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Mitigation of co-channel interferences in cognitive multi-carrier code division multiple access system by singular value decomposition techniques

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Abstract Efficient spectrum usage is important criteria for next generation wireless systems. In this paper, to utilize the spectrum in useful manner, cognitive radio approaches are used along with multi-carrier code division multiple access schemes (MC-CDMA). But MC-CDMA systems are greatly affected by co-channel interference (CCI). To mitigate CCI interference, multi-user detection (MUD) technique is the design choice. When the user population increases complexity level of MUD algorithms are increases linearly. Also power consumption of mobile station also increases. Hence as a design alternate, in this paper we developed a singular value decomposition based pre-processing approaches to mitigate CCI interferences. The proposed technique is tested with real time channel models and the result shows that superior performance obtained with proposed techniques.

Keywords Cognitive radio · Co-channel interference · LTE · SUI · CDMA

1 Introduction

CDMA is capable of providing a maximum data rate of 384 kbps.The current requirement for data range for exponentially increased users is around 2–10 Mbps. A large data rate can be achieved through multi-carrier modulation (MCM) according to various literature surveys. OFDM is the basic example of the MCM technique. But OFDM is very sensitive to non-linear amplification, high peak to average power ratio (PAPR), frequency and phase offset problems in sub carriers. Since MCM is viewed as the only way to achieve this data rate, we consider integrating the OFDM technique with conventional single carrier CDMA system. In the MCM approach, each user data is converted into a number of parallel low rate sub-streams. Then each sub-stream is modulated with separate sub-carriers. Due to this operation, symbol rate on parallel sub-stream is less than the symbol rate on the conventional single carrier modulation approach. The delay spread of the multipath is reduced, and this results giving lower inter symbol interference (ISI) to the user. This is turn eliminates the equalizer at the receiver side and reduces the complexity of the receiver. Hence MCM, systems have high flexibility, improvement in narrow band noise reduction and greater spectral efficiency. Even when there is a huge hue and cry about spectrum allocation and optimizing spectrum usage, the report on management and utilization of the spectrum published by the Federal Communication Commission (FCC), has brought to fore gross underutilization of the allocated spectrum. This has paved way for the development of the cognitive radio (CR) technology. This technique mainly operates on altering the transmission and reception parameters to optimize the available channel capacity. Thus this paves way for spectrum sensing, spectrum management and spectrum sharing and spectrum mobility.

As per the FCC reports the spectrum range of TV Bands has the characteristics of low ionospheric reflections and industrial noises, better non-line-of-sight (NLOS) propagation characteristics. This is due to the fact that the signal can easily penetrate the walls. Hence this band can easily find its application in sparsely populated rural areas. The sharing of geographically unused spectrum, allocated on a non-interfering basis to the television broadcast service, is the objective of the MC-DS/CDMA system. This ultimately aims to provide broadband access to remote, sparsely populated environments, and hence this method has the potential

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for universal application. Another advantage of this system is that they operate on TV broadcast bands, ensuring no harmful interference to the existing operation (i.e digital and analog TV broadcasting) and low power licensed devices such as wireless microphones.

Alleviation of the interference effects mainly Co-Channel Interference (CCI) in the case of cognitive based MC-DS/CDMA systems is mainly aimed at in this system modeling. Multi-User Detection (MUD) techniques always come to our rescue due to its low power consumption and affordable battery size. But since the complexity is a nagging problem in the case of MUDs, Transmitter Pre-processing (TP) essentially aims to bring down the complexity of MUDs by simple signal processing techniques. This can be implemented at both the BSs and MSs.

After in depth analysis of the different MUD techniques Singular Value Decomposition (SVD) was found to be the most efficient one, and hence we aim at designing a cognitive based TP assisted MC- DS/CDMA system employing singular value decomposition method. We simulate the results and compare it with the previously considered system and find the BER performance of the improved system to be better.

The rest of the article is organized as follows: Sect. 2 describes the different methods to eliminate CCI interferences in MC-CDMA systems. System model of the CR-MS-CDS/CDMA is briefly outlined in Sect. 3 with necessary equations. Performance results of the proposed technique and comparison with existing MUD techniques are provided in Sect. 4. Finally, paper is concluded in Sect. 5.

