Comparative Investigation on Spatial Multiuser Diversity for Downlink MIMO in TDD System

Guangyi LIU, Jianhua ZHANG
Research Institute of China Mobile, Beijing University of Posts & Telecoms
Email liuguangyi@chinamobile.com, jhzhang@bupt.edu.cn

***Abstract*- MIMO can enhance the performance of wireless system greatly. However, the limited battery life and terminal size of the UE in a cellular system put a constraint on the performance enhancment by MIMO. Especially when the tranmitter has more antenna than the receiver in downlink, the conventional MIMO schemes can only exploit partial spatial multiplexing gain and diversity gain. For different users' independent locations lead to independent spatial fading one another, the spatial multiuser diversity is proposed to achieve the tradeoff between the multiplexing gain and spatial diversity gain available. In this paper, the enhanced MIMO schemes with multiuser diversity for this scenario are compared, Zero Forcing Beamforming (ZFB), Dual Space Time Block Coding (DSTBC), Singular Value Decomposition (SVD) and Vertical Bell labs LAyered Spatial Time code plus Antenna Selection (VBLAST-AS). From the simulation results, the ZFB has achieved the best spectrum efficiency, and the gain over the VBLATS-AS and DSTBC is more than 50%.**

I. INTRODUCTION

Recently, MIMO has been proved to be very promising to improve the cellular system capacity greatly. By configuring multiple antennas at both the Node B and User Equipment (UE), the channel capacity may be improved to be proportional to the minimum number of the antennas at the transmitter and receiver [1]. Exploiting the Channel Status Information (CSI) at both the transmitter and receiver perfectly, the MIMO channel capacity can be approached by SVD with water-filling power allocation [2]. Another simple MIMO scheme is Vertical Bell labs LAyered Spatial Time code (VBLAST) [3], which requires full CSI only at the receiver. Exploiting the CSI at the transmitter, VBLAST can also approach the MIMO capacity [4]. Another MIMO scheme is Spatial Time Block Coding (STBC). The simplest STBC is the Alamouti code, which is proposed in [5], and can obtain the full diversity gain in 1×2 MISO scenario.

For different UEs experience independent spatial fading for their independent location one another, different antenna at the Node B may be assigned to different UEs to exploit the spatial multiuser diversity and spatial multiplexing gain, and achieve the best cell throughput if the interference among different antennas can be canceled. In [6], an improved round robin scheduler for antenna assignment is proposed for multiuser downlink with VBLAST to exploit the spatial multiuser diversity. In [7], a Greedy antenna assignment is proposed for VBLAST downlink to exploit the spatial multiuser diversity gain.

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However, for the limited terminal size and battery life, UE usually has fewer antennas than Node B in a cellular system. In this scenario, the conventional VBLAST can't be adopted in downlink directly. To obtain the diversity gain and spatial multiplexing gain as much as possible, Dual Space Time Blocking Coding (DSTBC) and VBLAST with Antenna Selection(VBLAST-AS) is proposed in [8] [9] respectively. DSTBC can exploit the full transmit diversity gain, but partial multiplexing gain, while VBLAST-AS can achieve full spatial multiplexing gain from the available antennas, but partial transmit diversity gain. To exploit the full spatial multiuser diversity gain, Zero Forcing Beamforming (ZFB) is proposed in [10]. ZFB exploit the CSI of all UEs at the transmitter, and select the different antennas from different UEs to receive independent data streams respectively without interference to one another. Because the pre-processing has been done before the transmission, and no further spatial processing is required at the receiver.

In this paper, the downlink performances of the DSTBC, VBLAST-AS, ZFB and SVD mentioned above are compared in a MIMO system when the transmitter has more antennas than receiver and full CSI is available at the transmitter. Since TDD is assumed in this paper, the full CSI can be obtained at Node B by channel reciprocity. The Greedy scheduling is adopted in this paper to obtain the maximum system capacity. By exploiting the full CSI of MIMO at the transmitter, the spatial multiuser diversity gain can be exploited as much as possible though the equal power allocation on different antennas or data streams is adopted. From the simulation results, ZFB can achieve best system performance because it can achieve the full spatial multiplexing gain and spatial multiuser diversity gain.

This paper is organized as follows. The system model of DSTBC, VBLAST-AS, ZFB and SVD are introduced in Section II. The simulation parameters and results are presented and analyzed in section III, and the conclusions are drawn in section IV.

