OFDM-MIMO AND V-BLAST ALGORITHM-KEY TO HIGH SPEED WIRELESS COMMUNICATION

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ABSTRACT

Orthogonal frequency division multiplexing (OFDM) is a multi-carrier modulation scheme, which may be combined with antenna arrays at the transmitter and receiver to increase the diversity gain and/or to enhance the system capacity on time-variant and frequency-selective channels, resulting in a multiple-input multiple-output (MIMO) configuration. This paper presents an overview of the OFDM-MIMO wireless technology covering channel models, performance limits and transceiver system. The significance of OFDM lies in its inherent capability to reduce inter-symbol interference (ISI) using cyclic prefix. Using simulations, the OFDM signal has been generated with the help of mathematical transforms namely the Fourier transform. The comparison of bit error rate (BER) and signal to noise ratio (SNR) for various modulation schemes has been performed and the best one is selected for transmission. Also the comparison of BER and SNR for Single Input Single Output (SISO), Single Input Multiple Output (SIMO) and Multiple Input Multiple Output (MIMO) is graphically observed. And with MIMO proving to be the best, the effect on capacity is observed for increased number of antennas. For MIMO systems, Vertical Bell Labs Space Time Algorithm (V-BLAST) is an ordered successive cancellation method applied to receiver and at every stage the stream with the highest SNR is decoded. This paper also presents an overview of the V-BLAST architecture.

Keywords: Bit error rate (BER), Cyclic prefix, Inter-symbol interference (ISI), Multiple-input multiple-output (MIMO), Orthogonal frequency division multiplexing (OFDM), Signal to noise ratio (SNR), Vertical Bell Labs Space Time Algorithm (V-BLAST).
1. INTRODUCTION

The growing demand of multimedia services and the growth of Internet related contents lead to increasing interest to high speed communications. The requirement for wide bandwidth and flexibility imposes the use of efficient transmission methods that would fit to the characteristics of wideband channels especially in wireless environment where the channel is very challenging. In wireless environment the signal is propagating from the transmitter to the receiver along number of different paths, collectively referred as multipath. While propagating the signal power drops of due to three effects: path loss, macroscopic fading and microscopic fading. Fading of the signal can be mitigated by different diversity techniques. To obtain diversity, the signal is transmitted through multiple (ideally) independent fading paths e.g. in time, frequency or space and combined constructively at the receiver. A promising solution for significant increase of the bandwidth efficiency and performance under noise is the exploitation of the spatial dimension. Multiple input-multiple-output (MIMO) exploits spatial diversity by having several transmit and receive antennas [1].

OFDM is modulation method known for its capability to mitigate multipath. In OFDM the high speed data stream is divided into narrowband data streams, corresponding to the subcarriers or sub channels. As a result the symbol duration is several times longer than in a single carrier system with the same symbol rate. The symbol duration is made even longer by adding a cyclic prefix to each symbol. As long as the cyclic prefix is longer than the channel delay spread OFDM offers inter-symbol interference (ISI) free transmission. The paper explains these concepts in detail with the help of equations providing a better understanding [2]. Another key advantage of OFDM is that it dramatically reduces equalization complexity by enabling equalization in the frequency domain. OFDM, implemented with IFFT at the transmitter and FFT at the receiver, converts the wideband signal, affected by frequency selective fading, into narrowband flat fading signals thus the equalization can be performed in the frequency domain [3].

The combination MIMO-OFDM is very natural and beneficial since OFDM enables support of more antennas and larger bandwidths since it simplifies equalization dramatically in MIMO systems. The combination of MIMO and OFDM has been designed to improve the data rate and the Quality of Service of the wireless system by exploiting the multiplexing gain and/or the diversity gain which is a major problem in communication. This paper provides a general overview of this promising transmission technique. [4]

In order to separate the N simultaneously transmitted signals at the receiver, several space time coding (STC) and space division multiplexing (SDM) techniques are developed. STC introduces a spatiotemporal correlation among all the transmitted signals for the improvement of information protection, while the aim of SDM is to enhance the data rate.

