New Adaptive Cooperative-MIMO for LTE

Sukhreet Kaur, Dr. Amita Soni

Punjab Engineering College, Chandigarh, India

Abstract-- Multiple Input Multiple Output (MIMO) systems have been widely used in an area of wireless cellular communication system, providing the both increased capacity and reliability. However, the use of multiple antennas in mobile terminals may not be very practical due to limited space and other implementation issues. In this paper, cooperative MIMO has been used in a way to optimise the implementation and working of conventional MIMO systems in terms of BER and Spectral Efficiency while maintaining a minimal number of antennas on each handset. Cooperative MIMO with V-BLAST transmission over Rayleigh flat fading channels and amplify and forward protocol with one relay node for modulation techniques like BPSK, QPSK, QAM using various decoding techniques has been analysed. Decoding algorithms like ZF, MMSE and ML have been analysed with respect to their BER performances. Since, there is throughput loss in cooperative MIMO due to extra resources required for relaying, adaptive modulation has been used with C-MIMO to meet the demands for high data rates in Long Term Evolution Network.

Keywords-- *Amplify and Forward (AF), MRC (Maximal Ratio Combining), V-BLAST (Vertical Bell Laboratories Layered Space-Time), Zero Forcing (ZF), Minimum Mean Square Error (MMSE), Maximum Likelihood (ML), BER, Spectral Efficiency (SE), BPSK, QPSK*

I. INTRODUCTION

MIMO System has emerged as one of the powerful technique in the field of wireless communication improving reliability to a great extent. However, the antennas on a MIMO device should have sufficient spacing for uncorrelated fading. If the spacing between antennas reduces, independent fading cannot be achieved for each pair of antennas and the efficiency of MIMO will be degraded. Moreover, real-time implementation of multiple antennas in a small device like mobile is very unreal and cost ineffective because of extra RF hardware.

To overcome the problems faced in MIMO Systems, a new cooperative MIMO is a practical solution which allows a source node to communicate with destination node with the help of wireless relays which are capable of achieving spatial diversity in a distributed manner.
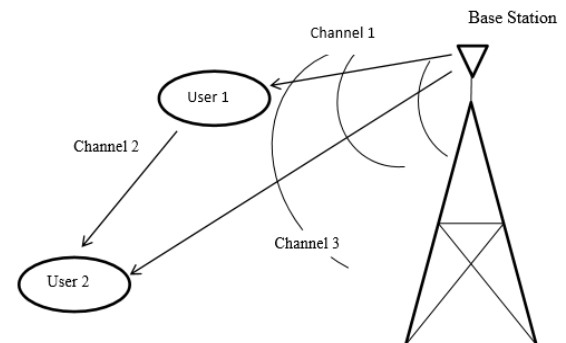

Figure 1: Cooperative Communication

In Figure 1, it is shown that two mobile users are communicating with base station. Because of the inherent broadcast nature of wireless devices at base station, it is quite possible that one user may receive the information intended to receive by another user and so it can help forward some version of received information to the intended user. Since fading channels are statistically independent to both the users, so receive diversity is generated.

Because of this diversity, the negative effects of shadowing and small-scale fading can be reduced as well error probabilities are also decreased. However, one main challenge in cooperative MIMO is throughput loss due to extra resources required for relaying. So, in order to nullify this effect, adaptive modulation is used.

This paper analyses the BER and Spectral Efficiency of the cooperative MIMO system aided by adaptive modulation scheme over the Rayleigh fading channel under perfect CSI.

II. RELATED WORK

Many researches have been done focussing on Adaptive modulation in Cooperative MIMO finding a way to improve spectral efficiency. In [9], a new joint adaptive modulation and MIMO transmission algorithm has been studied under imperfect CSI. In [10], various AM schemes have been studied in MIMO-OSTBC to analyse the performance of Variable-power Adaptive Modulation with imperfect CSI. In [11], adaptive modulation for OFDM system over frequency selective fast fading channel was studied. The performance analysis of adaptive modulation in MIMO system-based Imperfect CSI showed that significant gains can be achieved with rate adaptation even with imperfect CSI in [12]. A novel hybrid Cooperative AMC mechanism is suggested by authors in [14] for improving hybrid link quality. Therefore, adapting constellation size of transmitted signal to changing channel conditions can track the wireless channel properties and thus sending more bits in good channel state and less bits in poor channel state can help increasing spectral efficiency.

III. COOPERATIVE TRANSMISSION PROTOCOLS

Few common relaying protocols are:

1. Amplify and Forward - In AF, received signal is scaled at relay node and transmitted to end user node after amplification.

2. Decode and Forward - In DF, the received signal is first decoded and then re-encoded. So, there is no amplified noise in received signal at end node.

3. Compress and Forward - In CF, a signal is quantized and compressed by relay and then forwarded to user node.

IV. DETECTION TECHNIQUES FOR MIMO SYSTEM

Objective of the detection - to differentiate the transmitted signals on the basis of observation of the received signal vector and the channel matrix.

