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ADAPTIVE TRANSMIT ANTENNA SELECTION AND POWER ALLOCATION SCHEME FOR TURBO-BLAST SYSTEM WITH IMPERFECT CHANNEL STATE INFORMATION

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Abstract—In this paper, a new technique that combines adaptive transmit antenna selection, transmit power allocation and iterative detection is introduced for the modified Turbo-BLAST system. At the transmitter, in order to minimize the BER performance of the overall system, an adaptive transmit antenna selection scheme is proposed to select the appropriate antenna subset for the actual transmission, and the proper power is allocated for the selected antennas subject to the total transmit power constraint. At the receiver the modified MMSE detector taking the imperfect CSI into account is used to remove the co-antenna interference. Finally the turbo principle is employed for iterative detection to further lower the BER results. Simulation results show that the introduced adaptive transmit antenna selection and power allocation algorithm can significantly improve the BER performance, and the iterative detection technique can further enhance the performance.

1. INTRODUCTION

Multiple-input multiple-output (MIMO) communication systems can provide a significant capacity increment over the conventional one through appropriate space-time processing [1, 2]. Bell-Labs Layered Space-Time (BLAST) is one of the promising architectures thanks to the advantages of low detection complexity and high data rates [3]. This new system combined BLAST structure with turbo principle is

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called Turbo-BLAST that can offer a reliable and practical solution to high rate transmission for wireless communications.

There have been some attempts to improve the performance of a traditional MIMO system. One such an approach is to incorporate a transmit power allocation strategy [4–8] into conventional MIMO system with equal power assigned to all the transmit antennas. But due to a large number of radio frequency chains, the increased implementation complexity seems to be a serious impact that limits its practical applications for MIMO system. However, the so-called transmit antenna selection technique could be an effective means of circumventing this drawback [9–12]. The performance of transmit antenna selection and power allocation methods are closely related to the channel state information (CSI). Practically, CSI at the receiver is subject to the error performance because of the non-real time data processing, quantization error and imperfect channel estimations [13–16].

In this paper, we propose a new strategy of adaptive transmit antenna selection and transmit power allocation (*ATAS/TPA*) scheme based on a postdetection signal-to-interference-plus-noise ratio (SINR) for the modified Turbo-BLAST system in the presence of imperfect CSI, which aims at minimizing the BER performance of the whole system. At the transmitter, the *ATAS/TPA* scheme is used to choose the appropriate antenna subset for data transmission and allocates proper power to every selected antenna subject to the total transmit power constraint, while at the receiver the iterative turbo strategy is employed for signal detection to further enhance the error performance. The theoretical analysis and numerical results show that the proposed approach is an effective method to improve bit error rate (BER) performance for Turbo-BLAST system.

This paper is organized as follows: after the introduction in Section 1, the basic channel model and system description are briefly introduced in Section 2. Section 3 is concerned with a new scheme of transmit antenna selection and power allocation with imperfect CSI. Section 4 presents a modified iterative detection algorithm for Turbo-BLAST system where the proposed *ATAS/TPA* scheme is adopted. The simulation results are given in Section 5. Finally, Section 6 summarizes the conclusion of the paper.

2. BASIC CHANNEL MODEL AND SYSTEM DESCRIPTION

Consider a Turbo-BLAST system with n_A transmit antennas, n_R receive antennas and n_T antennas selected from the total of n_A

antennas for the actual data transmission. Usually, $n_R \geq n_T$ is adopted to achieve the diversity gain in a rich scattering environment. Some research activities have been also dedicated to study the improved technique for V-BLAST system with $n_T \geq n_R$ [17]. Fig. 1 shows an illustrative diagram of a modified Turbo-BLAST system, where a data stream is first encoded, bit-interleaved by a random permuter, and then the interleaved bits are mapped into a symbol stream that is subsequently demultiplexed into n_T substreams with each of them allocated to appropriate power for the transmission.

The transmitted signals are received by the n_R antennas with the received signal at a sampling instant expressed as

$$\mathbf{r} = \mathbf{HPx} + \mathbf{n} \tag{1}$$

where $\mathbf{x} = [x_1, \ldots, x_{n_T}]^T$ and $\mathbf{r} = [r_1, \ldots, r_{n_T}]^T$ denote the transmit and receive column vectors at a sampling instant, respectively, $\mathbf{H} \in \mathbb{C}^{n_R \times n_T}$ denotes the complex channel matrix for the selected antennas. Similarly, $\mathbf{n} = [n_1, \ldots, n_{n_T}]^T$ is a column vector of additive Gaussian noise variables, where each component is independent and identically distributed (i.i.d) zero-mean complex Gaussian variables with the variance of σ_n^2. $\mathbf{P} = \mathrm{diag}(\sqrt{P_1}, \ldots, \sqrt{P_{n_T}})$ is the diagonal transmit power matrix with total power constraint $\sum_{k=1}^{n_T} P_k = n_T$.

