

Differential Space Time Frequency Codes for MIMO OFDM Systems

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Abstract

In general coherent detection, channel estimation requires huge number of symbols for transmission in Multiband Orthogonal Frequency Division Multiplexing (MB-OFDM) Ultra Wide Band (UWB) system, due to this bandwidth efficiency reduces. The proposed Differential Space-Time-Frequency Code (DSTFCs) for multiband-OFDM Ultra-WB communications is increases the efficiency of bandwidth. DSTFC system does not require Channel State Information (CSI). Due to this, the system bandwidth efficiency is possible to increase with DSTFCs. The proposed DSTFCs are derived both coding and decoding algorithms for 64 QAM (Quadrature Amplitude Modulation). The Simulation outcomes show that the use of DSTFCs can improve the coherent MB-OFDM (without STFC), differential MB-OFDM (without OFDM) bit error performance. The performance of DSTFCs almost reaches the STFCs performance even in the absence of channel state information.

Keywords: CSI, DSTFC, OFDM, QAM, STFC, UWB

1. Introduction

The Multi-Band (MB) Orthogonal Frequency Division Multiplexing (OFDM) Ultra-Wide Band (UWB)^{1,2} Space-Time-Frequency Codes (STFCs), and also Multiple-Input Multiple-Output (MIMO) technologies may provide development system capacity, maximum communication range, BER (Bit Error Rate), data rate. The multiple mixture of MB-OFDM UWB, Multiple Input Multiple Output (MIMO) and STFCs, usually called as STFC MB-OFDM UWB systems³⁻⁸.

To achieve coherent detection, CSI is the channel state information at the receiver is implicit to be recognized. The PLCP (The Physical Layer Convergence Protocol) preamble needs to send six MB-OFDM symbols for estimating channel between every couple of transmitter (Tx) and receiver (Rx). This provides coherent detection at the receiver. The multiple input multiple output system is having M no. of Tx and N number of Rx antennas, for this reason the necessary number of symbols as large as $6M$, except superimposed training techniques^{9,10}, are used to decrease transmitted symbols for channel estimation

in the preamble. Therefore, the system bandwidth efficiency reduces radically by the transmission of a huge capacity of MB-OFDM symbols for channel evaluation. Furthermore, in high data rate systems or in fast fading channels, in the above cases, differential detection (or non-coherent detection) would be the best candidate. This non-coherent detection is useful, where the receiver does not require CSI for decoding signals.

In common OFDM systems related with a MIMO model, differential transmission techniques include in the literature, such as¹¹⁻¹³. There are two major differences among in conventional OFDM systems and in MB-OFDM ultra wideband ones channel characteristics. First, channels are more dispersive in latter technique compared to former; the average number of multipath will reach some thousands. Second, in the former channel coefficients are in general Rayleigh distributed, the latter are log-normally circulated. Therefore, the multi band OFDM systems incorporating with Ultra wide band, differential transmission and MIMO must be analyzed, several similarities were exists between conventional OFDM, MIMO and differential transmission.

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2. Related Work

For differential transmission as a rule of OFDM frameworks connected with a MIMO model. There are two major principle contrasts among direct qualities in customary OFDM frameworks and in MB-OFDM UWB. In the first place, diverts in the recent are considerably further dispersive than in previous, with normal number of multi paths potentially coming to a few thousands. Second, divert coefficients are typically thought to be Rayleigh conveyed in the previous, while in the last are log-regularly circulated. In this way, the frameworks joining MBOFDM UWB, differential transmission and MIMO must be all the more particularly examined, however there survive a few likenesses among the frameworks and the frameworks using customary OFDM, MIMO and differential transmission.

