# Dual Stream Low Complexity BICM Reception and MIMO Broadcast Strategy

Rizwan Ghaffar, Raymond Knopp
Eurecom Institute, 2229 route des Crêtes B.P.193
06904 Sophia Antipolis Cedex FRANCE
Email: rizwan.ghaffar@eurecom.fr, raymond.knopp@eurecom.fr

***Abstract*—In this paper we consider channel coding for dual data streams with unequal error protection (UEP) for the objectives of low complexity receiver structures and prioritized handling of data in MIMO broadcast systems. We focus on high spectral efficiency bit interleaved coded modulation (BICM) MIMO OFDM system where two independently coded spatial streams of symbols are simultaneously transmitted by an antenna array using antenna cycling. In some sense, the receiver then views a multiple access channel (MAC) and consequently the reception is based on successive interference cancellation (SIC). The limited adaptability of the proposed system helps gear up to a higher data rate as channel conditions improve without any adjustment at the transmitter. This leads to devising a broadcast strategy incorporating different levels of service. Standard receiver solutions for such schemes employ sub-optimal linear minimum mean square error (MMSE) successive stripping decoders. We propose a novel low complexity near optimal demodulator based on match filter outputs for a dual stream system which exhibits better performance and lower complexity as that of MMSE based demodulator.**

## I. INTRODUCTION

Multiple antenna communication systems being capable of considerably increasing the capacity of a wireless link [1] are the focus of attention over the past decade. The requisite antenna spacing combined with the complexity constraints restrict future MIMO based communication systems to the maximum of 4 spatial streams whereas it is reduced to dual spatial streams in most scenarios. The existing and forthcoming MIMO based standards as IEEE 802.11n [2], IEEE 802.16m [3] and Third Generation Partnership Project Long Term Evolution (3GPP LTE) [4] substantiate this argument. Researchers persist to strive for better performance and reduced receiver complexity for such systems. These communication systems need robust coding schemes and an appropriate solution in todays wireless world is bit interleaved coded modulation (BICM) [5]. BICM MIMO OFDM therefore provides a promising choice for next-generation wireless networks where MIMO enhances the spectral efficiency, OFDM reduces the complexity of equalization and BICM stands as a robust coding scheme for fading channels.

These rationales have stimulated us to consider in this paper a low dimensional dual stream BICM MIMO OFDM broadcast system where 2 independently coded spatial streams are simultaneously transmitted by an antenna array using antenna cycling. Due to this transmission strategy, the receiver views a multiple access channel (MAC). Shamai [6] termed the approach of single code layer at each transmit antenna as *MAC-outage approach*. The reception is consequently based on successive interference cancellation (SIC) i.e. sequential decoding and subtraction (stripping) of spatial streams. Independent encoders and modulation on two spatial streams introduce unequal error protection (UEP). We propose a broadcast strategy based on UEP (rate distribution) between two spatial streams which incorporates two levels of performance. The reliably decoded information rate depends on the state of the channel which is determined by monitoring the received SNR being above or below a certain threshold. Transmitter is operating at a constant power and data rate but the limited adaptability of the system helps receivers to gear up to a higher data rate as channel conditions improve.

The idea of dual data streams with UEP adds flexibility to the system which can be exploited for having prioritized users or advanced services in MIMO broadcast systems and in multimedia broadcast multicast services (MBMS). For instance it can be the broadcast of 2 multimedia streams with different rates (quality) of same data and the users decoding the lower or higher rate stream depending on the received SNR. It can also be the broadcast of low and high rate streams (as audio and video) with prioritized or high SNR users decoding both streams while low SNR users decoding only the low rate stream. It is also applicable to high-definition TV (HDTV) scenario where low priority/quality users are able to receive standard-definition TV (SDTV) transmission while high priority/quality users access HDTV. The idea has a limited similarity to superposition codes [7] whose signal space has a cloud/satellite topology. Cloud centers because of relatively higher distance amongst them carry information for low quality receiver whereas the better receivers having larger noise tolerance can resolve up to the actual transmitted satellite symbol within the cloud.

Standard receiver solutions for such schemes including V-BLAST [8] [9] use stripping decoders which incorporate sub-optimal minimum mean square error (MMSE) filters [10] against the yet undecoded streams at each successive cancellation stage. We propose a low complexity near optimal demodulator for this system. Literature discusses SIC and PIC detection schemes for CDMA systems in reference to different rates in multi user context [11].

