with the respect to Optimal Allocation function (Ri)

$$pr\{error/s_l\} \langle \int_{-\infty}^{0} f_{nx}(n_x \div \tilde{s}_x, \sigma_n) dnx . \int_{-\infty}^{\infty} f_{ny}(n_y \div \tilde{s}_y, \sigma_n) dny \quad (15)$$

Conditional probability bound is given by

$$pr\{error/s_l\} \langle Q(\mathrm{Re}(\tilde{s}_l) \div \sigma_n) + Q(\mathrm{Im}(s_l) \div \sigma_n) \quad (16)$$

$$p_s = 1/N \sum_{k=1}^{N} pr\{error/s_k, s_{k-1}, s_{k-2}\} \quad (17)$$

The approach implies that the recovery of a selected symbol impose the conditional Probability of the received symbol given the transmitted symbol thereby the decision region free from interference can be identified. The probability of weight of the symbol is analysed in both transmission and reception determine the Bit Error Probability for different set of subcarriers with a desired level of SNR. The decision boundary plays a vital role in identifying the effectiveness of decoding procedure in the Multiuser Interference Cancellation receiver. By fixing appropriate set of symbol vectors and subcarriers, percentage of optimal allocation can be determined using computer simulation for different set of sub allocation variables, each variable represents the function with respect to frequency. This approach clearly depicts the fact that the increase in capacity of the system enhances the net desired signal strength which differentiates the proposed system from the conventional system. The numerical results derived for demonstrating the operation of Interference cancellation decoder increase the percentage of allocation for different sub allocation variables ranging from 1 to 24. Each iteration of the receiver derives the optimal schedule to achieve a target BER using a minimum number of decoders for successive interference SNR requirements added up and also the nature of the channel determines how well the transmitted signal can be received with optimum signal strength. The target of achieving higher signal strength and greater synchronization with minimum bit error rate is clearly depicted in the results. By proper frequency selection, BER is optimized to retain original signal strength at the receiver which is considered to be best signal at receiver. The proposed system offers high level of immunity for interference and noise to provide best services for future wireless communications.

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4 SIMULATION RESULTS

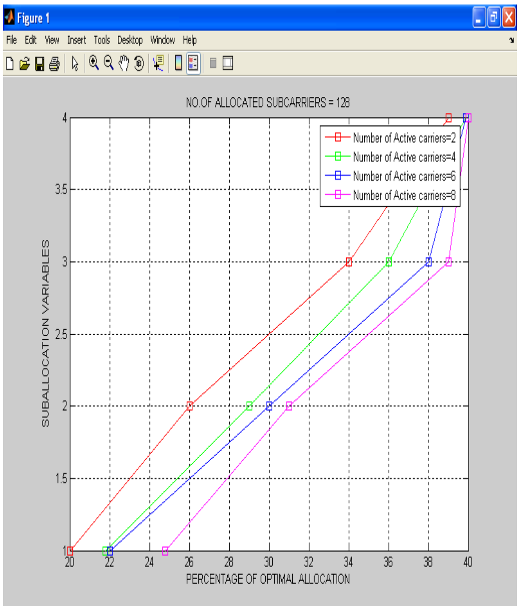

Fig. 1. Percentage Of Optimal Allocation Vs Sub Allocation Variables Using A Target BER Of 10^{-7} And SNR Of 40db With Allocated Subcarriers Of 128

From Fig.1 it is observed that the Multiuser Interference Cancellation algorithm achieves better performance in terms of bandwidth allocation for active carrier 'j' which increases the overall efficiency of the system thereby mitigating the probability of interference getting added up with the desired carrier for the optimal allocation R_i which varies as a function of sub allocation variables [1, 2, 3, 4] for k^{th} subcarrier out of available subcarriers i =128.The results depict that the increase in sub allocation variables from 1 to 4 preserves 60 percent of the available bandwidth which in turn reflects the accurate decoding of the desired carrier based on target BER and available SNR.