2.1 Implementation of Space-Time-Frequency Code in MB- OFDM UWB Communications

This system consisting of M number of Tx and N no. of Rx antennas. $\mathbf{s}_t = \{\bar{s}_{t,m}\}_{T \times M}$ is the transmitted matrix, where T is the time required for transmission of STFC block. $T_{SYM} = 312.5$ ns is time slot of MB-OFDM, including the zero padded suffix duration of $T_{ZPS} = 70.08$ ns and the time period of FFT/IFFT $T_{FFT} = 242.42$ ns. S is the code matrix can be structured as orthogonal space-time block codes (OSTBCs)¹⁴⁻¹⁶ except $\bar{s}_{t,m}$ element is not a complex number, but the column vector defined as $\bar{s}_{t,m} = [s_{t,m,1} \ s_{t,m,2} \ \dots \ s_{t,m,N_{fft}}]^T$.

The original transmitted data is compressed before IFFT by vectors $\bar{s}_{t,m}$. From QAM (Quadrature Amplitude Modulation) the symbols $s_{t,m,k}$ for $k = 1, \dots, N_{fft}$, are drawn, DCM (Dual Carrier Modulation) Denote $X = \{\bar{x}_{OFDM,t,m}\}_{T \times M}$ is the matrix and the elements are N_{fft} -point IFFTs of S_p then

Denote $\bar{k}_{t,m,n} = kt, m, n, 1, kt, m, n, 2 \dots kt, m, n, Lm, n$ is the m -th Tx and n -th Rx antennas of channel vector.

The transmission symbol t -th MB-OFDM, at the n -th RX antenna the received signal is calculated as

$$\bar{r}_{ZP,t,n} = \sum_{m=1}^M (\bar{x}_{ZP,t,n} * \bar{k}_{t,m,n}) + \bar{n}_{t,n} \quad (1)$$

MB-OFDM systems, a transmitted symbol $\bar{x}_{ZP,t,n}$ is created by $N_{ZPS} = 37$ is the length of zero padded symbol appended to every $\bar{x}_{OFDM,t,n}$ symbol at the transmitter. At

the receiver, before FFT an OAAO must be performed. $\mathbf{r}_{ZP,t,n}$ is the received symbol having N_{ZPS} samples, at the received symbol beginning $(N_{fft} + 1)$ to $(N_{fft} + N_{ZPS})$, are added. Then, to decode the transmitted symbol the first N_{fft} samples will be used. As a outcome, the received signal will be $\bar{r}_{ZP,t,n}$ after performing the OAAO in Equation (1) then the first N_{fft} resulting samples, denoted as $\bar{r}_{OFDM,t,n}$ the following equation will be

$$\bar{r}_{OFDM,t,n} = \sum_{m=1}^M (\bar{x}_{OFDM,t,m} * \bar{k}_{t,m,n}) + \bar{n}_{t,n} \quad (2)$$

For the circular convolution

$$\begin{aligned} & \bar{x}_{OFDM,t,m} * \bar{k}_{t,m,n} \\ &= IFFT\{FFT\{\bar{x}_1(OFDM, t, m)\} \cdot FFT\{\bar{k}_1(t, m, n)\}\} \\ &= IFFT\{\bar{S}_{t,m}\} \cdot \{\bar{k}_{t,m,n}\} \end{aligned} \quad (3)$$

Where $\bar{k}_{t,m,n}$ is N_{fft} point channel vector $\bar{k}_{t,m,n}$ i.e. $\bar{k}_{t,m,n} = FFT\{\bar{k}_{t,m,n}\}$

We denote^T. the no. of channel multipaths is smaller than the length of ZPS. In fact $N_{ZPS} = 37$ is much lesser than number of multipaths \bar{N}_p of UWB channels. This may attain a few thousands. Therefore exact quality will not emerge for this transmission, but an estimate.