II. SYSTEM MODEL

To make full use of the MIMO channel capacity, four MIMO schemes are introduced to improve the system spectrum efficiency, VBLAST-AS [9], DSTBC [8], ZFB [10] and SVD. In this section, the basic principles of them are introduced.

1. VBLAST-AS

For VBLAST, the receiver antenna number is required to be more than that at the transmitter to obtain robust detection performance. However in a cellular system, the UE usually

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has fewer antennas than Node B for the limited terminal size and battery life. So the conventional VBLAST can't be adopted in the downlink directly. A possible solution to use VBLAST in downlink is to select partial of the transmitter antennas to transmit independent data streams according to the CSI at the transmitter as Figure 1.

Based on the CSI at the transmitter, the UE to receive and the antennas of the transmitter can be selected to maximize the total system capacity. After the antenna selection, the total power available at the Node B is allocated on the selected antennas equally. At the receiver, the Zero Forcing equalization is adopted to detect the different data streams.

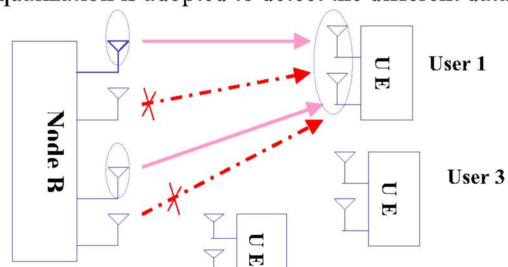

Figure 1 VBLAST-AS

Based on the Channel Impulse Response (CIR) at the UE, the transmitter antenna is selected and the corresponding post-detection SNR can be estimated for every transmitter antenna at Node B; The UE who can obtain the maximum capacity is scheduled to receive. The CIR experienced by user i is presented as:

$$\mathbf{H}^i = \left[H^i_{m,n} \right]_{N\times M} \tag{1}$$

Where N and M are the receiver and transmitter antenna number respectively, and $M > N$. And the UE is selected as following:

$$\mathbf{H} = \max_i C(\mathbf{H}^i) \tag{2}$$

$C(\mathbf{H}^i)$ means the channel capacity of $\mathbf{H}^i$. According to the decremental antenna selection algorithm [11], the same number of antennas as UE is selected to maximize the MIMO capacity available. The selected sub-matrix of MIMO is expressed as $\mathbf{H}^{'}$. The received signal from the transmitter is expressed as:

$$\mathbf{r} = \mathbf{H}^{'}\mathbf{d} + \mathbf{V} \tag{3}$$

Where $\mathbf{V}$ is the AWGN vector with variance σ^2 for every element, and $\mathbf{d}$ is the symbol vector transmitted from antennas of the Node B. In this paper, Zero Forcing (ZF) detection is adopted for VBLAST. For the same power is allocated for different Node B antennas selected, the post-detection SNR for the signal from transmitter antenna j can be estimated as:

$$SNR_j = \frac{P_T}{M_T}\frac{1}{\sigma^2 \left\|\mathbf{w}_j\right\|^2} \tag{4}$$

Where N is the selected antenna number at the Node B, P_T is the total transmitter power, σ^2 is the noise power experienced by the signal transmitted from antenna j, $\mathbf{w}_j$ is the detection weight for the signal transmitted from antenna j by Zero Forcing detection.

$$\mathbf{w}_j = \left(pinv\left(\mathbf{H}^{'}\right)\right)_j \tag{5}$$

Where $pinv$ means the pseudo-inversion, and $(\ )_j$ means the row j of the matrix.

The capacity of the MIMO channel can be expressed as following:

$$c = \sum_{j=1}^{N}\log_2\left(1+SNR_j\right) = \sum_{j=1}^{N}\log_2\left(1+\frac{P_T}{M}\frac{1}{\sigma_i^2\left\|\mathbf{w}_j\right\|^2}\right) \tag{6}$$

Further, the different transmitter antenna can also be assign to different UE, which is called multiuser Per Antenna Rate Control (MU-PARC) in this paper. The transmitter antenna is assigned to the user who can achieve highest capacity.

2. DSTBC

Dual STBC [8] is also called as multi-layer STBC or Grouped VBLAST. The antennas of the transmitter are divided into several groups (named as multiple layers), which have two antennas, and STBC is applied to every layer. Then at the receiver, the stronger layer is detected first, and its signal is reconstructed and subtracted from the left layers, and thus the interference from the stronger layers can be cancelled. The full transmission diversity gain can be achieved by DSTBC.

