# A MIMO Broadcast Strategy and Interference Cancellation in Single Frequency Cellular System

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***Abstract*—In this paper we consider channel coding for dual spatial streams with unequal error protection (UEP) for the objectives of prioritized handling of data in MIMO broadcast systems and interference cancellation in cellular networks. We present a broadcast strategy based on UEP for the dual-stream MIMO system which incorporates two levels of performance. The techniques presented here can be applicable to broadcast/multicast services in next generation cellular networks (e.g. Multimedia Broadcast Multicast Service i.e. MBMS). 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 two spatial streams have different rates and the reliably decoded information rate depends on the state of the channel which is determined by monitoring the received signal to noise ratio. The limited adaptability of the system helps gear up to a higher data rate as channel conditions improve without any adjustment at the transmitter. Standard receiver solutions for such schemes employ sub-optimal linear minimum mean square error (MMSE) successive stripping decoders. We use the newly proposed low complexity near optimal demodulator which is based on match filter outputs. We further extend this idea of dual data streams with UEP in MIMO systems to intracell interference cancellation at mobile station for single frequency reuse cellular networks.**

## 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 2 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. 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, BICM stands as a robust coding scheme for fading channels and OFDM reduces the complexity of equalization.

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. Shamai [6] termed the approach of single code layer at each transmit antenna as *MAC-outage approach*. Due to this transmission strategy, the receiver views a multiple access channel (MAC) and consequently the reception is based on successive interference cancellation (SIC) i.e. sequential decoding and subtraction (stripping) of spatial streams. We present a broadcast strategy based on unequal error protection (UEP) 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. Standard receiver solutions for such schemes including V-BLAST [7] [8] use stripping decoders which incorporate minimum mean square error (MMSE) filters [9] against the yet undecoded streams at each successive cancellation stage. This solution is complex and suboptimal. We use the newly proposed low complexity near optimal demodulator based on match filter outputs [10] for this system. We focus on equal-power non-uniform rate distribution between these spatial streams in view of successive stripping. First, the lower rate stream is detected and subsequently stripped off leading to the detection of higher rate stream. The literature discusses SIC and PIC detection schemes for CDMA systems in reference to different rates in multi user context [11].

We propose the idea of rate distribution for spatial streams with UEP in BICM MIMO broadcast systems with regard to a SIC detection scheme. 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. The idea has a limited similarity to superposition codes [12] whose signal

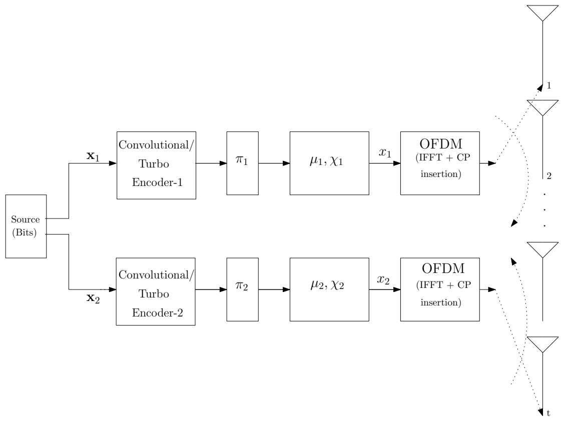


Fig. 1. Block diagram of Transmitter of $t \times 2$ BICM MIMO OFDM system. $\pi_1$ denotes random interleaver, $\mu_1$ labeling map and $\chi_1$ signal set for $\mathbf{x}_1$

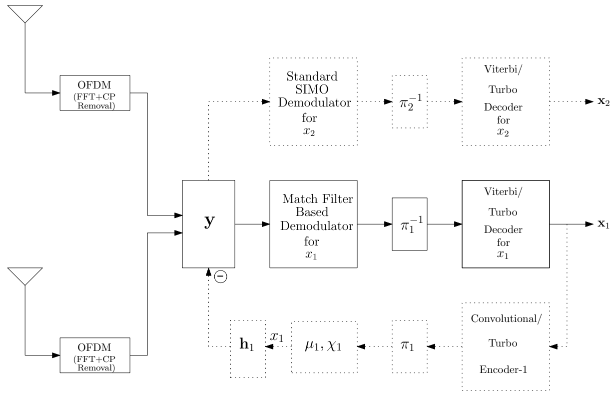


Fig. 2. Block diagram of SIC Receiver of BICM MIMO OFDM system. $\pi_1^{-1}$ denotes deinterleaver and $\mathbf{h}_1$ denotes the channel seen by $\mathbf{x}_1$.

