BER Performance Analysis of A Cooperative BICM System based on Post-BSC Model

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***Abstract*—A Generic Cooperative BICM system is described and an analytical model capturing relay error through a binary symmetric channel (BSC) is presented. The analytical model is called Post-BSC model as the BSC channel is placed after encoder of the relay node. Tight BER upper bound is derived for the presented model and close match between simulation and analysis for the presented model is observed. However it is also observed that the proposed model is optimistic and fails to effectively model the original system at low SNR conditions of the source to relay link. Despite this fact the incorporation of the Post-BSC model based maximum likelihood decoding greatly improves the system BER with respect to the original DF scheme.**

***Index Terms*—relay channel, cooperative, coding, higher order modulation, BICM**

I. Introduction

In cooperative relay channel a number of relay nodes participate in a communication between a source and destination node. The main objective of this involvement is improvement of the overall communication performance in terms of bit or packet error rate, and throughput. One of the basic strategies in a cooperative communication is "decode and forward" (DF) [1]-[3]. DF scheme allows for change of modulation order and coding rate at relay and thus system parameters can be better optimised to effectively exploit the relay to destination link condition. When this link is highly reliable relay can increase its modulation order and forward its signal in much shorter time. Consequently the overall spectrum efficiency of the system will be boosted.

Bit interleaved coded modulation (BICM) [4]-[5] is a coding technique that effectively exploits Hamming distance structure of the binary codes when used in conjunction with a higher order modulation over fading channels. In this regard BICM will be a potential candidate when higher order modulations are employed in a cooperative transmission over fading channels.

Analysis of a cooperative communication technique with respect to different conditions of its constituent point-to-point links in conjunction with the employed system parameters such as modulation order and coding rate will be very useful in proper configuration of the system. In this regard here we provide a comprehensive analysis of a generic cooperative BICM system which allows for different modulations and coding to be used for the source and relay transmissions. The analysis of the system will be based on a proposed equivalent model. Maximum likelihood decoding as well as a tight upper bound on BER performance will be derived for the proposed model. The proposed model is quite generic and covers multiple antenna transmission. It can also be easily extended to multiple relay scenario and multiple hops. However due to limitation of space only single-relay and single-antenna transmission results are provided and discussed in this paper.

II. System Model

Let assume a simple cooperative communication system composed of three nodes: source node S, relay node R, and destination node D. We assume that nodes transmission-reception is based on a simple protocol composed of two phases. In the first phase of this protocol S broadcasts its signal to R and D, and in the second phase only R transmits to D. Even though more efficient approach is to allow S and R jointly transmit in the second phase, for the convenience of introduction of the analysis we adhere to this simple protocol. A Cooperative communication system model using this protocol is depicted in Figure 1. The links S-R, S-D, and R-D are enumerated with 0, 1, and 2, respectively. The building blocks of the model are as follows

1) Encoders ENC1 and ENC2 are at S and R, respectively. These encoders use binary codes $\mathcal{C}^1$, and $\mathcal{C}^2$, and generate code sequences $\underline{c}^1 \in \mathcal{C}^1$, and $\underline{c}^2 \in \mathcal{C}^2$, respectively. We define the binary code $\mathcal{C} = (\mathcal{C}^1, \mathcal{C}^2)$.
2) Bit interleavers π_1 and π_2 are at S and R, respectively. A bit interleaver π in BICM scheme establishes a one-to-one correspondence $\pi : k \to (k', i)$, where k denotes the time ordering of the bit sequence before interleaving, k' denotes the time ordering of the modulated signals, and i indicates the position of bit in the label of the signal.
3) Modulators MOD1=$(\mu_1, \mathcal{X}_1)$ and MOD2=$(\mu_2, \mathcal{X}_2)$ are at S and R, respectively. They are memoryless and are over signal sets $\mathcal{X}_1 \subset \mathbb{C}^{L_1}$ and $\mathcal{X}_2 \subset \mathbb{C}^{L_2}$ with size $|\mathcal{X}_1| = M_1 = 2^{m_1}$, and $|\mathcal{X}_2| = M_2 = 2^{m_2}$, and use one-to-one binary labeling maps $\mu_1 : \{0,1\}^{m_1} \to \mathcal{X}_1$, and