2 Related works

Foschini and Gans of Lucent Technologies in a seminal information theory paper in [1] show that the capacity of MIMO systems can increase linearly with the number of transmit antennas. It also says that this deduction holds well only when the number of receive antennas is greater than to equal to the number of transmit antennas. Also they showed that in an idealized MIMO channel, the amount of available capacity increases linearly with transmitted power. However, this is valid only for one instance of the channel if the channel is time variant. Transmit Diversity and Spatial Multiplexing are the two main advantages offered by MIMO systems. In [2], the vertical Bell laboratories layered space time (VBLAST) architecture that offers spatial multiplexing is elucidated by showing its ability of simultaneous transmission of data streams over all antennas. Even though a high data rate can be provided by VBLAST-MIMO, without increasing bandwidth and at a affordable complexity, inter-channel interference (ICI) and inter-antenna interference (IAI) cause degradation of the system. In [3] the Alamouti code is described. This demonstrates the transmit diversity with two transmit antennas aided by space time block codes (STBC). The same performance can also be achieved for receiver diversity and this is also shown in this work. . The evaluation of the multi-user detection (MUD) techniques such as zero-forcing (ZF) and minimum mean-square error (MMSE), in MC-DS-CDMA systems has been addressed in [4].

Rao and Prabhu, in [5] elucidated the three steps involved in Successive Interference Cancellation (SIC), an iterative detection method. They are zeroing, quantization, and interference cancelation. This work also showed that iterative repetition of these steps must be done until all the transmitted symbols are detected. ZF or ZF-MMSE method is used to detect one symbol in every iteration and then it is quantized. Subtraction of the influence of this symbol is performed after quantization. Since error propagation (detection of one erroneous symbol causes all the other symbols to be detected erroneously), ordered SIC (OSIC) is used. This OSIC technique is demonstrated in [6], uses encoding of transmitted bits to ensure a very accurate decoding. The articles [7] and [8], concentrate on the channel spacing that must be maintained between the transmitter and receiver antennas in a MIMO system. To avoid channel correlation due to insufficient antenna spacing, the authors demonstrate that about tens of antenna spacing in the base station (BS) [8], and about half-wavelength antenna spacing at the MS for a uni-polarized antenna is needed to achieve the desired gain for MIMO systems. The spacing constraints can be improved by the employment of a dual polarized antenna in place of uni polarized antennas. Here a single dual-polarized antenna replaces the two spatially separated antennas. Thus by utilizing lesser number of physically reliable antenna elements, a higher spectral efficiency is obtained from this orthogonal structure. The fact that SNR penalties and multiplexing deficits are incurred by single-polarized antenna array configurations of MIMO systems when compared with dual-polarized cases, is demonstrated by Lempiainen and Laiho-Steffens in [9]. This work also evaluates the polarization diversity gain for both LOS and non-LOS (NLOS) environments and is compared with the space diversity, for different inclinations of the mobile antenna. The mobile antenna inclination angle is reported to not have an effect on the polarization diversity gain, regardless of the polarization diversity scheme applied. Apart from all these factors the main motive behind considering dual polarized antenna as an alternative for uni-polarized antennas in multiple antenna system configurations are reduction of the installation cost and antenna element spacing.

Polarization diversity is characterized by the cross polarization discrimination (XPD) and envelope correlation coefficient. The different power considerations between the co-polarized and cross polarized pairs with reference to the obstacles in the propagation environment that contributes to the depolarization effects are shown in the literatures [10, 11]. In [12], the presentation of dual-polarized MMO Interleave Division Multiple Access has been made. This has been considered by employing the iterative decoding algorithm which has been explained in [13]. These articles have thrown light on the fact that a higher performance can be obtained with a reduced size of the mobile unit using the considered DSTTD system. Shiro Kondo and his team in [14] have explained the performance of the Multi-Carrier (MC) DS-CDMA. Additionally they have elucidated the superior BER performance in interference limited wireless channels of such a system in this work. In [15], the superiority of a MC DS-CDMA system over a single carrier MIMO assisted CDMA system has been demonstrated by Mohammed S. Aljerjawi and Walaa Hamouda when communicating over Rayleigh Fading Channels. Li and Aaron Gulliver in [16] have validated the performance of successive interference cancellation technique for a DS- CDMA system. They have considered this system to have the quality of transmit diversity while performing this evaluation.

