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Optimal Power Allocation Strategy for TBLAST Based 4G Systems

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ABSTRACT

There is a big demand for increasing number of subscribers in the fourth generation mobile communication systems. However, the system performance is limited by multi-path propagations and lack of efficient power allocation algorithms in conventional wireless communication systems**.** Optimal resource allocation and interference cancellation issues are critical for the improvement of system performance such as throughput and transmission reliability. In this paper, a turbo coded bell lab space time system (TBLAST) with optimal power allocation techniques based on eigen mode, Newton and convex optimization method and carrier-interference-and-noise ratio (CINR) are proposed to improve link reliability and to increase throughput with reasonable computational complexity. The proposed scheme is evaluated by Monte-Carlo simulations and is shown to outperform the conventional power allocation scheme.

Keywords: Carrier Interference and Noise Ratio (CINR), Convolutional Turbo Coded Bell Space Time (TBLAST), Eigen Mode (EM), Optimal Power Allocation (OPL), Automatic Differentiation (AD), Symbolic Derivative (SD)

1. Introduction

This decade has witnessed incredible development in mobile wireless communications. Multiple-input and multiple-output (MIMO) techniques and adaptive antenna system (AAS) have been adopted in the 4th generation (4G) systems, e.g., worldwide interoperability microwave access (WiMAX) and long term evolution (LTE) systems. It is well known that wireless communication systems are interference limited, i.e. their throughput and quality of service are largely affected by various impairments such as multiuser inference (MUI), intersymbol interference (ISI) and spatial correlation, etc..

MIMO and orthogonal frequency division multiplexing (OFDM) techniques have been adopted in 4G systems. OFDM technique transforms a frequency selective fading channel into parallel flat fading channels which provides an efficient way to improve MIMO and AAS system performance. The single-carrier frequency division multiple access (SC-FDMA) and orthogonal frequency division multiple access (OFDMA) have been employed in the uplink of the WiMAX (IEEE802.16e) and LTE systems, respectively, to mitigate the effect of channel fading and interference. In 4G systems, the channel quality is measured by the carrier-interferer-noise-ratio (CINR), defined by the ratio between the power of useful subcarriers in the OFDM and the power of noise plus interference.

The issues of allocating power among subcarriers in OFDM systems have been investigated extensively [1,2]. The power control of an OFDM system and its subchannels is an efficient way to improve system performance such as maximizing system capacity and reducing bit error ratio (BER). Thus, the power allocation schemes and their application in the MIMO-OFDMA as well as AAS systems have attracted a lot of attention from both academia and industry.

It has also been reported that in 4G systems, there exists carrier frequency offset which destroys the orthogonality between subcarriers, leading to inter-carrier interference [3] which can deteriorate system performance significantly. In addition, spatial correlation has more impact on the uplink than on the downlink [4] of 4G systems. Interference cancellation (IC) techniques have been recommended as an efficient solution to tackle this problem. In 4G systems, optimal resource allocation (OPL) can be implemented by adaptive modulation and coding (AMC) as well as with channel state information at the transmitter (CSIT). Precoding (beamforming) with CSIT is a technique that can effectively utilize optimal resource to maximize throughput or improve transmission link quality.

In 4G systems, CINR [5] gives an indication for the underlying channel condition, and has been used in WiMAX and LTE systems as feedback information from mobile terminals to base station. Conventional optimal methodologies usually have prohibitive computation complexity which prevents them from practical implementation. Eigenvalue mode (EM) has been regarded as an efficient way to achieve desirable performance with reasonable complexity. For these reasons, we consider the use of CINR and develop an EM based algorithm in this paper.

Space time coding (STC) and spatial multiplexing (SM) also called the BLAST have been considered in the 4G standards [6]. In this paper, we investigate BLAST techniques, which can achieve good performance with low computational complexity by successive interference cancellation (SIC) algorithm [7]. The disadvantage of Vertical BLAST is the lack of diversity for transmission link. To tackle this problem, parallel convolutional coding (PCCC) coded BLAST can be employed to compensate the diversity loss in the conventional VBLAST. Turbo BLAST (TBLAST) was proposed in [6] to reduce the complexity of such systems. The principle is to repeat the process of passing soft information instead of hard decision between the MIMO detector and the channel decoder. As such, the system performance can be improved in an iterative manner.

