# Enhancement of bandwidth efficiency for SLM SC-FDMA MIMO with side information

A. Khelil, D. Slimani, L. Talbi and J. LeBel

*Abstract*— This paper presents a modified selective mapping (MSLM) based on the peak-to-average power ratio (PAPR) reduction technique for the single carrier frequency division multiple access with multiple input multiple output uplink system (SC-FDMA MIMO). The main idea of the proposed scheme is to use the same phase vectors for all antennas unlike the conventional scheme when each antenna has its own phase vectors. The branches of the same rang of all $N_T$ transmitting antennas are then multiplied point to point by the same phase vector. Then, the signal with minimum PAPR of each antenna is chosen to be transmitted. Simulation results show that the proposed scheme can achieve the same PAPR reduction performance as that of the conventional SLM SC-FDMA MIMO technique with 50% reduction on terms of number of side information bits and bandwidth degradation. Hence, it improves the bandwidth efficiency of the system. However, no improvement of the computational complexity is achieved over the conventional SLM SC-FDMA MIMO.

*Keywords*— SC-FDMA, MIMO, SLM, PAPR, Side Information, Bandwidth efficiency

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## I. Introduction

Multiple-input-multiple-output (MIMO) communication schemes are used in the last years to enhance the performances of wireless communication [1]-[5]. These schemes are based on the use of multiple~~s~~ antennas at the transmitter and receiver. Compared to single input single output (SISO) systems, the MIMO systems can provide a significant capacity gain. Spatial diversity and spatial multiplexing are the principals' keys of MIMO systems to provide a good bit error rate (BER) and a higher data throughput respectively [3]. Therefore MIMO technique has been combined with all modern wireless communication systems such as orthogonal frequency division multiple accesses (OFDMA). This multicarrier access is very used in modern wireless communication as WiMAX, 4G LTE and IEEE 802.11 a/e/g. The coverage, the spectral efficiency, the flexible frequency allocation and the simple equalization are the main advantages of this system [6].

The authors are with the Electrical Engineering Department, Eloued University, Algeria

A DFT-precoding OFDMA radio interface named single carrier frequency division multiple access (SC-FDMA) is chosen by the third partnership project (3GPP) standard~~s~~ for long term evolution (LTE) uplink transmission because of its significant low PAPR over conventional OFDMA, but the combination between SC-FDMA and MIMO loses this property.

To further reduce the PAPR of SC-FDMA signal~~s~~, many techniques have been proposed in the literature. Partial transmit sequence (PTS) and selected mapping (SLM) schemes were proposed in [7]-[10]. The pulse shaping technique was proposed in [11]-[15]. For SC-FDMA MIMO, the authors in [16] proposed a modified space frequency block coding (SFBC) scheme, modified quasi orthogonal space frequency block coding (QOSFBC) and a combination of modified SFBC with FSTD schemes to reduce PAPR. In [17], the authors proposed several low complexity and no-overhead PAPR reduction methods for bandwidth aggregated systems with OFDMA and SC-FDMA in MIMO system configurations. In [18]-[19], new mapping schemes were proposed to reduce the PAPR of SC-FDMA signal~~s~~ with space frequency block coding (SFBC). Furthermore, the selective mapping SLM technique is widely used to reduce the PAPR in multicarrier system, because it can provide a significant gain of PAPR. Hence, it improves the power efficiency of the system [20]-[23]. The computational complexity and the transmission of SI, to allow the receiver to recover the transmitted data, are the major drawbacks of this technique. In [23]-[25], the authors have been proposed some SLM schemes without transmission of SI to avoid the bandwidth degradation. However, all these new schemes increase the computational complexity.

In this paper, we propose a modified SLM SC-FDMA MIMO for uplink system. The main idea of the proposed scheme is to use the same phase vectors for all antennas unlike the conventional scheme when each antenna has its own phase vectors. The branches of the same rang of all $N_T$ transmitting antennas are then multiplied point to point by the same phase vector. Then, the signal with minimum PAPR of each antenna is chosen to be transmitted. The proposed scheme reduces the number of side information and the bandwidth degradation. Hence, it improves the bandwidth efficiency of the system. On other hand, the gain of PAPR reduction and the computational complexity are the same of the conventional SLM SC-FDMA MIMO.