The paper is divided into five sections. In section II we define the system model while section III discusses the channel

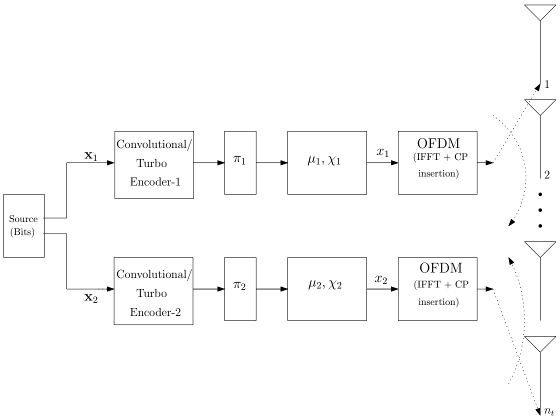

Fig. 1. Block diagram of Transmitter of $n_t \times n_r$ dual stream BICM MIMO OFDM system. $\pi_1$ denotes random interleaver, $\mu_1$ labeling map and $\chi_1$ signal set for $\mathbf{x}_1$

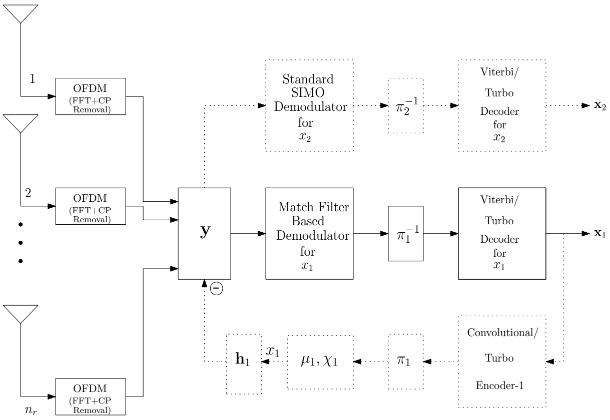

Fig. 2. Block diagram of SIC Receiver of dual stream BICM MIMO OFDM system. $\pi_1^{-1}$ denotes deinterleaver and $\mathbf{h}_1$ denotes the channel seen by $\mathbf{x}_1$.

capacity analysis of such a system and subsequently the proposed broadcast strategy. Section IV is dedicated to the proposed demodulator which is followed by simulation results and conclusions.

## II. SYSTEM MODEL

In this section we consider a MIMO broadcast system (without CSIT) which is a $n_t \times n_r$ ($n_t \geq 2$, $n_r \geq 2$) BICM MIMO OFDM system with 2 equal power and non-uniform rate spatial streams. We effectively reduce this to $2 \times n_r$ system by antenna cycling at the transmitter [1] with each stream being transmitted by one antenna in any dimension. The antenna used by a particular stream is randomly assigned per dimension so that each stream sees all degrees of freedom of the channel. Let the two spatial streams be $\mathbf{x}_1$ and $\mathbf{x}_2$ with $x_1$ being the symbol of $\mathbf{x}_1$ with variance $\sigma_1^2$ and $x_2$ being the symbol of $\mathbf{x}_2$ with variance $\sigma_2^2$. The block diagram of the transmitter and receiver are shown in the figures 1 and 2 respectively. The well known baseband model of the system at each frequency tone is given as:-

$$\mathbf{y} = \mathbf{h}_1 x_1 + \mathbf{h}_2 x_2 + \mathbf{z} \tag{1}$$

where $\mathbf{y}, \mathbf{z} \in \mathbb{C}^{n_r}$ are the vectors of received symbols and circularly symmetric complex white Gaussian noise of variance $N_0$ at the $n_r$ receive antennas. $\mathbf{h}_1 \in \mathbb{C}^{n_r}$ is the vector characterizing flat fading channel response from first transmitting antenna to $n_r$ receive antennas with $E\left[|h_i|^2\right] = 1$. It is assumed that each channel path between the transmitter and the receiver is independent. The complex symbols $x_1, x_2$ are also assumed independent.

