Enhanced Downlink Performance of TD-SCDMA LTE System with Multiuser MIMO SDM

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Abstract- Since the channel reciprocity can be obtained in TD-SCDMA LTE system, the Channel Status Information (CSI) can be exploited at the transmitter to implement multiuser Spatial Division Multiplexing (SDM) and obtain both the spatial multiplexing gain and multiuser diversity gain efficienctly. In this paper, Zero Forcing Beamforming (ZFB) and Multiuser Per Antenna Rate Control with Antenna Selection (MU-PARC-AS) based SDM is proposed to enhance the downlink performance of TD-SCDMA LTE, and a joint spatial frequency Proportional Fairness (PF) scheduling is proposed to achieve the tradeoff between the user fairness and the system throughput of None-Real Time (NRT) service. For 10MHz bandwidth, the system throughput of ZFB approaches 18Mbps and 27Mbps for 1×2 and 2×4 MIMO scenarios respectively, and the spectrum efficiency is achieved as 1.8bps/Hz and 2.7bps/Hz respectively. The cell throughput of ZFB is 38% and 17% higher than that of MU-PARC-AS for 1×2 and 2×4 MIMO scenarios respectively.

I. INTRODUCTION

As fast increasing of data rate required by the mobile services, 2Mbps of 3G systems is not enough any more in several years. Recently, WiMax based on OFDM has been proposed to provide wide area coverage for high data rate service, which can provide 75Mbps peak data rate in 20MHz bandwidth. To make 3G competitive in several years, Long Term Evolution (LTE) of 3G is issued in 3GPP. The basic idea of LTE is to implement the functions of B3G partially in current 3G or any available spectrum. The objective of LTE is to provide packet-based high-data-rate service with enhanced spectrum efficiency, coverage, capacity, and low latency and low cost. The data rate of 100Mbps in downlink and 50Mbps in uplink are expected for 20MHz channel.

To fulfill the requirements of 3G LTE, OFDMA is proposed for LTE downlink [1] for its excellent capability to mitigate the frequency selective fading of the mobile environment and provide high spectrum efficiency. Further, OFDMA provides a natural multiple access method by assigning different users with orthogonal subcarriers, and multiuser diversity gain in frequency domain can be exploited by subcarrier scheduling [2]. By configuring multiple antennas at both ends of communication link, the MIMO channel capacity may be improved to be approximate to the minimum number of the antennas at the transmitter and receiver [3]. Exploiting the CSI at the transmitter, VBLAST can also approach the capacity of MIMO channel. Besides, spatial multiuser diversity and

multiplexing can be exploited to achieve better cell throughput. [4] [5] have proposed the improved round robin and greedy antenna scheduler respectively for multiuser downlink with VBLAST to exploit the spatial multiuser diversity.

For TDD system, the channel reciprocity between uplink and downlink can be used to implement the spatial multiuser scheduling very conveniently. In [10], the initial performance evaluation on TD-SCDMA LTE downlink has been performed based on the Multiuser Per Antenna Rate Control with Antenna Selection (MU-PARC-AS). In this paper, Zero Forcing Beamforming (ZFB) [11] is proposed to enhance the multiuser MIMO performance in downlink. The cost of the Mobile terminal and per bit data can be reduced because ZFB can achieve higher system throughput, simplify the mobile receiver and move the complicated MIMO processing to the Node B where more powerful processing unit and hardware are available. To achieve the tradeoff between the user fairness and the system throughput, a spatial-frequency Proportional Fairness (PF) scheduler is proposed for None-Real Time (NRT) service. Based on it, the performance of the ZFB and MU-PARC-AS are evaluated in multi-cell scenario with soft frequency reuse [7]. For 10MHz bandwidth, the system throughput of ZFB converges to 18Mbps and 27Mbps for 1×2 and 2×4 MIMO scenarios respectively, and the spectrum efficiency is achieved as 1.8bps/Hz and 2.7bps/Hz respectively. The cell throughput of ZFB is 38% and 17% higher than that of MU-PARC-AS for 1×2 and 2×4 MIMO scenarios respectively.