The rest of the paper is organized as follows: the principals of SC-FDMA MIMO system are presented in section II. Section III describes the SLM SC-FDMA MIMO system. In section IV, we present the principals of the proposed

Where $B_v^{(u)} = e^{j\varphi_v^{(u)}}$, $\varphi_v^{(u)} \epsilon [0,2\pi]$, $v = 0, 1, \dots, N-1$ and $u = 0, 1, \dots, U$

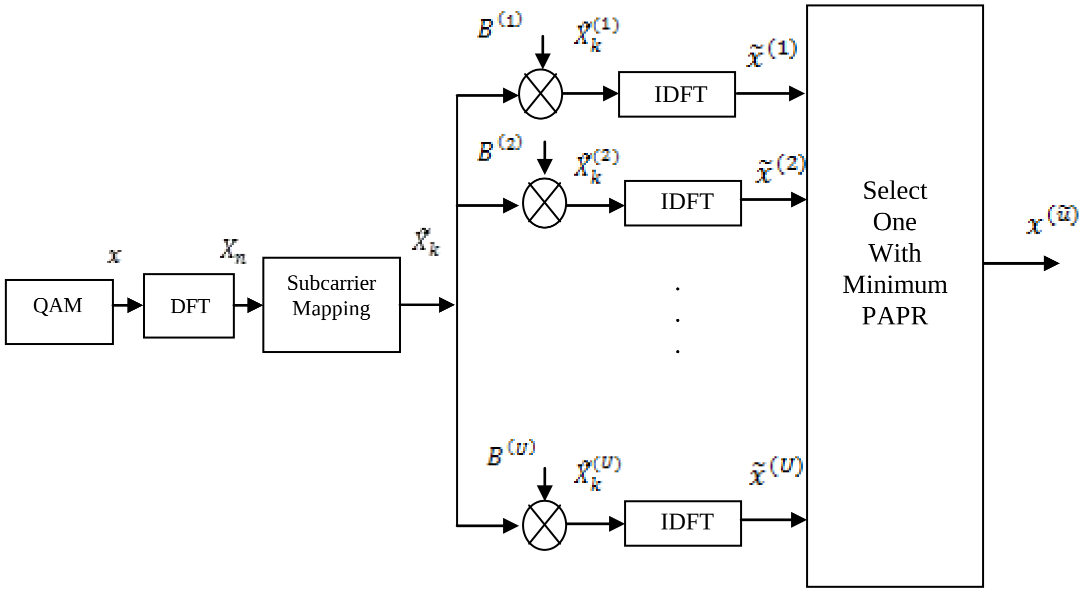


Fig. 1 Block diagram of SISO SLM SC-FDMA uplink system.

MSLM SC-FDMA MIMO system. The simulation results are presented in section V and section VI concludes the paper.

## II. SISO SLM SC-FDMA SYSTEM

Fig. 1 shows the block diagram of SISO SLM SC-FDMA uplink system. In this system modulated symbols are grouped into blocks of length M, then the modulated symbols are passed through S/P converter which generated a complex vector of the same size M that can be written as $x = [x_0 \ x_1 \dots \ x_{M-1}]^T$. The DFT precoded is applied to this complex vector. The output signal can be written as follow

$$X_n = DFT\{x\} = \frac{1}{M}\sum_{l=0}^{M-1} x_l e^{-j2\pi\frac{n}{M}l} \quad n = 0, 1, 2, \dots, M-1 \quad (1)$$

The resulting signal is than mapped to N orthogonal subcarriers and we get

$$\tilde{X}_k = [\tilde{X}_0 \ \tilde{X}_1 \dots \tilde{X}_{N-1}]^T \quad (2)$$

Then, generate $U$ different phase sequences using to modified $\tilde{X}_k$ of Eq. (2)

$$B^{(u)} = [B_0^{(u)} \ B_1^{(u)} \ \dots \ B_{v-1}^{(u)}] \quad (3)$$

The data block $\tilde{X}_k$ is point to point multiplied by all the $U$ phase sequences $B^{(u)}$, resulting $U$ different SC-FDMA blocks. This can be written as

$$\tilde{X}_k^{(u)} = \tilde{X}_k .* B^{(u)} = [\ \tilde{X}_0^{(u)} \ \tilde{X}_1^{(u)} \dots \tilde{X}_{N-1}^{(u)}]^T \quad (4)$$

