Double Single-Carrier Space Frequency Block Coding for SC-FDMA MU-MIMO: Performance Evaluation

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***Abstract*—Previous studies already introduced Single Carrier Space Frequency Block Coding (SC-SFBC), a robust and flexible Alamouti-based transmit diversity technique compatible with Single Carrier Frequency Division Multiple Access (SC-FDMA). SC-SFBC was proposed, optimized and evaluated for single-user (SU)- Multiple-Input Multiple-Output (MIMO) configurations. In this paper, we investigate specific techniques of parameter optimization for multi-user (MU)-MIMO SC-SFBC, taking into account performance and complexity considerations.**

***Index Terms*—SC-FDMA, transmit diversity, single-carrier space frequency block coding, multi-user MIMO, peak to average power ratio.**

I. Introduction

Single-Carrier Frequency Division Multiple Access (SC-FDMA) is a multiple access technique particularly interesting for uplink wireless transmissions due to its low envelope fluctuations [1]. SC-FDMA is in fact a Direct Fourier Transform (DFT)-precoded Orthogonal Frequency Division Multiple Access (OFDMA) scheme.

Several transmit diversity schemes based on the well-known Alamouti block codes [2] have been proposed in the literature for SC-FDMA. One of these schemes, called Single-Carrier Space-Frequency Block Coding (SC-SFBC) [3] relies on an innovative mapping and has the nice property of preserving the good PAPR (Peak to Average Power Ratio) properties of SC-FDMA without imposing any constraint on the number of SC-FDMA symbols present in a transmission burst. This is a significant advantage with respect to the classical solutions proposed in [4]. This advantage is obtained by accepting to apply Alamouti precoding in the frequency domain between frequency samples situated onto non-adjacent subcarriers, as shown in Fig. 1. In an SC-FDMA system, the precoding module described in Fig. 1 is inserted after DFT precoding and prior to OFDMA modulation, operating onto the frequency samples s_k, k=0…M-1 situated onto the M subcarriers allocated to a certain user. SC-SFBC specific mapping is controlled by a parameter p, representing the maximum distance between two subcarriers involved in Alamouti precoding. Large precoding distance (larger than the channel's coherence bandwidth) may lead to interference within an Alamouti pair, and thus to some performance loss, negligible in most practical scenarios [3].

In single-user (SU)- Multiple-Input Multiple-Output (MIMO) configurations, the optimal choice for p is the even integer that is closest to the half of number of allocated subcarriers. But in multi-user (MU)-MIMO scenarios egoistic optimal choices of parameters at user level are not necessarily globally optimal at system level. In this paper, we assess the performance of two different double SC-SFBC schemes in MU-MIMO configurations: Misaligned double SC-SFBC, which directly applies the principles of Double-Alamouti SC-SFBC regardless of the user pairing, and Aligned double SC-SFBC, which makes use of a parameter optimization in function of bandwidths allocated to users overlapping in the frequency domain in order to operate a tradeoff between performance and decoding complexity.

II. System Model And Problem Statement

We consider that several users, disposing of at least 2 transmit antennas each, are managed by the same base station (BS). Each such user implements SC-SFBC as a transmit diversity scheme. To optimize the spectral occupancy and increment the throughput, it is interesting to allow some spectral superposition between users having either the same or different spectral allocations. Let us consider that two mobile stations (MS), denoted MS_0 and MS_1, operating in MU-MIMO mode have different communication needs and are allocated different numbers of subcarriers M_0 and M_1 respectively. Their respective datastreams are FEC (Forward Error Correction) coded separately before SC-SFBC encoding with respective p parameters p_0 and p_1. At the reception side, MMSE (Minimum Mean Square Error) decoding with Successive Interference Cancellation (SIC) is employed to minimize the inter-user interference.

For the sake of clarity, let us assume that M_0=12 and M_1=8. We distinguish two transmission scenarios:

A. Misaligned double SC-SFBC

Each user is allowed to egoistically use its own optimum p parameter (p_0=6, p_1=4) in order to try and improve its individual performance by minimizing the interference within Alamouti pairs due to precoding on distant subcarriers. From an Alamouti precoding point of view, the first subcarrier is paired with:

- the 6th subcarrier in the case of MS_0 (see Fig. 1);
- the 4th subcarrier in the case of MS_1 (SC-SFBC precoding with M_1=8, p_1=4).

Global MMSE decoding of such a scheme involves jointly detecting M_0+M_1=20 symbols, and thus inverting a large matrix of size M_0+M_1. In practice, the detector will need to be dimensioned for the worst case scenario where multiple users overlap with each other on different portions of a large bandwidth, which would lead to inverting matrices of order hundreds or thousands.

