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PERFORMANCE ANALYSIS OF DIGITAL MODULATION TECHNIQUES USING MIMO-OFDM SYSTEM AND V-BLAST ALGORITHM FOR MULTI USER DETECTION

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Abstract - This paper is aimed at analyzing the Bit Error Rate performance of the Orthogonal Frequency Division Multiplexing (OFDM) system in Multi-Input Multi-Output (MIMO) environment for increasing the transmission capacity and improving the spectrum efficiency for wireless communication by varying number of users. The main motivation for using OFDM in a MIMO channel is the fact that OFDM modulation turns a frequency-selective channel into a set of parallel-flat frequency MIMO channel, in order to achieve the efficient usage of the available bandwidth. Multi-user Detection (MUD) is the intelligent estimation of transmitted bits in the presence of Multiple Access Interference (MAI).Conventional detectors based on the matched filter just treat the MAI as additive white Gaussian noise (AWGN). However, unlike AWGN, MAI has a nice correlative structure quantified by the cross-correlation matrix of the signature sequences. Hence, detectors that take into account this correlation would perform better than the conventional matched filter-bank. MUD is basically the design of signal processing algorithms. These algorithms take into account the correlative structure of the MAI. This paper deals with the possible analysis of various digital modulation techniques such as QPSK, 16 QAM and 64 QAM. These are compared based on their Minimum Bit Error Rates (MBER) to their corresponding Signal to Noise Ratio (SNR) values and best promising combination is proposed. In this analysis, MIMO-OFDM based Wireless Communication System considers using MMSE (Minimum Mean Square Error) and V-BLAST (Vertical Bell Laboratories layered Space-Time) technique. We compare results for Rayleigh Channel.

Keywords: OFDM, MIMO, V-BLAST, MMSE, MUD.

I. INTRODUCTION

For high data rate wireless communications, Orthogonal Frequency Division Multiplexing (OFDM) is one of the most promising technologies due to its high spectral efficiency, robustness, frequency selective fading and low computational complexity. OFDM can be used with Multi Input Multi Output (MIMO) transceiver to increase the diversity gain and the system capacity by exploiting spatial domain. MIMO-OFDM is considered a key technology in emerging high-data rate systems such as 4G because the OFDM system effectively provides numerous parallel narrowband channels [11].

MIMO communication uses multiple antennas at both the transmitter and receiver to exploit the spatial domain for spatial multiplexing and spatial diversity. In this paper MIMO OFDM is analyzed for Rayleigh channel and each sub-carrier being modulated with different digital modulation scheme (such as M –QAM and QPSK) at a low symbol rate, maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth. The primary advantage of OFDM over single-carrier schemes is its ability to cope with severe channel conditions. The low symbol rate makes the use of a guard period between symbols affordable, making it possible to eliminate inter-symbol interference (ISI).

The analysis and simulation of the MIMO OFDM V-BLAST system to reduce ISI and frequency selective fading is considered in two stages. The first stage involves the implementation of a system architecture model with vertical encoding, OFDM modulation demodulation, V-BLAST signal processor with nulling for each OFDM sub carrier, and conventional decoding. The second stage compares the SNR performance of the system for various digital modulation techniques by varying transmitting power. [12].

II. SYSTEM ARCHITECTURE

A. Orthogonal Frequency Division Multiplexing System

In order to solve the bandwidth efficiency problem, Orthogonal Frequency Division Multiplexing (OFDM) was proposed, which employs orthogonal carriers to modulate the signals. The carriers are spaced at frequency intervals equal to the symbol rate and are capable of separation at the receiver. This carrier spacing provides optimum spectral efficiency. It has been found that the OFDM symbols can actually overlap in the frequency domain and still be separated at the receiver. This property stems from the fact that symbols are orthogonal over time rather than frequency. Although OFDM is robust to ISI, it is not immune to the effects of flat fading which can cause unacceptable performance degradation.