However, the OPL and interference cancellation techniques as well as TBLAST have not been considered in the current WiMAX and LTE standards. This paper provides a feasibility study of utilizing the OPL and TBLAST techniques on the transmitter and receiver side, respectively. It is reasonable to believe that the results obtained from this study are of direct relevance to the future development of 4G standards.

2. Literature Review

2.1. Review of CINR Utilization

Channel estimation and resource optimisation are the two key issues that can determine the physical layer system performance in both LTE and WiMAX systems. Recently, major equipment vendors issued a proposal that involved Physical CINR and power allocation to improve the WiMAX system performance [8,9] in WiMAX Forum. Channel estimation is performed based on CINR. CSIT or PCINR information can be in the form of precoding matrix index (PMI) in both WiMAX and LTE systems.

The eigen mode relies on the analysis of CINR, which is equivalent to one form of Shannon capacity [9]. In [10, 11], compensation-booting assisted OPL and AMC have been used to improve wireless system performance. However, there is lack of specific methodologies and application in 4G systems. In WiMAX beamforming or LTE precoding techniques, eigen mode based techniques can be considered for weight calculation or code book selection in the precoding mode of transmission in base station. OPL can be achieved by feedback of fast feedback (FFB) channel and CSIT from customer premise equipment (CPE) in a closed-loop system.

2.2. Review of Water-Filling (WF) and SVD in Wireless Communication

Power allocation schemes for the wireless communication systems mainly fall into three categories, i.e. equal power allocation, water filling power allocation that based on singular value decomposition SVD and Newton and convex optimization method based power allocation. The principle of SVD can be described briefly with the following equations:

$$\mathbf{H} * diag(\boldsymbol{\lambda}) = \mathbf{v} * diag(\boldsymbol{\lambda}) \quad \textbf{(1)}$$

$$\boldsymbol{\lambda} = [\lambda_1\ \lambda_2 \cdots \lambda_n],\ \lambda_1 \geq \lambda_2 \geq \lambda_n$$

where $\mathbf{H}$ is a normalised $n \times m$ channel complex matrix, each element of which represents the complex channel gain with zero mean and unit variance; $\{\lambda_i\}$ are eigenvalues of $\mathbf{H}$ corresponding to the power of each subchannel, and the relevant eigenvectors that can be regarded as weights in the beamforming or choice of PMI are as follows:

$$\mathbf{v} = [v_1, v_2 ... v_n] \quad \textbf{(2)}$$

which can be utilized to form precoding matrix in MIMO systems. Water-filling (WF) or water pouring schemes

