LD-STBC-VBLAST Receiver for WLAN systems

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Abstract: - In this article, a multistream orthogonal frequency division multiplexing (OFDM) transmission is analyzed, in which a part of spatial streams is space time block coded (STBC) and linear dispersion (LD) theory is employed. Using a simulation model made in MATLAB environment, the quality of transmission of the wireless-LAN (WLAN) system with channel type E is investigated. We present the simulation results for two models of receivers WLAN 802.11n data transmission. The performance of ZF and LD-STBC-VBLAST receivers has been assessed and compared. The bit error rate (BER) and packet error rate (PER) has been determined for different numbers of spatial streams in use. The results show how the LD-STBC structure employed in the transmitting and receiving parts may improve the quality of WLAN transmissions.

Key-Words: - MIMO transmission, wireless receiver, space time block coding, bit error rate, WLAN, OFDM

1 Introduction

In recent times WLANs have gained on popularity as regards telecommunication applications. This is due to the fact that thanks to the advanced technologies they already offer high quality (with low error rate) and high speed transmissions. Simultaneously, constant grow of demand in even higher speed and quality transmission are observed. Therefore, insightful research on WLANs is necessary to change the existing standards [1]. As theoretical and practical research carried out lately [2-4] has shown, transmission through multi-path wireless channels may improve the system’s capacity if used adequately. According to [3] a multiple input multiple output (MIMO) system enables increasing of a wireless channel’s capacity proportionally to the growing number of transmit and receive antennas. A practical implementation of a MIMO system is shown in [5]. It is the so-called Vertical Bell Laboratories Layered Space Time (V-BLAST) system, which has a simple structure, yet it offers high spectral efficiency. In V-BLAST a single data stream is divided into several sub-streams transmitted simultaneously by several antennas as a result of which transmission speed may be improved. Literature suggests many options to form receivers that would receive signals transmitted in MIMO system [2-5]. One of the methods is maximum likelihood (ML). This detection method offers the lowest error rate but is rather difficult to implement. Paper [5] proposes MIMO signal detection based on the zero-forcing (ZF) criterion. The ZF method is characterized by relatively low computational requirements. However, its weakness is certainly the so-called noise enhancement occurring in the case of minor SNR values. Considerably effective detection algorithms that use the so-called QR decomposition of channel matrix have been proposed in [6, 7].

Another advantage of MIMO transmission is quality improvement with reference to drop in error rate. This is obtained by using Space Time Block Codes (STBC) [8]. The superior purpose of spatial multiplexing is to maximize data transmission speed while the essence of space-time coding is to ensure high quality resulting from maximizing the diversification. These two advantages offered by MIMOs exclude each other. The so-called Linear Dispersion (LD) method was proposed in [9]. The method attempts to use both the aforesaid advantages of MIMO transmission: spatial multiplexing and diversification gain. As test results show [9-12], owing to the method high transmission speed may be obtained with any configuration of antenna systems on both sides of the radio connection with simultaneous code gain. Solutions known for the MIMO transmission, such as the V-BLAST algorithm or ZF, may be applied for receiving [4-7].

The LD-STBC-VBLAST method was used by the authors hereof for an OFDM transmission in a WLAN system. Simulation test results for selected two (ZF and LD-STBC-VBLAST) receive algorithms that may be used for WLAN 802.11n
MIMO/OFDM (Multiple Input, Multiple Output) system are presented. The examined system uses a multi-stream transmission in which part of spatial streams is STBC-coded and part is transmitted without coding. It was assumed that individual subcarriers are modulated with 2-PSK, 4-PSK or 16-QAM signal. The purpose hereof is to compare the operation of the aforesaid system for two different receivers: LD-STBC-VBLAST, using the LD (Linear Dispersion) algorithm [9] and ZF (Zero-Forcing) [5] and to check the suitability of the abovementioned receivers for the improvement of data transmission quality in WLAN 802.11n.

