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 simple power allocations 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. It provides an effective alternative solution when the strict condition for the traditional optimal power allocation scheme such as water-filling is not fulfilled.

Keywords:
carrier Interference and Noise Ratio (CINR), convolutional Turbo coded Bell Space Time (TBLAST), eigen mode (EM), optimal power allocation (OPL), Automatic Differentiation (AD)

I. 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 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), inter symbol interference (ISI) and spatial correlation. 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 [1] which can deteriorate system performance significantly. In addition, spatial correlation has more impact on the uplink than on the downlink [2] 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) is a technique that can effectively utilize optimal resource to maximize throughput or improve transmission link quality. In 4G systems, carrier-interferer-noise-ratio (CINR) [3] gives indications 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.

BLAST (Bell lab space time) [4] can achieve good performance with low computational complexity by successive interference cancellation (SIC) algorithm. 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 [4] 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 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.

II. Literature Review

A. 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 involves Physical CINR and power allocation to improve the Wimax system performance [5, 6] 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 [6]. In [7, 8], 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 the closed-loop system.

B. 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:

$$\mathbf{H}^* \text{diag} (\lambda) = \mathbf{V}^* \text{diag} (\lambda)$$  \hspace{1cm} (1)$$

$$\lambda = [\lambda_1, \lambda_2, \ldots, \lambda_n], \quad \lambda_1 \geq \lambda_2 \geq \lambda_n$$

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 sub-channel, and the relevant eigenvectors that can be regarded as weights in the beamforming or choice of PMI are as follows:

$$\mathbf{v} = [v_1, v_2, \ldots, v_n]$$

which can be utilized to form precoding matrix in MIMO systems.

Water-filling (WF) or water pouring schemes [11] 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

$$\{p_i\} = \left(p_c - \sum_{i=1}^n \lambda_i^{-1}\right)^+ \quad i = 1, 2, \ldots, m$$  \hspace{1cm} (2)$$

where

$$p_c = n \left(\mathbf{Q Q}^H\right)$$  \hspace{1cm} (3)$$

where $p_c$ is the transmit power constraint; $\mathbf{Q}_i$ 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 [14]. Furthermore, some strict conditions for the WF are not always satisfied, e.g. it requires the knowledge of full channel state information (CSI) which is difficult to acquire in some situation, such as for fast fading channels. The proposed optimal power allocation scheme can be employed under such circumstances.

### III. System Model and The Proposed Power Allocation Scheme

In this section, we describe the proposed transceiver system.
In Fig. 1, the data source is first separated into \( m \) sub-streams and then encoded by different PCCC encoders. Subsequently, each coded sub-stream 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 that based on CINR and the feedback of CPE.

Fig. 2 illustrates the proposed TBLAST receiver architecture. 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 maximum a posteriori (MAP) or a posteriori 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 baseline techniques can be used for weight calculation or codebook 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 [9, 10]:

$$\gamma(p_i) = \frac{a_i p_i}{\sum_{j \neq i} b_j p_j + n_i}$$

$$= \left[ \frac{\| v_i p_i \mathbf{H} \|^2}{\sigma^2 \| v_i \|^2 + \sum_{j \neq i} \| v_j, p_j \mathbf{H} \|^2} \right]$$

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

In 4G systems, the maximum signal to noise ratio (MSNR) based precoding scheme is equivalent to the maximum SINR based scheme. The system capacity can be presented as follows:

$$C = \log \left( \det \left( \mathbf{H} \mathbf{Q} \mathbf{H}^H + \sigma^2 \mathbf{I} \right) \right)$$

$$= \sum_{n=1}^{N} \log \left( 1 + \text{SINR}_{k,n} \right)$$

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 \( \sigma^2 \) denotes the variance of the noise.

In practice, the ergodic capacity in MIMO systems, which is defined as the maximum average mutual information for complex Gaussian identical independent distribution (i.i.d) channels with perfect CSI at receiver and no CSI information in transmitter, used to be considered in the application of wireless communication systems rather than the equation of (5) and can be expressed as:

$$f(p_i) = E_{\mathbf{H}} \left[ \log_2 \left[ \det \left( 1 + \frac{p_i}{m} \mathbf{H} \mathbf{Q} \mathbf{H}^H \right) \right] \right] \text{b/s/Hz}$$

$$= \frac{1}{m} \sum_{i=1}^{m} \log \left( 1 + \frac{p_i \lambda_i}{\sigma^2} \right)$$

where \( p \) denotes the average SNR; \( ( \cdot )^H \) 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.

It is a technique that selects the received layer with the highest signal noise ratio (SNR) and then remove 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 that more power allocation will be allocated to the layers with high SNR, and a good system performance can be achieved in this manner.

The min-max [10] equation with power constraint is described as:

\[
\max \left[ f(p_i) \right] - \sum_{i=1}^{m} k_i g_i(p_i)
\]  

(7)

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

\[ g_i(p_i) = P_c - k_i \sum_{i=1}^{m} p_i \hat{\lambda}_i \]  

(8)

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

\[ e_i = \frac{dL(p_i, k_i, r_i)}{dp_i} = \frac{df(p_i, r_i)}{dp_i} - k_i \frac{dg(p_i, r_i)}{dp_i} \]  

(9)

The solution can be derived by setting equation (9) to zero, and we can then perform optimal search within certain steps or iterative number that depends on the Automatic Differentiation (AD) method [15]. 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.

**IV. Numerical Results**

In this section, the proposed system performance is evaluated by computer simulations and numerical results are given to demonstrate the effectiveness of the proposed schemes. The simulation parameter setting is tabulated in Table I.
<table>
<thead>
<tr>
<th>Simulation model</th>
<th>Mento Carlo</th>
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<tbody>
<tr>
<td>Transmit antenna</td>
<td>3 elements</td>
</tr>
<tr>
<td>Receive antenna</td>
<td>6 elements</td>
</tr>
<tr>
<td>Fading channel</td>
<td>Rayleigh, Jakes model</td>
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<td>20 Hz</td>
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<td>Encoder &amp; rate</td>
<td>OFDM QPSK</td>
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<td>Data modulation</td>
<td>Log-Map</td>
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<td>Decoding algorithm</td>
<td>extrinsic information</td>
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<tr>
<td>Constraint length</td>
<td>4, 6</td>
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<tr>
<td>Feedback polynomial</td>
<td>111 (L=4), 11011 (L=6)</td>
</tr>
<tr>
<td>Feedforward polynomial</td>
<td>101 (L=4), 11001 (L=6)</td>
</tr>
<tr>
<td>Number of iterative</td>
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<td>CSI</td>
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<tr>
<td>System</td>
<td>PCCC, Closed-loop</td>
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</tbody>
</table>

![Graph](image)

Fig. 3 BER Performance comparison: OPL versus equal power allocation
In Fig. 3, we show the comparison of the BER performance between the proposed OPL and equal power allocation scheme. Simulation results indicate that there is 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 Fig. 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 mean to allocating transmit power for the 4G systems.

V. Conclusion

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.
References

Knowledgeable scientists in the relevant fields

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