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Coded Downlink Multi-user MC-CDMA System using Transmitter Pre-processing: Performance Results

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ABSTRACT In this treatise, we evaluate the error-rate (ER) performance of turbo-coded multi-carrier code division multiple access scheme (MC-CDMA) for downlink (DL) transmission. The transmitter pre-processing (TP) technique is a promising signal processing technique, which is carried out at the transmitter side to reduce the burden of each mobile station (MS) in the context of DL communication. We formulate minimum mean-square-error-aided TP matrix using noisy feedback of vector-quantized estimated channel information (CI) for frequency-division duplexing system. Clearly, we estimate the CI and perform vector quantization (VQ) at each MS and transmit the index of the quantized value through dedicated low rate noisy channel. Finally, we acquire CI of all active users using known estimation algorithm in order to build TP. We realize time-frequency domain signature sequence to support more user population. In particular, we analyze the ER performance of coded MC-CDMA system with TP for Stanford University Interim channel model. The ER curve shows that coded MC-CDMA system based on TP approach provides better performance with less signal-to-noise ratio while offering low complexity of MS. In addition, performance curve shows that there is an improvement in the ER performance when perfect CI is utilized to build TP matrix compared with noise-contaminated VQ-CI.

INDEX TERMS
Code division multiple access (CDMA), interleave division multiple access (IDMA), minimum mean-square-error (MMSE), transmitter pre-processing (TP), vector quantization(VQ), zero forcing (ZF).

I. INTRODUCTION

Next generation, wireless network needs huge content transfer with high quality for the transmission of voice, data and video, which is difficult to implement without calling for additional larger bandwidth. In order to achieve such demands, multiple-input multiple-output (MIMO) structure considering multi antennas at both transmitter and receiver can be exploited. But it is difficult to realize, multiple antennas at the mobile station (MS) as it increases it's size. Additionally, we require complex detection algorithm at MS to mitigate multiple access interference (MAI) problem, in order to achieve better quality of voice, picture and video transmissions. Verdu introduced the concept of multi-user detection (MUD) with high computational complexity to suppress the effect of MAI for code division multiple access (CDMA) system. Moreover, such high complexity algorithm is not tolerable to realize at MS with huge antennas and hence it is not realizable for downlink (DL) communication. Under such situations, transmitter pre-processing (TP) technique can be employed to mitigate the above mentioned problem, to enhance the error-rate (ER) results of a system. TP technique for multi-user communication requires the channel information (CI) of all active users in order to construct the TP matrix at base station (BS) and reduces the complexity of MS, because we need low complexity DL and MS with high power-efficiency. TP approach can be implemented for time-division duplexing system. The author Yang in [1] addressed the performance of zero forcing (ZF) based multi-user TP(MUTP) for different accessing schemes. Further, the author explicated the ER analysis for Direct Sequence (DS)-CDMA system considering random spreading sequence and gold sequence. The author has also constructed the pre-processing matrix using an orthogonal subspace without depending on eigen analysis and suggested that a better ER curve can be achieved with low complexity in MS. The authors in [2] have performed ER

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analysis of MUTP assisted SDMA system for Uplink (UL) reception and DL communication.

CDMA is a broadly recommended data communication scheme for 5G wireless networks. The authors in [1] and [3] have elucidated that, we can support more user population using CDMA by mitigating the effects of MAI through effective methods such as MUTP etc., The authors in [3] suggested that Multi-carrier (MC)-CDMA based on MUTP achieves diversity gain by mitigating the effects of MAI in Relay, MAI and Inter-Relay-Interference (IRI)in destination mobile unit for relay aided cooperative communication. In [4], the authors have investigated the ER analysis of co-operative communication and suggested that MC-CDMA with MUTP provides a better achievable ER by eliminating interference at each relay, MAI along with IRI at each MS. In [5], Singular value decomposition (SVD) based MUTP has been investigated for IDMA system, considering a realistic channel model based on Stanford University Interim (SUI) model and Long-term Evolution (LTE) channel model specifications in order to alleviate the interference effects such as MAI and co-channel interference (CCI). In [6], the result analysis of MC DS CDMA system has been carried-out and it has been demonstrated that it provides better ER in interference limited time-varying channel. The authors in [7] have elucidated MIMO-CDMA system performance for correlated Rayleigh Channels. In [8], the authors have elucidated error-rate analysis of ZF and Minimum Mean-Square-Error (MMSE) aided MC-CDMA system. In paper [9], the authors have illustrated the ER curve of coded MC-IDMA. In this paper [10], the authors have considered MIMO assisted DS-CDMA system and addressed that a better ER results can be obtained using Successive Interference Cancellation technique through transmit diversity. In [4], it has been elucidated the error-rate performance for MC-CDMA DL transmission, when MUTP is realized in the relay aided co-operative communication. In [11], the authors elucidated the ER study of co-operative communication using MUTP aided CDMA. The author Forney in [12] has proposed the structure of concatenated coding schemes and elucidated that better ER can be achieved with less SNR. The authors C. Berrou and his team in [13] have explicated the performance of the parallel concatenated turbo code. Further, the authors have demonstrated that we can obtain better information rate (IR) in the limited bandwidth wireless network through the fading and noisy channel environment. Several efficient turbo coded system have been proposed in the literature [14]–[16]. The author Benedetto *et al.* [17], has considered the Serially concatenated convolutional codes and illustrated that achievable ER performance can be obtained using iterative decoder. The authors in [18], have illustrated the performance of iterative decoding algorithm for triply-Polarized MIMO-CDMA system and suggested that better ER performance can be obtained for coded system.

