出國報告 **(出國類別：國際會議)**

參加 WCE 2015
國際學術研討會議

服務機關：國立虎尾科技大學 飛機工程系

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派赴國家：英國

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摘要

WCE 2015 (World Congress on Engineering)是全球工程領域上重要的國際學術研討會。本年度會議是在英國首都倫敦市的國王學院南肯辛頓校園內舉辦，研討會為期三天(7/1 – 7/3)，共有 713 篇文章投稿，僅有 362 篇被大會接受刊登。今年大會一共安排 15 種不同研究領域的場次，讓研討會內容更為廣泛豐富。與會期間除了積極參加各種不同研究領域的論文發表外，我們也發表一篇研究論文，題目為 On space-frequency water-filling precoding for multi-user MIMO communications，論文內容是針對在多用戶存取在多天線傳輸的通道環境下，研究以注水原理對於傳輸訊號進行空間時間上的資料編碼與使用所題出的編碼技術對於系統性能提升之模擬與討論。

參加此次研討會除了發表近期的研究成果並與來自世界各地的專家學者面對面討論與意見交換，同時也可收集相關研究領域最新的研究主題與內容，也可以跟國際知名學者相互認識與對於研究相關問題進行討論，雖然時間短暫，但卻收獲豐碩。

目次

壹、目的

這次出國主要的目的是在通訊技術領域中發表研究論文，並與來自各國專家學者進行面對面討論與資訊交流，進而提升個人的研究與外語能力。其次，藉由參加這次國際研討會以及大會所提供寶貴的資料，可以了解最近一年各國專家學者相關的研究主題與成果，對於個人未來研究能力的提升以及研究領域的拓廣有相當的助益。在會場中也可以認識各國知名的研究人員與專業人士，也可以增進與國內外知名學者的交流機會，並可進行實質的國民外交，進而提升台灣的國際知名度。

基於上述之目的，我們所選擇參與 2015 年世界工程會議 (World Congress on Engineering 2015)。世界工程會議(WCE)是由非營利性質的國際工程協會主辦。此會議聚集從工業和計算機領域的專業研究人士，會議主題包括資訊工程、計算機工程、訊號處理與無線網路等等的相關研究領域。在此會議中，各國專家學者分別發表這些領域中目前最新的技術。本次出國主要目的除了發表研究論文之外，也藉由參與此一會議也可認識相關領域的專家學者，進而達到雙向交流，也提升個人的研究能力與國際觀。

貳、過程

2015 年世界工程會議 (World Congress on Engineering 2015)是在英國首都倫敦市的國王學院南肯辛頓校園內舉辦，國王學院是英國相當著名的大學，在英國的高等教育中也享有盛譽，校園內所提供會議空間可足夠容納此次大型研討會。

一、 議場主題

- 會議共安排 15 種不同研究領域的場次，分別列表如下:

ICAEM	The 2015 International Conference of Applied and Engineering Mathematics
ICCIIS	The 2015 International Conference of Computational Intelligence and Intelligent Systems
ICCSDE	The 2015 International Conference of Computational Statistics and Data Engineering
ICCSE	The 2015 International Conference of Computer Science and Engineering
ICDMKE	The 2015 International Conference of Data Mining and Knowledge Engineering
ICEEE	The 2015 International Conference of Electrical and Electronics Engineering
ICFE	The 2015 International Conference of Financial Engineering
ICIE	The 2015 International Conference of Information Engineering
ICISIE	The 2015 International Conference of Information Security and Internet Engineering
ICME	The 2015 International Conference of Mechanical Engineering
ICMEEM	The 2015 International Conference of Manufacturing Engineering and Engineering Management
ICPDC	The 2015 International Conference of Parallel and Distributed Computing
ICSBB	The 2015 International Conference of Systems Biology and Bioengineering
ICSIE	The 2015 International Conference of Signal and Image Engineering
ICWN	The 2015 International Conference of Wireless Networks

- 會議的 Invited Talks 一共邀請了 6 位傑出的講者，分別是：

演講者	單位	主題
Professor Alexander M. Korsunsky	Department of Engineering Science, University of Oxford, U.K	
Professor Len Gelman	School of Aerospace, Transport and Manufacturing Cranfield University, UK;	
Professor Sergei Sazhin	School of Computing, Engineering and Mathematics, University of Brighton, UK	Modelling of automotive fuel droplet heating and evaporation: recent results and unsolved problems
Dr. Mark Leeson	University of Warwick, UK	Coding and Protocols for Molecular Communications
Dr. Manosh Paul	University of Glasgow, UK	Combustion and Gasification
Dr. Maaruf Ali	University of East London, UK	

二、 會議議程

會議期間自 7/1 起至 7/3 止共 3 天，詳細議程參考如下 4 頁。我們的論文發表時間為 7/2 下午。

三、　報告議題

我們發表的論文主題為：On space-frequency water-filling precoding for multi-user MIMO communications，內容為介紹在第四代行動無線系統中，由於多載波正交分頻多工系統結合多輸入多輸出天線技術在多用戶存取的環境下，會造成嚴重的多用戶與多重存取的干擾問題，利用方塊對角化(BD)結合強制歸零(GZI)演算法是一種簡單而又有效率的編碼技術可以用來消多用戶與多重存取的干擾問題。然而利用方塊對角化結合強制歸零演算法是以均勻的方式進行訊號的功率分配，但對於行動無線通道還境下，均勻的功率分配方法不是一個最佳的選擇。本篇論文提出以注水原理結合無線通道的特性來進行傳輸訊號在空間時間上的資料編碼以及訊號的功率分配，並針對所提出的編碼技術對於整體系統性能提升進行模擬與討論其成效。論文摘要請參見附錄。

2015 世界工程會議時程表 (WCE 2015)

Reception Tea (30 June, 2015, Tuesday, 15:00 – 17:00)

- **Day One (1 July, 2015, Wednesday)**

	Room A	**Room B**	**Room C**	**Room D**
9:00 – 10:45	WCE Keynote Speech II & ICISIE Invited Speech	ICSIE I	ICME I	---
10:45 – 11:15	Tea/Coffee Break			
11:15 – 13:00	ICEEE Invited Speech & ICEEE I & ICME Invited Speech I	ICISIE I	ICMEEM I	ICSBB I
13:00 – 14:00	WCE Congress Lunch			
14:00 – 15:45	ICMEEM II	ICEEE II	ICME II	ICDMKE I
15:45 – 16:15	Tea/Coffee Break			

16:15 – 18:00	ICMEEM III	ICEEE III	ICME III	ICDMKE II
The End of the First Day of the Congress				

