Multi-Antenna Uplink Transmission for LTE-A

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***Abstract*—Clustered DFT-S-OFDM has been accepted as the uplink multiple access scheme for LTE-Advanced. In this paper, a new transmit diversity with four transmit antennas is proposed for Clustered DFT-S-OFDM system. A modified Frequency Switched Transmit Diversity (FSTD) algorithm is proposed, where the multiple clusters can be divided into two groups by four antennas, thus the number of clusters on each antenna will be reduced. As a result, the PAPR performance of each antenna has been improved. Meanwhile, in order to obtain additional frequency diversity gain, the proposed scheme has introduced more channels by a symbol-based dynamic cluster allocation method, which makes one turbo coded stream transmitted multiple channels. Moreover, the Space-Time Block Coding (STBC) is employed for the two antennas in each group to achieve spatial diversity and coding gain. Simulation results show that the proposed scheme has good PAPR and Bit Block Error Rate (BLER) performance on frequency selective MIMO channels**.

I. INTRODUCTION

Single carrier frequency division multiple access (SC-FDMA) can be regarded as discrete Fourier transform (DFT)-spread OFDMA, where time domain data symbols are transformed to frequency domain by DFT before going through OFDMA modulation [1-2]. One prominent advantage over OFDMA is that the SC-FDMA has lower PAPR because of its inherent single carrier structure [3]. SC-FDMA has drawn great attention as an attractive alternative to OFDMA, especially in the uplink communications where lower PAPR greatly benefits the mobile terminal in terms of transmit power efficiency. It is currently a strong candidate for uplink multiple access scheme in 3G Long Term Evolution of 3GPP [4].

In LTE-Advanced, bandwidth is wider than that of LTE. SC-FDMA was adopted as LTE uplink multiple access scheme, which allows only continuous resource allocation. However, continuous resource allocation will not make full use of multi-user diversity in broadband channel. Therefore Clustered DFT-S-OFDM has been adopted as standard technology for LTE-Advanced [5-6]. With Clustered DFT-S-OFDM, output of DFT is allowed to be mapped to multiple clustered resource blocks in frequency domain. Although this feature provides more frequency diversity gain, it has the disadvantage of increasing the PAPR compared with SC-FDMA.

The use of Multiple Input Multiple Output (MIMO) techniques in future wireless systems is inevitable. The presence of multiple antennas both at the transmitter and at the receiver side opens the way to significant improvements towards meeting the ever higher demands in data rate and reliability. In future generation wireless communications networks, mobile terminals used for data transmission will be equipped with multiple antennas (typically 2 or 4), that can be used for various reasons: increasing throughput, increasing diversity and/or reduce interference from other users. Transmit diversity techniques [7-9] have lately gained much attention, and are very attractive especially in the case of a terminal with bad propagation conditions (e. g., located at cell edge), whose priority will not necessarily be increasing data rate by spatial multiplexing, but rather increasing diversity and coverage by spatial precoding. When only two transmit antennas are available, the well known Alamouti scheme [7] gives a very simple and elegant orthogonal design which does not increase the throughput but provides full diversity. However, it is incompatible with the low PAPR constraints. An improved STBC is proposed to keep the single carrier nature of SC-FDMA [10]. When for more than 2 transmit antennas, it has been proven that complex orthogonal designs with full diversity and transmission rate one are not possible. Joint STBC [10] with FSTD [9] for more than two transmit antennas have already been introduced [11]. In this scheme [11], each cluster has transmitted over one antenna to mitigate the PAPR. However, this also lost some frequency diversity gain compared with Clustered DFT-S-OFDM.

Motivated by the above issues, we propose an enhanced transmit diversity scheme with four transmit antennas for Clustered DFT-S-OFDM to reduce the PAPR meanwhile provide good BLER performance. First, a modified FSTD algorithm is proposed, in which a dynamic cluster grouping scheme is introduced into FSTD to resolve the PAPR problem for Clustered DFT-S-OFDM. Second, to enhance the performance, the STBC transmit diversity is applied to the two antennas of each group. We remark that, we only consider two DFT blocks. It is straightforward to apply the proposed scheme for the cases with more than two clusters. The simulation results prove that the proposed scheme outperforms the transmit diversity [11] in sense of BLER performance. The remainder of this paper is organized as follows: Section II introduces the system model of Clustered DFT-S-OFDM. Section III presents the existing transmit diversity scheme and our proposed scheme. Simulation results are given in section IV. Finally, conclusion is given in section V.

