An Adaptive Rank Selection Method in 3GPP 5G NR Systems

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***Abstract* — A user equipment (UE) estimates channel state information (CSI) which includes the rank indicator (RI), the precoding matrix indicator (PMI), and the channel quality indicator (CQI), and feedbacks the CSI to the base station (BS). Rank Indicator is a number (indicator) that represents how well a Multiple Input Multiple Output (MIMO) system communication works. Therefore, the RI estimation and selection is an important issue for system efficiency. In this paper, we propose an adaptively adjusted RI selection method to accommodate the channel condition. Simulation results demonstrate that the performance of the proposed adaptive method satisfies the performance requirements of the IMT-2020 evaluation. Furthermore, the proposed adaptive method works well in a low-mobility indoor scenario.**

***Index Terms*— Rank selection, IMT-2020**

I. Introduction

As the demand for a new generation of mobile networks grows, the 3rd Generation Partnership Project (3GPP) develops new radio access technology (RAT) for fifth-generation (5G) mobile networks, namely 5G New Radio (NR). It is a global standard for the air interface of 5G networks [1]. 3GPP submits the 5G NR systems specification [1, 2] to International Telecommunication Union (ITU) as a candidate 5G mobile communication system, which is expressed as the IMT-2020 system.

5G NR systems support MIMO technologies [4] to meet a high data rate requirement and maximize system capacity. MIMO channel capacity highly depends on the rank, and the rank depends on the antenna correlation, represented by RI. Maximum RI number is related to the number of antennas, including the Tx or Rx. Maximum RI means no correlation among antennas and no interference to each other. In this case, the system shows an outstanding performance [5]. Therefore, the rank selection is an important issue for system efficiency.

However, interference is unavoidable in real communication systems. A real-time CSI estimation is not practical, either. Some researches have been studied in [6]. Based on the characteristic of the time-varying channel, this paper proposes a rank selection method that considers the channel variation in the time domain. An adaptive approach with low complexity is applied to select RI to accommodate the channel variation.

This paper evaluates the performance of the proposed adaptive RI selection method according to the 5G NR system specifications submitted by 3GPP [1, 2] and compares it with the IMT-2020 performance requirements defined by the ITU [3]. In this paper, WiSE System Level Simulator (SLS) [7, 8] is used to evaluate the system performance, including the system efficiency and the error rate.

The remainder of this paper is organized as follows. Section II describes the process of rank selection for downlink transmission. We propose our adaptive rank selection method in section III and evaluate the performance in section IV. Finally, section IV gives concluding remarks.

II. Rank Selection

A UE feedbacks the estimated RI to a BS in the uplink direction according to its receiving capability. The BS determines the number of layers based on the feedback RI. The process of RI feedback is shown in Fig. 1. The steps are as follows [9]:

Step1. BS periodically transmits Channel State Information-Reference Signals (CSI-RS) to UE for CSI measurement.

Step2. UE measures the received CSI-RS to obtain channel state information. RI is estimated according to the channel situation.

Step3. UE feedbacks the estimated information to BS, including RI, PMI, and CQI.

Step4. BS transmits the Physical Downlink Share Channel (PDSCH) by considering the feedback information.

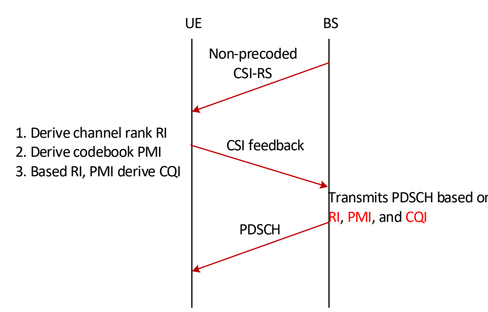

Fig. 1. An example of rank selection

For a UE, a heuristic method to estimate RI is to use an exhaustive search method to evaluate its performance for each RI. UE returns a RI that could achieve maximum efficiency. However, this exhaustive search method takes a long time to complete a RI selection since all cases are evaluated to obtain the system performance. In addition, it takes a delay time for the RI feedback to the BS. This causes the channel state at the transmission time to be different from the estimated time. Therefore, the exhaustive search method requires a high computational time and shows an inaccurate estimation due to the time-varying channel.