- **Day Two (2 July, 2015, Thursday)**

	Room A	**Room B**	**Room C**	**Room D**
9:00 – 10:45	WCE Keynote Speech I & ICME IV	ICFE I & ICCSDE I	ICEEE IV	---
10:45 – 11:15	Tea/Coffee Break			
11:15 – 13:00	ICME V	ICAEM I	ICEEE V	ICMEEM IV
13:00 – 14:00	WCE Congress Lunch			
14:00 – 15:45	ICME VI	ICAEM II	ICCIIS I	ICMEEM V
15:45 – 16:15	Tea/Coffee Break			
16:15 – 18:00	ICME VII	ICAEM III	ICCIIS II & ICWN III	ICMEEM VI
The End of the Presentations of the Second Day of the Congress				
18:30 – 20:30	WCE Congress Drink and Dinner			
The End of the Second Day of the Congress				

- **Day Three (3 July, 2015, Friday)**

	Room A	**Room B**	**Room C**	**Room D**
9:00 – 10:45	ICMEEM VII	ICME VIII	ICAEM IV	ICIE I
10:45 – 11:15	Tea/Coffee Break			
11:15 – 13:00	ICMEEM VIII	ICME IX	ICAEM V	ICPDC I & ICCSE I
13:00 – 14:00	WCE Congress Lunch			

14:00 – 15:45	WCE Keynote Speech III & ICME X	ICMEEM IX	ICWN I	ICCSE II
15:45 – 16:15	Tea/Coffee Break			
16:15 – 18:00	ICME XI	ICMEEM X	ICWN II	ICCSE III
The End of the Congress				

參、 心得與建議

一、 感謝能有這次機會可以參加 2015 年世界工程會議，這個會議涵蓋大部分工程方面相關的研究主題，主要是聚焦在工程理論、應用科學、計算機科學等的相關研究內容與技術發展趨勢。此次會議中有數量相當多且研究領域相當廣泛的論文發表。參加這次會議，除了在自己研究領域與國際學者專家相互交流，還能接觸到不同研究領域的新發展、新趨勢，是一個相當值得參與的國際研討會。

二、 在本此會議中，我們在無線通訊領域之訊號處理議題上發表研究論文，並與各國相關研究領域的專家學者相互討論研究心得，對於個人未來的研究方向，收獲相當豐碩。參加會議的人士中，也有些是來自於產業界、工程人員與系統開發人員，利用這個難得的機會，搭起學術界與產業界聯繫的管道，從相互交流中了解彼此需求，對於研究內容的具體商品化也實有幫助。

三、 第一次來到英國倫敦，對倫敦的感覺，是個保有傳統歷史建築及文化的高度現代化大都會，各種硬體設施都相當完備，光機場就有 5 個，運量大的機場距離倫敦市中心較遠，適合各國的觀光客出入；運量小的機場離市中心很近，方便商務人士進出。市區中有許多重要的地標，像是白金漢宮、倫敦眼、西敏寺、國會大廈、倫敦塔橋，都聚集了相當多的觀光客來參觀。市區的捷運系統四通八達，到市區各地都有多條路線可以到達，搭乘相當

便利。倫敦是個國際知名大都市，各種膚色的市民一起生活沒有障礙，曾經看過國小生戶外教學同學相處十分和樂的模樣，令人印象深刻。英國國民的高素質與高涵養在全球國家中是非常著名，也是國民教育相當成功的國家，這是一個國家持續進步的原動力，也是台灣人民需要加強與學習之處；像是在交通秩序上，台灣人開車還不太會禮讓行人，在英國市區的路上開車都是以行人為第一優先。作為一個教育執行者，在授課的過程中，可以找適當的時間，給學生適當的機會教育，將出國的經驗與心得分享給學生，讓學生瞭解先進國家為何能強大進步，有那些優點之處值得我們去學習。

四、 國內無線通訊系統的訊號處理之相關研究，無論是理論研究或實務經驗方面均有不錯的基礎，建議政府相關機構及國內產業界可以大力地給予支持，讓國內的無線通訊上相關研究可以持續的進步。

附件：

論文摘要

Abstract—**Multiuser multi-input multi-output (MU-MIMO) system has been widely used in 4G communication system. MU-MIMO has high data rate and improved capacity. However, it has multiuser interference (MUI) and multiple access interference (MAI). Block diagonalization (BD) is one of the methods to solve MUI and MAI, which uses precoding algorithm to separate each user in the system. A generalized zero-forcing channel inversion (GZI) algorithm is the simplest precoding method to improve BD. However, the BD/GZI algorithms use uniform power distribution. The water-filling technology performs power allocation based on channel environment of each user. In this paper, the BD/GZI algorithms are combined with water-filling technology to perform power allocation and MUI/MAI cancellation for the MU-MIMO systems. The proposed algorithms are with space-frequency water-filling. Some simulation examples are given to demonstrate the effectiveness of the proposed algorithm.**

On Space-Frequency Water-Filling Precoding for Multi-User MIMO Communications

Yu-Kuan Chang, Ye-Shun Shen[2], Fang-Biau Ueng and Shao-Hua Tsai

Abstract—**Multiuser multi-input multi-output (MU-MIMO) system has been widely used in 4G communication system. MU-MIMO has high data rate and improved capacity, however, it has multiuser interference (MUI) and multiple access interference (MAI). Block diagonalization (BD) is one of the methods to solve MUI and MAI, which uses precoding algorithm to separate each user in the system. A generalized zero-forcing channel inversion (GZI) algorithm is the simplest precoding method to improve BD. However, the BD/GZI algorithms use uniform power distribution. The water-filling technology performs power allocation based on channel environment of each user. In this paper, the BD/GZI algorithms are combined with water-filling technology to perform power allocation and MUI/MAI cancellation for the MU-MIMO systems. The proposed algorithms are with space-frequency water-filling. Some simulation examples are given to demonstrate the effectiveness of the proposed algorithm.**

Index Terms—**block diagonalization, water-filling, optimal power allocation, multiuser multi-input multi-output.**

