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BER Analysis for Q-OFDMA using OSTBC and Spatial Multiplexing

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Abstract-- **A Quadrature OFDM (Q-OFDMA) system has been recently proposed in the single-input single-output environment to reduce the high peak-to-average power ratio (PAPR), high complexity in user terminal and sensitivity to carrier frequency offset (CFO) problems in current orthogonal frequency division multiple access (OFDMA) systems. Based on the relationship between frequency-domain signal and intermediate- domain, we propose an OSTBC encoded in the intermediate domain for Q-OFDMA systems to exploit the transmit - and receive- diversity. In contrast to extend spatial multiplexing techniques, where the main objective is to provide higher bit rates compared to a single-antenna system, spatial diversity techniques predominantly aim at an improved error performance. This is accomplished on the basis of a diversity gain and a coding gain. Indirectly, spatial diversity techniques can also be used to enhance bit rates, when employed in conjunction with an adaptive modulation/channel coding scheme. In order to further improve the performance of space-time coded MIMO systems, the space-time encoder can be concatenated with an outer channel encoder. This is of particular interest for OSTBCs, which offer only a diversity gain, but no built-in coding gain.**

Index terms – Q-OFDMA, space-time block code, spatial multiplexing, PAPR, OSTBC.

I. INTRODUCTION

Over the last few years, several band-efficient communication techniques including spatial multiplexing (SM) and space-time block codes (STBC) have been developed to exploit the spatial diversity provided by the multiple transmit receive paths in a multiple-input multiple-output (MIMO) channel. SM scheme utilizes spatial degrees of freedom to increase data rate by sending independent data streams simultaneously whereas STBC focuses on the diversity advantage of multiple antennas to improve the MIMO system performance. The trade-offs between the two schemes are being considered recently. Given a MIMO system, both diversity gain and spatial multiplexing gain can be obtained simultaneously. Previous work has been carried out in the case where the combination is over time by switching between STBC and SM scheme.

Quadrature OFDMA (Q-OFDMA) systems overcome the aforementioned problems, resulting in lower PAPR, lower CFO sensitivity, higher frequency diversity and improved reliability. Based on the concept of layered fast Fourier transform (FFT) structure, Q-OFDMA introduces an intermediate domain between the time domain and frequency domain.

Generally speaking, Q-OFDMA bridges conventional OFDMA and SC-FDMA systems by the adaptable parameter P, the Q-OFDMA sub channel length. Although there has been much research effort in signaling and detection for multi-input multi-output (MIMO)-OFDMA systems, there is little dealing with the combination of multiple antenna techniques with SC-FDMA schemes. Most MIMO extensions for SC-FDMA systems are studied within the 3GPP LTE-Advanced, for which the original SC-FDMA signal structure has been destroyed. For Q-OFDMA systems, with signals in time, intermediate and frequency domains, MIMO brings new challenges in signaling techniques and decoding algorithms.

In this paper, we study the realization of MIMO diversity and multiplexing- oriented methods for Q-OFDMA systems. By elaborating the idea presented, we propose a new set of Altamonte-like space-time block code (STBC) codes for Q-OFDMA systems where full diversity from both Q-OFDMA signals and STBC coding transmission is achievable. In order to retain the simple one-tap equalization advantage as OFDMA, a key feature is that STBC encoding is undertaken in the intermediate domain at the transmitter, and decoding is undertaken in the frequency domain at the receiver. According to the conjugation property in the Fourier transform theorem for complex conjugation operation, we judiciously define a new operation on signals of each sub channel in intermediate-domain, in order to achieve Altamonte encoding in intermediate-domain. For the first time, a comprehensive BER analysis is presented here, which is sufficiently general and can be applied to most modulation schemes, such as BPSK, QPSK and M-ary QAM, and can be extended to any precoded OFDMA systems, including SC-FDMA. Simple detection for spatial multiplexing (SM) Q-OFDMA systems is studied to show that Q-OFDMA systems can be implemented flexibly and efficiently in a MIMO framework, similar to conventional OFDMA systems.