The diagonally-layered space-time architecture proposed by Foschini, now known as diagonal Bell Laboratories Layered Space-Time or D-BLAST, is one such approach. D-BLAST utilizes multi-element antenna arrays at both transmitter and receiver and an elegant diagonally layered coding structure in which code blocks are dispersed across diagonals in space-time. However, the diagonal approach suffers from certain implementation complexities which make it inappropriate for initial implementation. D-BLAST faced certain implementation complexities and was replaced by a simplified version of BLAST, known as vertical BLAST or V-BLAST and is found exceptional in its spectral efficiency which ranges from 20-40 bps/Hz for a reasonable range of SNR 24-34 dB. V-BLAST seems to provide the best trade-off between the system performance and implementation complexity. A general overview of the V-BLAST architecture has also been discussed in the paper.
2. ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING

Orthogonal Frequency Division Multiplexing (OFDM) is simply defined as a form of multi-carrier modulation. The original bandwidth is split into smaller and narrower sub-bands, known as “sub-band” carriers where the carrier spacing is carefully selected so that each sub-carrier is orthogonal to the other sub-carriers. Nulls in each sub-carrier’s spectrum land at the centre of all other sub-carriers.

2.1 Principle of OFDM transmission technology

The “orthogonal” part of the OFDM name indicates that there is a precise mathematical relationship between the frequencies of the carriers in the system. It is possible to arrange the carriers in an OFDM signal so that the sidebands of the individual carriers overlap and the signals can still be received without adjacent carrier’s interference. Two signals are orthogonal if their dot product is zero. That is, if we take two signals multiply them together and if their integral over an interval is zero, then two signals are orthogonal in that interval. If a sine wave of frequency \( m \) is multiplied by a sinusoid (sine or cosine) of a frequency \( n \), then the product is given by:

\[
f(t) = \sin(m \omega t) \times \sin(n \omega t)
\]

where both \( m \) and \( n \) are integers. By simple trigonometric relationship, this is equal to a sum of two sinusoids of frequencies \((n-m)\) and \((n+m)\). Since these two components are each a sinusoid, the integral is equal to zero over one period. So when a sinusoid of frequency \( n \) multiplied by a sinusoid of frequency \( m \), the area under the product is zero. In general for all integers \( n \) and \( m \), \( \sin mx \cos mx, \cos nx, \sin nx \) are all orthogonal to each other. These frequencies are called harmonics. The orthogonality allows simultaneous transmission on a lot of sub-carriers in a tight frequency space without interference from each other.

2.2 OFDM Transmission and Reception

Single high-rate bit stream is converted to low-rate \( N \) parallel bit streams. Each parallel bit stream is modulated on one of \( N \) sub-carriers [5]. Each sub-carrier can be modulated differently, e.g. BPSK, QPSK or QAM. To achieve high bandwidth efficiency, the spectrum of the sub-carriers is closely spaced and overlapped. This overlapping property makes OFDM more spectral efficient than the conventional multicarrier communication schemes. The block diagrams of OFDM transmitter and receiver are as represented below:

![OFDM-MIMO Transmitter block diagram](image-url)
A guard interval is inserted between symbols to avoid inter symbol interference (ISI) caused by multipath distortion.

### 2.2.1 Serial to Parallel Conversion

Data to be transmitted is typically in the form of a serial data stream. In OFDM, each symbol typically transmits 40-4000 bits, and so a serial to parallel conversion stage is needed to convert the input serial bit stream to the data to be transmitted in each OFDM symbol. The data allocated to each symbol depends on the modulation scheme used and the number of subcarriers. At the receiver the reverse process takes place, with the data from the subcarriers being converted back to the original serial data stream.

### 2.2.2 Interleaver

OFDM is invariably used in conjunction with channel coding (forward error correction), and almost always uses frequency and/or time interleaving. Frequency (subcarrier) interleaving increases resistance to frequency-selective channel conditions such as fading. For example, when a part of the channel bandwidth fades, frequency interleaving ensures that the bit errors that would result from those subcarriers in the faded part of the bandwidth are spread out in the bit-stream rather than being concentrated. Similarly, time interleaving ensures that bits that are originally close together in the bit-stream are transmitted far apart in time, thus mitigating against severe fading as would happen when travelling at high speed.