The fact that a better performance can be achieved by the usage of transmitter preprocessing technique of a relay aided, multi-user downlink DS-CDMA system explicated by Prabagarane Nagaradjane and his team in [17]. A better BER performance is observed inspite of higher complexity in the construction of a pre-processing matrix since it employs channel state information. Cooperative diversity can be employed to improve the performance of multi-user transmitter pre-processing (MUTP) assisted MC-CDMA system. This has been studied and shown in [18], wherein the system is considered for downlink communication and under the premise that the mobile station (MS) is situated far away from the base station (BS). In [19], Prasaanth M. et al. carried out a detailed investigation on the SVD aided multi-user transmitter preprocessing techniques (MUTP) in the context of single cell and multi-cell multi-user MIMO systems. It is shown by them that MUTP can result in signal detection with less detection complexity. Also, they have demonstrated that employment of MUTP can obviate the need for MUDs to achieve significant performance in terms of achievable bit error rate (BER) and symbol error rate (SER). In [20] Vojcic and Jang have addressed a transmitter preprocessing technique in the context of synchronous multi-user communications and transmitter pre-coding in downlink MC CDMA systems respectively. In [21], Liu and Krzumien invoked THP for multi-user MIMO downlink transmissions and provided its performance results.

To the best of our upstanding, no study in the literature uses SVD as a design choice for CR based MC-DS/CDMA systems. Hence Sect. 3 describes the system model of proposed CR-MC-DS/CDMA systems.

3 System model

Co-Channel Interference (CCI) occurs when two base stations uses the same frequency of operation. The main causes of CCI are poor frequency planning, poor frequency reuse and undesirable weather condition leads to troposphere ducting effect. CCI can severely affect the performance of mobile stations (MSs) when we use for voice applications. Figure 1 shows the effect of CCI in multi-cell multi-user downlink scenario in which H_{BS1-k} indicates the impulse response of the channel from base station 1 to k^{th}user. Similarly H_{BSL-k}denotes impulse response of the channel from base station L to k^{th}MS. Here we assume desired k^{th}user locating in the region BS-1. Hence signal from BS-2 to BS-L denotes the CCI interference to desiredk^{th}user. This CCI effect can be eliminated by multi-user detection (MUD) techniques at the k^{th}MS. Some of the popular MUD techniques used at MSs are linear MUDs such as ZF and MMSE approach or non linear MUD techniques such as Decision Feedback (DF) and Turbo MUDs. The complexity of these algorithms increases exponentially when the number of users population increases. Also at the MSs we need the accurate channel conditions and user information of all the MSs located in the cell.

Hence interference cancellation at MSs by MUDs technique is not a feasible solution. Since, once the user population increases complexity at MSs increases, it informs that large amount of power usage by MSs. If we employ high power battery at MS, increase the size of MSs unit. Therefore MUDs are not suitable for eliminating multi-user interference (MUI), multiple access interference (MAI) and CCI at MSs.

As a design choice, in this work we develop a transmitter pre-processing (TP) assisted interference cancellation method. The TP systems in which, Base station form the pre-processing matrix(P). It can be generated at BSs by Lloyd's algorithm, in which each MS's sends the quantized values of channel state information (CSI) to desired BS via low rate feedback channel. Based on the information received from MSs, BS develops a pre-processing matrix(P).

It is given by the following equation.

$$(P)=\left([A_{1s}|A_{2s}\cdots\cdots\cdots\cdots A_{ks}]^{H}\right)^{+} \tag{1}$$

where A_{ks}^{H} represents signal space of the decomposed channel matrix H_k of the k^{th} user.

Once pre-processing matrix developed, it is multiplied with user data d.

Let us assume a cell with K users; the signal transmitted from BS-1 to k^{th}user is given by,

