International Journal of Electrical and Computer Engineering (IJECE)
Vol.x, No.x, September 201x, pp. xx~xx
ISSN: 2088-8708

Performance measurements of IEEE 802.11n WLAN Technology using MIMO-STBC 4x4 with Antenna Correlation and Ray Tracing Channel Model

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Article Info

Article history:

Received Jun 12th, 201x
Revised Aug 20th, 201x
Accepted Aug 26th, 201x

Keyword:

IEEE 802.11n
WLAN
MIMO
STBC
Channel correlation
Ray tracing

ABSTRACT

Indoor channel with high correlated fading degraded the performance of telecommunication system such as IEEE 802.11n WLAN (Wireless LAN) System. We proposed a method for preserving SER (Symbol Error Rate) of the IEEE 802.11n standard in MIMO-OFDM (Multiple-Input Multiple-Output-Orthogonal Frequency Division Multiplexing) correlated channel as a performance parameter. In order to improve its reliability without complexity, it used STBC (Space Time Block Coding) using Alamouti algorithm. This algorithm could be implemented with STBC 2x1, 2x2, 3x1, 3x2, 3x3, 4x1, 4x2, 4x3, and 4x4 using BPSK, QPSK, 16-QAM, and 64-QAM modulation. Impulse respons of indoor channel, then so-called LTE-UBD channel, could be modeled by using a ray tracing method. The channel gave delay spread and rms delay of 71.94 ns and 1.5 ns respectively. The ergodic channel capacity declined steadily as the channel correlation became worse. This problem also caused a decrease in SNR (Signal-to-Noise Ratio) performance to achieve the SER of 10^{-3} with various modulations. Fortunately, this did not have significant influence on WLAN system that used the STBC with four antennas in each of the transmitter and receiver.

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1. INTRODUCTION

Many features such as MIMO, SDM (Spatial Division Multiplexing), and STBC (Space Time Block Coding) can be found in IEEE 802.11n WLAN system. The combination of the MIMO and STBC using Alamouti algorithm has become an attractive solution to improve range and reliability in this system [1]. A simple decoding method makes WLAN technology appropriate to be used in the portable receivers, like notebooks and cellphones with limited power. Furthermore, some studies related to the WLAN on channel measurements or modeling have been done in [2]–[4]. In [2], modeling a large number of multipath in the 5 GHz frequency band was applied by placing the transmitter and receiver in parallel without being given any information about the phase when the signals arrived in the receiver. Therefore, it was difficult to determine whether the signal arrives in the phase or not.

At 2.4 GHz channel, a simulation with measurement comparison was performed using a real signal as in [3]. In this scenario, the losses should be ignored as the distance between the transmitter and receiver was very close, that was from 1 to 2.5 m. Moreover, this scenario could not be used for modeling a real channel because of the neglect of material losses on its signal propagation. The real channel with its characteristic was simply modeled with a method named Ray-Tracing (RT). As mentioned in [5], this method could be used to portend signal strength and delay spread for indoor/outdoor configuration. For example in [6], channel capacity for SISO and MIMO system was shown, but it did not involve a channel correlation and mention any essential channel parameter such as delay spread. This correlation affected the ergodic channel capacity assuming which the channel information state (CSI) was known at the receiver [7]. A study in the case of multi-user with correlated channels was also done in [8], but it still assumed the channel condition.

The receivers, fixed or mobile stations, are highly vulnerable to experience signal fading. It can cause errors as the frame or the received data is not synchronized, so that time synchronization is needed [9]. Indoor channel is very susceptible to signal attenuation due to propagation phenomena (reflection, diffusion, refraction etc) through a variety of materials such as wood walls, etc so that it is necessary to combat the signal attenuation such in [10]. The STBC with particular coding, so-called HSTBC, can cope with fading and improve the capacity of the IEEE 802.11 WLAN standard [11]. Nevertheless, it does not evaluate a higher order modulation for correlated MIMO channel.