1. Zero-Forcing: ZF nullifies the interference by WZF matrix, which is the pseudo inverse of channel matrix H i.e. $W_{ZF} = (H^TH)^{-1}H^T$.

2. Minimum Mean Square Error (MMSE): This performs better than the ZF under noisy conditions. It is not able to discard ISI like ZF but however, it reduces the total noise power received at the receiver side. The MMSE filter is calculated by minimizing the mean-square error (MSE) as: $W_{MMSE} = (H^TH + \sigma^2 I_N)^{-1}H^T$ where σ is Ratio of received signal power to noise power and IN is Identity matrix.

3. Maximum Likelihood (ML): The decision is taken according to the minimum Euclidean distance between the received signal vector and the product of all possible transmitted signal vectors with channel H, and one with the least distance is found.

V. COMBINING TECHNIQUES

Incoming signals with same information have to be combined if more than one in number. Some of these combining techniques are:

Maximum Ratio Combining (MRC), Equal Gain Combiner, Fixed Ratio Combining, Signal to Noise Ratio Combining, Estimated SNR Combining In this paper, MRC scheme is used. In MRC, each radio channel is weighted with the complex conjugate of the respective channel gain assuming that channels' phase shift and attenuation is perfectly known at the receiver.

VI. COOPERATIVE MIMO OVER RAYLEIGH FADING CHANNEL SIMULATION MODEL
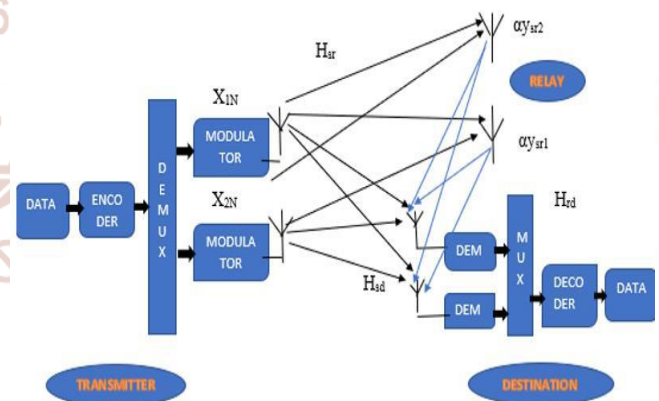

Figure 2: System Model of Cooperative MIMO

To evaluate the performance of Cooperative MIMO, all nodes are placed at equal distance with Ns=Nr=Nd=2 as shown in Fig 2 where Ns, Nr, Nd are number of antennas at source, relay and destination respectively such that Nd ≥Ns=Nr in order to separate and detect the x transmitted signals. Thus, a block fading half-duplex channel model with N fading blocks is assumed here, with L symbol periods in each

block. On each block, Fading is assumed to be flat and constant but independently Rayleigh distributed on different blocks. Further, Average power is fixed per user due to uniform energy distribution with an assumption of perfect CSI available at the receiver side only.

There are two phases in which communication occurs. In phase one, the signal transmitted by source undergoes fading and is sent to relay. In phase two, depending upon the relay protocol, transceiver complexity, relative channel conditions and also user location, relay cooperate with the destination node. In this paper, Amplify and Forward protocol with variable relay gain is considered.

The equivalent cooperative MIMO NdNr x Ns (4x2) with NdNr (2) virtual receiving antennas representation for the proposed MIMO system using relays is given as:

$$\begin{bmatrix} y_{d,1nl} \\ y_{d,2nl} \end{bmatrix} = \underbrace{\begin{bmatrix} \sqrt{E_s} H_{sdnl} \\ \frac{E_s}{4} H_{rdnl} \propto_{nl} H_{srnl} \end{bmatrix}}_{H_{eqnl}} x_{nl} +$$

$$\begin{bmatrix} I_{N_s N_r} & 0 & 0 \\ 0 & \sqrt{\frac{E_s}{2}} H_{rdnl} \propto_{nl} & I_{N_s N_r} \end{bmatrix} \begin{bmatrix} n_{sdnl} \\ n_{srnl} \\ n_{rdnl} \end{bmatrix} \quad (1)$$

Where yd,1 nl and yd,2 nl are the received signals at the user end during the phase one and phase two respectively, Es is the average power per antenna of each symbol at the source. Hsrnl and Hsdnl denotes the nth block fading channel matrix of source-relay and source-destination link respectively. The vectors nsrnl and nsdnl are the noise due to source transmit the signal to relay and destination respectively. Index notation (nl) is used to emphasize more on the block fading nature of channel. ∝nl is a gain factor of variable gain relay. The transmit signal from relay is:

xrnl = αnlyrnl (2)

Therefore, the equivalent channel matrix for relayed link is:

Heqrsdnl = Fnl = HrdnlHsrnl (3)

While equivalent noise at receiver side is:

neqrsdnl = Hrdnl αnl nsrnl + nrdnl (4)

After these two phases of cooperative transmission, the signals received at destination will be combined using one of the combining techniques discussed above and as the two networks source-destination and source-relay-destination links are different, so

independent combining is done and then estimated values are summed up to get the final results.

