Static and Dynamic Channel Estimation Techniques for MIMO-Constant Envelope Modulation

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Abstract— The authors have proposed Multi-Input Multi-Output (MIMO)-Constant Envelope Modulation (MIMO-CEM), as power and complexity efficient alternative to MIMO-OFDM, suitable for wireless backhaul networks. One of the major problems to withstand real application of MIMO-CEM is to estimate MIMO channel characteristics. The MIMO-CEM is based upon two contrary schemes; one is nonlinear Maximum Likelihood Sequence Estimator (MLSE), which needs accurate channel information to replicate the received signal passing through it. The other is a low resolution analog-to-digital converter (ADC), e.g., 1-bit in the default operation that removes the received signal amplitude fluctuation. This paper considers channel estimation problem in MIMO-CEM. First, we propose a MIMO-CEM adaptive channel estimator, in static and quasi-static channel conditions, based upon Code Division Multiplexing (CDM) preambles transmission, where channel parameters are iteratively estimated by observing the received MIMO preambles. Then, we extended the proposed CDM preamble method to Decision Directed Channel Estimation (DDCE) to track MIMO-CEM channel in high Doppler frequency conditions and clarify the effectiveness of MIMO-CEM in dynamic channel conditions.

Keywords- (Multi-Input-Multi-Output) MIMO; Constant envelope modulation; Channel estimation; adaptive channel estimation; Decision directed channel tracking, Low resolution ADC.

I. INTRODUCTION

Multi-Input Multi-Output Constant Envelope Modulation, MIMO-CEM, has been introduced as an alternative candidate to the currently used MIMO-Orthogonal Frequency Division Multiplexing (OFDM) [1]. One of the major disadvantages of OFDM is that the transmit signal exhibits noise like statistics with high Peak to Average Power Ratio (PAPR). This signal requires high power consumption RF power amplifier (PA) [2] and high resolution analog to digital converter (ADC) [1]. Due to the stringent linearity requirements on handling OFDM signal, nonlinear power efficient PA like class C cannot be used for OFDM transmission. Instead, linear power inefficient PA should be used like class A and class A/B. In consequence, many efforts have been made so far to solve this vital problem in OFDM systems for the recent years [3] [4]. All these drawbacks prevent OFDM from scalable design when it is extended to MIMO due to hardware complexity [5].

To cope with this issue, the authors suggested using Constant Envelope Modulation (CEM) as a method to improve power-efficiency at PA on the transmitter side and reduce power consumption at ADC on the receiver side [1]. In this system, constant envelope Phase Modulation (PM) is used at the transmitter. Since PM signal can be viewed as differential coded frequency modulated (FM) signal, information is carried over frequency domain rather than over amplitude domain. Therefore, it is allowed to use nonlinear PA at transmitter subject to reducing spurious emission. Therefore, drastic improvement of power efficiency is highly expected as compared with OFDM. On the receiver side, intermediate frequency (IF) sampling results in allowing us to use low resolution ADC subject to shorter sampling interval than that required for baseband sampling. We suggest using 1-bit ADC as CEM default operation. Although compensation of high-nonlinearity caused by 1-bit ADC requires advanced digital signal processing techniques on the receiver side, there will be a great reduction in power consumption and hardware complexity.

On the other hand, OFDM has higher spectral efficiency than CEM. This drawback of CEM is diminished by introducing MIMO; CEM should be subjected to higher MIMO branches than OFDM. Although, such a MIMO basis design of the proposed CEM transceiver necessitates high computational power required for digital signal processing, we can view the concern with optimistic foresight because cost for digital signal process is being reduced every year. A little improvement in power efficiency of major analog devices such as PA has been observed for the last few decades. In contrast, we have seen drastic improvements of digital devices for the same decades [6].

