A New Generation of OFCDMA Based on Innovative Integration Techniques

Ahmed Hassan Mansour, Mona Zakria Saleh, and Salwa H. ElRamly

***Abstract*—Orthogonal Frequency Code Division Multiple Access (OFCDMA) system is one of the most promising multi-user wireless communications systems. It outperforms Orthogonal Frequency Division Multiplexing (OFDM) because of the utilization of two dimensional (2D) spreading. This paper proposes innovative integration techniques with OFCDMA system for better data rate increase and Bit Error Rate (BER) performance enhancement. The paper is divided into two parts; integration techniques that target improvement in the downlink transmission, and the other part targets the uplink transmission improvement. In the downlink, the proposed system represents an integration of Multiple–Input Multiple Output (MIMO) and OFCDMA systems through the usage of Space Time Spreading (STS) and OFCDMA. This exploits transmit diversity needed for BER enhancing and data rate boosting. Further BER improvement was achieved through applying an effective Iterative Interference Cancellation (IIC) algorithm at the receiver. In the uplink, A MIMO-OFCDMA system based on new set of codes called Complete Complementary Codes (CCC) is proposed. The authors present an analytical analysis for the proposed systems performance in addition to simulation results. The proposed systems attained better BER performance compared to Single-Input Single-Output (SISO) OFCDMA systems and the OFCDMA system that use the traditional codes. The achieved BER performance was very close to Maximal Ratio Receive Combining (MRRC) diversity system with 1Tx and 4Rx. A considerable improvement was also obtained by increasing the number of IIC iteration loops.**

***Index Terms*—5G, CCC, MIMO, OFCDMA, spatial diversity (STS).**

I. Introduction

One of the future mobile communications systems (e.g. 5G) main targets is to provide extremely high speed data transmission demanded by multimedia services, e.g. high speed internet access and broadcast services. In such applications, the services nature invokes significantly higher data traffic in the downlink than that in the uplink [1]. Therefore, diverse wireless access schemes have been proposed for the broadband downlink transmission. These schemes can be classified based on the employed multiple access technique, e.g. Code Division Multiple Access (CDMA) in third generation systems (3G) and Orthogonal Frequency Division Multiplexing (OFDM) in fourth generation systems (4G) [2]-[6]. In Single-Carrier Direct Sequence CDMA (SC-DS-CDMA), each user's symbols are spread by a user-specific code. Such spreading increases the required transmission bandwidth compared to the actual data bandwidth [2], [3]. Thus, SC-DS-CDMA is unsuitable for broadband channel transmission due to Multi-Path Interference (MPI) [4]. Alternatively, multi-carrier approaches such as OFDM have proved its high MPI withstanding capability in high speed wireless communications. OFDM system employs a large number of orthogonal subcarriers to transmit symbols in parallel with large symbol duration. Consequently, it can combat Inter-Symbol Interference (ISI) caused by MPI. Although OFDM is an attractive option for high speed wireless communications, it does not support frequency diversity [7]. Furthermore, in mobile cellular systems, OFDM suffers from adjacent cell interference due to the frequency reuse. Thus, spreading has been introduced to OFDM to provide frequency diversity and facilitate one cell frequency reuse in a cellular environment. Combining Time Domain and frequency domain spreading (two dimensional (2D) spreading) with OFDM, an Orthogonal Frequency Code Division Multiple Access (OFCDMA) system has been proposed for the downlink transmission in future mobile networks [4]. Broadband OFCDMA provides not only all advantages of OFDM but also additional benefits through applying 2D spreading. The OFCDMA system performance with hybrid receiver structure was investigated under the effect of different channel conditions in [8]-[11]. The results showed a significant improvement in Bit Error Rate (BER) performance compared to other receivers which structures depend on a single technology.

The performance of the aforementioned systems can be ameliorated through combining them with spatial diversity techniques such as Multiple-Input Multiple-Output (MIMO) [12]-[14]. A combination of Space Time Block Coding (STBC) and Orthogonal Frequency Code Division Multiplexing (OFCDM) techniques were studied in [15] to improve the OFCDM system performance. An effort to improve downlink air interface with high data rate and BER performance enhancement was done by the authors in [16]. This was achieved through proposing an integration of OFCDMA system and spatial diversity followed by a comparison between the proposed system and another system that use beamforming. In the present paper, the authors are targeting both downlink and uplink air interfaces with high data rate and BER performance enhancement based on their work in [16]. This was accomplished through combining MIMO and OFCDMA systems via the usage of Space Time Spreading (STS) transmit diversity technique proposed for OFCDMA system (MIMO-STS-OFCDMA) in downlink. In addition, a further BER improvement was achieved through introducing an Iterative Interference Cancellation (IIC)

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algorithm at the receiver (MIMO-STS-OFCDMA-IIC). In order to emphasize on the BER improvement achieved by the OFCDMA system, two performance comparisons are presented. First, a performance comparison between the Single-Input Single-Output-OFCDMA (SISO-OFCDMA) system with frequency diversity and the Multi-Carrier CDMA (MC-CDMA) system is introduced. Second, the performances of SISO-OFCDMA system with frequency diversity and STS (2Tx, 1Rx) without frequency diversity were compared with the proposed MIMO-STS-OFCDMA-IIC system performance in order to focus on the significant BER and data rate amelioration achieved by the proposed system. Furthermore, the effects of FD spreading factor and number of iteration loops used in IIC algorithm were investigated. Finally, for the uplink, the performance of STS-OFCDMA integrated with the new codes set (Complete Complementary Codes-CCC) was also investigated.