I. Introduction

THE new generation of wireless communication systems is providing multimedia services that require very high data rates. The high spectral efficiency can be achieved by using multiple antennas at both the transmitter and receiver, so multiple-input multiple-output (MIMO) systems have gained popularity due to their capability in delivering high spectral efficiency and their robust performance against fading. MIMO communication technologies have recently received much interest due to the promising capacity gain when employing multiple transmit and receive antennas. Information theoretic results show that MIMO systems can offer significant capacity gains over traditional single-input single-output systems. This capacity increase is enabled by the fact that the signals from each individual transmitter appear highly uncorrelated at each of the receive antennas in rich scattering wireless environments. The receiver can exploit these differences in spatial signatures to separate the signals originated from different transmit antennas. In multipath channel, the received signal in a MIMO receiver is corrupted by the inter-symbol interference (ISI), spatial interference, and co-antenna interference (CAI). Single-user MIMO (SU-MIMO) considers only the dimensions of multiple antennas for a single mobile device. However, multiuser MIMO (MU-MIMO) can deploy multiple users as spatially distributed transmission resources at the cost of more complex signal processing, and is also known as spatial division multiple access (SDMA). Thus, multiuser MIMO considers the overall capacity of network when several users are accessing the same link simultaneously. Due to transmission array gain, diversity gain, spatial multiplexing gain and interference cancellation gain, MIMO techniques can increase system throughput and transmission reliability without increasing the required bandwidth that makes MIMO communication technologies become one of the most promising ways for wireless communication by dirty paper coding (DPC) [1-13]. The purpose of DPC is to pre-cancel interference at the transmitter using know full channel state information (CSI). Block diagonalization (BD) is one of the well-known precoding algorithms near DPC techniques [4-5]. A generalized zero-forcing channel inversion (GZI) algorithm is the simplest precoding method to improve BD.

Water-filling technique has been proposed by [8] and has been used in MIMO system that uses each antenna CSI to find maximum eigenvalue to do power allocation as the spatial domain water filling. In [5, 7, 9, 17], the spatial domain water-filling with BD algorithm is employed in multiuser MIMO system to find maximum sum capacity. The frequency domain water-filling technique has been proposed by [13, 14] that the time-domain signal is transferred to frequency domain and then each subcarrier is water- filling processed. In this paper, the BD/GZI algorithms are combined with both spatial-domain and frequency-domain water-filling technologies to perform power allocation and MUI/MAI cancellation for the MU-MIMO systems. The rest of this paper is organized as follows. In Section 2, the BD precoding algorithm and GZI precoding algorithm for MU-MIMO downlink system is described. The proposed spatial-frequency water-filling algorithm is described in Section 3. Simulation results and conclusions are provided in Section 4 and Section 5, respectively.

Notation: Vectors and matrices are denoted by boldface letters; superscripts of $(\cdot)^*$, $(\cdot)^T$, $(\cdot)^H$, and $(\cdot)^{-1}$ denote the complex conjugate, transpose, Hermitian transpose, and inverse, respectively; $\otimes$ stands for the Kronecker product; and $diag\{\cdot\}$ denotes a diagonal matrix; $\mathbf{I}_K$ is the $K \times K$ identity matrix; $E\{\cdot\}$ denotes the statistical expectation.

II. Block Diagonalization for Multiuser MIMO System

A. Block Diagonalization

The multiuser MIMO downlink system with K

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independent users can be shown as Figure 1. The transmitted signal goes through precoding matrix and then received with receiver filter to decode the desired user signal. Block diagonalization (BD) is the well-known precoding method for the system [1-5]. Define the transmitted symbol vector x, noise w and the precoding matrix P as follows,

$$\mathbf{x} = \begin{bmatrix}\mathbf{x}_1^T & \mathbf{x}_2^T & \dots & \mathbf{x}_K^T\end{bmatrix}^T$$
$$\mathbf{w} = \begin{bmatrix}\mathbf{w}_1^T & \mathbf{w}_2^T & \dots & \mathbf{w}_K^T\end{bmatrix}^T \quad (1)$$
$$\mathbf{P} = \begin{bmatrix}\mathbf{P}_1 & \mathbf{P}_2 & \dots & \mathbf{P}_K\end{bmatrix}$$

The received signal can be described as

$$\mathbf{y} = \begin{bmatrix}\mathbf{y}_1^T & \mathbf{y}_2^T & \dots & \mathbf{y}_K^T\end{bmatrix} = \mathbf{HPx} + \mathbf{w} \quad (2)$$

where $\mathbf{H}$ is the channel information matrix and can be defined as $\mathbf{H} = \begin{bmatrix}\mathbf{H}_1^T & \mathbf{H}_2^T & \dots & \mathbf{H}_K^T\end{bmatrix}^T$

The received signal can be rewritten as follows,

$$\mathbf{y} = \mathbf{H}_j\mathbf{P}_j\mathbf{x}_j + \mathbf{H}_j\sum_{k=1,k\neq j}^{K}\mathbf{P}_k\mathbf{x}_k + \mathbf{w} \quad (3)$$

Define the received filter $\mathbf{M}$ for all users as follows,

$$\mathbf{M} = diag\{\mathbf{M}_1 \quad \mathbf{M}_2 \quad \dots \quad \mathbf{M}_K\} \quad (4)$$

The desired output signal $\hat{\mathbf{x}}_j$ can be shown as

$$\hat{\mathbf{x}}_j = \mathbf{M}_j\mathbf{H}_j\mathbf{P}_j\mathbf{x}_j + \mathbf{M}_j\mathbf{H}_j\sum_{k=1,k\neq j}^{K}\mathbf{P}_k\mathbf{x}_k + \mathbf{M}_j\mathbf{w} \quad (5)$$

The key idea of the BD is to design the precoding matrix that satisfies the following condition,

$$\mathbf{H}_j\mathbf{P}_j = 0 \quad \forall j \neq k,\ 1 \le j,k \le K \quad (6)$$

So $\mathbf{P}_j$ should be in the null space of $\tilde{\mathbf{H}}_j$ that is defined as follows,

$$\tilde{\mathbf{H}}_j = \begin{bmatrix}\mathbf{H}_1^T & \dots & \mathbf{H}_{j-1}^T & \mathbf{H}_{j+1}^T & \dots & \mathbf{H}_K^T\end{bmatrix}^T \quad (7)$$

