MIMO MC-CDMA with Differential Unitary Space Time Frequency Modulation In High Mobility Scenario

Dhoni Putra Setiawan, Rina Pudji Astuti, Sugihartono
School of Electrical Engineering, Telkom University, Bandung, Indonesia

***Abstract*— Transmission techniques with coherent receiver that is widely employed nowadays need good channel estimation to give good transmission performance. However, there are conditions where channel information practically cannot be acquired, for example, when the channel condition is rapidly changing. Non coherent scheme without channel information is considered as the most potential scheme to combat this kind of channel condition. In this paper the combination between MC-CDMA and Differential Unitary Space Time Frequency Modulation (DUSTFM) with non-coherent detection process for downlink transmission side is analysed. The simulations result show non-coherent transmission scheme combining MIMO MC-CDMA and DUSTFM is a very potential scheme for high mobility scenario.**

***Index Terms*—MIMO, differential modulation, STFC, DUSTF, MC-CDMA**

I. Introduction

Modern communication systems require high data rate and high mobility communication which has good performance, good resistance to errors and good spectral efficiency. Multicarrier transmission technique is the most potential technology to realize high data rate communication system. Multicarrier technique can mitigate the frequency selective fading, make it possible to implement a broadband communication system. Multicarrier transmission schemes that widely used nowadays need channel state information (CSI) to help receiver recovering the original transmitted symbols. However, in high mobility condition, when the channel condition change rapidly, it makes the channel information becomes inaccurate. The used of pilots also makes the spectral efficiency become worse. For this kind of condition non-coherent transmission scheme (with differential modulation), without CSI and pilots, would be the most potential scheme. [1][2][3]

Many non-coherent transmission schemes that is using Differential Modulation technique for various communication systems have been proposed to transmit data without knowing the channel condition. For multi in multi out (MIMO) system several non-coherent schemes with differential modulation has been proposed; for example Differential Space Time Block Code (DSTBC)[4][5][6], Differential Unitary Space Time Modulation (DUSTM)[7][8], Differential Unitary Space Time Frequency Modulation (DUSTFM)[1][3][9] and also Differential Unitary Space Time Modulation [10]. The performance of LTE with differential modulation also has been analysed in [2].

In this paper the performance of modified multicarrier Code Division Multiple Access (MC-CDMA) scheme, which is combination between Orthogonal Frequency Division Multiplexing (OFDM) and CDMA scheme with Differential Unitary Space Time Frequency Modulation (DUSTFM) for high mobility scenario on downlink side is analysed. The combination between MC-CDMA and DUSTFM scheme is expected to give good performance transmission in high mobility condition. The DUSTFM scheme that has been proposed by Tran [1] is assumed every antenna uses different frequency band, while in this paper all antennas use one frequency band. Therefore a symbol detection technique to separate the transmitted symbols from different transmitters without channel estimation is introduced in this paper.

This paper is organized as follows: Section II describes the system model, the transmitter model that adopted from [1] including the DUSTFM and MC-CDMA model, the channel model, and the receiver model that employ maximum likelihood detection. Section III shows the result of the proposed system. The result of the proposed system in this paper is compared with the conventional differential modulation, conventional differential modulation combined with STFC and also non-coherent OFDM scheme. Section IV is the conclusion.

II. System Model

The model that is proposed in this paper is basically used to exploit the merits between MIMO, MC-CDMA and DUSTFM that is a combination between unitary STFC and differential modulation to achieve high quality transmission performance on high mobility scenario, where the present of CSI become inaccurate or uneconomical with the use of pilots [1][3]. The basic concept of the proposed system is shown in Fig. 1 and Fig. 2 represents the MC-CDMA model.