In MIMO-CEM receiver, nonlinear equalization is needed to deal with severe quantization error caused by the low resolution ADC. Maximum Likelihood Sequence Estimator (MLSE) is one of nonlinear equalizations that takes into account severe quantization error when it equalizes the inter-symbol interference (ISI). MLSE needs accurate multipath channel states information which is hard task in presence of the low resolution ADC; in which the received signal amplitude fluctuation is completely removed in the default 1-bit resolution operation and seriously affected even in few bit resolutions. Therefore, MIMO-CEM channel estimation in presence of the low resolution ADC is a big challenge to the real application. The authors in [7] have solved the SISO-CEM channel estimation problem using adaptive channel estimator. To easily extend the SISO-CEM channel estimator to the MIMO-CEM case, they suggested using Time Division Multiplexing MIMO preambles transmission [7]. In [8], we have proposed a decision directed channel estimation (DDCE) method using the adaptive channel estimator in order to track MIMO-CEM channels in time varying channel conditions. Although the MIMO TDM preambles transmission is simple method, it is not sufficient to estimate low bit ADC MIMO-CEM channels.
In this paper, we propose a MIMO-CEM channel estimation method using Code Division Multiplexing (CDM) preambles transmission in order to improve channel estimation accuracy, where adaptive filter-bank is used to estimate channel characteristics. First, we investigate the performance of the proposed channel estimator in quasi-static channel conditions and clarify that the proposed method achieves better performance than the conventional TDM based MIMO-CEM channel estimator in [7]. Then, we show that the proposed method is extendable to DDCE in order to track MIMO-CEM channel in dynamic channel conditions with high Doppler frequencies.

This paper is organized as follows. Section II gives detailed construction of the MIMO-CEM transceiver system. The structure of the proposed MIMO-CEM channel estimator is given in Section III. Performance evaluations are given in Section VI followed by the conclusion in Section V.

II. MIMO-CEM TRANSCIEVER SYSTEM

Figure 1 shows the system block diagram of 2x2 MIMO-CEM. In Fig.1, the input binary information data (Inp(0/1)) is convolutional-encoded and interleaved (Enc+II) (InpEnc) in order to enhance BER performance of MIMO-CEM especially in the default 1-bit ADC operation. InpEnc is then split into number of streams equal to the number of the transmit antennas Mt. Constant envelope PM modulation is applied to each data stream using differential encoder followed by MSK or GMSK frequency modulation which results in constant envelope transmitted MIMO signals X_q, 1 ≤ q ≤ Mt. The received signals are affected by MIMO Rayleigh fading multipath channels from transmit antenna q to receive antenna p, e.g., H_{pq}, 1 ≤ p ≤ Mr, 1 ≤ q ≤ Mt and Additive White Gaussian Noise (AWGN) N_p associated with each receive antenna p. At each receive antenna and in the IF band, analog BPF filter is used to improve Signal to Noise power Ratio (SNR) of the IF signal corrupted by AWGN noise. After that, the signal is converted into digital one using low resolution ADC (Q) sampled at IF band and digitally converted into baseband (IF-BB) and low pass filtered (LPF) (Y_p).

The 1-bit ADC at each receive antenna induces high nonlinear distortion expressed as a hard limiter function:

\[ H_{rdlt}(\Theta)= \begin{cases} 1 & \text{if } \Theta \geq 0 \\ -1 & \text{if } \Theta < 0 \end{cases} \]  

(1)

Hence, the received LPF vector at each receive antenna Y_p can be expressed as:

\[ Y_p = f(\sum_{q=1}^{Mt} H_{pq} X_q + N_p), \quad 1 \leq p \leq Mr \]  

(2)

where f denotes the nonlinear \( H_{rdlt} \) function followed by the linear LPF function, \( f(\Theta) = LPF(\Theta) \). \( H_{pq} \) denotes channel Toeplitz matrix of size \( BxB \) from transmit antenna \( q \) to receive antenna \( p \), where \( B \) is the transmitted \( X_q \) and received \( Y_p \) streams length, given by:

\[
H_{pq} = \begin{bmatrix}
 h_{pq0} & h_{pq1} & \cdots & h_{pq(M-1)} \\
 h_{pq2} & h_{pq3} & \cdots & h_{pq(M-2)} \\
 \vdots & \vdots & \ddots & \vdots \\
 h_{pq(B-1)} & h_{pq(B-2)} & \cdots & h_{pq0}
\end{bmatrix}
\]