The SVD of $\tilde{\mathbf{H}}_j$ can be described as

$$\tilde{\mathbf{H}}_j = \tilde{\mathbf{U}}_j\tilde{\mathbf{\Lambda}}_j\begin{bmatrix}\tilde{\mathbf{V}}_j^{(1)} & \tilde{\mathbf{V}}_j^{(0)}\end{bmatrix}^H \quad (8)$$

where $\tilde{\mathbf{U}}_j$ and $\tilde{\mathbf{\Lambda}}_j$ denote the left singular vector matrix and the matrix of ordered singular values of $\tilde{\mathbf{H}}_j$, respectively. The matrix $\tilde{\mathbf{V}}_j^{(1)}$ and $\tilde{\mathbf{V}}_j^{(0)}$ denote the right singular matrices each consists of the singular vectors corresponding to nonzero singular values of $\tilde{\mathbf{H}}_j$ and zero singular values of $\tilde{\mathbf{H}}_j$. The desired user has non-interfering block channel $\mathbf{H}_j\tilde{\mathbf{V}}_j^{(0)}$. In order to decouple this block channel into n_j parallel sub channels, the SVD of $\mathbf{H}_j\tilde{\mathbf{V}}_j^{(0)}$ is computed as

$$\mathrm{SVD}\left(\mathbf{H}_j\tilde{\mathbf{V}}_j^{(0)}\right) = \mathbf{U}_j^{\left(\mathbf{H}_j\tilde{\mathbf{V}}_j^{(0)}\right)}\mathbf{\Lambda}_j^{\left(\mathbf{H}_j\tilde{\mathbf{V}}_j^{(0)}\right)}\mathbf{V}_j^{\left(\mathbf{H}_j\tilde{\mathbf{V}}_j^{(0)}\right)H} = \mathbf{U}_j^{(b)}\mathbf{\Lambda}_j^{(b)}\mathbf{V}_j^{(b)H} \quad (9)$$

Employing $\mathbf{P}_j = \tilde{\mathbf{V}}_j^{(0)}\mathbf{V}_j^{(b)}$ and $\mathbf{M}_j = \mathbf{U}_j^{(b)H}$ in (5), the desired user's signal vector $\hat{\mathbf{x}}_j$ can be shown as follows,

$$\hat{\mathbf{x}}_j = \mathbf{\Lambda}_j^{(b)}\mathbf{x}_j + \mathbf{U}_j^{(b)H}\mathbf{w}_j \quad (10)$$

Finally, we can find the precoding matrix $\mathbf{P}$ as follows,

$$\mathbf{P} = \begin{bmatrix}\tilde{\mathbf{V}}_1^{(0)}\mathbf{V}_1^{(b)} & \tilde{\mathbf{V}}_2^{(0)}\mathbf{V}_2^{(b)} & \dots & \tilde{\mathbf{V}}_K^{(0)}\mathbf{V}_K^{(b)}\end{bmatrix} \quad (11)$$

The all user's received filter can be described as follows,

$$\mathbf{M} = diag\left\{\mathbf{U}_1^{(b)H} \quad \mathbf{U}_2^{(b)H} \quad \dots \quad \mathbf{U}_K^{(b)H}\right\} \quad (12)$$

B. *Generalized Zero-Forcing Channel Inversion*

For the so-called Generalized Zero-Forcing Channel Inversion (GZI) method [5], we need to perform the pseudo-inverse operation of the channel matrix $\mathbf{H}_i$ as follows,

$$\hat{\mathbf{H}}_i = \mathbf{H}_i^H\left(\mathbf{H}_i\mathbf{H}_i^H\right)^{-1} = \begin{bmatrix}\hat{\mathbf{H}}_1 & \hat{\mathbf{H}}_2 & \dots & \hat{\mathbf{H}}_K\end{bmatrix} \quad (13)$$

Consider the QR decomposition of matrix $\hat{\mathbf{H}}_j$ with dimension $N_t \times n_j$ as follows,

$$\hat{\mathbf{H}}_j = \hat{\mathbf{Q}}_j\hat{\mathbf{R}}_j \text{ for } j = 1,\dots,K \quad (14)$$

where $\hat{\mathbf{R}}_j$ is an $n_j \times n_j$ upper triangular matrix and $\hat{\mathbf{Q}}_j$ is an $N_t \times n_j$ matrix whose columns form an orthonormal basis for $\hat{\mathbf{H}}_j$. In (13), due to $\tilde{\mathbf{H}}_j\hat{\mathbf{H}}_j = 0$, we have $\tilde{\mathbf{H}}_j\hat{\mathbf{Q}}_j\hat{\mathbf{R}}_j = 0$. Since $\hat{\mathbf{R}}_j$ is invertible, it follows that $\tilde{\mathbf{H}}_j\hat{\mathbf{Q}}_j = 0$. As in the BD algorithm, in order to decouple this block channel into parallel sub channels, the SVD of $\mathbf{H}_j\hat{\mathbf{Q}}_j$ is computed as follows,

$$\mathrm{SVD}\left(\mathbf{H}_j\hat{\mathbf{Q}}_j\right) = \mathbf{U}_j^{\left(\mathbf{H}_j\hat{\mathbf{Q}}_j\right)}\mathbf{\Lambda}_j^{\left(\mathbf{H}_j\hat{\mathbf{Q}}_j\right)}\mathbf{V}_j^{\left(\mathbf{H}_j\hat{\mathbf{Q}}_j\right)H} = \mathbf{U}_j^{(vp)}\mathbf{\Lambda}_j^{(vp)}\mathbf{V}_j^{(vp)H} \quad (15)$$

Employing $\mathbf{P}_j = \hat{\mathbf{Q}}_j\mathbf{V}_j^{(vp)}$ and $\mathbf{M}_j = \mathbf{U}_j^{(vp)H}$ in (5), the desired user's signal vector $\hat{\mathbf{x}}_j$ can be described as follows,

$$\hat{\mathbf{x}}_j = \mathbf{\Lambda}_j^{(b)}\mathbf{x}_j + \mathbf{U}_j^{(vp)H}\mathbf{w}_j \quad (16)$$

Finally, we can find the precoding matrix $\mathbf{P}$ as follows,

$$\mathbf{P} = \begin{bmatrix}\hat{\mathbf{Q}}_1\mathbf{V}_1^{(vp)} & \hat{\mathbf{Q}}_2\mathbf{V}_2^{(vp)} & \dots & \hat{\mathbf{Q}}_K\mathbf{V}_K^{(vp)}\end{bmatrix} \quad (17)$$

The all user's received filter can be shown as

$$\mathbf{M} = diag\left\{\mathbf{U}_1^{(vp)H} \quad \mathbf{U}_2^{(vp)H} \quad \dots \quad \mathbf{U}_K^{(vp)H}\right\} \quad (18)$$