Where (.*) refers to point by point multiplication

IDFT is performed to obtain the time domain of each $\tilde{X}_k^{(u)}$

$$\tilde{x}^{(u)} = IDFT\{\tilde{X}_k^{(u)}\} \quad (5)$$

The vector $u$ is chosen so that the PAPR can be minimized which is given as

$$\tilde{u} = \underset{u=0,1,\dots,U}{\operatorname{argmin}}\left(max\left|\tilde{x}^{(u)}\right|\right) \quad (6)$$

Finally, the signal with the lowest PAPR is selected for transmission

## III. MIMO SLM SC-FDMA SYSTEM

Fig. 2 shows the block diagram of MIMO SLM SC-FDMA uplink system. The output signal of the DFT precoder is demultiplexed in $N_T$ branches

The data block $\tilde{X}_k^{(\vartheta)}$ is point to point multiplied by all $u^\vartheta$ phase vectors. This can be written as

$$\tilde{X}_k^{(u^\vartheta)} = \tilde{X}_k^{(\vartheta)} .* B^{(u^\vartheta)} \left[\ \tilde{X}_0^{(u^\vartheta)}\ \ \tilde{X}_1^{(u^\vartheta)} \dots \tilde{X}_{N-1}^{(u^\vartheta)}\right]^T \quad (10)$$

Transform each $\tilde{X}_k^{(u^\vartheta)}$ to time domain to obtain

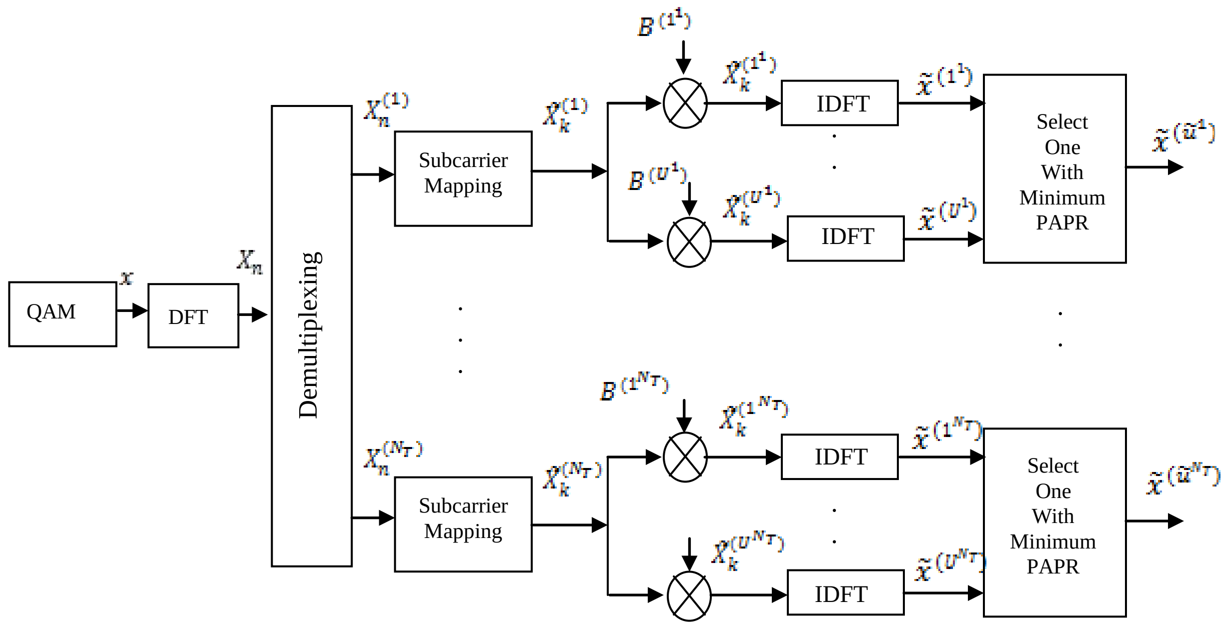


Fig. 2 Block diagram of SLM SC-FDMA MIMO uplink system.

$$X_n^{(1)} = [X_0\ \ X_{N_T} \dots X_{M-N_T}]$$
$$\vdots \quad (7)$$
$$X_n^{(N_T)} = [X_{N_T-1}\ \ X_{2N_T-1} \dots X_{M-1}]$$