After the FFT operation from Equation (2) and (3) at the receiver signal will be

$$FFT\{\bar{r}_{OFDM,t,n}\} = \sum_{m=1}^M \bar{S}_{t,m} \cdot \bar{k}_{t,m,n} + FFT\{\bar{n}_{t,n}\}$$

After FFT is applied to $\{\bar{r}_{OFDM,t,n}\}$ is

$$\mathbf{R}_t = \sum_{m=1}^M \bar{S}_{t,m} \cdot \bar{k}_{t,m,n} + FFT\{\bar{n}_{t,n}\}$$

It can be rewritten as $R_t = S_t K_t + N_t$ (4)

Channel coefficients implicit to be identified at the receiver for coherent detection, each MB-OFDM symbol $\bar{S}_{t,m}$ in this case, column vector sized as $(N-1)$, this can be decoded independently.

3. Proposed System Model

DSTFC MB OFDM UWB system is not essential channel estimation symbols for transmission is depicted in Figure 1, two novel blocks are introduced one is Multiplexing (MUX) block and other is De-Multiplexing (DEMUX) block. These two novel blocks are transparent

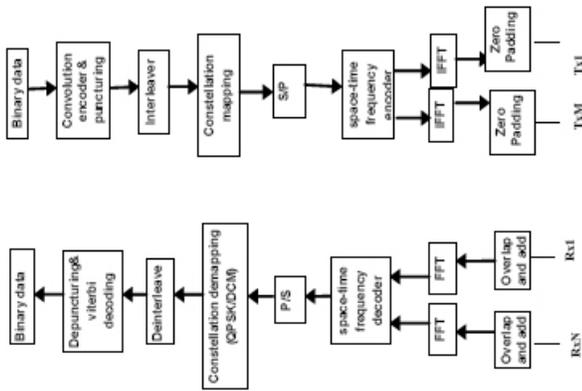


Figure 1. Space time frequency coding for MB-OFDM UWB system.

Table 1. Different multipaths N_p10dB , $N_p85\%$ and N_p

	CM1	CM2	CM3	CM4
N_p10dB	12.5	15.3	24.9	41.2
$N_p85\%$	20.8	33.9	64.7	123.3
N_p	287.9	739.5	1463.7	3905.5

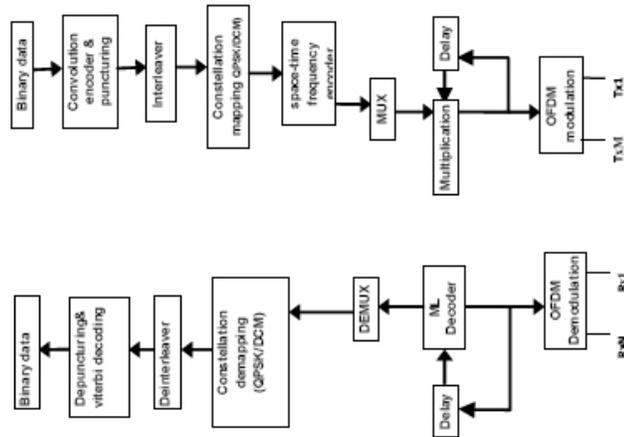


Figure 2. The proposed DSTFC MB-OFDM UWB system.

if the constant envelop modulation schemes (e.g., PSK and 64QAM) are used, but in DCM scheme the novel blocks are not transparent.

Let us consider the Alamouti STFC application.

$$M_t = \frac{1}{\sqrt{2}} \begin{bmatrix} \bar{m}_{t,1} & \bar{m}_{t,2} \\ -\bar{m}_{t,2}^* & \bar{m}_{t,1}^* \end{bmatrix} \quad (5)$$

Where $\bar{m}_{t,m}$ is the MB-OFDM symbol, for $m = 1, 2$. The symbols corresponding to N_{fft} sub-carriers, i.e., $\bar{m}_{t,m} = [m_{t,m,1} \ m_{t,m,2} \ \dots \ m_{t,m,N_{fft}}]^T$.

In DSTFC MB-OFDM systems, i.e., during $2KT_{SYM}$ (ns), where T_{SYM} is the MB-OFDM symbol interval $T_{SYM} = 312.5$ ns AND K is an integer number.