B. *Aligned double SC-SFBC*

$p_{0,1}$ are optimized in function of $M_{0,1}$ and of the spectral overlapping, between users with an algorithm that will be detailed in the final paper. In our numerical example, this will result in choosing p_0=8 and p_1=0, which are no longer optimum from a user-egoistic point of view and might engender some performance loss. But note that from an Alamouti precoding point of view, the first subcarrier is paired with the 8th subcarrier for both MSs. In the overlapping part of the spectrum, we can identify couples of subcarriers carrying double Alamouti pairs which can benefit from MMSE separate decoding. In our numerical example, we will need to invert 4 matrices of order 4 (corresponding to the double Alamouti pairs on the 8 subcarriers of overlapping between MS_0 and MS_1) and 2 matrices of order 2 (corresponding to the simple Alamouti pairs on the 4 subcarriers of MS_0 not overlapped with MS_1). Inverting matrices of (fixed) order 2 or 4 can be done with low complexity. The decoding complexity is highly reduced with respect to Misaligned double SC-SFBC.

III. Simulation Results

Let us investigate from a performance point of view the performance-complexity trade-off between Aligned and Misaligned double SC-SFBC. We consider two users occupying M_0=60 and respectively M_1=20 subcarriers in a SC-FDMA system with 512 subcarriers out of which only 300 are active data carriers to fit within a bandwidth of 5MHz. Different symbol mapping (QPSK, 16QAM, 64QAM) and turbo code with different coding rates are employed. Each user performs SC-SFBC-based transmit diversity. To maintain the same receive power, the channel corresponding to MS_0 is supposed to have a pathloss of 7 dB superior to that of MS_1. The channel model is 3GPP TU (Typical Urban), which corresponds to a coherence bandwidth of 13 subcarriers. The BS is equipped with N_{Rx}=4 receive antennas. Ideal channel estimation is assumed.

We investigate the throughput in function of the signal-to-noise (SNR) ratio. Results in Fig. 2 show that the Aligned double SC-SFBC scheme exhibits similar performance with Misaligned double SC-SFBC scheme. The aligned scheme is therefore preferred considering its satisfying performance and much lower complexity. In the final paper, an exhaustive performance comparison will be conducted, taking into account the impact of the pathloss imbalance and the way that the

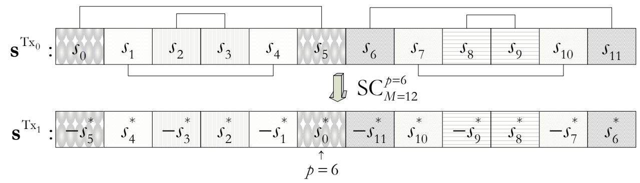

Fig. 1. SC-SFBC mapping example for M=12, p=6.

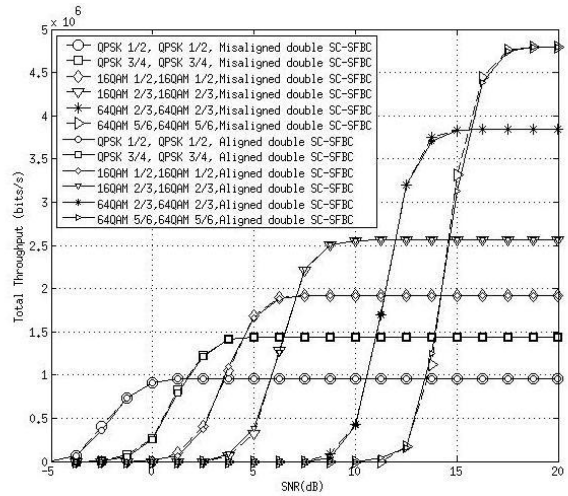

Fig. 2. Performance comparison between Misaligned double SC-SFBC and Aligned double SC-SFBC, spectral allocation (60, 20) subcarriers, N_{Rx}=4

modulation and coding scheme (MCS) of one user influences the performance of the other user.

IV. Conclusion

We investigated specific techniques of parameter optimization for MU-MIMO SC-SFBC. We assessed the performance of two different double SC-SFBC schemes in MU-MIMO configurations: Misaligned double SC-SFBC and Aligned double SC-SFBC. The performances of these two schemes are similar, but the second one demands much lower decoding complexity. With the aligned scheme, the system performances in terms of throughput with different MCSs and pathloss were evaluated. The simulation results showed the way how MCS used by one can impact the performance of the other user, which will be detailed in the final paper.

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