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II. SYSTEM MODEL

We consider Clustered DFT-S-OFDM system for two clusters with same size, which is shown in Fig.1. One turbo coded and modulated stream $\mathbf{b}=\{b_0,\cdots,b_{M-1}\}$ performs M-point DFT operation, and obtain corresponding one block of M DFT samples as $\mathbf{B}=\{B_0,B_1,\cdots,B_{M-1}\}$, where

$$B_i=\sum_{m=0}^{M-1} b_m e^{\frac{-j2\pi mi}{M}} \quad (1)$$

After DFT operation, $\mathbf{B}$ is split into two clusters as $\mathbf{X},\mathbf{Y}$ with size L=M/2 , where

$$\mathbf{X}=\{X_i \mid X_i=B_i, i=0,\cdots,L-1\} \quad (2)$$

$$\mathbf{Y}=\{Y_i \mid Y_i=B_{i+L}, i=0,\cdots,L-1\} \quad (3)$$

$\mathbf{X}$ and $\mathbf{Y}$ are mapped to the first frequency band and second frequency band respectively to obtain the subcarrier set $\mathbf{S}=\{S_0,\cdots,S_{N-1}\}$ as follows

$$S_k=\begin{cases} X_i, & k=i+k_1, i=0,\cdots,L-1 \\ Y_i, & k=i+k_2, i=0,\cdots,L-1 \\ 0, & otherwise \end{cases} \quad (4)$$

where subcarriers through k_1 to k_1+L-1 and k_2 to k_2+L-1 are active, and since the two frequency bands are not adjacent thus k_1 and k_2 are satisfied with $|k_1-k_2|>L$. The deactivated subcarrier is equivalent to zero padding. The transmitted single carrier signal at sample time n is given by

$$s_n=\frac{1}{\sqrt{N}}\sum_{k=0}^{N-1} S_k e^{\frac{j2\pi nk}{N}}, n=0,\cdots,N-1 \quad (5)$$

where N is the IFFT size.

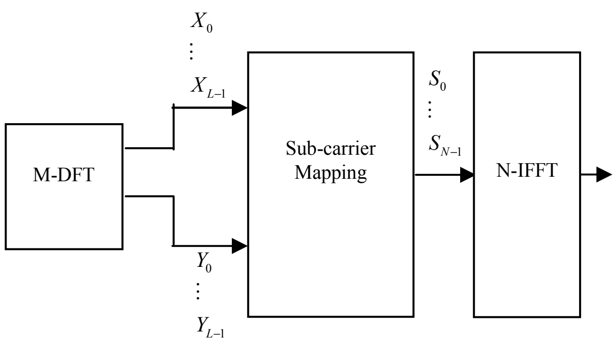

Fig.1 Transmit structure of Clustered DFT-S-OFDM

The PAPR of the transmitted signal of(5) is defined as

$$\mathrm{PAPR}=\frac{\max|s_n|^2}{E[|s_n^2|]} \quad (6)$$

Here E [·] denotes the expected value. Then, the complementary cumulative distribution function (CCDF) of he PAPR for a given level PAPR_0, is the probability that the PAPR of a symbol exceeds the given threshold PAPR_0, which can be expressed as

$$\mathrm{CCDF}=\Pr(\mathrm{PAPR}>\mathrm{PAPR}_0) \quad (7)$$

It is known that in existing Clustered DFT-S-OFDM, the two clusters of data are mapped to the two frequency bands which include the subcarriers from k_1 to k_1+L-1 and k_2 to k_2+L-1. This non-contiguous resource block allocation provides more frequency diversity gain in frequency selective channels. However it has the disadvantage of increasing PAPR, compared with SC-FDMA.