A bit (BER) and packet (PER) error rate was determined for the E type transmission channel model [13]. The simulation referred to transmission through E type WLAN channel because, as test results show in e.g. [4], the lowest error rate has been obtained in a MIMO transmission using the channel. It was also assumed that the Channel State Information (CSI) is known in the receiver.

This paper is organized as follows: Section 2 describes the simulation model, Section 3 presents the types of receivers used for simulation, Section 4 contains simulation results that have been carried out, and, finally, Section 5 includes a summary and conclusions.

2 Simulation Model

In order to assess the quality of operation of the LD-STBC-VBLAST receiver in WLAN, a series of simulations have been made in MATLAB environment. The model of the simulated system enables BER and PER determination. A block diagram of the transmitting part of the simulated system is presented in Fig. 1.

In the transmitter the information sequences \( d \) are coded by a convolutional encoder \([171 133]\) with rate \( R = \frac{1}{2} \), used in the 802.11n standard [1]. The coded \( u \) sequence generated by the encoder is divided into \( N_{ss} \) spatial streams \( u_1, \ldots, u_{N_{ss}} \). Three different variants of MIMO transmissions are possible: a non-coded multistream transmission, an STBC-coded stream transmission, a transmission where a part of streams is non-coded and a part is STBC-coded.

Each of the spatial streams is subject to interleaving in blocks reflecting the successively assigned OFDM symbols as per the 802.11n recommendation [1]. Depending on the valence of the applied modulation, the bits of the interleaved sequence \( v \) are adequately grouped and mapped into the elements of 2-PSK, 4-PSK or 16-QAM constellations. Signals \( X_t(k) \) represent the signals transmitted on the \( k \)-subcarrier of the OFDM symbol. Signals that modulate subcarriers within the \( t \)-symbol OFDM form a vector of \( X_t \) signals. Samples of the OFDM symbol in time domain are formed using the IFFT algorithm. They make up the \( x_t \) vector. Then, samples of the OFDM symbol are supplemented with a cyclic prefix (CP) and transformed from digital to analogue (D/A).

To adhere to the 802.11n standard [1], in the tested system each OFDM symbol uses the 52 subcarriers to transmit data, 4 subcarriers are used to transmit the so-called pilot signals. OFDM is performed with the use of the 64-point Fourier transform. The duration time of a single OFDM symbol is 4\( \mu \)s with the sampling frequency of...
20MHz. To avoid the intersymbol interference, the 0.8µs cyclic prefix is added. The transmission throughput of the analyzed system depends on the number of spatial streams that were used and valence of modulation applied to each subcarrier of the OFDM signal. A specification of the analyzed system variants is shown in Table 1.

### Table 1. Analyzed system variants

<table>
<thead>
<tr>
<th>No.</th>
<th>Modulation</th>
<th>Number of spatial streams</th>
<th>throughput [Mbps]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2-PSK</td>
<td>2</td>
<td>13</td>
</tr>
<tr>
<td>2</td>
<td>2-PSK</td>
<td>3</td>
<td>19.5</td>
</tr>
<tr>
<td>3</td>
<td>4-PSK</td>
<td>2</td>
<td>26</td>
</tr>
<tr>
<td>4</td>
<td>4-PSK</td>
<td>3</td>
<td>39</td>
</tr>
<tr>
<td>5</td>
<td>16-QAM</td>
<td>2</td>
<td>52</td>
</tr>
<tr>
<td>6</td>
<td>16-QAM</td>
<td>3</td>
<td>78</td>
</tr>
</tbody>
</table>

### 3 Receive Algorithms

In the analyzed system, data transmission is performed using two, three or four spatial streams. Correct synchronization and estimation of the channel state in the receiver was assumed. A total of signals transmitted by all transmit antennas (modified as a result of channel passing) reaches each receive antenna. The signal from receive antenna after sampling is transformed (with the FFT transform) from time domain to frequency domain and subsequently demodulated. Two receiving methods have been analyzed in the paper, ZF and LD-STBC-VBLAST receivers. Applying the Zero-Forcing (ZF) algorithm to receive, the transmitted data estimate \( \hat{a} \) is determined of the symbol given by multiplication of the received vector \( r \) and Moore-Penrose \( H^* \) pseudo-inversion channel matrix \( H \) [1], determined from the estimated matrix of the \( H \) channel transmittance:

\[
H^* = [H^H H]^{-1} * H^H
\]  

(1)

\[
\hat{a} = H^r
\]  

(2)

where \( (.)^H \) is the Hermitian matrix. Low complexity is the advantage of the ZF method. However, noise enhancement constitutes its drawback [4, 5].