Several contributions have been made in this paper. We outlined how the MIMO-STBC can maintain Symbol Error Rate (SER) in a multipath fading channel environment. We also modeled the real channel in laboratory, so-called LTE-UBD, with one dimensional Ray-Tracing method for NLOS (Non Light-of-Sight) scenario which yielded channel delay spread and rms delay. Ergodic channel capacity and SER curves as a function of the SNR were given as a measure of performance. The rest of the paper is organized as follows: Section II describes the IEEE 802.11n physical parameter standard. Section III provides an overview of the STBC and indoor propagation. Section IV describes the proposed method in the simulation design. The results and analysis are presented in Section V. Finally, the conclusion is drawn in Section VI.

2. IEEE 802.11N PHYSICAL PARAMETER

The IEEE 802.11n is WLAN (Wireless Local Area Network) technology that uses 20 or 40 MHz bandwidth channel and 2,4 or 5 GHz ISM (Industrial, Scientific and Medical) band for mandatory features. As ilustrated in [1], it uses 56 subcarriers that consist of 52 data carrier located at -26, -25, ..., -2, -1, 1, 2, ..., 25, 26, and 4 pilot carriers located at -21, -7, 7, 21. A 64-FFT/IFFT point results 4 μs symbol (a 3,2 μs OFDM symbol prepended by a 0,8 μs cyclic prefix). The packet that omits backward compatibility with the previous WLAN is Greenfield (GF) packet as seen in Figure 1.

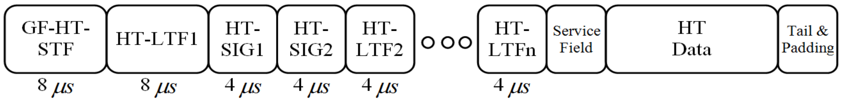

Figure 1. Greenfield packet structure

This packet consists of GF-HT-STF, GF-HT-LTF, HT-SIG 1 and 2 and Field Data. Each part contains different kinds of structure as listed below

- GF-HT-STF

  The GF-HT-STF (GF-High Troughput-Short Training Field) is defined based on the frequency domain sequence given in (1). Ten repetitions of 0.8 μs symbol in time domain produce 8 μs symbol.

$$S_{-28,28}=\sqrt{1/2}\begin{Bmatrix}0,0,0,0,1+j,0,0,0,-1-j,0,0,0,1+j,0,0,0,-1-j,0,0,\\ 0,-1-j,0,0,0,1+j,0,0,0,0,0,0,0,-1-j,0,0,0,-1-j,\\ 0,0,0,1+j,0,0,0,1+j,0,0,0,1+j,0,0,0,1+j,0,0,0,0\end{Bmatrix} \tag{1}$$

- GF-HT-LTF

  The HT-LTF (High Troughput-Long Training Field) consists of HT-LTF1 and HT-LTFn which consist of 8 μs (two repetitions 3.2 μs symbols prepended by 1.6 μs cyclic prefix) and 4 μs (3.2 μs symbols prepended by 1.6 μs cyclic prefix) length, respectively. The HT-LTF1 and HT-LTFn have the same basic frequency domain sequence as expressed in (2). Both are used for channel estimation.

$$HTLTF_{-28:28}=\begin{bmatrix}1,1,1,1,-1,-1,1,1,-1,1,-1,1,1,1,1,1,1,-1,-1,1,1,-1,1,-1,1,1,1,1,0,1,-1,\\ -1,1,1,-1,1,-1,1,-1,-1,-1,-1,-1,1,1,-1,-1,1,-1,1,-1,1,1,1,1,-1,-1\end{bmatrix} \tag{2}$$

- HT-SIG1 and HT-SIG2

The HT-SIG (High Troughput – Signal Field) consists of 48 information bits divided into HT-SIG1 and HT-SIG2. Each contains 24 information bits and 4 μs in length. The symbol is comprised of 3.2 μs symbol prepended by a 0.8 μs cyclic prefix.

- Field Data

The data field consists of 16 service field bits, HT-Data, 6 tail bits and pad bit. Pad bits are calculated based on N_{SYM}. N_{DBPS} – 8. *length* -16 – 6, where N_{DBPS} is number of data bits per OFDM symbol, *length* is a value of length field in the range of 0 to 65535 bytes and N_{SYM} is a number of OFDM symbol given in (3).

$$N_{SYM} = \left\lceil \frac{8.length + 16 + 6}{N_{DBPS}} \right\rceil \tag{3}$$

3. STBC AND INDOOR PROPAGATION

3.1. STBC (Space Time Block Coding)

The STBC uses Alamouti algorithm that gives full transmit diversity without the need for information on the channel and very little decoding complexity [12]. Figure 2 illustrates the Alamouti encoder with two transmit antennas.