II. SYSTEM MODEL OF Q-OFDMA

To compare the Q-OFDMA with the well-known OFDMA and SC-FDMA systems, Fig. 1 shows the schematic difference of the core baseband modules among three systems. At the transmitter, each user's data is first encoded, interleaved and mapped to a particular modulation constellation. Users are then assigned to sub channels. Unlike the sub channel in conventional OFDMA systems, which is defined in the one-dimension frequency domain, sub channels in Q-OFDMA systems are defined over an array of two dimensions in the intermediate domain [5].

Thanks to the judicious use of Divide and-

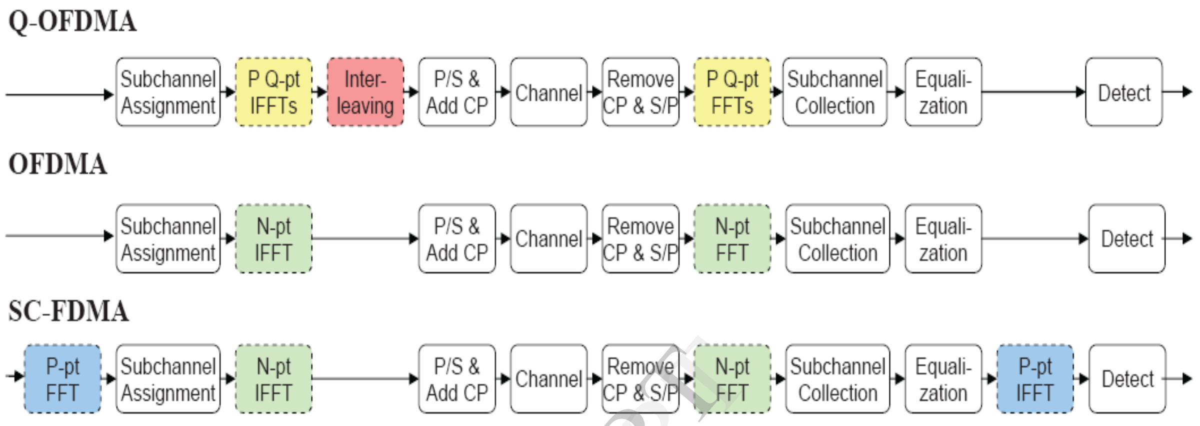

Fig.1. System Structure Comparison.

Conquer approach in the computation of discrete Fourier transform (DFT) [16], which is shown in Fig. 2, several smaller-size IFFTs/FFTs are utilized in the transmitter/receiver of Q-OFDMA to reduce complexity and PAPR.

The size of this array is $P \times Q$, where both P and Q are powers of 2, and $N = PQ$ is the equivalent to the total number of subcarriers in ordinary OFDMA systems.

Given two N-point time-domain symbol vectors x, h, and their noiseless circular convolution output y = x _ h, their DFTs have the relationship

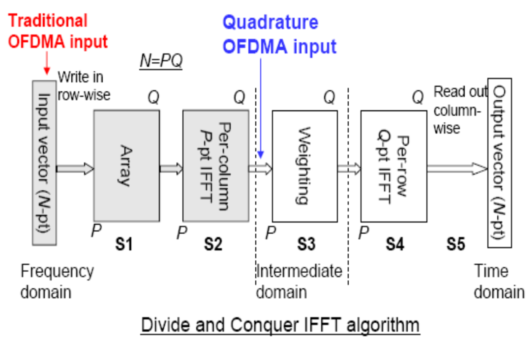

Fig.2 Layered IFFT structure which includes three Layers- frequency domain, intermediate domain and time domain layer