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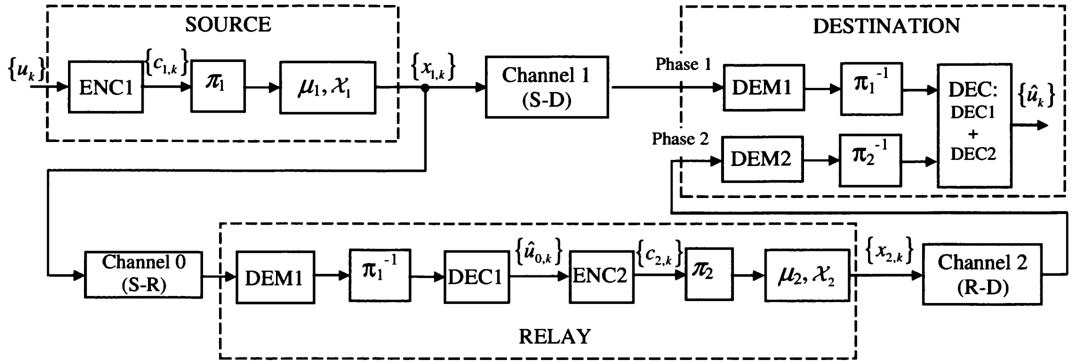

Figure 1 A Cooperative communication system model composed of a source, destination, and single relay.

$\mu_2:\{0,1\}^{m_2} \to \mathcal{X}_2$; respectively. $\mathbb{C}^{L_1}$, and $\mathbb{C}^{L_2}$ are the complex L_1, and L_2-dimentional Euclidean spaces.

4) Node-to-node stationary finite-memory vector channels with transition probability density functions (pdfs) $p_{\theta^j}\left(y^j \middle| x^j\right)$ for j=0,1,2,, where $x^0 = x^1 \in \mathbb{C}^{L_1}$, $x^2, y^0 \in \mathbb{C}^{L_2}$, $y^1, y^2 \in \mathbb{C}^{L_D}$, and θ^j denotes the channel state.
5) Demodulators DEM1 and DEM2 are at R and D, respectively. They play the role of bit metric calculators.
6) Bit metric deinterleavers π_1^{-1} and π_2^{-1} are at R and D, respectively.
7) Decoder DEC1 is at R and the final decoder DEC is at D.

The complex Euclidean spaces $\mathbb{C}^{L_1}, \mathbb{C}^{L_2}$, and $\mathbb{C}^{L_D}$ allow modeling of different signal transmissions. L_1, L_2, and L_D are positive integers. The single antenna transmission-reception can be modeled by setting all these parameters equal to1. Denoting the number of antennas at S, R, and D with M_S, M_R, and M_D, and setting L_1=M_S, L_2=M_R, L_D=M_D will model MIMO channel for all the constituting links with complex plane signals (like MPSK, and MQAM).

First and second phases are composed of N_1, and N_2 transmissions. Frequency-flat fading channels are assumed between any pair of the transmitting-receiving nodes. The transmitted signal sequences in the first and second phases are denoted by $\underline{x}^1 = \left(x_{1,1},\ldots,x_{1,N_1}\right)$, and $\underline{x}^2 = \left(x_{2,1},\ldots,x_{2,N_1}\right)$, respectively. The corresponding received signal sequences are denoted by $\underline{y}^0$, $\underline{y}^1$, and $\underline{y}^2$, where for each element the first subscript j=0,1,2 represents the link number. Both receivers at R and D are assumed to have perfect channel knowledge on their corresponding connected channels. No channel knowledge is assumed to be available at corresponding transmitters.

III. Post-BSC system model

As already evidenced earlier by [4], and then extended and elaborated by [5] the ideal interleaving assumption allows modeling a BICM system as a binary code transmitting its code sequence through parallel binary input channels where each channel corresponds to the label position of the transmitted bit. Such a model can also be presented for the considered cooperative BICM system. Figure 2 shows the Post-BSC model of the cooperative BICM system with ideal interleaving. The system consists of the two sets of parallel independent and memoryless binary input channels corresponding to S-D and R-D links (i.e. links j=1,2, respectively). Each channel in a set of parallel channels corresponds to a position in the label of the signals of $\mathcal{X}_j$. The conditional pdf of the binary input channel when label position i is selected is:

$$p_{\theta^j}\left(y^j \middle| b,i\right) = \frac{1}{2^{m_j-1}} \sum_{z\in\mathcal{X}_j(i;b)} p_{\theta^j}\left(y^j \middle| z\right) \quad \text{for } j=1,2, \tag{1}$$

and i=1,2,...,m_j.