The receive method based on the LD-STBC-VBLAST algorithm has been adopted by the authors from [10] to OFDM WLAN transmission. The method is applied in the case where in the MIMO system non-coded streams are transmitted by selected antennas and simultaneously STBC coded streams are transmitted by other antennas.

The transmit part of the LD-STBC-VBLAST system is presented in Fig. 1. The basic idea of the systems is concurrent transmission of spatial streams both non-coded and space-time block coded (STBC). Then, it was assumed to denote the system having \( n_s \) of non-coded spatial streams and \( n_B \) of STBC coded spatial streams as \( (n_s, n_B) \) LD-STBC-VBLAST, for example the description (0,2) denotes the system which use only two STBC encoded streams.

In the LD-STBC-VBLAST receiver, the theory of linear dispersion described in [9] was used to demodulate. Therefore, during modulation signals received from both non-coded and STBC coded streams may be treated the same.

Further on, the following designations have been assumed:

- \( n_A \) – number of antennas in a single STBC stream;
- \( N_T \) – number of transmit antennas;
- \( N_R \) – number of receive antennas;
- \( n_B \) – number of STBC coded streams;
- \( n_s \) – number of streams not coded with STBC

Table 2 below shows which signals are transmitted by two individual antennas in subsequent time intervals [11]. This constitutes a description of the time and space coding performed for a given antenna configuration [9].

### Table 2. Transmitted signals

<table>
<thead>
<tr>
<th>Time</th>
<th>Antenna ( V=1,\ldots,n_S )</th>
<th>STBC block: ( B=1,\ldots,n_B )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( T )</td>
<td>( s_{V,1} )</td>
<td>( s_{n_A,1} ) ( s_{n_A,2} )</td>
</tr>
<tr>
<td>( t+T )</td>
<td>( s_{V,2} )</td>
<td>( -s_{n_A,2} ) ( s_{n_A,1} )</td>
</tr>
</tbody>
</table>

The signal reaching the receiver is presented as follows [10]:

\[
\begin{bmatrix}
  y_1^{(1)} \\
  y_2^{(1)} \\
  \vdots \\
  y^{(1)}_{N_R}
\end{bmatrix} =
\begin{bmatrix}
  h_{11} & h_{12} & \cdots & h_{1N_T} \\
  h_{21} & h_{22} & \cdots & h_{2N_T} \\
  \vdots & \vdots & \ddots & \vdots \\
  h_{N_R1} & h_{N_R2} & \cdots & h_{N_RN_T}
\end{bmatrix}
\begin{bmatrix}
  s_{nc} \\
  s_{c}
\end{bmatrix}
\]  

(3)
In the above as well as in the formulas that follow the below notation has been applied:

- the subscripts signify numbers of relevant antennas;
- the superscripts signify the number of modulation interspace in a given time interval

The transmitted signal is specified as $S_{nC}$. It is composed of two separate matrixes of which each describes symbols transmitted in relevant streams: $nC$ – non-coded and $C$ – STBC-coded.

$$S_{nC} = \begin{bmatrix} s_1^{(1)} & s_1^{(2)} \\ s_2^{(1)} & s_2^{(2)} \\ \vdots & \vdots \\ s_{nS}^{(1)} & s_{nS}^{(2)} \end{bmatrix}$$ (4)

$$S_C = \begin{bmatrix} S_C^{(1)} \\ \vdots \\ S_C^{(nB)} \end{bmatrix} = \begin{bmatrix} S_{1A}^{(1)} & -s_{nA}^{*} \\ S_{1A}^{(2)} & s_{nA}^{*} \end{bmatrix}$$ (5)

And where each matrix element (13) is given as [10]:

$$\begin{bmatrix} S_B^{(1)} & S_B^{(2)} \end{bmatrix} = \begin{bmatrix} s_{nA}^{(1)} & -s_{nA}^{*} \\ S_{nB}^{(1)} & S_{nB}^{(2)} \end{bmatrix},$$ (6)

where $B=1,\ldots,n_B$.