## III. PROPOSED BROADCAST STRATEGY

### A. Channel Capacity Analysis

The capacity expression for dual streams [1] from the chain rule is

$$I\left(\mathbf{Y}; X_1, X_2|\mathbf{H}\right) = I\left(\mathbf{Y}; X_1|\mathbf{H}\right) + I\left(\mathbf{Y}; X_2|X_1, \mathbf{H}\right) \tag{2}$$

where $\mathbf{H} = [\mathbf{h}_1 \mathbf{h}_2]$. For the Gaussian inputs, the explicit expressions of mutual information for the two streams are

$$I\left(\mathbf{Y}; X_1|\mathbf{H}\right) = \log_2\left[\det\left\{\mathbf{I} + \sigma_1^2 \mathbf{h}_1 \mathbf{h}_1^\dagger \left(N_0 \mathbf{I} + \sigma_2^2 \mathbf{h}_2 \mathbf{h}_2^\dagger\right)^{-1}\right\}\right] \tag{3}$$

and

$$I\left(\mathbf{Y}; X_2|X_1, \mathbf{H}\right) = \log_2\left(1 + \frac{\sigma_2^2}{N_0}\left\|\mathbf{h}_2\right\|^2\right) \tag{4}$$

where † indicates conjugate transpose. For equal power distribution, $I\left(\mathbf{Y}; X_1|\mathbf{H}\right) < I\left(\mathbf{Y}; X_2|X_1, \mathbf{H}\right)$ dictating rate of first stream being less than rate of second stream ($R_1 < R_2$) as shown in fig. 3.

For finite size QAM constellation with $x_1 \in M_1$ and $x_2 \in M_2$, the mutual information expressions take the form

$$\begin{aligned} I\left(\mathbf{Y}; X_1|\mathbf{H}\right) &= \mathcal{H}\left(X_1|\mathbf{H}\right) - \mathcal{H}\left(X_1|\mathbf{Y}, \mathbf{H}\right) \\ &= \log M_1 - \frac{1}{M_1}\sum_{x_1}\int_{\mathbf{y}} p\left(\mathbf{y}|x_1\right)\log\frac{\sum_{x_1} p\left(\mathbf{y}|x_1\right)}{p\left(\mathbf{y}|x_1\right)}d\mathbf{y} \end{aligned} \tag{5}$$

where $\mathcal{H}\left(.\right) = -E\log p\left(.\right)$ is the entropy function. For our purposes, it suffices to note that for each choice of $x_1$ and $x_2$, there are two sources of randomness in the choices of channel and noise. The above quantities can be easily approximated numerically using sampling (Monte-Carlo) methods with $N_z$ realizations of noise and $N_H$ realizations of the channel.

$$\begin{aligned} I\left(\mathbf{Y};X_1|\mathbf{H}\right) \;&=\; \log M_1 - \frac{1}{M_1 M_2 N_z N_H}\sum_{\mathbf{x}}\sum_{\mathbf{H}}^{N_H}\sum_{\mathbf{z}}^{N_z} \\ &\log\frac{\sum_{x_1}\sum_{x_2}\exp\left[-\frac{1}{N_0}\left\|\mathbf{y}-\mathbf{H}\mathbf{x}\right\|^2\right]}{\sum_{x_2}\exp\left[-\frac{1}{N_0}\left\|\mathbf{y}-\mathbf{H}\mathbf{x}\right\|^2\right]} \end{aligned} \tag{6}$$

where $\mathbf{x} = \left[x_1 x_2\right]^T$. Similarly the mutual information of the second stream when the first stream has been detected is given by

$$\begin{aligned} I\left(\mathbf{Y}; X_2|X_1, \mathbf{H}\right) &= \mathcal{H}\left(X_2|X_1, \mathbf{H}\right) - \mathcal{H}\left(X_2|\mathbf{Y}, X_1, \mathbf{H}\right) \\ &= \log M_2 - \frac{1}{M_1 M_2}\sum_{\mathbf{x}}\int_{\mathbf{y}} p\left(\mathbf{y}|\mathbf{x}\right)\log\frac{\sum_{x_2} p\left(\mathbf{y}|\mathbf{x}\right)}{p\left(\mathbf{y}|\mathbf{x}\right)}d\mathbf{y} \end{aligned} \tag{7}$$