For every binary symbol c_k^j of a coded sequence $\underline{c}^j$, a position index $i \in \{1,\ldots,m_j\}$ is selected with uniform probability and independent of the other selections. The decoder receives two sequences $\underline{y}^j$ with length NB_j, for j=1,2. The post-BSC model captures the errors occurred in decoder of the relay node.

A. Genie clone of the relay node and Post-BSC model

To model the relay node's erroneous transmission we assume a genie clone of R, which has error free connection with S. Let's denote $\underline{c}^{g,2}$ as the code sequence generated by the encoder of the genie clone. The dependence between $\underline{c}^2$ and $\underline{c}^{g,2}$ can be modeled through a binary channel. If the source node's data are uniformly distributed, and BICM transmission over the S-R link is symmetrized, e.g., using random label complementing [5], then we can assume that the considered binary channel is symmetric. We further make an approximating assumption that the considered binary channel is memoryless. In fact the original system presented in Figure 1 defies this assumption as

the relay encoded sequences $\underline{c}^2$ are valid codewords while memoryless-BSC corrupted sequences are not. However as will be evidenced by simulation results in section VI, this approximation allows improve the system performance over the conventional DF based decoding.
As the communication between S and the genie relay is error free the output of DEC1 at the genie relay will be exactly $\underline{\boldsymbol{u}}$ and therefore there would be a one-to-one correspondence between $\underline{\boldsymbol{u}}$ and the codeword couple $\left(\underline{c}^1,\underline{c}^{g,2}\right)\in \mathcal{C}$.

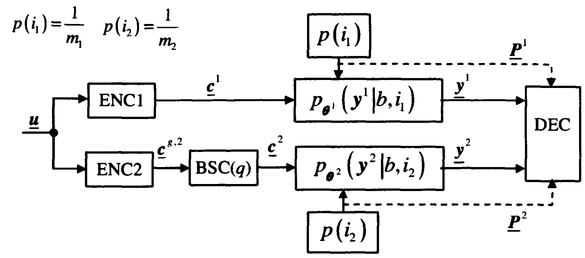

Figure 2 Equivalent cooperative BICM system model

IV. Maximum Likelihood Decoding

The ML criterion for decoding the observations $\underline{y}^1$ and $\underline{y}^2$, and given CSI $\underline{\boldsymbol{\theta}}^1$ and $\underline{\boldsymbol{\theta}}^2$, at D is written as

$$\left(\hat{\underline{c}}^1_{ML},\hat{\underline{c}}^2_{ML}\right)=\underset{\left(\underline{c}^1,\underline{c}^{g,2}\right)\in C}{\arg\max}\, p_{\underline{\theta}^1,\underline{\theta}^2}\left(\underline{y}^1,\underline{y}^2\middle|\underline{c}^1,\underline{c}^{g,2}\right), \tag{2}$$

Assuming ideal bit interleaving at S and R, and considering orthogonal reception of $\underline{y}^1$, and $\underline{y}^2$, the post-BSC model, and the memoryless property of the channels1 and 2, allows us to write the ML decoding of (2) as follows:

$$\left(\hat{\underline{c}}^1,\hat{\underline{c}}^2\right)=\underset{\left(\underline{c}^1,\underline{c}^{g,2}\right)\in C}{\arg\max} \tag{3}$$
$$\left(\sum_{k=1}^{NB_1}\frac{1}{2}\left(2c_k^1-1\right)\lambda_i\left(y_{k'}^1\right)+\sum_{k=1}^{NB_2}\frac{1}{2}\left(2c_k^{g,2}-1\right)\eta_i\left(y_{k'}^2\right)\right)$$