VII. COOPERATION BASED ON V-BLAST TRANSMISSION

Cooperative VBLAST transmission achieves high spectral efficiency by spatially multiplexing the coded or uncoded symbols transmitted by source in first phase over the fading channel. The received symbols are modified by relay and forwarded to destination in second phase. Using MRC technique, the total receive signal at the destination is given as follows:

ynl = HHsdnl yd,1 nl + HeqrsdnlH yd,2 nl (5)

In order to detect the transmitted signal x, put y in ZF, MMSE and ML detection scheme as y is in y = Hx + n form.

VIII. ADAPTIVE MODULATION IN COOPERATIVE MIMO

The basic purpose of adaptive modulation is to apply the modulation based on CSI (Channel State Information) available. When the channel is in good state, higher order modulation scheme is used, otherwise lower order scheme is preferred. The various parameters that can used to indicate the CSI are SNR (Signal to Noise Ratio), SINR (Signal to Noise Ratio plus Interference), PERs (Packet Error Rates) or BER (Bit error Rate). In this paper, the post detection of SNR at the output of ZF, MMSE and ML detectors is used as a metric for CSI as it directly measures the performance of communication system. This post SNR will correspond to BER information for each mode candidate and then threshold SNR is selected depending on the mode that yields the highest throughput remaining with BER constraints.

Since exact post SNR detection is impossible, it can be estimated by sending pilot sequence through the channel to have the knowledge of current CSI. In this paper, it is assumed that CSI is known at receiver terminal.

Adaptation based SNR in assisted cooperative AF MIMO with VBLAST transmission

In order to select the suitable modulation scheme based on the specified BER target, threshold SNR has to be determined at the output of ZF, MMSE and ML detectors for which it yields maximum throughput. For that, post SNR equations has to be derived at the output of these given detectors considering all direct and non-direct links with V-BLAST transmission at receiver only. In addition, the data streams are sent

independently to the relay and destination nodes and then collaboratively processed at destination to recover the original signal.

The equivalent channel matrices for direct and relayed links are given by Hsdnl and Fnl. For MRC technique the receive signal is: ynl = $(\Sigma\sqrt{Es}$ Nr i=1 (|hi1 dsnl |2 + |hi2 dsnl |2) + Es 4 $\propto$nl (|fi1 nl |2 + |fi2 nl |2) xnl + $\tilde{n}$nl (6)

Where $Fnl = HrdnlHsrnl$ and $\tilde{n}$nl is the equivalent noise channel evaluated at the output of MRC that is

$\tilde{n}$nl = FH nl (Hrdαnl nsrnl + nrdnl) + HH sdnl (7)

In matrix form (6) can be written as:

$$\begin{bmatrix} y_{1nl} \\ y_{2nl} \end{bmatrix} = \sqrt{E} \underbrace{\begin{bmatrix} u_{11nl} & 0 \\ 0 & u_{22nl} \end{bmatrix}}_{H_{nl}} \begin{bmatrix} x_{1nl} \\ x_{2nl} \end{bmatrix} + \begin{bmatrix} \tilde{n}_{11nl} \\ \tilde{n}_{21nl} \end{bmatrix} \quad (8)$$

u11nl = $\sqrt{E}$(|h11 dsnl|2 + |h21 dsnl|2) + Es 4 αnl (|f11 nl|2 + |f21 nl|2)

u22 nl = $\sqrt{Es}$(|h12 dsnl|2 + |h22 dsnl|2) + Es 4 αnl (|f12 nl|2 + |f22nl|2)

The covariance matrix of the equivalent noise $\tilde{n}$ (noise power) is

$$E\{\tilde{n}nl\tilde{n}nlH\} =$$
$$N_o \begin{pmatrix} \sum_{i=1}^{Nr}|f_{i1\,nl}|^2 \, |f_{i2\,nl}|^2 \left(1+\propto^2_{nl} \sum_{k=1}^{Nr}|h_{ik\,drnl}|^2 \right) \\ \sum_{i=1}^{Nr}|h_{i1\,dsnl}|^2 - |h_{i2\,dsnl}|^2 \end{pmatrix} \quad (9)$$

Where E{.}the expectation of {.}.