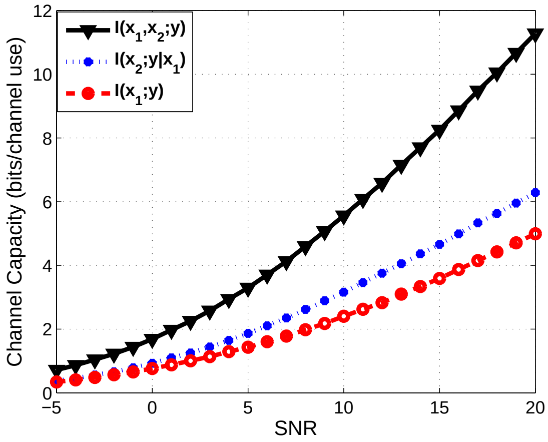

Fig. 3. Capacity of proposed dual-stream broadcast approach for Gaussian alphabets. Both streams have equal power.

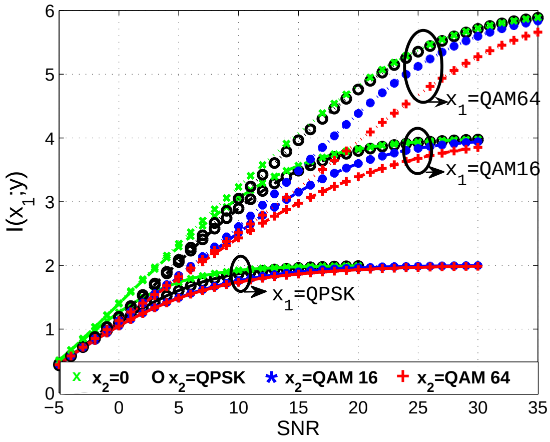

Fig. 4. Capacity of first stream in dual-stream broadcast approach for finite size alphabets once the second stream is not known. Both streams have equal power. $\mathbf{x}_2 = 0$ indicates the special case when the second stream has been decoded and stripped off. Note that SNR includes power of both streams.

Estimation of this quantity using Monte-Carlo simulation

$$I\left(\mathbf{Y};X_2|X_1,\mathbf{H}\right) = \log M_2 - \frac{1}{M_1M_2N_zN_H}\sum_{\mathbf{x}}\sum_{\mathbf{H}}^{N_H}\sum_{\mathbf{z}}^{N_z} \log\frac{\sum_{x_2}\exp\left[-\frac{1}{N_0}\left\|\mathbf{y}-\mathbf{Hx}\right\|^2\right]}{\exp\left[-\frac{1}{N_0}\left\|\mathbf{y}-\mathbf{Hx}\right\|^2\right]} \quad (8)$$

Fig. 4 shows the capacity of the first stream once the second stream is not yet decoded for different combinations of finite constellation alphabets. For moderate values of SNR, the capacity of first stream is a function of the yet undetected second stream and this capacity decreases as the rate (constellation size) of second stream increases. This degradation is not observed at low and high values of SNR as at low SNR, the two streams are orthogonal while at high SNR, the second stream can be perfectly stripped off leading to detection of first stream. Rate of first stream being a function of the rate on second stream leads to non-uniform rates in uniform power dual stream scenario and this leads to the following proposed broadcast strategy.

### B. *Strategy*

The proposed broadcast approach (*MAC-outage* [6]) is motivated by the capacity of a Gaussian broadcast channel with two users i.e.

$$\mathcal{C} = I\left(x_1;y_1\right) + I\left(x_2;y_2|x_1\right) \quad (9)$$

where user 2 sees a better channel and so is able to decode and strip off the interference.

We propose the transmission of two spatial streams of equal power and non-uniform rate. Low priority/quality users are able to decode low rate stream $\mathbf{x}_1$ while high priority/quality users are able to decode both low and high rate streams $\mathbf{x}_1$ and $\mathbf{x}_2$ by successive stripping. The rates of two streams are

$$R_1 \leq I\left(\mathbf{y};x_1\right) \quad (10)$$

and

$$R_2 \leq I\left(\mathbf{y};x_2|x_1\right) \quad (11)$$

The notion of priority/quality is typically the received SNR and/or stream decoupling. The users are divided into two groups i.e. near-in users and far-out users based on their received SNR. The lower rate stream $\mathbf{x}_1$ is designed for a lower value of SNR i.e. SNR$_1$ while the higher rate stream $\mathbf{x}_2$ is designed for higher value of SNR i.e. SNR$_2$. The received SNR of a particular user dictates two decoding options.

