Greedy Scheduling of MIMO OFDMA: TDMA, FDMA/TDMA, or SDMA/FDMA/TDMA

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***Abstract*-In multiuser MIMO system, multiuser multiplexing and diversity gain can be achieved by spatial scheduling. However, the limited battery life and terminal size of the User Equipment (UE) in a cellular system put a constraint on MIMO when the tranmitter has more antenna than the receiver in downlink, the conventional MIMO schemes can only exploit partial multiplexing gain and diversity gain. In a multiuser MIMO OFDMA system, multiuser diversity gain can be achieved by exploiting the independent frequency and spatial selective fading one another by joint spatial and frequency scheduling. In this paper, different multiuser multiple access schemes wih greedy scheduling of MIMO OFDMA are invstigated, e.g. TDMA, FDMA/TDMA and SDMA/FDMA/TDMA. For full spatial-frequency multiuser diversity gain and spatial multiplexing gain can be achieved, SDMA/FDMA/TDMA obtains highest spectrum efficiency. Its gain exceeds that of TDMA and FDMA/TDMA at least 80% and 40% respectively. The more antennas configured, the more gain can be observed from SDMA/FDMA/TDMA.**

I. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is very suitable for high data rate transmission, since it can mitigate the frequency selective fading and avoid the serious Inter-Symbol Interference (ISI) in a wideband wireless channel. If the subcarrier spacing is narrow enough, the fading on every subcarrier can be regarded as flat, and the MIMO equalization can be simplified on every subcarrier. Further, frequency multiuser diversity gain can be achieved by flexible subcarrier allocation for different user experiences independent frequency selective fading in OFDMA system.

Recently, Multiple Input and Multiple Output (MIMO) is proved to be very promising to improve the cellular system capacity. 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]. One practical MIMO scheme is Vertical Bell labs LAyered Spatial Time code (VBLAST) [2], which requires full Channel Status Information (CSI) only at the receiver. Exploiting CSI at the transmitter, it can also approach the capacity of MIMO [3]. Meanwhile multiuser diversity can be exploited to improve the system throughput since different UEs experience independent spatial and frequency selective fading for their independent location one another. [5] [6] has proposed some improved round robin scheduler and spatial greedy antenna assignment for multiuser MIMO downlink with VBLAST to exploit the spatial multiuser diversity respectively. To exploit the full spatial multiplexing gain and multiuser diversity gain, Zero Forcing Beamforming (ZFB) is proposed in [7]. ZFB exploits 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. The pre-processing is only necessary at the transmitter, and no further spatial processing is required at the receiver.

However, UE usually has fewer antennas than Node B in a cellular system for the limited terminal size and battery life. In this scenario, the conventional VBLAST can't be adopted in downlink directly and the performance is limited by the UE configuration. To obtain the diversity gain and spatial multiplexing gain as much as possible, VBLAST with antenna selection (VBLAST-AS) is proposed in [4], which can maximize the spatial multiplexing gain and diversity gain from the available antenna configuration.

Naturally, the joint spatial-frequency multiuser diversity can be achieved in MIMO OFDMA system by joint spatial-frequency scheduling.

In MIMO OFDM system, Time Division Multiple Access (TDMA) can be implemented by assign the whole timeslot to only one user during one scheduling period. If the same timeslot can be shared by several users during a scheduling period, Frequency Division Multiple Access (FDMA)/TDMA (F/TDMA) can be implemented; furthermore, the Space Division Multiple Access (SDMA)/TDMA/FDMA (S/F/TDMA) can be implemented by sharing the same subcarrier in a timeslot among several users during a scheduling period. In this paper, the performance of TDMA, F/TDMA and S/F/TDMA in MIMO OFDMA downlink system are compared and their performance with joint spatial frequency scheduling is investigated. From the simulation results, S/F/TDMA obtains the best system performance since it achieves the full spatial multiplexing gain and multiuser diversity gain in spatial-frequency domain. The gain of S/F/TDMA exceeds TDMA and F/TDMA at least 80% and 40% respectively.