The resulting signal of Eq. (7) is then mapped to N orthogonal subcarriers and we get

$$\tilde{X}_k^{(1)} = [\tilde{X}_0\ \ \tilde{X}_{N_T} \dots \tilde{X}_{N-N_T}]$$
$$\vdots \quad (8)$$
$$\tilde{X}_k^{(N_T)} = [\tilde{X}_{N_T-1}\ \ \tilde{X}_{2N_T-1} \dots \tilde{X}_{N-1}]$$

Then, generate $U^\vartheta$ phase vectors to modify the resulting signal of Eq. (8)

$$B^{(u^\vartheta)} = \left[B_0^{(u^\vartheta)}\ \ B_1^{(u^\vartheta)}\ \dots\ B_{v-1}^{(u^\vartheta)}\right] \quad (9)$$

Where $\vartheta = 1, \dots, N_T$

$$\tilde{x}^{(u^\vartheta)} = IDFT\left\{\tilde{X}_k^{(u^\vartheta)}\right\} \quad (11)$$

The vector $u^\vartheta$ is chosen so that the PAPR can be minimized which is given as

$$\tilde{u}^\vartheta = \underset{u=0,1,\dots,U}{\operatorname{argmin}} \left(max \left|\tilde{x}^{(u^\vartheta)}\right|\right) \quad (12)$$

Transmit $\tilde{x}^{(\tilde{u}^\vartheta)}$ corresponds for each antenna.

We define $PAPR_{mimo}$ as the maximum off all PAPR related to all $N_T$ MIMO paths

$$PAPR_{mimo} = \max_{\vartheta=1,\dots,N_T} \text{PAPR}\left\{\tilde{x}^{(\tilde{u}^\vartheta)}\right\} \quad (13)$$

## IV. MIMO MODIFIED SLM SC-FDMA

Fig.3 shows the block diagram of the proposed MIMO MSLM SC-FDMA uplink system. We propose to use the same phase vectors $B^{(u)}$ for each antenna in order to reduce the number of side information SI bits and bandwidth degradation

$$B^{(u)} = \left[B_0^{(u)}\ B_1^{(u)}\ \dots\ B_{v-1}^{(u)}\right] \tag{14}$$

The data block of each branch $\tilde{X}_k^{(\theta)}$ is point to point multiplied by all $B^{(u)}$ phase vectors. This can be written as

$$\tilde{X}_k^{(u^\theta)} = X_k^{(\theta)} .* B^{(u)} \left[\ X_0^{(u^\theta)}\ \tilde{X}_1^{(u^\theta)} \dots \tilde{X}_{N-1}^{(u^\theta)}\right]^T \tag{15}$$

$$PAPR = \frac{max[x(n)]^2}{E[|x(n)|^2]} \tag{17}$$

Where $E[.]$ is the expectation function.

The simulation assumption and parameters are summarized in Table 1

(15)