One of the main problems with this powerful technique has been the need for numerous oscillators at the transmitter and receiver. An elegant solution to this was found in the Fast-Fourier Transform (FFT). By simply performing an FFT on a signal, we can use a single oscillator at the transmitter and receiver. The main idea is that by passing a signal through an IFFT, we multiply each input by $e^{j2pnm/B}$, which is a sampled version of $e^{j2pnm/B}$. This corresponds to a frequency shift of *m/B*. While in the implementation without the FFT, we would need *L* modulators each having a distinct carrier frequency, *fi*, with the FFT we can simply have one modulator at the carrier frequency, while each of the symbols placed into the IFFT will be offset by *m/B* in frequency. The output of the IFFT will be time-domain OFDM symbols corresponding to the input symbols in the frequency-domain. The *cyclic extension* (also called guard interval or zero padding) is added to an OFDM symbol in order to combat the effect of multipath. ISI is avoided between adjacent OFDM symbols by introducing a guard period in which the multipath components of the desired signal are allowed to die out, after which the next OFDM symbol is transmitted. A useful technique to help reduce the complexity of the receiver is to introduce a guard symbol during the guard period. Specifically, this guard symbol is chosen to be a prefix extension to each block. The reason for this is to convert the linear convolution of the signal and channel to a circular convolution and thereby causing the FFT of the circularly convolved signal and channel to simply be the product of their respective FFT's. However, in order for this technique to work, the guard interval should be greater than the channel delay spread. Thus, we see that the relative length of the cyclic extension depends on the ratio of the channel delay spread to the OFDM symbol duration [7].

B. Multiple-Input Multiple-Output System Model

We consider a MIMO wireless communication system employing *M* transmit and *N* receive antennas; hence, the corresponding MIMO wireless communication channel is constituted by (N* M) propagation links. Grouping all the transmitted and received signal into vectors, the system can be viewed as N*1 vector signal X are transmitted through an N*M matrix channel H, with M*1 noise vector V added at the input of the receiver. The received signal is

$$Y = HX + V$$

Where Y is received the $(Mm, Nn)^{th}$ element of H, $h_{Mm,Nn}$ is the complex channel response from the Nn^{th} Transmit Antenna to Mm^{th} Receive Antenna. If the Channel is frequency selective, then the entire channel frequency response $h_{Mm,Nn}$ is function of the frequency. Then Received signal is

$$Y(f) = H(f)\,X(f) + V(f)$$

In OFDM, entire Channel is divided into a number of sub-channels, which are spaced orthogonally to each other such that no ISI is present at the sub- carrier frequency subject to perfect sampling and carrier synchronization. When we sampled at the Sub-carrier frequency of f_{NC}, the channel model becomes

$Y_{NC} = H_{NC} X_{NC} + V_{NC}$ ....., $NC = - f_C /2, \ldots\ldots\ldots f_C /2 -1$.

Where f_C is number of sub carrier. If f_C is sufficiently large, the sub channel at each of this sub carrier considers flat fading. Using OFDM , the MIMO detection over frequency –selective channels is transformed into MIMO detection over f_C Narrowband flat – fading channels. Therefore we focus on MIMO detection algorithms in flat –fading channels. We assume that channel matrix H is to be known for receiver only.

Theoretical analysis predicts that substantial capacity gains are achievable in communication systems employing MIMO architectures. Specifically, if the fading processes corresponding to different transmit–receive antenna pairs may be assumed to be independently Rayleigh distributed. Additionally, the employment of MIMO architectures allows for efficient exploitation of the spatial diversity available in wireless MIMO environments, thus improving the system's BER, as well as further increasing the system's capacity. At the transmitter, a single bit stream is horizontally encoded (HE) and demultiplexed into *N* sub streams, and each sub stream is mapped to a sym by the same constellation *A* and sent to its respective transmit antenna. Since total transmit power *Es* is preserved irrespective of the number of transmit antennas, there is no increase in the amount of interference caused to the other users or sub streams.

C. V-BLAST TECHNIQUES

One of the earliest communication systems that were proposed to take advantage of the promising capacity of MIMO channels is the BLAST architecture. It achieves high spectral efficiencies by spatially multiplexing coded or uncoded symbols over the MIMO fading channel. Symbols are transmitted through N antennas. Each receiver antenna receives a superposition of faded symbols. Theoretically, ML detection would be optimal for V-BLAST detection.

