DATA TRANSMISSION IN MIMO-OFDM TECHNOLOGIES FOR CURRENT AND FUTURE WIRELESS COMMUNICATION SYSTEM: FROM THEORY TO PRACTICE

[1]Ibrahim, J. *, [1]Mohammed, A., [2]Kabir, U., [3]Musa A.A.

[1]Department of Electrical and Electronics Engineering,

[2]Department of Computer Engineering,

[3]Department of Mechatronics Engineering,

College of Engineering, Hussaini Adamu Federal Polytechnic, P.M.B 5004 Kazaure, Jigawa State, Nigeria.

* Corresponding Author: ibrahim.jafar.elect@hafedpoly.edu.ng   TEL: (+234) 806 7312 549

_____

Abstract: This paper presents a Multiple-Input Multiple-Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM) communication system with space-time and space-Frequency block coded (STBC/SFBC) of present generation downlink channel. Space-time block coding (STBC) and space-frequency block coding are transmit diversity schemes used in a wireless communication system to mitigate the effect of channel fading. The system is aimed to reduce the Bits error rate (BER) by mitigating the effect of multipath fading which increase the quality of the system. In the proposed system, 2 transmit and 2 receive of MIMO antennas are used, to transmit modulated symbols of block N across an OFDM channel, using SFBC Alamouti's based encoding algorithm (SFBC-OFDM) derives from the basic criteria for space-time block codes (STBC). The signals from the first and second antennas are encoded and transmitted simultaneously in space and frequency over frequency-selective Rayleigh fading channel using two adjacent carriers. The work examines the SFBC and spatial diversity benefits realized based on the BER performance. The result is simulated effectively using MATLAB application software and the BER performance is compared with the conventional STBC-OFDM. It is shown that both STBC and SFBC techniques achieve similar performance with a diversity gain of four (4) over a slow fading channel with 2 antennas at both ends of the link under simple processing across the transmit and receive antennas.

Keywords: Alamouti coding, Bits error rate (BER), MIMO, Multipath fading channel, OFDM, Transmit diversity.

1. Introduction

Nowadays, mobile communications have become one of the daily necessities considering its vital role in the entire global communities. Since the 20th century, modern wireless communications techniques and services have been adopted worldwide which are beyond people's imaginations before (Zhang, 2008). In the past decades, Wireless communication systems become a significant area of often research in both academia and telecommunication industries due to the motivation by continuing increase in demand for high-rate and reliable data (Sibille et al., 2010). Multiple input multiple-output (MIMO) combined with orthogonal frequency division multiplexing (OFDM) provides good coverage, reliable transmission, high data rates and high spectrum efficiency (Sklar, 1997) and (Foschini & Gans, 1998). Furthermore, the use of MIMO and OFDM systems together has become a significant model for the deployment of the current and emerging wireless communication systems as witnessed by their existence in many recent technologies standards, such as IEEE 802.11n, IEEE 802.16ac, Worldwide Interoperability for Microwave Access (WiMAX) and 3GPP LTE/4G among others (Hampton, 2013). MIMO involves the use of multiple antennas at both ends of the communication link to exploit the multipath and improve the system performance without increasing the bandwidth or the transmit power, by creating spatial diversity which in return achieve high diversity order (Sibille et al., 2010). OFDM is employed potentially to provide a free space interface solution for future wireless communication systems (Sampath et al., 2002). It is suggested in wireless communications to combat the effect of multipath fading and prevents the communication channel against both the inter-symbol interference (ISI) and inter-carrier interference (ICI) by efficiently dividing the bandwidth into many narrow-bands, hence can also avoid the use of complex equalizers at the receiving end of the link.

In this paper, a coded MIMO-OFDM wireless transmission system with 2 transmits and 2 receive of MIMO antennas was designed. The complete system comprises many tasks such as; Data encoding, Data modulation, Space-frequency/MIMO encoding, OFDM modulation, OFDM demultiplexing, Space-frequency/MIMO detection, Data demodulation and decoding respectively.

2. Exploiting MIMO in Wireless Communication System

The basic idea behind a MIMO wireless system is to improve the performance of communications by taking the advantage of multipath and diversity (Sibille et al., 2010). Among the early contributions towards the MIMO concept for wireless communication systems was the work of (Seshadri, 1993) which proposed the techniques of using multiple antennas at both ends

of the link to transmit data from multiple users to improve the performance of the system using spatial diversity scheme. Winters et al., (1994) published another vital contribution, which exploits the benefits of using multiple antennas in the wireless communications link. Research studies on MIMO systems are still ongoing for the actual likelihood of continuing advances in the concept. MIMO system is considered to be the leading technology for our journey to a future generation of emerging wireless communication systems (Hanzo et al., 2011). **Figure 1** shows the timeline of key multi-antenna advances.
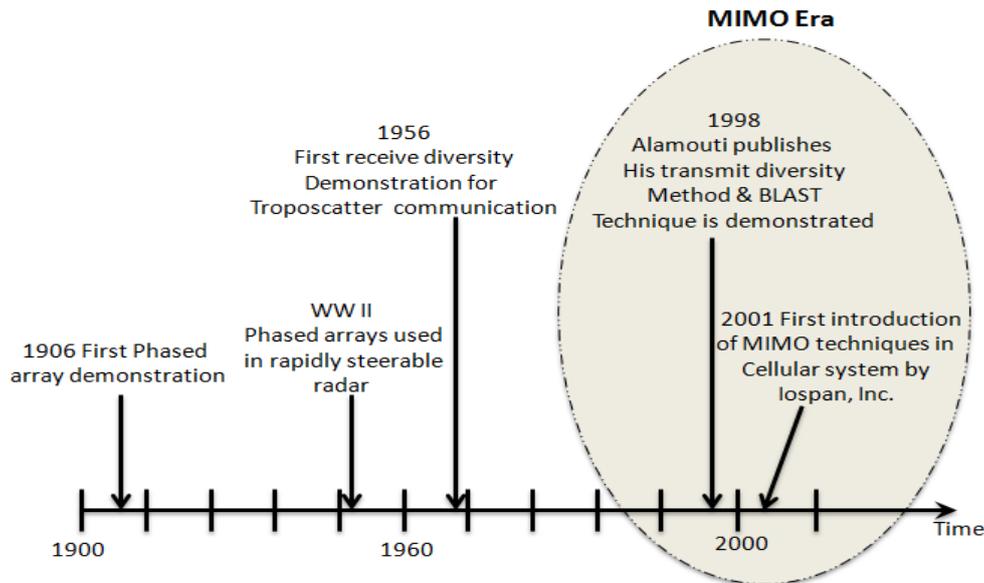
Figure 1. Timeline of key multi-antenna advances