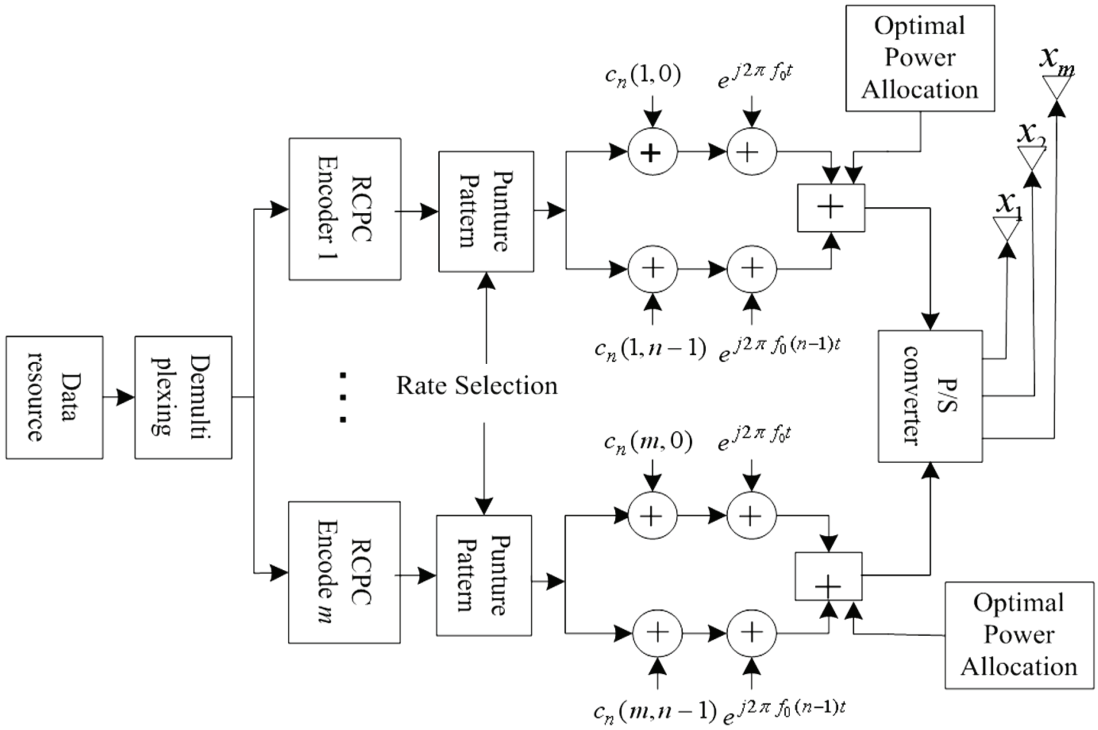

Figure 1. Block diagram of the proposed transmit system.

[12] have been proposed as iterative power allocation for transmit antennas after acquiring eigenvectors following channel estimation, covariance matrix calculation and SVD operation. In the water-filling scheme, the iterative power allocation is implemented for each user and can be expressed as

$$\{p_i\} = \left(P_c - \sum_{i=1}^{m} \lambda_i^{-1} \right)^+ \quad i = 1,2 \cdots m \quad \textbf{(3)}$$

$$P_c = tr\left(\mathbf{Q}\mathbf{Q}^H\right) \quad \textbf{(4)}$$

where m is the number of transmit antennas; P_c is the transmit power constraint; $\mathbf{Q}$ denotes the i^{th} signal sequence in the transmit system; $\{p_i\}$ are the power allocated to individual sub-streams in the transmitter and the $\{\lambda_i^{-1}\}$ are the water-filling levels.

However, the WF scheme is suboptimal for multiuser MIMO systems since it only considers separated power allocation for each user rather than joint power allocation for all the users [13,14]. More details can be seen in the following section of the proposed optimal method in the third part of the system model. In addition, the previous publications and research on the optimal power allocation of the VBLAST systems [14,15] have heavy computational complexity that prevents their application in practice. Furthermore, these researches only focus on uncoded VBLAST systems. In this paper, coded VBLAST systems with high efficiency have been investigated and the comparison with the previous optimal power allocation schemes will be addressed in the following section of the proposed optimal method.

3. System Model and the Proposed Power Allocation Scheme

In this section, we describe the proposed transceiver system.

3.1. Review of Transceiver System and Conventional Power Allocation Scheme

In Figure 1, the data source is first separated into m sub-streams and then encoded by different PCCC encoders. Subsequently, each coded substream can be beamformed by weight or coded by PMI mode. An inverse fast Fourier transform (IFFT) is then applied to the signal and each coded sub-stream is independently fed into its antenna. In addition, the power of the transmitted signals can be controlled by base station through closed-loop optimal power allocation based on CINR and the feedback of CPE.

Figure 2 illustrates the proposed TBLAST receiver structure. The communications channel with the highest signal-to-noise ratio (SNR) is chosen for detection by a linear adaptive MMSE scheme. In the decoder, a maxi-

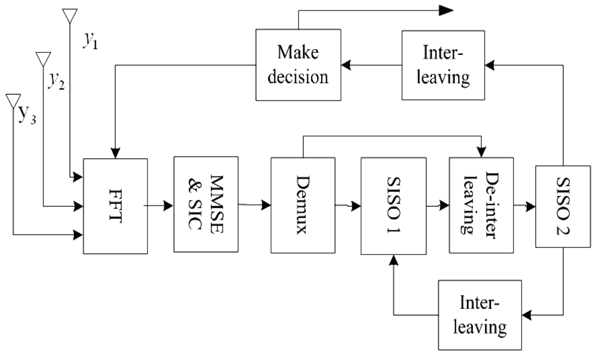

Figure 2. Block diagram of the proposed receiver system.

mum aposteriori (MAP) or aposteriori probability (APP)-based algorithm is utilized to extract the data from the received signal. After deriving soft decision and reconstructing each transmitted sub-stream, the detected signal is removed from the received signal by successive interference cancellation (SIC) algorithm before proceeding to the next iteration.