1) If SNR$_2$ >SNR≥SNR$_1$, the user decodes $\mathbf{x}_1$.
2) If SNR≥SNR$_2$, the user decodes both streams i.e. $\mathbf{x}_1$ and $\mathbf{x}_2$. The user first decodes low rate stream $\mathbf{x}_1$, strips it out and then decodes high rate stream $\mathbf{x}_2$.

This leads us to SIC detection based MIMO broadcast scenario with equal power and non-uniform rate spatial streams. We now propose a low complexity demodulator for such scenario.

## IV. MATCH FILTER BASED DEMODULATOR

Considering the system equation (1), the ML bit metric for bit $b$ at the $i$th position of $x_1$ is given as [5]

$$\lambda^i(\mathbf{y},b) = \log\sum_{x_1\in\chi^i_{1,b}}\sum_{x_2\in\chi_2}\frac{1}{\pi^2N_0^2}\exp\left[-\frac{1}{N_0}\left\|\mathbf{y}-\mathbf{h}_1x_1-\mathbf{h}_2x_2\right\|^2\right] \quad (12)$$

where $\chi_2$ denotes signal signal set of $x_2$ and $\chi^i_{1,b}$ denotes the subset of the signal set $x_1 \in \chi_1$ whose labels have the value $b \in \{0,1\}$ in the position $i$. Let

$$y_1 = \frac{\mathbf{h}_1^\dagger\mathbf{y}}{\|\mathbf{h}_1\|},\ y_2 = \frac{\mathbf{h}_2^\dagger\mathbf{y}}{\|\mathbf{h}_2\|},\ h_{21} = \frac{\mathbf{h}_2^\dagger\mathbf{h}_1}{\|\mathbf{h}_2\|},\ y_2^{'}\left(x_1\right) = y_2 - h_{21}x_1 \quad (13)$$

$y_1$ and $y_2$ are match filter outputs for stream 1 and 2 respectively while $h_{21}$ is the cross-correlation between $\mathbf{h}_1$ and $\mathbf{h}_2$. $y_2^{'}\left(x_1\right)$ is the match filter output of second stream after removing the contribution from first stream. Ignoring $\left\|\mathbf{y}\right\|^2$ and adding $\left|y_1\right|^2$

$$\lambda^i(\mathbf{y},b)=\log\frac{1}{\pi^2N_0^2}\sum_{x_1\in\chi_{1,b}^i}\exp\left[-\frac{1}{N_0}\left\{\left|y_1-\left\|\mathbf{h}_1\right\|x_1\right|^2\right\}\right]\times$$
$$\sum_{x_2\in\chi_2}\exp\left[-\frac{1}{N_0}\left\{-2\Re\left(x_2^*\left\|\mathbf{h}_2\right\|y_2^{'}(x_1)\right)+\left|\left\|\mathbf{h}_2\right\|x_2\right|^2\right\}\right]$$

where $\Re$ indicates the real part. We rewrite above equation as

$$\begin{aligned}\lambda^i(\mathbf{y},b) &= \log\frac{1}{\pi^2N_0^2}\times\\ &\sum_{x_1\in\chi_{1,b}^i}\exp\left[-\frac{1}{N_0}\left\{\left|y_1-\left\|\mathbf{h}_1\right\|x_1\right|^2-\left|y_2^{'}(x_1)\right|^2\right\}\right]\times\\ &\sum_{x_2\in\chi_2}\exp\left[-\frac{1}{N_0}\left\{\left|y_2^{'}(x_1)-\left\|\mathbf{h}_2\right\|x_2\right|^2\right\}\right] \quad (14)\end{aligned}$$

This equation effectively decouples $x_1$ and $x_2$ . We propose a slight suboptimality i.e. for each value of $x_1\in\chi_{1,b}^i$, we retain one constellation point of $x_2$ which results in the most dominant exponential. To reduce the computational complexity of finding this point, we decouple $x_2$ into its real and imaginary parts i.e.