$\tilde{y} = \tilde{x}$ _ $\tilde{h}$. If we reshape the frequency domain symbols $\tilde{x}$, $\tilde{h}$ and $\tilde{y}$ into $P \times Q$ matrices ($PQ = N$) row-wise according to the layered IFFT structure concept, as shown in Fig. 2 [5], the vectors $\tilde{x}_q$, $\tilde{h}_q$ and $\tilde{y}_q$ from the q-th ($q = 0, 1, \cdots, Q - 1$) column of the matrices retain the property

$$\tilde{\mathbf{y}}_q = \tilde{\mathbf{x}}_q \odot \tilde{\mathbf{h}}_q, \tag{1}$$

Where each element of the vectors are expressed by

$[\tilde{y}_q]_p = [\tilde{y}]_{pQ+q}$, $[\tilde{x}_q]_p = [\tilde{x}]_{pQ+q}$, $[\tilde{h}_q]_p = [\tilde{h}]_{pQ+q}$, respectively, and $p = 0, 1, \cdots, P - 1$.

We now introduce the intermediate-domain symbols $\{\check{x}_q, \check{h}_q, \check{y}_q\}$ as the IDFTs of $\{\tilde{x}_q, \tilde{h}_q, \tilde{y}_q\}$, given by $\check{x}_q = F_P^H \tilde{x}_q$, $\check{h}_q = F_P^H \tilde{h}_q$, $\check{y}_q = F_P^H \tilde{y}_q$, where F_P^H is the normalized P-point IDFT matrix. According to the convolution property of DFT, we have

$$\check{\mathbf{y}}_q = \check{\mathbf{x}}_q \circledast \check{\mathbf{h}}_q, \tag{2}$$

Which establishes the relationship of symbols in the intermediate domain, and can be expressed in matrix form as $\check{y}_q = \check{H}_q \check{x}_q$, where the $P \times P$ circulant matrix $\check{H}_q$ represents the dispersive channel, with $[\check{H}_q]_{i,j} = \check{h}(((i - j) \bmod P)Q + q)$, where $\check{h}(\cdot)$ denotes the channel response in the intermediate domain.

Based on the circular convolution property of the DFT, we now have a three-layer IFFT structure: the input layer (frequency domain), the intermediate layer $\{\check{x}_q, \check{H}_q, \check{y}_q\}$ and the output layer (time domain), as shown in Fig. 2. In principle, we can design systems by exploiting the data in any layer of this layered IFFT structure. Particularly the QOFDMA system focuses on the intermediate domain and assigns each user's transmitted data to one or multiple re-defined subchannels corresponding to the $\check{x}_q$. At the receiver of the QOFDMA system, in order to realize a one-tap equalization, the received Symbols are transformed from intermediate domain to frequency domain as

$$\tilde{\mathbf{y}}_q = \mathbf{F}_P \breve{\mathbf{y}}_q = \mathbf{F}_P \breve{\mathbf{H}}_q \breve{\mathbf{x}}_q + \mathbf{F}_P \breve{\mathbf{n}}_q = \mathbf{D}_q \mathbf{F}_P \breve{\mathbf{x}}_q + \tilde{\mathbf{n}}_q, \quad (3)$$

Where we now include ˘nq and ˜nq, the white Gaussian noise in intermediate and frequency domain, respectively. Dq = FP ˘HqFHP is a diagonal matrix with channel frequency coefficients ˜h p,q on its diagonal. In the above formulas we consider a single subchannel q. In frequency and intermediate domain each subchannel can be processed independently.

An interesting observation is that Equation (4) closely resembles a precoded OFDMA system [17], with a precoding matrix FP . Thus frequency diversity can be achieved without introducing additional complexity for precoders at the transmitter.

III. Space-Time Block Codes

In a general form, an STBC can be seen as a mapping of nN complex symbols {s1, s2, · · · , sN} onto a matrix S of dimension nt × N: {s1, s2, · · · , sN} → S An STBC code matrix S taking on the following form: S = XnN n=1 (¯snAn + j˜snBn), where {s1, s2, · · · , snN } is a set of symbols to be transmitted with ¯sn = Re{sn} and ˜sn = Im{sn} , and with fixed code matrices {An,Bn} of dimension nt × N are called linear STBCs. The following STBCs can be regarded as special cases of these codes.