III. Proposed Adaptive Method

In the process of determining the layers, the BS determines the number of layers to transmit based on the feedback RI. In order to determine the RI, the BS could use a formula of an MMSE capacity [10] to calculate the capacity of a rank for each subband. The formula is defined as

$$C_{r,b} = \log_2\left(\mathbf{I}_r + \mathrm{SINR}_r\, \mathbf{H}^{H}_{eq(r,b)} \mathbf{H}_{eq(r,b)}\right)^{-1} \tag{1}$$

where $\boldsymbol{C_{r,b}}$ is a capacity of a rank for each subband; $\boldsymbol{I_r}$ is the identity matrix; $\boldsymbol{SINR_r}$ is the SINR of each rank; $\boldsymbol{H_{eq(r,b)}}$ is the equivalent channel of the channel with the precoder of each rank of each subband. The equivalent channel is defined as

$$\mathbf{H}_{eq(r,b)} = \mathbf{H}_b \mathbf{V}_{b,r} \;, r = 1,\ldots,\max \text{ rank} \tag{2}$$

where $\boldsymbol{V_{b,r}}$ is the precoder derived by using SVD. $\boldsymbol{H_b}$ is a subband channel as the following.

$$\mathbf{H}_b = \mathbf{U}_b \Sigma \mathbf{V}_b \tag{3}$$

After calculating the capacity of each subband, the capacity of each RI is a sum of the subband capacity as the following.

$$C_r = \sum_b C_{r,b} \tag{4}$$

where $\boldsymbol{C_r}$ is the capacity of each rank. Therefore, a RI with the maximum capacity is determined as

$$\left[\hat{R}\right] = \arg\max_r \; C_r \tag{5}$$

Although the computational complexity compared to the exhaustive search method is reduced, the channel variation and the error rate tolerance are still not considered in the RI determination. Therefore, this paper further proposes an adaptive rank selection method to estimate RI using these two considerations.

A rank selection enhanced with an adaptive adjustment is proposed by further considering the channel variation and the error rate tolerance. The main idea is to make adjustments based on the previous transmission situation and the feedback RI. The error rate tolerance applied in this paper is Block Error Rate (BLER). For example, when the BLER is low, the channel condition is stable, and the data transmission is almost successfully received and decoded. When the BS knows that the BLER in the previous transmission is very low or under a threshold, the BS could assume that the feedback RI may adjust to a higher level to boost the system performance. Therefore, the RI value could be shifted to increase system performances by sacrificing the error rate. Otherwise, the RI value is determined without a shift. The steps of the proposed adaptive method are as follows:

Step1. BS periodically transmits CSI-RS to UE for CSI measurement.

Step2. UE measures the received CSI-RS to obtain channel state information. RI is estimated according to the channel situation.

Step3. UE feedbacks the estimated information to BS, including RI, PMI, and CQI.

Step4. BS further determines whether or not the BLER of the last transmission is less than a threshold:

- If the BLER is less than a threshold
    Increase the RI value
- Else
    Use the returned RI

Step5. The BS transmits the PDSCH by considering the feedback information.

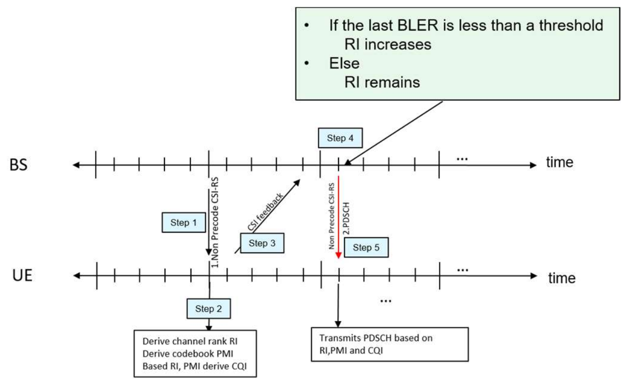

Fig. 2. The process of the proposed adaptive method

IV. Simulation Results

WiSE SLS [7, 8] is used to demonstrate the performance of the RI selection methods, including the exhaustive search method and the proposed methods with and without an adaptive selection. The indoor hotspot scenario [3] is selected for simulation. The simulation parameters of the scenario refer to the IMT-2020 evaluation, as shown in Table 1. The BLER threshold is configured as 0.1. The shift of RI value is configured as one level. The system simulation time is one second which is one hundred frames. The performance comparison includes the average spectrum efficiency and the 5th percentile spectrum efficiency under the FDD system.

