FAST RANK OPTIMIZATION SCHEME BY THE ESTIMATION OF VEHICULAR SPEED AND PHASE DIFFERENCE IN MU-MIMO

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ABSTRACT

Resent MU-MIMO (Multi User-Multi Input Multi Output) scheme is one of the important and advanced technologies. In particular, it is a suitable technique to increase the capacity from the point of view of solving cell load, which is one of the big issues in the contents of 5G commercial field optimization. While this MU-MIMO technology has an important advantage of cell capacity expansion, there is a disadvantage like an interference problem due to each multi-user beams. It is important to use the advanced beamforming technology for MU-MIMO to overcome these disadvantages. Therefore, by applying the interference cancelling technology among inter UE (User Equipment) beams to improve each UE's performance, it will contribute to improving the cell throughput. This paper introduces the various techniques of eliminating interference in MU-MIMO system. Also, it is important that UE reports rank indicator reflected the interference of multi-user beams. This paper analyses the problem of the conventional method of the rank decision in MU-MIMO system, estimates the vehicular speed quickly with the proposed rank optimization technique, and shows the DL (Downlink) UE's performance is improved by applying a proposed rank value suitable for vehicular speed. This technique will be effectively applied to increase the overall cell capacity by improving the DL UE's throughput in the MU-MIMO system.

KEYWORDS

MU-MIMO, 5G, multi-user, interference, UE, DL, rank indicator, cell capacity.

1. INTRODUCTION

As NR (New Radio) system was commercialized, many of the basic techniques required for wireless access became commercialized and stable. Now, beyond the basic techniques of 5G, 5G system is required to transmit the reliable traffic having high-quality to more users through more advanced technologies. Among them, MU-MIMO technology, which enables the cell capacity of 5G system to be dramatically increased, has attracted attention. The prerequisite for the commercialization of this MU-MIMO technology is to increase the single UE throughput by solving the interference problem between multi-user beams, and in order to do so, a rank optimization technique suitable for the MU-MIMO system is required. This paper introduces new MU-MIMO rank optimization technique suitable for MU-MIMO system and compares and analyses it with conventional technique.

David C. Wyld et al. (Eds): ARIA, SIPR, SOFEA, CSEN, DSML, NLP, EDTECH, NCWC - 2022
pp. 13-24, 2022. CS & IT - CSCP 2022 DOI: 10.5121/csit.2022.121502

2. BACKGROUND

This section mentions the definition of MU-MIMO, and the interference that occurs during MU-MIMO operation, and then introduces the main techniques at the transceiver necessary to eliminate the interference respectively.

2.1. MU-MIMO Definition

MU-MIMO is a set of MIMO technologies for multipath wireless communication, in which multiple users or terminals, each radioing over one or more antennas, communicate with one another. In contrast, SU-MIMO (Single-User Multi-Input Multi-Output) involves a single multi-antenna-equipped user or terminal communicating with precisely one other similarly equipped node. Analogous to how OFDMA (Orthogonal Frequency Division Multiplexing Access) adds multiple-access capability to OFDM (Orthogonal Frequency Division Multiplexing) in the cellular-communications, MU-MIMO adds multiple-user capability to MIMO in the wireless communication. Figure.1 is the summary picture of MU-MIMO.

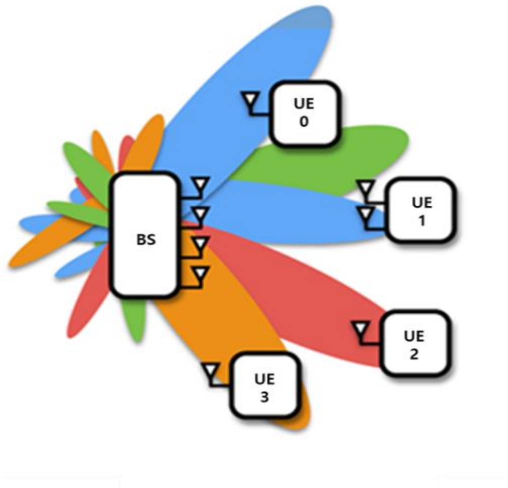

Figure 1. Definition of MU-MIMO

2.2. MU Interference

The inter-user interference characteristics are an essential factor for system evaluation. For example, when base station transmit UE1 beam and UE2 beam as below Figure.2, interference such as Figure.2 occurs when the interference between each beam is not taken into account at all. When the base station of upper Figure.2 transmits the blue UE1 main lobe beam, the power of the red UE2 side lobe beam on the lower Figure.2 is transmitted very strongly, so the SINR (Signal to Interference plus Noise Ratio) of the blue UE 1 main lobe beam becomes very small to -2dB. Similarly, when the base station of lower Figure.2 transmits the red UE2 main lobe beam, the power of the blue UE1 side lobe beam on the upper is strongly transmitted, so the SINR of the red UE2 main lobe beam becomes smaller to 4.8dB.