$$\begin{aligned}\left|\varphi_{x_2}^2\right|=\left|y_2^{'}(x_1)-\left\|\mathbf{h}_2\right\|x_2\right|^2 &= \Re^2\left(y_2^{'}(x_1)-\left\|\mathbf{h}_2\right\|x_2\right)+\\ &\Im^2\left(y_2^{'}(x_1)-\left\|\mathbf{h}_2\right\|x_2\right) \quad (15)\end{aligned}$$

where $\Im$ indicates the imaginary part. $\varphi_{x_2}$ is the match filter based metric for second stream for a particular symbol $x_1$ on first stream. The decoupling (15) combined with gray labeling in BICM reduces the search space for $x_2\in\chi_2$ to $\sqrt{M}/2$ points for $M$ ary QAM [12]. Quantization further reduces this to $1-4$ operations (depending on the constellation size of $x_2$) by looking for the closest real and imaginary parts of $y_2^{'}(x_1)$ to those of $\left\|\mathbf{h}_2\right\|x_2$. The constellation point of $x_2$ which minimizes (15) introduces little sub optimality in the bit metric which is now given as

$$\lambda^i(\mathbf{y},b)\approx\log\frac{1}{\pi^2N_0^2}\sum_{x_1\in\chi_{1,b}^i}$$
$$\exp\left[-\frac{1}{N_0}\left\{\left|y_1-\left\|\mathbf{h}_1\right\|x_1\right|^2+\left|\varphi_{x_2}\right|^2-\left|y_2^{'}(x_1)\right|^2\right\}\right] \quad (16)$$

Applying log sum approximation [5]

$$\lambda_1^i(\mathbf{y},b)\approx-\min_{x_1\in\chi_{1,b}^i}\left\{\left|y_1-\left\|\mathbf{h}_1\right\|x_1\right|^2+\left|\varphi_{x_2}\right|^2-\left|y_2^{'}(x_1)\right|^2\right\} \quad (17)$$

where $\left|y_1-\left\|\mathbf{h}_1\right\|x_1\right|^2$ is the metric for match filter output for $x_1$ ignoring $x_2$, $\left|\varphi_{x_2}\right|^2$ is the metric for the match filter output for $x_2$ taking into account $x_1$ and $\left|y_2^{'}(x_1)\right|^2$ can be termed as the correction factor.

The bit metric can be rewritten as

$$-\min_{x_1\in\chi_{1,b}^i}\left\{\left|y_1-\left\|\mathbf{h}_1\right\|x_1\right|^2+\left|\left\|\mathbf{h}_2\right\|x_2\right|^2-2\Re\left(x_2^*\left\|\mathbf{h}_2\right\|y_2^{'}(x_1)\right)\right\} \quad (18)$$

This implies reduction in complexity from $\mathcal{O}\left(\left|\chi_1\right|\left|\chi_2\right|\right)$ to $\mathcal{O}\left(\left|\chi_1\right|\right)$. Second stream $\mathbf{x}_2$ being high rate stream implies substantial reduction in complexity.

### A. *Complexity Analysis*

We compare the complexity of our proposed demodulator with that of MMSE SIC based demodulator. It is well known that for ML detection, the complexity for $x_1$ in dual stream BICM system is $\mathcal{O}\left(\left|\chi_1\right|\left|\chi_2\right|\right)$. In case of MMSE SIC based demodulator, the complexity reduces to $\mathcal{O}\left(\left|\chi_1\right|\right)$ for $x_1$. This complexity reduction has considerable overhead in the form of computing and employing MMSE filter followed by the unbiasing operation. The proposed demodulator also reduces the complexity to $\mathcal{O}\left(\left|\chi_1\right|\right)$ for the $x_1$ due to decoupling of $x_1$ and $x_2$ but has insignificant overhead. So a fair complexity comparison between two approaches would be the comparison of the complexity of overhead.

The minimum of (15) can be found by 1, 2 and 4 operations if $x_2$ belongs to QPSK, QAM16 and QAM 64 respectively. This is realized by quantizing the constellation of $\left\|\mathbf{h}_2\right\|x_2$. The sign and the magnitude of real and imaginary parts of $y_2^{'}(x_1)$ specify the quantized region of $\left\|\mathbf{h}_2\right\|x_2$ in which it lies which leads to finding the minimum in 1 to 4 operations (comparisons). The overhead for proposed demodulator therefore involves the computations given in (13) and $\eta_{x_2}$ i.e. the number of operations for finding $x_2$ which minimizes (15).