Then, the MIMO-CEM MLSE equalizer can be expressed as:

\[
\hat{y}_{pq} = \arg \min_{k} \sum_{t=0}^{L-1} \left\| y_{p,t} - f(H_{pq}^T \chi_k^T) \right\|^2
\]

(5)

where \( K = 2^J \) denotes the number of candidate sequences \( X_k^T \) in MLSE with memory equal \( J \), and \( J \) is a function of the channel memory \( M \) and number of transmit antennas \( Mt \). Therefore, the MLSE has the ability to equalize the received MIMO signal, with an acceptable BER, even if it is affected by the high nonlinear hard limiter (1-bit ADC) under the constraints of highly estimated MIMO channels (which is our main concern in this paper). Finally, De- interleaver and Viterbi decoding (Π²+Vit-Dec) are carried out for error correction, and output the estimated transmitted data \( \hat{y}_p[0,1] \).

III. PROPOSED MIMO-CEM CHANNEL ESTIMATOR

In this section, we first propose the CDM based adaptive filter bank channel estimator to estimate MIMO-CEM...
channel in static and quasi-static channel conditions. Then, Decision Directed Channel Estimation (DDCE), utilizing the proposed channel estimator, is proposed to estimate MIMO-CEM channel in time varying channel conditions with high Doppler frequencies.

A. MIMO-CEM Adaptive Channel Estimation

First, we give the TDM based adaptive channel estimator proposed by authors in [7], and then we show its inefficiency in estimating MIMO-CEM channel especially in case of 1-bit ADC. After that, we propose the CDM based MIMO-CEM adaptive filter bank channel estimator to accurately estimate MIMO-CEM channel.

1) TDM based MIMO-CEM Adaptive Channel Estimation

The main idea of the channel estimation proposed in [7] is to replicate the received preamble signal in presence of the nonlinear function \( f \). The estimated channel vector is determined so as to minimize the error between the actual received preamble and the replicated one, where an adaptive algorithm is used to minimize this error iteratively. Figure 2 shows the block diagram of SISO-CEM adaptive filter based channel estimator [7], where constant envelope PM modulated PN sequence \( X \) is transmitted as a known preamble training sequence for the adaptive channel estimator. The differential encoder before the MSK modulation gets the PN information to be on the peaks of \( X \), where \( X \) is the preamble complex MSK baseband signal. The received preamble signal after frequency-down conversion and LPF in digital domain is denoted as \( Y \), for 1-bit ADC:

\[
Y = f(HX + N)
\]  

(6)

where \( H \) is the SISO channel Toeplitz matrix Eq. (3). The replicated received signal \( Y_{est} \) is obtained by applying the known preamble \( X \) to the adaptively estimated channel vector \( H_{est} \) and a given ADC function, for 1-bit ADC:

\[
Y_{est} = f(H_{est}X)
\]  

(7)

Then, the estimator calculates the error between the actual received preamble vector \( Y \) and its replica \( Y_{est} \). The channel parameters \( H_{est} \) is determined so as to minimize the Mean Square Error (MSE) between \( Y \) and \( Y_{est} \) given by:

\[
MSE = \|Y - Y_{est}\|^2
\]  

(8)

where \( \Psi \) and \( \Psi \) denote the absolute and average values of vector \( \Psi \) respectively. Therefore, for no AWGN, the estimator tries to adaptively find \( H_{est} \) whose characteristics satisfy this nonlinear equation:

\[
f(H_{est}X) = f(HX)
\]  

(9)

From Eqs. (1) and (9), there are infinite number of \( H_{est} \) that can solve the nonlinear equality of Eq. (9), i.e., there are many local minimums of the MSE given by Eq. (8) as a function of \( H_{est} \). Hence, the adaptive estimator will converge to one of these local minimums results in \( H_{est} \) that may not equal actual \( H \) but satisfies Eq. (9). The authors used the adaptive block (B-) LMS algorithm to update channel information. The BLMS algorithm used in the adaptive process is [9]:

\[
H_{est}(n+1) = H_{est}(n) + \frac{B}{L} \sum_{l=0}^{L-1} X_{est}^\ast(b + l) e(nB + l)
\]  