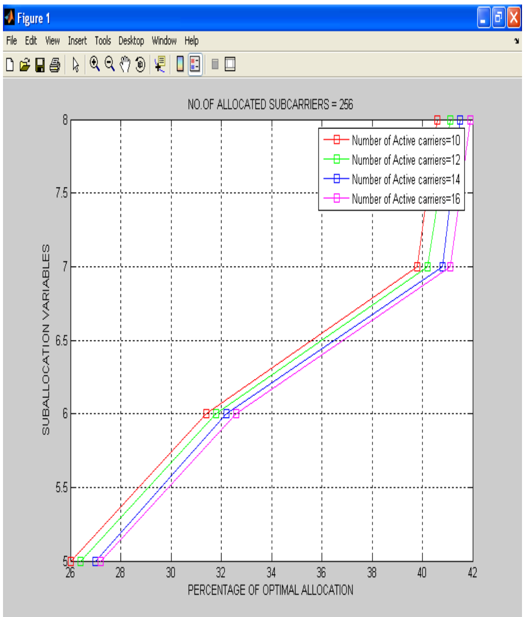

Fig. 2. Percentage Of Optimal Allocation Vs Sub Allocation Variables Using A Target BER Of 10^{-7} And SNR Of 40db With Allocated Subcarriers Of 256

From Fig.2 it is observed that the Multiuser Interference Cancellation algorithm achieves better performance in terms of bandwidth allocation for active carrier 'j' which increases the overall efficiency of the system thereby mitigating the probability of interference getting added up with the desired carrier for the optimal allocation R_i which varies as a function of sub allocation variables [5, 6, 7, 8] for k^{th} subcarrier out of available subcarriers i =256.The results depict that the increase in sub allocation variables from 5 to 8 preserves 58 percent of the available bandwidth which in turn reflects the accurate decoding of the desired carrier based on target BER and available SNR.

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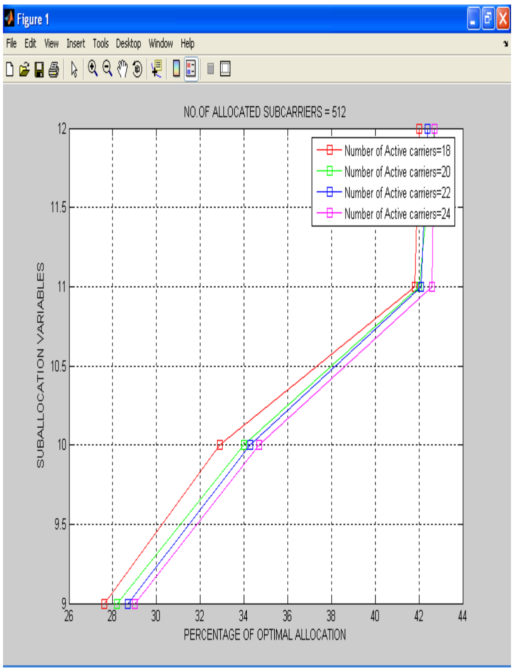

Fig. 3 Percentage Of Optimal Allocation Vs Sub Allocation Variables Using A Target BER Of 10^{-7} And SNR Of 40db With Allocated Subcarriers Of 512

From Fig.3 it is observed that the Multiuser Interference Cancellation algorithm achieves better performance in terms of bandwidth allocation for active carrier 'j' which increases the overall efficiency of the system thereby mitigating the probability of interference getting added up with the desired carrier for the optimal allocation R_i which varies as a function of sub allocation variables [9, 10, 11, 12] for k^{th} subcarrier out of available subcarriers i =512.The results depict that the increase in suballocation variables from 9 to 12 preserves 56 percent of the available bandwidth which in turn reflects the accurate decoding of the desired carrier based on target BER and available SNR.

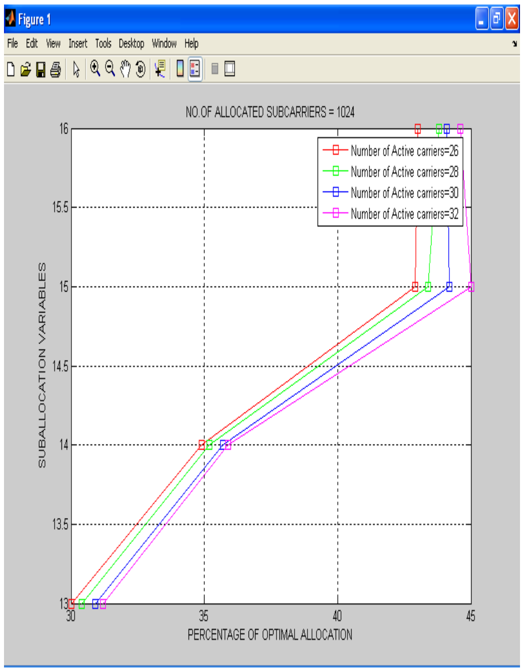

Fig. 4. Percentage Of Optimal Allocation Vs Sub Allocation Variables Using A Target BER Of 10^{-7} And SNR Of 40db With Allocated Subcarriers Of 1024