At the receiver, a practical sub-optimum detection strategy based

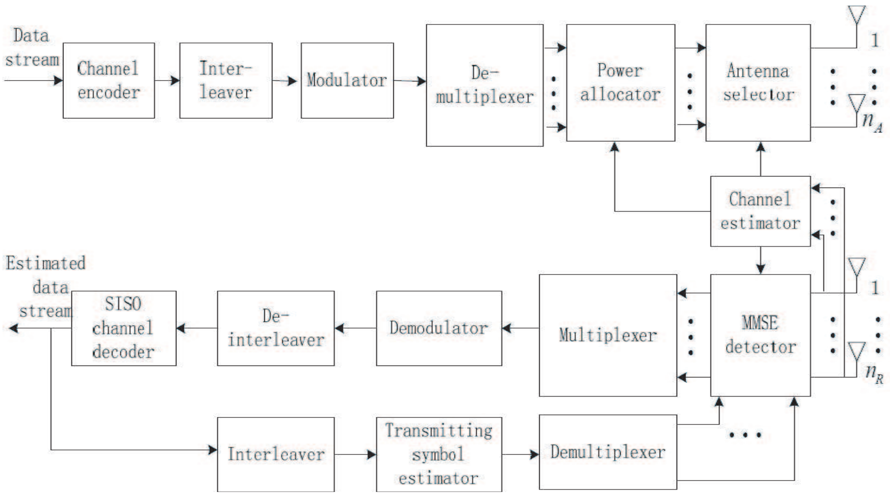

Figure 1. An illustrative diagram of a modified Turbo-BLAST system.

on the iterative "turbo" principle is used for the symbol detection. The encoding and interleaving for the data stream can be equivalently viewed as a serially concatenated encoding process as depicted in Fig. 1. The concatenated code can be decoded using a low-complexity iterative decoder which is similar as the iterative decoder for a serially concatenated turbo code. In the iterative decoding, the optimal decoding process can be separated into two stages, i.e., soft-input/soft-output (SISO) channel detector and SISO channel decoder, respectively, which mutually exchange the extrinsic information sent from one stage to another iteratively until the decoding process converges.

3. PROPOSED TRANSMISSION SCHEME WITH IMPERFECT CSI

3.1. Equivalent System Model

In this part we propose an equivalent system model for a Turbo-BLAST system using a novel adaptive strategy under the condition of imperfect CSI. The complex channel estimation matrix $\hat{\mathbf{H}} = [h_{ji}] \in \mathbb{C}^{n_R \times n_T}$ is corresponding to the selected antenna subset. Based on the imperfect channel model [14], the complex matrices $\mathbf{H}$ in (1) can be decomposed as

$$\mathbf{H} = \hat{\mathbf{H}} + \boldsymbol{\Xi} \tag{2}$$

where $\boldsymbol{\Xi} = [e_{ji}] \in \mathbb{C}^{n_R \times n_T}$ is a complex matrix related to the imperfect CSI. Note that the same CSI is known to both the transmitter and receiver. The elements of $\hat{\mathbf{H}}$ and $\boldsymbol{\Xi}$ can be modeled as independent complex Gaussian variables [14], which subsequently leads to the entries of $\mathbf{H}$ as complex Gaussian variables. Thus we can express their statistical distributions as $e_{ji} \sim \mathcal{CN}(0, \sigma_e^2)$ and $\hat{h}_{ji} \sim \mathcal{CN}(0, 1 - \sigma_e^2)$, which are all distributed by complex Gaussian law with σ_e^2 indicating the accuracy of the CSI.

Therefore in the presence of imperfect CSI, the received signal at a sampling instant can be formulated as

$$\mathbf{r} = \left(\hat{\mathbf{H}} + \boldsymbol{\Xi}\right)\mathbf{Px} + \mathbf{n} = \hat{\mathbf{H}}\mathbf{Px} + \boldsymbol{\Xi}\mathbf{Px} = \hat{\mathbf{H}}\mathbf{Px} + \hat{\mathbf{n}} \tag{3}$$

where $\hat{\mathbf{n}} \triangleq \boldsymbol{\Xi}\mathbf{Px} + \mathbf{n}$ is the equivalent additive noise consisting of the interference caused by the channel estimation errors and the complex Gaussian noise, respectively.

Let $\mathbf{f}$ be denoted as follows:

$$\mathbf{f} \triangleq \mathbf{\Xi P x}$$
$$= \begin{bmatrix} e_{11} & e_{12} & \dots & e_{1n_T} \\ e_{21} & e_{22} & \dots & e_{2n_T} \\ \vdots & \vdots & \ddots & \vdots \\ e_{n_R 1} & e_{n_R 2} & \dots & e_{n_R n_T} \end{bmatrix} \begin{bmatrix} \sqrt{P_1} & 0 & \dots & 0 \\ 0 & \sqrt{P_2} & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & \sqrt{P_{n_T}} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_{n_T} \end{bmatrix}$$
$$= \begin{bmatrix} \sum\limits_{k=1}^{n_T} e_{1k}\sqrt{P_k}x_k \\ \sum\limits_{k=1}^{n_T} e_{2k}\sqrt{P_k}x_k \\ \vdots \\ \sum\limits_{k=1}^{n_T} e_{n_R k}\sqrt{P_k}x_k \end{bmatrix} = \begin{bmatrix} f_1 \\ f_2 \\ \vdots \\ f_{n_R} \end{bmatrix} \tag{4}$$