III. TRNSMIT DIVERSITY TECHNIQUE

In this section, we shall analyze the existing transmit diversity method for four transmit antennas [11] as well as the proposed transmit diversity scheme.

A. The existing transmit diversity scheme

The transmitter structure of the improved STBC [10] with FSTD for Clustered DFT-S-OFDM is shown in Fig.2. In this scheme, space-time coding is made such that the symbols in one group of L-point DFT output are Alamouti coded with the corresponding symbols of the adjacent next group of L-point DFT output, e.g. X_0 and X_L, X_1 and X_{L+1}, and so on, and the coded symbols are mapped to two adjacent symbols of two transmit antennas as shown in this figure. Actually, the coding and mapping scheme can be regarded as a special Alamouti coding [7], which is based on two vectors rather than two scalar symbols. The special Alamouti coding can be represented as

$$\begin{bmatrix} \mathbf{C}_1 & -\mathbf{C}_2^* \\ \mathbf{C}_2 & \mathbf{C}_1^* \end{bmatrix} \quad (8)$$

where $\mathbf{C}_1=[X_0,\cdots,X_{L-1}]^T$ and $C_2=[X_L,\cdots,X_{2L-1}]^T$ represent two successive L-point DFT output vectors. In(8), the rows correspond to the two transmit antennas and the columns correspond to the two adjacent symbols. Thus the two symbol vectors mapped to the two symbols of the first antenna can be denoted as

$$\mathbf{Q}^{1,1}=[X_0,\cdots,X_{L-1}] \quad (9)$$

$$\mathbf{Q}^{1,2}=[-(X_L)^*,\cdots,-(X_{2L-1})^*] \quad (10)$$

And the symbols vectors mapped to the two symbols of the second transmit antenna can be represented as

$$\mathbf{Q}^{2,1}=[X_L,\cdots,X_{2L-1}] \quad (11)$$

$$\mathbf{Q}^{2,2}=[X_0^*,\cdots,X_{L-1}^*] \quad (12)$$

Similarly, the same operation is performed on $\mathbf{Y}$, and the two symbol vectors mapped to the two symbols of the third antenna can be denoted as

$$\mathbf{Q}^{3,1}=[Y_0,\cdots,Y_{L-1}] \quad (13)$$

$$\mathbf{Q}^{3,2}=[-(Y_L)^*,\cdots,-(Y_{2L-1})^*] \quad (14)$$

And the symbols vectors mapped to the two symbols of the fourth transmit antenna can be represented as

$$\mathbf{Q}^{4,1}=[Y_L,\cdots,Y_{2L-1}] \quad (15)$$

$$\mathbf{Q}^{4,2}=[Y_0^*,\cdots,Y_{L-1}^*] \quad (16)$$

After STBC operation, $\mathbf{Q}^{1,1}$ and $\mathbf{Q}^{1,2}$ are mapped to the two time intervals of the first frequency band on the first antenna denoted by $\mathbf{S}^{1,1}=\{S_0^{1,1},\cdots,S_{N-1}^{1,1}\}$ and $\mathbf{S}^{1,2}=\{S_0^{1,2},\cdots,S_{N-1}^{1,2}\}$ as follows

$$S_k^{1,1}=\begin{cases}Q_i^{1,1}, & k=i+k_1, i=0,\cdots,L-1\\ 0, & otherwise\end{cases} \tag{17}$$

$$S_k^{1,2}=\begin{cases}Q_i^{1,2}, & k=i+k_1, i=0,\cdots,L-1\\ 0, & otherwise\end{cases} \tag{18}$$

where $Q_i^{1,1}$ and $Q_i^{1,2}$ are the ith element of vector $\mathbf{Q}^{1,1}$ and $\mathbf{Q}^{1,2}$. Meanwhile, $\mathbf{Q}^{2,1}$ and $\mathbf{Q}^{2,2}$ are mapped to the two time intervals of the first frequency band on the second antenna denoted by $\mathbf{S}^{2,1}=\{S_0^{2,1},\cdots,S_{N-1}^{2,1}\}$ and $\mathbf{S}^{2,2}=\{S_0^{2,2},\cdots,S_{N-1}^{2,2}\}$ as follows