This paper is organized as follows. The system model of MIMO OFDMA is introduced in section II. The multiple access schemes of TDMA, F/TDMA and S/F/TDMA with greedy scheduling are introduced in Section III. The simulation parameters are presented in section IV, and results are compared in section V, and then conclusions are drawn in section VI.

II. System Model

Combined MIMO with OFDM, the frequency selective fading MIMO channel can be separated into many flat fading MIMO in parallel. And thus the complicated MIMO detection in frequency selective fading channel can be

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simplified as the detection in a flat fading channel. In the following context, the processing of MIMO OFDM system is simplified to be flat MIMO processing on every subcarrier, and the OFDM modulation is ignored in our description.

As the limited terminal size and battery life, UE usually has fewer antennas than Node B in a cellular system. So VBLAST can't be adopted in downlink directly. To make full use of the MIMO channel capacity, VBLAST-AS [4] is introduced to improve the system spectrum efficiency. ZFB is proposed in [7] to exploit the full spatial multiplexing gain and spatial multiuser diversity gain. In this section, the principles of VBLAST-AS and ZFB 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 the conventional VBLAST can't be adopted in the downlink directly for UE usually has fewer antennas than that of Node B in a cellular system. A possible solution to use VBLAST in this scenario is to select partial of the transmitter antennas according to the CSI at the transmitter as Figure 1.

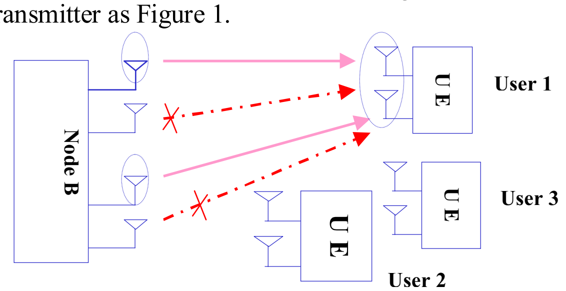

Figure 1 VBLAST-AS

The Channel Impulse Response (CIR) experienced by user i is presented as:

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

Where M and N are the receiver and transmitter antenna number respectively, and $N > M$.

Based on the CSI at the transmitter, the UE who can obtain the highest MIMO capacity is scheduled to receive.

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

$C(\mathbf{H}^i)$ means the channel capacity of $\mathbf{H}^i$. Based on the CSI at the transmitter, partial antennas at the transmitter are selected to maximize the total system capacity. The total power available on this subcarrier group is allocated on the selected antennas equally. At receiver, Zero Forcing (ZF) detection is adopted.

Here the decremental antenna selection algorithm [8] is adopted and M antennas are selected. The selected sub-matrix of MIMO channel is expressed as $\mathbf{H}^{'}$. The received signal from the transmitter can be expressed as:

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

Where $\mathbf{v}$ is AWGN noise vector with variance σ^2 for every element, and $\mathbf{d}$ is the symbol vector transmitted from Node B. Since the total power is distributed uniformly on every transmitter antenna of every subcarrier, post-detection SNR for the signal from transmitter antenna j is:

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

Where M is the selected antenna number at the Node B, P_T is the total transmitter power on the subcarrier, 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 on a subcarrier can be expressed as following:

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

The total system capacity is the sum of the capacity on all subcarriers.

2. 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. The CIR of the virtual UE can be expressed as:

$$\mathbf{H} = \left[\mathbf{H}^1 \quad \ldots \quad \mathbf{H}^i \quad \ldots \quad \mathbf{H}^K \right] \tag{7}$$

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 the Node B, the number of the selected receive antenna should be fewer than that at the Node B.