However, it's too complex to implement. For example, in the case of 4 transmit antennas and 16-QAM modulation, a total of $16^4 = 65536$ comparisons would have to be made for each transmitted symbol. Therefore, V-BLAST performs a non-linear detection that extracts data streams by a ZF or MMSE filter w(k) with ordered successive interference cancellation (OSIC). Co Channel Interference traditional approaches require nulling vector being orthogonal to *N*-1 rows of H whereas OSIC requires nulling vector being orthogonal to *N-i* undetected components per iteration *i*, and

- *Zero-Forcing* (ZF) is the decorrelating receiver of H

w(k) = (H*H)-1H*

- *Minimum Mean-Square Error* (MMSE) is the maximum SNR receiver

$$w(k) = (H^* H + \sigma_n{}^2/\sigma_d{}^2)^{-1} H$$

In above esq. $\sigma_n{}^2 / \sigma_d{}^2$ denotes the inverse of signal-to-noise ration at each receive antenna Detection order depends on which subset of (*M-i*)rows w_{ki} should be constrained by, since each component of the signal uses the same constellation, the component with the smallest w_{ki} will dominate the error performance. At each symbol time, it first detects the "strongest" layer (in the sense of SNR and w = E_s/N_o at the receiver branch), then cancels the effect of this strongest layer from each of the received signals, and then proceeds to detect the "strongest" of the remaining layers, and so on. It is assumed that the receiver perfectly knows the channel matrix H, which can be accomplished by classical means of channel estimation, e.g. insertion of training bits in the transmitted TDMA frames.

In V-BLAST algorithm following notations are used:

H_{ij}, I = 1, 2, ….,N and j = 1, 2, …..,M

- H_j denotes the j column of Matrix H.
- H_{kj} denotes the matrix obtained by zeroing the k_1, k_2, k_i column of H.
- $G = H^+$ denotes the Moore-Penrose pseudo inverse of H.

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- $w_i^T = G_i$ denotes the i row of the matrix G.
- H′ denotes the new matrix obtained by permuting the channel matrix H according to a given permutation.
- $B'_k = (H'_M, H'_{M+1}, H'_{M-k+1})$ denotes the last k columns of H′ after permuted according to an inversing ordering.
- $y = (y_1, y_2, \ldots y_M)^T$ denotes the detected signal in receiver.
- $\hat{a} = (\hat{a}_1, \hat{a}_2, \ldots \hat{a}_M)^T$ denotes the detected signal after slicing operation in receiver.
- $(*)^T$ denotes the transpose operation of a matrix.
- $(*)^H$ denotes the conj-transpose operation of a matrix.
- $(*)^\dagger$ denotes the Moore-Penrose pseudo inverse operation of a matrix.
- Q(*) denotes quantizing operation.

A low-complexity sub-optimal algorithm for V-BLAST detection consists of four recursive steps describe as follows:

V-BLAST detection procedure is as follows

1) Ordering: Determine the optimal detection order corresponds to choosing w_{ki} the row of w (k) with minimum Euclidian norm. w (k) is referred to as nulling matrix and w_{ki} as nulling vector.

2) Nulling: Use the nulling vector w_{ki} to null out all the "weaker" signals and obtain the "strongest" (high SNR) transmitted signal

$$y_{ki} = w_{ki}^T r$$

3) Slicing: The estimated value of the strongest transmit signal is detected by slicing to the nearest value in the signal constellation A.

$$\hat{a}_{ki} = \arg \{\min ||a - y_{ki}||^2\}$$

4) Canceling: Since the strongest transmit signal has been detected (assume $\hat{a}_{ki}=a_{ki}$), its effect should be cancelled from the received signal vector to reduce the detection complexity for remaining transmit

$r = r - \hat{a}_{ki} h_{ki}$ (h_{ki} is the k -th column of H)

$H = H - h_{ki}$ (k -th column of H zeroed)

Iteration: i = i + 1, and return to step 1 (i = 1,2, … M-1).