In WiMAX beamforming (BF) or LTE precoding techniques, eigenvalue base techniques can be used for weight calculation or code book selection in the precoder design at base station. The conventional OPL algorithms are designed according to utility functions using SINR, BER performance or system capacity. The cost function of signal to interference and noise ratio (SINR) can be expressed as [16,17]:

$$\gamma(p_i) = \frac{a_i p_i}{\sum_{j \neq i} b_j p_j + n_i} = \left(\frac{\|\mathbf{v}_i p_i \mathbf{H}_i\|^2}{\sigma^2 \|\mathbf{v}_i\|^2 + \sum_{j \neq i} \|v_{k_j} p_j \mathbf{H}_j\|^2} \right) \quad (5)$$

where $\{a_i\}$ denotes the processing gain; $\{b_j\}$ denotes the channel coefficient; $\{n_i\}$ is a zero mean Additive White Gaussian Noise (AWGN); $\mathbf{v}_i$ is the nulling vector and $\{p_i\}$ is the power allocated to individual sub-streams in the transmitter.

The maximum signal to noise ratio (MSNR) based precoding scheme is equivalent to the maximum capacity based scheme. The system capacity can be presented as follows [18]:

$$C = \log\left(\det\left(\mathbf{H}\ \mathbf{Q}\ \mathbf{H}^H + \sigma^2 \mathbf{I}\right)\right) = \sum_{n=1}^{N} \log\left(1 + SINR_{k,n}\right) \quad (6)$$

where $\mathbf{H}$ is a normalised $m \times n$ complex-valued channel matrix with unit variance, $\mathbf{Q}$ is the covariance matrix of the information data bits and the σ^2 denotes the variance of the noise

In MIMO systems, the ergodic capacity, defined as the maximum average mutual information for identical independent distribution (i.i.d) complex Gaussian channels with perfect CSI at receiver and no CSI information in transmitter can be expressed as [18]:

$$f(p_i) = E_H\left[\log_2\left[\det\left(\mathrm{I} + \frac{\rho}{m}\mathbf{HQH}^{\mathrm{H}}\right)\right] \text{b/s/Hz}\right] = \frac{1}{m}\sum_{i=1}^{m} \log\left(1 + \rho\frac{p_i \lambda_i}{\sigma^2}\right) \quad (7)$$

where ρ denotes the average SNR; $(\ )^H$ stands for the complex conjugate operator. The channel gain is normalized so as to meet the constant power constraint, m is the number of transmit antennas.

VBLAST is a technique that selects the received layer with the highest signal noise ratio (SNR) and then removes the relevant layer by SIC till the last layer is detected. Therefore, the first layer detection is critical to BLAST system performance. The principle of the optimal power allocation in the proposed BLAST system is to allocate more power to the layers with high SNR, and a good system performance can be achieved in this manner.

3.2. Review of Optimal Theory on Wireless Communications

Most optimization problems in practical wireless communication environments fall into the category of convex optimization. IPM (interior point method), which consists of quasi Newton method and Lagrangian method, has been regarded as the most efficient method in the optimal sense for resolving optimal convex problems with certain constraints.

The applications of IPM are classified into three catalogues, i.e. primal IPM, dual IPM and primal dual IPM methods. The optimal source management solutions in practical wireless communication systems can be dealt with by optimal primal-duality IPM theory that is actually a minimum-maximum or minmax problem [17] with power constraint:

$$\max[f(p_i)] - \sum_{i=1}^{m} k_i g_i(p_i) \quad (8)$$

The automatic differentiation (AD) method is highly efficient to achieve optimal solution with low computation complexity compared to the conventional optimal schemes. In the wireless communication systems, it can be described in terms of multiple variables as follows

$$F(p) = \begin{bmatrix} F_1(p) = f_1(p_1, p_2, \cdots p_n,) \\ \cdots \\ F_m(p) = f_m(p_1, p_2, \cdots p_n,) \end{bmatrix} \quad \textbf{(9)}$$