Table 1 SIMULATION ASSUMPTION FOR INDOOR-eMBB

Parameter	Value
Carrier frequency	4 GHz
BS antenna height	3 m
Total transmit power per TRP	21 dBm for 10 MHz bandwidth
MS power class	23 dBm
Inter site distance	20 m
TRP antenna configuration	(M, N, P, Mg, Ng; Mp, Np) = (4,4,2,1,1;4,4) for 32 ports;
MS antenna configuration	(M, N, P, Mg, Ng; Mp, Np) = (1,2,2,1,1;1,1)
Antenna element gain	5 dBi for BS; 0 dBi for MS
MS speeds	100% indoor, 3 km/h
Noise figure	5 dB for BS; 7 dB for MS
Traffic model	Full buffer
MS density	10 MSs per TRxP, randomly and uniformly dropped throughout the geographical area
Channel model	InH_A

A. Spectrum Efficiency

Fig. 3 and Fig. 4 respectively represent the average spectrum efficiency and the 5th percentile spectrum efficiency when the UE speed is 3km/h. The green line in the figure represents the requirements of ITU-R for the indoor hotspot scenario of IMT-2020 evaluation, which are 9 and 0.3 bits per second per Hz for the average spectrum efficiency and the 5th percentile spectrum efficiency [3]. The red lines are simulation results of each of the three methods.

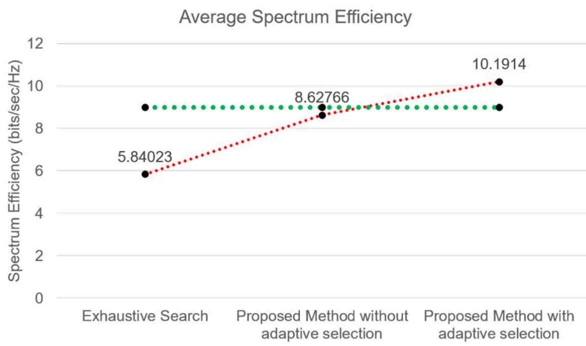

Fig. 3. Simulation results of the average spectrum efficiency

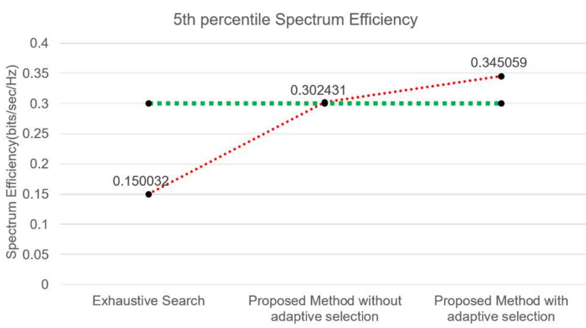

Fig. 4. Simulation results of the 5th percentile spectrum efficiency

The performance of the exhaustive search method is much lower than the requirements in Fig. 3 and Fig. 4. The proposed method without the adaptive selection approaches the IMT-2020 evaluation requirements and outperforms the exhaustive search method. The proposed method with the adaptive selection shows the highest performance among the three methods and meets the requirements. Compared to the performance of the exhaustive search method, the proposed method with the adaptive selection shows a 74% performance gain in the average spectrum efficiency and a 130% performance gain in the 5th percentile spectrum efficiency. Obviously, the adaptive selection considering the time-varying channel to adjust the RI value shows a significant improvement. Furthermore, the performance of the proposed adaptive method is competitive with other studies [11], as shown in Table 2.

Table 2 Simulation result comparison

bits/sec/Hz	Average Spectrum efficiency	5th percentile Spectrum efficiency
Proposed adaptive method	10.1914	0.345
OPPO [11]	10.410	0.300
Motorola Mobility / Lenovo [11]	9.180	0.400

Fig. 5 represents the modulation coding scheme (MCS) distribution. Interestingly, the MCS of the proposed method without adaptive selection has 95% of MCS 27. MCS 27 is represented as the code rate and the modulation order to the highest level, shown in Table 3 [12]. The error rate tolerance may play a role in the RI determination. Therefore, even if the BLER is lower than 0.1, it is unlikely to increase the MCS level by sacrificing BLER to achieve a better system performance.