The organization of this paper is as follows. The MU-PARC-AS and ZFB are introduced in section II; the Joint Spatial-Frequency PF scheduling is proposed in section III; the simulation parameters are given in section IV; the results are presented and analyzed in section V, and the conclusion are drawn in section VI.

II. SYSTEM MODEL

In downlink of TD-SCDMA LTE based on MIMO OFDMA, all users' packets are sent to spatial-frequency channel assignment module. After the subcarriers and spatial channel assignment, the data are mapped onto the spatial-frequency channels with Adaptive Modulation and Coding (AMC). After IFFT module, CP is added to the signal of every OFDM symbol in time domain and signal is transmitted out from the corresponding antennas. At the receiver, the reverse operation is done to decode and de-multiplexing the information bits for every user.

In this paper, the CSI is assumed to be known perfectly at the transmitter. Since MIMO processing can be done subcarrier by subcarrier, only one subcarrier is considered in this section and the subcarrier index is ignored.

1. MU-PARC-AS

For PARC [10] based SDM, the interference among the selected antennas should be canceled, and the antennas at the receiver should be more than that at the receiver to achieve robust detection performance. However, UE usually has fewer antennas than Node B for the limited terminal size and battery life, PARC can't be adopted in the downlink directly. A possible solution to use MU-PARC 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.
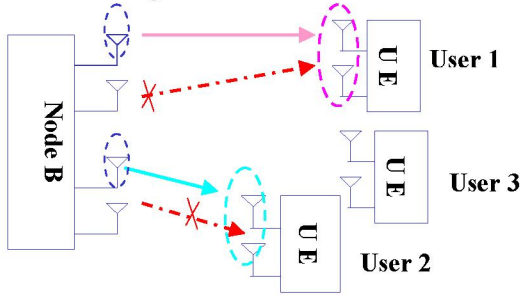

Figure 1 VBLAST-AS

Based on the full CSI at the transmitter, the transmitter antennas and the reception UE can be selected to maximize the total system capacity. At the selected reception UE, Zero Forcing (ZF) equalization is adopted to detect the data.

Assume that UE k is assigned transmission antenna j after antenna scheduling, and $\mathbf{H}^k$ is channel matrix. The received signal is:

$$\mathbf{r} = \mathbf{H}^k \mathbf{d} + \mathbf{v} \qquad (1)$$

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 BS. In this paper, ZF is adopted as the detection algorithm for MU-PARC-AS. For the same power is allocated for different Node B antennas selected, the post-detection SNR for the signal from transmitter antenna j for user k can be expressed as:

$$SNR_j = \frac{P_T}{M_R} \frac{1}{\sigma^2 \left\| \mathbf{w}_j \right\|^2} \qquad (2)$$

Where 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 ZF detection.

$$\mathbf{w}_j = \left(pinv \left(\mathbf{H}^{'} \right) \right)_j \qquad (3)$$

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

Then the total capacity of Node B is:

$$c = B \sum_{j=1}^{M_R} \log_2 \left(1 + \frac{P_T}{M_R} \frac{1}{\sigma_i^2 \left\| \mathbf{w}_j \right\|^2} \right) \qquad (4)$$

2. ZFB

The basic diagram of ZFB is as Figure 2. For multiuser multiplexing, different antennas are selected from the UEs to receive the independent data streams from Node B without interference each other since Zero Forcing Beamforming is done at the transmitter. Assume that the antennas of K users are selected to receive, and then the virtual MIMO channel matrix between transmitter and the UEs selected can be constructed as:

$$\mathbf{H} = \begin{bmatrix} \mathbf{H}^1 & \dots & \mathbf{H}^i & \dots & \mathbf{H}^K \end{bmatrix} \qquad (5)$$

Where $\mathbf{H}^i$ is MIMO channel response of UE i on the selected receiver antennas. 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.
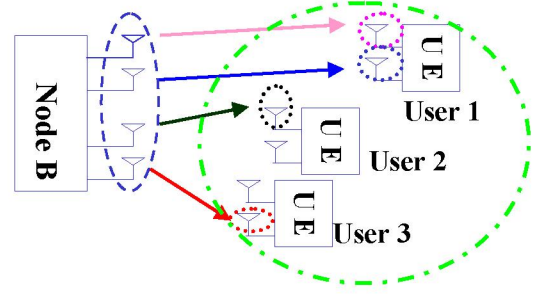