$$x_{BS-1,k}=P_{BS-1,k}d_{BS-1,k} \qquad k=1,2,\ldots K \tag{2}$$

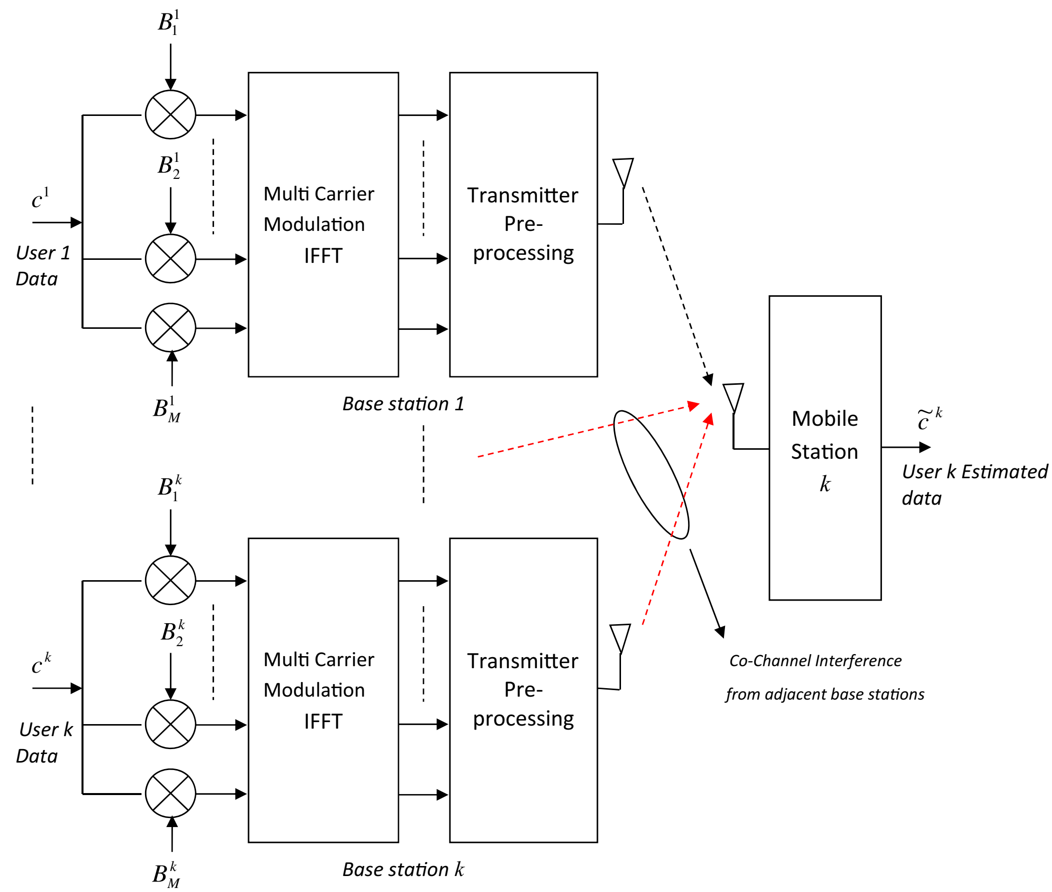

Fig. 1 Effect of CCI in multi-cell multi-user downlink scenario

Here $P_{BS-1,k} = \left[A_{ks}^{H}\right]^{+}$is preprocessing matrix of the k^{th}user form BS1 (6), $d_{BS1-k}$is data transmitted from the desired BS-1 to k^{th}MS.

In general case, let us assume system consists of Ldifferent BS's. Now overall data transmitted from the Lcells are given by,

$$X = \sum_{i=1}^{L} x_{BSi-k} = Pd$$

$$= \underbrace{x_{BS-1,k}}_{Desired\ user\ data} + \underbrace{\sum_{\substack{i \neq 1 \\ i = 2}}^{L} x_{BS-i,k}}_{CCI} \quad (3)$$

The first part of the above equation $x_{BS-1,k}$is the data transmitted from BS-1-to-*kth* user located in BS1 region. The second part is the signal from remaining BS to *kth* user. It causes CCI interference to desired user.

Now the received signal at the k^{th}MS is,

$$y_k = H_k X + N_k \quad (4)$$

$$= H_k P d + N_k$$

$$= H_{BS1-k} P_{BS1-k} d_{BS1-k} + \underbrace{\sum_{i=2}^{L} H_{BS_i-k} P_{BS_i-k} d_{BSi-k}}_{CCI} + N_k \quad k = 1, 2, \ldots K \quad (5)$$

Table 1 Simulation parameters

Parameters	Values
Carrier frequency	Unused spectrum in the frequency range 54–648 MHz
Bandwidth	6 MHz
Doppler shift	300 Hz
Number of channel realizations	25000
Modulation technique	BPSK
Channel models	SUI-1, SUI-3, SUI-5, LTE typical urban channel and LTE extended vehicular channel model specifications
Number of transmitter antenna	1
Number of receiver antenna	1

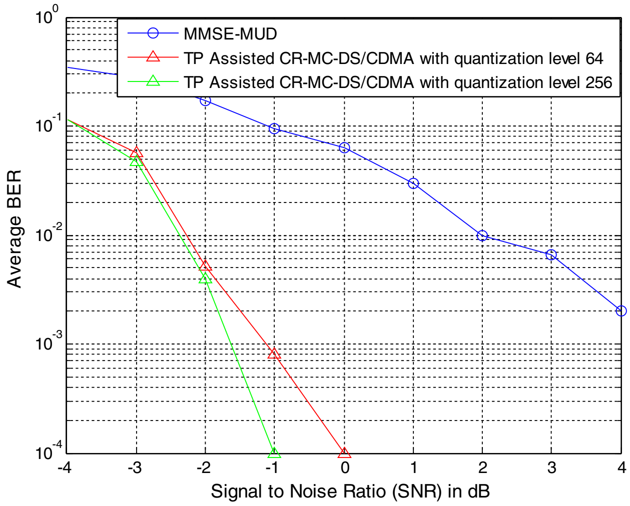

Fig. 2 BER Performance of CR TP MC-DS/CDMA system for SUI-1 channel model specifications