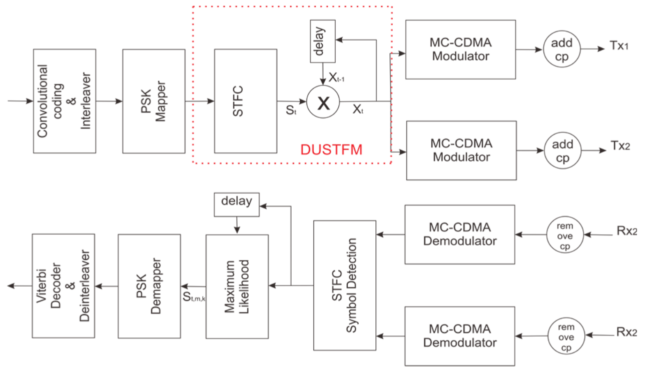

Figure 1. General model of MC-CDMA with DUSTFM

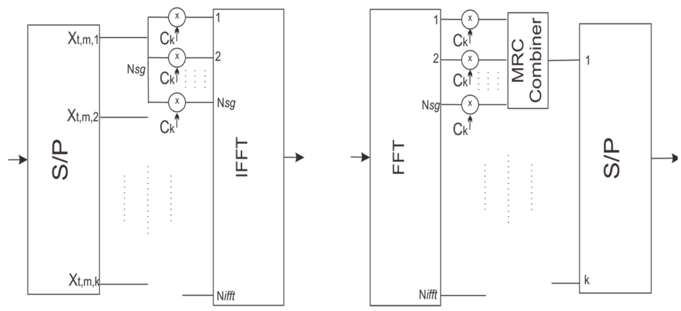

Figure 2. MC-CDMA model [12]

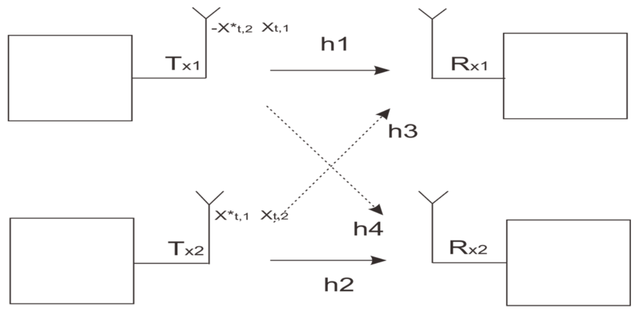

Figure 3. Channel model MIMO 2x2.

A. Transmitter

STFC formula for two transmit antennas as explained in the [1], is modified from STBC Alamouti:

$$S_t = \frac{1}{\sqrt{2}}\begin{bmatrix} S_{t,1} & S_{t,2} \\ -S_{t,2}^* & S_{t,1}^* \end{bmatrix} \quad (1)$$

The components of STFC's matrix are symbolized as $s_{t,m}$ matrix, where t represents the transmission time and $m = 1,2$ is the antenna number. $s_{t,m}$ is a column matrix size (N_{par} x 1), and N_{par} represent the number of parallel data entering the MC-CDMA Modulator. $s_{t,m} = [s_{t,m,1}, s_{t,m,2}, \ldots s_{t,m,k}]^T$, where k=1, ... N_{par}

Then the STFC matrix [1] can be written as follows:

$$S_t = \frac{1}{\sqrt{2}}\begin{bmatrix} diag(S_{t,1}) & diag(S_{t,2}) \\ diag(-S_{t,2}^*) & diag(S_{t,1}^*) \end{bmatrix} \quad (2)$$

This STFC can be represented into following form [1]:

$$S_t = 1/\sqrt{2}\sum_{m=1}^{m}\sum_{k=1}^{N_{fft}} Y_{t,m,k}S_{t,m,k}^R + iZ_{t,mk}S_{t,m,k}^I \quad (3)$$

$Y_{t,m,k}$ and $Z_{t,m,k}$ represent the weighting matrix of STFC. Then, the DSTFC symbol calculation process can be written as:

$$X_t = S_t X_{t-1} \quad (4)$$

The first DSTFC symbol, X_1, is the same as STFC symbol S_1, because there is no transmitted DSTFC symbol before X_1.

In MC-CDMA modulator the input DSTFC Symbols are copied N_{sg} times, N_{sg} itself represent the number of spreading gain that used in the system and in the MC-CDMA Demodulator MRC combiner is used to combine each of N_{sg} parallel symbols. Therefore, the number of subcarrier that used is $N_{fft} = N_{par}N_{sg}$.