Figure 2 Zero Forcing Beamforming

Then weight matrix for zero forcing beamforming is [11]:

$$\mathbf{B} = \mathbf{H}^\dagger \left(\mathbf{H} \mathbf{H}^\dagger \right)^{-1} \mathbf{D} \qquad (6)$$

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

$$d_k = 1 \bigg/ \sqrt{\left[\left(\mathbf{H} \mathbf{H}^\dagger \right)^{-1} \right]_{k,k}} \qquad (7)$$

If M_R 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:

$$\mathbf{x} = \mathbf{B} \mathbf{S} \qquad (8)$$

And after passing the channel, the total signal of all the UE is:

$$\mathbf{r} = \mathbf{H} \mathbf{x} + \mathbf{n} = \mathbf{H} \mathbf{B} \mathbf{S} + \mathbf{n} = \mathbf{D} \mathbf{S} + \mathbf{n} \qquad (9)$$

Because $\mathbf{D}$ is a diagonal matrix, the MIMO channel is decomposed into M_R 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 $P_T = \sum_{k=1}^{M_R} p_k$, then the total capacity is:

$$C = \sum_{k=1}^{M_R} B\log_2(1+SNR_k) = \sum_{k=1}^{M_R} B\log_2(1+\frac{p_k d_k^2}{\sigma^2}) \qquad (10)$$

III. JOINT SPATIAL-FREQUENCY SCHEDULING

In multiuser MIMO OFDMA system, different users experience independent spatial and frequency selective fading, and thus the multiuser diversity can be exploited by multiuser scheduling. In this paper, the frequency domain multiuser diversity of OFDMA and spatial multiuser diversity of MIMO are jointly considered and a Joint Spatial-Frequency Subcarrier and Antenna Assignment algorithm is proposed to exploit the multiuser diversity in spatial-frequency domain. To guarantee the user fairness, the Proportional Fairness scheduling is adopted.

Assume the set of M_R selected antennas from the transmitter or from all the UEs is presented as C_n, the selected optimal antenna set can be obtained optimally as following:

$$C_n^{'} = \arg_{C_n \in [1,M_T]} \arg_{U_n \in [1,K]} \max_{U_n} \sum C\left(C_n, U_n\right) \qquad (11)$$

Where $C\left(C_n, U_n\right)$ is the total capacity of the selected users and antennas. To find the optimal solution, all the possible sets are compared. It is too complicated to be implemented.

We propose a simple PF scheduling on every subcarrier as following:

$$\Pr_n^k(t) = \frac{R_n^k(t)}{T_k(t)} \qquad (12)$$

Where R_n^k is the theoretical data rate on subcarrier n of user k, and T_k is the average transmission data rate of user k, and it is updated as equation (19).

$$R_n^k = B\log_2\left(\det\left(\mathbf{I}+\rho\left(\mathbf{H}_n^k\right)^H \mathbf{H}_n^k\right)\right) \qquad (13)$$

Where B is the subcarrier spacing Here we assume that only one antenna at most can be assigned to one user on a subcarrier. Then on subcarrier n, M_T users' group C_n is selected as following:

$$\arg_{C_n \in [1,K]} \max \sum_{k \in C_n} \Pr_n^k(t) = \arg_{C_n \in [1,K]} \max \sum_{k \in C_n} \frac{R_n^k(t)}{T_k(t)} \qquad (14)$$

M_R users with highest priority are selected to transmit in next timeslot.

For MU-PARC-AS, every user is assigned a transmitter antenna to maximize the total system capacity.

For ZFB, one antenna of every selected UE is selected to maximize the total system capacity. Then the virtual MIMO

channel matrix on subcarrier n between Node B and the selected antennas of the selected UE can be expressed as:

$$\mathbf{H} = \left[\mathbf{H}_n^{C_n(1)} \quad ... \quad \mathbf{H}_n^{C_n(i)} \quad ... \quad \mathbf{H}_n^{C_n(M_T)}\right] \qquad (15)$$

Where $\mathbf{H}_n^{C_n(i)}$ is the selected channel of UE $C_n(i)$ on subcarrier n and $C_n(i)$ means the element i of C_n.