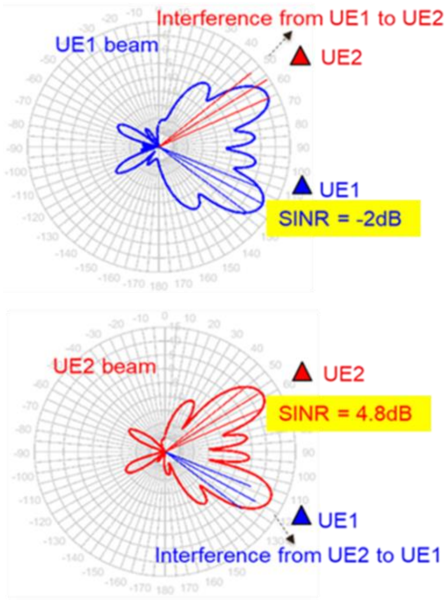

Figure 2. Beams before interference nulling

2.3. MU Interference Cancellation of Transmitter

To eliminate the interference between UE beams described in Figure.2, the nulling techniques of various methods are introduced in the section below. Figure.3 is a new MU-MIMO beam shape after nulling in these various ways. For example, when the upper base station transmits the blue UE1 main lobe beam on the upper Figure.3, the blue UE1 main lobe beam with the newly calculated weight with nulling algorithm may be slightly weakened, but the power of the red UE2 side lobe beam on the lower Figure.3 is considerably nulled, so the SINR of the blue UE1 main lobe beam is very large to 24.2dB. Similarly, when the lower base station transmits the red UE2 main lobe beam on the lower Figure.3, the red UE2 main lobe beam with the newly calculated weight with nulling algorithm can be slightly weakened, but the power of the blue UE1 side lobe beam on the upper Figure.3 is nulled, so the SINR of the red UE2 main lobe beam is restored to 24.7dB.

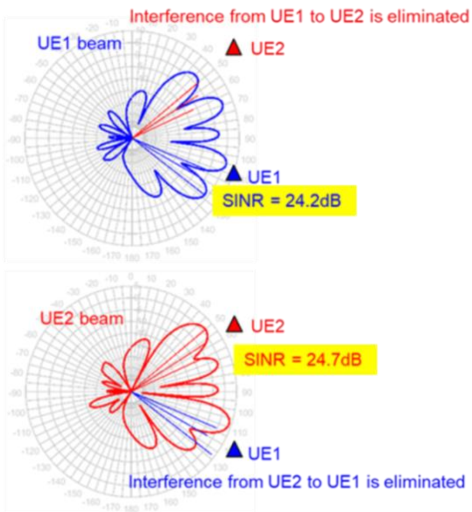

Figure 3. Beams after interference nulling

2.4. MU Interference Cancellation of Transmitter: Zero-Forcing Transmitter

Zero-forcing beamforming is a method of spatial signal processing by which a multiple antenna transmitter can null the multi-user interference in a multi-user MIMO wireless communication system. When the channel state information is perfectly known at the transmitter, then the zero-forcing beamformer is given by the pseudo-inverse of the channel matrix. Figure.4 briefly represents the channel model of MU-MIMO. Figure.5 represents a block diagram including a channel of MU-MIMO and zero-forcing beamforming. Here, the X character labeled I is an interference signal. Its mathematical model may be represented as shown in (1), and if the (1) is solved, each is represented (4), (5). The $h_1 w_2 s_2$ of (4) is the interference signal of UE2 beam. In addition, the $h_2 w_1 s_1$ of (5) is the interference signal of UE1 beam. In order to get rid of this interference signal, (6) that is, the zero-forcing beamforming function is assigned. As a result, the new weight is multiplied, such as (8), (9), and the interference signal is eliminated.