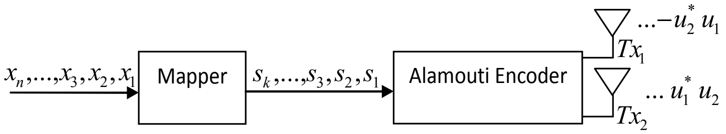

Figure 2. Alamouti encoder

Information bits $x_1, x_2, \ldots, x_n$, modulated with certain modulation scheme (BPSK, QPSK, 16-QAM or 64-QAM). Mapped symbols $s_1, s_2, \ldots, s_k$ are sent to the Alamouti encoder that uses transmitted codeword as in (4).

$$U = \begin{bmatrix} u_1 & -u_2^* \\ u_2 & u_1^* \end{bmatrix} \tag{4}$$

If s_1 and s_2 are the selected symbols at time one, the transmitter sends u_1 from antenna one (Tx1) and u_2 from antenna two (Tx2). Then at time two, symbols $-u_2$ and u_1 are transmitted from antenna one and two, respectively. The equations of (4) the results of the STBC code rate R = 1. Lower code rate, R=1/2, using three and four antennas are shown by $U_{3,complex}$ and $U_{4,complex}$ in (5), respectively.

$$\mathrm{U}_{3,\mathrm{complex}} = \begin{bmatrix} u_1 & -u_2 & -u_3 & -u_4 & u_1^* & -u_2^* & -u_3^* & -u_4^* \\ u_2 & u_1 & u_4 & -u_3 & u_2^* & u_1^* & u_4^* & -u_3^* \\ u_3 & -u_4 & u_1 & u_2 & u_3^* & -u_4^* & u_1^* & u_2^* \end{bmatrix}, \; U_{4,complex} = \begin{bmatrix} u_1 & -u_2 & -u_3 & -u_4 & u_1^* & -u_2^* & -u_3^* & -u_4^* \\ u_2 & u_1 & u_4 & -u_3 & u_2^* & u_1^* & u_4^* & -u_3^* \\ u_3 & -u_4 & u_1 & u_2 & u_3^* & -u_4^* & u_1^* & u_2^* \\ u_4 & u_3 & -u_2 & u_1 & u_4^* & u_3^* & -u_2^* & u_1^* \end{bmatrix} \tag{5}$$

The simple STBC 2x1 or MISO (Multiple Input Single Output) system with Maximum Likelihood (ML) detector is shown in Figure 3.

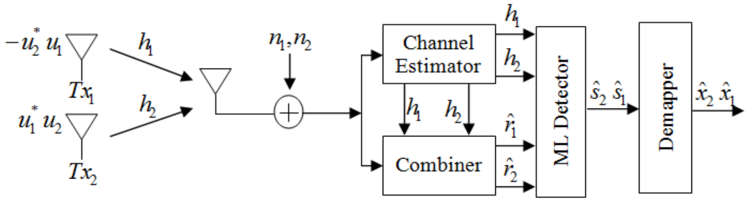

Figure 3. A Simple STBC 2x1 or MISO system

At the receiver, the combiner combines the received signals as $\hat{r}_1 = h_1^* r_1 + h_2 r_2^*$ and $\hat{r}_2 = h_2^* r_1 - h_1 r_2^*$, where $\hat{r}_1$ and $\hat{r}_2$ are the estimated symbols of $\hat{u}_1, \hat{u}_2$. Complex path gains from transmit antennas to the receive antenna are shown by h_1 and h_2. The symbols of r_1 and r_2 are the received signals at time t and $t + T_s$ respectively. Channel estimator estimates path gains h_1, h_2 from the received signals. For a coherent signal detection scheme where the receiver recognizes the channel path gains, the decision metric in (6) based on maximum-likelihood scheme can be performed.

$$\begin{gathered} d_{\min}{}^2(\hat{r}_1, h_1 u_1 + h_2 u_2) + d_{\min}{}^2(\hat{r}_2, -h_1 u_2^* + h_2 u_1^*) \\ \left|\hat{r}_1 - h_1 u_1 - h_2 u_2\right|^2 + \left|\hat{r}_2 + h_1 u_2^* - h_2 u_1^*\right|^2 \end{gathered} \tag{6}$$