This paper is organized as follows: Section II introduces the detailed structure of the proposed MIMO-STS-OFCDMA-IIC system for downlink transmission improvement where the transmitter, channel model, and receiver with IIC are discussed thoroughly. The detailed structure of the proposed STS-OFCDMA system based on CCC is presented in Section III as an improvement for the uplink transmission. Simulation results are illustrated in Section IV. Finally, the paper is concluded in Section V.

II. The Proposed MIMO-STS-OFCDMA-IIC System

The transmitter block diagram of the proposed MIMO-STS-OFCDMA-IIC system is shown in Fig. 1. The illustrated model has four transmit antennas ($n_t = 4$). For the k^{th} user, binary information bits are firstly processed by a Binary Phase Shift Keying (BPSK) mapper. The mapped symbols are then demultiplexed into U parallel streams through S/P converter where $U = M/N_F$ and M is the total number of employed subcarriers in the illustrated MIMO-STS-OFCDMA-IIC system, and N_F is the frequency domain spreading factor.

Consequently, only U BPSK symbols can be spread in frequency domain at the same time per transmit antenna using OFDM. For doubling the data rate, every stream of the U parallel streams is S/P converted into two sub-streams to be spread using the user-specific orthogonal time domain spreading codes C_k and C'_k where $C_k = [C^{N_T} \quad 0_{1\times N_T}]$, $C'_k = [0_{1\times N_T} \quad C^{N_T}]$ [17], C^{N_T} is a code word that belongs to Orthogonal Variable Spreading Factor (OVSF) code family [3], and N_T represents the time domain spreading factor. This spreading is performed using the two STS blocks [17] instead of using one STS encoder. Each output from the STS blocks belonging to the same u^{th} stream modulates the same set of N_F subcarrier frequencies using frequency domain spreading code $C_F^{N_F}$. Finally, for every transmit antenna, the set of M subcarriers are summed and modulated using IFFT. Thus, the transmitted signal at the p^{th} transmit antenna for one packet duration is given by:

$$x_{p,k,i}(t) = \sum_{u=0}^{U-1}\sum_{v=1}^{N_F} s_{k,u,p,v}(i)\, e^{\frac{j2\pi(v+uN_F)(t-iT_S)}{T_e}} f(t-iT_S)\ , \quad 1 \le i \le N_T \qquad (1)$$

where $T_S = T_e + T_g$ represents the duration of MIMO-STS-OFCDMA-IIC symbol, with T_e and T_g denoting the effective MIMO-STS-OFCDMA-IIC symbol duration and guard interval, respectively, and $f(t)$ is a rectangular pulse shaping filter. Furthermore, $s_{k,u,p,v}(i)$ can be defined through two steps; First, Let us define:

$$s_{k,u,p}(i) = \begin{cases} s^{o}_{k,u,p} = b_{k1}(n)C_k(i) + b_{k2}(n)C'_k(i)\,, & odd\ p\ index \\ s^{e}_{k,u,p} = b_{k2}(n)C_k(i) - b_{k1}(n)C'_k(i)\,, & even\ p\ index \end{cases} \qquad (2)$$

where $\{b_{k1}(n)\}$ and $\{b_{k2}(n)\}$ are identified as odd and even sub-streams inside the STS block [17], respectively; where n denotes the time index. Also $0 \le u \le U-1$, U is the number of multiplexed STS systems on a single IFFT block, p is the transmitter antenna index ($1 \le p \le n_t$), n_t is an even number of transmit antennas, and i is the chip index of the codes C_k and C'_k.

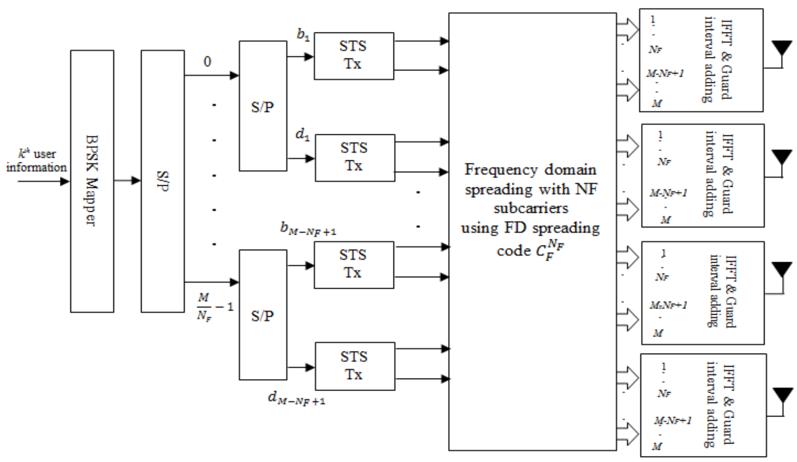

Fig. 1. MIMO-STS-OFCDMA-IIC transmitter.