The derivative matrix that depends on the Jacobian matrix can be described as

$$J = \frac{\partial F(p)}{\partial p_j} \quad \textbf{(10)}$$

$$J = \begin{bmatrix} y_1 = \frac{\partial F_1(p)}{\partial p_1} + \frac{\partial F_1(p)}{\partial p_2} + \cdots \frac{\partial F_1(p)}{\partial p_n} \\ \cdots \\ y_n = \frac{\partial F_m(p)}{\partial p_1} + \frac{\partial F_m(p)}{\partial p_2} + \cdots \frac{\partial F_m(p)}{\partial p_n} \end{bmatrix} \quad \textbf{(11)}$$

where the function $\mathbf{F}_i(p)$ is set up to meet the requirements of the wireless communication system functions; $p = \{p_{1,}\ p_{2,}\ \cdots p_m\}$ is the allocated power in the transmission system.

The symbolic derivative (SD) method has been regarded as a new area in mathematics and has been widely applied in industry, commerce and academia. It can be implemented by the solver package, which is an efficient software depending on IPM method, for resolving optimal convex solution by Newton method, in the processing of derivative. SD algorithms calculate derivative and estimate an approximate optimal solution in the formulas with less computational complexity and accuracy compared to conventional optimal schemes.

3.3. Proposed Optimal Method and Comparison with Conventional Schemes

In the classical single-user or multi-user Waterfilling scheme, the power is allocated for each individual substream in the transmitter iteratively until all Karush-Kuhn-Tucker (KKT) conditions are satisfied, which is a necessary condition and resolved by first order derivative in a non-linear equation and is actually a simplified application of IPM [19]. However, the conventional waterfilling schemes have many issues that will prevent their application and will be explained in the following paragraphs.

The proposed optimal power allocation scheme in the BLAST systems is different from the conventional waterfilling or any other power allocation schemes. Firstly, in the classical waterfilling scheme, the power will be cut off when the power allocated for individual substream is less than the waterfilling level u

$$\{p_i\} = \max\{p - u, 0\} \quad \textbf{(12)}$$

Consequently, the classical waterfilling will result in a reduced spectral efficiency due to the loss of spatial multiplexing gain when applied to the BLAST systems. Secondly, considering the error propagation problem inherent in the interference cancellation based receiver, the first layer detection is crucial for the system performance in terms of achievable system capacity and BER performance. For this reason, the substream with the highest SNR should be allocated more power. Thirdly, the conventional BLAST detection algorithms are only determined by the SINR. However, in coded BLAST systems with variable transmission rate, the choice of channel code and code rate in each substream will affect the BLAST systems performance significantly.

The conventional optimal power allocation algorithms for VBLAST have been investigated in [14,15], the SINR that can be expressed as

$$\gamma(p_i) = \frac{a_i p_i}{\sum_{j \neq i} b_j p_j + n_i} = \left(\frac{\|\mathbf{v}_i p_i \mathbf{H}_i\|^2}{\sigma^2 \|\mathbf{v}_i\|^2 + \sum_{j \neq i} \left\| v_{k_j} p_j \mathbf{H}_j \right\|^2} \right) \quad \textbf{(13)}$$

where $\{a_i\}$ denotes the processing gain; $\{b_j\}$ denotes the fading channel gain; $\{n_i\}$ is a zero mean AWGN; $\mathbf{v}_i$ is the nulling vector and $\{p_i\}$ is the power allocated to individual substream in transmitter.