where $\lambda_i\left(y_{k'}^1\right)$ and $\eta_i\left(y_{k'}^2\right)$ are bit reliabilities. Bit reliabilities $\lambda_i\left(y_{k'}^1\right)$ of the direct link are calculated based on the traditional non-cooperative BICM model [5]. Calculation of $\eta_i\left(y_{k'}^2\right)$ has to take Post-BSC model into account and will follow the same line of the derivation:

$$\eta_i\left(y_{k'}^2\right)=\log\frac{\sum_{\hat{b}=0}^{1}p_q\left(\hat{b}\middle|+1\right)\sum_{x\in\mathcal{X}_2\left(i;\hat{b}\right)}p_{\theta_{k'}^2}\left(y_{k'}^2\middle|x\right)}{\sum_{\hat{b}=0}^{1}p_q\left(\hat{b}\middle|-1\right)\sum_{x\in\mathcal{X}_2\left(i;\hat{b}\right)}p_{\theta_{k'}^2}\left(y_{k'}^2\middle|x\right)}, \tag{4}$$
$$\approx Clip\left(\lambda_i\left(y_{k'}^2\right);l_q\right)$$

where $l_i\left(x\right)$ denotes the bit value of the i-th label position of the symbol x. $l_q=\log\left(\left(1-q\right)/q\right)$ represents the link reliability of the BSC that has error probability of q. Clip function $Clip\left(\lambda;l_q\right)$ clips the argument λ at $\pm l_q$ levels. Generally reliability calculation for multihop links such as S-R-D in Figure 1 requires careful attention. The calculated reliability should reflect the reliability of each constituent link of the multihop path otherwise the received symbols reliability will be over credited by the link quality of the last hop. The bit reliabilities $\eta_i\left(y\right)$ effectively handle this issue. For example when S-R communication link is broken, q=0.5, the link quality l_q=0 will force the bit reliability $\eta_i\left(y\right)$ becomes zero regardless of the link quality of R-D.

V. Error probability analysis

In this section the BER analysis tools are driven for the cooperative BICM system based on the Post-BSC model provided in Figure 2. Let $\underline{c}=\left(\underline{c}^1,\underline{c}^{g,2}\right)$ and $\hat{\underline{c}}=\left(\hat{\underline{c}}^1,\hat{\underline{c}}^{g,2}\right)$ denote two distinct code sequences. Let $P\left(\underline{c}\rightarrow\hat{\underline{c}}\right)$ denote the pairwise error probability (PEP) as the probability that the decoder at D prefers $\hat{\underline{c}}$ to $\underline{c}$. We further assume that random label complementing proposed in [5] is also used to symmetrize the constituent binary channels of the cooperative BICM model of Figure 2. This will reduce the PEP dependency to the error sequence $\underline{c}\oplus\hat{\underline{c}}$ only. The complement $\bar{\mu}$ of the map μ is defined as the labeling obtained by complementing all the signal labels. Without loss of generality, in the following we assume that the difference between components of $\underline{c}$ and $\hat{\underline{c}}$ are in consecutive positions, Let us use the following notations:

i. $\boldsymbol{d}=\left(d_1,d_2\right)$ denote the Hamming distances between the corresponding component codewords of $\underline{c}$ and $\hat{\underline{c}}$;
ii. P^1, P^2 denote the corresponding randomly and independently selected label positions. $\underline{\boldsymbol{P}}=\left(\underline{\boldsymbol{P}}^1,\underline{\boldsymbol{P}}^2\right)$ denotes the sequences of label positions with $\underline{\boldsymbol{P}}^j=\left(i_1^j,i_2^j,\ldots,i_{d_j}^j\right)$ for j=1,2.
iii. F^1, F^2 denote binary random variables used to select the corresponding original or complemented labeling maps. $\underline{\boldsymbol{F}}=\left(\underline{\boldsymbol{F}}^1,\underline{\boldsymbol{F}}^2\right)$ denotes the binary flipping sequences with $\underline{\boldsymbol{F}}^j=\left(F_1^j,F_2^j,\ldots,F_{d_j}^j\right)$ for j=1,2.
iv. $\boldsymbol{\mu}=\left(\mu_1,\mu_2\right)$, $\boldsymbol{\mathcal{X}}=\left(\mathcal{X}_1,\mathcal{X}_2\right)$, and $\underline{\boldsymbol{\theta}}=\left(\underline{\boldsymbol{\theta}}^1,\underline{\boldsymbol{\theta}}^2\right)$