$$S_k^{2,1}=\begin{cases}Q_i^{2,1}, & k=i+k_1, i=0,\cdots,L-1\\ 0, & otherwise\end{cases} \tag{19}$$

$$S_k^{2,2}=\begin{cases}Q_i^{2,2}, & k=i+k_1, i=0,\cdots,L-1\\ 0, & otherwise\end{cases} \tag{20}$$

where $Q_i^{2,1}$ and $Q_i^{2,2}$ are the ith element of vector $\mathbf{Q}^{2,1}$ and $\mathbf{Q}^{2,2}$.

Similarly, $\mathbf{Q}^{3,1}$ and $\mathbf{Q}^{3,2}$ are mapped to the two time intervals of the second frequency band on the third antenna denoted by $\mathbf{S}^{3,1}=\{S_0^{3,1},\cdots,S_{N-1}^{3,1}\}$ and $\mathbf{S}^{3,2}=\{S_0^{3,2},\cdots,S_{N-1}^{3,2}\}$ as follows

$$S_k^{3,1}=\begin{cases}Q_i^{3,1}, & k=i+k_2, i=0,\cdots,L-1\\ 0, & otherwise\end{cases} \tag{21}$$

$$S_k^{3,2}=\begin{cases}Q_i^{3,2}, & k=i+k_2, i=0,\cdots,L-1\\ 0, & otherwise\end{cases} \tag{22}$$

where $Q_i^{3,1}$ and $Q_i^{3,2}$ are the ith element of vector $\mathbf{Q}^{3,1}$ and $\mathbf{Q}^{3,2}$.

Meanwhile, $\mathbf{Q}^{4,1}$ and $\mathbf{Q}^{4,2}$ are mapped to the two time intervals of the second frequency band on the fourth antenna denoted by $\mathbf{S}^{4,1}=\{S_0^{4,1},\cdots,S_{N-1}^{4,1}\}$ and $\mathbf{S}^{4,2}=\{S_0^{4,2},\cdots,S_{N-1}^{4,2}\}$ as follows

$$S_k^{4,1}=\begin{cases}Q_i^{4,1}, & k=i+k_2, i=0,\cdots,L-1\\ 0, & otherwise\end{cases} \tag{23}$$

$$S_k^{4,2}=\begin{cases}Q_i^{4,2}, & k=i+k_2, i=0,\cdots,L-1\\ 0, & otherwise\end{cases} \tag{24}$$

In this scheme, the two clusters are divided by the four antennas in static. The frequency band which includes subcarriers from k_1 to k_1+L-1 is allocated to the transmit antenna one and antenna two, and the other frequency band which include subcarriers from k_2 to k_2+L-1 is allocated to the antenna three and four , which is shown in Fig.2.

As we can be observed, each transmit antenna has only one cluster, thus the PAPR of each transmit antenna is identical to the SC-FDMA. However, the diversity gain of this scheme is lost compared with Clustered DFT-S-OFDM where two clusters are allocated on each antenna.