B. Receiver

The general model of the received signal is represented as:

$$R_t = X_t H_t + N_t \quad (5)$$

Where, the received symbol of 2x2 MIMO that employing the same frequency band between Tx1 and Tx2, and also Rx1 and Rx2 represent as follows:

$$\begin{bmatrix} r_{1,1} \\ r_{1,2} \end{bmatrix} = \begin{bmatrix} h_1 & h_3 \\ h_4 & h_2 \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} \quad (6)$$

We consider the received DSTFC symbols in the receiver is $r_{t,m}$ where t represents the time, and m represents the antenna number, therefore $r_{1,1}$ is DSTFC's symbol in the time 1 and antenna 1, and $r_{1,2}$ is the received symbol in the time 1 and antenna 2.

The transmitted DSTFC symbols X_t could be written as follows because of the consistent form of the X_t matrix after the differential calculation process as it has been proven at [1].

$$X_t = \begin{bmatrix} X_{t,1} & X_{t,2} \\ -X_{t,2}^* & X_{t,1}^* \end{bmatrix} \quad (7)$$

Because of this condition, the received DSTFC symbols can be written as:

$$\begin{aligned} r_{1,1} &= X_{t,1}h_1 + X_{t,2}h_3 + N_t \\ r_{1,2} &= X_{t,1}h_4 + X_{t,2}h_2 + N_t \\ r_{2,1} &= -X_{t,2}^*h_5 + X_{t,1}^*h_7 + N_t \\ r_{2,2} &= -X_{t,2}^*h_8 + X_{t,1}^*h_6 + N_t \end{aligned} \quad (8)$$

The channel coefficients h_5, h_6, h_7, h_8 respectively, are the channel coefficients in the time 2, after h_1, h_2, h_3, h_4 in the time 1, and N_t is the coefficient matrix's of noise. Although the channel coefficient for differential modulation usually assumed to be the same for at least two consecutive symbols, in this paper the channel coefficient is assumed to be different because the channel condition is assumed to change rapidly.

Therefore the received symbol matrix can be written as follows:

$$R_t = \begin{bmatrix} X_{t,1}h_1 + X_{t,2}h_3 + N_t & X_{t,1}h_4 + X_{t,2}h_2 + N_t \\ -X_{t,2}^*h_5 + X_{t,1}^*h_7 + N_t & -X_{t,2}^*h_8 + X_{t,1}^*h_6 + N_t \end{bmatrix}$$

Which is, (9)

$$R_t = \begin{bmatrix} r_{1,1} & r_{1,2} \\ r_{2,1} & r_{2,2} \end{bmatrix}$$

For the decoding process in order to this received DSTFC symbol can be decoded successfully without channel information in the receiver, the form of R_t must be formed into similar form as X_t matrix as follows:

$$D_t = \begin{bmatrix} r_{1,1} + r_{2,1}^* & r_{1,2} - r_{2,2}^* \\ r_{2,2} - r_{1,2}^* & r_{2,1} + r_{1,1}^* \end{bmatrix} \quad (10)$$

D_t is the received DSTFC matrix X_t that has been effected by the fading channel. The addition between the received $r_{t,m}$ components is chosen based on which symbols that are received in the same antenna, because even though the channel change very fast but the channel coefficient between t and $t-1$ still have a lot of similarity.

For Maximum Likelihood decoding for STFC decoding in this system we consider the following term:

$$C_t = C_t^R + iC_t^I \quad (11)$$

Where,

$$C_t^R = D_{t-1}^H D_t Y_{t,m,k}$$
$$C_t^I = D_{t-1}^H D_t Z_{t,m,k} \quad (12)$$

From the equations above, we can decode the $C_{t,m}$ matrix that is the received matrix from the transmitted $diag(S_{t,m})$. $C_{t,m}$ matrix diagonal matrix with the components of each diagonal node (non-zero components) is the $c_{t,m,k}$.