The power allocated to different data streams is expressed as p_n^k, and $P_T = \sum_{n=1}^{N} \sum_{k \in C_n} p_n^k$. If the user k is not scheduled to share the subcarrier n, then $p_n^k = 0$. Based on $\mathbf{H}$, the data rate of the user $C_n(k)$ on subcarrier n can be calculated as (4) and (10), and can be expressed as:

$$R_n^{C_n(k)} = B\log_2\left(1+SNR_n^{C_n(k)}\right) \qquad (16)$$

Where B is the subcarrier spacing. In fact, in our simulation, the data rate of every data stream is decided by the selected Modulation and Coding Scheme (MCS) adopted in this work according to the Signal to Interference and Noise Ratio (SINR) on the data stream of every subcarriers. By configuring proper SINR threshold for the switching among the different MCS, the highest system throughput can be achieved with adaptive Modulation and coding (AMC).

The total data rate of user k in the next scheduling period is:

$$R_k = \sum_{n=1}^{N} R_n^k \qquad (18)$$

Where N is the subcarrier number. T_k can be updated with R_k after the scheduling:

$$T_k = \begin{cases} (1-\alpha)T_k + \alpha R_k, & if\ user\ k\ is\ served. \\ (1-\alpha)T_k, & else \end{cases} \qquad (19)$$

Where $0 < \alpha < 1$ is the forgetting factor.

The total capacity of the system is:

$$C = \sum_{k=1}^{K} R_k = B\sum_{k=1}^{K}\sum_{n=1}^{N}\log_2\left(1+\frac{p_n^k\left(d_{n,k}\right)^2}{\left(\sigma_n^k\right)^2}\right) \qquad (20)$$

IV. SIMULATION PARAMETERS

In this paper, the frame structure from [8] is adopted in our simulation. Every 10ms is divided into two sub frames, and the structure of the sub frame is as Figure 3. Every sub frame has 7 service slots and 3 special slots. The service slot length is 0.675ms, and 6 slots can be used to transmit data. Every service time slot contains 9 OFDM symbols.

The MIMO channel model is 3GPP SCM [9], and the fixed Power Delay Profile (PDP) of Typical Urban (TU) is adopted. The user speed is 3km/h. The FTP service model is assumed for every user with 2Mbps average data rate.

AMC is adopted on every spatial and frequency sub-channel. The convolution coding are combined with QPSK, 16QAM to create 5 Modulation and Coding Schemes (MCS). Their throughput performance is as Figure 4. No H-ARQ is

considered in link level simulation, but the chase combining is adopted in system level simulation. To avoid heavy signaling loading, every continuous 8 subcarriers are combined together as a basic resource unit, called as sub-channel, in which the same modulation and coding scheme is used for all subcarriers. The antenna of one sub-channel is assigned to different user according to the algorithms we proposed above. The estimation of the received SNR of every data stream from the transmitter antenna on every sub-channel is based on the average on all 8 subcarriers. The scheduling is based on the sub-channel.
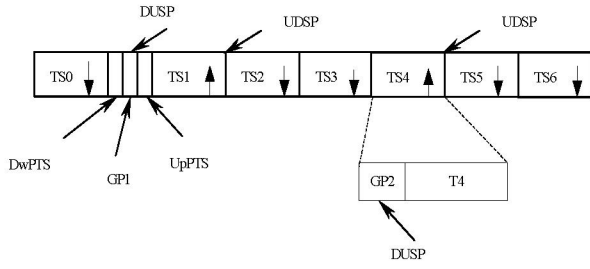