After the sum block, the index i indicates the STS symbol index. Referring to Fig. 1, $s^{e}_{k,u,p}$ indicates the even p index transmit antenna signal and $s^{o}_{k,u,p}$ indicates the odd p index transmit antenna signal. Second, the definition of $s_{k,u,p}(i)$ is extended to the $s_{k,u,p,v}(i)$ signal which represents the $s_{k,u,p}(i)$ signal with the v^{th} frequency domain spreading index, where $1 \le v \le N_F$. However in this paper, user differentiation using only time domain spreading is considered, so $C_F^{N_F} = [1,1,\ldots,1]$ for all users. The proposed MIMO-STS-OFCDMA-IIC system was simulated under highly frequency selective fading channel conditions [4], where the signal transmitted on each subcarrier experiences a flat fading channel. A slow fading channel model was assumed, i.e., channel parameters are static for one packet duration. Let $h_{q,p,m}$ denotes the complex channel fading coefficient from the p^{th} transmit antenna to the q^{th} receive antenna on the m^{th} subcarrier (where $m = v + uN_F$, $1 \le m \le M$ and $1 \le q \le n_r$) which amplitude and phase are Rayleigh distributed. It should be noted that in slow fading channels, the orthogonality in the TD can be kept among the users and the spreading in the TD has no influence on the system performance. Thus, the index k will be dropped in the forthcoming equations. Also, the availability of perfect Channel State Information at Receiver (CSI-R) was assumed. An iterative signal detection algorithm was proposed for the MIMO-STS-OFCDMA-IIC system to recover the data at the outputs of the TD despreader. Considering the system shown in Fig. 1, a proposed receiver structure is presented in Fig. 2 with two receive antennas.

The analytical approach is adopted for describing the receiver operation.

In Fig. 2, after guard interval removal and FFT, the data signal on the m^{th} subcarrier of the q^{th} antenna for certain user is given by:

$$y_{q,i,m} = \sum_{p=1}^{n_t} h_{q,p,m} s_{p,m}(i) + \eta_{q,i,m} \quad (3)$$

where η is zero mean and unit variance Additive White Gaussian Noise (AWGN) signal. For $n_t = 4$ and $n_r = 2$, the operation in (3) can be written in the following matrix form after substituting (2) in (3) for odd and even values of p, which yields:

$$\begin{bmatrix} y_{1,i,m} \\ y_{2,i,m} \end{bmatrix} = \begin{bmatrix} h_{1,1,m} & h_{1,2,m} & h_{1,3,m} & h_{1,4,m} \\ h_{2,1,m} & h_{2,2,m} & h_{2,3,m} & h_{2,4,m} \end{bmatrix} \begin{bmatrix} b_{1,m}(n)C(i) + b^{*}_{2,m}(n)C'(i) \\ b_{2,m}(n)C(i) - b^{*}_{1,m}(n)C'(i) \\ d_{1,m}(n)C(i) + d^{*}_{2,m}(n)C'(i) \\ d_{2,m}(n)C(i) - d^{*}_{1,m}(n)C'(i) \end{bmatrix} + \begin{bmatrix} \eta_{1,i,m} \\ \eta_{2,i,m} \end{bmatrix} \quad (4)$$

where $\{b_{k1}(n)\}$ and $\{b_{k2}(n)\}$ are substituted with $b_{1,m}$ and $b_{2,m}$ for transmit antennas 1, 2 and substituted with $d_{1,m}$ and $d_{2,m}$ for transmit antennas 3, 4, respectively. Referring to Fig. 2, $b_{1,m}$, $b_{2,m}$, $d_{1,m}$, and $d_{2,m}$ correspond to the m^{th} subcarrier odd and even sub-streams of b_m and d_m, respectively.