A. Zero Forcing detection

The received signal in Eq. 8 can be seen as the sum of the required signal xnl along with the noise. Extract $\hat{x}$nl out of the received signal by estimate the values that minimize the least square of ynl – Hnl$\hat{x}$nl and ynl - Gnl$\hat{x}$nl.

$$\mu_{MRCnl} = ||y_{nl} - H_{nl}\hat{x}_{nl}||^2 \quad (10)$$

This is solved by multiplying by a pseudo inverse matrix:

$$W_{MRCzfnl} = (H^H_{nl}H_{nl})^{-1}H^H_{nl} \quad (11)$$

$$\begin{bmatrix} \hat{x}_{1nl} \\ \hat{x}_{2nl} \end{bmatrix} = \begin{bmatrix} x_{1nl} \\ x_{2nl} \end{bmatrix} + (H^H_{nl}H_{nl})^{-1}H^H_{nl}\begin{bmatrix} \tilde{n}_{11nl} \\ \tilde{n}_{21nl} \end{bmatrix} \quad (12)$$

The post SNR detection j^{th} receive antenna at the output of ZF detector obtained from Eq. 12 given by: $\gamma_{j,nl} =$

$$\frac{E_s}{N_o\|W_{i,MRCzfnl}\|^2_F \left(\|F_{i,nl}\|^2_F + \propto^2_{nl}\|F_{i,nl}\|^2_F\|H_{i,rdnl}\|^2_F + \|H_{i,sdnl}\|^2_F \right)} \quad (13)$$

B. MMSE detection

In this scheme, the transmitted signal xnl can be evaluated by minimizing the mean square error. MMSE detection matrix is given as

$$W_{MRCmmse\,nl} = (H^H_{nl}H_{nl} + N_0I_{N_s})^{-1}H^H_{nl} \quad (14)$$

Multiplying Eq. 8 by Eq. 14, the estimate signal is

$$\begin{bmatrix} y_{1nl} \\ y_{2nl} \end{bmatrix} = W_{MRCmmse\,nl} \underbrace{\begin{bmatrix} u_{11nl} & 0 \\ 0 & u_{22nl} \end{bmatrix}}_{H_{nl}} \begin{bmatrix} x_{1nl} \\ x_{2nl} \end{bmatrix} +$$
$$W_{MRCmmse\,nl} \begin{bmatrix} \tilde{n}_{11nl} \\ \tilde{n}_{21nl} \end{bmatrix} \quad (15)$$

From Eq. 15, the post SNR detection for MMSE detection is given by:

$$\gamma_{i,nl} =$$
$$\frac{|W_{MRCmmse\,nl}|^2 \left(\frac{E_s(|h_{i1\,dsnl}|^2 + |h_{i2\,dsnl}|^2) +}{\frac{E_s}{4}\propto_{nl}|f_{i1\,nl}|^2 + |f_{i2\,nl}|^2)} \right)^2}{N_o\|W_{i,MRCmmse\,nl}\|^2_F \left(\|F_{i,nl}\|^2_F + \propto^2_{nl}\|H_{i,rdnl}\|^2_F + \|H_{i,sdnl}\|^2_F \right)} \quad (16)$$

C. ML detection

In Maximum likelihood (ML), distance between the received signal vector in (8) and the product of all possible transmitted signal vectors with the given channel Hnl, Gnl, gives us the value of Euclidian distance and xnl with the min. distance metrics is chosen.

$$d^2(y_{1nl}, u_{11nl}\, x_{1nl}) + d^2(y_{2nl}, u_{22nl}\, x_{1nl}) \quad (17)$$

The estimated value of the transmitted signal vector x by ML detection is given as:

$$\hat{x}_{nl} = \underset{\{\hat{x}_{1nl}, \hat{x}_{2nl}\}}{argmin} \|y_{nl} - H_{nl}x_{nl}\|^2 \quad (18)$$

Where C is set of signal constellation symbol point possible value of $\{\hat{x}_{1nl}, \hat{x}_{2nl}\}$.

The post detection SNR $\gamma_{j,nl}$ MRC of the receive signal at the output of ML respectively from Eq. 19 given by

$$\gamma_{i,nl} = \frac{\left(\begin{array}{c} E_s\left(|h_{i1\,dsnl}|^2 + |h_{i2\,dsnl}|^2\right) + \\ \frac{E_s}{4}\alpha_{nl}\left(|f_{i1\,nl}|^2 + |f_{i2\,nl}|^2\right) \end{array} \right)^2}{N_0\left(\begin{array}{c} \left(|f_{i1\,nl}| + |f_{i2\,nl}|^2\right)\left(1 + \alpha^2_{nl}\sum_{k=1}^{N_r}|h_{ik\,drnl}|^2\right) + \\ |h_{i1\,dsnl}|^2 + |h_{i2\,dsnl}|^2 \end{array} \right)} \quad (19)$$

The threshold for adaptive modulation has been derived above for ZF, MMSE and ML detectors by determining post SNR as a function of Channel State Information.

IX. SIMULATION RESULTS

Simulation of adaptive modulation based cooperative MIMO is done in Matlab environment with all the parameters set according to LTE standard. For all simulations, classical relay model is considered and equal power is given to each node with independent identically distributed (i.i.d) Rayleigh fading channel matrix elements. Cooperative and Non- Cooperative transmissions are compared in terms of BER and Spectral Efficiency.