The overall possible values of u_1 and u_2 result $\hat{s}_1$ and $\hat{s}_2$ respectivelly are based on

$$\hat{s}_1 = \arg\min_{u_1 \in C}\left(\left(|h_1|^2 + |h_2|^2 - 1\right)|u_1|^2 + d_{\min}{}^2(\hat{r}_1, u_1)\right)$$
$$\hat{s}_2 = \arg\min_{u_2 \in C}\left(\left(|h_1|^2 + |h_2|^2 - 1\right)|u_2|^2 + d_{\min}{}^2(\hat{r}_2, u_2)\right) \quad (7)$$

As noted in (7), the full search for all possible pairs of symbols (u_1, u_2) must be utilized. Therefore, the complexity grows exponentially as the number of transmit antennas increases.

3.2. Indoor Propagation

Various models for indoor channel modeling in [13], one of them is an exponential model developed into the Saleh-Valenzuela (S-V) channel model. The design of impulse responses is based on a cluster model used in channel model B, D and E. One of them is illustrated in Figure 5 [1].The delay spread is calculated based on the delay between the first and the last path, in this case 80 ns. The amount of the attenuation at the indoor channel environment is strongly influenced by environmental conditions such as partition loss from [5]. The path loss occuring in a free space with distance *d* can be modeled as follows [14]

$$L(d) = L_{FS}(d),\ d \le d_{BP}$$
$$L(d) = L_{FS}(d_{BP}) + 3{,}5.10 Log_{10}(d / d_{BP}),\ d > d_{BP} \quad (8)$$

where d is distance between Tx and Rx, d_{BP} is breakpoint distance to the channel model B, D and E which is equal to 5, 10 dan 20 m respectively. Free Space Path Loss, L_{FS}, can be expressed from [15] by

$$L_{FS}(d) = 10\ Log_{10}\left(\frac{(4\pi d)^2}{\lambda^2}\right) \quad (9)$$

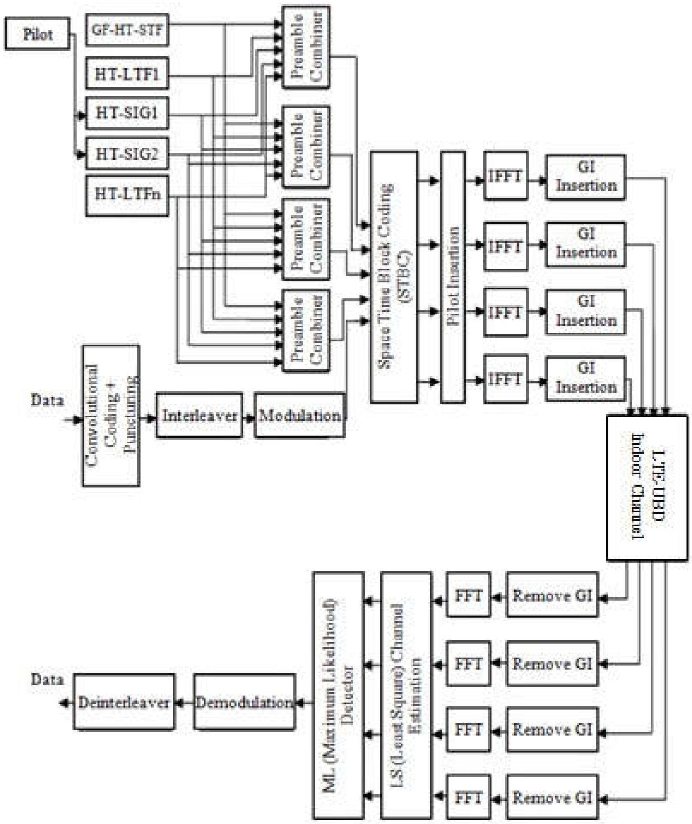

Figure 4. Transmitter and Receiver Block Diagram at LTE-UBD Indoor Channel

4. PROPOSED METHOD

In this paper, we modeled WLAN transmitter, an indoor channel with antenna correlation and receiver.

4.1. Transmitter modelling

Two main points in designing the transmitter are preamble and data coding which both use the Greenfield packet format. This type of the packet consists of GF-HT-STF, HT-LTF1, HT-SIG1, HT-SIG2, HT-LTF2 preambles. Figure 4 shows transmitter and receiver block diagram of the WLAN 802.11n. HT encoding of data begins with convolution coding and puncturing process. Punctured symbols are used for modulation input in accordance with the standard [16]. STBC encoding is done after modulation based on (4) and (5) followed by the insertion of pilot symbols.

4.2. Indoor channel modelling with the five path ray tracing method

In this simulation, indoor channel at LTE-UBD was investigated. The angles of arrival from the Access Point were selected randomly for 10^0, 20^0, 35^0, 40^0 and 47^0 as depicted in Figure 5.

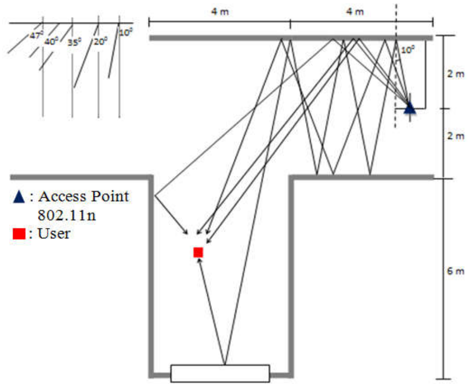

Figure 5. Path pattern for 10^0, 20^0, 35^0, 40^0 and 47^0 angle of arrival

Based on the calculation, the propagation delay of the components with relative power is shown in Table 1.

Table 1. The propagation delay with corresponding path

Path number k	Propagation delay (ns) τ_k	Relative power α_k^2 normal scale	Relative power α_k^2 dB
1	34,56	$2{,}275x\ 10^{-07}$	-66,43
2	36,96	$2{,}275x\ 10^{-07}$	-66,43
3	39	$1{,}140\ x\ 10^{-08}$	-79,43
4	58,5	$5{,}715\ x\ 10^{-10}$	-92,43
5	106,5	$5{,}715\ x\ 10^{-13}$	-122,43

In the implementation stage, there is an effect of channel correlation due to physical factors, antennas and fading. Modeling correlation channels by [17] can be implemented by the following steps:

1. Calculate the transmit covariance matrix ($\underline{R}_t$) of dimension n x n and receive covariance matrix ($\underline{R}_r$) of dimension m x m as expressed in (10) and (11).

$$\underline{R}_t = \begin{bmatrix} 1 & \rho^t_{(1,2)} & \cdots & \rho^t_{(1,j-1)} & \rho^t_{(1,j)} \\ \rho^t_{(2,1)} & 1 & \rho^t_{(1,2)} & \vdots & \rho^t_{(1,j-1)} \\ \vdots & \rho^t_{(2,1)} & 1 & \rho^t_{(1,2)} & \vdots \\ \rho^t_{(j-1,1)} & \vdots & \rho^t_{(2,1)} & 1 & \rho^t_{(1,2)} \\ \rho^t_{(j,1)} & \rho^t_{(j-1,1)} & \cdots & \rho^t_{(2,1)} & 1 \end{bmatrix} \tag{10}$$

$$\underline{R}_r = \begin{bmatrix} 1 & \rho^r_{(1,2)} & \cdots & \rho^r_{(1,i-1)} & \rho^r_{(1,i)} \\ \rho^r_{(2,1)} & 1 & \rho^r_{(1,2)} & \vdots & \rho^r_{(1,i-1)} \\ \vdots & \rho^r_{(2,1)} & 1 & \rho^r_{(1,2)} & \vdots \\ \rho^r_{(i-1,1)} & \vdots & \rho^r_{(2,1)} & 1 & \rho^r_{(1,2)} \\ \rho^r_{(i,1)} & \rho^r_{(i-1,1)} & \cdots & \rho^r_{(2,1)} & 1 \end{bmatrix} \tag{11}$$

with $\rho^t_{(j,j)}$ is the correlation on the transmitting antenna j, $\rho^r_{(i,i)}$ is the correlation on receiving antenna i.