By considering a communication system with N_T and N_R antennas at both ends of the link, the aim is to transmit separate data streams on the separate antennas, as a function of time t, which can be denoted as S_i (t). The transmitted signal from the i-th transmit antenna might use a different path to arrive at the j-th receive antenna, i.e direct and indirect paths along with various reflections. This concept is known as Multipath. In general, if we assumed all the multipath components of the system (between i-th and j-th antennas) are summed up into a single term $h_{ji}(t)$. Because the transmit signals are sent at the same frequency, therefore, the j-th receive antenna will receive the signals from all N_T transmitters not just from i-th when we omit the noise for the first instance and simplicity, this can be represented by the following equation (Tarokh et al., 1998).

$$r_j = \sum_{i=0}^{nTx} h_{j,i}(t) s_i(t) \qquad (1)$$

On the other hand, a matrix notation can be used to represent all the received signals into a single equation (Tarokh et al., 1999b).

$$\boldsymbol{S}(t) = \begin{pmatrix} s_1(t) \\ s_2(t) \\ \vdots \\ s_{nTx}(t) \end{pmatrix}, \boldsymbol{r}(t) = \begin{pmatrix} r_1(t) \\ r_2(t) \\ \vdots \\ r_{nRx}(t) \end{pmatrix} \& \boldsymbol{H}(t) = \begin{pmatrix} h_{11}(t) & h_{12}(t) & \dots & h_{1nT}(t) \\ h_{21}(t) & h_{22}(t) & \dots & h_{2nT}(t) \\ \vdots & \vdots & \ddots & \vdots \\ r_{nR2}(t) & r_{nR2}(t) & \dots & r_{nRnT}(t) \end{pmatrix} \quad (2)$$

This can be written as

$$\mathbf{r}(t) = \mathbf{H}(t)\mathbf{s}(t) \quad (3)$$

That is:

$$\begin{pmatrix} r_1(t) \\ r_2(t) \\ \vdots \\ r_{nRx}(t) \end{pmatrix} = \begin{pmatrix} h_{11}(t) & h_{12}(t) & \dots & h_{1nT}(t) \\ h_{21}(t) & h_{22}(t) & \dots & h_{2nT}(t) \\ \vdots & \vdots & \ddots & \vdots \\ r_{nR2}(t) & r_{nR2}(t) & \dots & r_{nRnT}(t) \end{pmatrix} \begin{pmatrix} s_1(t) \\ s_2(t) \\ \vdots \\ s_{nTx}(t) \end{pmatrix} \quad (4)$$

Briefly, since MIMO techniques are designed to work in a scattering environment, this paper also focuses on the channel phenomena that increases this scattering called the Multipath channel phenomenon (Hampton, 2013). In the absence of scattering and multipath, channels between different sets of transmitting and receiving antennas become correlated, resulting in poor MIMO performance (Hanzo et al., 2011). Therefore, having good knowledge of propagation is significant for predicting and understanding the performance of MIMO communication systems (Hampton, 2013). In this research work, a multipath fading channel is considered where the transmitter does not know the channel at all but is perfectly known at the receiver.

Over Rayleigh flat fading channel, MIMO system with N_T transmit and N_R receive antennas jointly with channel noise can be represented by the following equation, and let y^T denote the transpose of any vector y, (Tarokh et al., 1999).

$$r(t) = \mathbf{H_i}(t)\mathbf{s}(t) + \mathbf{n}(t) \quad (5)$$

Where,

$$s(t) = [s_1(t), s_2(t), \dots, s_{nT}(t)]^T \quad (6)$$

and

$$r(t) = [r_1(t), r_2(t), \dots, s_{nT}(t)]^T \quad (7)$$

and

$$n(t) = [n_1(t), n_2(t), \dots, n_{nT}(t)]^T \tag{8}$$

In which s(t), r(t) and n(t) are the transmit, receive signal and the noise vectors between the transmit and receive antennas respectively, and each element is circularly symmetric complex Gaussian random vector with variance $N_o/2$ per complex dimension (Tarokh et al., 1999). $\mathbf{H_i}(t)$ is channel matrix for a MIMO channel. **Figure 2** shows the schematic diagram of the generic MIMO system.
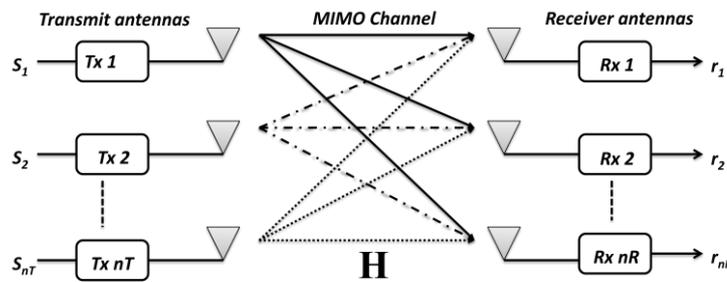
Figure 2. Schematic diagram of the generic MIMO system

3. Transmission Diversity Model

This paper proposed to consider a wireless communication system transmission model with **n** transmit antennas and **m** antennas at the receive station, in a similar way with (Tarokh et al., 1999) which define and consider the received signal $\mathbf{r_t^j}$, at the receive antenna *j*, as:

$$r_t^j = \sum_{i=1}^{n} \alpha_{i,j}\, c_t^j + n_t^j \tag{9}$$

Where $\mathbf{n_t^j}$ is the noise samples, which are independent samples of zero-mean complex Gaussian random variables with variance **n/(2 SNR)** per complex dimension (Tarokh et al., 1999).