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.

To cope with the ever-increasing demands on higher spectral efficiency, a tight frequency reuse will be adopted for future mobile systems as 3GPP LTE [4]. Moreover diversified data services will lead to high and different user data rates which combined with a tight frequency reuse factor will result in an interference-limited system. 3GPP is currently studying some intercell interference mitigation techniques [13]: interference cancellation (IC), interference coordination and interference randomization. Interference cancellation approach is based on spatial filtering and it requires the employment of multiple antennas user equipment. Intercell interference coordination approach capitalizes on efficient radio resource management techniques to coordinate the channel allocation in nearby cells and minimize the interference level. Finally, interference randomization policy spreads the users transmission over a distributed set of subcarriers in order to randomize the interference scenario and achieve frequency diversity gain. Amongst the three, future mobile stations (MS) being equipped with multiple antennas signify IC techniques which involve equalization and subtractive cancellation. Many sub-optimal linear detectors such as zero forcing and MMSE [14][15] have been proposed. We further extend the idea of dual-stream with UEP to intercell interference cancellation at MS for single frequency reuse cellular networks basing on the fact that space and cost constraints shall be confining upcoming MS to two antennas for quite some time. For this space diversity, we propose an interference canceling algorithm.

The paper is broadly divided into two sections. In section II we focus on dual-stream BICM MIMO broadcast scenario while section III is dedicated to interference cancellation in single frequency cellular networks.

## II. Dual-Stream BICM MIMO OFDM Broadcast System

### A. System Model

In this section we consider a MIMO broadcast system (without CSIT) which is a $t \times 2$ ($t \geq 2$) BICM MIMO OFDM system with 2 equal power and non-uniform rate spatial streams. We effectively reduce this to $2 \times 2$ 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 $\mathbf{x}_1$ and $x_2$ being the symbol of $\mathbf{x}_2$. 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 $n$-th frequency tone is given as:-

$$\mathbf{y}_n = \mathbf{h}_{1,n} x_1 + \mathbf{h}_{2,n} x_2 + \mathbf{z}_n, \qquad n = 1, 2, \cdots, N$$

where $N$ is the total number of frequency tones. We can conveniently drop the frequency index and can rewrite the system equation as

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

where $\mathbf{y}, \mathbf{z} \in \mathbb{C}^2$ are the vectors of received symbols and circularly symmetric complex white Gaussian noise of variance $N_0/2$ per real component (double-sided power spectral density) at the 2 receive antennas. $\mathbf{h}_1 \in \mathbb{C}^2$ is the vector characterizing flat fading channel response from first transmitting antenna to 2 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 $x_1, x_2$ of 2 streams are also assumed independent.

### B. Channel Capacity Analysis

The capacity of above described MIMO system with power constraint $P_T$ as given in [16] is

$$C = E_H \left\{ \log_2 \left[ \det \left( I + \frac{\rho}{2} H H^\dagger \right) \right] \right\} \tag{2}$$

where $\dagger$ indicates conjugate transpose, $I$ is $2 \times 2$ identity matrix and $H = [\mathbf{h}_1 \mathbf{h}_2]$ is the channel matrix. In this case $\rho = \frac{P_T}{N_0}$ is the average SNR at each receiver branch. The capacity expression for dual streams [1] from the chain rule is

$$I\left(\mathbf{y}; x_1 x_2 | H\right) = I\left(\mathbf{y}; x_1 | H\right) + I\left(\mathbf{y}; x_2 | H, x_1\right) \qquad (3)$$

For the Gaussian inputs, the explicit expressions of mutual information for the two streams are

$$I\left(\mathbf{y}; x_1 | H\right) = \log_2\!\Big[\det\Big\{\mathbf{I}+\sigma_1^2 \mathbf{h}_1 \mathbf{h}_1^\dagger \left(N_0 \mathbf{I}+\sigma_2^2 \mathbf{h}_2 \mathbf{h}_2^\dagger\right)^{-1}\Big\}\Big] \qquad (4)$$

and

$$I\left(\mathbf{y}; x_2 | H, x_1\right) = \log_2\left(1 + \frac{\sigma_2^2}{N_0}\left\|\mathbf{h}_2\right\|^2\right) \qquad (5)$$