2. Calculate the value of R by $\underline{R} = \underline{R}_t^T \otimes \underline{R}_r$
3. Find eigenvalue, Λ,and eigenvector, U_R,of matrix $\underline{R}$ with $\underline{R} = U_R \Lambda V_R^H$
4. Find channel matrix H by $vec(H) = U_R \sqrt{\Lambda} vec(H_w)$

   with $\underline{H}_w$ is independent and is identically distributed vector (i.i.d), varian =1, mean $= \alpha_k$.U_R is the eigenvector column matrix $\underline{R}$. $\underline{\Lambda}$ is diagonal matrix with its elements on the eigen value of $\underline{R}$.
5. MIMO channel matrix H with a certain correlation is generated as shown in (12)
6.

$$H = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1j} \\ h_{21} & h_{22} & \cdots & h_{2j} \\ \vdots & \vdots & \ddots & \vdots \\ h_{i1} & h_{i2} & \cdots & h_{ij} \end{bmatrix} \tag{12}$$

The SNR of the WLAN 802.11n can be derived from [18]

$$SNR\ (dB) = \frac{E_b}{N_0}(dB) + 10\ Log\ (\frac{N_{data} + N_{pilot}}{N_{FFT}}) + 10\ Log\ (N_{BPSCS}\ r) \tag{13}$$

where

E_b = energy per bit
N_o = variance of random variable ZMCSCG (Zero Mean Circularly Symmetric Complex Gaussian)
N_{data} = 56, N_{pilot} = 4, N_{FFT} = 64,
N_{BPSCS} = Number of bit per subcarrier per stream (QPSK=2, 16-QAM=4, 64-QAM=6)
r = BCC (Binary Convolutional Code) code rate

4.3. Receiver Modelling

Signal detection and channel estimation are the main parts of the receiving system. LS (Least Square) channel estimation by utilizing HT-LTF symbols is performed after FFT (Fast Fourier Transform). Received symbols can be expressed by

$$\left[Y_{t_1}^k, Y_{t_2}^k, \quad, Y_{t_{N_{LTF}}}^k\right] = \begin{bmatrix} H_{11}^k & H_{12}^k & \cdots & H_{1N_{STS}}^k \\ H_{21}^k & H_{22}^k & \cdots & H_{2N_{STS}}^k \\ \vdots & \vdots & \ddots & \vdots \\ H_{N_{RX}1}^k & H_{N_{RX}2}^k & \cdots & H_{N_{RX}N_{STS}}^k \end{bmatrix} . \mathrm{P_{HTLTF}} . \mathrm{HTLTF_k} + [Z_{t_1}^k, Z_{t_2}^k, \quad, Z_{t_{N_{LTF}}}^k] \tag{14}$$

where

$Y_{t_n}^k$: receiving HT-LTF vector with its element numbers equalwith the number of receiver antennas, N_{RX}
N_{LTF} : the number of HT-LTF symbols;
$\mathrm{HTLTF_k}$: symbol training given by equation (2);
$\mathrm{P_{HTLTF}}$: an ortogonal HT-LTF that is given as in (15)

$$P_{HTLTF} = \begin{bmatrix} 1 & -1 & 1 & 1 \\ 1 & 1 & -1 & 1 \\ 1 & 1 & 1 & -1 \\ -1 & 1 & 1 & 1 \end{bmatrix} \tag{15}$$

The LS Channel estimation is given by

$$\begin{bmatrix} \hat{H}_{11}^k & \hat{H}_{12}^k & \cdots & \hat{H}_{1N_{STS}}^k \\ \hat{H}_{21}^k & \hat{H}_{22}^k & \cdots & \hat{H}_{2N_{STS}}^k \\ \vdots & \vdots & \ddots & \vdots \\ \hat{H}_{N_{RX}1}^k & \hat{H}_{N_{RX}2}^k & \cdots & \hat{H}_{N_{RX}N_{STS}}^k \end{bmatrix} = \left[Y_{t_1}^k, Y_{t_2}^k, \cdots, Y_{t_{N_{LTF}}}^k\right] P_{HTLTF}^T \cdot \frac{1}{HTLTF_k} \tag{16}$$

The results of the channel estimation are then used to estimate the transmitted symbols by performing Maximum Likelihood detection.