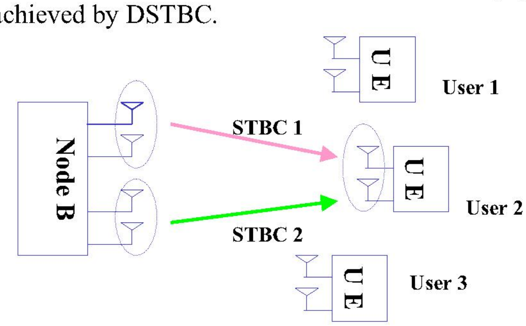

Figure 2 D-STBC

The transmitted data symbol after the STBC is:

$$\mathbf{A} = \begin{bmatrix} a_1 & -a_2^* \\ a_2 & a_1^* \\ a_3 & -a_4^* \\ a_4 & a_3^* \end{bmatrix} = \left[\mathbf{a}(1)\mathbf{a}(2)\right] \tag{7}$$

The received signal of this scheme can be reconstructed [8] and expressed as following:

$$\begin{aligned}\mathbf{r} &= \mathbf{H}\mathbf{a}(1)+\mathbf{n} = \begin{bmatrix}\mathbf{H}_{A,1} & \mathbf{H}_{B,1}\\ \mathbf{H}_{A,2} & \mathbf{H}_{B,2}\end{bmatrix}\mathbf{a}(1)+\mathbf{n}\\ &= \mathbf{H}_D\mathbf{a}(1)+\mathbf{n}\end{aligned} \tag{8}$$

Where N is the receiver antenna number, and

$$\mathbf{H}_{A,n} = \begin{bmatrix} h_{n,1} & h_{n,2} \\ -h_{n,2}^* & h_{n,1}^* \end{bmatrix}, \quad \mathbf{H}_{B,n} = \begin{bmatrix} h_{n,3} & h_{n,4} \\ -h_{n,4}^* & h_{n,3}^* \end{bmatrix} \tag{9}$$

Then the capacity of the DSTBC can be expressed as:

$$C = \frac{1}{2}\log_2\left(\mathbf{I}_4 + \frac{P_T}{4\sigma^2}\mathbf{H}_D^H\mathbf{H}_D\right) \tag{10}$$

Further, the different transmitter antenna group can also be assigned to different UEs to achieve more multiuser diversity gain, which is called as Multiuser D-STBC (MU D-STBC).

3. Zero Forcing Beamforming

In this scheme, all the antennas of UEs are constructed as a virtual UE, which owns all the antennas from different UEs. And then the CIR of the virtual UE can be constructed as:

$$\mathbf{H} = \left[\mathbf{H}^1 \quad \ldots \quad \mathbf{H}^i \quad \ldots \quad \mathbf{H}^K\right] \tag{11}$$

Where $\mathbf{H}^i$ is MIMO channel response of UE i. Then the receiver antenna selection is executed to select partial antennas to receive at the virtual UE. To guarantee the orthogonality among the independent data streams from Node B, the number of the selected receiver antenna should be fewer than that at the Node B. In this paper, the decremental antenna selection algorithm [11] has been adopted even it is much complex when the user number is large. Every time, one antenna is deleted from the receiver of the virtual UE, which contributes minimum to the total capacity.

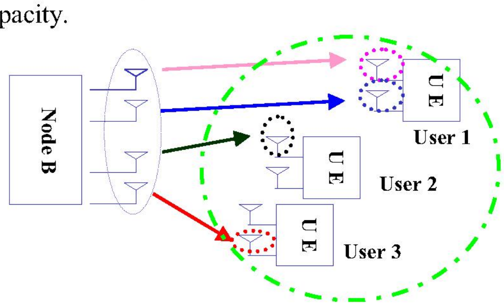

Figure 3 Zero Forcing Beamforming

With the CIR selected, the zero forcing beamforming can be applied. The beamforming weights for the data streams are calculated as following [10]:

$$\mathbf{B} = \mathbf{H}^H\left(\mathbf{H}\mathbf{H}^H\right)^{-1}\mathbf{D} \tag{12}$$

Where $\mathbf{D} = diag\left(d_1, \ldots d_k, \ldots, d_M\right)$ is the diagonal matrix which keeps the transmit power unchanged after beamforming, and H means the hermit transpose. M is the antenna number selected at the virtual UE, which is also the number of independent data stream.

$$d_k = 1 \Big/ \sqrt{\left[\left(\mathbf{H}\mathbf{H}^H\right)^{-1}\right]_{k,k}} \tag{13}$$