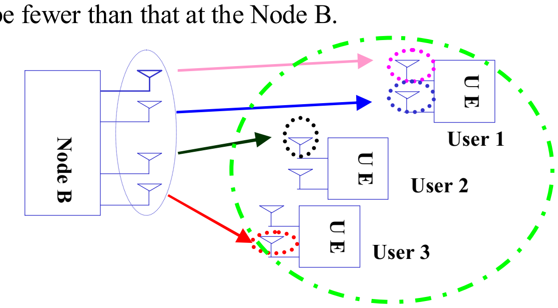

Figure 2 Zero Forcing Beamforming

With the CIR selected, the zero forcing beamforming is applied. The beamforming weights for the data streams are calculated as following [7]:

$$\mathbf{B} = \mathbf{H}^{\dagger} \left(\mathbf{H}\mathbf{H}^{\dagger} \right)^{-1} \mathbf{D} \tag{8}$$

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 $\dagger$ means the hermit transpose.

$$d_k = 1 \Big/ \sqrt{\left[\left(\mathbf{HH}^{\dagger}\right)^{-1}\right]_{k,k}} \quad (9)$$

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:

$$\mathbf{x} = \mathbf{BS} \quad (10)$$

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

$$\mathbf{r} = \mathbf{Hx} + \mathbf{n} = \mathbf{HBS} + \mathbf{n} = \mathbf{DS} + \mathbf{n} \quad (11)$$

Because $\mathbf{D}$ is a diagonal matrix, the MIMO channel is decomposed into M SISO channels with channel gain d_k. The total power of the Node B is distributed uniformly on every data streams to maximize the total system capacity.

If the power allocated to data stream k is expressed as $p_k = P_T / M / N$, then the capacity is expressed as:

$$C = \sum_{k=1}^{M} \log_2(1 + SNR_k) = \sum_{k=1}^{M} \log_2\left(1 + \frac{P_T d_k^2}{MN\sigma^2}\right) \quad (12)$$

III. MULTIUSER SCHEDULING

To show the maximum multiuser diversity gain, the greedy scheduling is adopted in our work. The subcarrier and antennas are allocated to maximize the total system capacity. The scheduling is executed every time slot and the user fairness are not considered in this work.

1. TDMA

For TDMA system, the time slot is assigned to only one UE, but not shared by multiple UEs. For this scenario, the VBLAST-AS is adopted on every subcarrier. The time slot is allocated to the user who can achieve the highest system capacity. The total system capacity is the capacity of the UE selected during the timeslot.

$$C = \underset{i}{Max} \sum_{j=1}^{N} C_j^i \quad (13)$$

2. F/TDMA

For FDMA/TDMA system, the basic radio resource is identified as a subcarrier of one time slot. One subcarrier is occupied by only one user, and thus the VBLAST-AS is adopted on every subcarrier too in this scenario. For the greedy scheduling, every basic radio resource unit is allocated to UE who can achieve highest capacity.

$$C_j = \underset{i}{Max} C_j^i \quad (14)$$

Where C_j^i is the capacity of UE i on subcarrier j, and N is the subcarrier number, *Max* means to find the user who can maximize the capacity on the subcarrier. The total system capacity is the sum of the capacity on all subcarrier:

$$C = \sum_{j=1}^{N} C_j = \sum_{j=1}^{N} \underset{i}{Max} C_j^i \quad (15)$$

3. S/F/TDMA

In SDMA/FDMA/TDMA scenario, SDMA can be applied to transmit different data streams on orthogonal beams to different UE, so the ZFB can be applied in this scenario to maximize the spatial multiplexing gain and spatial multiuser diversity gain. The basic radio resource unit is identified as a beam space of ZFB on a subcarrier during a time slot. On every subcarrier, the antennas are selected from all the UE antennas to maximize the total system capacity.

$$C_{j,k} = \underset{i}{Max} C_{j,k}^i \quad (16)$$

Where $C_{j,k}^i$ is the capacity of beam k on subcarrier group j of UE i if UE i has been selected to receive on the beam k. $C_{j,k}$ is the capacity on the beam k on subcarrier group j after the scheduling.