For equal power distribution, $I\left(\mathbf{y}; x_1 | H\right) < I\left(x_2; \mathbf{y} | H, x_1\right)$ dictating $R_1 < R_2$ 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

$$I\left(\mathbf{y}; x_1\right) = H\left(x_1\right) - H\left(x_1 | \mathbf{y}\right)$$
$$= \log M_1 - \frac{1}{M_1} \sum_{x_1} \int_{\mathbf{y}} p\left(\mathbf{y}|x_1\right) \log \frac{\sum_{x_1} p\left(\mathbf{y}|x_1\right)}{p\left(\mathbf{y}|x_1\right)} d\mathbf{y} \qquad (6)$$

where $H\left(.\right) = -E \log p\left(.\right)$ 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 $H$ and $\mathbf{z}$. The above quantities can be easily approximated numerically using sampling (Monte-Carlo) methods with $N_n$ realizations of noise and $N_H$ realizations of the channel.

$$\begin{aligned} I\left(\mathbf{y}; x_1\right) &= \log M_1 - \frac{1}{M_1 M_2 N_z N_H} \sum_{\mathbf{x}} \sum_{H}^{N_H} \sum_{\mathbf{z}}^{N_z} \\ &\quad \log \frac{\sum_{x_1} \sum_{x_2} \exp\left[-\frac{1}{N_0}\left\|\mathbf{y} - H\mathbf{x}\right\|^2\right]}{\sum_{x_2} \exp\left[-\frac{1}{N_0}\left\|\mathbf{y} - H\mathbf{x}\right\|^2\right]} \end{aligned} \qquad (7)$$

Similarly the second mutual information expression is given by

$$I\left(\mathbf{y}; x_2 | x_1\right) = H\left(x_2 | x_1\right) - H\left(x_2 | \mathbf{y}, x_1\right)$$
$$= \log M_2 - \frac{1}{M_1 M_2} \sum_{\mathbf{x}} \int_{\mathbf{y}} p\left(\mathbf{y}|\mathbf{x}\right) \log \frac{\sum_{x_2} p\left(\mathbf{y}|\mathbf{x}\right)}{p\left(\mathbf{y}|\mathbf{x}\right)} d\mathbf{y} \qquad (8)$$

Estimation of this quantity using Monte-Carlo simulation

$$\begin{aligned} I\left(\mathbf{y}; x_2 | x_1\right) &= \log M_2 - \frac{1}{M_1 M_2 N_z N_H} \sum_{\mathbf{x}} \sum_{H}^{N_H} \sum_{\mathbf{z}}^{N_z} \\ &\quad \log \frac{\sum_{x_2} \exp\left[-\frac{1}{N_0}\left\|\mathbf{y} - H\mathbf{x}\right\|^2\right]}{\exp\left[-\frac{1}{N_0}\left\|\mathbf{y} - H\mathbf{x}\right\|^2\right]} \end{aligned} \qquad (9)$$

Fig. 4 shows the capacity of the first stream once the second stream is not yet decoded for different combinations of finite constellation alphabets. It clearly shows that 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.

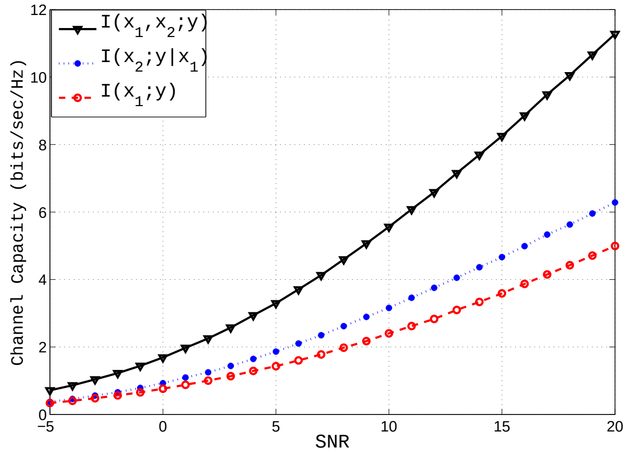


Fig. 3. Capacity of proposed dual-stream broadcast approach for Gaussian alphabets. Both streams have equal power.