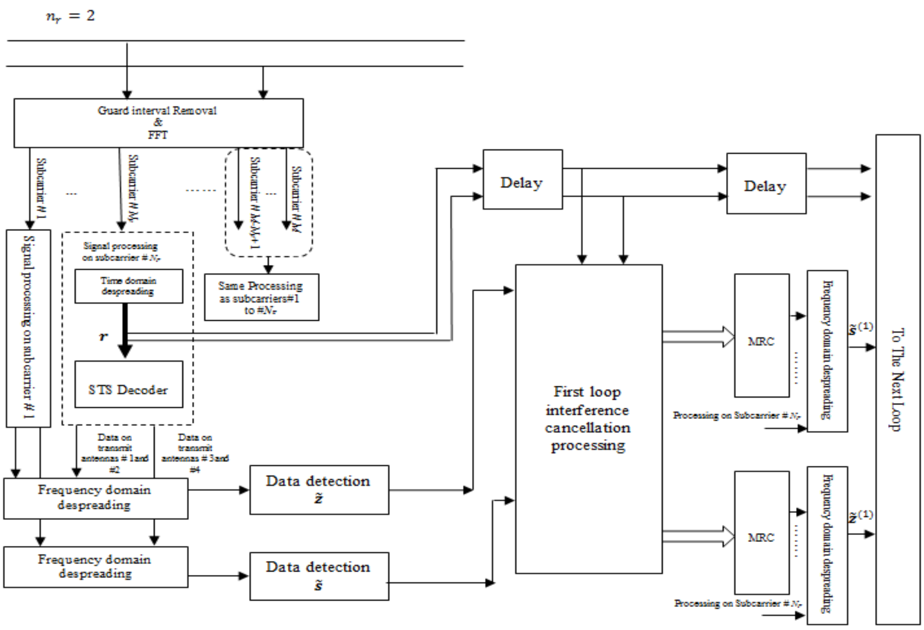

Fig. 2. MIMO-STS-OFCDMA-IIC receiver.

Complex data transmission was assumed [17] where $(.)^{*}$ indicates the conjugate operation.

Thereafter, for every subcarrier, the signal in (4) is TD despread using the C code word as in (5):

$$r_{q,n,m} = \frac{1}{N_T} \sum_{i=1}^{2N_T} y_{q,i+2nN_T,m}\, C(i) \quad (5)$$

The TD despreading in (5) is performed for every two consecutive packet durations ($2N_T$), over which the codes are also orthogonal. The TD despread version of y is r which is then used to detect $b_{1,m}$, $b_{2,m}$, $d_{1,m}$ and $d_{2,m}$ as follows:

$$\begin{bmatrix} r_{1,n,m} \\ r_{2,n,m} \end{bmatrix} = \begin{bmatrix} h_{1,1,m} & h_{1,2,m} & h_{1,3,m} & h_{1,4,m} \\ h_{2,1,m} & h_{2,2,m} & h_{2,3,m} & h_{2,4,m} \end{bmatrix} \begin{bmatrix} b_{1,m}(n) \\ b_{2,m}(n) \\ d_{1,m}(n) \\ d_{2,m}(n) \end{bmatrix} + \begin{bmatrix} \varepsilon_{1,n,m} \\ \varepsilon_{2,n,m} \end{bmatrix} \quad (6)$$

Similarly, using the C'codes despreading:

$$\begin{bmatrix} r'_{1,n,m} \\ r'_{2,n,m} \end{bmatrix} = \begin{bmatrix} h_{1,1,m} & h_{1,2,m} & h_{1,3,m} & h_{1,4,m} \\ h_{2,1,m} & h_{2,2,m} & h_{2,3,m} & h_{2,4,m} \end{bmatrix} \begin{bmatrix} b^*_{2,m}(n) \\ -b^*_{1,m}(n) \\ d^*_{2,m}(n) \\ -d^*_{1,m}(n) \end{bmatrix} + \begin{bmatrix} \varepsilon'_{1,n,m} \\ \varepsilon'_{2,n,m} \end{bmatrix} \quad (7)$$

where ε and ε′are AWGN signal vector with zero mean and $1/N_T$ variance. In the forthcoming equations, calculations are done per subcarrier, thus index m is dropped. Both (6) and (7) are combined and rearranged in the following form where the index *n* is also dropped for simplicity:

$$\boldsymbol{r} = \begin{bmatrix} \boldsymbol{H_1} & \boldsymbol{G_1} \\ \boldsymbol{H_2} & \boldsymbol{G_2} \end{bmatrix} \begin{bmatrix} b_1 \\ b_2 \\ d_1 \\ d_2 \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon'_1 \\ \varepsilon_2 \\ \varepsilon'_2 \end{bmatrix} \quad (8)$$

where:

$$\boldsymbol{H_1} = \begin{bmatrix} h_{1,1} & h_{1,2} \\ -h^*_{1,2} & h^*_{1,1} \end{bmatrix} \quad (9)$$

$$\boldsymbol{H_2} = \begin{bmatrix} h_{2,1} & h_{2,2} \\ -h^*_{2,2} & h^*_{2,1} \end{bmatrix} \quad (10)$$

$$\boldsymbol{G_1} = \begin{bmatrix} h_{1,3} & h_{1,4} \\ -h^*_{1,4} & h^*_{1,3} \end{bmatrix} \quad (11)$$

$$\boldsymbol{G_2} = \begin{bmatrix} h_{2,3} & h_{2,4} \\ -h^*_{2,4} & h^*_{2,3} \end{bmatrix} \quad (12)$$