The total system capacity is calculated as following:

$$C = \sum_{j=1}^{L} \sum_{k=1}^{M} C_{j,k} = \sum_{j=1}^{L} \sum_{k=1}^{M} \underset{i}{Max} C_{j,k}^i \quad (17)$$

Where M is the transmitter antenna number, which decides the maximum beam number available at the transmitter for the orthogonality among the different beams is required. L is the subcarrier number in the MIMO OFDMA system.

IV. SIMULATION PARAMETERS

In this paper, the 3GPP SCM [9] channel model is adopted, but it is modified to suit for the wider bandwidth 10MHz. Meanwhile, the Power Delay Profile (PDP) is changed to be fixed as the Typical Urban (TU) channel required by 3GPP [10]. According to the mobility of the user, the angle information required by SCM channel model is updated. The mobile speed is 3km/h. For TDD system is assumed, the Channel Status Information (CSI) of the UE is assumed to be available at the transmitter.

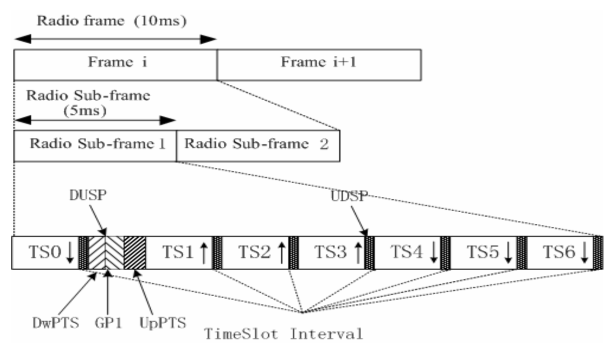

Figure 3 the frame structure of LTE TDD system

As a reference, the frame structure of TD-SCDMA Long term Evolution (LTE) [11] as Figure 3 is considered in our simulation. A 10 ms frame is divided into 2 equally sized 5 ms radio sub-frames, one radio sub-frame consists of seven traffic time slots (TS0~TS6). The synchronization and guard period is between TS0 and TS1, whose duration is 0.275ms including DwPTS, GP and UpPTS. The TTI can be 0.675ms, the same as duration of one traffic time slot. In this paper, 6 TS is assumed for downlink transmission and 7 OFDM symbols can be contained in traffic TS.

AMC is implemented by combing QPSK and 16QAM with convolution coding. The Modulation and Coding Schemes (MCS) selected is given in Table 1.

TABLE 1 THE MCS AND THE ES/N0 THRESHOLD

MCS	Mod	Code Ratio	data bits	SNR threshold
1	QPSK	1/3	2/3	0.5dB
2	QPSK	1/2	1	3.7dB
3	QPSK	3/4	3/2	6.3dB
4	16QAM	1/2	2	10dB
5	16QAM	3/4	3	10dB

The throughput performance of the selected MCSs is presented as Figure 4 and the other simulation parameters are given in Table 2.

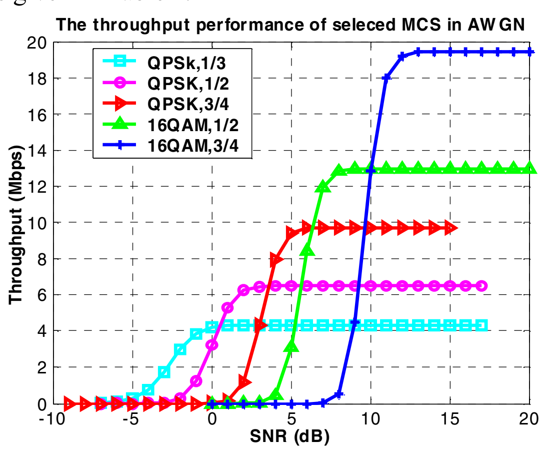

Figure 4 throughput performance of the selected MCS.