5. RESULTS AND ANALYSIS

5.1. Bandwidth coherent analysis of LTE-UBD Indoor channel

Based on the results of the measurement presented in Table 1, the propagation delay from path one to path five provides 71.94 ns delay spread and 1.5 ns rms delay (σ_τ). As mentioned in Section II, the IEEE 802.11n uses 3,2 μs symbol duration (T_s). This value is much smaller than the delay spread, so that the signals experience flat fading. We can also notice this phenomenon, flat fading, by analysing the coherent bandwidth (B_c) in (17) compared with the signal bandwidth.

$$B_C = \frac{1}{50\sigma_\tau} \qquad (17)$$

With rms delay 1.5 ns, the result is B_c= 13.3 MHz. Since it is much bigger than the signal bandwidth 312.5kHz (20 MHz/64 subcarrier), the signals experience flat fading. The influence of the Doppler effects is ignored.

5.2. STBC Performance Comparison

The simulation results STBC 2x1 and 2x2 are shown in Figure 6. Based on the simulation results, to produce SER 10^{-3} with 16-QAM modulation, STBC 2x2 needs to 9 dB smaller than STBC 2x1because of the receiver diversity. At the same level of the SER with higher modulation such as 64-QAM, the STBC 2x2 needs 7.6 dB smaller compared with the use of only one receiving antenna.

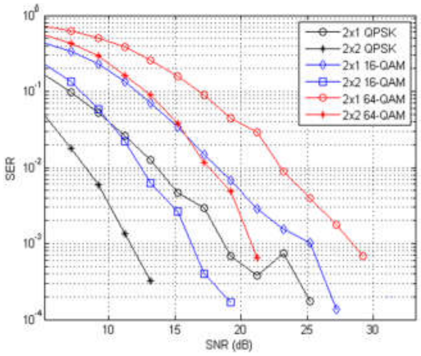

Figure 6. Symbol Error Rate (SER) of STBC 2x1 and 2x2 with QPSK, 16-QAM, 64-QAM

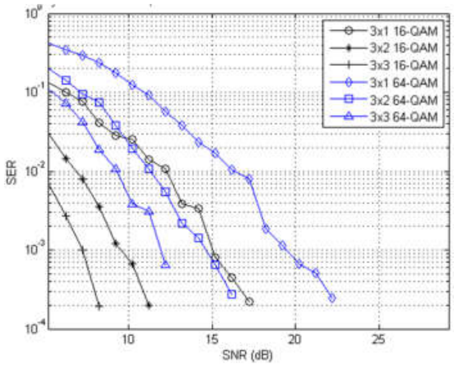

Figure 7. SER of STBC 3x1, 3x2,3x3 LTE-UBD Indoor channel

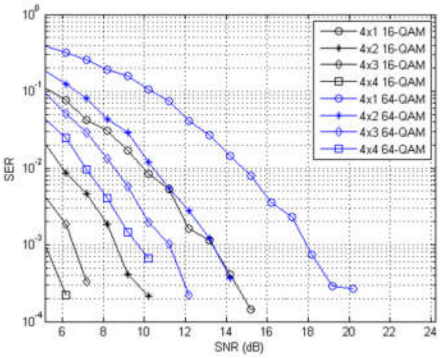

Figure 8. SER of STBC 4x1 to 4x4 without channel correlation

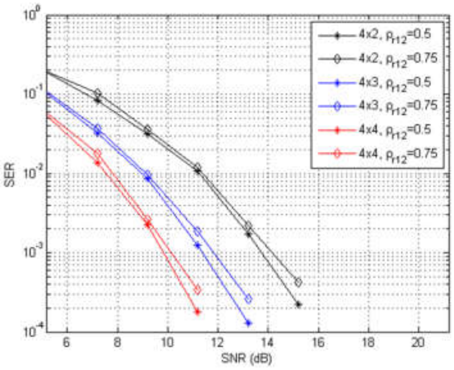

Figure 9. SER of STBC 4x2, 4x3 and 4x4 with 64-QAM modulation and channel correlation

The simulation results of the STBC 3x1, 3x2, 3x3 with 16-QAM and 64-QAM modulation are shown in Figure 7. For 16-QAM modulation type on SER 10^{-3}, STBC 3x3 requires only 5.43 dB SNR. It is 2.3 dB and 7.8 dB smaller than using 3x2 and 3x1 system respectively. When using higher order modulation, 64-QAM, at the same level of the SER, the STBC 3x3 requires 7.5 dB and 2.7 dB SNR lower compared with the STBC 3x1 and 3x2. The STBC 4x1, 4x2, 4x3 and 4x4 without channel correlation are shown in Figure 8. From the simulation, to achieve SER 10^{-3} with 16-QAM modulation, the STBC 4x4 requires 3.43 dB SNR. It is 8 dB which is better than the STBC 4x1.