Table 1: Simulation Parameter

| Parameter	Type / Value
Channel	Rayleigh flat fading
Transmit, receive and relay antennas number	2,2 and 2 respectively
Transmit power	normalized at all nodes
Modulation Scheme	BPSK, QPSK,16 QAM and 64 QAM
Combining techniques	MRC
Detectors	ZF, MMSE and ML
MIMO scheme	Spatial multiplexing with V-BLAST
Relay protocol	AF protocol
Threshold BER or BERth	$BER_{th} \leq 10^{-2}$
Performance Metrics	BER and SE

Performance of 2×2 V-BLAST scheme with MRC
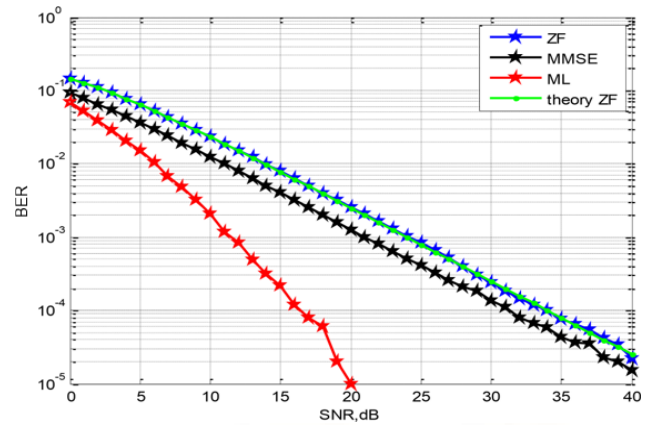
Figure 3: BER performance of 2×2 V-BLAST MIMO using BPSK modulation for different detection scheme

In Figure 3, it is seen that for a fixed BER of 10-3, SNR required for ZF, MMSE and ML detection is approximately 24.5, 21.5 dB and 11.5 dB respectively. ZF and MMSE detectors showed almost same performance but ML has a better performance than these.

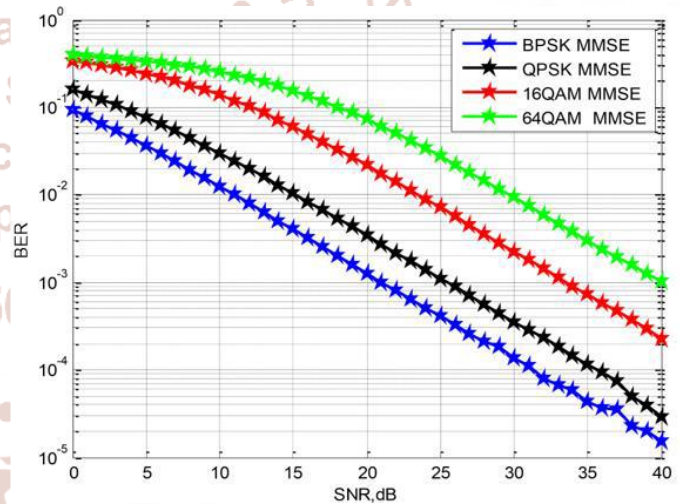*2×2 V-BLAST scheme (MRC) for MMSE detection*

Figure 4: BER performance of 2×2 V-BLAST MIMO system using MMSE detection for different modulation

In Figure 4, it can be seen that a change in constellation size affects the BER performance a lot. A change in M=6 to M=2 indicates performance betterment close to 8.5 dB at a BER = 10-3 in MIMO VBLAST using MMSE detection.
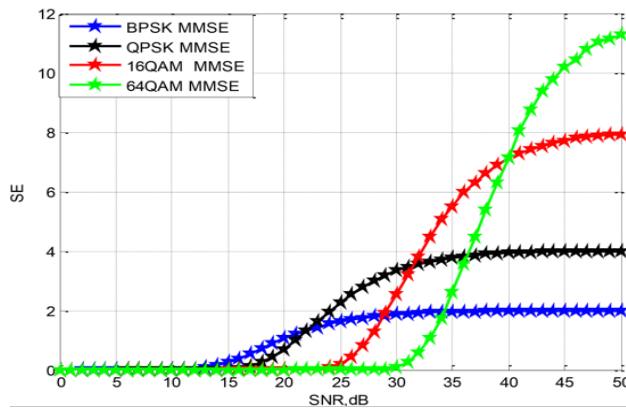
Figure 5: Spectral efficiency of 2×2 V-BLAST MIMO using MMSE detection for different modulation.

In Figure 5, Throughput curves are obtained for MMSE detection for different modulation techniques. Also, switching criterion is obtained corresponding to given modulation types for already set value of BER assuming it to be 10^{-2} so that realistic BER $\leq 10^{-2}$.
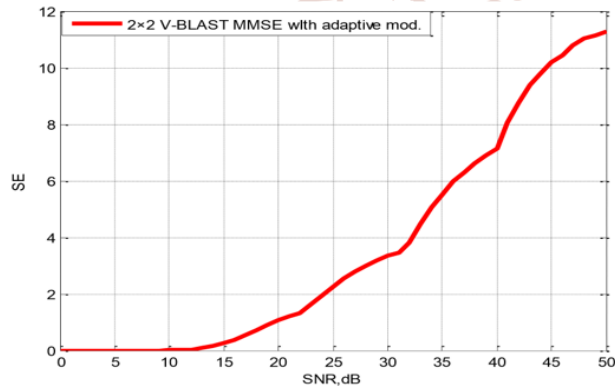

Figure 6: Spectral efficiency of adaptive modulation 2×2 V-BLAST MIMO using MMSE detection

In Figure 6, the simulation results of the adaptive modulation in 2×2 V-BLAST MIMO system for MMSE detection are presented. For different SNR ranges, we can select most suitable modulation type as given in the following Table 2 making the system adaptive.