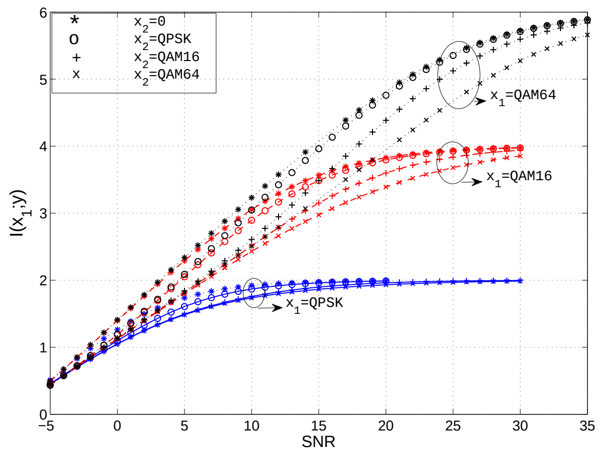


Fig. 4. Capacity of first stream in dual-stream broadcast approach for finite size alphabets once the second stream is not known. Both streams have equal power. $x_2 = 0$ indicates that second stream has been decoded and stripped off. Note that SNR includes power of both streams.

## C. Proposed Broadcast Strategy

The proposed broadcast approach (*MAC-outage* [6]) is motivated by the capacity of a Gaussian broadcast channel [18] with two users i.e.

$$\mathcal{C} = I\left(x_1; y_1\right) + I\left(x_2; y_2 | x_1\right) \qquad (10)$$

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 where the non-uniform rate is dictated by the above capacity analysis for finite constellations. 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

$$R_1 \leq I(\mathbf{y}; x_1) \tag{11}$$

and

$$R_2 \leq I(\mathbf{y}; x_2|x_1) \tag{12}$$

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. $\mathrm{SNR}_1$ while the higher rate stream $\mathbf{x}_2$ is designed for higher value of SNR i.e. $\mathrm{SNR}_2$. The received SNR of a particular user dictates two decoding options.

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

This leads us to SIC detection based MIMO broadcast scenario with equal power and non-uniform rate spatial streams. We use the newly proposed low complexity near optimal bit metric [10] for bit $b$ at the $i$th location of the $x_1$ which is based on decoupling of $x_1$ and $x_2$

$$\lambda_1^i(\mathbf{y}, b) \approx -\frac{1}{N_0}\left[\min_{x_1 \in \chi_{1,b}^i} \psi_b^i(x_1)\right] \tag{13}$$

where

$$\psi_b^i(x_1) = |y_1 - \|\mathbf{h}_1\| x_1|^2 + |\|\mathbf{h}_2\| x_2|^2 - 2\Re\left(x_2^* \|\mathbf{h}_2\| y_2'(x_1)\right) \tag{14}$$

and

$$y_1 = \frac{\mathbf{h}_1^\dagger \mathbf{y}}{\|\mathbf{h}_1\|},\ y_2 = \frac{\mathbf{h}_2^\dagger \mathbf{y}}{\|\mathbf{h}_2\|},\ h_{21} = \frac{\mathbf{h}_2^\dagger \mathbf{h}_1}{\|\mathbf{h}_2\|},\ y_2'(x_1) = y_2 - h_{21}x_1 \tag{15}$$

$\Re$ indicates the real part and $\chi_{1,b}^i$ denotes the subset of the signal set $x_1 \in \chi_1$ whose labels have the value $b \in \{0, 1\}$ in the position $i$.

### D. *Probability of Error*

Due to SIC detection algorithm, probability of error of second stream depends on whether the first stream has been detected correctly or not. Let $P$ denotes the block and $p$ the bit error probability. $P_1$ is the block error probability for first stream once second stream is undetected, $P_2^c$ is the error probability of second stream once first stream has been correctly detected and $P_2^w$ is the error probability of second stream once first stream has been wrongly detected. The block error probability of the system is given as

$$P_{sys} = P_1 + P_2^c(1 - P_1) + P_2^w P_1 \tag{16}$$

Using similar notational rules, the bit error probability of the system is given as