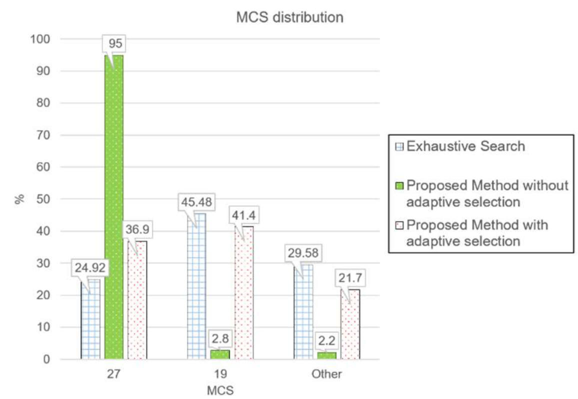

Fig. 5. MCS distribution of different methods

Table 3 MCS index table 2 for PDSCH

MCS Index I_{MCS}	Modulation Order Q_m	Target code Rate R x [1024]	Spectral efficiency
0	2	120	0.2344
1	2	193	0.3770
2	2	308	0.6016
3	2	449	0.8770
4	2	602	1.1758
5	4	378	1.4766
6	4	434	1.6953
7	4	490	1.9141
8	4	553	2.1602
9	4	616	2.4063
10	4	658	2.5703
11	6	466	2.7305
12	6	517	3.0293
13	6	567	3.3223
14	6	616	3.6094
15	6	666	3.9023
16	6	719	4.2129
17	6	772	4.5234
18	6	822	4.8164
19	6	873	5.1152
20	8	682.5	5.3320
21	8	711	5.5547
22	8	754	5.8906
23	8	797	6.2266
24	8	841	6.5703
25	8	885	6.9141
26	8	916.5	7.1602
27	8	948	7.4063
28	2	reserved	
29	4	reserved	
30	6	reserved	
31	8	reserved	

Fig. 6 represents the RI distribution. Since the exhaustive search method and the proposed method without adaptive selection do not consider the effect of the time-varying channel, a lower RI value would be selected with a high probability. The RI distribution (the exhaustive search method, the proposed method without adaptive selection) is (42.76%, 50.9%) for Rank 1 and (36.93%, 39%) for Rank 2. Obviously, the RI value may be under-estimated when the error rate tolerance is not considered. On the other hand, the RI distribution of the proposed adaptive selection method shows an aggressive RI determination. The RI distribution is 5.67% for Rank 1, 46.41% for Rank 2, 42.83% for Rank 3, and 5.075% for Rank 4. The spectrum efficiency improvement can be seen in Fig. 3 and Fig. 4.

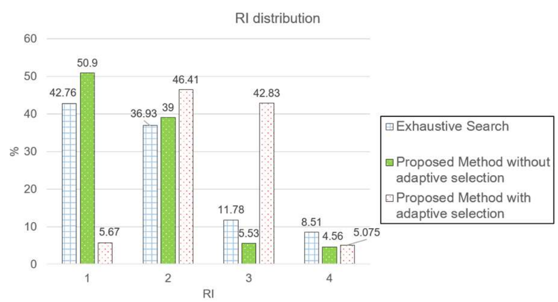

Fig. 6. RI distribution of different method

B. BLER Distribution

Fig. 7 represents the BLER distribution in the exhaustive search method when the UE speed is 3 km/h. Since the channel variation is not considered, the BLER distribution is mostly higher than 0.1. This phenomenon denotes that a UE cannot correctly receive and decodes signals at a desired error rate. The feedback RI may be over-estimates correspondingly.

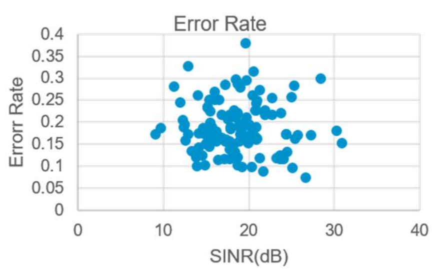

Fig. 7. BLER distribution of Exhaustive Search Method

Fig. 8 represents the BLER distribution of the proposed method without the adaptive selection. It can be observed that the error rate is far below 0.1, which means that shifting up the RI level could improve the system performance.