$$C_{t,1} = C_t(1,1) + C_t(2,2)$$
$$C_{t,2} = C_t(1,2) + C_t(2,1) \quad (13)$$

For the maximum likelihood decoding we consider $\Re(a)$ and $\Im(a)$ are the symbol to denote the Real and Imaginary parts of a complex number a. Finally, maximum likelihood decoding for $\hat{s}_{t,m,k}$ as the received symbols can be written as follow:

$$\hat{s}_{t,m,k} = \arg min_{s_{t,m,k} \in C} \{ (\Re|c_{t,m,k} - s_{t,m,k}|)^2 + (\Im|c_{t,m,k} - s_{t,m,k}|)^2 \} \quad (14)$$

This maximum likelihood detection is only suitable when BPSK or QPSK is used as mapper.

III. Simulation Result

Table 1 shows the simulation parameter of our system, the main system is MC-CDMA with DUSTFM with 2 times of spreading gain, and the mapper is BPSK.

TABLE I
SIMULATION PARAMETERS

Parameter	Value
Subcarrier	256
Carrier	2.6Ghz
Subcarrier Spacing	15khz
Number of Data	10 Million bits
Channel Model	Rayleigh fading channel
Channel Coding	Convolutional Coding (1/2) Viterbi Decoder
STFC decoding at nodes	Maximum Likelihood decoding
Vehicle speed	350 km/h
Mapper	QPSK, BPSK
Spreading Gain	No Spreading (OFDM), 2x, 4x, 8x
Cyclic Prefix	25% of subcarrier

Fig. 4 shows the simulation result of OFDM compared to MC-CDMA scheme with different number of spreading gain as comparison. Both of OFDM and MC-CDMA is simulated using our proposed scheme. The number subcarrier (N_{fft}) is set constant 256 subcarriers, while every additional of spreading gain (N_{sg}) the number of N_{par} is proportionally decreasing. As shown in the Fig. 4, MC-CDMA clearly overcomes the performance of OFDM. At BER 10^{-3} MC-CDMA with 2 times of spreading gain could give gain about 2dB compared to OFDM, and every addition of spreading gain, at least 2dB of gain is given by MC-CDMA at BER 10^{-3}. It is also shown that the performance of both MC-CDMA and OFDM when both of them are using the proposed scheme is almost comparable in high SNR.

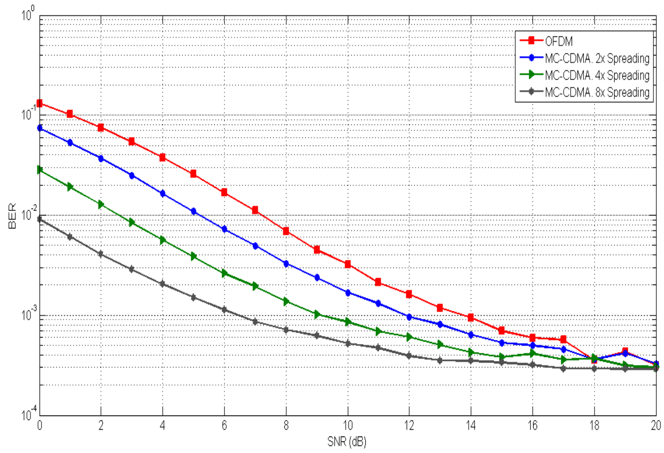

Figure 4. MC-CDMA with DUSTFM vs OFDM with DUSTFM

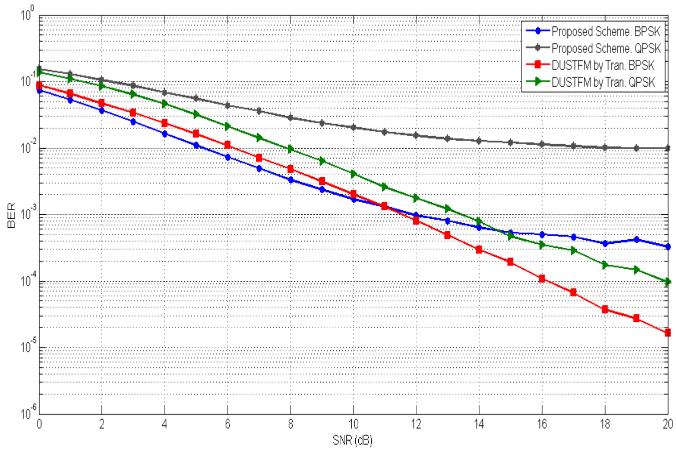

Figure 5. Proposed scheme vs Reference Scheme by Tran [1]