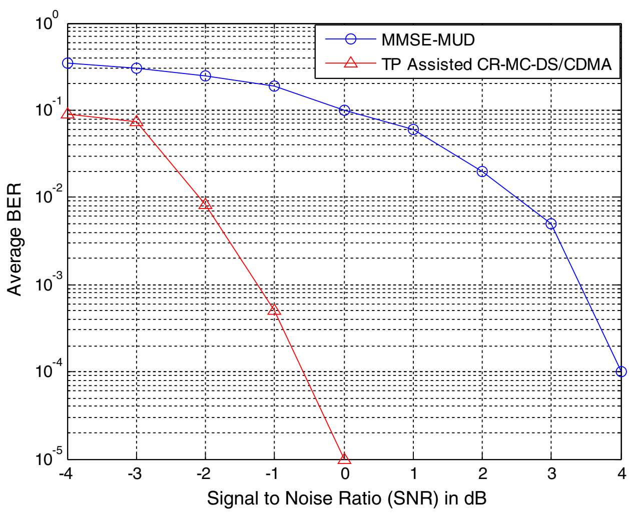

Fig. 3 BER Performance of CR TP MC-DS/CDMA system for SUI-3 channel model specifications

where P_{BS1-k} is the preprocessing matrix of the desired user from the serving BS1 and $N_k$is the zero mean Gaussian complex random variable.

Using SVD, $H_k$can be decomposed into following manner

$$H_k = \left[H_{BS1-k} \,|H_{BS2-k}| \cdots\cdots\cdots\cdots H_{BSL-k}\right] \tag{6}$$

H_{BS1-k}Represents channel matrix form first BS to k^{th} user.

H_{BSL-k}represents channel matrix from L^{th}BS to k^{th}user When we find SVD on H_k(13), we obtain

$$H_k = U_k \left[\wedge_k^{1/2}, 0\right] A_K^H \tag{7}$$

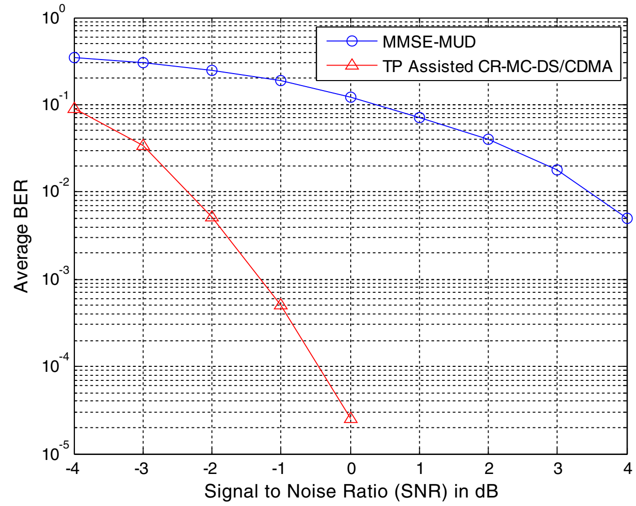

Fig. 4 BER Performance of CR TP MC-DS/CDMA system for SUI-5 channel model specifications

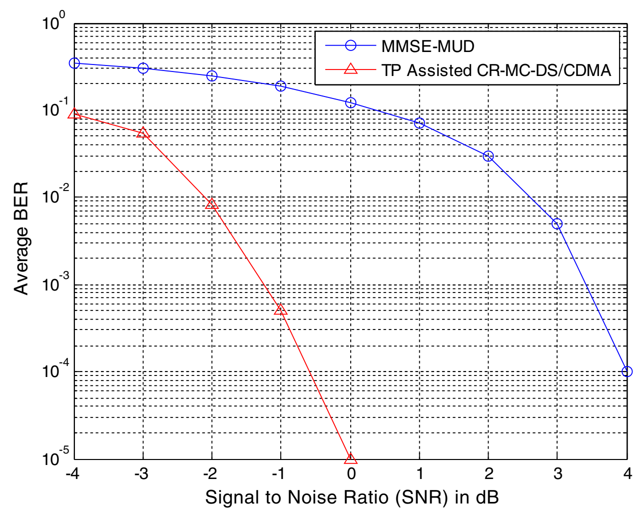

Fig. 5 BER Performance of CR TP MC-DS/CDMA system for LTE typical urban channel model specifications