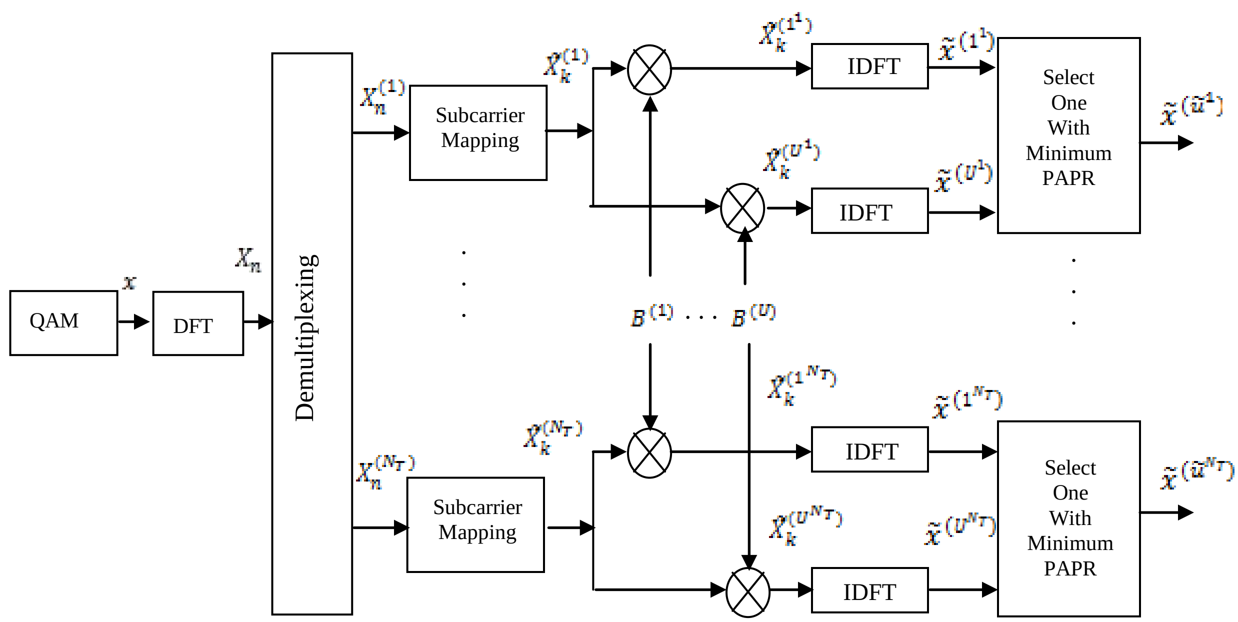


Fig. 3 Block diagram of modified SLM SC-FDMA MIMO uplink system.

## V. Simulation And Results

In this section, we compare between the conventional SLM SC-FDMA MIMO and the proposed MSLM SC-FDMA MIMO. The PAPR reduction gain, the number of SI bits and the bandwidth losses are used in this comparison.

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### A. *PAPR reduction*

The PAPR performance of SLM schemes is evaluated in this section. For comparison SC-FDMA MIMO is also simulated. In order to evaluate the PAPR performance, we use complementary cumulative distribution function (CCDF) as an informative metric. This metric means that the probability of the PAPR is higher than a certain PAPR value. The CCDF can be expressed as:

$$CCDF = \Pr(PAPR > PAPR_0) \tag{16}$$

The PAPR expression can be written as:

Table 1 Simulation parameters.

| Parameters | Values |
|---|---|
| Channel bandwidth | 5Mhz |
| Random data block | $10^5$ |
| Input subcarrier number (M) | 256 |
| Total subcarrier number (N) | 512 |
| Modulation | 16QAM |
| Subcarrier mapping | LFDMA and IFDMA |
| Spreading factor | 2 |
| Vector number (U) | 4 and 8 |
| Oversampling factor | 4 |
| RC pulse shaping factor | Alpha =1 |

Fig. 4 and 5 show the comparison of PAPR performance of MSLM SC-FDMA MIMO scheme, SLM SC-FDMA MIMO and SC-FDMA MIMO for N=512 and M=256. The proposed MSLM scheme provides a gain as like as conventional SLM scheme compared with SCFDMA MIMO. The gains provided are around 1.2 dB (U=4) and 2.05 dB (U=8) for localized mapping and around 1.12 dB (U=4), 1.94 dB (U=8) for interleaved mapping. So, no PAPR reduction improvement over the conventional SLM MIMO SC-FDMA is achieved.

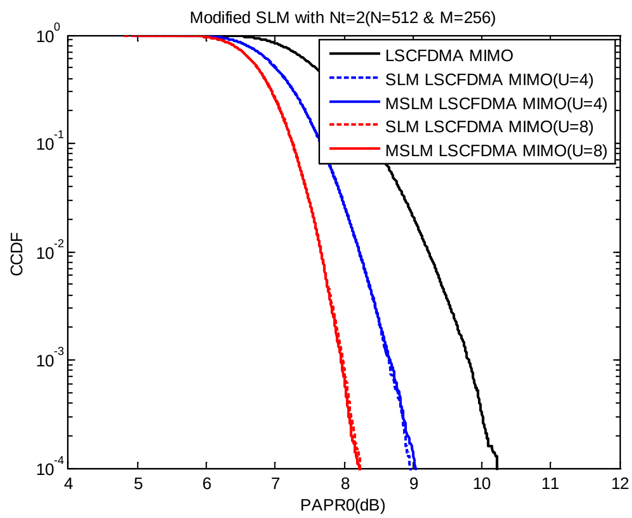


Fig. 4 PAPR performance of SLM LSC-FDMA MIMO schemes with Nt=2, N=512 and M=256.