We let the ordered set S= {k_1, k2,…k_{NT}} be a detection order of sub-streams. According to the basic SIC algorithm, the ZF V-BLAST detection algorithm can be described as a recursive procedure, including determination of the optimal ordering.

Initialization

1. $i \leftarrow 1$
2. $r1 = r$
3. $G1 = H^+$
4. $K1 = \arg\min_j \left\|\left(G1\right)_j\right\|^2$

Recursion

1. $wk1 = \left(G_i\right)_{ki}$
2. $y_{ki} = w_{ki}^T ri$
3. $\hat{a}_{ki} = Q\left(y_{ki}\right)$
4. $r_{i+1} = r_i - \hat{a}_{ki}(H)_{ki}$
5. $G_{i+1} = H_{ki}^{\pm}$
6. $K_{i+1} = \arg\min_{j \notin \{k_1, \ldots k_i\}} \left\|\left(G_{i+1}\right)_j\right\|^2$
7. $i \leftarrow i+1$

Please note that in recursion step 3 (and 6) $\arg\min_j \left\|\left(G_i\right)_j\right\|$ is used to pick the strongest symbol.

The algorithm spends most of its time in steps (5) and (6) where the nulling vectors and optimal ordering are computed, and both of the steps involve the computation of matrix pseudo inverse. The complexity of the nulling vector and optimal ordering computation grows as a fourth power of the number of antennas, as there are recursion steps for finding out pseudo inverse oh channel matrix.

III. SYSTEM MODEL

The system works in an indoor environment. The proposed system is a single-TDMA stream scheme capable to handle rates ranging adaptively from 64 kbps to 100 Mbps after variable-rate adaptive modulation is implemented, according to the sub-carrier SNR and target BER.

The MIMO OFDM V-BLAST system operates in the 17 GHz unlicensed frequency band with an available bandwidth of 200 MHz (17.1–17.3 GHz) that is divided into four 50 MHz-width channels not simultaneously selectable. OFDM with $L = 128$ sub-carriers (frequency sub channels) is designed for each of these 50 MHz wide channels. The indoor coverage ranges from 5 m for non line-of-sight to 20 m for line-of sight (LOS).

The indoor environment is the ideal rich-scattering environment necessary by the V-BLAST processing to get CCI cancellation at the receiver. V-BLAST algorithm with OSIC processing implements a non-linear detection technique based on Zero MMSE filtering combined with symbol cancellation to improve the performance. Because it takes the background noise into account ,the MMSE detector generally provides a better probability of error performance than Zero forcing Algorithm. The idea is to look at the signals from all the receive antennas simultaneously, first extracting the strongest sub-stream from the received signals, then proceeding with the remaining weaker signals, which are easier to recover once the strongest signals have been removed as a source of interference. Transmit space diversity techniques and V-BLAST receiver requires flat fading channel. The OFDM approach makes this assumption, for each frequency sub channel, reasonable.

A. Transmitter

In figure I the transmitter have an array of 4-antennas and perform a MIMO vertical encoding (VE). At transmitter encode the bit stream from the information source. Then according to the type of modulation technique, coded bits are mapped to some symbols.

The symbol frame is passed through a one to four demultiplexer (1:4) ,which maps symbols on the *4* space channels(sub-streams of the original frame). Each symbol sub-stream is then put through a serial-to-parallel (S/P) converter which produces 512 parallel output symbols corresponding to the OFDM sub-band channels. These channels modulated by different sub carriers. These symbols are put through the IFFT and 512 parallel output symbols convert into serial sub-stream and then transmitted by the antenna n ($n = 1, 2, \dots, 4$).

Because each input to IFFT corresponds to a OFDM sub-carrier, at the output we get a time-domain OFDM symbol that corresponds to the input symbols in the frequency domain.