In this contribution, we investigate the problems of mitigating the effects of MAI for frequency-division duplexing (FDD) based coded MC-CDMA using MMSE-MUTP technique. We consider the parallel concatenated convolutional encoder along with the information bit stream to suppress noise component with MAI thereby, we can enhance the ER performance. We estimate the CI at the MS and quantize it using vector quantization (VQ). We perform VQ using Lloyd's algorithm by which we can map large set of digital values to a smaller set. The vector quantized values have both magnitudes and phases. The BS receives index of VQ values as feedback through the dedicated low rate channel which is contaminated by noise and fading. At the BS, we recover noise infected VQ-CI to build TP matrix. We construct multi-user TP to suppress MAI for DL communication. Further, we consider standard channel model based on SUI with rich multi-path scattering environments to study the error-rate performance of our considered system.

The remaining content of the paper is framed as follows-Section-II gives a vivid description of System configuration. Section-III describes about Power Allocation Regime. Section-IV explains Vector Quantization. Section-V describes Iterative Decoder employed in our contribution. The Simulation results and its implications are outlined in Section-VI and followed by conclusion in Section-VII.

Notations: $[.]^T$ indicates transpose of the arguments, $(.)^{-1}$ denotes inverse of the argument, $(.)^H$ stands for Hermitian transpose, $\|.\|$ represents norm operation, $Ex\{.\}$ is the expectation of the argument, $(.)^{\dagger} = max(., 0)$ gives the maximum of the argument, $e_d(.)$ stands for Euclidean distance.

II. SYSTEM CONFIGURATION

We contemplate DL CDMA system which employ single antenna both at the BS and MS to accommodate $\boldsymbol{K}$ DL users. Fig. 1 shows the block diagram representation of our considered coded system. Let us define the input serial bit stream for k^{th} user be $\boldsymbol{d}_k$. Indicating total number of bits to be m, let $\boldsymbol{u}_k$ be the transmitted signal from the k^{th} user after channel encoding. Where

$$\boldsymbol{u}_k = [u_{k1}, u_{k2}, \ldots, u_{km}]^T, k = 1, 2, \ldots, K \tag{1}$$

In order to remove burst error, bit stream is interleaved by a random interleaver. Further, it is spread by time and frequency (TF) domain spreading sequence. Let N_p and N_t represents length of frequency (F)-domain and time (T)-domain spreading sequence respectively. The product N_pN_t is chosen such that $N_pN_t \geq K$.

Let $\boldsymbol{C}_f^k$ be the F-domain spreading sequence [3] for the k^{th} user. Where

$$\boldsymbol{c}_f^k = [c_{f1}, c_{f2}, \ldots, c_{fm}], k = 1, 2, \ldots, K \tag{2}$$

Then

$$\boldsymbol{C}_f^k = \frac{1}{N_p} \begin{bmatrix} c_{f1,1} & c_{f1,2} & \cdots & c_{fm,1} \\ c_{f2,1} & c_{f2,2} & \cdots & c_{fm,2} \\ . & . & \cdots & . \\ . & . & \cdots & . \\ . & . & \cdots & . \\ c_{f1,N_p} & c_{f2,N_p} & \cdots & c_{fm,N_p} \end{bmatrix} \tag{3}$$

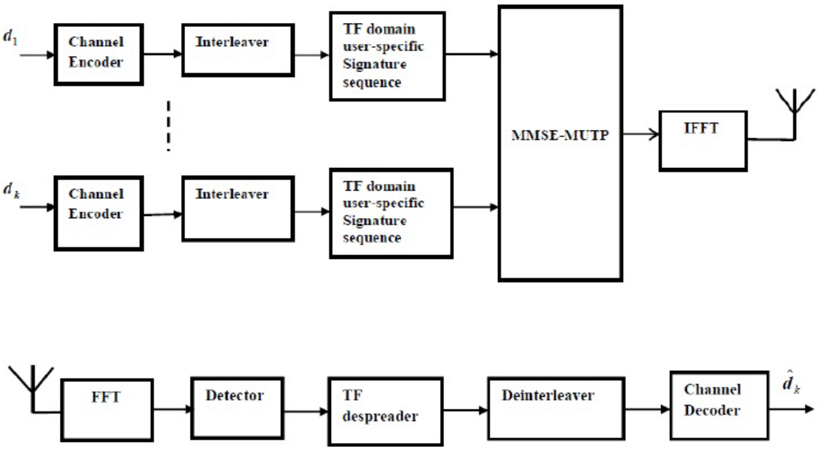

FIGURE 1. Transmitter and receiver structure of MMSE-MUTP assisted coded MC-CDMA system

Let $\boldsymbol{s}_f^k$ be the F-domain spread sequence having N_p length vector.