(10)

\[
e(nB + l) = Y(nB + l) - Y_{est}(nB + l)
\]  

(11)

where \( H_{est}(n) = [h_{est1}(n), ..., h_{estM}(n)]^T \) is the estimated channel vector of length \( M \) at iteration step \( n \), \( u(n) \) is variable step size of recursive calculation in adaptive filter, and \( B \) is the length of the complex baseband training transmitted PM signal \( X_b \). The variable step size \( u(n) \), adjusted via simulations, is used to accelerate the convergence speed of the scheme so low complex estimator is obtained. Suffixes \( T \) and \( \ast \) denote transpose and complex conjugate respectively.

To shorten the required number of iterations, reduce computational complexity and accelerate the convergence rate in the adaptive estimator, the authors also proposed a correlator estimator to roughly estimate the initial states of \( H_{est}(0) \) given by:

\[
h_{est}^{(0)}(m) = \frac{1}{L} \sum_{l=0}^{L-1} Y_{(l+m)T_s} X_{est}^\ast \quad m = 0, ..., M - 1
\]  

(12)

where \( L \) is the PN sequence length and \( M \) denotes the number of branches in the correlator bank (\( L > M \)). \( Y_{(l+m)T_s} \) is the signal \( Y \) sampled at time \( (l+m)T_s \). \( X_{est}^\ast \) is the complex conjugate of \( X \), sampled at every \( IT_s \).

In order to extend the SISO-CEM adaptive channel estimator into MIMO-CEM channel estimation, the authors proposed to use TDM MIMO preambles transmission. In MIMO TDM scheme, PN preambles are transmitted from the transmit antennas in a sequential fashion in time domain. That is, to estimate the channels associated with certain transmit antenna, this antenna is the only one allowed to transmit the preamble packet while other transmit antennas are not allowed to transmit. In this way, the authors claimed that the SISO-CEM adaptive channel estimator can be directly used in MIMO-CEM channel estimation without modifications.
2) CDM based MIMO-CEM Adaptive Channel Estimation

The TDM based channel estimator can be expressed for 1-bit ADC MIMO-CEM as:

\[ Y_{p,TDM} = \sum_{l=0}^{mt} f(H_{pq}X_{q,TDM} + N_p), \quad 1 \leq p \leq Mr \]  

(13)

TDM converts MIMO channels estimation into parallel SISO channels estimation as we previously explained. In consequence, channel estimates \( H_{eqpq} \) are estimated to satisfy the following equation (assuming no AWGN):

\[ f(H_{eqpq}X_{q,TDM}) = f(H_{pq}X_{q,TDM}) \]  

(14)

where \( H_{eqpq} \) is optimized to reduce the MSE between the SISO received preamble and its replicated version (as previously explained). Therefore, sufficient MIMO-CEM equalization is not achieved using those SISO estimated channels Eq. (5). Instead, due to the nonlinear effect of the function \( f \) upon the data multiplexed MIMO signal at each receive antenna Fig.1, sufficient MIMO-CEM equalization is obtained by jointly optimize MIMO-CEM channels to satisfy this equation (assuming no AWGN):

\[ Y_{eqp} = Y_p \]

(15)

\[ \text{i.e.}, f(\sum_{q=1}^{Mt} H_{eqpq}X_q) = f(\sum_{q=1}^{Mt} H_{pq}X_q), \quad 1 \leq p \leq Mr \]

Therefore, we suggest using CDM preambles transmission instead of TDM to accurately estimate MIMO-CEM channel. In MIMO CDM technique, orthogonal preambles are simultaneously transmitted from the transmit antennas. For 1-bit ADC MIMO-CEM, this can be expressed as:

\[ Y_{p,CDM} = f(\sum_{q=1}^{Mt} H_{pq}X_{q,CDM} + N_p), \quad 1 \leq p \leq Mr, \]  