By applying the linear dispersion theory (LD) [9] equation (11) may be noted as follows [10]:

$$\begin{bmatrix} y_1^{(1)} \\ y_1^{(2)} \end{bmatrix} = [H_{nC} \quad H_C]S_{LD} + \begin{bmatrix} n_1^{(1)} \\ \vdots \\ n_{nR}^{(1)} \\ n_1^{(2)} \end{bmatrix}$$ (7)

In the matrix notation, equation (15) may be noted like this:

$$Y_{LD} = H_{LD}S_{LD} + N_{LD},$$ (8)

where all matrixes are called LD matrixes.

The matrix of the transmitted signal may also have the form of the LD matrix:

$$S_{LD} = \begin{bmatrix} S_{nC}^{LD} \\ S_C^{LD} \end{bmatrix},$$ (9)

In the receiver, similarly to [10], the so-called QR decomposition of the channel matrix $H$ is used. This decomposition consists in splitting the channel matrix into two matrixes whose product equals the channel matrix:

$$H_{LD} = Q_{LD}R_{LD}$$ (10)

Matrix $Q$ is a rectangular matrix $2N_R \times n_{SYM}$. Whereas matrix $R$ is a square, upper triangular matrix $n_{SYM} \times n_{SYM}$, where $n_{SYM}=2(n_S+n_B)$. A detailed description of the QR decomposition algorithm may be found in [6].

After determining the $Q$ and $R$ matrix for the $H$ channel matrix, linear detection of the received signal takes place in the receiver. The detection algorithm [7] is as follows:

**Initialization:**

$$k = N_f$$ (11)

$$w = Q^Hn$$ (12)

$$\hat{s} = Q^Hy = Rs + w$$ (13)

**Successive iterations (1):**

$$\hat{s}(k) = Q \left[ \hat{s}(k) / R(k,k) \right]$$ (14)

If $k$ equals $0$ – end of algorithm operation

$$i = k + 1$$ (15)

$$k = k - 1$$ (16)

**Successive iterations (2):**

$$\text{interf}(k) = \text{interf}(k) + R(k,i) \cdot \hat{s}(i)$$ (18)

$$i = i + 1$$ (19)

**End of loop (2):**

$$\hat{s} = Rs + w - \text{interf}$$ (20)

or

$$\hat{s} = Q^Hy - \text{interf}$$ (21)

**End of loop (1).**

where, $y$ is received signal vector, $s$ is transmit signal vector, $\hat{s}$ decision statistic for transmit signal, $\hat{s}$ estimate for transmit signal $Q^H$ the hermitian transpose of $Q$, $n$ represents the white gaussian noise of variance $\sigma_n^2$ observed at the $N_R$ receive antennas while the average transmit power of each antenna is normalized to one.

The presented detection algorithm is based on successive interference reduction. The decisions on transmitted signals $\hat{s}$ are determined allowing for the calculated information on interfering signals (interf) coming from other transmit antennas.

### 4 Simulation Results

By means of the Monte Carlo simulation the authors have determined the BER and PER depending on the SNR value. An assumption has been made that transmission takes place in E type WLAN channel [13]. A comparison of the quality of MIMO systems operation using the following two
types of receivers has been presented: LD-STBC-VBLAST and ZF depending on the number of spatial streams and selected modulations: 2-PSK, 4-PSK, 16-QAM. In the simulations, ideal synchronization has been assumed as well as that the receiver knows the channel state information (CSI). The transmitted packets were 1000-byte long. OFDM technique has been applied. The 64-point IFFT/FFT has been implemented, where data is transmitted on 52 subcarriers. Additionally, four subcarriers have been used to transmit pilot signals and 8 subcarriers constituted a protection interval. To assess correctness of operation of the proposed simulation model, a series of tests confirming the results taken from literature [4, 5, 7] have been performed. Different combinations of parameter setups for the investigated MIMO systems have been simulated. The most representative results have been selected for the presentation.