$$= U_k \left[\wedge_k^{1/2}, 0\right] \begin{bmatrix} A_{ks}^H \\ A_{kn}^H \end{bmatrix}$$

$$= U_k \wedge_k^{1/2} A_{ks}^H \tag{8}$$

where U_k is the Unitary matrix, $\wedge_k^{1/2}$ is the eigen values matrix, A_{ks}^H is the signal component, A_{kn}^H is the noise component of the k^{th} user.

Substitute (8) in (4)

The received signal at *kth* MS can be expressed as,

$$y_k = U_k \wedge_k^{1/2} A_{ks}^H Pd + N_k$$

In the above equation, we know that pre-processing matrix of the k^{th}user is$[A_{ks}^H]^+$. Therefore, $P$and $[A_{ks}^H]^+$both are cancelled with each other.

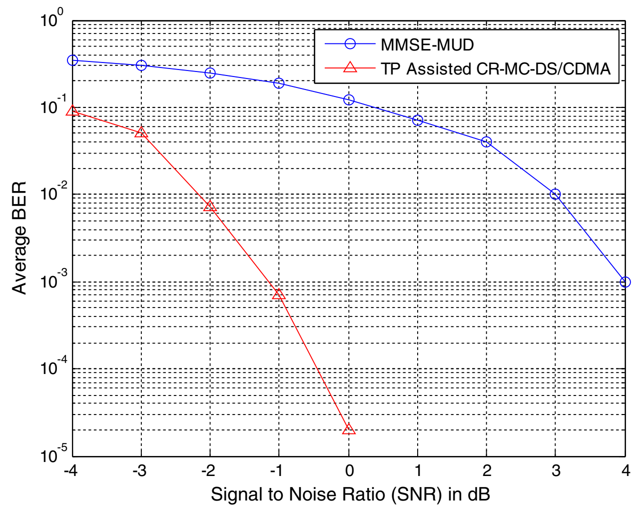

Fig. 6 BER Performance of CR TP MC-DS/CDMA system for LTE extended vehicular channel model specifications

Now pre-multiply the post-processing matrix G, the resultant received matrix is

$$y_k = GU_k \wedge_k^{1/2} d + GN_k \tag{9}$$

where $G = [U_k]^+$

This result informs the elimination of CCI by without any additional overhead at MS.

4 Simulation results

In this section the BER performance of the considered cognitive based MC- DS/CDMA is obtained. We compare this result with our previously considered MIMO system using MUD technique. The system is modeled for the SUI and LTE channel model specifications. The simulation parameters are enlisted in the Table 1.

In Fig. 2 the BER performance of Cognitive based TP assisted MC- DS/CDMA system is shown. The system is modeled for two quantization levels (k=64 and k=256) in this case. From the figure it is clearly seen that the CR MC-DS/CDMA system exhibits a better BER performance for both cases of quantization when compared with the MMSE-MUD detection technique employed in CDMA.

Figure 3, the simulation of the same system on SUI-3 channel model specifications is done. Here it is explicitly observed that a BER of 10^{-2} is obtained only at 2 dB in MMSE–MUD technique, while in this CR TP MC-DS/CDMA system, this BER is obtained at a SNR of -2dB itself. Thus this indicates a better performance characteristic of this system.

Similar results of better BER performance are observed in CR TP based MC- DS/CDMA system for SUI-5, LTE typical urban channel model and LTE vehicular channel model specifications that are shown in Figs. 4, 5, 6 respectively.

5 Conclusion

As seen from the system modeling and simulation results, we can conclude with conviction that this cognitive radio (CR) based transmitter pre-processing (TP) assisted multi-carrier (MC)—DS/CDMA system provides a better performance curve when considered in all the real time channel models. The SVD technique that is considered for transmitter preprocessing exploits the signal space of the system and this further contributes to the reduction in complexity of the receiver. Furthermore, this can be implemented both in the BS and MS. These advantages of the considered system make it an improved one when compared with the single carrier MIMO-CDMA system employing MMSE algorithm. Finally, since this system can employ the CR technique which facilitates channel allocation in geographically unused spectrum, this system can find its application universally.

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