(16)

\[ X_{q,CDM} \in \text{orthogonal codes} \]

These orthogonal codes can be generated using phase shifted PN sequences, and this phase shift is greater than the maximum expected channel length, so some sort of orthogonality is maintained between the simultaneously transmitted preambles. In CDM, the received signal amplitude is fluctuated by code multiplexing of the preambles simultaneously transmitted from each antenna. This amplitude fluctuation is removed by the 1-bit ADC at the receiver, i.e., this fact suggests that the receiver experiences the nonlinear distortion caused by ADC therefore channel parameters can be optimized for MIMO-CEM. As a result, it is expected that CDM preambles transmission achieves better channels estimation performance than TDM. In order to handle CDM based MIMO-CEM channel estimation, we propose the MIMO-CEM Adaptive filters Bank channel estimator.

Figure 3 shows the 2x2 MIMO-CEM adaptive filters bank channel estimator for simultaneously estimating \( H_{est11}, H_{est12} \) and \( H_{est21}, H_{est22} \) in order to satisfy Eq. (15) for \( Y_1 \) and \( Y_2 \) respectively. In this scheme, utilizing the property that MIMO channels are uncorrelated, we can adaptively update channels vectors \( H_{eqpq} \) simultaneously and separately using the BLMS algorithm as follows:

\[ H_{eqpq}(n+1) = H_{eqpq}(n) + \frac{\mu(n)}{B} e_{1,CDM}X_{q,CDM}(nB) + e_{2,CDM}(nB) \]

(17)

\( e_{p,CDM}(nB+i) = Y_{p,CDM}(nB+i) - Y_{eqp,CDM}(nB+i) \)  

The nonlinear effect of the 1-bit ADC upon the multiplexed received MIMO signal can be taken into account through using this structure results in reducing the MSE between the actual received preamble signal \( Y_{p,CDM} \) and its replica \( Y_{eqp,CDM} \) with good optimization of Eq. (15). Utilizing the orthogonality between the transmitted PN preambles \( x_{q,CDM} \), the initial values for \( H_{eqpq} \) can be estimated simultaneously using \( MtxMr \) correlator estimators; one for each \( H_{eqpq} \) as follows:

\[ h_{eqp}(m) = \frac{1}{L} \sum_{l=0}^{L-1} Y_{p,CDM}(l+mI) X_{q,CDM}^* \]  

(19)

where \( Y_{p,CDM}(l+mI) \) is the LPF received signal at receive antenna \( p \) sampled at time \((l+m)T_\nu \), \( X_{q,CDM}^* \) is the complex conjugate of transmitted baseband PN preamble from transmit antenna \( q \) sampled at every \( T_\nu \).

B. DDCE for MIMO-CEM Channel Tracking

DDCE is an effective technique to track channel fluctuation during data transmission in high Doppler frequency systems. In this section, utilizing the CDM based MIMO-CEM adaptive channel estimator presented in Sec. 3.1.2, we present a block based DDCE for dynamic channel tracking in MIMO-CEM. Figure 4 shows the proposed 2x2 MIMO-CEM DDCE construction, including the 2x2 MIMO-CEM adaptive channel estimator shown in Fig. 3, in more details. The MIMO received LPF data vectors \( y_1^T, y_2^T, ..., y_{Mr}^T \) are divided into blocks \( y_{1(D1)}, y_{2(D1)}, ..., y_{Mr(D1)} \), \( 1 \leq D \leq \text{NoOfBlocks} \), which results from receiving the transmitted data blocks \( Inp_{D1} \). The block based DDCE is applied to these data blocks as follows (2x2 MIMO-CEM DDCE):