If M receiver antennas are selected, and $\mathbf{S} \in \mathbb{C}^{M\times 1}$ is the modulated symbol vector, the element s_k is the transmitted data symbol on the data stream k, the transmitted signal after beamforming is:

$$\mathbf{x} = \mathbf{B}\mathbf{S} \tag{14}$$

And after the channel, the receiver signal at the virtual UE can be expressed as:

$$\mathbf{r} = \mathbf{H}\mathbf{x} + \mathbf{n} = \mathbf{H}\mathbf{B}\mathbf{S} + \mathbf{n} = \mathbf{D}\mathbf{S} + \mathbf{n} \tag{15}$$

Because $\mathbf{D}$ is a diagonal matrix, the MIMO channel is decomposed into M SISO channels with channel gain d_k respectively. The total power of the Node B can be allocated among the different data streams to maximize the total system capacity.

If the power allocated to different data streams is expressed as p_k, and $P_T = \sum_{k=1}^{M} p_k$, then the capacity is expressed as:

$$C = \sum_{k=1}^{M}\log_2(1 + SNR_k) = \sum_{k=1}^{M}\log_2(1 + \frac{p_k}{\sigma^2}) \tag{16}$$

4. SVD

Since SVD requires vector processing at both transmitter and receiver, no multiple users multiplexing can be exploited. At one time, the antennas of Node B can only be assigned to the same UE. For the greedy scheduling, the UE with maximum channel capacity is selected to receive.

If the CIR of the selected UE is $\mathbf{H}$, the signal from the transmitter is:

$$\mathbf{x} = \mathbf{V}\mathbf{S} \tag{17}$$

Where $\mathbf{H} = \mathbf{U}\mathbf{D}\mathbf{V}^T$ is the singular value decomposition of $\mathbf{H}$, and $\mathbf{D}$ is the diagonal matrix with singular value on its diagonal elements, $\mathbf{U}$ and $\mathbf{V}$ are the corresponding singular matrix.

At the receiver, the vector processing is done as following:

$$\begin{aligned} y &= \mathbf{U}^T\mathbf{r} = \mathbf{U}^T(\mathbf{H}\mathbf{x} + \mathbf{n}) = \mathbf{U}^T\mathbf{H}\mathbf{V}\mathbf{S} + \mathbf{U}^T\mathbf{n} \\ &= \mathbf{U}^T\left(\mathbf{U}\mathbf{D}\mathbf{V}^T\right)\mathbf{V}\mathbf{S} + \mathbf{U}^T\mathbf{n} = \mathbf{D}\mathbf{S} + \mathbf{U}^T\mathbf{n} \end{aligned} \tag{18}$$

$\mathbf{U}^T$ is an unitary matrix, which will not change the power of the noise vector. So the MIMO channel is decomposed into several independent SISO channels with channel gain d_k respectively. The total power of the Node B can be allocated to maximize the total system throughput.

If the power allocated to different data streams is expressed as p_k, and $P_T = \sum_{k=1}^{N} p_k$, then the MIMO capacity by SVD is expressed as:

$$C = \sum_{k=1}^{N}\log_2(1 + SNR_k) = \sum_{k=1}^{N}\log_2(1 + \frac{p_k}{\sigma^2}) \tag{19}$$

III. SIMULATION PARAMETERS

In this paper, the MIMO channel with uncorrelated Rayleigh flat fading is adopted in our simulation. The system capacity is counted as Shannon capacity. The greedy scheduling is adopted to maximize the system capacity without considering the user fairness. The total power is allocated to different data streams equally. The total Signal to Noise Ratio is defined as:

$$\rho = \frac{P_T}{\sigma^2} = 10(dB) \qquad (20)$$

To observe the multiuser diversity gain in spatial domain, the path loss and the shadowing are not considered in our simulation. In fact, the path loss and the shadowing will lead to more multiuser diversity gain and bad user fairness when greedy scheduling is used since higher multiuser diversity gain can be obtained when the channel variance become larger.

IV. SIMULATION RESULTS

The spectrum efficiency of the schemes mentioned in section II is presented as Figure 4, Figure 5, Figure 6 and Figure 7. Generally, ZFB has achieved the best performance and its gain exceeds DSTBC and VBLAST-AS at least 50%.