The STFC in equation (5) can be rewrite in the subsequent form

$$M_t = \frac{1}{\sqrt{2}} \begin{bmatrix} \text{diag}(\bar{m}_{t,1}) & \text{diag}(\bar{m}_{t,2}) \\ -\text{diag}(\bar{m}_{t,2}^*) & \text{diag}(\bar{m}_{t,1}^*) \end{bmatrix} \quad (6)$$

An identity matrix with the transmission is initialized by the proposed DSTFC MB-OFDM system $W_0 = I_2 N_{fft}$. The below code matrices will be generated and transmitted by the following rule

$$G_t = M_t * G_{t-1} \quad (7)$$

The transmission model of Equation (7) can be expressed as follows

$$R_t = G_t H_t + N_t \quad (8)$$

For transmission of K consecutive Alamouti STFC As channels are supposed to be regular throughout the transmission of K successive Alamouti STFC blocks, that means a time window $2KT_{SYM}$ (ns). The proposed DSTFC MB- OFDM concept would works good, when the channel coefficients are assumed to be constant all through at least two consecutive DSTFC blocks ($K \geq 2$).

3.1 64-QAM Modulation

Fast algorithm is the technique used to develop the power and capacity of the mobile communication system. Quadrature Amplitude Modulation is a modulation having two carriers shifted by 90 degrees in phase is modulated and the ensuing output consists of phase variations and amplitude. In M -array QAM, the data bits opt for amplitude and phase shifts, one of M combinations that are apply to the carrier. 64-QAM modulation is having 6 bits per symbol. Diversity techniques are the efficient way for combating channel fading and improve reliable system

Table 2. Differences between BPSK, QPSK, 8PSK, 16QAM, 32QAM, 64QAM

Modulation	Symbol Rate	BER
BPSK	1/1 bit rate	1
QPSK	1/2 bit rate	2
8PSK	1/3 bit rate	3
16QAM	1/4 bit rate	4
32QAM	1/5 bit rate	5
64QAM	1/6 bit rate	6

The combination with limited interleaving and channel coding will provide time diversity. Various replicas of the transmitted signal are spaced in time and the time spacing among transmissions exceeds the coherence time of the channel.

4. Decoding for DSTFC MB-OFDM System

4.1 Constant Envelope Modulation Schemes

The decoding method used for DSTFC is Maximum Likelihood (ML) decoding^[2]. In ML decoding signal constellations with constant envelopes, such as QAM

The STFC in Equation (7) can be represent in the subsequent form

$$\mathbf{S}_t = \frac{1}{\sqrt{2}} \sum_{n=1}^2 \sum_{k=1}^{N_{fft}} (L_{t,n,l} \mathbf{s}_{t,n,l}^R + i M_{t,m,k} \mathbf{s}_{t,n,l}^I) \quad (9)$$

Where the real part is $\mathbf{s}_{t,n,l}^R$ and the imaginary part is $\mathbf{s}_{t,n,l}^I$ of symbol $s_{t,n,l}$ and $L_{t,n,l}$ and $M_{t,n,l}$ are real, orthogonal matrices. The corresponding weighting matrices are $L_{t,n,l}$ and $M_{t,n,l}$

$$S_t S_t^H = I_{2N_{fft}}, G_t G_t^H = I_{2N_{fft}}$$

To make the ML decoding metric for the $S_{t,n,l}$ symbol regard as the following term

$$B_{n,l} = B_{n,l}^R + i B_{n,l}^I \quad (10)$$

Where $B_{n,l}^R = \Re\{\text{tr}(\mathbf{R}_{t-1} \mathbf{R}_t^H L_{t,n,l})\}$ and $B_{n,l}^I = \Re\{\text{tr}(\mathbf{R}_{t-1} \mathbf{R}_t^H i M_{t,n,l})\}$. We have

$$B_{n,l}^R = \Re\{\text{tr}(\mathbf{R}_{t-1} \mathbf{R}_t^H L_{t,n,l})\} = \Re\{\text{tr}\left[\left((G_{t-1} K_t K_t^H G_{t-1}^H \mathbf{S}_t^H) + \mathbf{N}\right) L_{t,n,l}\right]\} \quad (11)$$