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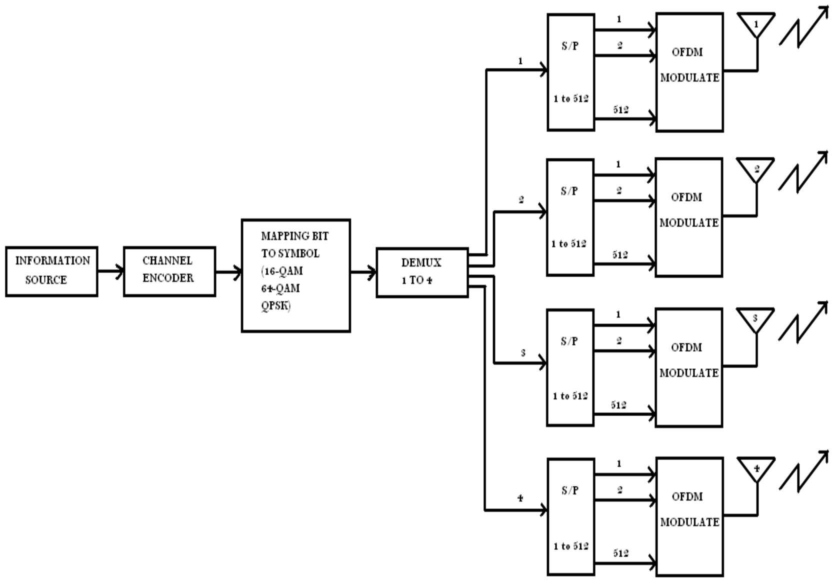

figure I MIMO OFDM V-BLAST Transmitter architecture

B. Receiver

Once we received the signal after the channel, first remove the cyclic extension. Then obtain the 512 parallel output symbols corresponding to the OFDM sub-band channels through s/p converter. The FFT is taken in each of the eight(M) receive antennas (V-BLAST requires $M \geq N$). Each antenna *m* receives a different noisy superimposition of the faded versions of the *4* transmitted signals (Figure II). If the transmit and receive antennas are sufficiently spatially separated (at 17 GHz it is about 0.9 cm) and there is a sufficiently rich scattering propagation environment, the transmitted signals arriving at different receive antennas undergo uncorrelated fading. Moreover, if the channel state is perfectly known at the receiver, V-BLAST receiver is able to detect the *N* transmitted sub-streams. The output of the OFDM demodulator, at the receive antenna *m*, is a set of *L(512)* signals, one for each frequency sub-channel. This sub-system is able to detect the *N* different space channels once flat fading is assumed (true because OFDM). This processing is repeated for each of the *L* sub-bands. The output of the *L* different VBLAST signal processors is passed through a parallel-to-serial converter (with a multiplexer N: 1 is included) and the symbols are demapped and decoded to destination [1].

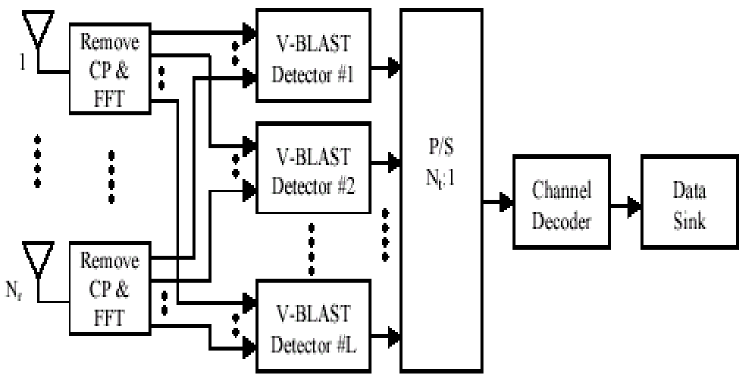

Figure: II OFDM MIMO V-BLAST Receiver model

IV. SIMULATION

Implementation of OFDM based MIMO system is performed in MATLAB7.0 Program on Intel Core 2 duo Processor , 3.2GHz CPU, 3.2GBDDR RAM, 120GB Hard Disk, for different number of users and digital modulation techniques such as QPSK,16-QAM and 64-QAM The conditions under which this OFDM MIMO V-BLAST model is presented in table I.