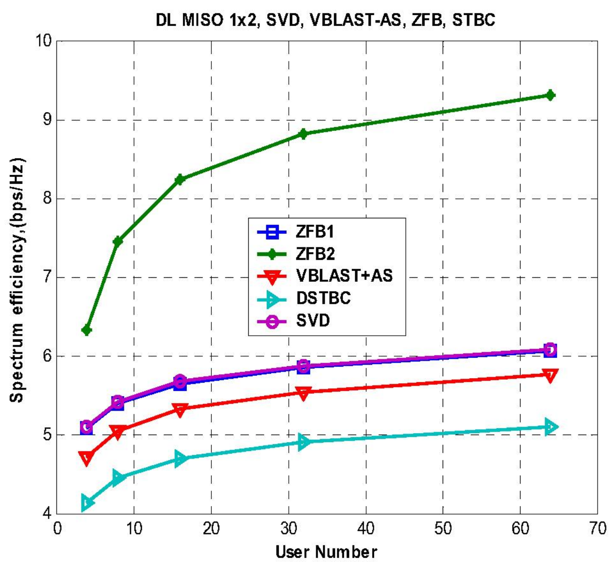

Figure 4 Spectrum efficiency Vs. UE number per cell (1×2)

In Figure 4, the 1×2 MISO scenario is investigated. For only 2 transmit antennas available at the transmitter, ZFB can transmit on two independent data streams at most. For D-STBC, only the conventional Alamouti spatial time block coding is adopted to transmit one data stream, while VBLAST-AS transmits one data stream with selective transmission diversity. From the results, ZFB can achieve the best spectrum efficiency, and the VBLAST-AS achieve better performance than the D-STBC. For the scheduling is done once every timeslot, the power can always be allocated to better transmitter antenna, and thus the effect like the water-filling is achieved by antenna selection for VBLAST, and then VBLAST-AS achieves better performance than D-STBC. For two independent data streams are transmitted and full spatial multiuser diversity gin can be achieved ZFB, it obtains the best performance. For ZFB with only one data stream, its performance is the same as that of SVD. The reason is that both ZFB and SVD do beamforming at transmitter in this scenario, and their beamforming gains are the same.

As the user number increases, the spatial multiuser diversity gain contributes more to the total spectrum efficiency and better performance is achieved for all the schemes mentioned above.

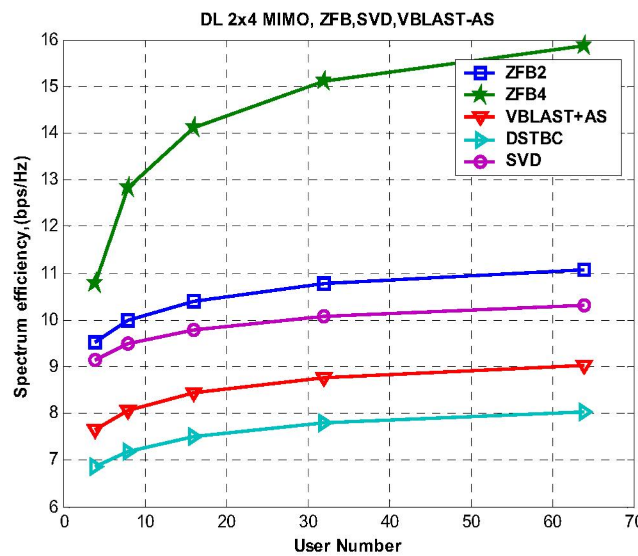

Figure 5 Spectrum efficiency Vs. UE number per cell (2×4)

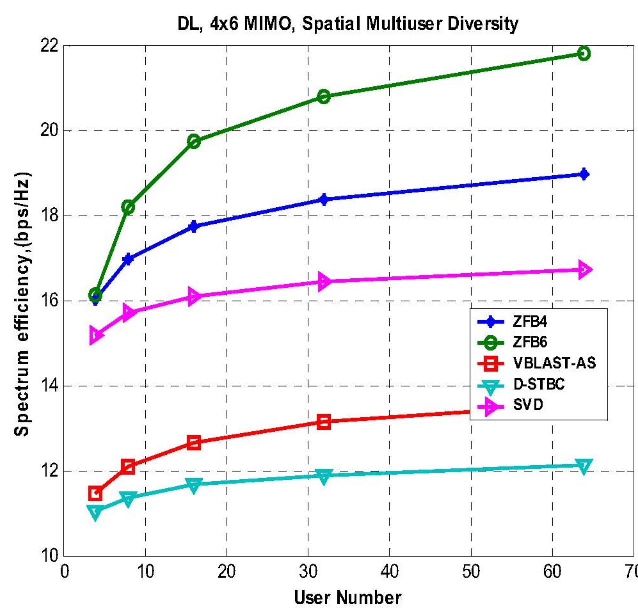

Figure 6 Spectrum efficiency Vs. UE number per cell (4×6)