As shown in Fig. 2, $b_1, b_2,\ d_1$ and d_2 are detected through multiplying $\boldsymbol{r}$ by $\boldsymbol{W}$ [18] in the STS decoder block. This implements the main idea behind the interference cancellation in the 0^{th} loop where a matrix $\boldsymbol{W}$ is defined as follows:

$$\boldsymbol{W} = \begin{bmatrix} \boldsymbol{I_2} & -\boldsymbol{G_1}\boldsymbol{G_2^{-1}} \\ -\boldsymbol{H_2}\boldsymbol{H_1^{-1}} & \boldsymbol{I_2} \end{bmatrix} \quad (13)$$

and,

$$\bar{\boldsymbol{r}} = \boldsymbol{W} \times \boldsymbol{r} = \begin{bmatrix} \bar{\boldsymbol{H}} & \boldsymbol{0} \\ \boldsymbol{0} & \bar{\boldsymbol{G}} \end{bmatrix} \begin{bmatrix} \boldsymbol{z} \\ \boldsymbol{s} \end{bmatrix} + \bar{\boldsymbol{\varepsilon}} \quad (14)$$

where,

$$\bar{\boldsymbol{H}} = \begin{bmatrix} \alpha_{1,1} & \alpha_{1,2} \\ -\alpha^*_{1,2} & \alpha^*_{1,1} \end{bmatrix} \quad (15)$$

$$\bar{\boldsymbol{G}} = \begin{bmatrix} \beta_{1,1} & \beta_{1,2} \\ -\beta^*_{1,2} & \beta^*_{1,1} \end{bmatrix} \quad (16)$$

$\boldsymbol{I_2}$ is an 2×2 identity matrix, $\boldsymbol{z} = [b_1 \quad b_2]^{\boldsymbol{T}}$, $\boldsymbol{s} = [d_1 \quad d_2]^{\boldsymbol{T}}$are the transmitted signal column vectors from transmit antennas $p = 1, 2$ and $p = 3, 4$, respectively . $\bar{\boldsymbol{\varepsilon}}$ has the same characteristics as $\boldsymbol{\varepsilon}$ and $\boldsymbol{\varepsilon}'$. Now, it can be seen from (14) that the data transmitted on the first two antennas can be detected with the other two antennas interference being canceled. Similarly, detecting the data transmitted on the other two antennas. Thus, the interference cancellation in the 0^{th} loop converts the data transmitted through the STS (4Tx, 2Rx) system into two independent STS (2Tx, 1Rx) systems.

Multiplying $\bar{\boldsymbol{r}}$ by $\begin{bmatrix} \bar{\boldsymbol{H}} & 0 \\ 0 & \bar{\boldsymbol{G}} \end{bmatrix}^H$ to exploit the employed space diversity; the decoded data can be expressed as:

$$\begin{bmatrix} \tilde{\boldsymbol{z}} \\ \tilde{\boldsymbol{s}} \end{bmatrix} = \begin{bmatrix} \bar{\boldsymbol{H}} & 0 \\ 0 & \bar{\boldsymbol{G}} \end{bmatrix}^H \begin{bmatrix} \bar{\boldsymbol{H}} & 0 \\ 0 & \bar{\boldsymbol{G}} \end{bmatrix} \begin{bmatrix} \boldsymbol{z} \\ \boldsymbol{s} \end{bmatrix} + \begin{bmatrix} \bar{\bar{\boldsymbol{\varepsilon}}}_1 \\ \bar{\bar{\boldsymbol{\varepsilon}}}_2 \end{bmatrix} \quad (17)$$

where $(.)^H$ denotes the Hermitian operator and $\begin{bmatrix} \bar{\bar{\boldsymbol{\varepsilon}}}_1 \\ \bar{\bar{\boldsymbol{\varepsilon}}}_2 \end{bmatrix} = \begin{bmatrix} \bar{\boldsymbol{H}} & 0 \\ 0 & \bar{\boldsymbol{G}} \end{bmatrix}^H \bar{\boldsymbol{\varepsilon}}$. Substituting (15) and (16) in (17), then the data sent over the m^{th} subcarrier is:

$$\tilde{\boldsymbol{z}}_m = (|\alpha_{1,1,m}|^2 + |\alpha_{1,2,m}|^2)\boldsymbol{z} + \bar{\bar{\boldsymbol{\varepsilon}}}_{1,m} \quad (18)$$

$$\tilde{\boldsymbol{s}}_m = \left(|\beta_{1,1,m}|^2 + |\beta_{1,2,m}|^2\right)\boldsymbol{s} + \bar{\bar{\boldsymbol{\varepsilon}}}_{2,m} \quad (19)$$