Fig.5 shows the performance comparison between the proposed scheme against the main reference scheme that has been proposed by Tran [1]. This figure shows how effective is the proposed symbol detection method. As shown above, the performance of the proposed system when BPSK is used as mapper, can overcomes Tran's [1] in low SNR bellow 11dB. However, while using QPSK as mapper, the performance is significantly decreased. The BER performance of our proposed scheme with QPSK as mapper only reaches bellow 10^{-2} while the SNR is higher than 17dB. This condition shows that the proposed symbol detection is not good enough to decode the QPSK symbol and higher order PSK mapper, which is the symbol, is represented by both real and imaginary number.

For 2x1 MISO scheme in combining with DUSTFM, a similar decoding model with proposed system is applied to decode the transmitted signal. However the result of this scheme as shown in the Fig. 6, the performance is even worse than conventional differential modulation. Fig. 6 also shows that the performance of the proposed scheme is clearly better than conventional differential modulation. At BER 10^{-2} the proposed scheme can give 5dB of gain compared to the conventional differential modulation. Fig. 6

also shows the usage of convolutional coding and interleaver in the proposed scheme could give gain about 3dB at BER 10^{-3}, this is almost the same with the gain that is given by using twice more spreading gain in the proposed scheme, for the record, both of them have the same spectral efficiency.

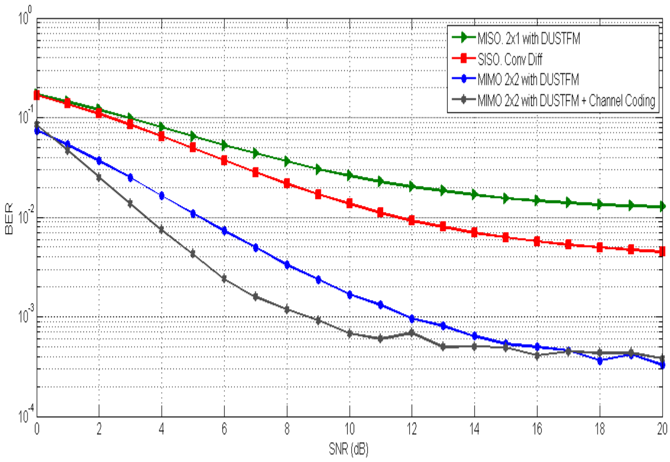

Figure 6. 2x2 MIMO MC-CDMA vs 2x1 MISO MC-CDMA vs MC-CDMA Convolutional Differential Modulation

IV. CONCLUSION

In this paper a symbol detection method without channel estimation is added to improve the DUSTFM scheme, result in all transmitters and receivers could operate in the same frequency band. As shown in the Section III the symbol detection method works well when BPSK is used as mapper but could not work well when QPSK is used as mapper. When BPSK is used as mapper the performance of the proposed scheme in low SNR is comparable with the performance of DUSTFM that has been proposed in [1] which uses 2 times wider bandwidths. Even though when BPSK is used as mapper the proposed scheme performance is worse than our main reference [1] in high SNR, but in case of high mobility condition which the probability of low SNR is very high, the proposed scheme has pretty much met our expectation.

MC-CDMA in combining with DUSTFM in this paper is shown could become a very potential scheme to combat against rapidly channel change, when the user is in high mobility condition. The bigger spreading gain in the MC-CDMA scheme naturally can improve the system performance but in the same time it decreases the spectral efficiency, therefore the number of spreading gain must be chosen wisely. An adaptive spreading gain technique can become an interesting technique for the future MC-CDMA scheme.

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