Table 2: Probability of choosing different modulation type for MMSE detection

SNR, dB, For BER$\leq 10^{-2}$	Modulation Type
< 11	No transmission
[11,22]	BPSK
[22,32]	QPSK
[32,40]	16 QAM
> 40	64 QAM

Performance of 2×2 V-BLAST scheme with MRC for ML detection

Figure 7 and Figure 8 shows BER performance and throughput curves for 2 X 2 VBLAST MIMO system.
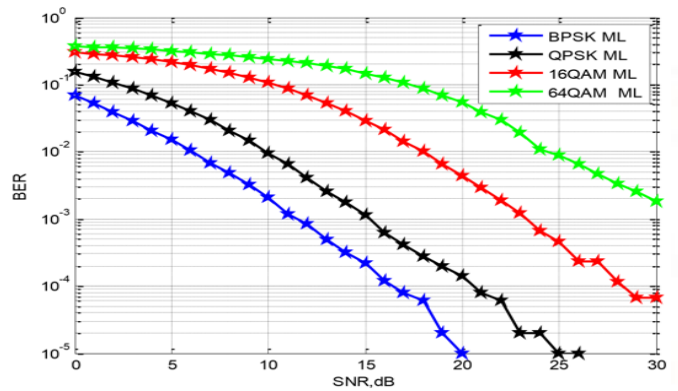

Figure 7: BER performance of 2×2 V-BLAST MIMO system using ML detection for different modulation

In Figure 7, for BER of 10^{-2}, ML detection improves performance of MMSE by 10dB using QPSK.

From Figures 6 and 8, adaptive modulation MIMO system for MMSE and ML respectively, it can be seen that at SNR of 20 dB the ML has throughput improvement of 26.3% over MMSE detection. The MMSE detection technique has to gain 12 dB to get the same throughput
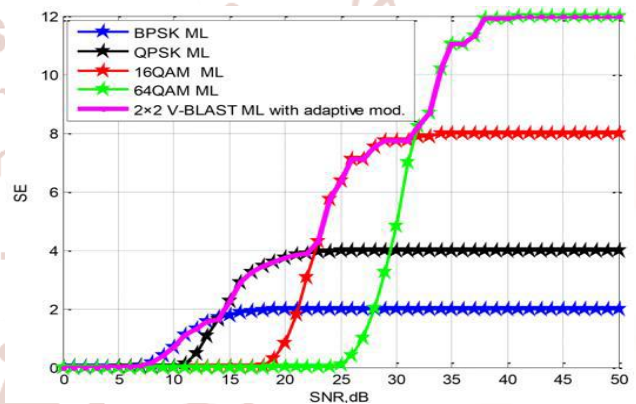

Figure 8: Spectral efficiency of adaptive modulation 2×2 V-BLAST MIMO using ML detection

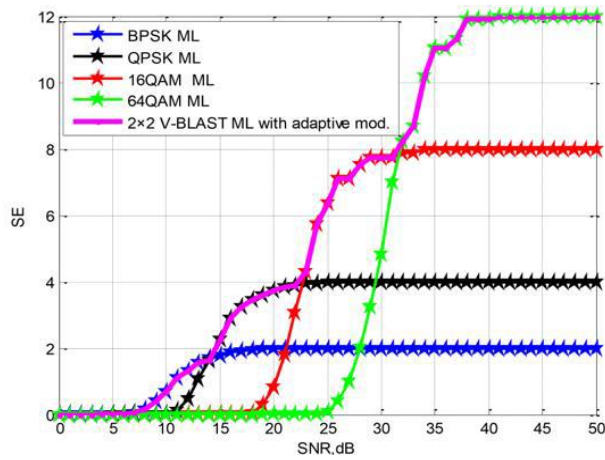***Performance of V-BLAST scheme with MRC (Cooperative)***

Figure 9: BER performance of cooperative diversity, 2×2 V-BLAST MIMO, and SISO with BPSK modulation.

Figure 9 shows BER performance of cooperative, 2X2 VBLAST MIMO, SISO with BPSK. It can be seen that simulated results for cooperative diversity are in accordance with the theoretically derived values. At BER of 10^{-3}, increasing the no. of antennas from single to two gains 6 dB over SISO. Also, on adding one AF relay node in between gains 7 dB gain over non-cooperative VBLAST MIMO system at same BER. Simulated results came out from diversity of direct link and assistance link of relay.