Where

$$\boldsymbol{s}_f^k = \boldsymbol{C}_f^k u_k, k = 1, 2, \ldots, K \tag{4}$$

Let $\boldsymbol{c}_k$ be T-domain spread sequence for the k^{th} user. Where

$$\boldsymbol{c}_k = \frac{1}{\sqrt{N_t}}[c_{k0}, c_{k1}, \ldots, c_{k(N_t-1)}]^T \tag{5}$$

$$\begin{aligned}\boldsymbol{s}_t^k &= (\boldsymbol{I}_{N_p} \otimes c_k)\boldsymbol{s}_f^k \\ &= (\boldsymbol{I}_{N_p} \otimes c_k)\boldsymbol{C}_f^k d_k, k = 1, 2, \ldots, K \end{aligned}\tag{6}$$

Now $\boldsymbol{s}_t^k$ is represented as

$$\boldsymbol{s}_t^k = \boldsymbol{C}^k u_k, k = 1, 2, \ldots, K \tag{7}$$

where

$$\boldsymbol{C}^k = (\boldsymbol{I}_{N_p} \otimes c_k)\boldsymbol{C}_f^k \tag{8}$$

$N_pN_t \times m$ component matrix. The interleaved spread sequences of the entire user's information are added. Hence the interleaved TF domain spread sum sequence is expressed as

$$\begin{aligned}\boldsymbol{s}_t &= \sum_{k=1}^{K} \boldsymbol{C}^k u_k \\ &= \boldsymbol{Cu}\end{aligned} \tag{9}$$

where

$$\boldsymbol{C} = [\boldsymbol{C}^1, \boldsymbol{C}^2, \ldots, \boldsymbol{C}^K] \tag{10}$$

$N_pN_t \times Km$ component matrix.

Let $\boldsymbol{P}$ be the overall pre-processing matrix that is formulated by invoking all the VQ estimated CI using MMSE algorithm [8] and is pre-multipled with $\boldsymbol{s}_t$. Let $\boldsymbol{x}$ be the transmitted sequence after pre-processing. where

$$\boldsymbol{x} = \boldsymbol{Ps}_t = \boldsymbol{PCu} \tag{11}$$

$\boldsymbol{P}$ is $(N_pN_t \times N_pN_t)$ component matrix.
$\boldsymbol{u}$ is $Km \times 1$ length vector.
$\boldsymbol{x}$ is $(N_pN_t \times 1)$ length vector. We can realize both TF domain spread matrix and pre-processing jointly [8]. Let $\bar{\boldsymbol{P}}$ be the joint realization of interleaved TF domain spread matrix and pre-processing with power normalization. Where

$$\bar{\boldsymbol{P}} = \boldsymbol{PC} \tag{12}$$

$(N_pN_t \times Km)$ component matrix.

$$\boldsymbol{x} = \bar{\boldsymbol{P}}u \tag{13}$$

$$\bar{\boldsymbol{P}} = [\bar{\boldsymbol{P}}_1, \bar{\boldsymbol{P}}_2, \ldots, \bar{\boldsymbol{P}}_K] \tag{14}$$

$\bar{\boldsymbol{P}}_k$ is the $(N_pN_t \times m)$ dimensional pre-processing matrix. $\bar{\boldsymbol{P}}_k$ is using noise contaminated VQ-CI of k^{th} user. Clearly, CI is estimated at the k^{th} user MS and quantized with the help of VQ technique. At BS, we retrieve the quantized value of CI embracing magnitudes and phases via devoted noisy channel from MS of k^{th} user. Henceforth, we calculate the TP matrix using the recovered noisy VQ-CI. Similarly, We calculate the pre-processing matrix for all remaining users.

In general, the TP matrix for ZF solution [8] is selected such that $\boldsymbol{C}_j^T \bar{\boldsymbol{H}}_k \bar{\boldsymbol{P}}_j = 0$ for $j \neq k$;$\boldsymbol{C}_j^T \bar{\boldsymbol{H}}_k \bar{\boldsymbol{P}}_j > 0$ for $j = k$. Therefore, $\boldsymbol{P}_k$ is calculated as follows: It is a subspace of $\boldsymbol{C}_k^T \bar{\boldsymbol{H}}_k$ and forms orthogonally to $(K-1)m$ rank subspace determined by $\boldsymbol{C}_j^T \bar{\boldsymbol{H}}_j, j = 1, 2, \ldots, K; j \neq k$. Clearly, for k^{th} user. TP is calculated using $(N_pN_t \times (K-1)m)$ component matrix accomplished with interfering users.

In our work, we have considered MMSE based TP technique and its expression is based on

$$\bar{\boldsymbol{P}}_k = (\bar{\boldsymbol{H}}_k^H \boldsymbol{C}_k \boldsymbol{C}_k^T \bar{\boldsymbol{H}}_k + \sigma^2 \boldsymbol{I}_{N_pN_t})^{-1} \bar{\boldsymbol{H}}_k^H \boldsymbol{C}_k \partial_k \tag{15}$$

where $\bar{\boldsymbol{H}}_k$ is the tainted noise VQ-CI for the k^{th} user and

$$\bar{\boldsymbol{H}}_k = \boldsymbol{diag}\{\boldsymbol{I}_{N_t} \times \bar{\boldsymbol{h}}_1^k, \boldsymbol{I}_{N_t} \times \bar{\boldsymbol{h}}_2^k, \ldots, \boldsymbol{I}_{N_t} \times \bar{\boldsymbol{h}}_{N_p}^k\} \tag{16}$$

having $(N_pN_t \times N_pN_t)$ component channel matrix.
$\bar{\boldsymbol{h}}_1$ is the estimated flat fading channel co-efficient for a single bit.