One of the most important advantages of OSTBCs is the fact that increasing the number of transmit antennas does not

A. Dimension

The block supports time and spatial domains for OSTBC transmission. It also supports an optional dimension, over which the encoding calculation is independent. This dimension can be thought of as the frequency domain. The following illustration indicates the supported dimensions for the inputs and output of the OSTBC Encoder block.

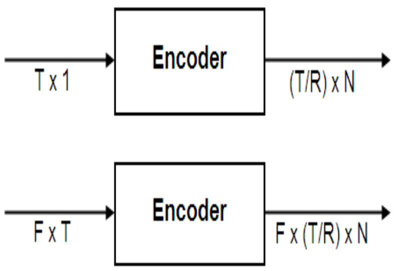

Fig 3. OSTBC Encoder

B. OSTBC Encoding Algorithms

The OSTBC Encoder block supports five different OSTBC encoding algorithms. Depending on the selection for Rate and Number of transmit antennas, the block implements one of the algorithms in the following table.

increase the decoding complexity substantially, due to the fact that only linear processing is required for decoding. The most prominent space-time block codes (STBCs) are orthogonal STBCs (OSTBCs) and the most popular OSTBC is the Alamouti code. A linear OSTBC_S has a code matrix of the dimension (nt × N) with the unitary property SHS =PN n=1 |sn|2I, where sn are complex symbols. OSTBCs provide full diversity using simple detection algorithms which can separately recover transmit symbols.

A complex orthogonal design of STBCs which provides full diversity and full transmission rate is not possible for more than two transmit antennas and the Alamouti code is the only OSTBC that provides full diversity at full data rate (1 symbol/time slot) for two transmit antennas. It is assumed that the transmitted code word C is an OSTBC code passing through the channel with matrix H and received by N antennas. The received signal can be demonstrated as:

$$r = C.H+N \quad (4)$$

IV. OSTBC Encoder

OSTBC Encoder is used to encode input message using orthogonal space-time block code (OSTBC). The OSTBC Encoder block encodes an input symbol sequence using orthogonal space-time block code (OSTBC). The block maps the input symbols block-wise and concatenates the output code

Words matrices in the time domain.

In each matrix, its (l, i) entry indicates the symbol transmitted from the ith antenna in the lth time slot of the block. The value of i can range from 1 to N (the number of transmit antennas). The value of l can range from 1 to the codeword block length

Table 2. Supported Data Types

Transmit Antenna	Rate	OSTBC Codeword Matrix
2	1	$\begin{pmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{pmatrix}$
3	1/2	$\begin{pmatrix} s_1 & s_2 & 0 \\ -s_2^* & s_1^* & 0 \\ 0 & 0 & s_1 \\ 0 & 0 & -s_2^* \end{pmatrix}$
3	3/4	$\begin{pmatrix} s_1 & s_2 & s_3 \\ -s_2^* & s_1^* & 0 \\ s_3^* & 0 & -s_1^* \\ 0 & s_3^* & -s_2^* \end{pmatrix}$
4	1/2	$\begin{pmatrix} s_1 & s_2 & 0 & 0 \\ -s_2^* & s_1^* & 0 & 0 \\ 0 & 0 & s_1 & s_2 \\ 0 & 0 & -s_2^* & s_1^* \end{pmatrix}$
4	3/4	$\begin{pmatrix} s_1 & s_2 & s_3 & 0 \\ -s_2^* & s_1^* & 0 & s_3 \\ s_3^* & 0 & -s_1^* & s_2 \\ 0 & s_3^* & -s_2^* & -s_1 \end{pmatrix}$

C. Block Parameters

- **Number of transmit antennas**

Sets the number of antennas at the transmitter side. The block supports 2, 3, or 4 transmit antennas. The value defaults to 2.