Clearly, $\mathbf{f}$ is a zero-mean complex Gaussian column vector with its component $f_q = \sum\limits_{k=1}^{n_T} e_{qk}\sqrt{P_k}x_k, (q = 1, 2, \dots, n_R)$, whose variance can be evaluated as

$$\begin{aligned} \sigma_{f_q}^2 &= E\left(f_q f_q^*\right) = E\left\{\left[\sum_{k=1}^{n_T} e_{qk}\sqrt{P_k}x_k\right]\left[\sum_{j=1}^{n_T} e_{qj}\sqrt{P_j}x_j\right]^*\right\} \\ &= \sum_{k=1}^{n_T} P_k E\left[\left(e_{qk}e_{qk}^*\right)\left(x_k x_k^*\right)\right] \\ &= \sum_{k=1}^{n_T} P_k E\left[|e_{qk}|^2\right]\varepsilon\left[|x_k|^2\right] = \sigma_e^2 \sum_{k=1}^{n_T} P_k = n_T\sigma_e^2 \end{aligned} \tag{5}$$

The component of $\hat{\mathbf{n}}$ is given as $\hat{n}_q = f_q + n_q, (q = 1, \dots, n_R)$ by the afore-mentioned definition with the variance calculated as

$$\begin{aligned} \sigma_{\hat{n}_q}^2 &= E\{\hat{n}_q\hat{n}_q^*\} = E\{(f_q + n_q)(f_q + n_q)^*\} \\ &= E\{|f_q|^2\} + E\{|n_q|^2\} = n_T\sigma_e^2 + \sigma_n^2 \end{aligned} \tag{6}$$

Unfortunately, an ideal system may not be suitable for the imperfect CSI scenario, thus the proposed transmit antenna selection scheme can be used to deal with this problem effectively.

3.2. Transmit Antenna Selection Scheme

Given the proposed equivalent system model, we give a transmit antenna selection scheme in this part, which aims at minimizing the BER results of the whole system in the presence of imperfect CSI.

Theoretically, the error probability of a system monotonically decreases with the increasing postdetection signal-to-interference-plus-noise-ratio (SINR) [4]. Thus choosing an appropriate antenna subset that ensures the highest SINR for each transmitted symbol will significantly reduce the error probability. Obviously, there are $\binom{n_A}{n_T}$ possible selected subsets with n_T postdetection SINR's for each selection if n_T antennas are chosen from a total of n_A transmit antennas.

For minimum mean square error (MMSE) detector the postdetection SINR ρ_k for the k-th symbol for any antenna subset with perfect CSI can be approximately expressed as [4]

$$\rho_k \approx P_k \cdot \frac{\left|(\mathbf{v}_k[\mathbf{H}]_{1\to k})_{1k}\right|^2}{\left(\sigma_n^2 \left\|\mathbf{v}_k\right\|^2 + \sum\limits_{\ell\neq k} \left|(\mathbf{v}_k\left[\mathbf{H}\right]_{1\to k})_{1\ell}\right|^2\right)} = \frac{P_k}{\Lambda_k} \tag{7}$$

where $[\,\cdot\,]_{1\to k}$ is the matrix formed by zero-forcing the first k columns of the matrix, $(\cdot)_{ij}$ denotes the component at the i-th row and j-th column of the matrix. For the k-th transmitted symbol, P_k is the allocated transmit power, $\mathbf{v}_k$ is the weighted vector with equally assigned power and $1/\Lambda_k$ is the postdetection SINR formulated as follows:

$$\frac{1}{\Lambda_k} = \frac{\left|(\mathbf{v}_k\left[\mathbf{H}\right]_{1\to k})_{1k}\right|^2}{\left(\sigma_n^2 \left\|\mathbf{v}_k\right\|^2 + \sum\limits_{\ell\neq k} \left|(\mathbf{v}_k\left[\mathbf{H}\right]_{1\to k})_{1\ell}\right|^2\right)} \tag{8}$$

Based on the previously discussed equivalent system model, we treat $\hat{\mathbf{H}}$ as the actual complex channel matrix and $\hat{\mathbf{n}}$ as the equivalent complex noise, so the postdetection SINR ρ_k in (7) for the k-th symbol with perfect CSI can be modified for the scenario of imperfect CSI as below:

$$\hat{\rho}_k \approx P_k \cdot \frac{\left|\left(\hat{\mathbf{v}}_k\left[\hat{\mathbf{H}}\right]_{1\to k}\right)_{1k}\right|^2}{\left((n_T\sigma_e^2+\sigma_n^2)\left\|\hat{\mathbf{v}}_k\right\|^2 + \sum\limits_{\ell\neq k}\left|\left(\hat{\mathbf{v}}_k\left[\hat{\mathbf{H}}\right]_{1\to k}\right)_{1\ell}\right|^2\right)} = \frac{P_k}{\hat{\Lambda}_k} \tag{9}$$

where $\hat{\mathbf{v}}_k$ and $1/\hat{\Lambda}_k$ are the estimated weighted vector and postdetection SINR, given by (10), for the k-th transmitted symbol with equally assigned power, respectively.