The decoded data is then FD despread over N_F subcarriers to detect the data on the 0^{th} loop as follows:

$$\tilde{\boldsymbol{z}} = \sum_{m=1}^{N_F} \tilde{\boldsymbol{z}}_m = \sum_{m=1}^{N_F} (|\alpha_{1,1,m}|^2 + |\alpha_{1,2,m}|^2)\boldsymbol{z} + \bar{\bar{\boldsymbol{\varepsilon}}}_{1,m} \quad (20)$$

$$\tilde{\boldsymbol{s}} = \sum_{m=1}^{N_F} \tilde{\boldsymbol{s}}_m = \sum_{m=1}^{N_F} (|\beta_{1,1,m}|^2 + |\beta_{1,2,m}|^2)\boldsymbol{s} + \bar{\bar{\boldsymbol{\varepsilon}}}_{2,m} \quad (21)$$

The same previous procedure is followed for every m^{th} subcarrier to obtain other OFDM multiplexed systems corresponding data. For further BER improvement, the previously decoded data in the 0^{th} loop is used for other next loops of IIC. To investigate this, the vector $\boldsymbol{r}$ in (8) is rewritten as follows:

$$\boldsymbol{r} = \begin{bmatrix} \boldsymbol{r}_1 \\ \boldsymbol{r}_2 \end{bmatrix} = \begin{bmatrix} \boldsymbol{H}_1\boldsymbol{z} + \boldsymbol{G}_1\boldsymbol{s} \\ \boldsymbol{H}_2\boldsymbol{z} + \boldsymbol{G}_2\boldsymbol{s} \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon'_1 \\ \varepsilon_2 \\ \varepsilon'_2 \end{bmatrix} \quad (22)$$

The data represented by $\boldsymbol{z}$ is to be detected first, thus both $\boldsymbol{G}_1\boldsymbol{s}$ and $\boldsymbol{G}_2\boldsymbol{s}$ in (22) are considered as multiple antenna interference (MTI). Referring to Fig. 2, the detected data in the 0^{th} loop is used for MTI regeneration as follows:

$$\boldsymbol{MTI}_1^{(1)} = \boldsymbol{G}_1\tilde{\boldsymbol{s}} \quad (23)$$

where $\boldsymbol{MTI}_1$ represents the 1^{st} loop interference components due to the $\tilde{\boldsymbol{s}}$ data and $(.)^{(e)}$ indicates the e^{th} iteration loop. Then, the calculated $\boldsymbol{MTI}$ component in (23) is subtracted from the delayed vector $\boldsymbol{r}$ components, $\boldsymbol{r}_1$ as follows:

$$\boldsymbol{r}_1^{(1)} = \boldsymbol{r}_1 - \boldsymbol{MTI}_1^{(1)} \quad (24)$$

Similarly, the same procedures are applied to obtain $\boldsymbol{MTI}_2^{(1)}$ in case of $\boldsymbol{G}_2\tilde{\boldsymbol{s}}$ interference. Hence, the resultant signal after interference cancellation for the m^{th} subcarrier is then maximal ratio combined as:

$$\tilde{\boldsymbol{z}}_m^{(1)} = \sum_{q=1}^{n_r} \boldsymbol{H}_{q,m}^H \boldsymbol{r}_{q,m}^{(1)} \quad (25)$$

Finally, (25) is FD despread over N_F subcarriers as:

$$\tilde{\boldsymbol{z}}^{(1)} = \sum_{m=1}^{N_F} \tilde{\boldsymbol{z}}_m^{(1)} \quad (26)$$

Hence, $\tilde{\boldsymbol{z}}^{(1)}$ represents the decoded signal obtained after the first loop of interference cancellation. This signal corresponds to data vector transmitted from transmit antennas $p = 1{,}2$. The same procedures are followed to get $\tilde{\boldsymbol{s}}^{(1)}$, where in this case, $\boldsymbol{H}_1\boldsymbol{z}$ and $\boldsymbol{H}_2\boldsymbol{z}$ in (22) are considered the MTI components. Moreover, the detected data $\tilde{\boldsymbol{z}}^{(1)}$ and $\tilde{\boldsymbol{s}}^{(1)}$ are used in the next loops for more interference cancellation.

III. The Proposed MIMO-OFCDMA System Based On CC Codes for Uplink

In this section the concept of using CC codes [19] is extended to be integrated with the proposed STS system. It is integrated with the STS system to gain the spatial diversity benefits in case of asynchronous uplink transmission.

Although the transmission direction considered here is the uplink transmission, in contrast to the downlink transmission considered in the previous section, this section can be considered as a proposal for using the proposed system in both downlink and uplink but with improved Multiple Access Interference (MAI)-free system in the uplink. The structure of the k^{th} user STS system ($n_t = 2$) based on CC codes is shown in Fig. 3. The transmitter of the system starts with copier that is responsible for copying the user information to M branches (flock size) to be ready for STS encoding in each branch of the M branches. The output from the STS encoder is directed to the IFFT block to modulate the spreaded information over the M subcarriers for each transmit antenna.