$$p_{sys} = p_1 + p_2^c(1 - P_1) + p_2^w P_1 \tag{17}$$

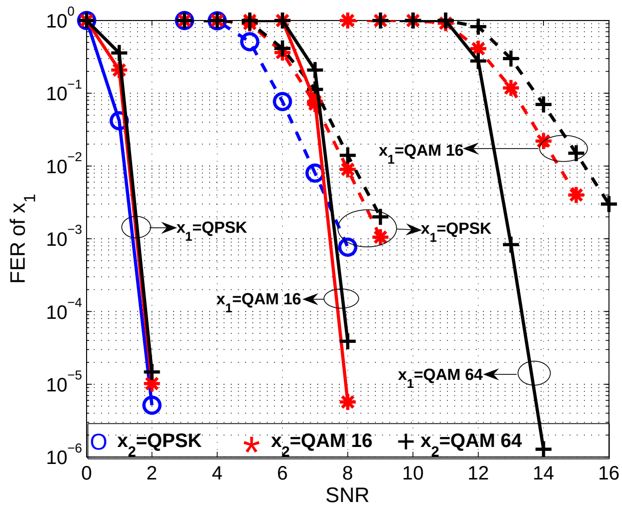


Fig. 5. Performance of low rate first stream in $2 \times 2$ BICM MIMO OFDM system with different rates (constellation sizes) of the second stream. Dashed lines indicate rate $1/2$ convolutional code (802.11n) while continuous lines indicate rate $1/3$ turbo code (3GPP LTE)

where $p_2^c$ is the bit error probability of the second stream once first stream has been correctly detected. The block and bit error probabilities are upper bounded by

$$P_{sys} \leq 2P_1 + P_2^c(1 - P_1) \tag{18}$$

$$p_{sys} \leq p_1 + p_2^c(1 - P_1) + \frac{1}{2}P_1 \tag{19}$$

where $P_2^c$ and $p_2^c$ are the block and bit error probabilities for standard $1 \times 2$ SIMO system respectively.

### E. *Simulation Results*

We consider a $2 \times 2$ equal power non-uniform rate BICM MIMO OFDM broadcast system using the *de facto* standard, 64 state rate-$1/2$ convolutional code of 802.11n standard [2] and rate-$1/3$ turbo code 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. Spatial streams of equal power and non uniform rate are transmitted in a $2 \times 2$ system. In this non-uniform rate broadcast 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 (SIMO system). The frame length of lower rate stream is fixed to 1296 bits as per 802.11n [2]. Fig. 5 shows the frame error rates for first stream once the second stream is not yet decoded for different QAM alphabets. Degradation of the performance for the first stream as the rate (constellation size) of second stream increases confirms that rate on first stream is a function of the rate on second stream for finite constellation sizes. Note that this is not the case for continuous codebooks generated from a Gaussian distribution as a capacity analysis revealed in the previous section.

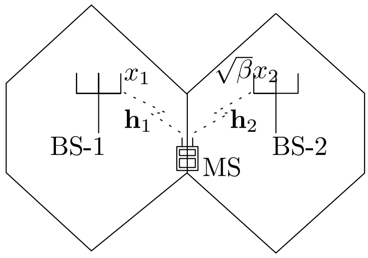


Fig. 6. Interference cancellation in single frequency cellular network. $x_1$ is the target signal, $x_2$ is the interference signal while $\beta$ is the interference ratio.

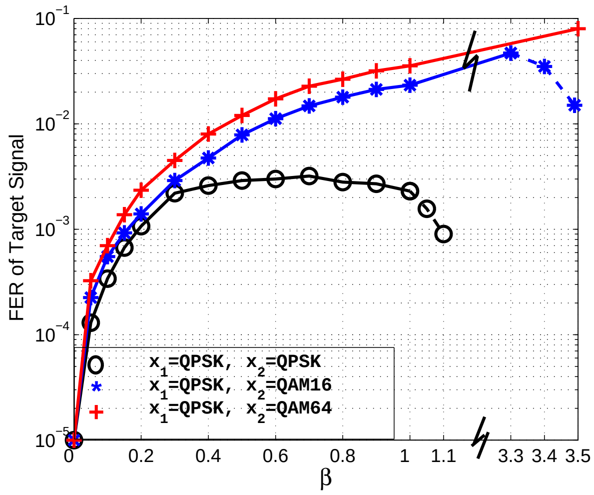


Fig. 7. Interference Cancellation. Continuous lines indicate BICM interference cancellation approach while dashed lines indicate BICM interference stripping approach. The target signal is $x_1$ QPSK. Convolutional Code. SNR is 4.5dB **NOTE**. The flash sign indicates discontinuity in the graph.