$$\frac{1}{\hat{\Lambda}_k} = \frac{\left|\left(\hat{\mathbf{v}}_k \left[\hat{\mathbf{H}}\right]_{1\to k}\right)_{1k}\right|^2}{\left(\left(n_T\sigma_e^2 + \sigma_n^2\right)\|\hat{\mathbf{v}}_k\|^2 + \sum\limits_{\ell\neq k}\left|\left(\hat{\mathbf{v}}_k \left[\hat{\mathbf{H}}\right]_{1\to k}\right)_{1\ell}\right|^2\right)} \tag{10}$$

Let $\hat{\mathbf{H}}_A \in \mathbb{C}^{n_R\times n_A}$ denote the complex estimated channel matrix for all the n_A antennas. We use the notation $\mathbf{\Phi}_A$ for a matrix subset whose element matrix $\mathbf{\Psi}_i$ is formed by taking any n_T distinct columns from n_A columns of $\hat{\mathbf{H}}_A$. Thus, $\mathbf{\Phi}_A$ can be expressed as $\mathbf{\Phi}_A = \{\mathbf{\Psi}_1, \ldots, \mathbf{\Psi}_i, \ldots, \mathbf{\Psi}_\upsilon\}$ where $\upsilon = \begin{pmatrix} n_\mathrm{A} \\ n_T \end{pmatrix}$. By (9) we can obtain all the SINR's for any matrix subset with n_T postdetection SINR's. The complex matrix $\hat{\mathbf{H}}$ associated with the selected subset is resulted by the following criterion to consequently guarantee the minimum BER results for the overall system.

$$\hat{\mathbf{H}} = \mathop{\arg\max}_{\hat{\mathbf{H}}\in\mathbf{\Phi}_\mathrm{A}} \left\{ \min_{k=1,\ldots,n_T} \hat{\rho}_k \right\} \tag{11}$$

At the transmitter, according to the CSI sent back from the receiver, the control unit is adopted to select the transmit antennas by controlling the transmit power of every antenna, i.e., it only allocates the transmit power to the selected antennas and ignores the others. In practical implementation, the control unit is used to decide the active antennas. Hence, the transmit antennas selection technique is used to reduce the complexity of the signal processing not the cost of the RF chains.

Based on (11) the proper power is allocated to the selected antennas by the proposed power allocation strategy to further improve BER performance that is described in the next part.

3.3. Transmit Power Allocation Scheme

Clearly, the information and parity-check bits of a concatenated code play two different roles in a coded system [18]. Optimal power allocation can improve the performance of a coded system with a small performance gain and is only suitable for BPSK modulation scheme [18]. Thus, in this paper we treat the information and parity-check bits equally in order to get a suboptimal solution. Given imperfect channel state matrix $\hat{\mathbf{H}}$ and the channel estimation errors matrix $\mathbf{\Xi}$, the BER of the k-th substream can be tightly approximated by an exponential function [19] of $\hat{\rho}_k$ expressed as

$$\mathrm{BER}_k \approx a\exp(-b\hat{\rho}_k) = a\exp\left(\frac{bP_k}{-\hat{\Lambda}_k}\right) \tag{12}$$

where $a = 0.2$ and $b = 1.6/(2^R - 1)$ for M-QAM modulation, and $a = 0.2$ and $b = 7/(2^{1.9R}+1)$ for M-PSK modulation with $R = \log_2 M$.

If the error propagations are ignored, the overall BER may be calculated as the following arithmetic mean of the BER for every symbol because the transmitted symbols are independent to each other.

$$\mathrm{BER} = \frac{1}{n_T}\sum_{k=1}^{n_T}\mathrm{BER}_k = \frac{1}{n_T}\sum_{k=1}^{n_T} a\exp\left(-\frac{bP_k}{\hat{\Lambda}_k}\right) \tag{13}$$

where the BER is subject to an optimization problem given as below:

$$\begin{aligned} &\underset{\{P_k:k=1,\ldots,n_T\}}{\text{minimize}} \quad \mathrm{BER} = \tfrac{1}{n_T}\sum_{k=1}^{n_T}\mathrm{BER}_k \\ &\text{subject to} \quad \sum_{k=1}^{n_T} P_k = n_T \end{aligned} \tag{14}$$

The Lagrange multiplier method is employed to find the optimized power allocation matrix that can minimize the overall BER with total transmit power constraint. The cost function is evaluated as

$$J\left(P_1,\ldots,P_{n_T}\right) = \mathrm{BER} + \lambda\left(\sum_{k=1}^{n_T} P_k - n_T\right) \tag{15}$$

where λ is the well-known Lagrange multiplier. Hence, we can get a set of n_T equations by letting $\partial J/\partial P_k = 0$, for $k = 1, 2, \ldots, n_T$.

$$\frac{\partial f}{\partial P_k}\left(a\exp\left(-\frac{bP_k}{\hat{\Lambda}_k}\right)\right) = -n_T\lambda, \quad k = 1, 2, \ldots, n_T \tag{16}$$

The solutions for the transmit power P_k and the Lagrange multiplier λ can therefore be found as

$$P_k = -\frac{\hat{\Lambda}_k}{b}\ln\left(\frac{n_T\lambda\hat{\Lambda}_k}{ab}\right) \tag{17}$$

$$\lambda = \exp\left(-\frac{bn_T + \sum_{i=1}^{n_T}\hat{\Lambda}_k\ln\left(\frac{n_T\hat{\Lambda}_k}{ab}\right)}{\sum_{i=1}^{n_T}\hat{\Lambda}_k}\right) \tag{18}$$

for $k = 1, 2, \ldots, n_T$. For the proposed equivalent system, we choose the appropriate antenna subset for the actual transmission using (11) and allocate the proper power to the selected antennas by (17).