For the BD and GZI algorithms, we assume that transmitter knows the channel station information perfectly. However, due to the mismatch between the transmitter and receiver, the transmitter can not accurately know CSI. Define $\mathbf{H}_{err}$ as the channel estimation error, the CSI can be described as follows,

$$\mathbf{H} = \mathbf{H}_{est} + \mathbf{H}_{err} \quad (19)$$

where $\mathbf{H}$ and $\mathbf{H}_{est}$ are the true CSI and the estimated CSI, respectively. We assume that $\mathbf{H}_{err}$ is uncorrelated with $\mathbf{H}_{est}$ and $\mathbf{x}$. $\mathbf{H}_{err}$ has i.i.d. elements with zero mean and estimation error variance $\sigma_{e,h}^2$. So the received signal in (2) can be rewritten as

$$\mathbf{y}_s = \mathbf{H}_{est}\mathbf{P}_s\mathbf{x}_s + \mathbf{H}_{err}\mathbf{P}_s\mathbf{x}_s + \mathbf{w}_s \quad (20)$$

where the $\mathbf{H}_{err}\mathbf{P}_s\mathbf{x}_s$ is the estimation error term, and we define the total error term is $e = \mathbf{H}_{err}\mathbf{P}_s\mathbf{x}_s + \mathbf{w}_s$. The total error variance σ_e^2 can be shown as follows,

$$\sigma_e^2 = \mathrm{E}\left[\|\mathbf{e}\|^2\right] = N_t\sigma_{e,h}^2\,\mathrm{Tr}\left(\mathbf{P}_s^H\mathbf{P}_s\right) + N_r\sigma_w^2 \quad (21)$$

For the BD algorithm, equation (7) can be rewritten as

$$\tilde{\mathbf{H}}_j = \begin{bmatrix}\mathbf{H}_{est,1}^T & \dots & \mathbf{H}_{est,j-1}^T & \mathbf{H}_{est,j+1}^T & \dots & \mathbf{H}_{est,K}^T\end{bmatrix}^T \quad (22)$$

For the GZI algorithm, equation (13) can be rewritten as

$$\hat{\mathbf{H}}_{est,i} = \mathbf{H}_{est,i}^H\left(\mathbf{H}_{est,i}\mathbf{H}_{est,i}^H\right)^{-1} = \left[\hat{\mathbf{H}}_{est,1} \quad \hat{\mathbf{H}}_{est,2} \quad \dots \quad \hat{\mathbf{H}}_{est,K}\right] \quad (23)$$

III. The Proposed Water-Filling Algorithm

A. Spatial-Domain Water-Filling

Please check with your editor on whether to submit your manuscript as hard copy or electronically for review. If hard copy, submit photocopies such that only one column appears per page. This will give your referees plenty of room to write comments. Send the number of copies specified by your editor (typically four). If submitted electronically, find out if your editor prefers submissions on disk or as e-mail attachments.

Consider the system shown as in Figure 3, the capacity for complex AWGN MIMO channel when $\mathbf{H}$ is perfectly known at the receiver can be expressed as follows [7, 8],

$$C_{fixedH} = \max_{p(x)} I(X;Y) = \log_a\left(\det\left(I + \frac{H^* \cdot Q \cdot H}{\sigma_n^2}\right)\right) \quad (24)$$

The capacity under ergodicity conditions when $\mathbf{H}$ is perfectly known at the receiver can be described as

$$C_{ergodic} = E_H\left\{\log_a\left(\det\left(I + \frac{H^* \cdot Q \cdot H}{\sigma_n^2}\right)\right)\right\} \quad (25)$$

where σ_n^2 is the noise covariance, $\sigma_n^2 = E\left\{n_i(t_k)n_j(t_l)^*\right\}$. The transmitter correlation matrix Q can be diagonalised as

$$Q = V \cdot D_Q \cdot V^*$$

$$D_Q = \begin{pmatrix} P_T & 0 & \cdots & 0 \\ 0 & 0 & & 0 \\ \vdots & & \ddots & \vdots \\ 0 & \cdots & \cdots & 0 \end{pmatrix} \quad (26)$$

We can obtain the result that the capacity is the sum of the capacity of the parallel channels, that is

$$C_{fixed\_H} = \log_a\left(\det\left(I + \frac{\left(U \cdot \Lambda_j^{(b)} \cdot V^*\right)\left(V \cdot D_Q \cdot V^*\right)\left(V \cdot \Lambda_j^{(b)*} \cdot U^*\right)}{\sigma_n^2}\right)\right)$$
$$= \sum_{i=1}^{\min(M,N)} \log_a\left(1 + \frac{\left|\Lambda_j^{(b)}\right|^2 \cdot \mathbf{\Phi}_j}{\sigma_n^2}\right) \quad (27)$$

The sum rate R_{BD} for the BD algorithm can be written in terms of the following maximization [5,6],

$$R_{BD} = \max_{\mathbf{\Phi}_j} \sum_{j=1}^{K} \log_2 \det\left(\mathbf{I} + \frac{\left(\mathbf{\Lambda}_j^{(b)}\right)^2 \mathbf{\Phi}_j}{\sigma_w^2}\right)$$
$$\text{subject to} \sum_{j=1}^{K} \mathrm{Tr}(\mathbf{\Phi}_j) \le P_{total} \quad (28)$$

The optimal power loading matrix $\mathbf{\Phi}_j$ can be calculated from the sum rate (28) by using the water-filling method [9-12],

$$\mathbf{\Phi}_j = \left(\mu - \frac{\sigma_n^2}{\left|\mathbf{\Lambda}_j^{(b)}\right|^2}\right)^+ \text{ with } \mu \text{ such that } \sum_{j=1}^{K} \mathbf{\Phi}_j = P_T \quad (29)$$

Using (23) and (25), the optimal capacity can then be described as

$$C = \sum_{j \text{ such that } \mu \ge \frac{\sigma_n^2}{\mathbf{\Lambda}_j^{(b)}}} \log_a\left(\frac{\mu\left|\mathbf{\Lambda}_j^{(b)}\right|^2}{\sigma_n^2}\right) \quad (30)$$

Finally, we can find the block diagonalization precoding matrix $\mathbf{P}^{BD}$ as

$$\mathbf{P}^{BD} = \left[\tilde{\mathbf{V}}_1^{(0)}\mathbf{V}_1^{(b)} \quad \tilde{\mathbf{V}}_2^{(0)}\mathbf{V}_2^{(b)} \quad \dots \quad \tilde{\mathbf{V}}_K^{(0)}\mathbf{V}_K^{(b)}\right]\mathbf{\Phi}^{\frac{1}{2}} \quad (31)$$

The all user's received filter can be shown as

$$\mathbf{M}^{BD} = diag\left\{\mathbf{U}_1^{(b)H} \quad \mathbf{U}_2^{(b)H} \quad \dots \quad \mathbf{U}_K^{(b)H}\right\} \quad (32)$$