In Figure 5, 2×4 MIMO scenario is investigated. For ZFB scheme, 2 or 4 independent data streams can be selected. Even the extra two data streams are little weaker than the first two, their contribution to the spectrum efficiency is also obvious. The spectrum efficiency of ZFB with 4 data streams is higher than DSTBC and VBLAST-AS about 50%. SVD can achieve the full spatial multiplexing gain and diversity gain of single user scenario, so its performance is better than that of VBLAST-AS. However, for all the antennas of the transmitter can only be assigned to one user, only partial multiuser diversity gain and multiuser multiplexing gain can be exploited, its performance is worse than that of ZFB. VBLAST-AS achieves higher spectrum efficiency than D-STBC about 10%. Although D-STBC can achieve full transmit and receive diversity, it consumes double power of VBLAST-AS and can only exploit part of spatial multiuser diversity like VBLAST-AS. So D-STBC has little worse performance than that of VBLAST-AS. Further, the spatial multiuser diversity gain increases as the user number increases in the system for all the MIMO schemes mentioned above.

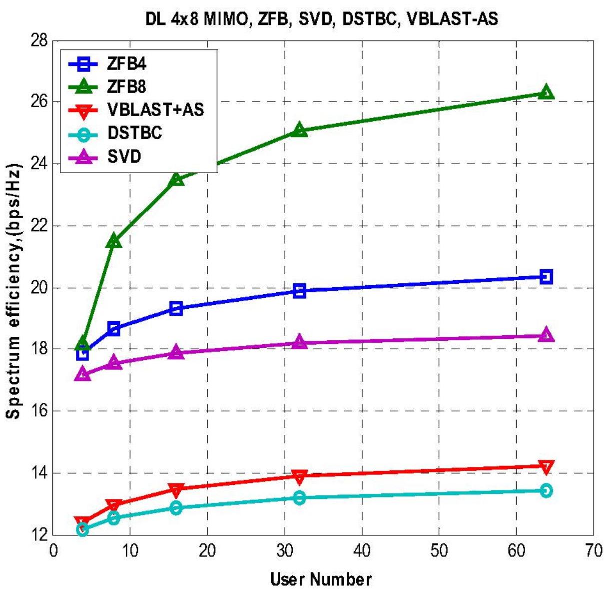

Figure 7 Spectrum efficiency Vs. UE number per cell (4×8)

Figure 6 and Figure 7 present spectrum efficiency of 4×6 and 4×8 scenarios. The differences among the MIMO schemes are similar as that in 2×4 scenario. For more antennas at the transmitter and receiver are available, the spatial multiuser diversity gain for ZFB is more obvious, but not for SVD, VBLAST-AS and DSTBC, where the transmitter antenna are all assigned to one UE. Thus the performance gain of the ZFB over VBLAST-AS and DSTBC become larger. Comparing Figure 6 and, the contribution of extra transmitter antennas to the spectrum efficiency is not obvious for VBLAT-AS and DSTBC. The multiuser diversity gain for them is not obvious either, and the performance of them has almost converged to their upper bound when 16 UE in the system. But for ZFB, more transmitter antenna and more users lead to higher spectrum efficiency because full spatial multiplexing gain and spatial multiuser diversity gain can be achieved. Comparing Figure 6 and Figure 7, two extra transmitter antennas contribute extra 18% spectrum efficiency even the total transmit power is the same.

V. CONCLUSION

In this paper, the spatial multiuser diversity gain is investigated in downlink MIMO in TDD system, where the transmitter has more antennas than the receiver. To exploit the spatial multiplexing gain or transmit diversity gain as much as possible, and achieve higher spectrum efficiency, DSTBC, VBLAST-AS, ZFB and SVD are compared. Although DSTBC can achieve full spatial transmit diversity gain, it allocates less power on every antenna, so its performance is the worst one. While SVD can achieve best diversity and multiplexing gain of single user, but it obtain less multiuser multiplexing gain and multiuser diversity gain, it achieves better performance than VBLAST-AS and DSTBC. For ZFB can achieve full spatial multiplexing gain and full spatial multiuser diversity gain, it achieves best spectrum efficiency. The gain of ZFB exceeds DSTBC and VBLAST-AS at least 50%.

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