From Fig.4 it is observed that the Multiuser Interference Cancellation algorithm achieves better performance in terms of bandwidth allocation for active carrier 'j' which increases the overall efficiency of the system thereby mitigating the probability of interference getting added up with the desired carrier for the optimal allocation R_i which varies as a function of sub allocation variables [13, 14, 15, 16] for k^{th} subcarrier out of available subcarriers i =1024.The results depict that the increase in suballocation variables from 13 to 16 preserves 55 percent of the available bandwidth which in turn reflects the accurate decoding of the desired carrier based on target BER and available SNR.

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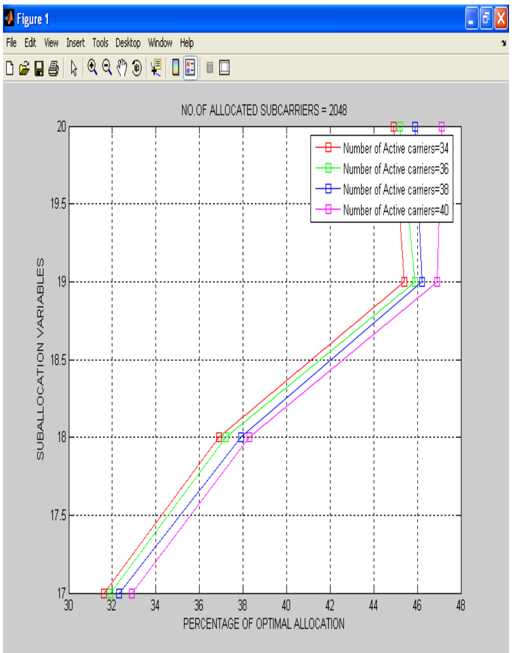

Fig. 5.Percentage Of Optimal Allocation Vs Sub Allocation Variables Using A Target BER Of 10^{-7} And SNR Of 40db With Allocated Subcarriers Of 2048

From Fig.5 it is observed that the Multiuser Interference Cancellation algorithm achieves better performance in terms of bandwidth allocation for active carrier 'j' which increases the overall efficiency of the system thereby mitigating the probability of interference getting added up with the desired carrier for the optimal allocation R_i which varies as a function of sub allocation variables [17, 18, 19, 20] for k^{th} subcarrier out of available subcarriers i =2048.The results depict that the increase in suballocation variables from 17 to 20 preserves 52 percent of the available bandwidth which in turn reflects the accurate decoding of the desired carrier based on target BER and available SNR.

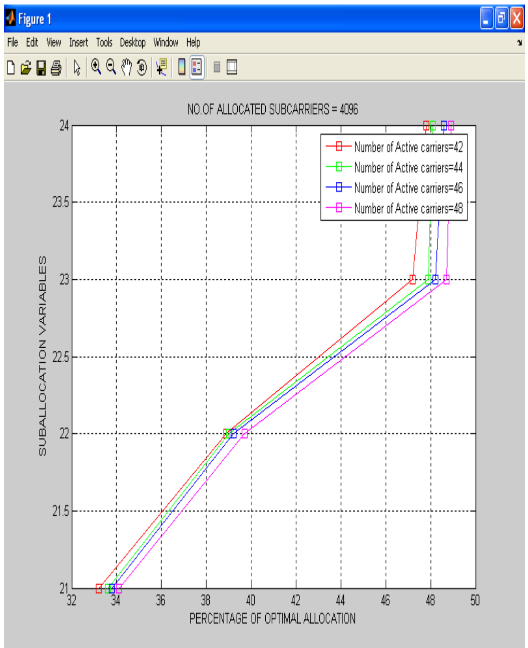

Fig. 6. Percentage Of Optimal Allocation Vs Sub Allocation Variables Using A Target BER Of 10^{-7} And SNR Of 40db With Allocated Subcarriers Of 4096

From Fig.6 it is observed that the Multiuser Interference Cancellation algorithm achieves better performance in terms of bandwidth allocation for active carrier 'j' which increases the overall efficiency of the system thereby mitigating the probability of interference getting added up with the desired carrier for the optimal allocation R_i which varies as a function of sub allocation variables [21, 22, 23, 24] for k^{th} subcarrier out of available subcarriers i =4096.The results depict that the increase in sub allocation variables from 21 to 24 preserves 50 percent of the available bandwidth which in turn reflects the accurate decoding of the desired carrier based on target BER and available SNR.