4. ITERATIVE DETECTION ALGORITHM FOR MODIFIED TURBO-BLAST SYSTEM

To further enhance the error performance, in this section the iterative detection strategy is employed for the modified Turbo-BLAST system with imperfect CSI.

Let $\mathbf{r}$ be the received symbol vector at a sampling instant, by (1) and (6) the vector $\mathbf{r}$, corrupted by the channel noise and interferences, is given as

$$\mathbf{r} = \hat{\mathbf{h}}_k \sqrt{P_k} x_k + \hat{\mathbf{H}}_{\bar{k}} \mathbf{P}_{\bar{k}} \mathbf{x}_{\bar{k}} + \hat{\mathbf{n}} \tag{19}$$

where x_k be the k-th transmitted signal at a sampling epoch, $\hat{\mathbf{h}}_k$ is the k-th column of the matrix $\hat{\mathbf{H}}$ and

$$\hat{\mathbf{H}}_{\bar{k}} \triangleq \left[\hat{\mathbf{h}}_1, \ldots, \hat{\mathbf{h}}_{k-1}, \hat{\mathbf{h}}_{k+1}, \ldots, \hat{\mathbf{h}}_{n_T}\right] \tag{20}$$

$$\mathbf{x}_{\bar{k}} \triangleq [x_1, \ldots, x_{k-1}, x_{k+1}, \ldots, x_{n_T}]^T \tag{21}$$

$$\mathbf{P}_{\bar{k}} \triangleq \operatorname{diag}\left(\sqrt{P_1}, \ldots, \sqrt{P_{k-1}}, \sqrt{P_{k+1}}, \ldots, \sqrt{P_{n_T}}\right) \tag{22}$$

By (20)–(22), the decision statistic of the k-th substream using a linear filter $\hat{\mathbf{w}}_k$ can be expressed as

$$y_k = \underbrace{\hat{\mathbf{w}}_k^H \hat{\mathbf{h}}_k \sqrt{P_k} \mathbf{x}_k}_{\hat{q}_k} + \underbrace{\hat{\mathbf{w}}_k^H \hat{\mathbf{H}}_{\bar{k}} \mathbf{P}_{\bar{k}} \mathbf{x}_{\bar{k}}}_{\hat{g}_k} + \underbrace{\hat{\mathbf{w}}_k^H \hat{\mathbf{n}}}_{\hat{z}_k} \tag{23}$$

where $\hat{q}_k$, $\hat{g}_k$ and $\hat{z}_k$ are the desired response filtered by $\hat{\mathbf{w}}_k$, the co-antenna interference and the phase-rotated equivalent noise, respectively, $(\cdot)^H$ denotes the complex conjugate transpose of a matrix.

The co-antenna interference can be removed from y_k by the proposed multi-substream detector and soft interference cancellation based on MMSE principle. The improved estimation of the transmitted symbol x_k can be formulated as

$$\tilde{x}_k = \hat{\mathbf{w}}_k^H \mathbf{r} - \hat{g}_k \tag{24}$$

where $\tilde{x}_k$ is the estimate of the symbol x_k, and $\hat{g}_k$ is the linear combination of the interfering substreams. The estimation error is defined as $\Delta x_k = \tilde{x}_k - x_k$. The weighted vector $\hat{\mathbf{w}}_k$ and the interference estimation $\hat{g}_k$ are optimized by minimizing the mean-square estimation error Δx_k between each substream and the related estimate, by the following cost function

$$\left(\hat{\hat{\mathbf{w}}}_k, \hat{\hat{g}}_k\right) = \arg \min_{(\hat{\mathbf{w}}_k, \hat{g}_k)} \quad E\left[\|\tilde{x}_k - x_k\|_2^2\right] \tag{25}$$

where the expectation is taken over the equivalent noise $\hat{\mathbf{n}}$ and the statistics of the data sequence $\mathbf{x}$.

Next we use standard minimization technique to solve the optimization problem that is expanded as (26) for the original expression in (25).