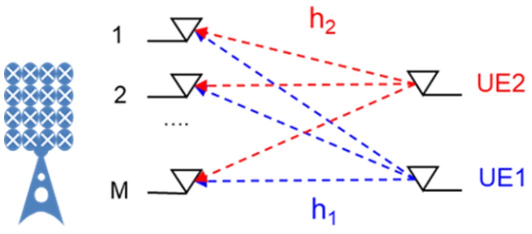

Figure 4. Channel modeling of MU-MIMO

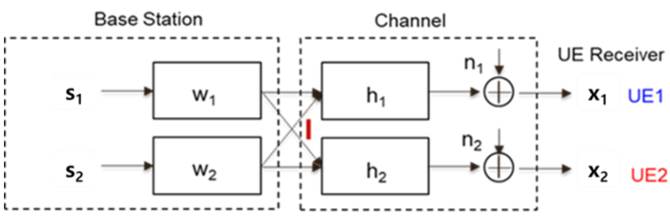

Figure 5. The Block diagram of MU-MIMO

$$x = HWs + n \quad (1)$$

$$\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} h_1 \\ h_2 \end{bmatrix} \begin{bmatrix} w_1 & w_2 \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \quad (2)$$

$$\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} h_1 w_1 & h_1 w_2 \\ h_2 w_1 & h_2 w_2 \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \quad (3)$$

$$x_1 = h_1 w_1 s_1 + h_1 w_2 s_2 + n_1 \quad (4)$$

$$x_2 = h_2 w_1 s_1 + h_2 w_2 s_2 + n_2 \quad (5)$$

$$W = H^H (HH^H)^{-1} \quad (6)$$

$$x = HWs + n = (HH^H (HH^H)^{-1})s + n \quad (7)$$

$$x_1 = h_1 w_{1,new} s_1 + n_1 \quad (8)$$

$$x_2 = h_2 w_{2,new} s_2 + n_2 \quad (9)$$

2.5. MU Interference Cancellation of Transmitter: SVD Transmitter

SVD (Singular Value Decomposition) is a method of obtaining pseudo inverse by decomposition with singular value, when the inverse matrix of the channel cannot be solved as an abbreviation of the singular value decomposition. This method does precoding in the transmitter by decomposing into singular value (Σ) and unitary matrix (U,V) as shown in the following (10), and post-coding in the receiver to obtain identity matrix. Overall, this overcomes the channel by pseudo-inverse as shown in (14).

$$H = U\Sigma V^H \quad (10)$$
$$\bar{x} = U^H(Hs + n) \quad (11)$$
$$\bar{x} = U^H(U\Sigma V^H s + n) \quad (12)$$
$$\bar{x} = U^H U\Sigma V V^H \bar{s} + U^H n \quad (13)$$
$$\bar{x} = \Sigma\bar{s} + \bar{n} \quad (14)$$

3. CONVENTIONAL RANK DECISION

The Conventional rank decision method is a popular method used by SU-MIMO. That is, it is a method of determining rank when the correlation coefficient among the path of UE is transmitted by CSI-RS (Channel State Information-Reference Signal) is a certain value or less. That is, by identifying the degree of correlation among the paths, it is a way to increase rank only when the signals among paths are guaranteed a certain level of independence. To use this method of independence among these paths in MU-MIMO, a special CSI-RS must be transmitted that can well reflect the characteristics of the signal among multi-users. A detailed description of this method is as follows.

3.1. The Use of NZP-CSI-RS-CM and NZP-CSI-RS-IM

RI (Rank Indicator) reported by the UE receives the CSI-RS transmitted by the base station to determine the independence among the UE paths. Therefore, in order to well represent the characteristics of the MU-MIMO beam, it is necessary to transmit a CSI-RS that represents the interference among UEs well. That's the signal of NZP-CSI-RS-CM (Non-Zero Power-Channel State Information-Reference Signal-Channel Measurement), NZP-CSI-RS-IM (Non-Zero Power-Channel State Information-Reference Signal-Interference Measurement). Figure.6 is an example of RE(Resource Element) mapping for transmitting NZP-CSI-RS-CM, NZP-CSI-RS-IM. When transmitting the CSI-RS to the base station as shown below, the UE will perform interference measurement by estimating the level of interference at the empty white color RE position and will determine the rank accordingly. The white empty RE position is defined as NZP-CSI-RS-IM in the base station to empty the signal, and the red RE position is defined as NZP-CSI-RS-CM in the base station to inform and transmit the CSI-RS-CM signal to the UE. In case of single UE beam, empty RE position doesn't exist intra-cell interference, and only exist inter-cell interference, so rank value can be high. However, in case of multi UE beams, empty RE position does exist the intra-cell interference relatively highly and inter-cell interference is also present, so the rank value is likely to be low. The characteristics of this conventional method are as follows.