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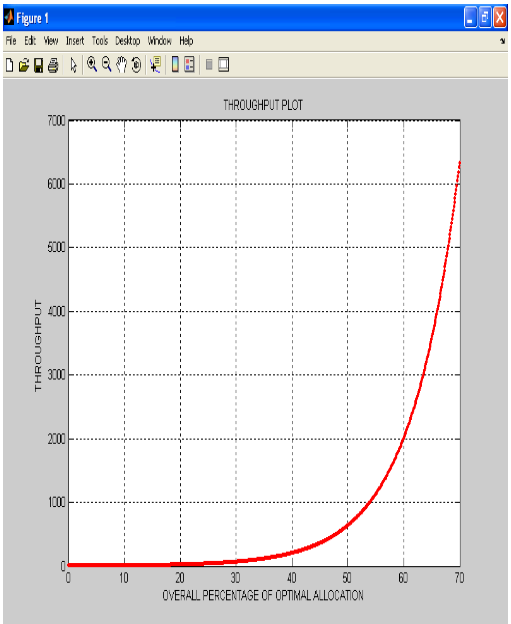

Fig. 7. Overall Percentage Of Optimal Allocation Vs Throughput Using A Target BER Of 10^{-7} And SNR Of 40db

From Fig.7 it is observed that the bandwidth allocated for each uninterrupted user is maintained constant for very low throughput values indicating the optimal level of interference cancellation for active carriers. When the throughput of the system is increased, signifying the increase in percentage of optimal allocation in a continuous manner .The result indicate that the system executes in a very efficient manner for high throughput values with which the level of SNR and BER are maintained to the required level even though the amount of interference getting added up with the system increases.

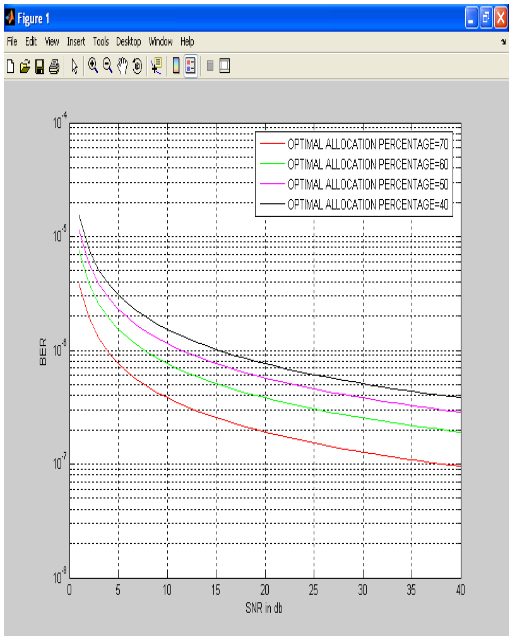

Fig . 8. BER Performance Of Multicarrier CDMA System With Percentage Of Allocation [70, 60, 50, 40] And Allocated Subcarriers [128, 256, 512, 1024, 2048, 4096] For MLSD Receiver.

From Fig.8. it is observed that the BER of the MC-DS-CDMA system is reduced to the desired level reaching up to 10^{-7} and enhancing the performance of the system thereby maintaining the level of SNR to 40 db with total number of subcarriers ranging from [256, 512 , 1024 , 2048 , 4096].It is evident that the system operated with high efficiency from the fact that increase in number of active carriers of the system reduces BER to 10^{-7} maintaining a constant SNR of 40 db throughout for different frequency ranges.

5 CONCLUSION

An MLSD receiver is optimized for interference cancellation through Multiuser Interference Cancellation algorithm. The results were used to derive SNR and BER which enabled analysis of the system in a high throughput system .We investigated the complexity of previous algorithms and the proposed method reduces the complexity up to the required level which satisfies the constraints of BER of a Multicarrier system. Furthermore, the proposed algorithm outperforms previous algorithms through reducing the variance of the per packet BER. Extensive computer simulation results demonstrate significant performance improvement of the developed approaches. By means of numerical simulations, we

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demonstrate that interference can be mitigated by using Multiuser Interference Cancellation algorithm and by assigning random spreading sequence over all subcarriers of a given user. The performance improvement was shown to depend on the number of subcarriers. An expression for approximate BER was obtained and was shown to match simulation results well in heavily loaded systems. These approaches can be directly used in future wireless communication systems. It will be interesting to evaluate and analyse the results for time varying conditions with unknown channel estimation parameters.

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