The PEP will be a function of $\boldsymbol{d}$, $\boldsymbol{\mu}$, and $\boldsymbol{\mathcal{X}}$: $P(\underline{c} \rightarrow \underline{\hat{c}}) = f(\boldsymbol{d}, \boldsymbol{\mu}, \boldsymbol{\mathcal{X}})$. The PEP can be used in conjunction with usual union bound to upper bound the BER. Hereafter, we focus on the calculation of the PEP $f(\boldsymbol{d}, \boldsymbol{\mu}, \boldsymbol{\mathcal{X}})$

A. BICM Union Bound

The BICM union bound presented in [5] can be extended to our cooperative BICM model. For given $\underline{\boldsymbol{P}}$, $\underline{\boldsymbol{F}}$, and channel state $\underline{\boldsymbol{\theta}}$, the conditional PEP $P(\underline{c} \rightarrow \underline{\hat{c}} | \underline{\boldsymbol{P}}, \underline{\boldsymbol{F}})$ can be written as:

$$P(\underline{c} \rightarrow \underline{\hat{c}} | \underline{\boldsymbol{P}}, \underline{\boldsymbol{F}}) = \Pr\left(\sum_{k=1}^{d_1} (2c_k^1 - 1) \lambda_{i_k^1}(y_k^1) + \sum_{k=1}^{d_2} (2c_k^{g,2} - 1) \eta_{i_k^2}(y_k^2) \le 0 \,\middle|\, \underline{\boldsymbol{P}}, \underline{\boldsymbol{F}} \right), \quad (5)$$

Applying the same arguments used in the derivation of the BICM union bound (30) in [5], and using the Laplace transform method to calculate tail probabilities [6] and after a lengthy derivation that due to lack of space is not presented here the following bound is obtained:

$$f(\boldsymbol{d}, \boldsymbol{\mu}, \boldsymbol{\mathcal{X}}) = E_{\underline{P}, \underline{F}} \left[P(\underline{c} \rightarrow \underline{\hat{c}} | \underline{\boldsymbol{P}}, \underline{\boldsymbol{F}}) \right] \le f_{ub}(\boldsymbol{d}, \boldsymbol{\mu}, \boldsymbol{\mathcal{X}}), \quad (6)$$

where $f_{ub}(\boldsymbol{d}, \boldsymbol{\mu}, \boldsymbol{\mathcal{X}})$ is called the *cooperative BICM Union Bound* (UB), and is expressed as follows:

$$f_{ub}(\boldsymbol{d}, \boldsymbol{\mu}, \boldsymbol{\mathcal{X}}) =, \quad \frac{1}{2\pi j} \int_{\alpha - j\infty}^{\alpha + j\infty} \left[\psi_{ub}^1(s) \right]^{d_1} \left[\psi_{ub}^2(s) \right]^{d_2} \frac{ds}{s} \quad (7)$$

where

$$\psi_{ub}^1(s) \triangleq \frac{1}{m_1 2^{m_1}} \sum_{i=1}^{m_1} \sum_{b=0}^{1} \sum_{\boldsymbol{x}^1 \in \mathcal{X}_1(i;b)} \sum_{\boldsymbol{z}^1 \in \mathcal{X}_1(i;\bar{b})} \Phi_{\Delta(\boldsymbol{x}^1, \boldsymbol{z}^1)}(s),$$

$$\psi_{ub}^2(s) \triangleq \frac{1}{m_2 2^{m_2}} \sum_{i=1}^{m_2} \sum_{b=0}^{1} \left((1-q) \sum_{\boldsymbol{x}^2 \in \mathcal{X}_2(i;b)} \sum_{\boldsymbol{z}^2 \in \mathcal{X}_2(i;\bar{b})} \Phi_{\bar{\Delta}(\boldsymbol{x}^2, \boldsymbol{z}^2)}(s) + q \sum_{\boldsymbol{x}^2 \in \mathcal{X}_2(i;\bar{b})} \sum_{\boldsymbol{z}^2 \in \mathcal{X}_2(i;\bar{b})} \Phi_{\bar{\Delta}(\tilde{\boldsymbol{x}}^2, \boldsymbol{z}^2)}(s) \right) \quad (8)$$