$$\begin{aligned}\text{Cost} &= E\left[\|\tilde{x}_k - x_k\|^2\right] = E\left[\left\|\hat{\mathbf{w}}_k^H \mathbf{r} - \hat{g}_k - x_k\right\|^2\right] \\ &= \hat{\mathbf{w}}_k^H E\left(\mathbf{r}\mathbf{r}^H\right)\hat{\mathbf{w}}_k - \hat{\mathbf{w}}_k^H E\left[\mathbf{r}(\hat{g}_k + x_k)^*\right] \\ &\quad - E\left[\mathbf{r}(\hat{g}_k + x_k)^*\right]^H \hat{\mathbf{w}}_k + E\left[(\hat{g}_k + x_k)(\hat{g}_k + x_k)^*\right] \qquad (26)\end{aligned}$$

where

$$\begin{aligned}E\left(\mathbf{r}\mathbf{r}^H\right) &= (\hat{\mathbf{h}}_k\sqrt{P_k})(\hat{\mathbf{h}}_k\sqrt{P_k})^H + (\hat{\mathbf{H}}_{\bar{k}}\mathbf{P}_{\bar{k}})E\left(\mathbf{x}_{\bar{k}}\mathbf{x}_{\bar{k}}^H\right)(\hat{\mathbf{H}}_{\bar{k}}\mathbf{P}_{\bar{k}})^H \\ &\quad + (n_T\sigma_e^2 + \sigma_n^2)\mathbf{I}_{n_R} \qquad (27)\end{aligned}$$

and

$$\begin{aligned}E\left[\mathbf{r}(\hat{g}_k + x_k)^*\right] &= E\left[(\hat{\mathbf{h}}_k\sqrt{P_k}x_k + \hat{\mathbf{H}}_{\bar{k}}\mathbf{P}_{\bar{k}}\mathbf{x}_{\bar{k}} + \hat{\mathbf{n}})(\hat{g}_k + x_k)^*\right] \\ &= \hat{\mathbf{h}}_k\sqrt{P_k} + \hat{\mathbf{H}}_{\bar{k}}\mathbf{P}_{\bar{k}}E(\mathbf{x}_{\bar{k}})\hat{g}_k^* \qquad (28)\end{aligned}$$

The cost function in (26) can be further evaluated as

$$\begin{aligned}\text{Cost} = \hat{\mathbf{w}}_k^H &\left[\left(\hat{\mathbf{h}}_k\sqrt{P_k}\right)\left(\hat{\mathbf{h}}_k\sqrt{P_k}\right)^H + \left(\hat{\mathbf{H}}_{\bar{k}}\mathbf{P}_{\bar{k}}\right)E\left(\mathbf{x}_{\bar{k}}\mathbf{x}_{\bar{k}}^H\right)\left(\hat{\mathbf{H}}_{\bar{k}}\mathbf{P}_{\bar{k}}\right)^H\right. \\ &+ \left.\left(n_T\sigma_e^2 + \sigma_n^2\mathbf{I}_{n_R}\right)\right]\hat{\mathbf{w}}_k - \hat{\mathbf{w}}_k^H\left[\hat{\mathbf{h}}_k\sqrt{P_k} + \hat{\mathbf{H}}_{\bar{k}}\mathbf{P}_{\bar{k}}E\left(\mathbf{x}_{\bar{k}}\right)\hat{g}_k^*\right] \\ &- \left[\hat{\mathbf{h}}_k\sqrt{P_k} + \hat{\mathbf{H}}_{\bar{k}}\mathbf{P}_{\bar{k}}E\left(\mathbf{x}_{\bar{k}}\right)\hat{g}_k^*\right]^H\hat{\mathbf{w}}_k \\ &+ E\left(\hat{g}_k\hat{g}_k^* + x_k\hat{g}_k^* + \hat{g}_k x_k^* + x_k x_k^*\right) \qquad (29)\end{aligned}$$

The linear combination of interfering substreams $\hat{g}_k$ and the weighted vector $\hat{\mathbf{w}}_k$ are obtained in (30) and (31) by letting $\partial\text{Cost}/\partial\hat{g}_k^* = 0$ and $\partial\text{Cost}/\partial\hat{w}_k^* = 0$, respectively.

$$\hat{g}_k = \hat{\mathbf{w}}_k^H(\hat{\mathbf{H}}_{\bar{k}}\mathbf{P}_{\bar{k}})E(\mathbf{x}_{\bar{k}}) \qquad (30)$$

$$\hat{\mathbf{w}}_k = \left[\mathbf{Q} + \mathbf{S} + (n_T\sigma_e^2 + \sigma_n^2)\mathbf{I}_{n_R}\right]^{-1}(\hat{\mathbf{h}}_k\sqrt{P_k}) \qquad (31)$$

where

$$\mathbf{Q} = (\hat{\mathbf{h}}_k\sqrt{P_k})(\hat{\mathbf{h}}_k\sqrt{P_k})^H \qquad (32)$$

$$\mathbf{S} = (\hat{\mathbf{H}}_{\bar{k}}\mathbf{P}_{\bar{k}})\left\{\mathbf{I}_{(n_T-1)} - \text{diag}\left[E(\mathbf{x}_{\bar{k}})E(\mathbf{x}_{\bar{k}})^H\right]\right\}(\hat{\mathbf{H}}_{\bar{k}}\ \mathbf{P}_{\bar{k}})^H \qquad (33)$$

Therefore the weighted vector $\hat{\mathbf{w}}_k$ is used for the modified Turbo-BLAST system in the presence of imperfect CSI. Thus (24) can be rewritten as

$$\begin{aligned}\tilde{x}_k = \hat{\mathbf{w}}_k^H\mathbf{r} - \hat{g}_k &= \left\{\left[\mathbf{Q} + \mathbf{S} + \left(n_T\sigma_e^2 + \sigma_n^2\right)\mathbf{I}_{n_R}\right]^{-1}(\hat{\mathbf{h}}_k\sqrt{P_k})\right\}^H \\ &\quad \left[\mathbf{r} - (\hat{\mathbf{H}}_{\bar{k}}\mathbf{P}_{\bar{k}})E(\mathbf{x}_{\bar{k}})\right] \qquad (34)\end{aligned}$$