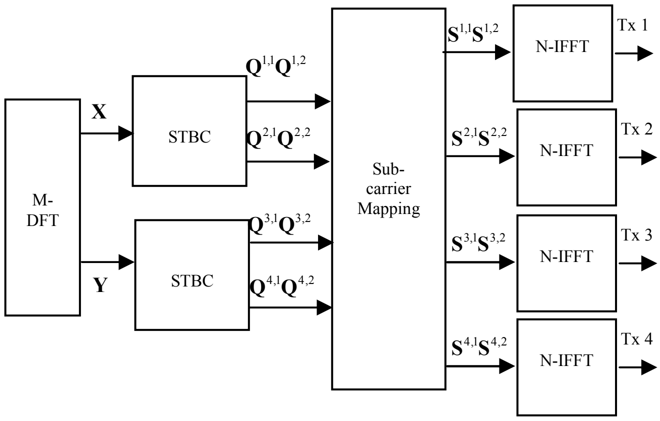

Fig.2 the existing transmit diversity scheme for four transmit antennas

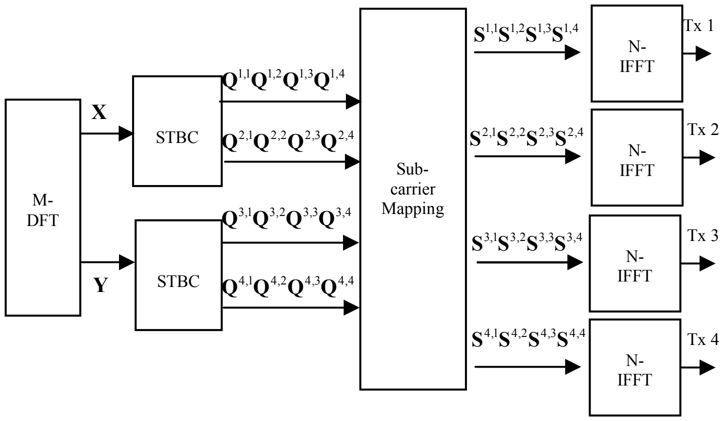

Fig.3 the proposed transmit diversity scheme for four transmit antennas

B. The proposed transmit diversity scheme

In this section, we propose an enhanced FSTD scheme by a dynamic sub-carrier allocation method, which is shown in Fig.3. In this scheme, at odd-index pair of symbols, the subcarriers through k_1 to k_1+L-1 is allocated to the first and second transmit antenna, and the subcarriers through k_2 to k_2+L-1 is allocated to the third and fourth antenna, while at even-index pair of symbols, the subcarriers through k_1 to k_1+L-1 is allocated to the third and fourth transmit antenna, and subcarriers through k_2 to k_2+L-1 is allocated to the first and second antenna. Thus it introduces more extra channels compared with the classical transmit diversity scheme. Then, we make each STBC branch transmitted across two frequency bands. In Fig.3, $\mathbf{Q}^{1,3}$ and $\mathbf{Q}^{1,4}$ are the next two symbols of the first STBC data stream on the first transmit antenna , $\mathbf{Q}^{2,3}$ and $\mathbf{Q}^{2,4}$ are the next two symbols of the first STBC data stream on the second transmit antenna, $\mathbf{Q}^{3,3}$ and $\mathbf{Q}^{3,4}$ are the next two symbols of the second STBC data stream on the third transmit antenna, $\mathbf{Q}^{4,3}$ and $\mathbf{Q}^{4,4}$ are the next two symbols of the second STBC data stream on the fourth transmit antenna. At first two symbols, the sub-carrier mapping format is same to the classical transmit diversity scheme, while at the next two symbols, $\mathbf{Q}^{1,3}$ and $\mathbf{Q}^{1,4}$ are mapped to the two time intervals of the second frequency band on the first antenna denoted by $\mathbf{S}^{1,3} = \{S_0^{1,3}, \cdots, S_{N-1}^{1,3}\}$ and $\mathbf{S}^{1,4} = \{S_0^{1,4}, \cdots, S_{N-1}^{1,4}\}$ as follows

$$S_k^{1,3} = \begin{cases} Q_i^{1,3}, & k = i + k_2, i = 0, \cdots, L-1 \\ 0, & otherwise \end{cases} \tag{25}$$

$$S_k^{1,4} = \begin{cases} Q_i^{1,4}, & k = i + k_2, i = 0, \cdots, L-1 \\ 0, & otherwise \end{cases} \tag{26}$$