- It uses UE beam, which is QCLed (Quasi-Co-Located) MU-MIMO CSI-RS beam.
- It depends on UE which reports RI.

It chooses multi-user as RRC (Radio Resource Control) configuration message transmitted by base station.

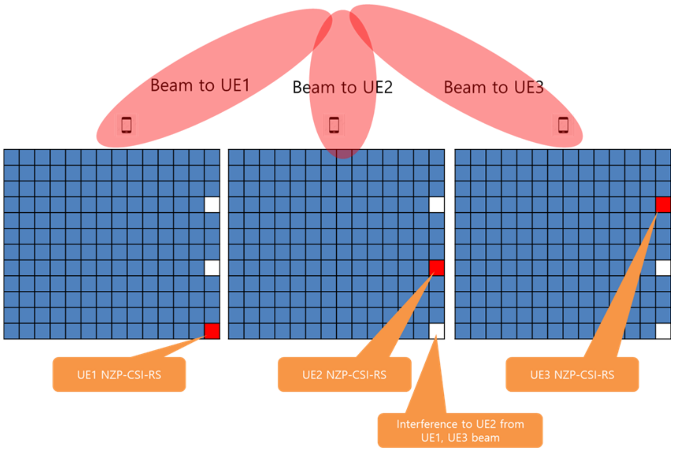

Figure 6. NZP-CSI-RS-CM, NZP-CSI-RS-IM in case 3 UEs

3.2. Disadvantage of Conventional Scheme

The method of changing the CSI-RS for MU pairing to RRC message is very slow, and is not suitable for mobile environments, because the MU-MIMO system, which has a lot of interference, is to be needed to change rank in real time faster than in a typical SU-MIMO system. Its performance is shown in the performance section 5. Also, the disadvantages of conventional scheme were described as follows.

- RRC message technique for MU pairing is slow to variation of channel.
- Because the UE depends on the RI value it reports, it reflects the characteristics of the UE type rather than the variation of channel.
- This is how the UE relies on the RI value it reports, which is unfavorable to the optimization of base station driving.
- Even if multi-user pairing is matched to each other instantaneously, the UE-specific CSI-RS beam must also guarantee the mobility as often as UE is moved.

4. OPTIMIZED RANK DECISION

To compensate for the disadvantages of this conventional method, the optimized method is introduced as follows. This new approach is divided into two main parts. The first scheme is the rank decision method according to the range of vehicular speed. The second proposed scheme is a method of estimating and calculating the vehicular speed in order to decide rank value. The combination of these two methods is not only based on a UE dependent scheme, but also based on a base station dependent scheme in the case rank decision. It is possible to cope with more precise and the variety of channel quickly. Table 1 is compares the pros and cons of conventional, proposed scheme.

Table 1. Pros and cons

Scheme	Pros	Cons
Conventional	High rank	Slow change of rank
Proposed	Fast change of rank	Complex implementation

4.1. Rank Value decided by Vehicular Speed Value

The first way to overcome these disadvantages in the high interference MU-MIMO environment is to estimate the vehicular speed at the base station to reduce rank when the speed is above a certain value. At this time, if there are no other fading elements, we can select the largest value from the range for each speed like table 2.

Table 2. Optimized rank estimation value each vehicular speed

Speed	Optimized Rank Indicator
0 ~ 2km/h	1 ~ 4
2 ~ 200km/h	1 ~ 3
200km/h ~	1 ~ 2

The background of the values 2km/h and 200km/h is the result of field test. Figure.7 and Figure.8 specify field test results at low and high speed, respectively. Figure.7 shows the throughput of rank 3 is better than that of rank 4 in case over 2km/h. Also, Figure.8 shows the throughput of rank 2 is better than that of rank 3 in case over 200km/h. These are fixed rank test results because of before being applied optimized rank scheme. Each commercial test condition of Figure.7 and Figure.8 was specified in table 3. The section below introduces the second technique, which is how to estimate the vehicular speed required to apply the optimized rank scheme above at the base station.