The BER $P_e(p_i)$ can be approximated and reduced to a simplified formula as [22, 23]

$$P_e(p_i) = \frac{1}{5} \exp\left(-\frac{1.5\gamma(p_i)}{(2R_i - 1)} \right) \quad \textbf{(14)}$$

where R_i is the data rate of the i^{th} transmit stream. The derivatives are subsequently taken for the Equations (3)-(41) subject to (3)-(39)

$$\frac{d(J(p_i))}{dp_i} = \frac{d(\xi f(p_i))}{dp_i} + \frac{d(P_e(p_i))}{dp_i} = 0 \quad \textbf{(15)}$$

Then the power allocation solution can be derived from an exhaustive search [23]

$$p_i = -0.625 \left(2^{R_i - 1}\right) \frac{\gamma(p_i)}{p_i} \ln \left(-\frac{3.125\ M \xi \left(2^{R_i - 1}\right) \gamma(p_i)}{\prod_1^{m-j} \left(1 + f(a_j)\right) p_i} \right) \quad \textbf{(16)}$$

where

$$\xi = \exp\left(- \frac{\frac{1.6m}{2^{R_i-1}} + \sum_{i=1}^{m} \frac{p_i}{\gamma(p_i)} \ln\left(- \frac{3.125m\, 2^{R_i-1}\gamma(p_i)}{\Pi_1^{m-j}\left(1+f(a_j)\right)} \right)}{\sum_{i=1}^{m} \frac{1}{\gamma(p_i)}} \right) \quad \textbf{(17)}$$

where the power allocation can be derived by an adaptive method such as LMS

$$p_i(k+1) = p_i(k) - u(i)\frac{\partial(J(p_i))}{\partial p_{k_i}}$$

$$= p_i(k) - u(i)\left(\frac{1}{m}\frac{\partial(J(p_i))}{\partial p_{k_i}} - \frac{1}{m^2}\sum_{i=1}^{m}\frac{\partial(J(p_i))}{\partial p_{k_i}} \right) \quad \textbf{(18)}$$

where $u(i)$ denotes the step function and m is the transmit antenna size.

It can be observed that the disadvantage of this optimal power allocation scheme is its heavy computational load to obtain the derivatives in the equation, which is impractical for real time communication environments. One solution is to employ the SD, which is efficient in the derivation and differential algebraic operations for optimal solution with less computational complexity compared to the conventional optimal methods.

The power allocated to each individual sub-stream can be expressed in the form of eigenvalues as

$$g_i(p_i) = p_c - k_i \sum_{i=l}^{m} p_i \lambda_i \quad \textbf{(19)}$$

where $\{k_i\}$ are the lagrangian coefficients. Subsequently, we can obtain the first order of derivative as:

$$e_i = \frac{dl(p_i, k_i, r_i)}{dp_i} = \frac{df(p_i, r_i)}{dp_i} - k_i \frac{dg(p_i, r_i)}{dp_i} \quad \textbf{(20)}$$

we can then derive the following equations

$$\Delta f(p_i) = \sum_{i=1}^{m} k_i \Delta g_i(p_i) \quad \textbf{(21)}$$

where $\nabla f(p_i)$ and ∇g_i are the gradient of the functions $f(p_i)$ and $g_i(p_i)$. The allocated power $\{p_i\}$ can be derived from solving following equations

$$\{p_1 p_2 \ldots p_m\} = solve(e_1 e_2 \cdots e_i\; g_1 g_2 \cdots g_i) \quad \textbf{(22)}$$

In the conventional VBLAST detection algorithm, the ordering procedure that is determined by SINR is expressed as [13]

$$G = \arg\max\left(\left(\mathbf{H}^H \mathbf{H} + \sigma^2 \mathbf{I}\right)^{-1} \mathbf{H}^H \right) \quad \textbf{(23)}$$

With optimal power allocation, the equation for ordering selection is replaced by

$$G_1 = \left((\mathbf{HP})^H (\mathbf{HP}) + \sigma^2 \mathbf{I}\right)^{-1} (\mathbf{HP})^H \quad \textbf{(24)}$$

Finally, we obtain the eigenmode power allocation for individual substream in the transmission system as

$$\{P_i\} = diag\left(\sqrt{p_1}, \sqrt{p_2} \cdots \sqrt{p_m}\right) \quad \textbf{(25)}$$

Table 1. Simulation environment.