It should be noted that the STS encoder for each branch of flock branches is using c_{km} and c'_{km} for the purpose of acquiring the time and space diversities, which are defined as following:

$$c_{km} = [c_{km}\ 0_{1\times length(c_{km})}]$$
$$c'_{km} = [0_{1\times length(c'_{km})}\ c'_{km}]$$

where c_{km} and c'_{km} are defined in [19]. The receiver is started by demodulating the received signal into M subcarriers using the FFT block. The m^{th} demodulated signal is then STS decoded. Finally, the M demodulated and decoded signals are summed for taking the effect of CC codes in cancelling the interference for MAI-free system creation.

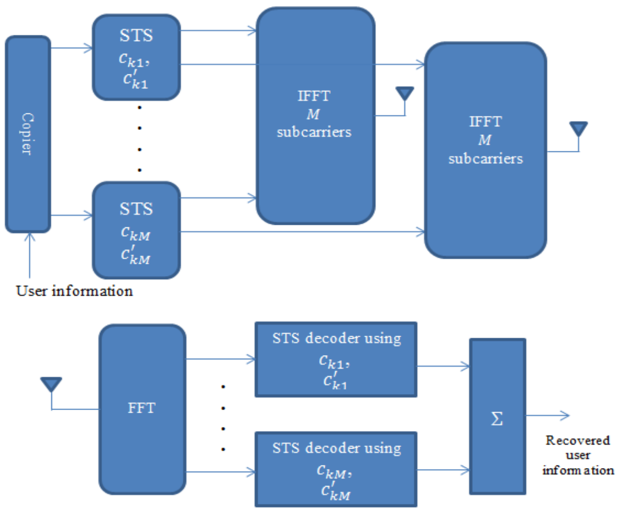

Fig. 3. The proposed OFCDMA-STS system based on CC codes.

IV. Simulation Results

First, the BER performance improvement of the SISO-OFCDMA system is illustrated through comparing it with the MC-CDMA system performance. Fig. 4 shows a comparison between MC-CDMA and OFCDMA systems under same channel conditions and also both systems have the same bit rate and the same signal to noise ratio [8]-[11]. This BER improvement is due to the utilization of 2D spreading in SISO-OFCDMA system.

In Fig. 5, the performance of a basic transmit diversity achieved through STS (2Tx, 1Rx) system with ZF receiver [17] is presented. The STS (2Tx, 1Rx) is considered as the basic building block in the proposed systems. This performance was compared against the theoretical performance of the Maximal Ratio Receive Combining (MRRC) system (1Tx, 2Rx) [20].

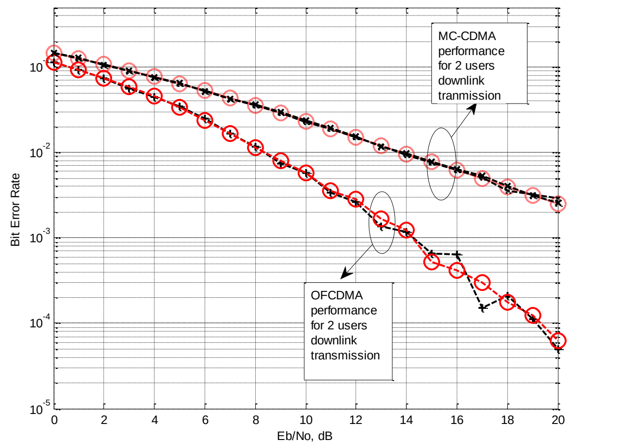

Fig. 4. The simulation results for MC-CDMA and OFCDMA systems, two users transmission, frequency fading channel model and the same used bit rate for both systems.

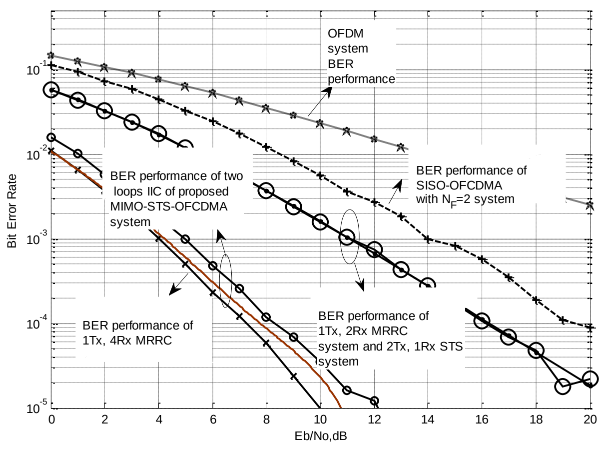

Fig. 5. The simulation results for the proposed MIMO-STS-OFCDMA-IIC system.