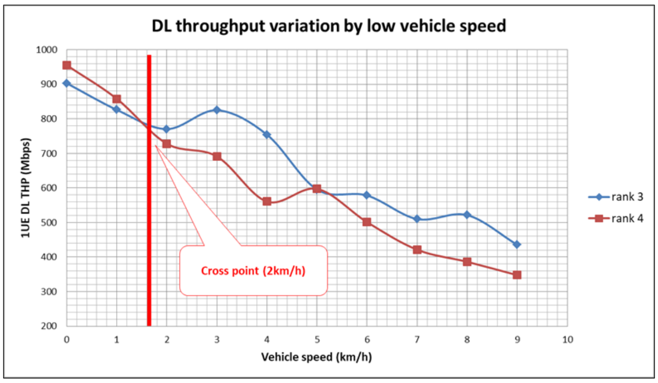

Figure 7. DL throughput variation in case of low vehicular speed

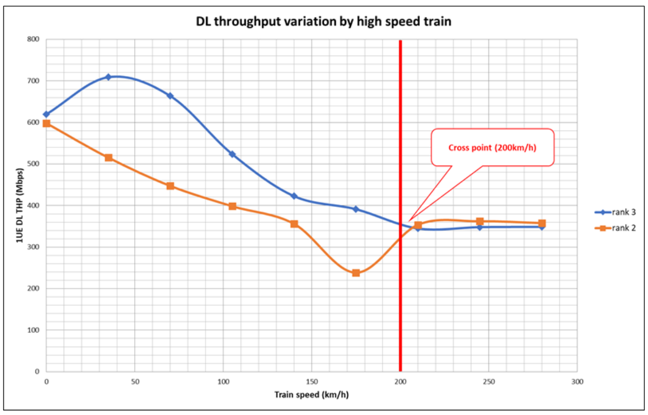

Figure 8. DL throughput variation in case of high speed train

Table 3. Test condition at commercial environment

Figure	Test condition
Figure 7, 8	LOS(Line of Sight)
	UMa(Urban Macro)
	MU-MIMO
	Rank Fixed
	Zero-forcing transmitter
	MMSE-IRC(Minimum Mean Square Estimation-Interference Rejection Combining) receiver

4.2. Speed Estimation by SRS Phase Difference

The second proposed scheme is what calculates vehicular speed by obtaining the difference between beamforming phase values and solving the distance by the pathloss estimated by the uplink SRS (Sounding Reference Signal). The procedure is as follows:

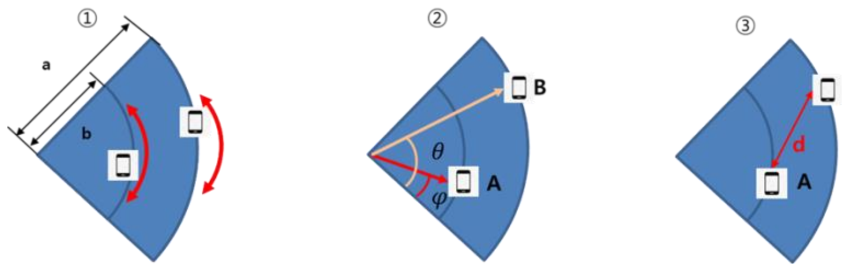

Figure 9. Speed calculation by channel estimation during SRS duration

①Derive the distance between the base station and the previous and subsequent points with SRS Pathloss, respectively.
②Derive the received beamforming angle(θ) by the SRS channel estimation.
③Calculate the vehicular speed by obtaining the distance by position change per SRS long duration.

$$\text{Speed (km/h)} = \frac{d_{A\sim B\text{ distance}}}{\text{TAS long duration}}$$

5. Performance Comparison

Figure.10 shows overall performance graph applied the new rank optimized scheme. The performance of stationary UE is similar regardless test conditions, and the performance of low speed UE has been significantly improved to 16.7% compared to the conventional method. Also, Figure.10 shows fixed low rank scheme for reference. This method was added to compare the DL performance in the stationary and mobile environment with fixed low rank scheme. In conclusion, optimized scheme performs slightly better than fixed low rank scheme and fixed low rank scheme is better than conventional scheme. However, its method has a limitation because it cannot follow the variation of channel.

Figure.11 is a commercial UE log when the conventional rank decision method is applied. Figure.12 is a commercial UE log when the new optimized rank decision scheme is applied. In Figure.11 and Figure.12, the red background is a part of the MU mode operation when the two UEs are separated from each other and the blue background is a part that SU mode operation when the distance of 2 UEs is very close to each other such as the map of Figure.13. The condition of commercial environment is like Table 4. This mode operation transition is designed to automatically switch to the MU mode operation if the correlation coefficient is increased and the SU mode operation if the value is decreased according to the correlation coefficient value of the two UEs. If you look at the RB(Resource Block) of Figure.11 and Figure.12, the RB falls down because the frequency regions must be shared with each other if SU mode operation as an easy separation method of SU and MU operation.