TABLE 2. SYSTEM PARAMETERS

Parameter	Assumption
Carrier Frequency	2GHz
Band width	10MHz
Sample Frequency	1.92 MHz
Sub-carrier spacing	15 kHz
CP length(μs/samples)	7.29/14
FFT Size	1024
Occupied Subcarriers number	601
Subcarrier Group number	75
Channel model	Typical Urban (TU) early simulations Spatial Channel Model (SCM) [9]

For the scheduling, every 8 localized subcarriers of one timeslot are regarded as a basic unit to avoid heavy overhead for the CSI at the transmitter and the Greedy algorithm as section III is adopted to maximize the system spectrum efficiency without considering the user fairness. The total power is distributed uniformly on different data streams of all subcarriers.

To observe the multiuser diversity gain in spatial domain obviously, 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 observed when the greedy scheduling and equal power allocation are adopted.

V. SIMULATION RESULTS

In this section, the performance of different multiple access schemes are presented. The throughput of the TDMA, F/TDMA and S/F/TDMA with greedy scheduling is compared in Figure 5, Figure 6 and Figure 7. Generally, for TDMA, the whole timeslot is allocated to only one user, and only partial multiuser diversity gain can be achieved. For F/TDMA, one timeslot can be shared by multiple users and user is identified by different subcarrier group. Since frequency scheduling can be exploited to improve the multiuser diversity, it can achieve more multiuser diversity gain in frequency domain than TDMA. For S/F/TDMA, every subcarrier group can be shared among multiple users by SDMA, and the user is identified by timeslot, subcarrier group and the beams of ZFB. So the joint spatial-frequency greedy scheduling can achieve more spatial multiplexing and spatial-frequency multiuser diversity gain than TDMA and F/TDMA. From the simulation results, S/F/TDMA achieves the highest system throughput, and F/TDMA has higher system throughput than TDMA. As user number increases, the multiuser diversity gain contributes more to the total system throughput for S/F/TDMA and F/TDMA, but the contribution of multiuser diversity to TDMA is not obvious.

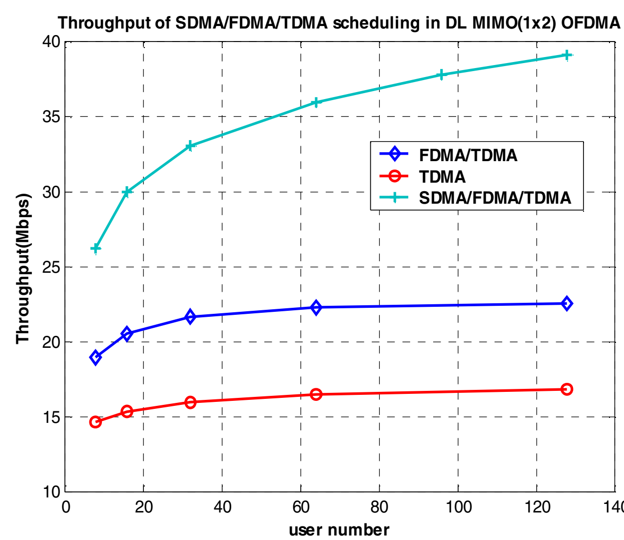

Figure 1 throughput Vs. UE number per cell (1×2)

In Figure 5, 1×2 MIMO scenario is compared. The multiuser diversity gain for F/TDMA and S/F/TDMA is very obvious as the user number increases. The gain of S/F/TDMA exceeds TDMA at least 80%, and the gain increases as the user number increases. The gain of S/F/TDMA exceeds F/TDMA about 40%~70% for more spatial multiplexing gain can be achieved by SDMA.