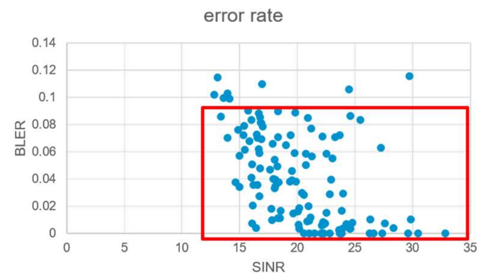

Fig. 8. BLER distribution of proposed method without adaptive selection

Fig. 9 represents the BLER distribution of the proposed method with the adaptive selection. It shows that the BLER distribution concentrates more on 0.1, different from the previous two figures. Obviously, the adaptive RI selection by considering the BLER performance could achieve a better system performance.

Fig.9. BLER distribution of proposed method with adaptive selection

C. Simulation Time

The execution time for the three methods is shown in Table 4. Since the exhaustive search method needs to calculate the transport block size (TBS) of each RI and to select the RI with the largest TBS, it requires the longest computational time. The proposed method by using the MMSE capacity formula to determine the RI value reduces the execution estimation time significantly. The proposed method without the adaptive selection reduces about 56.98% execution time compared to the exhaustive search method. The proposed method with the adaptive selection slightly increases the execution time to determine whether or not to adjust the RI value. Still, it can obtain a gain of 49.53% compared to the exhaustive search method. The proposed method with the adaptive selection reduces the computational time and achieves a better performance.

Table 4 Execution time

	Exhaustive Search	Proposed Method without adaptive selection	Proposed Method with adaptive selection
Execution time	3hr 33m 24sec	1hr 31m 48sec	1hr 47m 43sec

D. Mobility Evaluation

Since the proposed adaptive selection method relies on the previous transmission results, the channel variation may affect the system performance. Therefore, the performance of the proposed method under different UE speeds, including 10km/h and 30km/h, is simulated. Fig. 10 represents the average spectrum efficiency. Fig 11 illustrates the 5th percentile spectrum efficiency.

Compared the proposed method with the adaptive selection to the exhaustive search method, the gain of the average spectrum efficiency is 85.98%, and the gain of the 5th percentile spectrum efficiency is 120.85% when the UE speed is 3km/h. The gain of the average spectrum efficiency is 83.67%, and the gain of the 5th percentile spectrum efficiency is 114.50% when the UE speed is 10km/h. The gain of the average spectrum efficiency is 81.95%, and the gain of the 5th percentile spectrum efficiency is 113.09% when the UE speed is 30km/h.

Compared the proposed method with the adaptive selection to the proposed method without adaptive selection, the gain of the average spectrum efficiency is 21.84%, and the gain of the 5th percentile spectrum efficiency is 14.10% when the UE speed is 3km/h. The gain of the average spectrum efficiency is 19.33%, and the gain of the 5th percentile spectrum efficiency is 12.02% when the UE speed is 10km/h. The gain of the average spectrum efficiency is 19.96%, and the gain of the 5th percentile spectrum efficiency is 14.61% when the UE speed is 30km/h. Although the performance gain decreases as the mobility speed increases, the performance requirements are still satisfied.

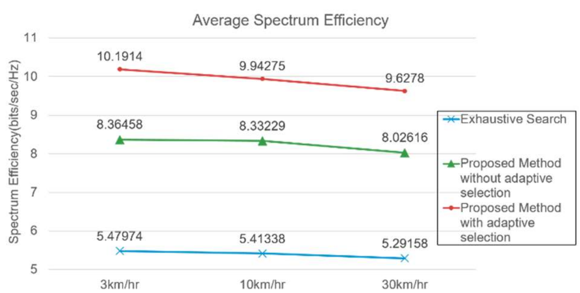

Fig. 10. Simulation result of average spectrum efficiency in different UE speed

Fig. 11. Simulation result of 5th percentile spectrum efficiency in different UE speed

V. CONCLUSION

By considering the time-varying channel, the BS can use the BLER to evaluate whether or not to increase the RI value according to the feedback RI value from UE. From the simulation results of WiSE SLS, it can be found that the proposed adaptive method improves the system performance. The computational time is reduced. Furthermore, the proposed adaptive method performs better in a stable scenario, e.g., an indoor hotspot scenario with low mobility.

ACKNOWLEDGMENT

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