Let us consider the following term

$$B_{n,l} = B_{n,l}^R + i B_{n,l}^I \quad (12)$$

Where $B_{n,l}^R = \Re\{\text{tr}(\mathbf{R}_{t-1} \mathbf{R}_t^H \mathbf{X}_{t,n,l})\}$ and $B_{n,l}^I = \Re\{\text{tr}(\mathbf{R}_{t-1} \mathbf{R}_t^H i \mathbf{Y}_{t,n,l})\}$. The below equation will be

$$B_{n,l}^R = \Re\{\text{tr}\left[\left(\mathbf{W}_{t-1} K_t K_t^H \mathbf{W}_{t-1}^H \mathbf{S}_t^H\right) + \mathbf{N}\right] L_{t,n,l}\} \quad (13)$$

Where $\mathbf{N} = \mathbf{W}_{t-1} \mathbf{H}_{t-1} \mathbf{N}_t^H + \mathbf{N}_{t-1} \mathbf{H}_t^H \mathbf{W}_t^H + \mathbf{N}_{t-1} \mathbf{N}_t^H$. During the transmission window, channel coefficients are constant. i.e., $\mathbf{H}_t = \mathbf{H}_{t-1}$.

Because \mathbf{S}_t and \mathbf{W}_{t-1} are square unitary matrices \mathbf{S}_t and G_{t-1} of size $2N_{fft}$ the weighting matrix of $\mathbf{s}_{t,n,l}^R$ is $\mathbf{X}_{t,n,l}$. Equation (13) becomes

$$B_{n,l}^R = \Re\{\text{tr}\left[\left(K_t K_t^H\right) \left(\mathbf{S}_t^H L_{t,n,l}\right)\right]\} + \Re\{\text{tr}(\mathbf{N} L_{t,n,l})\} \quad (14)$$

The first term in Equation (13) is calculated from Equation (9), as follows

$$L_{t,n,l}^H L_{t,n,l} \mathbf{s}_{t,n,l}^R \mathbf{s}_{t,n,l}^R + \sum_{\forall \tilde{n}, \tilde{l}, \{\tilde{n}, \tilde{l}\} \neq \{n, l\}} L_{t,n,l} L_{t,n,l} \mathbf{s}_{t,n,l}^R \mathbf{s}_{t,n,l}^R$$

From the weighting matrices properties for given value t . $\left(L_{t,n,l}^H L_{t,n,l} \mathbf{s}_{t,n,l}^R \mathbf{s}_{t,n,l}^R\right)^H = -\left(L_{t,n,l}^H L_{t,n,l} \mathbf{s}_{t,n,l}^R \mathbf{s}_{t,n,l}^R\right)$,

i.e., $\left(L_{t,n,l}^H L_{t,n,l} \mathbf{s}_{t,n,l}^R \mathbf{s}_{t,n,l}^R\right)$ is an antihermitian matrix, Thus

$$\Re\{\text{tr}\left[\left(K_t K_t^H\right) \left(L_{t,n,l}^H L_{t,n,l} \mathbf{s}_{t,n,l}^R \mathbf{s}_{t,n,l}^R\right)\right]\} = 0 \quad (16)$$

If Θ is a Hermitian matrix then it follows condition that $\Theta^H = \Theta$, then $\text{tr}(\mathbf{A}^H \mathbf{A} \Theta)$ is real value, thus $\Re\{\text{tr}(\mathbf{A}^H \mathbf{A} \Theta)\} = 0$. From Equation (16)