1. First, MIMO channels vectors are initially estimated \( (H_{est11}, H_{est12}, H_{est21}, H_{est22}) \) using the received LPF PN preambles \( Y_{1,CDM} \) and \( Y_{2,CDM} \) and transmitted PN preambles \( X_{1,CDM} \) and \( X_{2,CDM} \). This initial estimation is done using correlator and adaptive channel estimator described in Sec. 3.1.2.
2. These initially estimated channels are used to equalize the received data block \( Inp_{D1} \) using the MLSE equalizer Eq.(5) to obtain \( Inp_{Dec} \).
3. The $\hat{p}_{I,I}$ is encoded (Enc), interleaved (I), and split into two streams that PM modulated to estimate $X_{I,I}$ and $X_{Q,I}$. Then, they are fed back to the adaptive channel estimator. Current channels vectors estimates ($H_{dd1(I)}, H_{dd2(I)}, H_{at1(I)}$ and $H_{at2(I)}$) are estimated using ($H_{dd1(0)}, H_{at1(0)}, H_{at2(0)}$) as the adaptive filters bank initial values, sec 3.1), ($X_{I,I}$, $X_{Q,I}$) and ($Y_I(I), Y_Q(I)$).

4. Repeat steps 2, 3 until $\hat{p}_{I,I} = \hat{p}_{I,I}(NoOfBlocks)$.

Received MIMO Block $Y_{I,I}(n) = [Y_{I,I}^1(n), Y_{Q,I}^1(n)]$.

Figure 4. System configuration of 2x2 MIMO-CEM DDCE.

IV. PERFORMANCE EVALUATIONS

In this section, we give some BER performance simulations that show the effectiveness of the proposed estimators in quasi-static and dynamic channel conditions with high Doppler frequencies. We evaluate the BER performance of the SISO-CEM, 2x2 MIMO-CEM and 2x2 MIMO-CEM DDCE.

A. Simulation Parameters

In studying SISO (MIMO) – CEM channel(s) estimator performance, we make use of the simulation parameters shown in Table 1 with the following channel models.

For SISO-CEM simulations: we use channel model of 7-path Rayleigh fading channel, with equal power gain and RMS delay spread of $r_{rms} = 2T_s$ which is estimated by 7 paths with $T_s$ separation channel model, $T_s$ is the symbol duration.

For MIMO-CEM simulations: each MIMO channel is 4-path Rayleigh fading channel, with equal power gain and $r_{rms} = 1.1T_s$ which is estimated by 4 paths with $T_s$ separation channel model.

Due to CEM high nonlinearity, The variable step size $u(n)$ is adjusted (max, min and step values) via simulations.

B. Performance of the Proposed Channel Estimation in SISO-CEM

BER performance of GMSK SISO-CEM, in quasi-static channel conditions, is evaluated for various values of BT, where BT denotes 3 dB-bandwidth of Gaussian filter (GF) normalized by symbol frequency. The used simulation parameters are the same like Table 1 (channel model is described in Sec 4.1) except we use the transmit GF with $BT = 0.3, 0.5, 0.7$ and 1.0, and the receive GF with $BT = 1.0$. Figure 5 shows BER performances as a function of Eb/N0, where 1-bit ADC is used at the receiver and various BT values of 0.3, 0.5, 0.7 and 1.0 are used at the transmit GF.

For comparison, BER performance in case using prefect channel estimation is also shown. From this figure, as the BT value decreases, BER performance is degraded because ISI is increased. The best BER performance is obtained when BT=1.0. In addition, we can see that the proposed channel estimator works well even in GMSK modulation. As in this figure, it can be seen that the proposed channel estimator achieves BER performance comparable to case with perfect one even when 1-bit ADC and GMSK of BT=0.3 are used; which cause a hard limited high ISI received preamble. Hence, even in this severe condition, the proposed estimator can effectively replicate the preamble signal results in efficiently estimated equivalent channel $H_{est}$.