Simulation model	Monte Carlo
Transmit antenna Receive antenna	3 elements 6 elements
Fading channel	Rayleigh. Jakes model
Doppler frequency	20 Hz
Encoder & rate	CTC 1/2
Data modulation	OFDM QPSK
Decoding algorithm	Log-Map, extrinsic information transfer (EXIT)
Constraint length	4, 6
Feedback polynomial	111 (L=4), 11011 (L=6)
Feedforward polynomia	101 (L=4), 11001 (L=6)
Number of iterative	6
CSI	Perfect known
System	PCCC, Closed-loop

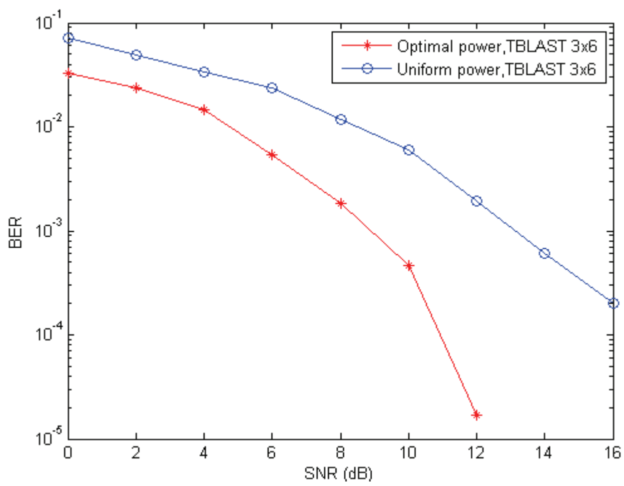

Figure 3. BER Performance comparison: OPL versus equal power allocation.

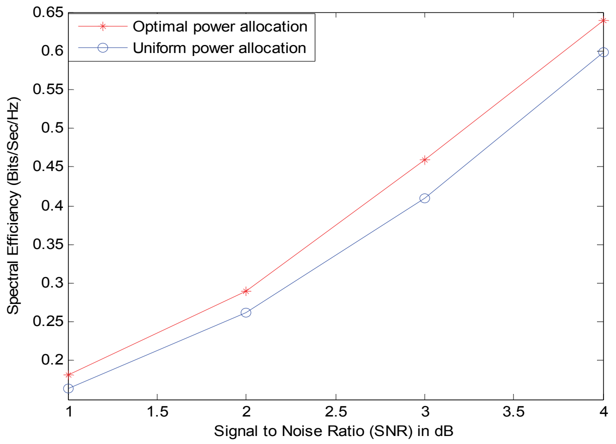

Figure 4. Comparison of spectral efficiency: OPL versus uniform power allocation.

In the VBLAST system, we selected the layer with the highest SINR and perform SIC to remove the detected layer. This procedure continues for subsequent iterations of detection and decoding process till the last substream is detected layer. The solution can be derived by setting Equation (9) to zero, then we can perform optimal search within certain steps or iterative number that depends on the AD method [16]. As a result, the derived solution can be applied to the transmitter to optimize resource allocation or relocate the power to the modulation and coding of transmission in the base station.

4. Numerical Results

In this section, the performance of different systems is evaluated by computer simulations and numerical results are provided to demonstrate the effectiveness of the proposed schemes. The simulation parameter setting is tabulated in Table 1.

In Figure 3, we show the comparison of the BER performance between the proposed OPL and the equal power allocation scheme. Simulation results indicate that there is a considerable improvement by the proposed scheme compared to the conventional equal power scheme. A gain of 4.5 dB has been observed at target BER=10^{-3}, and the gain becomes more obvious as SNR increases.

One can also see from Figure 4 that the spectral efficiency, which depends on received CINR, can be improved by the proposed scheme compared to the equal (uniform) power allocation. This is due to the fact that more power in the base station is allocated to the transmit layers with high SNR, leading to the improved system performance with SIC based layered processing.

In practical wireless communication systems such as LTE and WiMAX IEEE802.16e, only equal power allocation has been considered so far. However, this simple algorithm is highly suboptimal as indicated by our results. Also considering the fact that the conditions for performing iterative water-filling can not always be fulfilled in practical situations, the proposed algorithm provides an effective means to allocating transmit power for the 4G systems.

5. Conclusions

In this paper, a closed-loop TBLAST system with eigen mode and optimal power allocation is proposed and evaluated by means of simulations. Results show that it achieves a substantial performance gain in system performance with reasonable computational complexity compared to the conventional schemes. The work presented in this paper provides a useful source of information for the optimization of power allocation in the future 4G systems.

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