TABLE I
COMPUTATIONAL COMPLEXITY FOR CALCULATION OF LLR IN $n_r\times n_r$ SYSTEM

| Demodulator Type | No. of Complex Additions | No. of Complex Multiplications |
|---|---|---|
| MMSE SIC | $\mathbf{1}\left(4n_r^3-2n_r^2-n_r\right)$ $+\left\lvert\chi_1\right\rvert$ | $\mathbf{1}\left(4n_r^3+2n_r^2+3n_r\right)$ $+2\left\lvert\chi_1\right\rvert$ |
| Proposed Demodulator | $\mathbf{1}\left(5n_r-5\right)+$ $\left\lvert\chi_1\right\rvert\left(\eta_{x_2}+4\right)$ | $\mathbf{1}\left(5n_r\right)+$ $4\left\lvert\chi_1\right\rvert$ |

Table I shows the complexity for calculation of LLR for MMSE SIC approach and the proposed approach. Here we assume Gauss-Jordan elimination for matrix inversion. **1** indicates the operations which need to be done once during the period the channel remains constant. $\left|\chi_1\right|$ is the size of modulation alphabet of $x_1$. It is evident that complexity savings of proposed demodulator with respect to MMSE SIC shrinks as the alphabet size enhances while it expands with the increase in the size of system. An important point to underline here is that the proposed demodulator does not need estimation of noise variance while the same is required for MMSE based demodulator.

## V. SIMULATION RESULTS

We consider a $2\times2$ BICM MIMO OFDM system using the *de facto* standard, 64 state rate-$1/2$ convolutional encoder

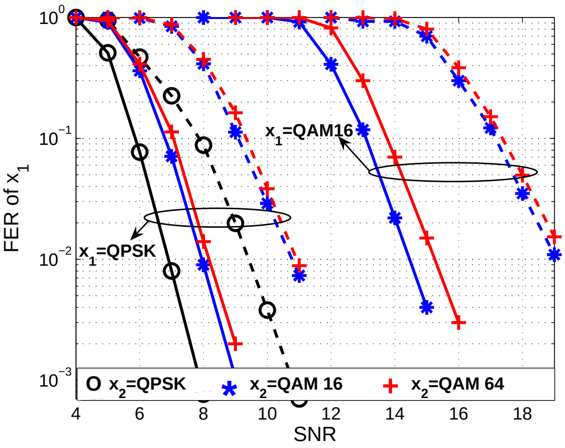

Fig. 5. Performance of low rate stream in $2 \times 2$ BICM MIMO OFDM system using 802.11n convolutional code. Continuous lines indicate proposed approach while dashed lines indicate MMSE approach. Note that the SNR is absolute SNR at each receiver branch (i.e. not $E_b/N_0$).

of 802.11n standard [2] and rate-$1/2$ punctured turbo code proposed for 3GPP LTE [4]. The MIMO channel has iid Gaussian matrix entries with unit variance. The channel is independently generated for each time instant and perfect CSI at the receiver is assumed. Furthermore, all mappings of coded bits to QAM symbols use Gray encoding. We consider MMSE approach [10] and the proposed approach. Spatial streams of equal power and non uniform rate are transmitted in $2 \times 2$ system. We focus on frame error rates for first stream (lower rate) as subsequent to stripping, the detection of second stream (higher rate) is trivial. The frame length of lower rate stream is fixed to 1296 information bits as per 802.11n [2]. Figs. 5 and 6 compare the performance of proposed approach with standard MMSE based approach. The proposed approach performs significantly better than the MMSE approach. Degradation of the performance for first stream as the rate (constellation size) of second stream increases confirms the earlier result of rate on first stream being a function of the rate on the second stream.

## VI. CONCLUSIONS

In this paper, we have focused on a broadcast strategy that exploits the UEP between the two spatial streams which is a consequence of SIC detection algorithm. For such a system, we have proposed a low complexity near optimal demodulator. Proposed demodulator is based on match filter outputs and results in a demodulation technique which has much reduced computational complexity and better performance than the standard linear equalizer based solutions. The idea of dual data streams with UEP has many potential applications with reference to prioritizing different data streams for different users in a broadcast scenario ,assigning two levels to multimedia codecs, MBMS and HDTV. The proposed scheme is valid for MIMO broadcast systems as WiMAX (802.16m).