As mentioned in many sections of this paper previously, the information will be transmitted using a 2x2 matrix based on Alamouti's scheme (Tarokh et al., 1998) as shown in **Figure 3**.
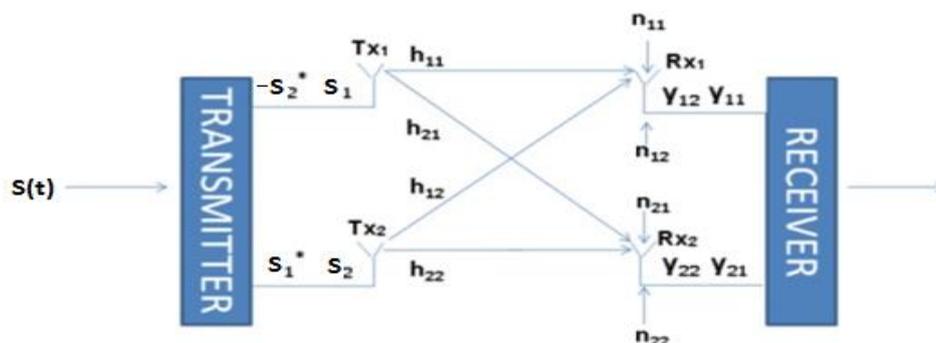
Figure 3. A complete system of 2x2 MIMO Alamouti' scheme

The received signal *y* can be obtained as:

$$y_r = H_k\, S_k + n_k \tag{10}$$

Where $\mathbf{n_k}$ are circularly symmetric complex Gaussian random variables and $\mathbf{S_k}$ is the transmit information signal given as in (Tarokh et al., 1998).

$$S_k = \begin{bmatrix} S_1 & -S_2^* \\ S_2 & S_1^* \end{bmatrix} \tag{11}$$

The Alamouti Space-time coded transmits symbols at first and second-time slot will be considered and designed as in (Tarokh et al., 1999).

For the general $\mathbf{m \times n}$ matrix, we know an estimate $\mathbf{\hat{s}_k}$ of transmit symbols $\mathbf{S_k}$ can be obtained by finding the pseudo-inverse of the matrix, which is defined as (Hampton, 2013).

$$\mathbf{H^+ = (H^H H)^{-1} H^H} \tag{12}$$

And the estimate can be obtained using the equation below (Sibille et al., 2010).

$$\begin{bmatrix} \hat{s}_1 \\ \hat{s}_2^* \end{bmatrix} = (\mathbf{H^H H})^{-1} \mathbf{H^H} \begin{bmatrix} y_1^1 \\ y_2^1 \\ y_1^{2*} \\ y_2^{2*} \end{bmatrix} \tag{13}$$

where $H^H H$ is:

$$H^H H = \begin{bmatrix} \alpha & 0 \\ 0 & \beta \end{bmatrix} \tag{14}$$

and

$$\alpha = |h_{11}|^2 + |h_{21}|^2 + |h_{12}|^2 + |h_{22}|^2 \tag{15}$$

$$\beta = |h_{11}|^2 + |h_{21}|^2 + |h_{12}|^2 + |h_{22}|^2 \tag{16}$$

Lastly, the decision is made using the maximum likelihood decoder (Anitha et al., 2015).

4. Space Frequency Block Codes in OFDM System

SFBC is a widely applied scheme using 2 transmit and M receives antenna to achieve a diversity order of 2M (Alamouti, 1998). Similarly, in this paper, 2x2 systems will be simulated, using the same SFBC techniques. 2 symbols are transmitted in two adjacent carriers simultaneously to achieve a full rate of (R=1). Alamouti's scheme was considered because it is the only orthogonal SFBC technique that achieves full rate and full diversity gain without requiring any data rate sacrifice under simple or complex modulation techniques (Alamouti, 1998).

Hence, a simple scheme with $N_T = 2$ and $N_R = 2$ is proposed here, it works by transmitting the sequence $\{s_1, -s_2^*\}$ on the first antenna and $\{s_2, s_1^*\}$ on the second antenna across two consecutive frequencies as is shown in **Figure 4** (Safatly et al., 2010).
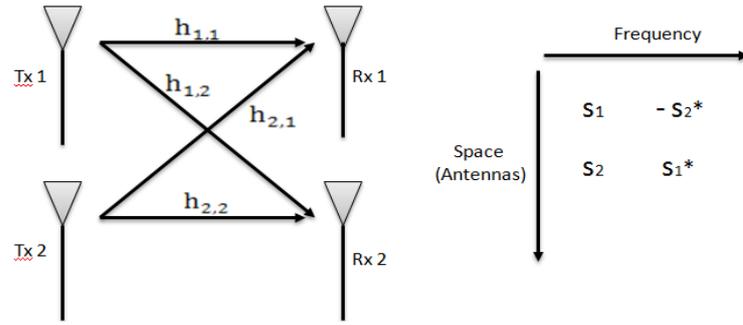
Figure 4. A description of Alamouti SFBC 2x2 schemes

We assumed the channel is frequency selective Rayleigh fading and perfectly known at the receiver. The four-channel coefficients are denoted by h_{11}, h_{12}, h_{21} and h_{22} and are considered to be in Rayleigh fading channel from i^{th} transmit to the jth receive antenna. At the receive antennas i^{th}, noise is added which has a Gaussian pdf. The received symbol r_j^k on the kth subcarrier and j receive antenna as illustrated in Figure 4, can be represented by the matrix notation as follows (Alamouti, 1998).

$$\begin{bmatrix} r_1^1 \\ r_2^1 \\ r_1^{2*} \\ r_2^{2*} \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \\ h_{12}^* & -h_{11}^* \\ h_{22}^* & -h_{21}^* \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + \begin{bmatrix} n_1^1 \\ n_2^1 \\ n_1^{2*} \\ n_2^{2*} \end{bmatrix} \tag{17}$$