Performance of Cooperative 2×2 V-BLAST scheme with MRC for MMSE detection
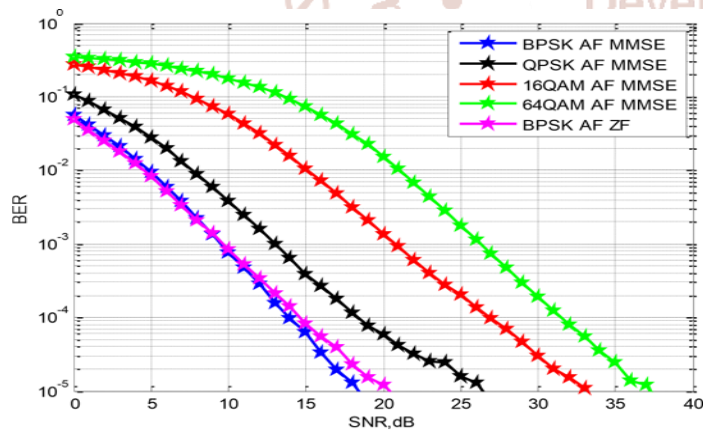

Figure 10: BER Performance of Cooperative 2×2 V-BLAST MIMO system using MMSE and ZF detections for different modulation schemes

Figure 10 shows BER performance of AF 2X2 VBLAST MIMO for MMSE and ZF detections. It can be seen that ZF and MMSE have almost performance in the SNR ≤ 18 dB range for BPSK modulation.
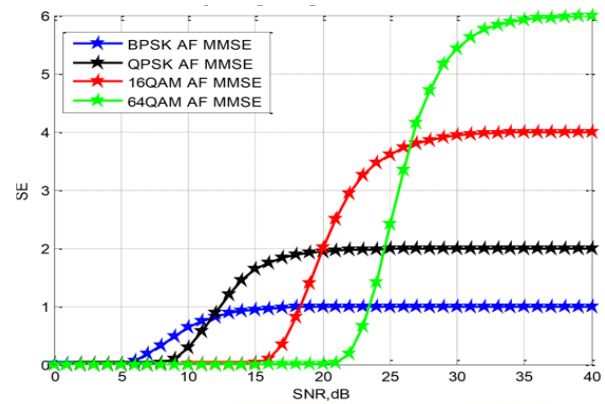

Figure 11: Throughput performance Cooperative 2×2 V-BLAST system using MMSE detection for different modulation

Figure 11 indicates the performance of cooperative VBLAST MIMO for MMSE detection. It is clearly visible that SE saturates to half as compared to non-cooperative results but this is due to half duplex transmission used. From Figure 5, a spectral efficiency of 3 bit/sec can be achieved with a SNR of about 31 dB with 16 QAM; for the same modulation this value is reduced to about 22 dB if Cooperative 2×2 V-BLAST MIMO with MMSE scheme is used as shows in Figure 11.

SNR Threshold values are obtained in Table 3 for Cooperative V-BLAST MIMO for MMSE detection scheme.

Table 3: SNR switching criterion of AF 2×2 V-BLAST MIMO system using MMSE detection

SNR, dB (for $BER_{th} \leq 10^{-2}$)	Modulation Type
< 5	No transmission
[5,12]	BPSK
[12,20]	QPSK
[20,27]	16 QAM
> 27	64 QAM

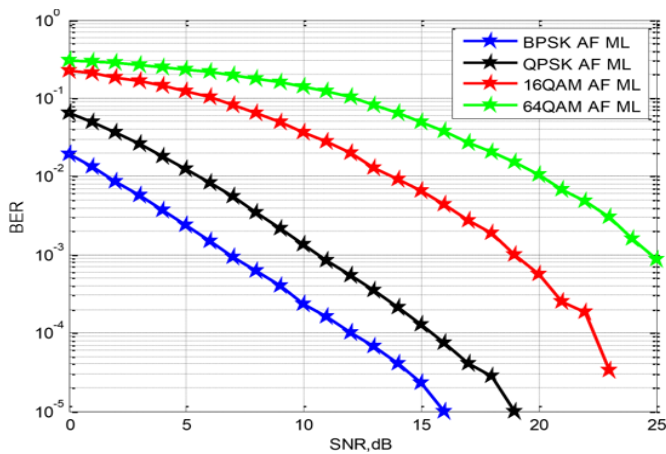***Performance of Cooperative 2×2 V-BLAST scheme with MRC for ML detection***

Figure 12: BER Performance of Cooperative 2×2 V-BLAST MIMO system using ML detection for different modulation scheme