Utilizing this $H_{est}$, the proposed scheme achieves good BER performance that matches with actual good channel $H$.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampling rate at ADC</td>
<td>$16 f_s$</td>
</tr>
<tr>
<td>BPF</td>
<td>6 order Butterworth, BW = 0.6</td>
</tr>
<tr>
<td>FEC Encoder</td>
<td>Convolutional encoder with Constraint length $g_1 = x^7+x^6+x^5+x^4+x^1$ and $g_2 = x^7+x^5+x^4+x^3+x^1$</td>
</tr>
<tr>
<td>FEC Decoder</td>
<td>Hard Decision (Soft Decision) Viterbi Decoder for Quasi-static (Dynamic) channels</td>
</tr>
<tr>
<td>The number of transmit antennas $M_t$</td>
<td>2 antennas</td>
</tr>
<tr>
<td>The number of receive antennas $M_r$</td>
<td>2 antennas</td>
</tr>
<tr>
<td>Adjusted PN length ($L_d$)</td>
<td>511-chip (Quasi-Static channels)</td>
</tr>
<tr>
<td>Adjusted Adaptive number of iterations ($N_{\text{iter}}$)</td>
<td>30-iteration</td>
</tr>
<tr>
<td>$T_{s}$</td>
<td>0.0002, 0.0005 and 0.001</td>
</tr>
<tr>
<td>Preamble PN length (DDCE)</td>
<td>63 chips for $T_{s}=0.0002$, and 31 chips for $T_{s}=0.0005$ and 0.001</td>
</tr>
<tr>
<td>Data Block length (DDCE)</td>
<td>16 Symbols for $T_{s}=0.0002$, and 12 symbols for $T_{s}=0.0005$ and 0.001</td>
</tr>
<tr>
<td>$R$ = (Preamble length) / (Total Frame length) for DDCE.</td>
<td>0.14</td>
</tr>
</tbody>
</table>

Figure 5. The BER comparisons in case using perfect and estimated channels for 1-bit ADC SISO-CEM and different GMSK BT values.
C. Performance of the Proposed Channel Estimation in MIMO-CEM.

Figure 6 shows the BER performance of the proposed CDM based 2x2 MIMO-CEM channel estimator in quasi-static channel conditions and ADC resolution is 1, 2, or 3-bit. For the purpose of comparison TDM based channel estimator proposed in [7] is also given. Two phase shifted PN sequences with length of 511-chip are used as the CDM preambles. The phase shift is set to a value greater than the expected channel length which is 4 paths in this simulation. Other simulation parameters are the same like Table 1. Also, only MSK modulation is used. From this figure, we can see that the proposed CDM scheme outperforms that of TDM scheme, especially in 1-bit ADC, and approximately matches the ideal case. This is because the proposed CDM channel estimator experiences nonlinear distortion caused by nonlinear quantization of the multiplexed signal, and therefore channel parameters can be optimized so as to minimize it. In contrast, TDM scheme (where each preamble is transmitted at the different timing) is not suited for optimizing MIMO channels parameters in the systems affected by high nonlinear quantization.

In this section, we evaluate the BER performance of the proposed CDM based MIMO-CEM DDCE time varying channel estimator for different $f_d T_s$ values using MSK modulation. Soft output MLSE and soft decision viterbi decoder are used. In our evaluations, we only concern about the high nonlinear 1-bit ADC case. Table 1 shows the simulation parameters used in these evaluations. The normalized preamble size is given as $R$ (preamble size / total frame size) = 0.14. Figure 7 shows the BER performance of the 2x2 MIMO-CEM DDCE for different $f_d T_s$ values of 0.0002, 0.0005 and 0.001. For comparison, the BER performance in case of perfect channel estimation is also given. Form this figure, it is shown that the proposed estimator works well without any error floor for the moderate and high dynamic channel conditions of $f_d T_s$ of 0.0002 and 0.0005, but there is an error floor appear at the too fast time varying channel conditions of 0.001. This figure proves the effectiveness of MIMO-CEM with the proposed DDCE channel tracking for time varying channel applications.

V. CONCLUSION

In this paper, we proposed CDM based adaptive channel estimation technique for SISO- and MIMO-CEM systems with low resolution ADC receiver in static and quasi-static channel conditions. We also proposed Block DDCE method to estimate MIMO-CEM channel in dynamic channel conditions with high Doppler frequencies. We proved the effectiveness of the proposed schemes in estimating channel parameters under different channel scenarios and different ADC resolutions.

References