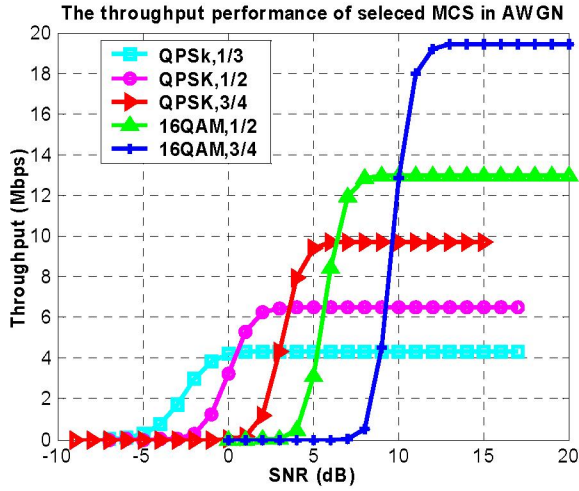**Figure 3 Frame structure of TD-SCDMA LTE**

Figure 4 the system throughput of the MCS in AWGN without H-ARQ

Furthermore, to avoid the serious inter-cell interference, Soft Frequency Reuse is adopted in this work as that of [7] [10]. The other system simulation parameters are as Table 1.

TABLE 1. SYSTEM PARAMETERS

Parameter	Assumption
Carrier Frequency	2GHz
Band width	10MHz
Sample Frequency	15.36 MHz
Sub-carrier spacing	15 kHz
CP length(μs/samples)	7.29/14
FFT Size	1024
Occupied Subcarriers number	601
Subcarrier Group number	75
Inter-site distance	2Km
Cell number	27 (9 clusters for the soft frequency reuse)
Distance-dependent path loss	L=128.1 + 37.6log10(.R), R in km
Lognormal Shadowing	Similar to UMTS 30.03, B 1.41.4
Shadowing standard deviation	8 dB

Correlation distance of Shadowing		50 m (See D,4 in UMTS 30.03)
Shadowing correlation	Between cells	0.5
	Between sectors	1.0
Penetration Loss		20dB
Channel model		Typical Urban (TU) early simulations Spatial Channel Model (SCM) later simulations [9]
Total BS TX power (Ptotal)		43dBm
UE power class		21dBm (125mW). 24dBm (250mW)
Minimum distance between UE and cell		>= 35 meters
User data rate		2Mbps
H-ARQ		Chase combining at system level

V. SIMULATION RESULTS

In our simulations, 1×2 and 2×4 MIMO scenarios are simulated. In Figure 5, the cell throughput Vs. UE number is presented. For the multiuser diversity gain from frequency and spatial domain, more users lead to higher cell throughput. For MU-PARC-AS, only part of the transmitter antennas are selected to transmit and partial spatial multiplexing gain can be obtained; while ZFB can exploit all the transmitter antennas even less power is allocated on every antenna and the full spatial multiplexing gain is obtained, so it is expected to achieves much higher system throughput than MU-PARC-AS.
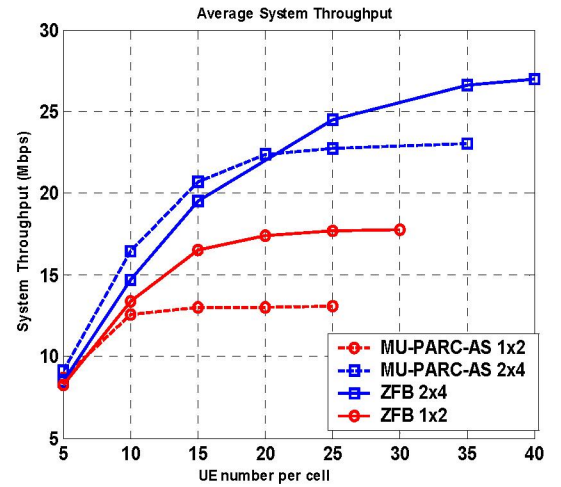

Figure 5 Cell throughput Vs. MT number per cell

In 1×2 scenario, the throughput of MU-PARC-AS converges to 13Mbps, while ZFB converges to 18Mbps. The throughput of ZFB is 38% higher than the forth. For the 2×4 MIMO scenario, the performance of the MU-PARC-AS is better than that of ZFB when few users are served in the system. One reason for this is that double power can be allocated on every selected antenna for MU-PARC-AS since less spatial multiplexing dimension is available. The other reason is that only one antenna at most can be allocated to one user on a subcarrier in ZFB scheme, some antenna and subcarriers may be wasted by bad user who can't transmit any bits for the worse SINR though the resource is reserved for it. When the user number is large enough, the multiuser