Figure 12 shows that BER performance of Cooperative VBLAST MIMO system is better for ML detection than that of MMSE detection. It also shows that as the constellation size increases, performance decreases
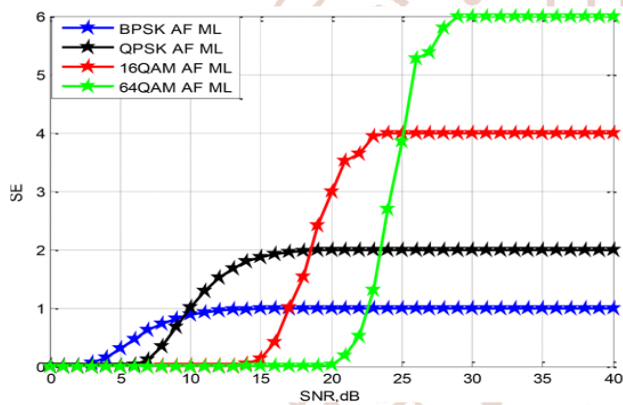

Figure 13: Throughput performance of Cooperative 2×2 V-BLAST system using ML detection for different modulation

Figure 13 depicts the Throughput performance for ML detection of Figure 12, at target of BER ≤ 10-2. In this figure, there is no modulation scheme that gives us performance below 10-2 at an SNR below 3dB.
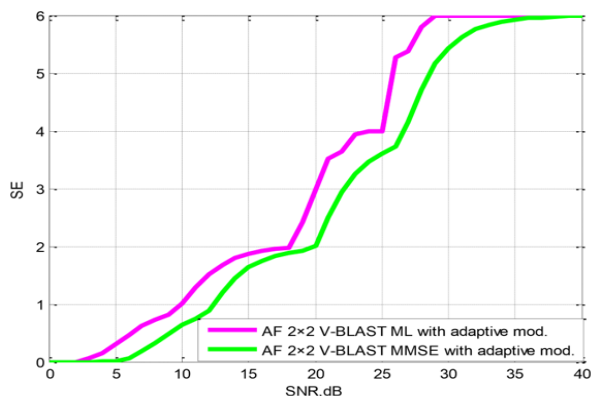

Figure 14: Throughput performance of adaptive modulation cooperative 2×2 V-BLAST MIMO using MMSE and ML detection.

Figure 14 shows the comparison between throughput performance of MMSE and ML detections. It can be seen that the ML Detection, in contrast to the MMSE Detection has improved spectral efficiency by approximately 2.5dB at medium or low SNRs. However, for SNR greater than 35 dB the gap is approximately nil.
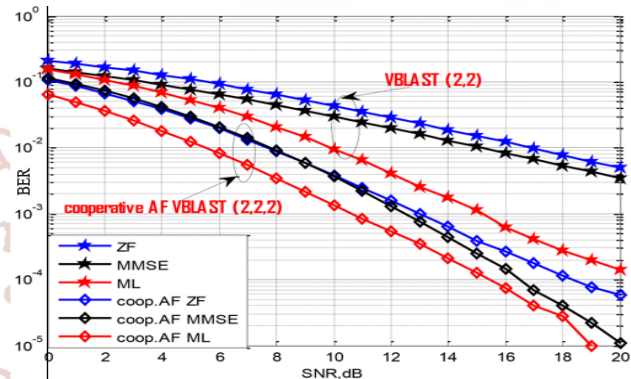

Figure 15: BER Performance curves of cooperative 2×2 V-BLAST MIMO system for different detectors (ML, ZF and MMSE).

Figure 15 shows the comparison of 2 X 2 VBLAST MIMO system with Cooperative AF 2 X 2 VBLAST MIMO system for all detection techniques. The result revealed that at BER of 10-2 there is approximately 1dB SNR difference between the ZF and MMSE detectors in 2×2 V-BLAST MIMO system. Cooperative 2×2 VBLAST MIMO system shows the performance curves of these two detectors close to each other, especially when the SNR is less than 11dB. The cooperative 2×2 V-BLAST MIMO system with ML detection yields a gain of about 4.5 dB over the corresponding 2×2 V-BLAST MIMO system with ML detection at a BER of .

The SNR gains of cooperative MIMO using QPSK modulation over non-cooperative for ZF, MMSE and ML detections at a BER of 10-2 are listed in Table 4.

Table 4: SNR switching method of AF cooperative 2X2 V-BLAST MIMO system with MMSE detection

Modulation type	Systems						SNR Gains Cooperative MIMO		
	MIMO			Cooperative MIMO					
	ZF	MMSE	ML	ZF	MMSE	ML	ZF	MMSE	ML
QPSK	16 dB	15 dB	10 dB	8 dB	8dB	5.5 dB	8 dB	7dB	4.5 dB

CONCLUSION

The simulation results of Cooperative and Non-cooperative MIMO systems over Rayleigh fading channel for ZF, MMSE and ML detections using MRC combining have been analysed along with adaptive modulation. Results have shown that cooperative VBLAST MIMO in contrast to non-cooperative VBLAST MIMO system is capable of improved and better BER and SE performance at no penalty in complexity. ML detector proved to be optimal detector. Furthermore, adaptive modulation aided to select optimal modulation scheme in different SNR ranges achieving the highest SE with BER target set at 10-2.

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