When using 64-QAM modulation to achieve the same level of the SNR, the STBC 4x4 requires only 17.93 dB SNR. It is better of 8.27 dB, 3.68 dB and 1.55 dB compared with STBC 4x1, 4x2 and 4x3.

The SER performance of the four antennas with a correlation of channel can be shown in Figure 9. The results are then compared with the STBC system without correlation channels as shown in Figure 8 associated with SNR addition. At the same SER value, 10^{-3}, the STBC 4x2 requires an increase of 0.36 and 0.81 dB SNR at $\rho^{r}_{12} = 0,5$ and $\rho^{r}_{12} = 0,75$ channel correlation. At the same correlation, the STBC 4x3 requires additional SNR of 0.16 dB and 0.59 dB respectively. When we employ four antennas, the STBC 4x4 only requires 0.17 dB and 0.44 dB SNR at $\rho^{r}_{12} = 0,5$ and $\rho^{r}_{12} = 0,75$ channel correlation. As seen from the number of the additional SNR, the correlation channels do not have significant influence on the STBC that uses four antennas on the transmitter and receiver side.

5.3. MIMO Ergodic Channel Capacity

Based on Figure 10, the 25 dB SNR with a channel correlation 0.75 causes the loss of capacity of 1.14 bps/Hz compared with the no correlation channels.

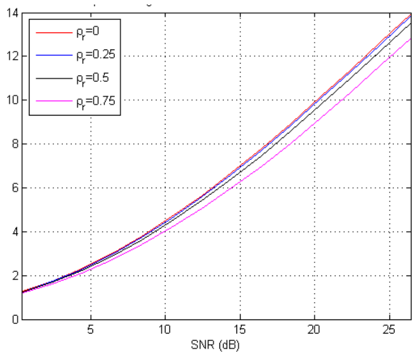

Figure 10. MIMO channel capacity due to the presence of Channel Correlation STBC 2x2, No channel knowledge on Tx.

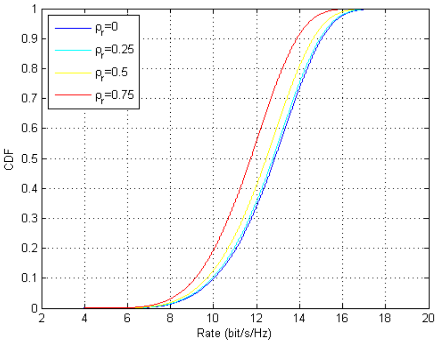

Figure 11. CDF CDF Channel Rate for 24 dB SNR

The ergodic capacity is shown by the median value of the CDF curve as presented in Figure 11. When there is no channel correlation, $\rho_r = 0$, this capacity increases 12.8537 bit/s/Hz. The capacity decreases due to the increasing correlation channels to be 12.7817 bit/s/Hz and 12.4765 bit/s/Hz for $\rho_r = 0,25$ and $\rho_r = 0,5$.

6. CONCLUSION

In this paper, the performance of the IEEE 802.11n in preserving SER in the correlated fading channel is proposed by adopting MIMO-STBC system with four antennas. We also modeled the channel with the ray tracing method as it gives information of its parameter such as delay spread and rms delay. Additionally, all material losses have to be given specifically in order to model the propagation channel and losses accurately. Based on the calculation, the LTE-UBD indoor channel provides 71.94 ns delay spread and 1.5 ns rms delay that caused IEEE 802.11n signals experience flat fading compared with the symbol duration and analysis of the coherence bandwidth. Channel correlation causes a decrease in the performance of the STBC as indicated by greater SNR required to obtain the same SER level,10^{-3}, and the ergodic channel capacity decreases 1.1 bits /s/Hz for channel correlation of 0.75. By employing four antennas in the transmitter and receiver side, the SNR level can be increased so that the SER degradation could be maintained. Furthermore, an intensive study about partition loss has to be done based on its own measurement to estimate appropriate losses that cause signal attenuation.

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