It can be realize that

$$\left(M_{t,n,l}^H L_{t,n,l} \mathbf{s}_{t,n,l}^I \mathbf{s}_{t,n,l}^I\right)^H = \left(L_{t,n,l}^H M_{t,n,l} \mathbf{s}_{t,n,l}^I \mathbf{s}_{t,n,l}^I\right)$$

i.e., $\left(M_{t,n,l}^H L_{t,n,l} \mathbf{s}_{t,n,l}^I \mathbf{s}_{t,n,l}^I\right)$ is a Hermitian matrix, thus

$$\Re\{\text{tr}\left[\left(K_t K_t^H\right) \left(\mathbf{Y}_{t,n,l}^H \mathbf{X}_{t,n,l} \mathbf{s}_{t,n,l}^I \mathbf{s}_{t,n,l}^I\right)\right]\} = 0 \quad \forall n, l, \tilde{n}, \tilde{l} \quad (17)$$

Let denote

$$\mathbf{C}_{t,n,l} = \left(K_t K_t^H\right) \left(L_{t,n,l}^H L_{t,n,l}\right)$$

Then $\mathbf{C}_{t,n,l}$ for values t, m and k then it is a constant matrix.

$$B_{n,l}^R = \frac{1}{\sqrt{2}} \text{tr}(\mathbf{C}_{t,n,l}) \mathbf{s}_{t,n,l}^R + \Re\{\text{tr}(\mathbf{N} L_{t,n,l})\}$$

$B_{n,l}^I$ term is calculated in a same way from Equation (12)

$$\mathbf{C}_{t,n,l} = \left(K_t K_t^H\right) \left(L_{t,n,l}^H L_{t,n,l}\right) = \left(K_t K_t^H\right) \left(M_{t,n,l}^H M_{t,n,l}\right)$$

We have $B_{n,l}^I = \frac{1}{\sqrt{2}} \text{tr}(\mathbf{C}_{t,n,l}) \mathbf{s}_{t,n,l}^I + \Re\{\text{tr}(\mathbf{N}_i \mathbf{Y}_{t,n,l})\}$

Therefore

$$D_{n,l} = D_{n,l}^R + i D_{n,l}^I = \frac{1}{\sqrt{2}} \text{tr}(\mathbf{C}_{t,n,l}) \mathbf{s}_{t,n,l} + \Re\{\text{tr}(\mathbf{N} \mathbf{X}_{t,n,l})\} + i \Re\{\text{tr}(\mathbf{N}_i \mathbf{Y}_{t,n,l})\} \quad (18)$$

The ML decoding can be derived for $s_{t,n,l}$ metric as follows

$$s_{t,n,l} = \arg \min \left| D_{n,l} - \frac{1}{\sqrt{2}} \text{tr}(\mathbf{C}_{t,n,l}) \mathbf{s}_{t,n,l} \right|^2 = \arg \min \left(|D_{n,l}|^2 + \frac{1}{2} \left(\text{tr}(\mathbf{C}_{t,n,l})\right)^2 - \sqrt{2} \text{tr}(\mathbf{C}_{t,n,l}) \Re\{D_{n,l}^* \mathbf{s}_{t,n,l}\} \right)$$

$$\hat{s}_{t,n,l} = \arg \min \left| D_{n,l} - \frac{1}{\sqrt{2}} \text{tr}(\mathbf{C}_{t,n,l}) \mathbf{s}_{t,n,l} \right|^2 = \arg \min \left(|D_{n,l}|^2 + \frac{1}{2} \left(\text{tr}(\mathbf{C}_{t,n,l})\right)^2 - \sqrt{2} \text{tr}(\mathbf{C}_{t,n,l}) \Re\{D_{n,l}^* \mathbf{s}_{t,n,l}\} \right) \quad (19)$$

Since $\mathbf{C}_{t,n,l}$ is a stable matrix for a given t, n and l and because $\text{tr}(\mathbf{C}_{t,n,l})$ is real number.

$$\hat{s}_{t,n,l} = \arg \max_{s_{t,n,l} \in \mathcal{C}} \Re\{D_{n,l}^* \mathbf{s}_{t,n,l}\} \quad (20)$$

Where $\bar{S}_{t,1}$ and $\bar{S}_{t,2}$ are the two MB-OFDM symbols can decoded independently. As a replacement for equally