Similarly, the GZI precoding matrix $\mathbf{P}^{GZI}$ is as follows,

$$\mathbf{P}^{GZI} = \left[\hat{\mathbf{Q}}_1\mathbf{V}_1^{(vp)} \quad \hat{\mathbf{Q}}_2\mathbf{V}_2^{(vp)} \quad \dots \quad \hat{\mathbf{Q}}_K\mathbf{V}_K^{(vp)}\right]\mathbf{\Phi}^{\frac{1}{2}} \quad (33)$$

The all user's received filter is

$$\mathbf{M}^{GZI} = diag\left\{\mathbf{U}_1^{(vp)H} \quad \mathbf{U}_2^{(vp)H} \quad \dots \quad \mathbf{U}_K^{(vp)H}\right\} \quad (34)$$

B. Spatial-Frequency Domain Water-Filling

The multiuser MIMO downlink system with space-frequency domain water filling can be shown as Fig. 4. The transmitted signal goes through precoding matrix and water filling and then received with receiver filter to decode the desired user's signal. If the GZI method is employed to perform space- domain water filling, the signal before FFT operation can be described as follows,

$$\mathbf{x}_S = \left[\mathbf{x}_S^1 \quad \mathbf{x}_S^2 \quad \dots \quad \mathbf{x}_S^K\right]$$
$$= \left[\mathbf{P}_{S1}\hat{\mathbf{Q}}_1^{(vp)}\mathbf{V}_1^{(vp)}\mathbf{x}_1 \quad \mathbf{P}_{S2}\hat{\mathbf{Q}}_2^{(vp)}\mathbf{V}_2^{(vp)}\mathbf{x}_2 \quad \dots \quad \mathbf{P}_{SK}\hat{\mathbf{Q}}_K^{(vp)}\mathbf{V}_K^{(vp)}\mathbf{x}_K^T\right] \quad (35)$$

Then after N-point FFT operation, the frequency-domain signal of the jth user is as follows,

$$\mathbf{X}_j = \left[\mathbf{X}_1^T \quad \mathbf{X}_2^T \quad \dots \quad \mathbf{X}_N^T\right]^T = \mathbf{F}\left\{\mathbf{P}_{Sj}\hat{\mathbf{Q}}_j^{(vp)}\mathbf{V}_j^{(vp)}\mathbf{x}_j\right\} \quad (36)$$

Collecting the all user signal we obtain

$$\mathbf{X} = \left[\mathbf{X}_1^T \quad \mathbf{X}_2^T \quad \dots \quad \mathbf{X}_K^T\right]^T$$
$$= \left[\mathbf{F}\left\{\mathbf{P}_{S1}\hat{\mathbf{Q}}_1^{(vp)}\mathbf{V}_1^{(vp)}\mathbf{x}_1\right\}^T \quad \dots \quad \mathbf{F}\left\{\mathbf{P}_{SK}\hat{\mathbf{Q}}_K^{(vp)}\mathbf{V}_K^{(vp)}\mathbf{x}_K\right\}^T\right]^T \quad (37)$$

Let N be the number of subcarrier, f_i be the i -th sub-channel, $P[i]$ be the transmitted power of the i -th subchannel. The capacity of the k-th subchannel is given[14,15],

$$C(f_k) = \Delta f \log_2\left(1 + \left|H[k]\right|^2 \frac{P[k]}{N_0}\right) \quad (38)$$

Where Δf , $H[k]$, $P[k]$ and N_0 denote the subcarrier spacing, frequency response, transmission power and noise variance of the k-th subchannel. The total channel capacity is given by the sum of the capacity for individual subcarriers,

$$C = \sum_{k=0}^{N-1} C(f_k) \quad (39)$$

Given the SNR for each subcarrier, we may allocate different powers to different subcarriers so as to maximize the total system capacity, that is

$$\max_{P_0,\dots,P_{N-1}} \sum_{k=0}^{N-1} C(f_k) = \max_{P_0,\dots,P_{N-1}} \sum_{k=0}^{N-1} \log_2\left(1+|H[k]|^2 \frac{P[k]}{N_0}\right) \quad \text{subject to} \quad \sum_{k=0}^{N_{used}-1} P[k] = NP \tag{40}$$

where P is the average power for each subcarrier available in the transmitter. Employing the Lagrange multiplier method for optimization with equality constraint in Equation (40), the following solution is obtained. We can find the optimum solution by maximizing the Lagrange function defined by [16],

$$L = -\sum_{k=0}^{N-1} \log_2\left(1+|H[k]|^2 \frac{P[k]}{N_0}\right) + \lambda\left(\sum_{k=0}^{N_{used}-1} P[k] - NP\right) \tag{41}$$

That is (42)

$$\frac{\partial L}{\partial P[k]} = \frac{\partial}{\partial P[k]}\left\{-\sum_{k=0}^{N-1} \log_2\left(1+|H[k]|^2 \frac{P[k]}{N_0}\right) + \lambda\left(\sum_{k=0}^{N_{used}-1} P[k] - N\cdot P\right)\right\} = 0$$

$$\frac{\partial L}{\partial \lambda} = \left(\sum_{k=0}^{N_{used}-1} P[k] - NP\right) = 0 \tag{43}$$

$$-\left(1+|H[k]|^2 \frac{P[k]}{N_0}\right)^{-1} + \lambda = 0$$

The solution is

$$P^*[k] = \left(\frac{1}{\lambda} - \frac{N_0}{|H[k]|^2}\right)^+ = \begin{cases} \dfrac{N_0}{\lambda |H[k]|^2} - \dfrac{N_0}{|H[k]|^2}, & \text{if } \dfrac{1}{\lambda} - \dfrac{N_0}{|H[k]|^2} \ge 0 \\ 0 & \text{otherwise} \end{cases} \tag{44}$$

where λ is the Lagrange multiplier that is chosen to meet the power constraint in Equation (44).