For the first iteration, we assume $E(\mathbf{x}_{\bar{k}}) = \mathbf{0}$, and thus the linear MMSE detection for the k-th substream becomes

$$\begin{aligned}\tilde{x}_k &= \left\{\left[\left(\hat{\mathbf{h}}_k\sqrt{P_k}\right)\left(\hat{\mathbf{h}}_k\sqrt{P_k}\right)^H + \left(\hat{\mathbf{H}}_{\bar{k}}\ \mathbf{P}_{\bar{k}}\right)\left(\hat{\mathbf{H}}_{\bar{k}}\mathbf{P}_{\bar{k}}\right)^H\right.\right.\\ &\quad \left.\left. +\ \left(n_T\sigma_e^2 + \sigma_n^2\right)\mathbf{I}_{n_R}\right]^{-1}\left(\hat{\mathbf{h}}_k\sqrt{P_k}\right)\right\}^H \mathbf{r}\\ &= \left(\hat{\mathbf{h}}_k\sqrt{P_k}\right)^H\left[\left(\hat{\mathbf{H}}\mathbf{P}\right)\left(\hat{\mathbf{H}}\mathbf{P}\right)^H + \left(n_T\sigma_e^2 + \sigma_n^2\right)\mathbf{I}_{n_R}\right]^{-1}\mathbf{r} \quad (35)\end{aligned}$$

Next, we assume that $E(\mathbf{x}_{\bar{k}}) \to \mathbf{x}_{\bar{k}}$ with the increasing number of iterations, where the MMSE interference canceller for the modified Turbo-BLAST system using optimal antennas selection and power allocation with imperfect CSI is

$$\begin{aligned}\tilde{x}_k &= \left[(\hat{\mathbf{h}}_k\sqrt{P_k})^H(\hat{\mathbf{h}}_k\sqrt{P_k}) + (n_T\sigma_e^2 + \sigma_n^2)\right]^{-1}\\ &\quad (\hat{\mathbf{h}}_k\sqrt{P_k})^H\left[r - \hat{\mathbf{H}}_{\bar{k}}\mathbf{P}_{\bar{k}}\mathbf{x}_{\bar{k}}\right] \quad (36)\end{aligned}$$

The performance of iterative scheme depends on the accuracy of the channel estimation matrix and the adaptive method.

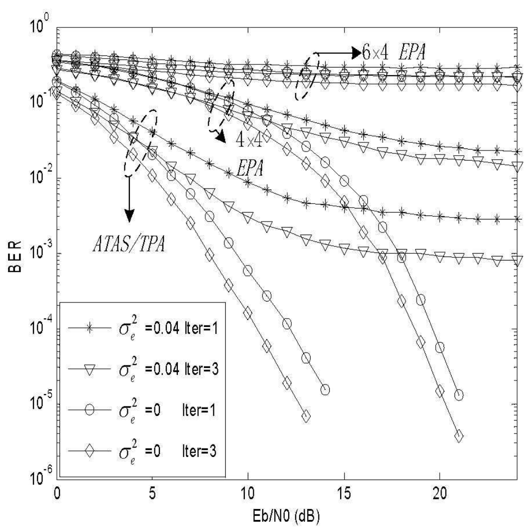

Figure 2. BER performance of traditional and modified Turbo-BLAST systems using 8-PSK modulation in different iterative detections under the conditions of perfect and imperfect CSI.

5. SIMULATION RESULTS

In this section we compare the BER performance of the traditional and modified Turbo-BLAST systems, where the proposed adaptive transmit antenna selection and power allocation strategy is adopted in the latter case. The Turbo-BLAST system studied here for the simulation has four receive antennas and a total of six transmit antennas with four of them chosen for the actual transmission. At the transmitter, the data stream is first encoded by a rate-1/2 convolutional code with generator (7, 5), then bit-interleaved by a random permuter and finally the interleaved bits are modulated by 8-PSK and 4-QAM modulation schemes, whose BER performance is given in Figs. 2–5, respectively. The modified Turbo-BLAST system employs the proposed adaptive transmit antenna selection and transmit power allocation denoted by "*ATAS/TPA*", while the traditional Turbo-BLAST system adopts the equal power allocation strategy denoted by "$n_R \times n_T$ *EPA*", where $n_R \times n_T$ denotes that the traditional Turbo-BLAST system is equipped with n_T transmit and n_R receive antennas.