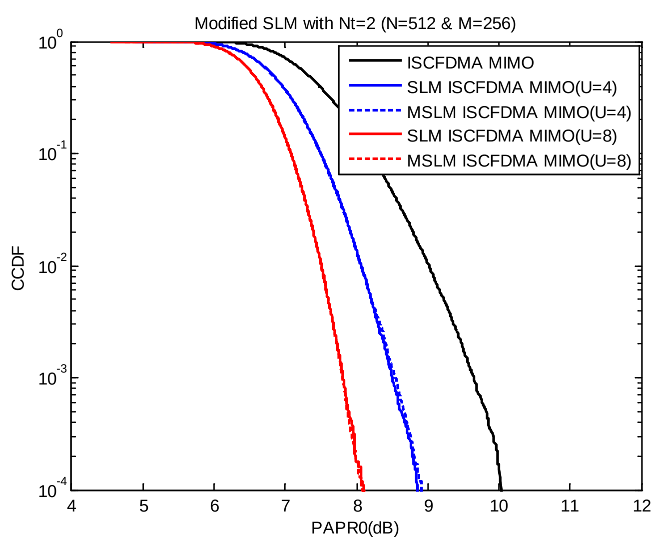


Fig. 5 PAPR performance of SLM ISC-FDMA MIMO schemes with Nt=2, N=512 and M=256.

Fig. 6 and 7 show the comparison of PAPR performance of MSLM SC-FDMA MIMO scheme, SLM SC-FDMA MIMO and SC-FDMA MIMO for N=256 and M=128. The proposed MSLM scheme provides a gain as like as conventional SLM scheme compared with SC-FDMA MIMO. The gains provided are around 1.52 dB (U=4) and 2.28 dB (U=8) for localized mapping and around 1.53 dB (U=4), 2.43 dB (U=8) for interleaved mapping. So, no PAPR reduction improvement over the conventional SLM MIMO SC-FDMA is achieved.

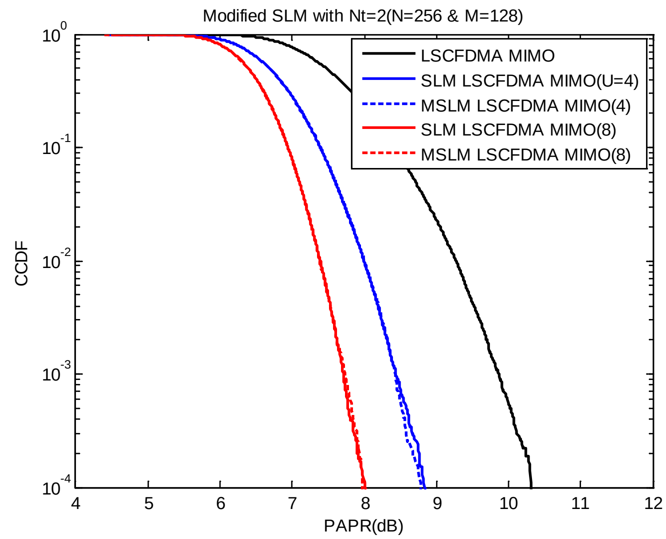


Fig. 6 PAPR performance of SLM LSC-FDMA MIMO schemes with Nt=2, N=256 and M=128.

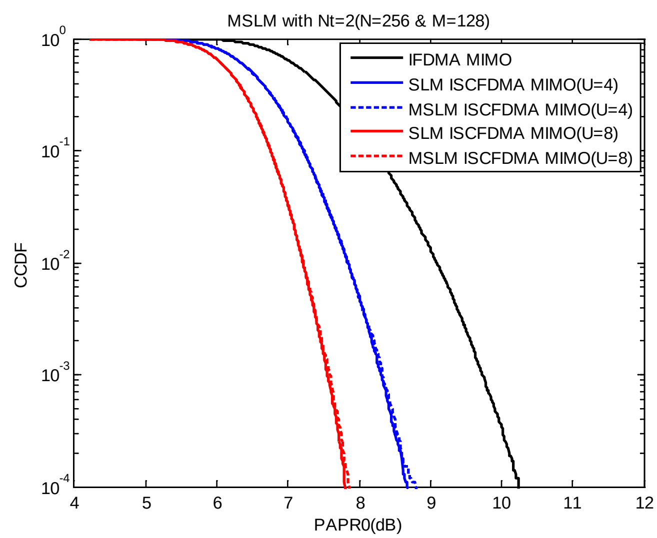


Fig. 7 PAPR performance of SLM ISC-FDMA MIMO schemes with Nt=2, N=256 and M=128.