Each frequency-domain user signal is then multiplied frequency-domain water-filling operation and can be express as follows,

$$\begin{aligned} \mathbf{X}_f &= \left[\mathbf{X}_1^T \quad \mathbf{X}_2^T \quad \dots \quad \mathbf{X}_K^T\right]^T \\ &= \left[\mathbf{P}_{f1}\mathbf{F}\left\{\mathbf{P}_{S1}\hat{\mathbf{Q}}_1^{(vp)}\mathbf{V}_1^{(vp)}\mathbf{x}_1\right\}_1^T \quad \dots \quad \mathbf{P}_{fK}\mathbf{F}\left\{\mathbf{P}_{SK}\hat{\mathbf{Q}}_K^{(vp)}\mathbf{V}_K^{(vp)}\mathbf{x}_K\right\}_K^T\right] \end{aligned} \tag{45}$$

The total transmit signal can be described as

$$\begin{aligned} \mathbf{S} &= \left[\mathbf{S}_1^T \quad \mathbf{S}_2^T \quad \dots \quad \mathbf{S}_{Nt}^T\right]^T \\ &= \left[(\mathbf{X}_1+\mathbf{X}_2+\dots+\mathbf{X}_K)_1^T \quad \dots \quad (\mathbf{X}_1+\mathbf{X}_2+\dots+\mathbf{X}_K)_{Nt}^T\right] \end{aligned} \tag{46}$$

IV. Simulation Results

In this section, we provide some simulation examples to demonstrate the performance of the proposed method. The results will be verified by Monte Carlo simulation method, and the adopted channel model is the COST 207 RA/TU/BU environments. We compare the BER performance of our proposed algorithm with that without water-filling. The simulated modulated signal format is QPSK. The simulated number of active users is K=2. For the TU channel model, the number of paths L is equal to 12. For the BU channel model, the number of paths L is equal to 21. For the simulations, two precoding algorithms, BD and GZI algorithms, are employed to combined with spatial-domain and frequency-domain water-filling technology for the MU-MIMO system. For the MU- MIMO system, the base station is equipped with four antennas and the mobile station is equipped with two antennas.

In Fig. 5, we compare the bit error rate (BER) performances of the MU-MIMO systems with and without BD algorithm, an further compare the BER performances with 1-D (spatial-domain) water-filling and 2-D (spatial-domain and frequency-domain) water-filling. Fig. 5 shows that the proposed 2-D water-filling BD algorithm has superior performance compared with 1-D BD algorithm and conventional BD algorithm. In Figs. 6-7, we show the performance degradation of the conventional BD/GZI precoding algorithms and the water-filling BD/GZI algorithm in the situation of channel mismatch, respectively. The proposed water-filling BD/GZI algorithm outperforms the conventional BD/GZI algorithm, especially in the low signal-to-noise ratio condition. In Figs. 8-9, we compare the BER performances of the GZI algorithm with and without water-filling technology in COST-207 TU and BU channels, respectively. Figs. 8-9 show that 2-D water-filling GZI precoding algorithm outperforms 1-D or conventional GZI, even though the transmission power is one half of that of conventional GZI. In Figs. 10-11, we show the performance degradation of the proposed 2-D water-filling GZI precoding algorithms in the situation of channel mismatch in COST-207 TU and BU channels, respectively. The proposed 2-D water-filling GZI algorithm has BER 0.001 at SNR 15 dB even though channel mismatch exists.

V. Conclusion

The water-filling technology performs power allocation based on channel environment of each user and has been used in MIMO system that uses each antenna CSI to find maximum eigenvalue to do power allocation as the spatial domain water filling. In this paper, the BD/GZI algorithms are combined with water-filling technology to perform power allocation and MUI/MAI cancellation for the MU-MIMO systems. The proposed algorithms are with space-frequency water-filling. Some simulation examples are given to demonstrate the effectiveness of the proposed algorithm.

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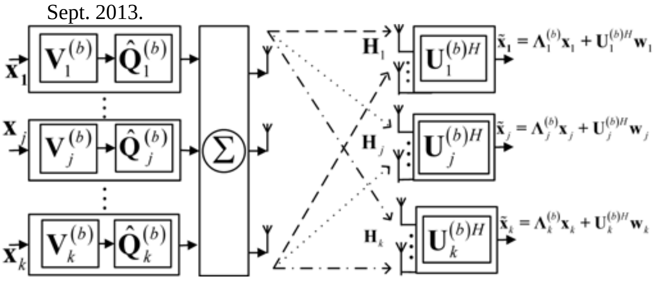

Fig. 1: Block diagonalization algorithm for multiuser MIMO downlink system.

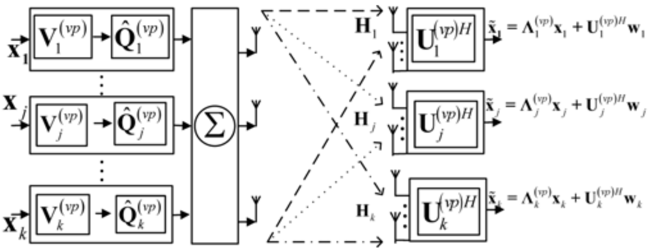

Fig. 2: GZI algorithm for multiuser MIMO downlink system.

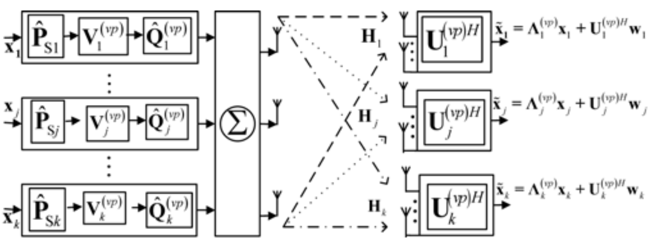

Fig. 3: GZI with 1D-water filling multiuser MIMO downlink system.

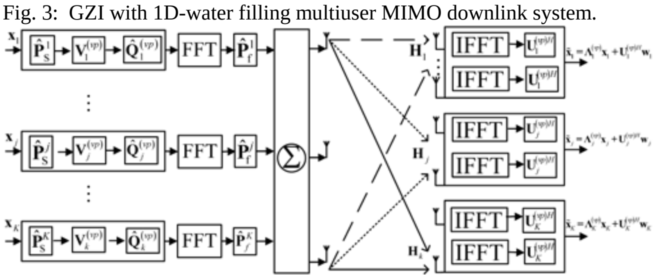

Fig. 4: GZI with 2D-water filling multiuser MIMO downlink system.

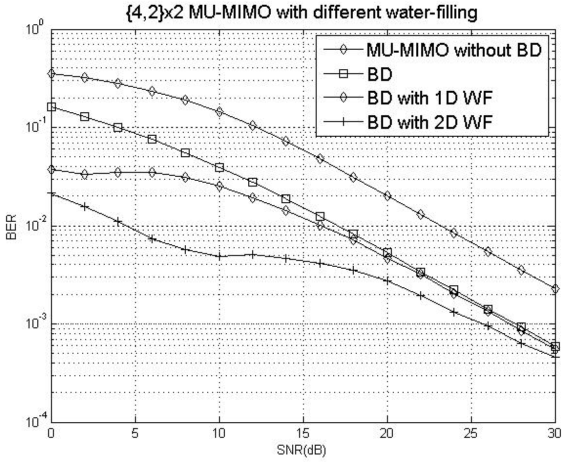

Fig. 5: BER performance comparisons of the proposed 2D water-filling algorithm and some existing algorithms: 4 transmit antenna, 2 receive antenna, 2 users.