Table I

FFT and IFFT size	512 – point
Number of Sub Carriers	360
Number of pilot sub carrier	60
Number of Guard band sub carrier	92
Channel BW	20 MHz
Sub carrier frequency spacing (KHz)	39.06
Useful Symbol Time (us)	25.6
Guard time (us) (12%)	3.07
OFDM Symbol Duration (us)	28.6
Channel used	Rayleigh
Transmit antennas	4
Receive antennas	8
Bit Rate	20Mbps
SNR Range	0 to 30 Db

The simulation is of limited complexity. Interleaving and OFDM cyclic extension are not considered in this Simulation (the latter because no delay spread between transmitter and receiver is assumed). The incoming bit stream is first encoded with conventional Hamming (nh,k) with k =3 and nh = 2k-1. Mb-QAM gray-coded (to minimize the effect on bit error should a symbol error occur) constellation for bit to symbol mapping is implemented. Depending on Mb, many different constellations are possible, however for the purposes of this simulation only square constellations are considered and furthermore only constellations of size Mb = 4 and 16 were simulated. The block time is defined as nh*log2(Mb) = 7*4 = 28 bit periods for 16-QAM. The output of the QAM modulator is then blocked further into a block of L=128 complex numbers, which represent the different sub carriers to be transmitted. These are put through an IFFT. The outputs of one symbol constitute an OFDM symbol. Other parameters considered in the analysis and simulation of the MIMO OFDM V-BLAST was:

- Total radiated power Es independent of N (Es/N by each transmitter)
- Flat channel frequency response (delay spread is negligible) in each OFDM sub carrier
- Slow changing channel (quasi-static during block time)
- Complex path gains hi,j is uncorrelated. Correlation in hij is also evaluated
- Rich scattering and adequate antenna spacing
- Receiver perfectly knows the channel matrix **H**
- No feedback for estimation of parameters in transmitter isrequired
- Path delays for all spatial channels are the same and perfect symbol timing synchronization (for sampling) is assumed at the receiver.
- Same multipath-averaged SNR (Es/ No) at any receiver branch for a given location
- MMSE filtering is evaluated with V-BLAST detection.
- Comparing results for different number of users.

V. PERFORMANCE ANALYSIS

A MIMO OFDM architecture that significantly increases the
Achievable bit rate of the system as well as decreases the Co Channel Interference has been studied and analyzed. Simulation results are shown the effectiveness of the considered System.

We analyzed SNR performance of QPSK, 16 QAM and 64 QAM based on OFDM- MIMO systems with arrays of 4*8 number of transmitter *receiver antenna for different users with same transmitted power. SNR Performance is showed in Figure III, IV and V for 2user, 4 user and 8 user respectively. As can be seen, increasing number of user, bit error rate goes down and increase performance. Another interesting note is the fact that for 16-QAM, the BER does not seem to go down very far compare to QPSK, despite a high SNR. This is because for higher order QAM systems,

there must be some channel inversion at the receiver to allow for proper decoding. This unfortunately amplifies the noise as well as the signal.

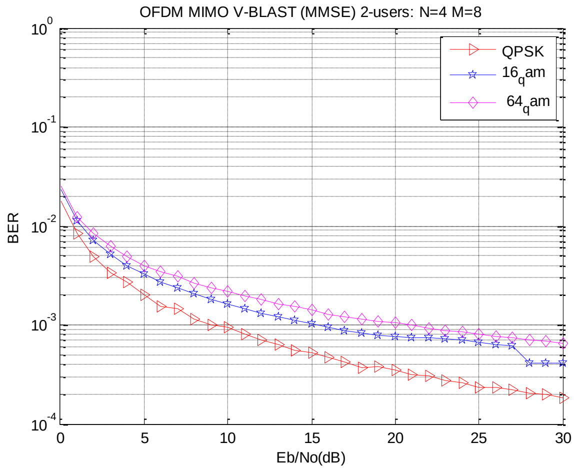

Figure III System Performance Comparison for Various Digital Modulation Techniques for 2 users.