The reason why interleaving is used on OFDM is to attempt to spread the errors out in the bit-stream that is presented to the error correction decoder, because when such decoders are presented with a high concentration of errors the decoder is unable to correct all the bit errors, and a burst of uncorrected errors occurs.

### 2.2.3 Signal Mapping

A large number of modulation schemes are available allowing the number of bits transmitted per carrier per symbol to be varied. Digital data is transferred in an OFDM link by using a modulation scheme on each subcarrier. A modulation scheme is a mapping of data words to a real (In phase) and imaginary (Quadrature) constellation, also known as an I-Q constellation. The number of bits that can be transferred using a single symbol corresponds to $\log_2(M)$, where $M$ is the number of points in the constellation, thus 256-QAM transfers 8 bits per symbol. Increasing the number of points in the constellation does not change the bandwidth of the transmission, thus using a modulation scheme with a large number of constellation points, allows for improved spectral efficiency. For example 256-QAM has a
spectral efficiency of 8 b/s/ Hz, compared with only 1 b/s/Hz for BPSK. However, the greater the number of points in the modulation constellation, the harder they are to resolve at the receiver.

2.2.4 Frequency to Time Domain Conversion

The OFDM message is generated in the complex baseband. Each symbol is modulated onto the corresponding subcarrier using variants of phase shift keying (PSK) or different forms of quadrature amplitude modulation (QAM). The data symbols are converted from serial to parallel before data transmission. The frequency spacing between adjacent subcarriers is $N\pi/2$, where $N$ is the number of subcarriers. This can be achieved by using the inverse discrete Fourier transform (IDFT), easily implemented as the inverse fast Fourier transform (IFFT) operation.

As a result, the OFDM symbol generated for an $N$-subcarrier system translates into $N$ samples, with the $i^{th}$ sample being at the receiver, the OFDM message goes through the exact opposite operation in the discrete Fourier transform (DFT) to take the corrupted symbols from a time domain form into the frequency domain. In practice, the baseband OFDM receiver performs the fast Fourier transform (FFT) of the received message to recover the information that was originally sent.

2.2.5 Inter symbol interference

In OFDM, ISI usually refers to interference of an OFDM symbol by previous OFDM symbols. For OFDM the system bandwidth is broken up into $N$ subcarriers, resulting in a symbol rate that is $N$ times lower than the single carrier transmission. This low symbol rate makes OFDM naturally resistant to effects of Inter-Symbol Interference (ISI) caused by multipath propagation. In multipath propagation, multiple signals arrive at the receiver at different times due to the transmission distances being different. This spreads the symbol boundaries causing energy leakage between them.

2.2.6 Guard period

The effect of ISI on an OFDM signal can be further improved by the addition of a guard period to the start of each symbol. This guard period is a cyclic copy that extends the length of the symbol waveform. Each subcarrier, in the data section of the symbol has an integer number of cycles. Because of this, placing copies of the symbol end-to-end results in a continuous signal, with no discontinuities at the joints. Thus by copying the end of a symbol and appending this to the start results in a longer symbol time. Figure 3 shows the insertion of a guard period, also known as cyclic prefix. The transmitted signal consists of a sequence of these OFDM symbols. To denote different OFDM symbols when a sequence of symbols
rather than a single symbol is being considered we need to extend the notation to include a time index.

Let \( x(i) = [x_0(i)x_1(i)x_2(i) \ldots x_{N-1}(i)]^T \) be the output of the IFFT in the \( i \)th symbol period. In most OFDM systems, a CP is added to the start of each time domain OFDM symbol before transmission. In other words a number of samples from the end of the symbol is appended to the start of the symbol \([6]\). So instead of transmitting:

\[ x(i) = [x_0(i)x_1(i)x_2(i) \ldots x_{N-1}(i)]^T \] (3)

the sequence,

\[ x_{CP}(i) = [x_{N-G}(i) \ldots x_{N-1}(i), x_0(i) \ldots x_{N-1}(i)]^T \] (4)

is transmitted, where \( G \) is the length of the cyclic prefix.

The total length of the symbol is \( T = T_s + T_g \), where \( T_s \) is the total length of the symbol in samples, \( T_g \) is the length of the guard period in samples. In addition to protecting the OFDM from ISI, the guard period also provides protection against time-offset.

### 3. OFDM EQUATIONS

Let \( \{s_{n,k}\}_{k=0}^{N-1} \) be the complex symbols transmitted at the \( n \)th OFDM block, then the OFDM modulated signal can be represented by:

\[
s_n(t) = \sum_{k=0}^{N-1} s_{n,k} e^{j2\pi k\Delta f t} \] (5)

where \( T_s, \Delta f \) and \( N \) are the symbol duration, the sub channel space and the number of sub channels of OFDM signals, respectively. For the receiver to demodulate the OFDM signal the symbol duration should be long enough such that \( T_s \Delta f = 1 \) which is also called the orthogonal condition since it makes \( e^{-j2\pi k\Delta f t} \) orthogonal to each other for different \( k \). With the orthogonal condition, the transmitted symbols \( s_{n,k} \) can be detected at the receiver by:

\[
s_n(t) = \frac{1}{T_s} \int_0^{T_s} s_n(t) e^{-j2\pi k\Delta f t} dt \] (6)

The sampled version of the baseband OFDM signal \( s(t) \) in (2) can be expressed as:

\[
s_n \left( \frac{T_s}{N} \right) = \sum_{k=0}^{N-1} s_{n,k} e^{j2\pi k\Delta f mT_s/N} = \sum_{k=0}^{N-1} s_{n,k} e^{j2\pi mk/N} \] (7)

which is actually the inverse discrete Fourier transform (IDFT) of the transmitted symbols \( \{s_{n,k}\}_{k=0}^{N-1} \) and can efficiently be calculated by fast Fourier transform (FFT). It can easily be seen that demodulation at the receiver can be performed using DFT instead of the integral in (6).
A cyclic prefix is critical for OFDM to avoid inter symbol interference caused by the delay spread of wireless channels. Without the CP, the length of the OFDM symbol is $T_s$. With the CP, the transmitted signal is extended to $T = T_g + T_s$ and can be expressed as:

$$\tilde{s}_n(t) = \sum_{k=0}^{N-1} s_{n,k} e^{j2\pi k ft - T_g - t} \leq t \leq T_s$$  \hspace{1cm} (8)

It is obvious that:

$$s(t) = s_n(t + T_s) \text{ for } -T_g \leq t \leq 0,$$  \hspace{1cm} (9)

which is why it is called the Cyclic prefix.

**4. MULTIPLE INPUT MULTIPLE OUTPUT (MIMO) TECHNIQUE**

Multiple-Input-Multiple-Output (MIMO) is a cutting edge antenna technology transmitting multiple data streams on multiple transmitters to multiple receivers. Multiple antennas are used especially when the link has Non-Line-of-Sight. MIMO increases the range and data rates both.

![SISO, SIMO, and MISO representation](image)

Fig.4 SISO, SIMO AND MISO representation

Now the capacity of different antenna systems will be studied in order to see the dramatic increases in capacity obtained by using MIMO systems. The expressions are approximate, but they give an intuition for the derived benefits in terms of channel capacity when using multiple antennas.

**4.1 Types of smart antenna technology**

**4.1.1 Single-Input, Single-Output (SISO)**

Assume that for a given channel, whose bandwidth is $B$, and a given transmitter power of $P$ the signal at the receiver has an average signal-to-noise ratio of $SNR_0$. Then, an estimate for the Shannon limit on channel capacity, $C$, is

$$C \approx B \log_2 (1 + SNR_0)$$  \hspace{1cm} (10)

**4.1.2 Single-Input, Multiple-Output (SIMO)**

For the SIMO system, we have $N$ antennas at the receiver. If the signals received on these antennas have on average the same amplitude, then they can be added coherently to produce an $N^2$ increase in the signal power. Hence, there is an overall increase in the SNR,

$$SNR \approx \frac{N^2(SIGNAL\ POWER)}{N(NOISE)} = N \cdot SNR_0$$  \hspace{1cm} (11)
Thus, the channel capacity for this channel is approximately equal to

$$C = B \cdot \log_2 (1 + N.SNR_0)$$

(12)

4.1.3 Multiple-Input, Single-Output (MISO)

In the MISO system, we have $M$ transmitting antennas. The total transmitted power is divided up into the $M$ transmitter branches. If the signals add coherently at the receiving antenna we get approximately an $M$-fold increase in the $SNR$ as compared to the SISO case.

Thus, the overall increase in $SNR$ is approximately,

$$SNR = \frac{M^2(SIGNALPOWER/M)}{NOISE} = M.SNR_0$$

(13)

Channel capacity for this channel is approximately equal to:

$$C = B \cdot \log_2 (1 + M.SNR_0)$$

(14)

4.1.4 Multiple-Input, Multiple-Output (MIMO)

Different signal transmitted by each antenna, in MIMO using the same bandwidth and still be able to decode correctly at the receiver. The capacity of each one of these channels is roughly equal to:

$$C = B \cdot \log_2 (1 + \frac{N}{M}.SNR_0)$$

(15)

But, since we have $M$ of these channels ($M$ transmitting antennas), the total capacity of the system is,

$$C = M.B \cdot \log_2 (1 + \frac{N}{M}.SNR_0)$$

(16)

Thus, as we can see from (16), we get a linear increase in capacity with respect to the number of transmitting antennas. So, the key principle at work here, is that it is more beneficial to transmit data using many different low-powered channels than using one single, high-powered channel.

4.2 MIMO System Model

Fig.5 2×2 MIMO System Model
Let us consider single user MIMO communication system with 2 antennas at the transmitter and 2 antennas at the receiver. Consider that we have a transmission sequence is \( \{x_1, x_2, \ldots, x_n\} \). In normal transmission, we send \( x_1 \) in the first time slot, \( x_2 \) in the second time slot and \( x_n \) in the \( n \)th time slot. Now we have two transmit antennas, we may groups the symbols into groups of two. In the first time slot, send \( x_1 \) and \( x_2 \) from the first and second antenna. In the second time slot, send \( x_3 \) and \( x_4 \) from the first and second antenna and in next time slot \( x_5 \) and \( x_6 \) and so on. Let us consider for 2 x 2 MIMO. The signal received on the first antenna is given by:

\[
r_1 = h_{11}s_1 + h_{12}s_2 + n_1
\]  

(17)

The signal received on the second antenna is given by:

\[
r_2 = h_{21}s_1 + h_{22}s_2 + n_2
\]  

(18)

where, \( y_1 \) and \( y_2 \) are the received symbol on the first and second antenna respectively, \( h_{11} \) is the channel from 1st transmit antenna to 1st receive antenna, \( h_{12} \) is the channel from 2nd transmit antenna to 2nd receive antenna, \( h_{21} \) is the channel from 1st transmit antenna to 2nd receive antenna, \( h_{22} \) is the channel from 2nd transmit antenna to 2nd receive antenna, \( s_1 \) and \( s_2 \) are the transmitted symbols and \( n_1 \) and \( n_2 \) is the noise on 1st and 2nd receive antennas respectively.

Eqn (1) and Eqn (2) can be represented in matrix form:

\[
\begin{bmatrix}
y_1 \\
y_2
\end{bmatrix} = \begin{bmatrix}
h_{11} & h_{12} \\
h_{21} & h_{22}
\end{bmatrix} \begin{bmatrix}
s_1 \\
s_2
\end{bmatrix} + \begin{bmatrix}
n_1 \\
n_2
\end{bmatrix}
\]  

(19)

The sampled baseband representation of signal is given by:

\[
y = H x + n
\]  

(20)

For a system with \( M_T \) transmit antennas and \( M_R \) receive antennas, the MIMO channel at a given time instant may be represented as a \( M_R \times M_T \) matrix:

\[
\begin{bmatrix}
H_{1,1} & \cdots & H_{1,M_T} \\
\vdots & \ddots & \vdots \\
H_{M_R,1} & \cdots & H_{M_R,M_T}
\end{bmatrix}
\]  

(21)

5. MIMO OFDM CONJUNCTION

All Wireless links are affected by three common problems of speed, range and reliability. These parameters are interlinked to each other by strict rules. Speed could be increased only by sacrificing range and reliability. Range could be extended at the expense of speed and reliability. And reliability could be improved by reducing speed and range. MIMO-OFDM provides the 'all in one package' by providing the speed, range and reliability simultaneously.

With OFDM, a single channel within a spectrum band can be divided into multiple, smaller sub-signals that transmit information simultaneously without interference. Because MIMO technology is able to link together many smaller antennas to work as one, it can receive and send these OFDM's multiple sub-signals in a way that allows the bandwidth to be substantially increased to each user as required.
OFDM is the technique used to mitigate the multipath propagation problem and MIMO is used for the efficient usage of spectral bandwidth thus combining these techniques results in wireless system that has best spectral coverage, reliable transmission in highly obstructive environment, and data rates in 100's of megabits.

MIMO caters the spatial diversity whereas OFDM can use either FDD or TDD multiplex technique. In the spatial domain, MIMO provide greater capacity. In the time domain, the modulation method OFDM simplifies the equalization process by eliminating the inter symbol interference (ISI). With the combination of MIMO and OFDM, greater channel capacities could be realized with robustness to channel impairments like ISI through cyclic prefix (CP) and multipath fading through adaptive bit loading.

OFDM creates the slow time varying channel streams and MIMO has capacity of transmitting the signals over multiple channels by use of an array of antennas thus the combination of OFDM and MIMO can generate extremely beneficial results. OFDM signals are greatly affected by the presence of objects, while on the other hand the MIMO takes its advantage from multipath propagation. So the concept is to generate the OFDM signals and subject to MIMO antennas.

5.1 MIMO OFDM System Model

The general transceiver structure of MIMO-OFDM is presented above. The system consists of N transmit antennas and M receive antennas. The OFDM signal for each antenna is obtained by using inverse fast Fourier transform (IFFT)[7] and can be detected by fast Fourier transform (FFT). The received MIMO-OFDM symbol of the n:th subcarrier and the m:th OFDM symbol of the i:th receive antenna after FFT can be written as:

\[
R_i[n,m] = \sum_{j=1}^{N} H_{i,j}[n,m]A_j[n,m] + W_i[n,m] \tag{22}
\]

where \(A_j[n,m]\) is the transmitted data symbol on \(n:th\) carrier and \(m:th\) OFDM symbol, \(W_i[n,m]\) is the additive noise contribution at \(i:th\) receive antenna for the corresponding symbol in frequency domain and \(H_{i,j}[n,m]\) is the channel coefficient in the frequency domain between the \(j:th\) transmit antenna and the \(i:th\) receive antenna:

\[
H[n, m] = \sum_{i=0}^{I-1} h_i[m]e^{-j2\pi i n/T} \tag{23}
\]

where \(n\) takes values between 0 to \(N-1\) \(I\) is the number of channel taps in time domain and \(h[m]\) is modelled as an independent zero-mean random Gaussian process. The impulse response of the Rayleigh fading channel can be expressed as:

\[
h(t,\tau) = \sum_{i=0}^{l-1} h_i(t)\delta(\tau - \tau_i(t)) \tag{24}
\]

where \(h_i\) is the tap gain and \(\tau_i\) is the delay associated to the \(i:th\) tap. This delay can be considered to be time invariant. The channel impulse response is assumed to be static over one OFDM channel symbol duration \(T_{channel}=T+T'\), where \(T\) is the OFDM symbol duration and \(T'\) is the cyclic prefix duration. This corresponds to a slowly varying channel where the coherence time is longer than the channel symbol duration. This assumption prevents from experiencing inter-carrier interference (ICI). The channel matrix \(H\) is an \(N \times M\) matrix corresponding to the \(n:th\) subcarrier and \(m:th\) OFDM symbol.
\[ \hat{H}[n,m] = \begin{bmatrix} H_{1,1}[n,m] & H_{1,2}[n,m] & \cdots & H_{1,N}[n,m] \\ \vdots & \ddots & \vdots \\ H_{M,1}[n,m] & H_{M,2}[n,m] & \cdots & H_{M,N}[n,m] \end{bmatrix} \]  \tag{25}

Taking the received data symbols of all antennas into account, the expression of the received data symbol can be presented in the matrix form as follows:

\[ \bar{R}[n,m] = \bar{H}[n,m] \bar{A}[n,m] + \bar{W}[n,m] \]  \tag{26}

where

\[ \bar{A}[n,m] = [A_1[n,m] A_2[n,m] \ldots A_N[n,m]]^T \]  \tag{27}

\[ \bar{R}[n,m] = [R_1[n,m] R_2[n,m] \ldots R_N[n,m]]^T \]  \tag{28}

are the Nx1 and Mx1 vectors of the transmitted and received data symbols. To obtain the transmitted data symbols equation (25) should be solved which is called MIMO-OFDM equalization.

The useful power \( P_U = E[|C(k)|^2] \) interference power can be expressed as,

\[ P_U = E[|I(k)|^2] \]  \tag{29}

The carrier to interference ratio (CIR) is given by:

\[ \text{CIR} = \frac{P_U}{P_I} \]  \tag{30}

The bit error rate (BER) of MIMO-OFDM system employing QAM can be derived from CIR as

\[ P_b = \frac{3}{8} \left[ 1 - \left( \frac{1}{\sqrt{1 + 5/(\text{CIR}/2)}} \right) \right] \]  \tag{31}

6. V-BLAST OVERVIEW

V-BLAST (Vertical-Bell Laboratories Layered Space-Time) is a detection algorithm to the reception of multi antenna MIMO systems. Its principle is quite simple, first it detects the most powerful signal with the highest SNR, and then it regenerates the received signal from this user from available decision. Then, the signal regenerated is subtracted from the received signal and with this new signal; it proceeds to the detection of the second user's most powerful signal, since it has already cleared the first signal and so forth. This gives less interference to a vector received.

6.1 V-BLAST System

In V-BLAST, the vector encoding process is simply a de-multiplex operation followed by independent bit-to-symbol mapping of each sub stream. V-BLAST utilizes a combination of old and new detection techniques to separate the signals in an efficient manner, permitting operation at significant fractions of the Shannon capacity and achieving large spectral efficiencies in the process. In procedure of V-BLAST detection, it is generally assumed that the channel matrix estimate has no estimation error. In the real system, however there exist the channel estimation errors, thereby causing degradation of system performance.
A single data stream is de-multiplexed into $M$ sub streams, and each sub stream is then encoded into symbols and fed to its respective transmitter. Transmitters 1-$M$ operate co-channel at symbol rate $1/T$ symbols/sec, with synchronized symbol timing. Each transmitter is itself an ordinary QAM transmitter. The collection of transmitters in effect, comprises, a vector-valued transmitter, where components of each transmitted $M$-vector are symbols drawn from a QAM constellation. We assume that the same constellation is used for each sub-streams, and that transmissions are organized into bursts of $K$ symbols. The power launched by each transmitter is proportional to $1/M$ so that the total radiated power is constant and independent of $M$.

At the receiver, an array of antennas is again used to pick up the multiple transmitted sub streams and their scattered images. Receivers 1-$N$ are, individually, conventional QAM receivers. These receivers also operate co-channel, each receiving the signals radiated from all $M$ transmit antennas. Each receiver antenna sees all of the transmitted sub-streams but superimposed and not separately. However, if the multipath scattering is sufficient, then the multiple sub-streams are all scattered slightly differently, because they originate from different transmit antennas that are located at different points in space. By using sophisticated signal processing, these slight differences in scattering allow the sub-streams to be identified and recovered. In effect, the unavoidable multipath is exploited to provide a very useful spatial parallelism that is used to greatly improve data transmission.

6.2 Decoding Algorithm of V-BLAST

V-BLAST detection uses of linear combinatorial nulling techniques such as ZF or MMSE or non-linear methods like symbol cancellation. Each sub stream turn by turn is considered to be the desired signal and all the others are interferers. Nulling is obtained by linear weighting of the received signals [8]. For V-BLAST, no channel knowledge required at transmitter.