It should be noted that the receive diversity of the MRRC system was substituted by transmit diversity in the STS system which interprets the performance correspondence in Fig. 5. This correspondence was attained with the advantage of fewer antennas at the receiver on condition that the transmit power per antenna is assumed to be the same in both systems [21] which is more practically feasible. Furthermore, under the same channel conditions, the BER performances of the SISO-OFDM and OFCDMA were compared for the purpose of emphasizing the gained improvement achieved by the STS diversity system. Finally, the performance improvement achieved by MIMO-STS-OFCDMA-IIC system (4Tx, 2Rx) due to the application of two loops IIC receiver is illustrated where the performance becomes very close to the performance of MRRC system (1Tx, 4Rx) after two iteration loops as shown in Fig. 5.

The FD spreading factor effect on the performance of MIMO-STS-OFCDMA-IIC system was examined as shown in Fig. 6. Unless for the 0^{th} iteration loop, the system performance was enhanced with N_F increase. This enhancement was a result of exploiting both frequency and space diversities.

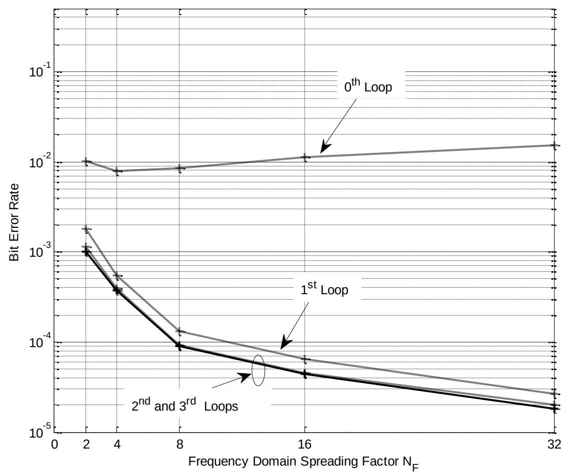

Fig. 6. The effect of the frequency domain spreading the for proposed MIMO-STS-OFCDMA-IIC system.

As shown in Fig. 6, for the 0^{th} loop the BER is almost flat and it even degrades after $N_F = 8$. This degradation appears as the corresponding correlation rises when N_F increases. On the contrary, for the 1^{st} and 2^{nd} loops the improvement is obviously seen due to decreasing the MTI.

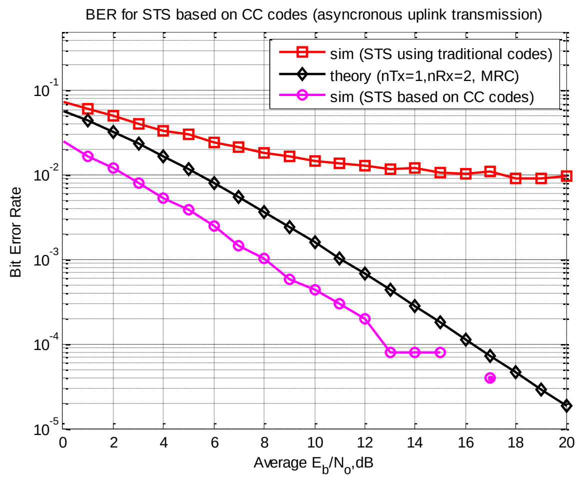

Fig. 7. MIMO-STS-OFCDMA based on CC codes simulation results.

The simulation results for MIMO-STS-OFCDMA based on CC codes are shown in Fig. 7. For the purpose of focusing on BER improvement provided by the system based on CC codes, the simulation results for the same proposed system but based on the traditional codes are presented for comparison.

The simulation results show that the BER performance of the STS based on CC codes outperforms the system performance that uses the traditional codes in case of asynchronous uplink transmission.

This assures the advantages of using system based on CC codes on the uplink transmission in spite of the complexity added to the system and the usage of subcarrier frequencies for the flock codes transmission.

V. Conclusions

In this paper, different innovative combinations that are based on an integration of the MIMO-STS, CCC and OFCDMA systems were proposed for downlink and uplink transmission improvement. In the downlink, the MIMO-STS-OFCDMA system was proposed. It targets the improvement in BER and data rate through the utilization of both 2D spreading and MIMO transmit diversity benefits. An iterative interference cancellation algorithm was introduced at the MIMO-STS-OFCDMA receiver for more BER improvement which was also manifested through the mathematical analysis presented throughout the paper. The data rate was doubled without the need for extra spectrum resources through the extension of STS (2Tx, 1Rx) to STS (4Tx, 2Rx) and combining with OFCDMA system to form the proposed MIMO-STS-OFCDMA-IIC system. The results showed that the proposed MIMO-STS-OFCDMA-IIC system performance was very close to MRRC (1Tx, 4Rx). A considerable improvement in BER was obtained with a few number of iteration loops. The system performance was also improved significantly as the frequency domain spreading factor N_F increases. In the uplink, the MIMO-STS-OFCDMA based on new CC codes was proposed. The proposed integration eliminates the effect of MAI in case of asynchronous transmission. The results showed an improvement in BER performance compared the systems that use tradition codes. Further performance enhancement is expected if adaptive modulation, coding, massive MIMO, and power adaptation are combined with MIMO-STS-OFCDMA-IIC system.

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