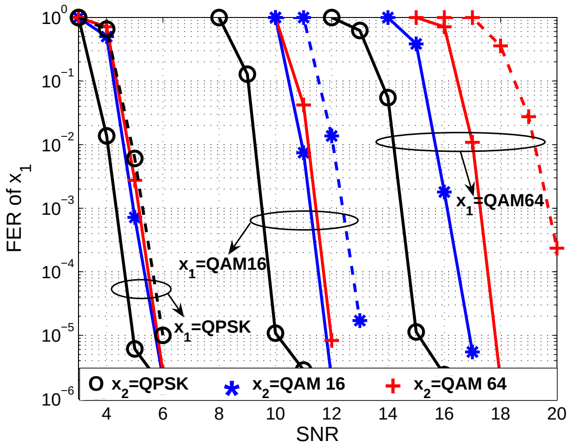

Fig. 6. Performance of low rate stream in $2 \times 2$ BICM MIMO OFDM system using 3GPP LTE turbo code. Continuous lines indicate proposed approach while dashed lines indicate MMSE approach. Block length of low rate stream is 1296 bits while number of iterations are 5.

## ACKNOWLEDGMENTS

Eurecom's research is partially supported by its industrial partners: BMW, Bouygues Telecom, Cisco Systems, France Télécom, Hitachi Europe, SFR, Sharp, ST Microelectronics, Swisscom, Thales. The research work leading to this paper has also been partially supported by the European Commission under the IST FP7 research network of excellence NEWCOM++.

## REFERENCES

[1] G. J. Foschini and M. J. Gans, “On limits of wireless communication in a fading environment when using multiple antennas,” *Wireless Pers. Commun.*, vol. 6, no. 3, pp. 311-335, Mar. 1998.

[2] IEEE 802.11 WG. IEEE 802.11n/D1.0 Draft Amendment: “Enhancements for Higher Throughput,” Mar. 2006.

[3] IEEE 802.16m-07/037r1, “Draft IEEE 802.16m Evaluation Methodology,” 2007

[4] 3GPP TR 25.913, “Requirements for Evolved UTRA (E-UTRA) and Evolved UTRAN (E-UTRAN),” v.7.3.0, Mar. 2006.

[5] G. Caire, G. Taricco, and E. Biglieri, “Bit-interleaved coded modulation,” *IEEE Trans. Inf. Theory*, vol. 44, pp. 927-946, May 1998.

[6] S. Shamai (Shitz) and Avi Steiner, “A Broadcast Approach for a Single-User Slowly Fading MIMO Channel,” *IEEE Trans. Inform. Theory*, vol. 49, no. 10, pp. 2617 - 2635, Oct. 2003.

[7] Y. Liu, K. N. Lau, C. Y. Takeshita and M. P. Fitz, “Optimal rate allocation for superposition coding in quasi static fading channels,”*in Proc. IEEE ISIT*, Lausanne, Switzerland, JunJul 2002.

[8] P. W. Wolniansky, G. J. Foschini, G. D. Golden, and R. A. Valenzuela, “V-BLAST: an architecture for realizing very high data rates over the rich scattering wireless channel,” in *Proc. ISSE*, Pisa, Italy Sep. 1998.

[9] G. D. Golden, G. J. Foschini, R. A. Valenzuela, and P. W. Wolniansky, “Detection algorithm and initial laboratory results using V-BLAST space time communication architecture,” *Electron. Lett.*, vol. 35, no. 1, pp. 14-16, Jan. 1998.

[10] I. Medvedev, B.A. Bjerke,R. Walton, J. Ketchum, M. Wallace and S. Howard, “A Comparison of MIMO Receiver Structures for 802.11N WLAN - Performance and Complexity” *Proc. IEEE PIMRC*, Sep. 2006

[11] G. Caire, S. Guemghar, A. Roumy and S. Verdu,“Maximizing the Spectral Efficiency of Coded CDMA Under Successive Decoding,”*IEEE Trans. Inf. Theory*, vol. 50, no. 1, pp. 152-164, Jan. 2004

[12] E. Akay and E. Ayanoglu, “Low complexity decoding of bit interleaved coded modulation”, *Proc. IEEE ICC*, vol. 2, Paris, France, June 2004, pp. 901-905.