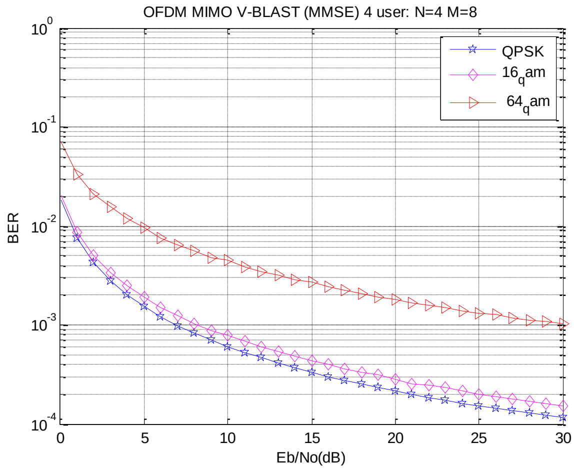

Figure IV System Performance Comparison for Various Digital Modulation Techniques for four users.

As can be seen , for QPSK bit error rate is nearly achieved 10^{-2} at 25 dB SNR. After that if we increase transmitter power , no effective improvement on bit error rate. For 16 QAM, increasing transmitted power up to 20dB SNR is reduce bit error rate, then no significant improvement on error rate. Figure VI. Shown Profile Plot Rayleigh Channel and for two user. All simulation results are shown for two users.

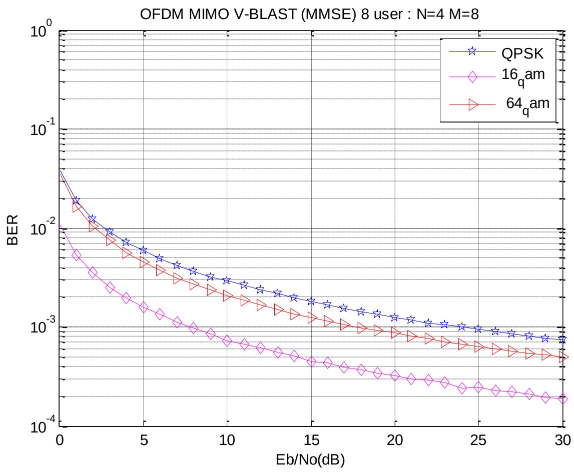

Figure V System Performance Comparison for Various Digital Modulation Techniques for eight users

Function name	Calls	**Total Time**	Self Time*	Total Time Plot (dark band = self time)
channel.rayleigh (Opaque-function)	1560	1099.016s	function is recursive	
channel.multipath.filter	320	1097.21 s	function is recursive	
channel.multipath.filterblock	680	1071.734 s	8.469 s	
channel.channelfilter.filter	680	975.484 s	975.359 s	
channel.interpfilter.filter	680	86.625 s	0.109 s	
...l.interpfilter.filter>polyphaseFilter	680	86.484 s	73.109 s	
...el.multipath.filter>ComputeStatistics	320	15.297 s	2.938 s	

Figure VI. Profile Plot of Rayleigh Channel and for two user.

VI. CONCLUSION

In this paper, we have compare three digital modulation techniques for multiple- antenna systems in frequency-flat, correlated, Rayleighfading channels. The analytical methodology we propose is general and can be used for arbitrary correlation on one side (transmitter or receiver).

For high data rates, the combination of OFDM and BLAST offers a robust approach that cannot be achieved with traditional wireless technologies. QPSK based system is having better BER performance compared to 16 - QAM and 64 - QAM system for lower data rates. But since, QPSK system transmits less information than 16 - QAM and 64 - QAM, it is should not be preferred as choice with V - BLAST MIMO OFDM. For 2 users there is best improvement in BER in QPSK MMSE compared to 16 QAM in the range 20dB to 30dB.

Further research would describe the effect –under different array configurations and propagation conditions- of MMSE filtering in V-BLAST processing, Trellis encoding and Viterbi decoding, and variable-rate adaptive modulation schemes in the MIMO OFDM V-BLAST analyzed in this study.

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