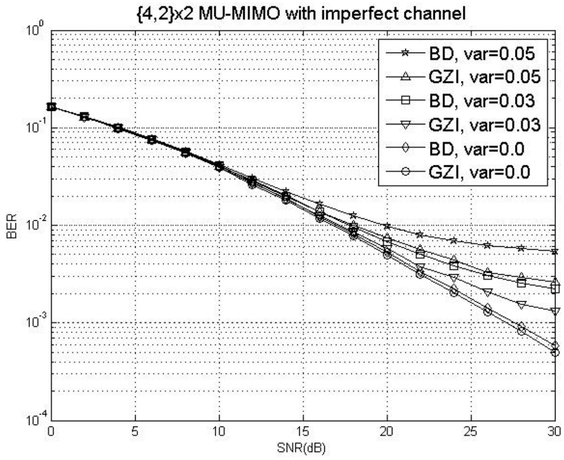

Fig. 6: BER performance comparisons of the BD/GZI algorithms (without water-filling) with channel mismatch: 4 transmit antenna, 2 receive antenna, 2 users.

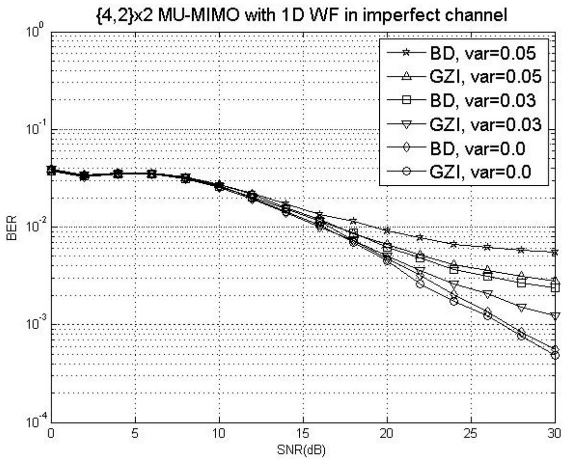

Fig. 7: BER performance comparisons of the BD/GZI algorithms (with 1D water-filling) with channel mismatch: 4 transmit antenna, 2 receive antenna, 2 users.

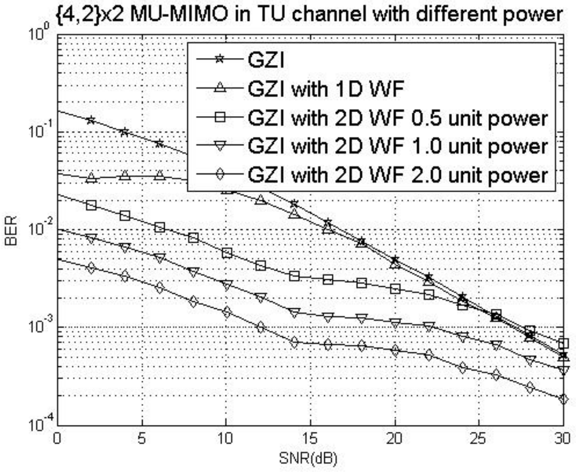

Fig. 8: BER performance comparisons of the proposed GZI water-filling algorithm with different power: 4 transmit antenna, 2 receive antenna, 2 users and TU channel.

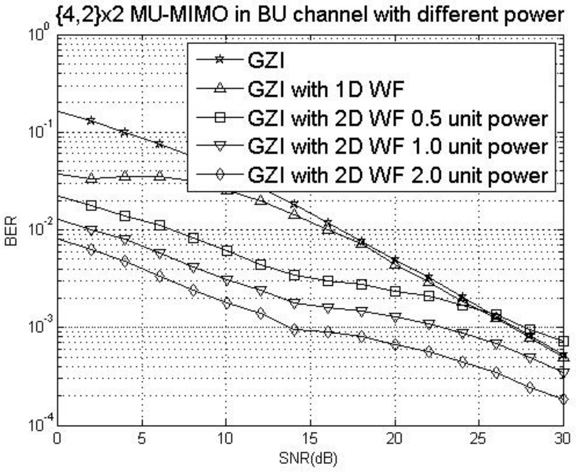

Fig. 9: BER performance comparisons of the proposed GZI water-filling algorithm with different power: 4 transmit antenna, 2 receive antenna, 2 users and BU channel.

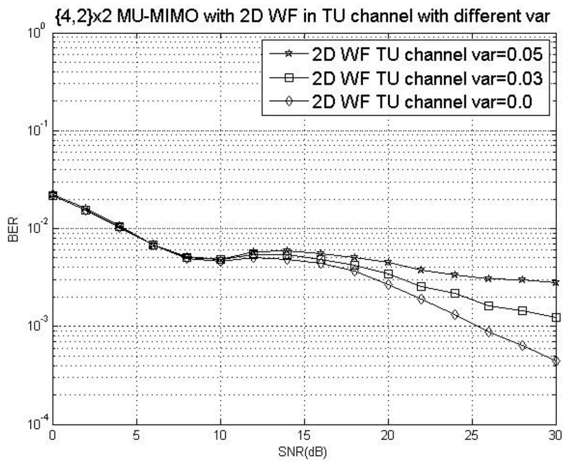

Fig. 10: BER performance comparisons of the proposed GZI 2D water-filling algorithm with channel mismatch: 4 transmit antenna, 2 receive antenna, 2 users and TU channel.

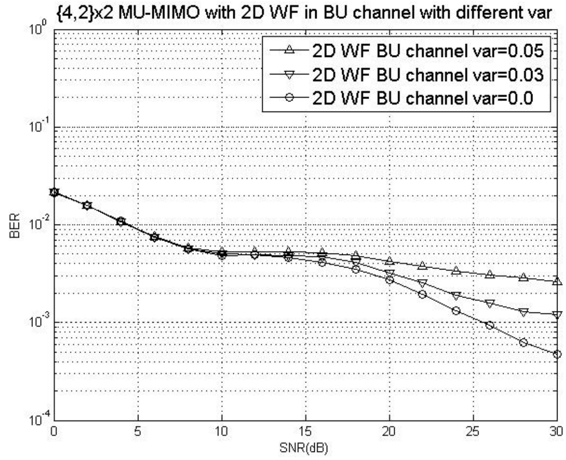

Fig. 11: BER performance comparisons of the proposed GZI 2D water-filling algorithm with channel mismatch: 4 transmit antenna, 2 receive antenna, 2 users and BU channel.