$\Phi_{\Delta(\boldsymbol{x}^1, \boldsymbol{z}^1)}(s)$ and $\Phi_{\bar{\Delta}(\boldsymbol{x}^2, \boldsymbol{z}^2)}(s)$ are the Laplace transforms of the pdf of the metrics $\Delta(\boldsymbol{x}^1, \boldsymbol{z}^1)$ and $\bar{\Delta}(\boldsymbol{x}^2, \boldsymbol{z}^2)$:

$$\Delta(\boldsymbol{x}^j, \boldsymbol{z}^j) = \log p_{\boldsymbol{\theta}^j}(\boldsymbol{y}^j | \boldsymbol{x}^j) - \log p_{\boldsymbol{\theta}^j}(\boldsymbol{y}^j | \boldsymbol{z}^j), \text{ for } j=1,2,$$
$$\bar{\Delta}(\boldsymbol{x}^2, \boldsymbol{z}^2) = Clip(\Delta(\boldsymbol{x}^2, \boldsymbol{z}^2); l_q), \quad (9)$$

and

$$\Phi_{\Delta(\boldsymbol{x}^1, \boldsymbol{z}^1)}(s) = E_{\boldsymbol{y}^1, \boldsymbol{\theta}^1}\left[e^{-s\Delta(\boldsymbol{x}^1, \boldsymbol{z}^1)} \right],$$
$$\Phi_{\bar{\Delta}(\boldsymbol{x}^2, \boldsymbol{z}^2)}(s) = E_{\boldsymbol{y}^2, \boldsymbol{\theta}^2}\left[e^{-s\bar{\Delta}(\boldsymbol{x}^2, \boldsymbol{z}^2)} \right]. \quad (10)$$

$\Phi_{\bar{\Delta}(\tilde{\boldsymbol{x}}^2, \boldsymbol{z}^2)}(s)$ and $\bar{\Delta}(\tilde{\boldsymbol{x}}^2, \boldsymbol{z}^2)$ are defined similarly. $\tilde{\boldsymbol{x}}^2$ is any arbitrary point in the subset $\mathcal{X}_2(i;b)$. The parameter α in (7) belongs to the intersection of the region of the convergence of $\psi_{ub}^1(s)\psi_{ub}^2(s)$ with the real positive line.

B. BICM Expurgated Union Bound

Due to union bound technique coupled with random modulation nature of BICM scheme, the BICM UB in [5] and consequently the cooperative BICM UB presented here, contain large number of overlapping error events that make the bound quite loose. Depending on the constellation and antenna configuration a number of error events can be expurgated to provide tighter bound. Reference [7] extends the BICM UB expurgation into MIMO fading channels and presents the necessary and sufficient conditions for removal of some error events. Interestingly due to the monotonic nature of the clipping that is used in the cooperative BICM UB, the expurgation of the bound is still possible. The same condition presented for MIMO BICM UB expurgation still holds for our problem. Removing irrelevant error events in (6) will result in the *cooperative BICM Expurgated Bound.*