It can be observed from Figs. 2 and 3 that the modified Turbo-BLAST system outperforms the traditional system in all cases under the same conditions, regardless of the modulation schemes and the status of CSI. This implies that the proposed transmit antenna

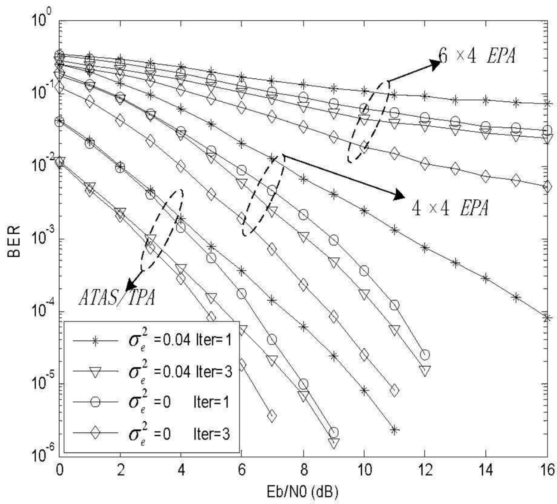

Figure 3. BER performance of traditional and modified Turbo-BLAST systems using 4-QAM modulation in different iterative detections under the conditions of perfect and imperfect CSI.

selection and power allocation strategy is an effective means to improve BER performance even with the imperfect CSI. For example, at a BER of 10^{-4}, we can see from Figs. 2 and 3 for 8-PSK and 4-QAM that there are 7 dB and 5 dB gains for the modified system over the traditional one in the 1st detection iteration under the condition of perfect CSI, i.e., $\sigma_e^2 = 0$. Moreover, the BER results are quickly lowered with the increasing detection iterations. For instant, in the 3rd iterative detection for 8-PSK and 4-QAM, there are 1 dB and 2 dB gains attained for the modified Turbo-BLAST system using *ATSA/TPA* over the conventional one under the condition of perfect CSI. Clearly, the BER performance of 6×4 EPA system provides even more worse performance than the 4×4 EPA system because the co-channel interferences become more significant when the number of transmit antennas is increased.

Figures 4 and 5 offer the BER performance in different SNR's (signal to noise ratio) with imperfect CSI, which exhibit that the BER values will be gradually unchanged as constants when the obtained CSI is more accurate. For example, $\sigma_e^2 \leq 10^{-4}$ as a threshold for 8-PSK while $\sigma_e^2 \leq 10^{-3}$ as a threshold for 4-QAM. Figs. 4 and 5 also clearly demonstrate that the impact of CSI is more severe for the higher SNR cases because that when SNR is very high, i.e., $\sigma_n^2 \to 0$, the BER performance mainly depends on the accuracy of CSI.

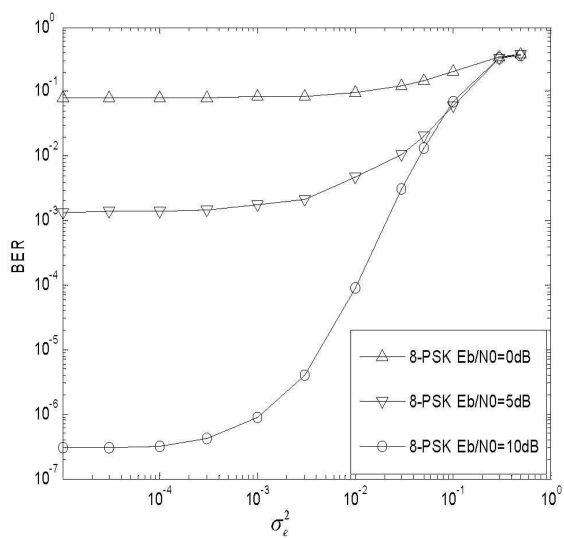

Figure 4. BER performance of modified Turbo-BLAST systems using 8-PSK modulation in different values of Eb/N0 with imperfect CSI.

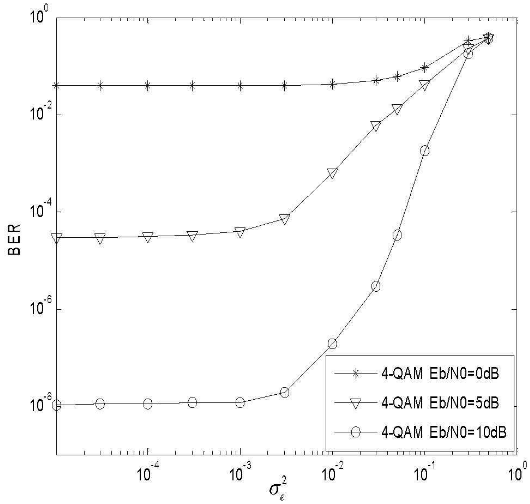

Figure 5. BER performance of modified Turbo-BLAST systems using 4-QAM modulation in different values of Eb/N0 with imperfect CSI.

6. CONCLUSION

In this paper, we propose a new strategy that combines adaptive transmit antenna selection, power allocation and iterative detection techniques into one synergy to improve the BER performance for the modified Turbo-BLAST system.

Based on the equivalent system model used in this paper and the derived variance of the equivalent noise, the approximate postdetection SINR for MMSE detector is theoretically obtained and the optimal antenna subset is chosen to ensure the minimum BER results. The Lagrange multiplier method is then employed to find the optimized power allocation matrix which can minimize the BER results for the whole system subject to the total transmit power constraint. Finally, the iterative detection technique is adopted for the modified Turbo-BLAST system to further improve the BER performance.

Simulation results show that the newly introduced method is an effective means to enhance the performance of Turbo-BLAST system in both cases of perfect and imperfect CSI.

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