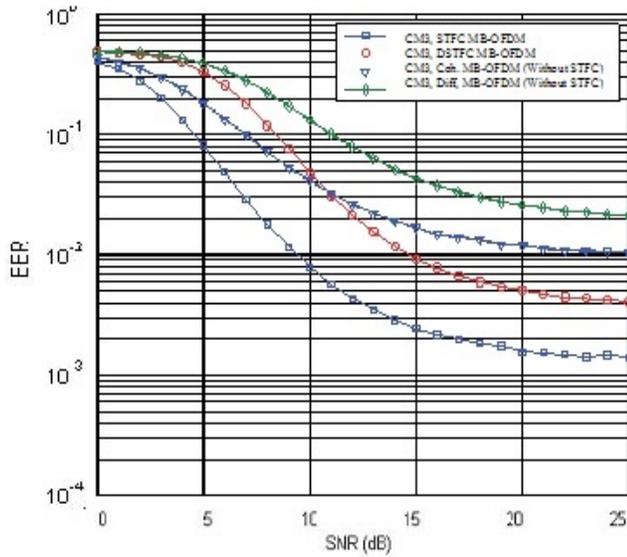


Figure 3. Comparison among STFC MB-OFDM, DSTFC MB-OFDM, Coherent MB-OFDM (without STFC), differential MB-OFDM (without STFC) With QPSK.

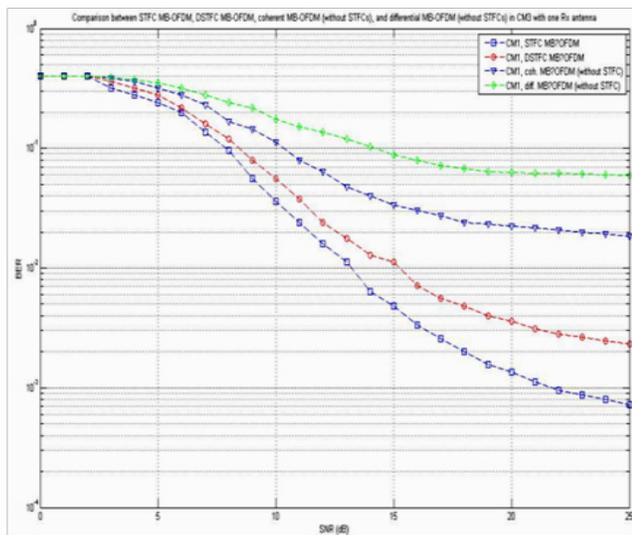


Figure 4. Comparison between STFC MB-OFDM, DSTFC MB-OFDM, coherent MB-OFDM (without STFC), differential MB-OFDM (without STFC) with 64QAM.

decoding all $2^{N_{fft}}$ symbols $S_{t,m,l}$ within $\bar{S}_{t,1}$ and $\bar{S}_{t,2}$ at a time, every symbol can be separately decoded. The decoding process does not require CSI.

5. Simulation Results

Simulation was prepared on MATLAB R2010a, the outcome was shown that the BER performance is superior

compared to conventional methods. To study improvement of the proposed DSTFC MB-OFDM.

Figure 3 provides the relationship between STFC MB-OFDM, DSTFC MB-OFDM, Coherent MB-OFDM (without STFC), D-MB-OFDM (without STFC).

Above figure provides the relationship between different techniques and One can examine that the differential as well as coherent MB-OFDM systems are have the same diversity orders and there exists single 3db as a penalty of omitted CSI next to the receiver.

6. Conclusions

Differential Space Time Frequency Codes (DSTFC's) based on 64QAM (Quadrature Amplitude Modulation) for MB-OFDM UWB communications have been used effectively for increasing the system bandwidth efficiency. without any increase of total transmission power this development is achieved. The proposed DSTFC principle may be applied to further wireless systems such as Wi-Max-MIMO.

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