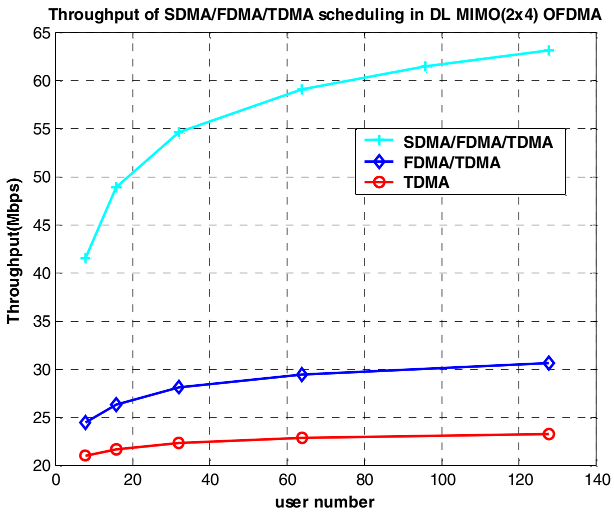

Figure 6 throughput Vs. UE number per cell (2×4)

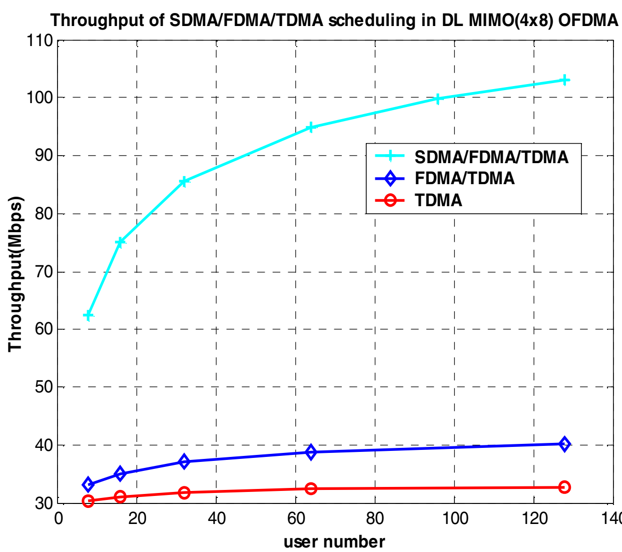

Figure 7 throughput Vs. UE number per cell (4×8)

In Figure 6 and Figure 7, 2×4 and 4×8 MIMO scenario are compared. Similar conclusion as that from Figure 5 can be drawn. However, the difference between TDMA, F/TDMA and S/F/TDMA become larger for more spatial multiplexing gain can be achieved by ZFB when more antenna available at the transmitter. Compared to Figure 5, the gain of S/F/TDMA exceeds TDMA more than 100% and the gain of S/F/TDMA exceeds F/TDMA about 68%~100% for 2×4 MIMO. For 4×8 MIMO, more gain can be observed from S/F/TDMA.

VI. Conclusion

In this paper, the different multiple access schemes for MIMO OFDMA downlink system is compared with multiuser diversity. For TDMA, the whole timeslot is allocated to only one user, and only partial multiuser diversity gain can be achieved. For F/TDMA, one timeslot can be shared by multiple users and user is identified by different subcarrier group. So it can achieve more multiuser diversity gain in frequency domain. For S/F/TDMA scheduling, one subcarrier group can be shared among multiple users by SDMA, and the user is identified by timeslot, subcarrier group and the beams of ZFB. So it can achieve more spatial-frequency multiuser diversity gain and full spatial multiplexing gain. From the simulation results, S/F/TDMA with greedy scheduling achieves the highest system throughput, and the system throughput of F/TDMA is higher than that of TDMA. For TDMA, the multiuser diversity gain is not obvious, but the multiuser diversity increases as the user number increases for F/TDMA and S/F/TDMA. The gain from S/F/TDMA is higher than TDMA and F/TDMA more than 80% and 40% respectively, the more antenna configured, the more gain can be observed from S/F/TDMA.

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