VI. Simulation Results

Here we provide some simulation results to demonstrate the tightness of the provided bounds. The S-R and R-D links' SNRs are adjusted relative to the direct link S-D SNR: $\gamma_0 = \Delta_{sr} \cdot \gamma_1$, $\gamma_2 = \Delta_{rd} \cdot \gamma_1$, where Δ_{sr} and Δ_{rd} represent SNR offsets of these two links. S and R are assumed to be single antenna and 2 receive antennas are used at D. S and R are assumed to use an identical 1/2 rate 4-state convolutional code with octal generator (5,7). Information block size is 598 bits that along with 2 zero tail bits used for termination of the code results in a coded block size of 1200 bits. Pseudo random patterns are used for bit interleaving. Different interleaving patterns are used for the source and relay node's transmissions. The interleaving patterns are kept fixed for all the simulations. QPSK modulation is used for the source node and 16QAM, for the relay node. Gray labeling is used for all the considered constellations. The constituent channels are assumed to be Rayleigh fast fading. Calculation of all the presented bounds becomes intractable due to existence of a large number of governing parameters. Therefore, we resorted to Monte Carlo method for calculation of the bounds. The Post-BSC cooperative BICM system model is simulated with R-D link SNR offset of Δ_{rd}=5 dB. Figure 4 provides the BER simulation and analytical expurgated (EX) and Bhattacharyya (BUB) bounds for different values of the direct link's SNR and BSC error probabilities of: q=0, 10^{-2}, 10^{-1}, 0.5. Due to shortage of space the derivation of Bhattacharyya bound is not provided in this paper. A very good match is observed between EX bound and simulation results for all the cases. EX bound is quite tight at moderate and high SNRs the feature that was also observed for single antenna original BICM system [5]. An interesting observation from this figure is about the sensitivity to the Post-BSC error rate. As it is seen the difference between perfect, i.e. q=0, and erroneous q=10^{-2} relay reception is around 0.7 dB at BER of 10^{-5}. This robustness is obtained through properly clipping the bit reliabilities received from the relay node.

Figure 4 compares the simulated BER performance of the original cooperative BICM system (Figure 1) with the Post-BSC model (Figure 2). Also shown is the performance of the original DF scheme when metric clipping is not used. The BER performance in this figure is plotted versus the S-R SNR offset. For each SNR condition the simulated BER of the S-R link is used as parameter q for the analytical Post-BSC model as well as the metric clipping for both systems. Presented also are the corresponding analytical EX bounds for Post-BSC model. While the analysis and simulation of the Post-BSC model are very consistent, the Post-BSC model fails to effectively capture the original system error performance at low values of Δ_{sr}. The main reason for this behavior is that the error $\underline{c}^{g,2} \rightarrow \underline{c}^{2}$ in the original model is from a codeword to another codeword while in the Post-BSC model $\underline{c}^{2}$ is not necessarily a codeword. This makes the error recovery due to relay error in the original system more difficult than the Post-BSC model. As it is observed metric clipping of equation (4) has significant improvement in low S-R SNR values.

VII. Conclusion

In this paper an analytical model is presented for BER performance evaluation of a cooperative BICM system. This model called Post-BSC model suggests clipping of the bit reliabilities calculated from relay forwarded signal. A tight upper bound based on the extension of the original BICM expurgated bound is derived. The Post-BSC loses its accuracy at low S-R SNR values. Incorporation of metric clipping suggested by the Post-BSC model considerably improves the system BER performance with respect to the original DF scheme. The proposed clipping will require estimation of S-R link BER and its signaling to the destination node.

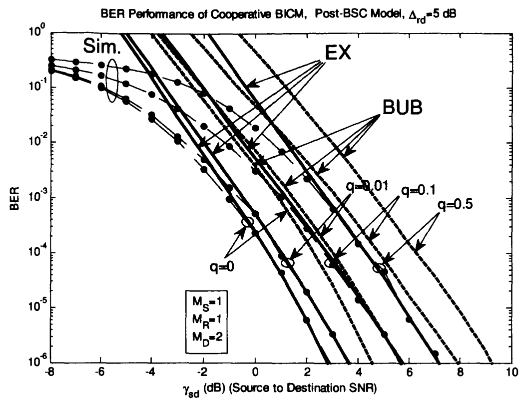

Figure 4 BER Performance of Cooperative BICM Post-BSC model.

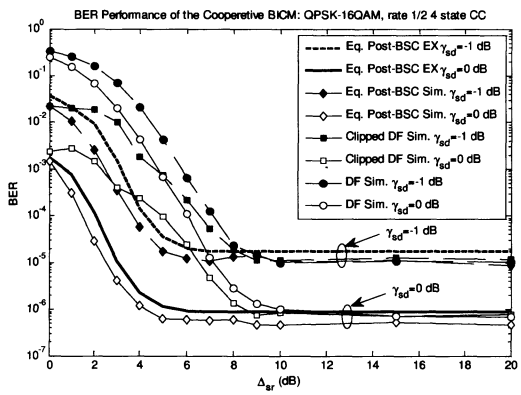

Figure 4 BER Performance Comparison of the original and Post-BSC model.

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