## B. *Number of SI bits*

The implementation of SLM SC-FDMA scheme requires $(U) IFFT$ and $N_{SI} = \log_2 U$ bits (SI). Hence, SLM MIMO SC-FDMA required $(N_T \times U)\ IFFT$ and $N_{SI} = N_T . \log_2 U$ bits. For-the proposed system MSLM MIMO SC-FDMA, the branches of the same rang of all $N_T$ transmitting antennas are then multiplied point to point by the same phase sequence. So, only $N_{SI} = \log_2 U$ bits of SI are required. However, no complexity reduction is achieved over SLM SC-FDMA MIMO.

Table 2 Number of SI bits and IFFT operations required for the different SLM scheme with $N_T$=2.

| | U=4 | | U=8 | | U=16 | |
|---|---|---|---|---|---|---|
| | $N_{SI}$ | No. IFFT | $N_{SI}$ | No. IFFT | $N_{SI}$ | No. IFFT |
| SLM MIMO LSC-FDMA | 4 | 8 | 8 | 16 | 16 | 32 |
| MSLM MIMO LSC-FDMA | 2 | 8 | 4 | 16 | 8 | 32 |
| SLM MIMO ISC-FDMA | 4 | 8 | 8 | 16 | 16 | 32 |
| MSLM MIMO ISC-FDMA | 2 | 8 | 4 | 16 | 8 | 32 |

Table 3 Bandwidth losses for different SLM-SC-FDMA MIMO schemes.

| | U=4 | | U=8 | | U=16 | |
|---|---|---|---|---|---|---|
| | Uncoded | Coded | Uncoded | Coded | Uncoded | Coded |
| SLM MIMO LSCFDMA | 0.390 | 0.781 | 1.562 | 3.125 | 6.25 | 12.5 |
| MSLM MIMO LSCFDMA | 0.195 | 0.390 | 0.781 | 1.562 | 3.125 | 6.25 |
| SLM MIMO ISCFDMA | 0.390 | 0.781 | 1.562 | 3.125 | 6.25 | 12.5 |
| MSLM MIMO ISCFDMA | 0.195 | 0.390 | 0.781 | 1.562 | 3.125 | 6.25 |

Table 2 presents a comparison between the number of SI bits and the number of IFFT required for the implementation of SLM–SC-FDMA MIMO schemes with $N_T$ =2. According to the Table 2, it is clear that the MSLM reduces the number of SI bits by 50% compared to the conventional SLM scheme.

### *C. Bandwidth degradation*

SLM schemes need the transmission of SI bits to allow the receiver to recover the transmitted data. This transmission occupies a part of system bandwidth and affects the spectral efficiency. The authors of [26] present an expression that can be used to evaluate the bandwidth losses $B_{loss}$ .

$$B_{loss} = \left(1 - \frac{N.m - (\log_2 U / C_r.m)}{N.m}\right).100 = \frac{\log_2 U}{N.m^2.C_r}.100\ \%$$

Where $m$ is the number of bits per symbol and $C_r$ is the coding rate.

In Table 3, we present a comparison of $B_{loss}$ between the different SLM SC-FDMA MIMO schemes. Channel coded and uncoded, 4-QAM transmission and $U = 4, 8\ and\ 16$ are considered in this comparison. It is clear from the Table 3 that the proposed MSLM reduces the bandwidth degradation by 50% over the conventional SLM SC-FDMA MIMO.

## VI. Conclusion

In this paper, we present MSLM technique on based SC-FDMA MIMO uplink system for PAPR reduction. Simulation results show that the proposed scheme can achieve the same PAPR reduction performance as that of the conventional SLM SC-FDMA MIMO technique with 50% reduction on terms of number of side information bits and bandwidth degradation. Hence, it improves the bandwidth efficiency of the system. However, no improvement of the computational complexity is achieved over the conventional SLM SC-FDMA MIMO.

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