## III. Interference Cancellation

Adaptive modulation and coding schemes will be supported in the next generation wireless systems 3GPP LTE [4] leading to variable transmission rate streams which combined with tight frequency reuse will lead to interference limited systems. Different combinations of diversity and interference cancellation techniques are usually considered to make a receiver robust against variable rate interference [14]. Linear MMSE based approaches are being discussed for equalization and subtractive cancellation in 3GPP LTE[17]. We now extend the idea of dual-stream to interference cancellation in single frequency cellular networks with synchronized base stations and propose an algorithm for next generation mobile systems.

### *A. System Model*

Consider a single frequency reuse cellular network as shown in fig. 6. The system model is similar to the model of the previous section but now the two spatial streams arriving at the MS originate in two different base stations. The MS is equipped with two antennas. The received signal by MS is

$$\mathbf{y} = \mathbf{h}_1 x_1 + \sqrt{\beta}\mathbf{h}_2 x_2 + \mathbf{z} \tag{20}$$

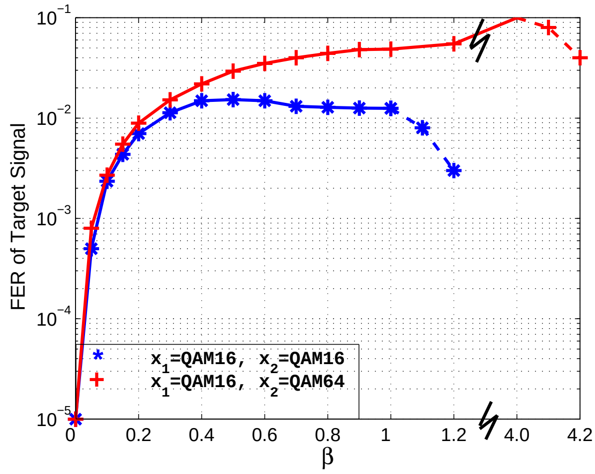


Fig. 8. Interference Cancellation. Continuous lines indicate BICM interference cancellation approach while dashed lines indicate BICM interference stripping approach. The target signal is $x_1$ QAM 16. Convolutional Code is used. Target stream is QAM16. SNR is 11dB.

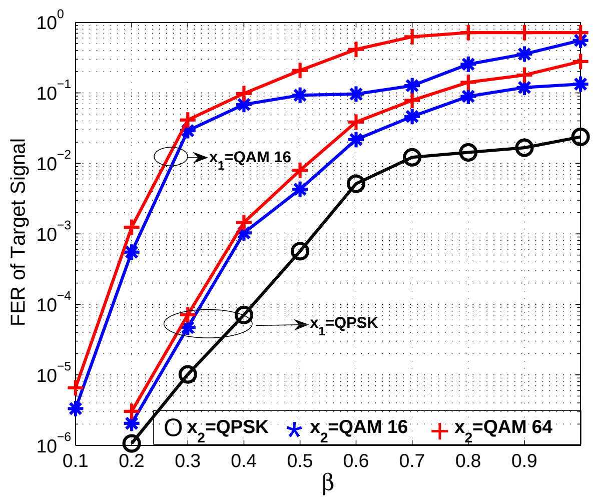


Fig. 9. Interference Cancellation. The target signal is $x_1$. Turbo Code with block length of 1296 bits of target stream and 5 iterations. SNR is -2dB when target signal is QPSK and is 3.5 dB when the target signal is QAM 16. BICM interference cancellation approach is used.

where $x_1$ is the target signal, $x_2$ is the interference signal and $\beta$ is the interference ratio. The earlier assumptions for symbols, channel vectors and noise remain valid for this system model.

Standard solutions for interference cancellation at downlink in 3GPP LTE are based on linear MMSE filters [17]. We propose an interference canceling algorithm with the the newly proposed demodulator [10]. In the proposed algorithm, there are two decoding options.

1) Decode the interfering stream with the bit metric (13). Strip out the interference and decode the target stream without interference. We refer this approach as BICM interference stripping.