In Figures 2 and 3 PER and BER curves are illustrated for the ZF and LD-STBC-VBLAST receive systems including two and three spatial streams for different number of transmit $N_t$ and receive $N_r$ antennas. Transmission in these systems takes place at the speed of 52 and 78 Mbps respectively with the WLAN channel type E [13].

Considering the transmission with two spatial streams (Fig. 2), with PER at $10^{-3}$, (0,2) LD-STBC-VBLAST system proved the best properties. Here, transmission takes place using four transmit and receive antennas. The (0,2) LD-STBC-VBLAST system offers 1% PER with about 17 dB. The (1,1) LD-STBC-VBLAST system including three transmit and receive antennas is by approximately 6 dB inferior. The system employing ZF receiver, where the number of antennas equals the number of spatial streams for the same level of PER (at $10^{-3}$), is inferior to (1,1) LD-STBC-VBLAST system by 1 dB. The (0,2) LD-STBC-VBLAST system offers approximately 7 dB and 8 dB gains comparing to the (1,1) LD-STBC-VBLAST and ZF systems with the BER of about $10^{-4}$, respectively. The throughput for these systems is equal 52Mbps.

Fig. 3 represents the simulation results for systems with three spatial streams and obtained throughput 78Mbps. For 1% PER the best results have been noted in the case of (1,2) LD-STBC-VBLAST system including five transmit and receive antennas. This level is obtained when SNR equals 19 dB. The (2,1)-LD-STBC-VBLAST systems is inferior by 3.5 dB. It has four transmit and receive antennas. The number of antennas in the system employing ZF receiver equals the number of spatial streams and is equal 3. This has proven to perform poorer than the best presented (1,2) LD-STBC-VBLAST system by 8 dB. The (1,2) LD-STBC-VBLAST system offers approximately 3 dB and 4.5 dB gains comparing to the (2,1) LD-STBC-VBLAST and ZF systems with the BER of about $10^{-4}$, respectively.

A system that uses LD-STBC-VBLAST receive enables enhancement of transmission speed with coincident quality improvement through application of an additional spatial stream. To improve quality, an STBC coding on additional spatial stream must be used. If the number of spatial streams grows from one to two, a 100% increment of speed is obtained with simultaneous minor improvement in PER for 2-PSK, 4-PSK and 16-QAM modulation. If the number of spatial streams grows from two to three, the speed increment is 50% with 1% improvement in PER by 3 dB for 2-PSK modulation and by 4 dB for modulations 4-PSK and 16-QAM.
5 Conclusion

This paper presents a proposal of modification of the 802.11n standard with a hybrid transmission. A multistream transmission is suggested where a part of spatial streams is STBC coded and a part is transmitted without any codes. The impact of transmit diversification on the quality of transmission has been analyzed. Based on the test results it may be clearly observed that the transmit diversification offers better properties of the transmission system. The LD-STBC-VBLAST receiver proves the best results in BER and PER when compared to the system with a ZF receiver at the cost of increased number of antennas.

As it results from the performed tests, the method that has been applied (LD-STBC-VBLAST) allows increasing of the transmission speed with no deterioration of the error rate through suitable selection of the transmitted spatial streams.

The system with LD-STBC-VBLAST receiver allows iterative reduction of interference. Therefore, the BER and PER results are considerably better than in the case of the ZF receiver system. However, one must remember that the complexity of the system is much higher than that of the ZF receive system. Given the presented simulation results, we can suppose that the investigated LD-STBC-VBLAST system could be successfully used in next generation wireless networks which are currently being developed.

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References: