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Bit Error Rate Performance Measurement of Wireless MIMO System Based on FPGA

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Abstract

To measure the bit error rate (BER) performance validation of digital baseband communication systems on a field-programmable gate array (FPGA). The proposed BER tester (BERT) integrates fundamental baseband signal processing modules of a typical wireless communication system along with a realistic fading channel simulator and an accurate Gaussian noise generator onto a single FPGA to provide an accelerated and repeatable test environment in a laboratory setting. Using a developed graphical user interface, the error rate performance of single- and multiple-antenna systems over a wide range of parameters can be rapidly evaluated. The FPGA-based BERT should reduce the need for time-consuming software-based simulations, hence increasing the productivity. This FPGA-based solution is significantly more cost effective than conventional performance measurements made using expensive commercially available test equipment and channel simulators.

1. Introduction

Future wireless communication networks will need to support extremely high data rates in order to meet the rapidly growing demand for broadband applications such as high quality audio and video. Existing wireless communication technologies cannot efficiently support broadband data rates, due to their sensitivity to fading. Recent research on wireless communication systems has shown that using MIMO at both transmitter and receiver offers the possibility of wireless communication at higher data rates, enormous increase in performance and spectral efficiency compared to single antenna systems. The information-theoretic capacity of MIMO channels was shown to grow linearly with the smaller of the numbers of transmitter and receiver antennas in rich scattering environments, and at sufficiently high signal-to-noise (SNR) ratios .MIMO wireless systems are motivated by two ultimate goals of wireless communications: high-data-rate and high-performance.

During recent years, various space-time (ST) coding schemes have been proposed to collect spatial diversity and/or achieve high rates. Among them, V-BLAST (Vertical Bell Labs Layered Space-Time) transmission has been widely adopted for its high spectral efficiency and low implementation complexity.

When maximum-likelihood (ML) detector is employed, V-BLAST systems also enjoy receives diversity, but the decoding complexity is exponentially increased by the number of transmit-antennas. Although some (near-) ML schemes (e.g., sphere-decoding (SD), semi-definite programming (SDP)) can be used to reduce the decoding complexity, at low signal to-noise ratio (SNR) or when a large number of transmit antennas and/or high signal constellations are employed, the complexity of near-ML schemes is still high. Some suboptimal detectors have been developed, e.g., successive interference cancellations (SIC),

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2. System Description

A. Modulation

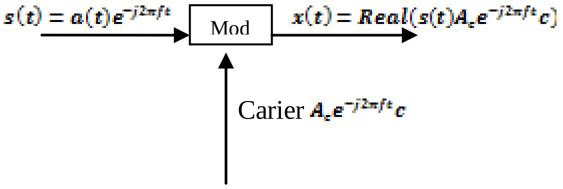
Baseband signals are generated at low rates; therefore these signals are modulated onto a radio frequency carrier for transmission. Baseband signal *s*(*t*) is complex, and can be represented mathematically as

$$S(t) = a(t)e^{j\phi(t)} \qquad (1)$$

Where: *a*(*t*) is the amplitude and _(*t*) is the phase Assuming a sampling rate the same as the Nyquist rate, the low-pass reconstruction filter extends from _*fm* to *fm*(see Figure 4.15). The maximum frequency *fm* of *s*(*t*) is an approximate measure of its bandwidth. The Fourier transform of *s*(*t*) is given by

$$s(f) = \int_{-\infty}^{\infty} s(t)e^{-j2\pi f t}\ dt \qquad (2)$$

A functional block diagram of a generic modulation procedure for signal *s*(*t*)is given in Figure



A_c = amplitude factor
f_c = carrier factor

Fig: 1. Functional Block Diagram of A Generic Modulator

The modulation can be classified as linear modulation or nonlinear modulation. A modulation process is linear when *a*(*t*) cos_(*t*) and *a*(*t*)sin_(*t*) are linearly related to the message information signal. Examples of linear modulation are amplitude modulation, where the modulating signal affects only the amplitude of the modulated signal, and phase modulation, where the modulating signal affects only the phase of the modulated signal (i.e., when _(*t*) is a constant over each signaling (symbol) interval and *a*(*t*) is constant for any *t*).

The modulation process is nonlinear when the modulating signal *s*(*t*) affects the frequency of the modulated signal. The definition of a nonlinear system is that superposition does not apply. The modulation process is nonlinear whether or not the amplitude of the modulating signal is a function of time. We consider a frequency modulation process and let *a*(*t*) _ *a* for any *t*. Then, the nonlinear modulated signal is *x*(*t*) _ *aA*cos[2_*fct* _ _(*t*)], where _(*t*) is the integral of a frequency function. Selection of modulation and demodulation schemes is based on spectral efficiency, power efficiency, and fading immunity. During the late 1970s and early1980s, constant envelope modulation schemes were used for cellular systems to achieve a high-power efficient terminal with a *C* class amplifier. As a result, Gaussian minimum shift keying (GMSK is the widely used modulation scheme in the GSM and DECT systems. In the mid-1980s, when cellular systems' capacity became a serious problem, developments of linear modulations with two bits per second per Hz (bps/Hz) transmission capability were initiated. To apply a linear modulation in a wireless communication system, we need high spectral efficiency as well as high-power efficiency at the same time. _/4- quadrature phase shift keying (QPSK) was used in the Japanese and North American digital cellular and personal systems.

- Performance Parameters of Coding and Modulation Scheme:

The most important parameter of a coding and modulation scheme is the bandwidth requirement, which is determined by the spectrum of the modulated signal usually presented as a plot of power spectral density (PSD) against frequency.

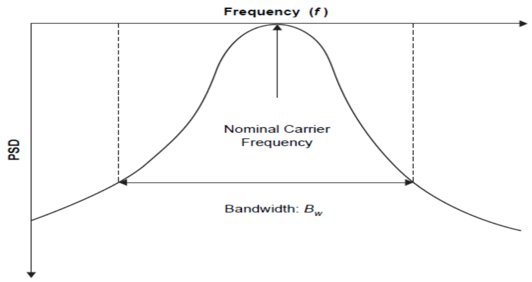


Fig: 2. PSD Versus Frequency

Ideally, the PSD should be zero outside the band occupied. However, in practice this can never be achieved, and the spectrum extends to infinity beyond the band. This is either because of the inherent characteristics of the modulation scheme, or because of the practical implementation of filters. Hence, we must define the bandwidth, *Bw* such that the signal power falling outside the band is below a specified threshold. In practice, this threshold is determined by the tolerance of the system to adjacent channel interference.

The coding and modulation selection should be based on the following factors:

- Bit error rate probability (*Pb)*
- Bandwidth efficiency,
- Signal-to-noise density ratio,

Eb/*N*0 (*Eb* is the energy per bit and *N*0 is the noise density) complexity of transmitter/receiver the bandwidth efficiency (or spectrum efficiency), _, of a coding and modulation scheme determines the bandwidth requirement. This is defined as the information bit rate; *Rb*, per unit bandwidth occupied, and is measured in bits/sec/Hz (bps/Hz).

$$\eta = \frac{R_b}{B_w} \tag{3}$$

An ideal coding and modulation system should provide a small *Pb* with a high bandwidth efficiency and a low signal-to-noise density ratio (*Eb/N*0).The information rate, *Rb*, is related to the number of waveforms, *M*, used by the modulator and the duration of these waveforms, *Ts*

$$R_b = \frac{\log_2 M}{T_s} \tag{4}$$

The average power used by the modulator is *P =Es/Ts*, where *Es* is the average energy of the modulator signals. Each signal carries a log2 *M* information bit.

$$\therefore P = \frac{E_b \log_2 M}{T_s} = E_b R_b \tag{5}$$

The signal-to-noise ratio (SNR) is the ratio between the average signal power and the average noise power over the signal bandwidth

$$\mathrm{SNR} = \frac{P}{N_0 B_w} = \left(\frac{E_b}{N_0}\right) \cdot \left(\frac{R_b}{B_w}\right) \tag{6}$$

Equation shows that SNR is the product of (*Eb*/*N*0) and (*Rb/Bw*).the bandwidth (or spectral) efficiency of a modulation scheme.

- Binary Phase Shift Keying Analytical Expression:

The transmitted BPSK signal is given by Rappaport (2002) and Sklar (2003) as

$$s_{BPSK}(t) = \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_c t + \phi_c) \qquad 0 \leq t \leq T \tag{7}$$

(For binary 1) and

$$s_{BPSK}(t) = \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_c t + \phi_c + \pi) \tag{8}$$

Where, Eb = energy per bit, Tb = transmitted symbol, *c*φ=the phase.

BPSK is generally represented by

$$s_{BPSK}(t) = m(t)\sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_c t + \phi_c) \tag{9}$$

m(t) = binary data which takes on one of two possible pulse shapes

- Quadrature Phase Shift Keying Analytical Expression:

Here, two bits are transmitted in a single modulation. The QPSK signal for this set of symbols states is given as

$$s_{QPSK}(t) = \sqrt{\frac{2E_s}{T_s}} \cos\left[2\pi f_c t + (i-1)\frac{\pi}{2}\right]$$

$$(14) \qquad 0 \leq t \leq T;\ I = 1,2,3,4 \tag{10}$$

Rayleigh distribution:

This is used to describe the statistical time varying nature of the envelope of an individual multipath component. The Rayleigh distribution is given by Vijay (2007) as

$$P(r) = r/\sigma^2 \exp(-r/\sigma^2) \quad 0 \leq r \leq \infty \qquad (11)$$

Where, σ = rms value of the received signal, r/2= instantaneous power, σ/2 = local average power of the received signal before detection

B. Bit Error Rate (BER)

Bit error rate is a key parameter that is used in assessing systems that transmit digital data from one location to another. BER is applicable to radio data links, Ethernet, as well as fiber optic data systems. When data is transmitted over a data link, there is a possibility of errors being introduced into the system. If this is so, the integrity of the system may be compromised. As a result, it is necessary to assess the performance of the system, and BER provides an ideal way in which this can be achieved. BER assesses the full end to end performance of a system including the transmitter, receiver and the medium between the two BER is defined as the rate at which

BER expression is given by

$$BER = \int_0^\infty P_b\,(E/r)P(r)dr \qquad (12)$$

Where,

$P_b(E/r)$ = the conditional error probability,

P(r) = the pdf of thr SNR

C. White Noise

White noise is a random signal with a flat power spectral density; that is, the signal contains equal power within fixed bandwidth at any center frequency. White noise is usually applied in context of frequency domain and hence, white noise is commonly applied to a noise signal in the spectral domain. Gaussian white noise is a good approximation of many real-me situations and it generates mathematical traceable models. But because these models are so frequently used, the term additive has been added. Additive White Gaussian Noise (AWGN) has become a statistical tool for analysis and application in telecommunication engineering.

D. Smart Antenna Techniques

Smart antenna techniques, such as multiple-input multiple-output (MIMO) systems, can extend the capabilities of the 3G and 4G systems to provide customers with increased data throughput for mobile high-speed data applications. MIMO systems use multiple antennas at both the transmitter and receiver to increase the capacity of the wireless channel With MIMO systems, it may be possible to provide in excess of 1 Mbps for 2.5G wireless TDMA EDGE and as high as20 Mbps for 4G systems. With MIMO, different signals are transmitted out of each antenna simultaneously in the same bandwidth and then separated at the receiver. With four antennas at the transmitter and receiver this has the potential to provide four times the data rate of a single antenna system without an increased in transmit power or bandwidth.

MIMO techniques can support multiple independent channels in the same bandwidth, provided the multipath environment is rich enough. What this means is that high capacities are theoretically possible, unless there is a direct line of-sight between the transmitter and receiver. The number of transmitting antennas is *M*, and the number of receiving antennas is *N*, where *N* _ *M*. We examine four cases:

- Single-Input, Single-Output (SISO)
- Single-Input, Multiple-Output (SIMO)
- Multiple-Input, Single-Output (MISO)
- Multiple-Input, Multiple-Output (MIMO)

Single-input, single-output: The channel bandwidth is *B*, the transmitter power Is*Pt*, the signal at the receiver has an average signal-to-noise ratio of SNR0, then the Shannon limit on channel capacity *C* is

$$C \approx B\log_2(1 + \mathrm{SNR}_0) \qquad (13)$$

Single-input, multiple-output: There are *N* antennas at the receiver. If the signals received on the antennas have on average the same amplitude, then they can be added coherently to produce an *N*2 increase in signal power. There are *N* sets of noise sources that are added coherently and result in an *N*-fold increase in noise power. Hence, the overall increase in SNR will be:

$$\mathrm{SNR} \approx \frac{N^2 \times (\text{signal power})}{N \times (\text{noise})} = N \times \mathrm{SNR}_0 \qquad (14)$$

The capacity for this channel is approximately equal to

$$C \approx B\log_2[1 + N \times \mathrm{SNR}_0] \qquad (15)$$

Multiple-input, single-output: We have *M* transmitting antennas. The total power is divided into *M* transmitter branches. If the signals add coherently at the receiving antenna, we get an *M*-fold increase in SNR as compared to SISO. Because there is only one receiving antenna, the noise level is same as SISO. The overall increase in SNR is approximately

$$\mathrm{SNR} \approx \frac{M^2 \cdot [(\text{signal power})/M]}{\text{noise}} = M \times \mathrm{SNR}_0 \qquad (16)$$

Multiple-input, multiple-output: MIMO systems can be viewed as a combination of MISO and SIMO channels. In this case, it is possible to achieve approximately an *MN*-fold increase in the average SNR0 giving a channel capacity equal to

$$C \approx B\log_2(1 + M \times N \times \mathrm{SNR}_0) \qquad (17)$$

Assuming *N* _ *M*, we can send different signals using the same band width and still be able to decode correctly at the receiver. Thus, we are creating a channel for each one of the transmitters. The capacity of each one of these channels is roughly equal to

$$C_{\text{single}} \approx B\log_2\left(1 + \frac{N}{M} \times \mathrm{SNR}_0\right) \qquad (18)$$

- OFDM-MIMO Systems

OFDM and MIMO techniques can be combined to achieve high spectral efficiency and increased throughput. The OFDM-MIMO system transmits independent OFDM modulated data from multiple antennas simultaneously. At the receiver, after OFDM demodulation, MIMO decodes each sub channel to extract data from all transmits antennas on all the sub channels.

E. Performance Analysis of Mimo Technology Using V-Blast Technique for Different Linear Detectors in A Slow Fading Channel

- Maximum Likelihood (ML)*:*

The ML receiver performs optimum vector decoding and is optimal in the sense of minimizing the error probability. ML receiver is a method that compares the received signals with all possible transmitted signal vector which is modified by channel matrix H and estimates transmit symbol vector x according to the Maximum Likelihood principle , which is shown as:

$$\hat{x} = \arg_{x_k \in \{x_1, x_2 \ldots x_N\}} min\|r - Hx_k\|^2 \qquad (19)$$

Where the minimization is performed over all possible transmit estimated vector symbols .Although ML detection offers optimal error performance, it suffers from complexity issues. It has exponential complexity in the sense that the receiver has to consider |A|M possible symbols for an M transmitter antenna system with A is the modulation constellation.

V-BLAST Zero Forcing *(ZF)* characteristic*:*

We can reduce the decoding complexity of the ML receiver significantly by employing linear receiver front-ends to separate the transmitted data streams, and then independently decode each of the streams. Simple linear receiver with low computational complexity and suffers from noise enhancement. It works best with high SNR. The solution of the ZF is given by:

$$\hat{x} = (H^*H)^{-1}Hx = H^+x \qquad (20)$$

The ZF receiver converts the joint decoding problem into M single stream decoding problems there by significantly reducing receiver complexity. This complexity reduction comes, however, at the expense of noise enhancement which in general results in a significant performance degradation (compared to the ML decoder). The diversity order achieved by each of the individual data streams equals N - M + 1.

V-BLAST with Minimum Mean Square Error (MMSE):

The MMSE receiver suppresses both the interference and noise components, whereas the ZF receiver removes only the interference components. This implies that the mean square error between the transmitted symbols and the estimate of the receiver is minimized. Hence, MMSE is superior to ZF in the presence of noise. Some of the important characteristics of MMSE detector are simple linear receiver, superior performance to ZF and at Low SNR, MMSE becomes matched filter. Also at high SNR, MMSE becomes Zero-Forcing. MMSE receiver gives a solution of:

$$\hat{x} = D \cdot x = \left(\frac{1}{SNR} I_{N_R} + H^H H\right)^{-1} \cdot H^H x$$

At low SNR, MMSE becomes ZF:

$$\left(\frac{1}{SNR} I_{M_R} + H^H H\right)^{-1} H^H \approx \frac{1}{SNR} H^H \ldots \qquad (20)$$

3. Implementation

A. MATLAB Simulation method

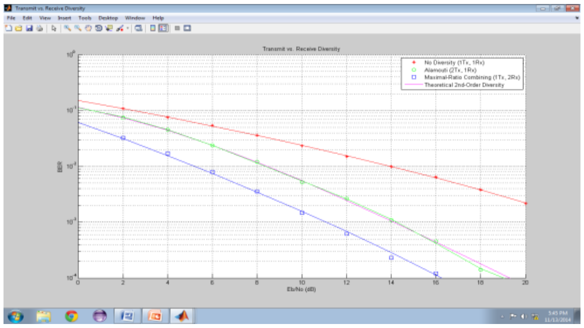
The simulation of the model under study was carried out using MATLAB application package because of the controllability and repeatability of parameters, which is very difficult to do at highway speeds in the field test. The simulation was carried out with each of the different data sources namely: random data and parrot image data. The data sources are converted to binary using MATLAB's de2bi() function, reshaped, gray-coded and modulated with BPSK and QPSK scheme in turn. Then copies of the faded signal were created and MRCDFE performed accordingly.

The following parameters and system configurations were used:

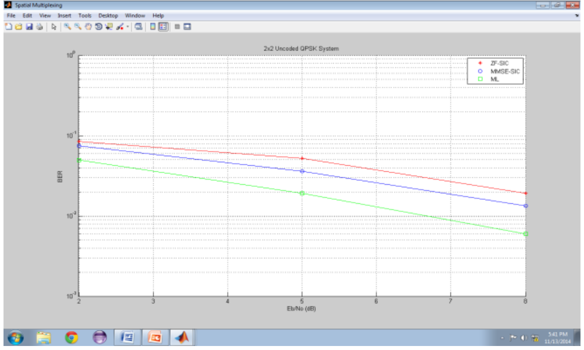
- Modulation: BPSK and QPSK
- Carrier frequency: 900 MHz
- Bandwidth of signal: 200 ns
- Noise: AWGN
- Receive & Transmit Filter: Square-root raised cosine pulse shaping
- Number of MRC Paths: 2
- Equalizer algorithms: LMS and RLS
- Number of feedback weights: 17
- Mobile speed: 90 km/h
- Fading type: Rayleigh fading

Comparison of Ber for Qpsk & Bpsk with Various Diversity Techniques:

BPSK



QPSK



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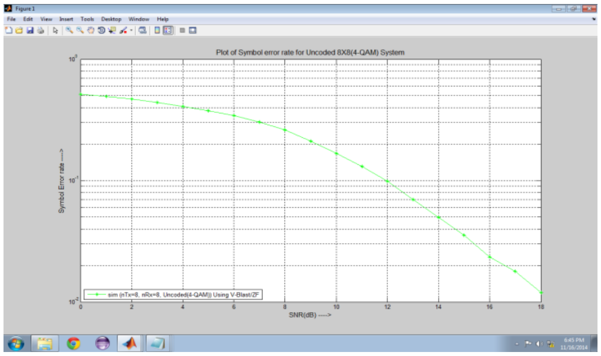

4. Conclusion

In this paper analyze the performance of linear detectors for MIMO V-BLAST systems in slow fading channels for different modulations and different channels, which exhibit the best trade-off between performance and complexity among spatial multiplexing techniques. We show that conventional linear equalizers can only collect diversity N r – N t +1 for MIMO V-BLAST systems though they have very low complexity. By investigating and simulating each receiver concepts, it was shown that V-BLAST implements a detection technique, i.e. SIC receiver, based on ZF or MMSE combined with symbol cancellation and optimal ordering to improve the performance, although ML receiver appears to have the best SER performance. In this paper, the MIMO principle is based on a rich multipath environment without a normal Line-of-Sight (LOS) that is the Rayleigh flat fading channel, due to movement or other changes in the environment, LOS situation can arise. So finally we proposed that ML detector for MIMO-V-Blast in slow fading channel with QPSK modulation is the ultimate optimization technique in the next generation broadband communication system.

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