∂_k is the power normalization co-efficient and is calculated using the expression

$$\boldsymbol{\partial_k} = \sqrt{m/Trace(\bar{\boldsymbol{P}}_k(\bar{\boldsymbol{P}}_k)^H)} \tag{17}$$

Then, MC modulation is implemented using IFFT block after pre-processing. Let received vector at the k^{th} user MS after MC demodulation be represented as $\boldsymbol{y}_k$. Where

$$\boldsymbol{y}_k = \bar{\boldsymbol{H}}_k x + N_k \tag{18}$$

$$N_k = \underbrace{\sum_{i=1, i\neq k}^{K} \bar{\boldsymbol{H}}_k \bar{P}_i x_i}_{MAI} + \boldsymbol{n}_k \tag{19}$$

$\boldsymbol{n_k}$ is the noise component that has mean=0 and variance=1 $\boldsymbol{n_k}$ is $(N_p N_t \times 1)$ component vector.

The decision variable for $\bar{\boldsymbol{y}}_k$

$$\bar{\boldsymbol{y}}_k = \boldsymbol{C}_k^T \bar{\boldsymbol{H}}_k x + \hat{\boldsymbol{N}}_k \tag{20}$$

$\hat{\boldsymbol{N}}_k$ is also a noise component that has mean=0 and variance=1 $\bar{\boldsymbol{y}}_k$ is the estimate of $\boldsymbol{u}_k$.

The TP eliminates MAI and noise components. The estimated value of $\boldsymbol{u}_k$ is decoded with the aid of log-MAP decoding algorithm [12] to estimate $\hat{\boldsymbol{d}}_k$. Similarly, we can detect all the other users information.

III. POWER ALLOCATION REGIME

The power allocation scheme is designed such that the total power transmitted from the BS is same before and after TP [19]–[22]. Hence

$$Ex[\left\|\bar{P}d\right\|^2] \leq Ex[\|d\|^2] = KN_r \tag{21}$$

and

$$trace(\bar{P}\bar{P}^H) \leq KN_r \tag{22}$$

where $Ex\{.\}$ indicates the expectation of the argument. N_r denotes receive antenna. $\bar{\boldsymbol{P}}$ is the overall pre-processing matrix.

$$\bar{\boldsymbol{P}} = \tilde{P}\partial \tag{23}$$

where

$$\tilde{\boldsymbol{P}} = [\tilde{P}_1, \tilde{P}_2, \ldots, \tilde{P}_K]$$
$$\partial = diag\{\partial_1, \partial_2, \partial_3, \ldots, \partial_K\}$$
$$\tilde{\boldsymbol{P}}_k = (\bar{\boldsymbol{H}}_k^H \boldsymbol{C}_k \boldsymbol{C}_k^T \bar{\boldsymbol{H}}_k + \sigma^2 \boldsymbol{I}_{N_p N_t})^{-1} \bar{\boldsymbol{H}}_k^H \boldsymbol{C}_k \tag{24}$$

where ∂ is overall normalization co-efficient.

Let us define $o = \bar{P}\bar{P}^H$. We have assumed that $[o_{ww}, 1 \leq w \leq KN_r]$ is the diagonal elements of the product $\bar{P}\bar{P}^H$ with the condition that $\{o_{ww}\} > 0$. Hence, the power constraint can now be represented as

$$\sum_{w=1}^{KN_r} o_{ww}\partial_{ww}^2 \leq KN_r \tag{25}$$

The overall information rate (IR) can be indicates by considering entire DL users receive antennas

$$IR(\hat{d}, d) = \frac{1}{KN_r} \sum_{w=1}^{KN_r} log_2[1 + \frac{\Sigma_w}{\zeta^2}\partial_{ww}^2] \tag{26}$$

where ∂_{ww}^2 can be determined using the expression [21]

$$\partial_{ww}^2 = (o - \frac{\zeta^2}{\Sigma_{ww}})^{\dagger}, w = 1, 2, \ldots, KN_r \tag{27}$$

Here the value of o in the above equation is decided in order to satisfy the power constraint in the equation (23).

IV. VECTOR QUANTIZATION

We formulate the pre-processing matrix with the knowledge of CI of all the active users at the BS for DL transmission. In our work, we have considered FDD type wireless system, where each MS will send CI through feedback channel. In this contribution, the CI is estimated using least square error (LSE) estimation technique and the channel spatial information is obtained by decomposing CI using SVD technique. Then, we perform (VQ) [23], [24] at each MS to achieve magnitude and phases component of its channel spatial information. Finally, each MS will transmit the index of the quantized values to the BS through a noisy and fading feedback channel. The algorithm of VQ is summarized as follows:

Let $\{\zeta_n\}$ represents a real and continuous valued source vector and that has to be quantized. These source vectors consign magnitude and phases. Let us assume that, this source vector has to be modeled as a zero mean, stationary and ergodic process. Further, source vector constitutes the DL CI's magnitudes or phases, that belong to the N-dimensional hyperspace R_N.

Let $\{\zeta_n\} \in R_N$. Here, the VQ encoder [25], [26] maps $\{\zeta_n\}$ to a finite exactitude representation of $G_n \in G_Z$ where $G_Z = 1, 2, \ldots, Z - 1$ indicates the Z VQ centriods i.e. $G_n = \Phi(\zeta_n)$. This results, the VQ encoder's mapping function which can be represented as $\Phi : R^N \rightarrow G_Z$. Z partition denotes that the CI hyperspace by $R_{i=0}^{Z-1}$, all the partitions will have VQ encoded centroid $\{\boldsymbol{cbs}_i\}_{i=0}^{Z-1}$ such that $\boldsymbol{cbs}_i \cong Ed(\zeta_n|G_n = i) = E(\zeta_n|\zeta_n \in R^i)$. After that, the VQ encoder has to connect each of the unquantized source vectors with the i^{th} cell or region as, $\zeta_i \in R^i \Rightarrow G_n = i$ where $'i'$ is the generated index of VQ encoded centroid $\{\boldsymbol{cbs}_i\}_{i=0}^{Z-1}$. Because of this, the VQ code book has Z VQ encoded centroids or code words $\{\boldsymbol{cbs}_i\}_{i=0}^{Z-1}$. Now this code book is updated with the help of Lloyd's algorithm [19]. Let huge amount of data samples, say ν is generated such that $M = [\zeta_1, \zeta_2, \ldots, \zeta_u]$. Let $j = 1$, initially code book $\boldsymbol{CBS}_j = [\boldsymbol{cbs}_0^{(j)}, \boldsymbol{cbs}_1^{(j)}, \boldsymbol{cbs}_2^{(j)}, \ldots, \boldsymbol{cbs}_{M-1}^{(j)}]$ is formulated by choosing Z values randomly from the data set M. The code book is updated as per the procedure mentioned in Table-1. From the table, $e_d(.)$ indicates Euclidean distance.

The studies have shown that there is a different distribution for magnitude and phase, i.e., phases will follow uniform distribution whereas magnitudes will

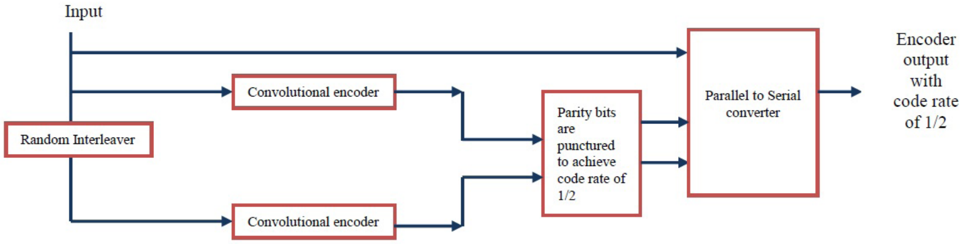

FIGURE 2. Systematic parallel-concatenated convolutional Encoder.

follow Rayleigh. In our contribution, we make use of two vectors to vector quantize the phases and magnitudes separately. Let $bi_l(i), l = 0, 1, 2, \ldots, N - 1$ indicate the bits representing the integer which is corresponding to VQ code book index $i \in G_M$. After $bi_l(i)$ transmitted through a feedback channel, the endured $bi_l(i)$ at BS with noise and fading is denoted as

$$\boldsymbol{f}_l^f(i) = h_l^f\, bi_l(i) + n_l^f, \quad l = 0, 1, 2, \ldots, N-1 \qquad (28)$$

Where h_l^f is the feed back channel gain
we assume to be Rayleigh distribution and
n_l^f is the Gaussian distributed noise where mean=0 and variance=1.

When the phase is known at the BS for specific channel, then phase can be exploited, (28) and which is expressed as

$$\boldsymbol{f}_l^f(i) = \left|h_l^f\right| bi_l(i) + n_l^f, l = 0, 1, 2, \ldots, N-1 \qquad (29)$$

Now, received CI is extracted with the help of MMSE detector. By observing $\boldsymbol{f}_l^f, l = 0, 1, 2, \ldots, N-1$, $\{\hat{\zeta_n}\}$ of $\{\zeta_n\}$ are the estimates of either the phases or magnitudes of the CI. As far as or till now, we have assumed that there is a zero delay feedback. But, in realistic feedback delay exists. So, CI has to be characterized, the temporal variation is modeled by first order Markov process [27], [28].

$$\boldsymbol{H}(t) = \xi \boldsymbol{H}(t - \vartheta) + \sqrt{1 - \xi^2}\mu(t) \qquad (30)$$

Here ξ is the temporal correlation co-efficient,
ϑ is the delay for feedback, signal processing and other system delays. The innovation term μ has entries with mean=0 and variance=1,i.e., $\mu_{j,i}$ $CN(0, 1)$. For the notation convenient, the above equation (28) can be expressed as

$$\boldsymbol{H} = \xi \bar{\boldsymbol{H}} + \sqrt{1 - \xi^2}\mu \qquad (31)$$

Where $\bar{\boldsymbol{H}}$ represents the CI with feedback delay,
$\boldsymbol{H}$ denotes CI without delay.
The correlation co-efficient ξ is related to the delay ϑ by adopting the Jakes' model [29].

V. ITERATIVE TURBO DECODER

Notations:$\boldsymbol{\varsigma}_l(st)$ denotes the probability of forward recursion.
$\mu_l(st)$ represents probability of backward recursion.

$\boldsymbol{LP}(d_k)$ represents a priori probability $(a - pri - p)$
$\boldsymbol{LP}_c$ [5], [18] denotes the channel measurement, it is consider to be 4 times of received value.

TABLE 1. Updating codebook using lloyd's algorithm.

```
loop for $i_v = 1 to L$
for $k = 1 to L$
if $e_d(\phi_t, \boldsymbol{csb}_i^{(j)}) < e_d(\phi_t, \boldsymbol{csb}_k^{(j)})\ \forall i \neq k$
$\phi_t \rightarrow \boldsymbol{csb}_i^{(j)}$
Else if $e_d(\phi_t, \boldsymbol{csb}_i^{(j)}) > e_d(\phi_t, \boldsymbol{csb}_k^{(j)})$
$\phi_t \rightarrow \boldsymbol{csb}_k^{(j)}$
else
$\mu_t \rightarrow \boldsymbol{csb}_k^{(j)}$
Find $Ed_{j+1} = \frac{1}{\nu}\sum_{i=0}^{L}\sum_{\mu_k \in R_i}\left|\mu_k - \boldsymbol{csb}_i^{(j+1)}\right|^2$
if $|Ed_{j+1} - Ed_j| < threshold$
$\boldsymbol{CSB} = [\boldsymbol{csb}_0, \boldsymbol{csb}_1, \ldots, \boldsymbol{csb}_{L-1}]$
else
Go to loop
End
```

$\boldsymbol{LP}_e(d_k)$ indicates the extrinsic information(EI).
$\boldsymbol{LP}(d_k/u)$ indicates the posteriori probability $(a - post - p)$.
$\beta_l(st, st')$-conditional probability that the received symbol. u_k at time l and current state is st_l knowing state from which connecting branch came from st_{l-1} in the trellis diagram.

The structure of turbo encoder is represented in the Fig. 2. We have constructed the turbo code using two convolutional encoder. The second encoder is preceded by an interleaver. We realize random type interleaver. We designate convolutional encoders output as parity bit stream. We form puncturing matrix using parity bit stream and input information. We puncture certain bits of parity bit stream in order to obtain code rate 1/2.

The block diagram of iterative turbo decoder is shown in the Fig. 3.

The max Log-MAP decoding algorithm [30] is used to realize the component based on BCJR algorithm. The inner decoder calculates $a - post - p$ based on the expression

$$\begin{aligned}\boldsymbol{LP}(d_k/u) = &\overset{*}{\max_{u=1}}[E_{l-1}(st') + \rho(st', st) + Z_l(st)] - \\ &\overset{*}{\max_{u=-1}}[E_{l-1}(st') + \rho(st', st) + Z_l(st)]\end{aligned} \qquad (32)$$

where

$$\boldsymbol{E}_l(st) = Log_e[\kappa_l(st)] \qquad (33)$$
$$\boldsymbol{Z}_l(st) = Log_e[\nu_l(st)] \qquad (34)$$
$$\boldsymbol{\rho}(st', st) = Log_e[\beta_l(st', st)] \qquad (35)$$

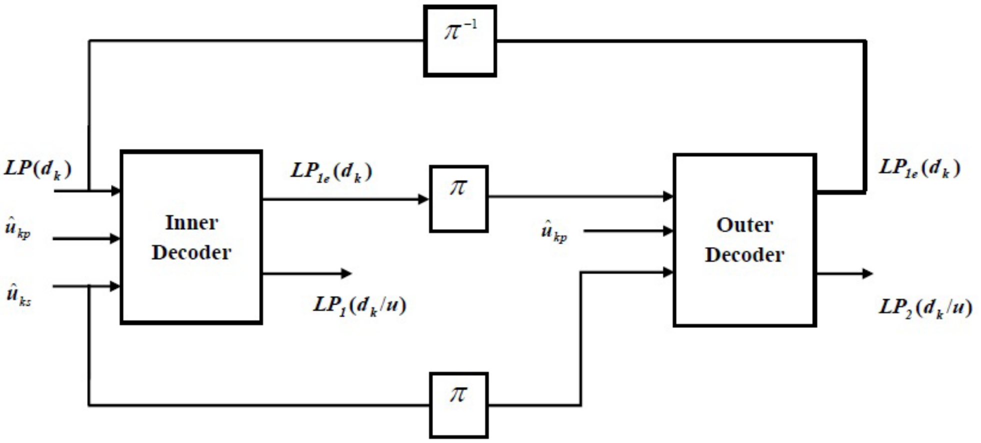

FIGURE 3. Iterative Turbo Decoder.

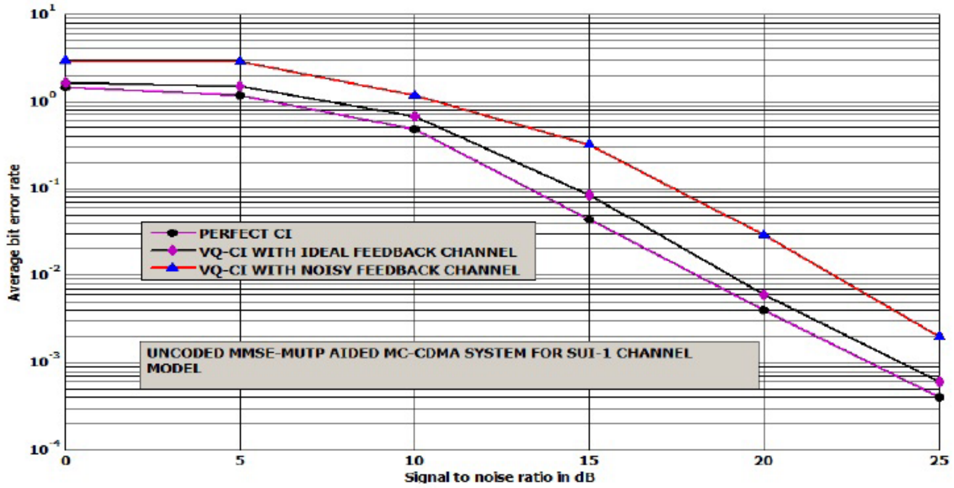

FIGURE 4. Average ER performance of MMSE-MUTP aided uncoded MC-CDMA system for DL transmission with MUTP realized on perfect CI, VQ-CI with ideal feedback and VQ-CI with noise contaminated feedback.

$\boldsymbol{E}_l(st)$ is calculated using

$$\boldsymbol{E}_l(st) = \max_{st'}[E_{l-1}(st) + \rho_l(st', st)] \tag{36}$$

$\boldsymbol{\rho}(st', st)$ is calculated using the expression

$$\boldsymbol{\rho}(st', st) = \frac{d_k LP(d_k)}{2} + \frac{LP_e}{2}\sum_{a=1}^{2} u_a \varpi_a \tag{37}$$

We substitute $\boldsymbol{LP}(d_k) = 0$ initially $u_a\varpi_a$ product of received sequence and corresponding output between state st' and st from trellis diagram.

$E_l(st)$ is chosen such that one of the two branches in the trellis diagram arriving at each state st. Therefore, the probability $E_l(st)$ is desired by higher value of the sum probability $[E_{l-1}(st') + \rho_l(st', st)]$ with initial conditions

$$\begin{aligned} \boldsymbol{E}_0(st) &= 0, st = 0 \\ \boldsymbol{E}_0(st) &= \infty, st \neq 0 \end{aligned} \tag{38}$$

It is similar to Viterbi algorithm as there is a surviving branch and an eliminated branch and finally $Z_l(st')$ is evaluated using the expression

$$\boldsymbol{Z}_l(st') = \max_{st}[Z_l(st) + \rho_l(st', st)] \tag{39}$$

with initial conditions

$$\begin{aligned} \boldsymbol{Z}_N(st) &= 0, st = 0 \\ \boldsymbol{Z}_N(st) &= \infty, st \neq 0 \end{aligned} \tag{40}$$

Then, EI is estimated with the help of $a - post - p$ with the expression

$$\boldsymbol{LP}_e(d_k) = LP(d_k/u) - LP_a(d_k) - \hat{u}_{ks} \tag{41}$$

it is considered as $a - pri - p$ for outer decoder. The outer decoder calculates $\boldsymbol{LP}_{2e}(d_k)$ it is de-interleaved and is used as $a - pri - p$ for the next iteration for single input single output (SISO) decoder-1. The final output is derived from $\hat{\boldsymbol{d}}_k = \boldsymbol{LP}_2(d_k/u)$ after sufficient iteration [30]. The procedure is same for entire users.

VI. PERFORMANCE RESULTS AND DISCUSSION

We present ER results of MMSE-MUTP aided MC-CDMA for SUI-1channel [31]. We describe the channel model

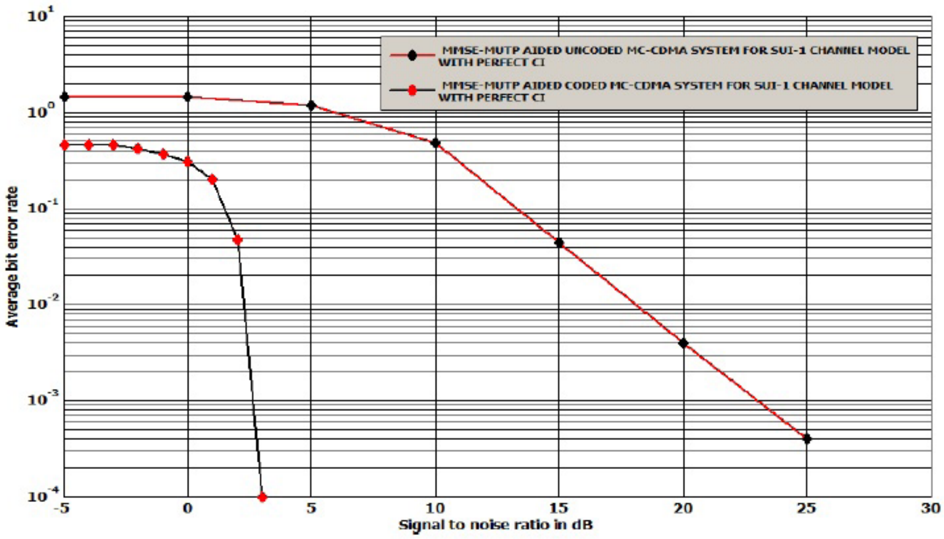

FIGURE 5. Average ER performance comparison of MMSE-MUTP aided uncoded MC-CDMA system with coded MC-CDMA system for SUI-1 channel model.

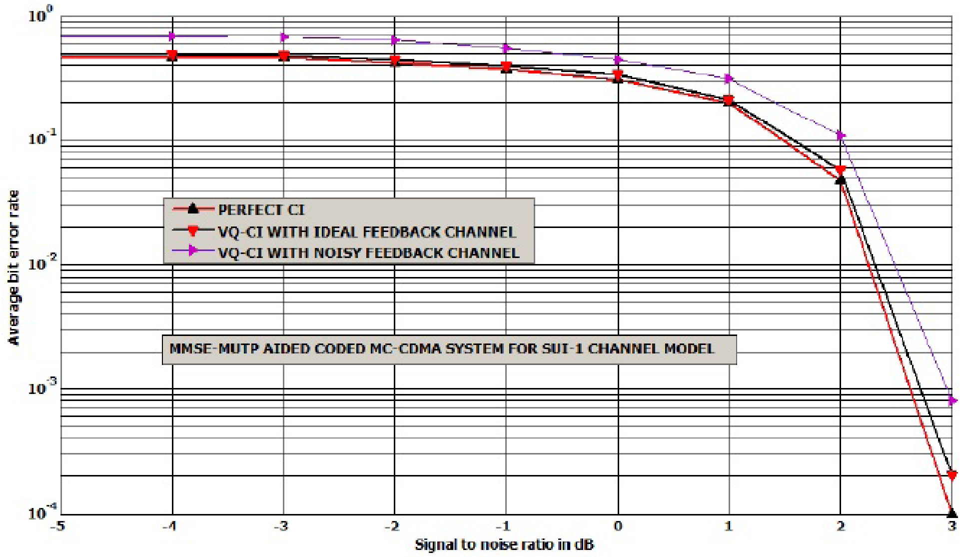

FIGURE 6. Average ER performance of MMSE-MUTP aided coded MC-CDMA system for DL transmission with MUTP realized on perfect CI, VQ-CI with ideal feedback and VQ-CI with noise contaminated feedback.

in Table-II. We indicate the channel parameter in the Table-III. For each value of SNR, we carry-out simulation with 20,000 channel realizations. We realize Binary PSK technique. We calculate ER for ten user's sum signal. We assume TF domain spreading N_pN_t length of 128 and 0.2 Hz Doppler shift respectively. We consider IFFT block size of 256. We realize the MUTP based on VQ CI matrix. Clearly, we approximate the CI using LSE algorithm and perform VQ on the estimated CI using Lloyd's algorithm. Then the quantized values of magnitude and phase are feedback through the noisy channel. At BS, we acquire the noise tainted CI using linear detector and finally pre-processing matrix is built.

Fig. 4 illustrates the ER performance of MUTP supported uncoded MC-CDMA for SUI-1 channel model when perfect CI, VQ-CI sent via ideal feedback channel and noise contaminated VQ-CI are utilized for constructing

the pre-processing matrix. It is witnessed that ER performance of VQ-CI with the code book size of 256 attained through ideal feedback is closer to that of perfect CI for uncoded MC-CDMA system. When VQ-CI acquired via noise contaminated channels are considered for the construction of the TP matrix, the average ER performance of MC-CDMA system degrades.

Fig. 5 shows the average ER performance comparison of MMSE-MUTP supported uncoded with coded MC-CDMA system for SUI-1 channel model. It is witnessed that when iterative decoding algorithm is invoked for MMSE-MUTP aided MC-CDMA system, the turbo coded system outperforms uncoded system requiring 20dB less

TABLE 2. Channel model.

Path number	SUI-1 channel specifications	
(l)	Delay (μs) $\psi(\tau_p)$	Power (dB)
1	0	0
2	0.4	-15
3	0.9	-20

TABLE 3. Simulation parameters.

Parameters	Attributes
Modulation Technique	BPSK
Channel Spacing	20 MHz
Sample frequency	22.5 MHz
No.of transmit antennas	1
No.of receive antennas	1
Channel Model	SUI-1 channel model
Number of Users	2,4,6
Channel coding	Turbo

SNR for achieving average BER of 10^{-3} for DL communication.

Fig. 6 elucidates the average ER performance of the MMSE-MUTP supported turbo coded FDD type MC-CDMA system for SUI-1 channel model when perfect CI, VQ-CI directed via ideal feedback channel and noise affected VQ-CI are used for formulating TP matrix. As in the previous case, the turbo coded MC-CDMA system with iterative decoding algorithm aided by MMSE-MUTP based on noise infected VQ-CI shows poor ER performance compared to the perfect CI and VQ-CI with 256 code book size acquired via ideal feedback channel.

VII. CONCLUSION

In this article, we explored ER performance of a MMSE-MUTP supported coded MC-CDMA for SUI-1 channel model. We constructed MMSE-MUTP with the support of perfect CI, VQ-CI and noise contaminated VQ-CI. Our performance study reveals that MMSE assisted MUTP technique along with iterative decoding algorithm achieves a better ER performance with less SNR for multi-user MC-CDMA system. Our simulated ER performance divulge that for DL MC-CDMA system, TP which is constructed using perfect CI, eliminates the MUI while TP that is formulated using noise contaminated VQ-CI, results in rudimentary removal of MUI. Further, our investigation for MUTP aided MC-CDMA system reveals that VQ-CI which is acquired via ideal feedback provides the same error-rate performance as compared to that of perfect CI. Additionally, ER performance of MC-CDMA system degrades when noise contaminated VQ-CI are demoralized to formulate TP matrix compared to its perfect CI counterpart. We conclude that for FDD system, VQ with higher level of code book size is recognized as powerful technique for quantizing CI and feedback them to construct TP matrix at BS.

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