6.2.1 Main Steps for V-BLAST detection

1. Ordering: choosing the best channel.
2. Nulling: using ZF, MMSE, ML.
3. Slicing: making a symbol decision
4. Canceling: subtracting the detected symbol
5. Iteration: going to the first step to detect the next symbol.

The detection process consists of two main operations:
1. Interference suppression (nulling): The suppression operation nulls out interference by projecting the received vector onto the null subspace (perpendicular subspace) of the subspace spanned by the interfering signals. After that, normal detection of the first symbol is performed.
2. Interference cancellation (subtraction): The contribution of the detected symbol is subtracted from the received vector.
7. RESULTS AND SIMULATIONS

Fig. 7 OFDM Transmitted Spectrum

Fig. 8 Performance comparison for all modulation techniques

Fig. 9 Effect of number of antennas on MIMO

Fig. 10 Effect of Doppler shift on MIMO systems

Fig. 11 Performance comparison of SISO and MIMO
The signal represented in the Figure 7 represents the OFDM transmitted spectrum. The signal to noise ratio \( (E_b/N_0) \) and the bit error rate (BER) for various modulation techniques was compared and it was proved that QAM-32 is the most efficient modulation technique as seen in Figure 8. The effect of Doppler shift was studied on the MIMO-OFDM system as seen in Figure 10. The value \( ep \) in figure gives the various values of normalized Doppler shift. With increase in the Doppler Shift the BER increases thereby decreasing the signal quality [6]. Now, the number of receive and transmit antennas is increased progressively i.e. 2, 3, 4 antennas are used. In the Figure 9, NT and NR denote the number of antennas used at transmitter and receiver respectively. As the number of antennas is increased, the throughput increases and also the signal to noise ratio increases. Thus, system performance improves with increased antennas. The signal to noise ratio \( (E_b/N_0) \) and the bit error rate (BER) for single input single output (SISO) and multiple input multiple output (MIMO) antenna systems was compared. It is observed that the bit error rate progressively decreases with a simultaneous increase in the Signal to Noise ratio as observed from Figure 11. The increase in signal to noise ratio is indication of good quality signal and low bit error rate indicates lesser erroneous transmissions. Overall, MIMO shows better performance on both fronts. As seen above, MIMO system shows better performance than SISO.

AREAS FOR FUTURE RESEARCH

OFDM-MIMO has been adopted in several wireless standards such as digital audio broadcasting (DAB), digital video broadcasting (DVB-T), the IEEE 802.11 and the IEEE 802.16a standards. OFDM is also being pursued for dedicated short-range communications (DSRC) and as a potential candidate for fourth-generation (4G) mobile wireless systems. However, the various problems in the area of OFDM-MIMO need to be addressed so that the gains promised by the technology can be fully leveraged in practical systems. Another critical area for research is MIMO OFDM channel estimation.

This paper provides the basis for system implementation characterized by a complete design flow, starting from the initial idea and the algorithm definition, through the software and finally to the hardware implementation using FPGA platform. Also, the V-BLAST approach that significantly improves spectral efficiencies, and robustness as well as acceptable BER, while offering simple VLSI could be explored as a next-generation solution.

CONCLUSION

OFDM is a modulation technique which is now used in most new and emerging broadband wired and wireless communication systems because it is an effective solution to inter-symbol interference caused by a dispersive channel. In this paper, we have briefly described OFDM for wireless communications. A typical OFDM transmitter and receiver are described and the roles of the main signal processing blocks explained. The time and frequency domain signals at various points in the system are described. It is shown that if a cyclic prefix is added to each OFDM symbol, any linear distortion introduced by the channel can be equalized. In this paper, we provide an overview of general multiple antenna system and the general V-BLAST system. It is observed that with increase in the Doppler Shift the BER increases thereby decreasing the signal quality. The capacity of MIMO systems increases with increase in number of transmitting and receiving antennas. OFDM and MIMO together can generate extremely beneficial results. OFDM signals are greatly affected by the presence of objects, while on the other hand the MIMO takes its advantage from multipath propagation. V-BLAST is a detection algorithm to the reception of multi antenna MIMO systems and shall form the backbone of next generation MIMO systems.

In conclusion, OFDM-MIMO is a very promising technology for wireless communications.
REFERENCES