Where:

$$r_1^1 = h_{11}s_1 + h_{12}s_2 + n_1^1 \tag{18}$$

$$r_2^1 = h_{21}s_1 + h_{22}s_2 + n_2^1 \tag{19}$$

$$r_1^2 = h_{11}s_2^* + h_{12}s_1^* + n_1^2 \tag{20}$$

$$r_2^2 = h_{21}s_2^* + h_{22}s_1^* + n_2^2 \tag{21}$$

and the channel matrix

$$\mathbf{H} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \\ h_{12}^* & -h_{11}^* \\ h_{22}^* & -h_{21}^* \end{bmatrix} \tag{22}$$

5. SFBC-OFDM Transmission and Detection Techniques

Table 1 indicates the space frequency block encoding. **Figure 5** shows the SFBC sub-carriers transmitting technique when using two transmit antennas with the OFDM system (Alamouti, 1998).

Table 1. Space frequency block encoding

Subcarriers	Antenna 1	Antenna 2
f_1	S_1	S_2
f_2	$-S_2{}^*$	$S_1{}^*$
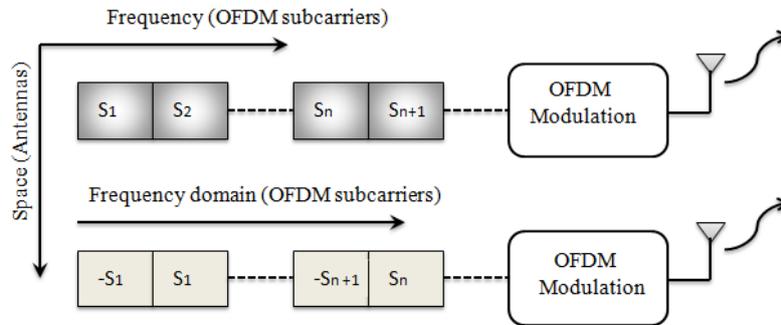
Figure 5. SFBC transmitter techniques with 2 transmit antennas

Where N is also the fast Fourier transform (FFT) size of the OFDM system and depends on the system considered (WiFi or LTE) during the design of the implementation process. Assumed, we consider the system using Long Term Evolution (LTE) commonly known as 4G LTE, from the standard (Zhang, 2008). the total size of N will not be loaded with data especially when it comes to practical implementation. For example, if we use a 10MHz or 5MHz spectrum, the size of N=1024 or N=512. So, only 600 of the 1024 or 300 of the 512 will be usable. At the other end of the link, 2 receive antennas are used to receive the transmitted data streams, the signals at the receiver will be received on odd and even frequency indexes assembled in the order of $\mathbf{r}_{odd} = [r_1, r_3, ... r_{N-3}, r_{N-1}]$ and $\mathbf{r}_{even} = [r_2, r_4, ... r_{N-2}, r_N]$ and expressed by the equations (Yiu et al., 2012).

$$r^1_{1\,odd} = h_{11}{}^{odd}s_1{}^{odd} + h_{12}{}^{odd}s_2{}^{odd} + n^1_{1\,odd} \tag{23}$$

$$r^1_{2\,even} = h_{21}{}^{eve}s_1{}^{eve} + h_{22}{}^{2\,eve}s_2{}^{eve} + n^1_{2\,even} \tag{24}$$

$$r^2_{1\,odd} = h_{11}{}^{2\,odd}s_2{}^{odd} + h_{12}{}^{2\,odd}s_1{}^{odd} + n^2_{1\,odd} \tag{25}$$

$$r^2_{2\,even} = h_{21}{}^{eve}s_2{}^{eve} + h_{22}{}^{2\,eve}s_1{}^{eve} + n^2_{2\,even} \tag{26}$$

Where;

$h_n^{odd} = [\, H_n[1], H_n[3], \ldots, H_n[N-3], H_n[N-1]\,]$, $h_n^{eve} = [H_n[2], H_n[4], \ldots, H_n[N-2], H_n[N]]$,   and $n = 1, 2$, $s_1^{odd} = [s_1, s_3, \ldots s_{N-3}, s_{N-1}]$, $\boldsymbol{s}_2^{even} = [s_2, s_4, \ldots s_{N-2}, s_N]$, $s_2^{eve} = [s_1^*, s_3^*, \ldots s_{N-3}^*, s_{N-1}^*]$, $s_1^{eve} = [-s_2^*, -s_4^*, \ldots -s_{N-2}^*, -s_N^*]$, $n_{odd} = [\, n[1], n[3], \ldots, n[N-3],\ n[N-1]]$ and $n_{even} = [n[2], n[4], \ldots, n[N-2], n[N]]$

It is important to note that;

$$s_1^{eve} = -s_2^{*\,odd} \text{ and } s_2^{eve} = s_1^{*\,odd} \tag{27}$$

Thus, (24) and (26) can be written as

$$r_{2\,even}^1 = h_{21}^{\,eve}{-s_2^{*\,odd}} + h_{22}^{\,2\,eve}s_1^{*\,odd} + n_{2\,even}^1 \tag{28}$$

$$r_{2\,even}^2 = h_{21}^{\,eve}s_1^{*\,odd} + h_{22}^{\,2\,eve}{-s_2^{*\,odd}} + n_{2\,even}^2 \tag{29}$$

By examining (23) and (28), it can be seen that they can be written in matrix form $r_{\mathrm{F}}[j] = B_{\mathrm{F}}[j]h_{\mathrm{F}}[j] + n[j],\ 1 \leq j \leq N/2$ as follows

$$\begin{bmatrix} r_1^1{}_{2j-1} \\ r_2^1{}_{2j} \end{bmatrix} = \begin{bmatrix} s_{2j-1} & s_{2j} \\ -s_{2j}^* & s_{2j-1}^* \end{bmatrix}\begin{bmatrix} H_1^1[2j] \\ H_2^1[2j] \end{bmatrix} + \begin{bmatrix} n_1^1[2j-1] \\ n_2^1[2j] \end{bmatrix} \tag{30}$$

And (25) and (29), can also be written in the same way as

$$\begin{bmatrix} r_1^2{}_{2j-1} \\ r_2^2{}_{2j} \end{bmatrix} = \begin{bmatrix} s_{2j} & s_{2j-1} \\ s_{2j-1}^* & -s_{2j}^* \end{bmatrix}\begin{bmatrix} H_1^2[2j] \\ H_2^2[2j] \end{bmatrix} + \begin{bmatrix} n_1^2[2j-1] \\ n_2^2[2j] \end{bmatrix} \tag{31}$$

Now, it is clear from (30) and (31) that the signals obtained at each receiver can be combined using the conventional method proposed by (Alamouti, 1998).

$$\begin{bmatrix} \hat{s}_{2j-1} \\ \hat{s}_{2j}^* \end{bmatrix} = \begin{bmatrix} H_1[j]^* & H_2[j] \\ H_2[j]^* & -H_1[j] \end{bmatrix}\begin{bmatrix} r_1^2{}_{2j-1} \\ r_2^2{}_{2j} \end{bmatrix}, 1 \leq j \leq N/2 \tag{32}$$

The same for the second antenna and these combined signals from both receivers will the sent to the detector for detection. Hence SFBC-OFDM achieves the diversity order of 2M, even in frequency selective channels with condition that the channel maximum delay spread is less than the length of the CP. **Figures 6(a)** and **6(b)** show SFBC-OFDM transmitter using 2 transmits and 2 receive antennas and SFBC-OFDM receiver using 2 transmits and 2 receive of MIMO antennas respectively.
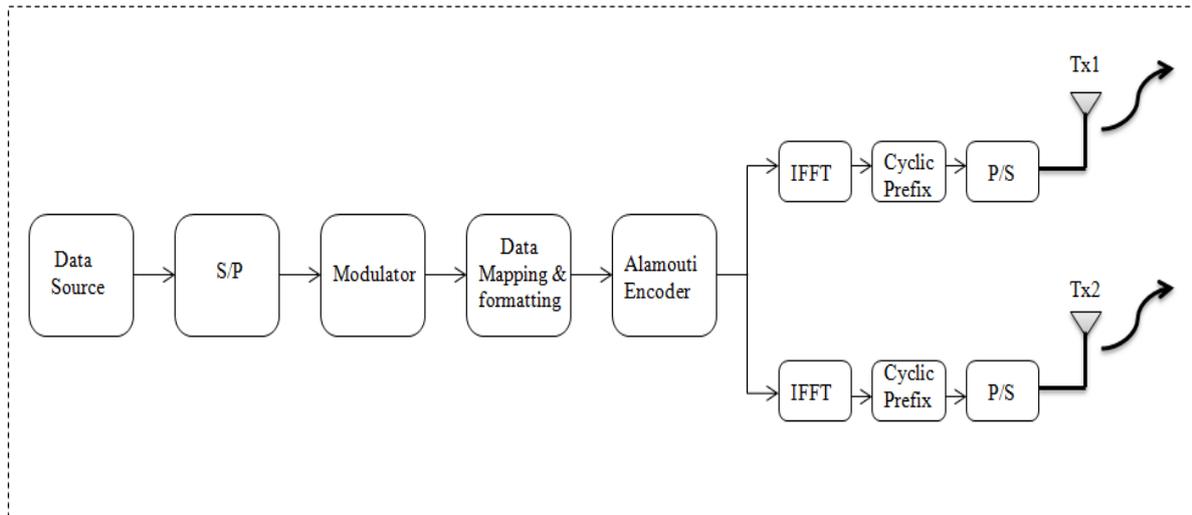
Figure 6(a). SFBC-OFDM transmitter using 2 transmits and 2 receive of MIMO antennas
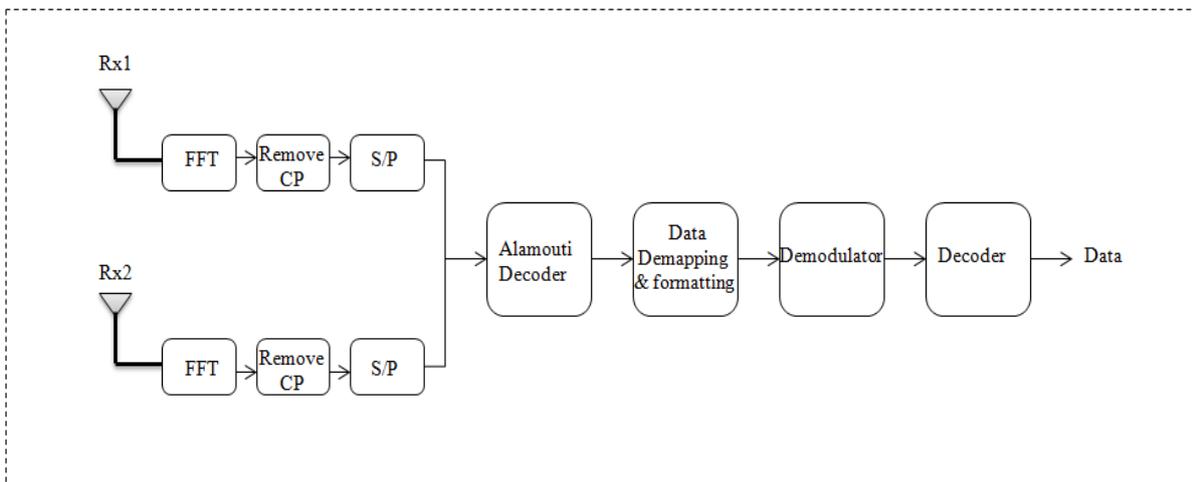
Figure 6(b). SFBC-OFDM receiver using 2 transmits and 2 receive of MIMO antennas

6. SFBC-OFDM Encoding and Transmission Performance

The modulated information is mapped onto each block code based on Alamouti's code block orthogonal design scheme using two transmit antennas, the encoding is done in space and frequency (space-frequency coding) using two adjacent sub-carriers (Alamouti, 1998). The information is transmitted through the OFDM channel, the modulated symbols of N sub-carriers is converted from serial to parallel form prior to being fed into OFDM modulators to perform inverse fast Fourier transform (IFFT) on a block of N length. Let assume the N length of the data symbols block is $Y = Y_O, Y1,...., Y_{N-1}$. A serially converted parallel sequence symbols $y = y_o, y_1, ..., y_{n-1}$ in the time domain is produced after the IFFT operation. Cyclic prefixes (CP) of length $Tp > \tau_m$ are pre-appended, by taking the length N_{cp} period at the end of each frame and appending it at the beginning of each frame, where τ_m is the maximum delay spread

(Nizmaldeen, & Al-Qaradaghi, 2012). The data is converted back from parallel to serial form. Random channels impulse responses were also generated and the OFDM signals are applied to the channel in the time domain and the noise is added to the signals and reshaped back to parallel form individually. At the receiver side, the cyclic prefixes are removed, and fast Fourier transform (FFT) is performed by the OFDM demodulators back to the frequency domain. Finally, the estimate transmits symbols are detected similar to the conventional method proposed in (Alamouti, 1998), by multiplying the pseudo-inverse of the matrix **H** by the received signals as well as their conjugations separately**.** The decision is made using zero-forcing techniques prior to the data demodulation and counting errors. Finally, the simulation result is plotted successfully using MATLAB software.

7.   Simulation Parameters Used and Results Achieved

The MIMO-OFDM parameters used for the simulation of this work are considered based on the LTE/4G standard as shown in **Table 2**.

Table 2. Parameters of the LTE/4G physical layer

Parameters	Range
Channel Bandwidth (MHz)	10
FFT Size	1024
Occupied subcarriers	601
Guard Subcarriers	423
Cyclic prefix (%)	72
Number of bits/frame	9600
Occupied Channel Bandwidth (MHz)	9.015
Number of frames	10000
Bandwidth efficiency (DL)	90%

This work is simulated in two ways, with tap weight (EPA model) and without tap weight (uniform) and was also plotted with a theoretical graph as shown in **Figures 7(a)**, **7(b)** and comparisons in **Figure 7(c)**. Both are simulated and achieve fourth-order diversity with two antennas at both ends of the link. The EPA model achieves a better performance than the system without tap weight, below.
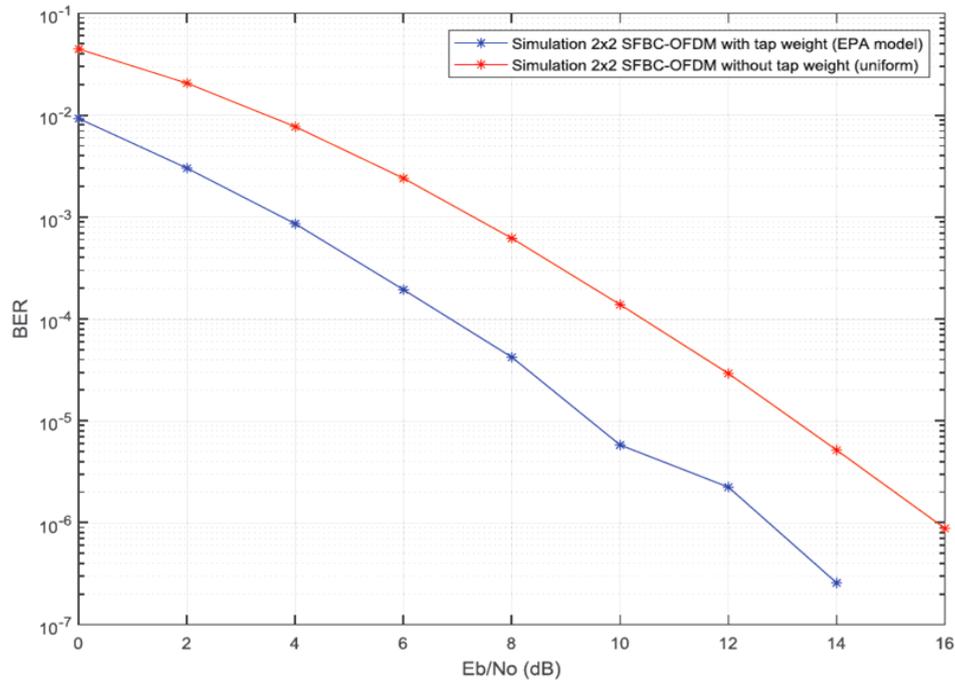
Figure 7(a). Performance of the simulated 2x2 SFBC-OFDM (uniform) and (EPA model)
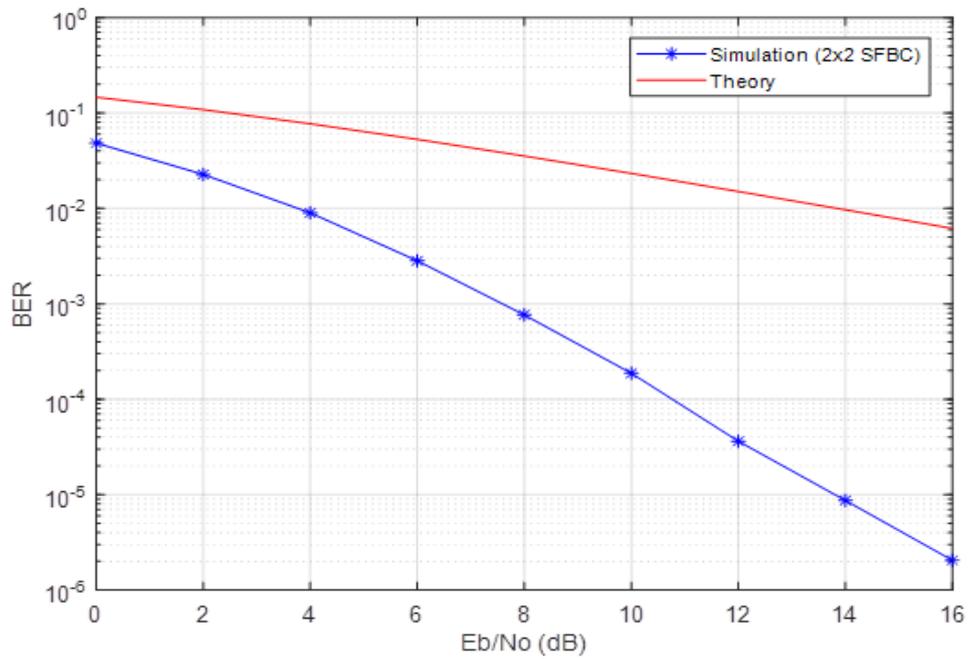
Figure 7(b). Performance of simulated SFBC 2x2 MIMO-OFDM Alamouti's Scheme
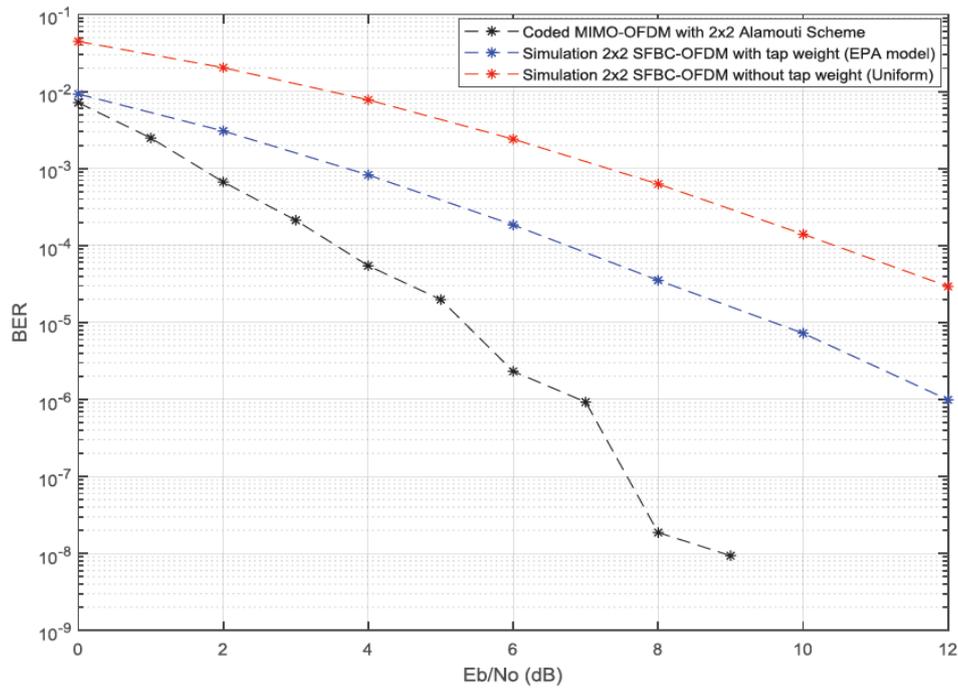
Figure 7(c). Performance comparison of the simulated 2x2 coded and the non-coded systems

8. Discussion

The work is done perfectly, and the results are obtained using SFBC Alamouti coding scheme with 2 transmits and 2 receive of MIMO antennas (NT = NR = 2). Figure 6a shows the result of 2 transmits and 2 receive SFBC-OFDM with tap weight (EPA model) and without tap weight (uniform). While, Figure 6b shows the result of 2 transmits and 2 receive of SFBC MIMO-OFDM Alamouti's Scheme. Figure 6c displays the comparison result of 2 transmits and 2 receive of MIMO coded and MIMO non-coded systems. Both simulations are modulated over binary phase shift keying (BPSK) modulation scheme. The results obtained are very effective and achieved high performance. The results attained a diversity gain of around four (4) which is quite reasonable and precisely similar to the result achieved in (Alamouti, 1998) and (Safatly et al., 2010). For STBC/SFBC and SFBC-OFDM with 2 transmits and 2 receive antennas of MIMO system respectively.

8.1 Practical Implementation Aspects

Most of the proposed results for research interests were limited to theoretical analysis and simulation only. Thus, they ignored the practical aspects and the drawbacks encountered when practical implementation needs arise, e.g. Packet loss, Packet handling jitters and many other defects. These problems need to be taken into consideration when it comes to the implementation aspect. The main challenge facing the practical Implementations of wireless communication systems is to provide high-speed wireless access at high QoS (Bolcskei, 2006).

Alamouti (1998) outline some practical implementation issues to be considered when transferring the theoretical findings into practice, such as power requirement (radiated power and amplifier(s) power handling), channel estimation error, delay effects, antenna configurations etc. Likewise, regarding the implementation of this system, similar approaches should be adopted since it is based on a similar scheme. i.e. For the radiation power, the energy to be allocated to each symbol should be half of the total transmit power, to have the total transmit power from the two transmit antennas used, which result in 3dB disadvantage in the error performance and may be advantageous for power amplifier handling considering the power reduction factor of two (2). For the channel estimation, the channel information can derive using minimum mean square error (MMSE) or Least Squares (LS) channel estimators. The performance of MMSE is quite good, but it has high complexity, while LS has low complexity, but its performance is low compared to MMSE (Khlifi & Bouallegue, 2011). The channel can be estimated by pilot symbol insertion and extraction and can be done using training symbols that are applied to the entire subcarriers of the OFDM and assumed the receiver has all the channel information (CI). Yet some factors may affect this system, such as, when the channel is varied rapidly over time, mismatched interpolation coefficient and quantization (Alamouti, 1998). Synchronization is required in the system when OFDM baseband signals are applied, which will cause synchronization error due to symbol time offset (STO), phase offset (PO) etc. Which is aimed to estimate and correct the time offset and the frequency difference between the two antennas at the ends of the link (transmit and receive). Channel emulation may be required, to choose a suitable channel model that can fit the system and support the transfer of possible high data rates across the system. As for the delay effect, since the multicarrier system is considered in this work and the copies are also sent at N sub-carriers from both antennas using N branch diversity, hence the decoding delay will be N symbol periods (Alamouti, 1998). When it comes to the antenna configurations, in practice, the signals from the transmit antennas should be sufficiently uncorrelated with equal average power (< 3dB) difference to improve the diversity (Alamouti, 1998). For the impact on interference, since the system requires the synchronous transmission of the signals from the two transmit antennas each transmitting half power, it emerges that the number of possible interferers is twice, each with interference power of half. In some applications, interference cancellation schemes may be applied effectively (Alamouti, 1998). Therefore, these and more practical aspects like soft failure need to be considered when it comes to system practical implementation. Moreover, for the modem complexity, since the receiver is assumed to have all channel information, the system does not require any feedback from the receiver to the transmitter, which in turn adds complexity to both ends of the link.

Besides, the computation complexity of the system is simple and straightforward (Alamouti, 1998).

9. Conclusion

In this paper, a MIMO-OFDM wireless transmission system using 2 antennas at both ends of the link has been presented. The concept of the SFBC-OFDM system is proposed and its performance is analysed in terms of BER and diversity gain using standard 4G downlink channel parameters. The modulated data encoding and detection processes are explained for 2 transmit and 2 receive antennas. The transmitted data symbols are successfully detected at the receiver using a simple linear processing technique as in the STBC-OFDM system. The system is simulated in MATLAB software environment and quite achieved a better performance as justified by the simulation results above. The result indicates that the space-frequency block coding (SFBC) scheme can sufficiently achieve a remarkable performance increase over multipath fading channels compared to conventional orthogonal frequency division multiplexing (OFDM) techniques. SFBC-OFDM has a high sensitivity to channel gain over frequency, while STBC-OFDM has over time as already attained and justified in this project. Furthermore, the SFBC attained similar diversity gain with STBC in a slow fading channel, though it is more robust in a fast fading channel compared to the STBC scheme (Sampath et al., 2002). Conclusively, 4G and beyond SFBC-OFDM can only achieve optimal performance when the channel remains constant for at least two successive subcarriers.

References

Alamouti, S. M. (1998). A simple transmit diversity technique for wireless communications. *IEEE Journal on Selected Areas in Communications*, 16 (8), pp. 1451-1458.

Anitha, M., Priya, R. S., Lakshmi, M. R., Vijayalakshmi, S. (2015). MIMO system performance using various modulations under different channels with STBC, ZF and MRC. *IEEE International Conference on Electrical, Computer and Communication Technologies (ICECCT)*, pp. 1-5.

Bolcskei, H. (2006). MIMO-OFDM wireless systems: basics, perspectives, and challenges. *IEEE Wireless Communications*, 13 (4), pp. 31-37.

Foschini, G. J., Gans, M. J. (1998). On limits of wireless communications in a fading environment when using multiple antennas. *Wireless Personal Communications*, 6 (3), pp. 311-335.

Hampton, J. R. (2013) Introduction to MIMO communications. Cambridge University Press.

Hanzo, L., Akhtman Y., Wang, L., and Jiang, M. (2011). MIMO-OFDM for LTE, WiFi and WiMAX: Coherent versus non-coherent and cooperative turbo transceivers. John Wiley & Sons.

Khlifi, A., & Bouallegue, R. (2011). Performance analysis of LS and LMMSE channel estimation techniques for LTE downlink systems. *International Journal of Wireless Mobile Network,* pp. 141-149.

Nizamaldeen, S. A., and Al-Qaradaghi, T. M. (2012). A comparison between STBC-OFDM and SFBC-OFDM. *International Journal of Arts & Sciences*, 5 (4), pp. 157-166.

Safatly, L., Andrieux, G., and Diouris, J. F. (2010). LTE multi-antenna techniques based on Alamouti SFBC with correlated channels. *International Conference on Software, Telecommunications and Computer Networks*, pp. 214-218.

Sampath, H., Talwar, S., Tellado, J., Erceg, V., and Paulraj, A. (2002). A fourth-generation MIMO-OFDM broadband wireless system: design, performance, and field trial results. *IEEE Communications Magazine*, 40 (9), pp. 143-149.

Sibille, A., Oestges, C., and Zanella, A. (2010). MIMO: From theory to implementation. Academic Press.

Sklar, B. (1997). Rayleigh fading channels in mobile digital communication systems. I. Characterization. *IEEE Communications Magazine*, 35 (7), pp. 90-100.

Tarokh, V., Naguib, A., Seshadri, N., and Calderbank, A. R. (1999). Combined array processing and space-time coding. *IEEE Transactions on Information Theory*, 45 (4), pp. 1121-1128.

Tarokh, V., Seshadri, N., and Calderbank, A. R. (1998). Space-time codes for high data rate wireless communication: Performance criterion and code construction. *IEEE Transactions on Information Theory*, 44 (2), pp. 744-765.

Winters, J. H., Salz, J., and Gitlin, R. D. (1994). The impact of antenna diversity on the capacity of wireless communication systems. *IEEE Transactions on Communications*, 42 (234), pp. 1740-1751.

Seshadri, N. (1993). Two signals schemes for improving the error performance of FDD transmission systems using transmitter antenna diversity. In *Proc. IEEE Vehicular Technology Conference, (VTC43rd),* pp. 508-511.

Yiu, S., Calin, D., Kaya, O., and Yang, K. (2012). Distributed STBC-OFDM and distributed SFBC-OFDM for frequency-selective and time-varying channels. *IEEE Wireless Communications and Networking Conference (WCNC)*, pp. 251-255.

Zhang, L. (2008). Signal processing for future MIMO-OFDM wireless communication systems. Cardiff University (United Kingdom).