Meanwhile, $\mathbf{Q}^{2,3}$ and $\mathbf{Q}^{2,4}$ are mapped to the two time intervals of the second frequency band on the second antenna denoted by $\mathbf{S}^{2,3} = \{S_0^{2,3}, \cdots, S_{N-1}^{2,3}\}$ and $\mathbf{S}^{2,4} = \{S_0^{2,4}, \cdots, S_{N-1}^{2,4}\}$ as follows

$$S_k^{2,3} = \begin{cases} Q_i^{2,3}, & k = i + k_2, i = 0, \cdots, L-1 \\ 0, & otherwise \end{cases} \tag{27}$$

$$S_k^{2,4} = \begin{cases} Q_i^{2,4}, & k = i + k_2, i = 0, \cdots, L-1 \\ 0, & otherwise \end{cases} \tag{28}$$

Similarly, $\mathbf{Q}^{3,3}$ and $\mathbf{Q}^{3,4}$ are mapped to the two time intervals of the first frequency band on the third antenna denoted by $\mathbf{S}^{3,3} = \{S_0^{3,3}, \cdots, S_{N-1}^{3,3}\}$ and $\mathbf{S}^{3,4} = \{S_0^{3,4}, \cdots, S_{N-1}^{3,4}\}$ as follows

$$S_k^{3,3} = \begin{cases} Q_i^{3,3}, & k = i + k_1, i = 0, \cdots, L-1 \\ 0, & otherwise \end{cases} \tag{29}$$

$$S_k^{3,4} = \begin{cases} Q_i^{3,4}, & k = i + k_1, i = 0, \cdots, L-1 \\ 0, & otherwise \end{cases} \tag{30}$$

Meanwhile, $\mathbf{Q}^{4,3}$ and $\mathbf{Q}^{4,4}$ are mapped to the two time intervals of the first frequency band on the fourth antenna denoted by $\mathbf{S}^{4,3} = \{S_0^{4,3}, \cdots, S_{N-1}^{4,3}\}$ and $\mathbf{S}^{4,4} = \{S_0^{4,4}, \cdots, S_{N-1}^{4,4}\}$ as follows

$$S_k^{4,3} = \begin{cases} Q_i^{4,3}, & k = i + k_1, i = 0, \cdots, L-1 \\ 0, & otherwise \end{cases} \tag{31}$$

$$S_k^{4,4} = \begin{cases} Q_i^{4,4}, & k = i + k_1, i = 0, \cdots, L-1 \\ 0, & otherwise \end{cases} \tag{32}$$

In LTE-Advanced, the channel is varying in spatial domain and frequency domain during one turbo coded stream. As we can be observed, each branch STBC coded stream has transmitted across two antennas and two frequency bands, thus four-branch diversity gain has been achieved.

IV. SIMULATION RESULTS

In this section, PAPR and BLER are presented to compare the performance of the proposed transmit diversity scheme (denoted as improved STBC+FSTD), the existing transmit diversity scheme (denoted as classical STBC+FSTD) [11] and clustered DFT-S-OFDM [5-6]. The two clusters are assumed to allocate the same size of resource blocks in these simulations. The two groups of resource blocks on two clusters are separated by 120 subcarriers.

A. PAPR Property

Simulation results are made to evaluate the PAPR of the scheme proposed in this paper under the conditions of N=1024 and M=120 in case of QPSK modulation. The simulation results are shown in Fig.4.

From Fig.4, it can be observed that the proposed transmit diversity scheme has about 1dB gain over the Clustered DFT-S-OFDM. It is reasonable since in the proposed transmit diversity scheme, one antenna has one frequency band compared with the Clustered DFT-S-OFDM where one antenna has two frequency bands, hence brings some PAPR reduction. In addition, the proposed transmit diversity scheme has the same PAPR performance to the existing transmit diversity scheme.

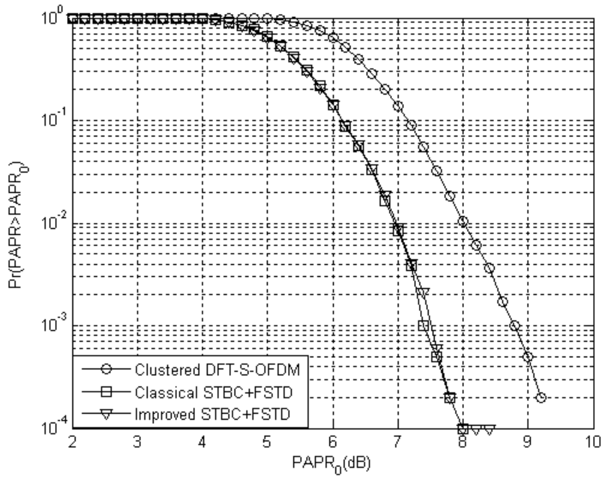

Fig.4 CCDF of PAPR

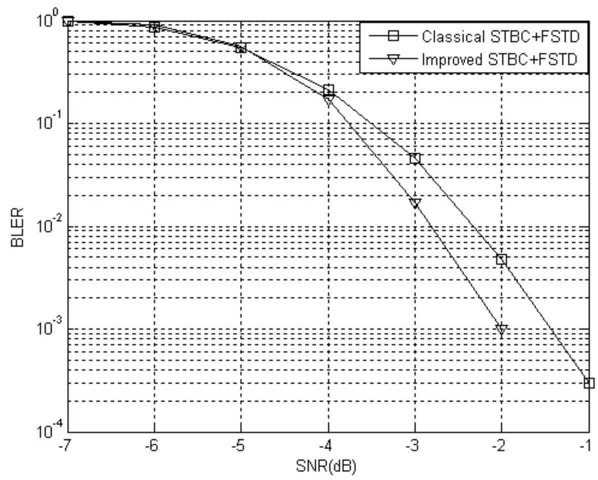

Fig.5 BLER performance

B. BLER Performance

In the second example, BLER simulations are presented to compare the performance of the proposed transmit diversity scheme and the classical transmit diversity scheme. The basic simulation parameters and assumptions are described in Table 1. The adopted channel parameters [12] for Urban Macro scenario, which is a simplification of the extended Spatial Channel Model (SCME) accepted by 3GPP [13] for link level evaluation. More explicitly, the adopted channel is time selective and frequency selective channel. At the receiver, the linear MMSE detection in frequency domain is employed to tradeoff the inter-symbol interference (ISI) and noise power.

TABLE I. BLER SIMULATION PARAMETERS AND ASSUMPTIONS

Parameters	Values
Carrier frequency	2.0 GHz
Transmission bandwidth	10 MHz (IFFT size N=1024)
TTI length	1.0 ms (i.e., 1 subframe or 2 slots)
Number of allocated RUs	10
DFT size (M)	120
Modulation	QPSK
Channel coding	Turbo encoding with rate of 1/2
Subcarrier mapping	Localized
Spatial Channel model	3GPP SCME with fixed parameters
Scenario	Urban macro (NLOS)
Velocity	30kmph
Channel Estimation	Perfect channel estimation
MIMO receiver	MMSE receiver
Turbo decoder	Linear-log-MAP (i.e., MAX-log-MAP plus linear correction function) with 8 iterations
Definition of SNR	The total received power per receive antenna to the noise power ratio in frequency domain
Number of subframes simulated	10000
Antenna configurations	4 antennas at Mobile Station (MS) with 0.5 wavelength spacing 4 antennas at Base Station (BS) with 10 wavelengths spacing

The simulation result of the proposed scheme is shown in Fig.5. From the fig.5, we can see that the proposed scheme outperforms the existing transmit diversity scheme about 1dB. This is because the proposed transmit diversity scheme has made use of more diversity.

V. CONCLUSIONS

Clustered DFT-S-OFDM has been accepted as the main multiple access by the LTE-Advanced. It is very important to investigate the transmit diversity scheme with low PAPR and high diversity gain. In this work, we propose one novel transmit diversity method by joint frequency switched transmit diversity with space-time coding for four transmit antennas. In the proposed scheme, space-time coding is employed to achieve spatial diversity and coding gain, while the improved FSTD scheme has reduced the PAPR and obtained the additional frequency diversity gain. Our simulation figures clearly demonstrate that in all examples, the proposed transmit diversity scheme is shown to consistently enjoy a significantly improved PAPR and BLER performance as compared to the Clustered DFT-S-OFDM and the existing transmit diversity scheme.

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