2) Decode the target stream using the bit metric (13). Interfering stream is not decoded. We refer this approach as BICM interference cancellation.

In case when the interfering stream is of higher rate, the BICM interference cancellation option is used while when interfering stream is of lower rate, then BICM interference stripping option is used. However the interference ratio may dictate vice versa i.e. for higher values of $\beta$, BICM interference stripping option may be adopted for the scenario of higher rate interfering stream when higher interference ratio permits the decoding of higher rate interfering stream.

Therefore for the desired performance at the received SNR, the selection of either of the two decoding options is dictated by the comparative rate of interfering stream with respect to the desired stream and the interference ratio. The requisites for this algorithm are the knowledge of interference channel and MCS of interfering stream at the MS. A point to underline here is that MMSE based IC needs only the knowledge of interference channel at the MS.

### *B. Simulation Results*

The system settings for simulations are same as the settings in the previous section. We focus on rate $1/2$ convolutional code of 802.11n and rate-$1/3$ turbo codes of 3GPP LTE [4]. Figs. 7, 8 and 9 show the frame error rates of target stream for different values of $\beta$ and a given value of SNR for the proposed IC scheme.

Out of the two proposed decoding options, the adopted option for different values of interference ratio $\beta$ for detection of target stream is shown. For higher rate interfering stream, at lower values of $\beta$, BICM interference cancellation approach leads to better performance while for higher values of $\beta$, BICM interference stripping interference approach leads to improved performance. However the threshold value of $\beta$ at which switching from one to other approach takes place depends on the received SNR and the rate of interfering stream. For a given interference level, performance is generally degraded as the rate (constellation size) of the interfering stream increases even in the regime of moderate to low interference ratio. Convergence to SIMO performance for lower values of $\beta$ is evident in the simulation results.

## IV. CONCLUSIONS

We have focused on two ideas in this paper, firstly dual-stream broadcast scenario with UEP employing the novel optimal demodulator for BICM MIMO OFDM system using SIC and secondly interference cancellation in single frequency cellular networks as 3GPP LTE. 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 and assigning two levels to multimedia codecs. The proposed scheme is valid for MIMO broadcast systems as WiMAX (802.16m). We have then extended the idea to interference cancellation in single frequency reuse cellular networks (3GPP LTE). Exploiting the spatial diversity at the MS, we have presented two strategies of BICM interference cancellation and BICM interference stripping basing on the interference ratio and the rate of interfering stream.

## 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] 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.

[8] 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.

[9] 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

[10] Rizwan Ghaffar and Raymond Knopp , "Low Complexity BICM Demodulation for MIMO Transmission," submitted to *IEEE SPAWC 2008*

[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] 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,

[13] 3GPP Technical Report TR 25.814, Physical layer aspects for the evolved Universal Radio Access (E-UTRA), Release 7, 2006.

[14] David Bladsjö, Anders Furuskär, Stefan Jäverbring and Erik Larsson. "Interference Cancellation using Antenna Diversity for EDGE - Enhanced Data Rates in GSM and TDMA/136", *Proc IEEE VTC-Fall* vol. 4, pp. 1956-1960, 1999

[15] M. Debbah, B. Muquet, M. de Courville, M. Muck, S. Simoens, P. Loubaton,"A MMSE successive interference cancellation scheme for a newadjustable hybrid spread OFDM system,"*IEEE VTC-Spring* vo. 2, pp. 745-749, 2000

[16] H. Shin and J. Lee, "Capacity of multiple antenna fading channels: spatial fading correlation, double scattering and keyhole", *IEEE Trans. Inf. Theory*, vol. 49, no. 10, pp. 2636-2647, Oct. 2003.

[17] E. Dahlman, H. Ekstrom, A. Furuskar, Y. Jading, J. Karlsson, M. Lundevall, S. Parkvall, "The 3G Long-Term Evolution - Radio Interface Concepts and Performance Evaluation," *IEEE VTC-Spring 2006*. pp. 137-141 May 2006.

[18] T. Cover, "Broadcast Channels," *IEEE Trans. Inform. Theory,* vol. IT-18, pp. 2 - 14, Jan. 1972.

[19] S. Verdú, "Minimum Probability of Error for Asynchronous Gaussian Multiple-Access Channels." *IEEE Trans. Inf. Theory*, vol. 32, pp.85-96, Jan. 1986.