diversity gain become obvious for ZFB, and the throughput performance of ZFB become better than MU-PARC-AS. The upper bound of ZFB throughput performance is 17% higher than that of MU-PARC-AS.
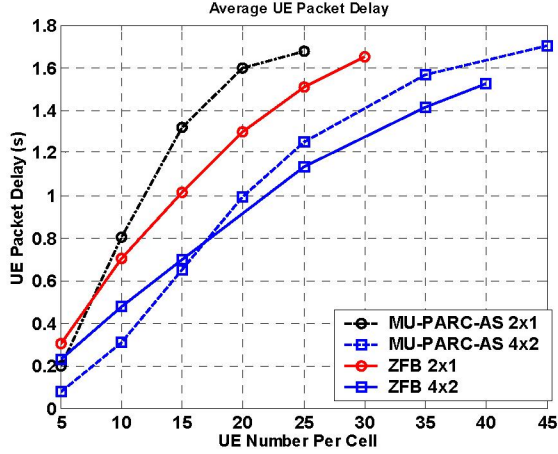

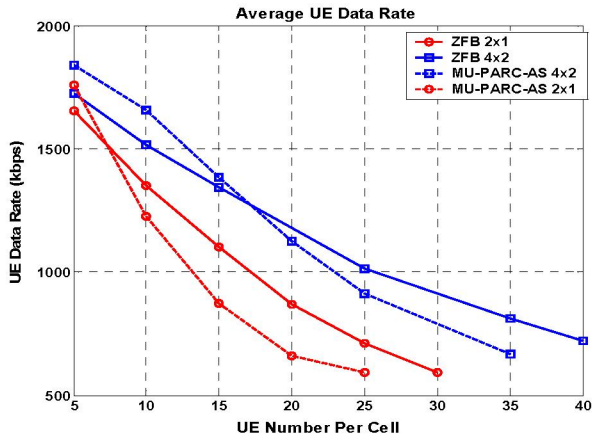Figure 6 Packet delay Vs. MT number per cell

Figure 7 Average data rate Vs. User Number per cell

In Figure 6, the performance of packet delay is presented. The performance of the average packet delay Vs. user number of every cell is compared for 1×2 and 2×4 MIMO scenarios. More antennas at the UE lead to less packet delay for higher transmission capability can be achieved by extra independent spatial channel. Since the transmission efficiency influences the packet delay directly, similar conclusions as from Figure 5 can be drawn when the packet delay performance of MU-PARC-AS and ZFB is compared, and the explanation for the phenomenon in Figure 6 is also similar as that for Figure 5.

Figure 7 presents the distribution of average user data rate when the user number per cell varies. Generally the average user data rate decreases as the user number increases since the user fairness is guaranteed in the scheduling. Similar conclusion as Figure 5 can be drawn when the average user data rates of MU-PARC-AS and ZFB are compared, and the

explanation for the phenomenon in Figure 7 is also similar as that for Figure 5.

VI. CONCLUSION

In this paper, multiuser ZFB and MU-PARC-AS is proposed to enhance the downlink performance of TD-SCDMA LTE system, and a PF based joint spatial frequency scheduling is proposed to exploit the spatial multiplexing and multiuser diversity gain in spatial and frequency domain of multiuser MIMO downlink with guaranteed user fairness. Since the multiuser diversity gain is achieved jointly from frequency and spatial domain, more users lead to much higher cell throughput. MU-PARC-AS utilizes only part of the transmitter antennas and partial spatial multiplexing gain is achieved; while ZFB can exploit all the transmitter antennas even less power is allocated on every antenna, the full spatial multiplexing gain is obtained. So ZFB achieves much higher system throughput than MU-PARC-AS. For 10MHz bandwidth, the system throughput converges to 18Mbps and 27Mbps for 1×2 and 2×4 MIMO scenarios respectively by ZFB, and the spectrum efficiency is achieved as 1.8bps/Hz and 2.7bps/Hz respectively. The cell throughput of ZFB is 38% and 17% higher than that of MU-PARC-AS for 1×2 and 2×4 MIMO scenarios respectively.

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