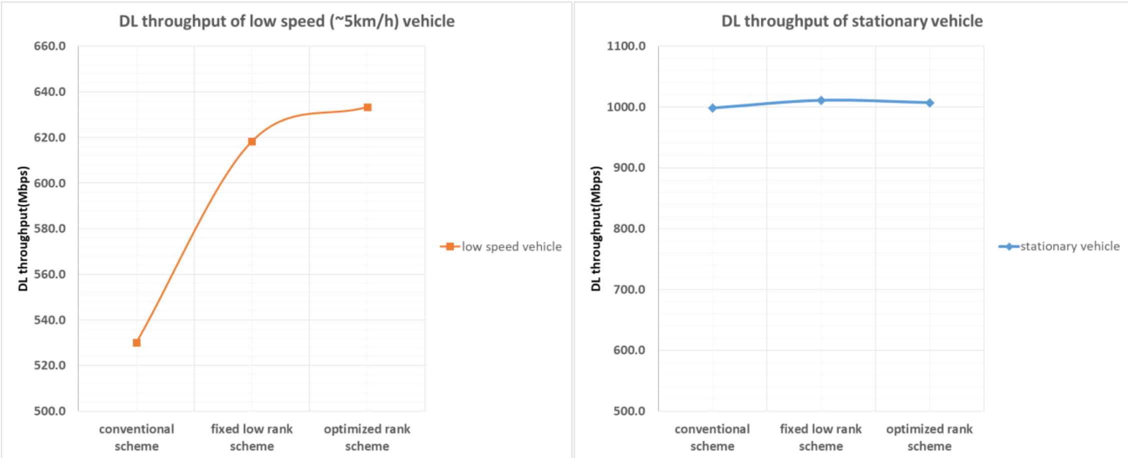

Figure 10. Overall performance comparison

Figure 11. UE's log of conventional rank decision method

Figure 12. UE's log of optimized rank decision method

Figure 13. The map of commercial test's environment in KT laboratory, Seoul

Table 4. Overall test condition of commercial environment

Parameter	**Value**
Morphology	UMa
MIMO	MU-MIMO, SU-MIMO
The number of UEs	2
Field environment	LOS
Maximum number of layer/UE	4
Maximum number of layer/cell	8
UE Mobility	0 ~ 20km/h
Modulation	QPSK ~ 256QAM
BS(Base Station) antenna height	20m
BS-UE distance	50 ~ 150m
Interference cancelling of transmitter	Zero-forcing
Interference cancelling of receiver	MMSE-IRC

6. CONCLUSIONS

MU-MIMO technique is one of the important and advanced technologies. Also, it is a suitable technique to increase the capacity from the point of view of solving cell capacity. However, there is a disadvantage that interference due to each multi-user beams is increased. It is important to use the advanced MU-MIMO beamforming technology to overcome these inter-beam interferences. Also, rank optimization technique is very important to increase the performance in MU-MIMO environment. However, the conventional MU-MIMO rank optimization scheme has several problems. The problem of the conventional method is slow to channel change, there are many steps, and it is only a way of relying on the RI of the UE.

This paper proposes the new first scheme to be sensitive to variation of channel. It is that the base station estimates the vehicular speed by uplink SRS. And second new scheme is that decides the optimal rank value experimentally determined suitable for the calculated vehicular speed. By these two ways, we raise the user performance as much as possible by optimal rank value.

As a result, the mobile UE was significantly improved by 16.7% compare with to the conventional method. The reason is that the conventional scheme was a method of relying only on the value that the UE reports using CSI-RS, but the new scheme was the method of quickly calculating the vehicular speed directly from the base station to respond sensitively to variation of channel and applying an optimized rank value according to the vehicular speed.

ACKNOWLEDGEMENTS

I would like to express my deep gratitude to Kyung-Yup Kim, Sang-Wook Kim, and Jae-Hyung Koo my research supervisors, for their patient guidance, enthusiastic encouragement and useful critiques of this research work.

I would also like to thank Hye-Soo Chang, for her advice and assistance in keeping my progress on schedule. My grateful thanks are also extended to Dong-Un Cha for his help in doing the data analysis, to them for their support in the site measurement.

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