- **Rate**

Rate sets the symbol rate of the code. You can specify either 3/4 or 1/2. This field only appears when using more than 2 transmit antennas. This field defaults to for more than 2 transmit antennas. For 2 transmit antennas, there is no rate option and the rate defaults to 1.

- **Overflow mode**

Sets the overflow mode for fixed-point calculations. Use this parameter to specify the method to be used if the magnitude of a fixed-point calculation result does not fit into the range of the data type and scaling that stores the result. For more information refer to Precision and Range in DSP System.

Table 2. Supported Data Types

Port	Supported Data type
In	Double-precision floating point single-precision floating point signed fixed point
Out	Double-precision floating point single-precision floating point signed fixed point

D. Spatial Multiplexing

MIMO is generally used for enhancing data transmission capacity, where multiple antennas are used to send the data and the more antennas means the more data transfer speed. Suppose, you have 5 antennas in the transmitting side an 5 antennas in the receiving side and you have a data stream of 100 bits for transmission. If you use each antenna to send 20 bits each then it would take five times less to send all the data if you only used a single antenna. By the use of MIMO increasing the data transmission speed is known as spatial multiplexing.

Several different data bits are transmitted via several independent (spatial) channels.

V. SIMULATION RESULTS

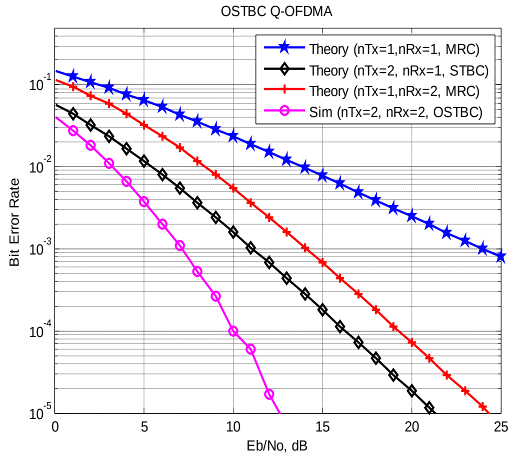

Fig.4 BER performance comparison of SM Q-OFDMA systems between different antenn a constellations

Figure shows the BER performance comparison of SM Q-OFDMA systems between different antenna constellations, using 16-QAM modulation and MMSE equalizer, simulated in a dense multi- path indoor channel environment (CM2 channel model). It can be seen that SM Q-OFDMA with different antenna pairs have similar BER trend, and the 4 × 4 SM QOFDMA has better performance than SISO Q-OFDMA using channel gain by 3 dB (at 10−4 BER). Although the power of the transmitted signal per transmit antenna decreases as the numbers of transmit and receive antennas increase, the MMSE equalizer reduces the gaps between different transceiver pairs.

VI. CONCLUSIONS

In this paper, we improve the spatial diversity of MIMO and multiplexing for Q-OFDMA systems. We propose an Alamouti-like STBC encoded in the intermediate domain for Q-OFDMA systems to exploit the transmit- and receive-diversity based on the relationship between frequency-domain signal and intermediate- domain. We present the receiver architecture with the decoder and simple ZF/MMSE equalizers in the frequency domain. The increased linearity of complexity with the number of the transmit antennas is shown. The proposed STBC takes advantages of both inherent frequency diversity in QOFDMA and full diversity introduced by STBC. Based on the bridging character of Q-OFDMA, we propose a universal BER analysis that can be extended to conventional OFDMA and SC-FDMA systems. Simple detection for SM Q-OFDMA systems is studied to show the flexible and efficient implementation of multiplexing techniques for Q-OFDMA systems. Simulation results demonstrate that MIMO Q-OFDMA systems can achieve a good balance between complexity and performance, and bridge between SC-FDMA and OFDMA systems.

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