Improved Proportional Fair Scheduling Mechanism with Joint Gray-Mapping Modulation for NOMA

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Abstract. Non-orthogonal multiple access (NOMA) is a promising technique with high spectral efficiency to meet requirements for 5G. This paper mainly introduces key algorithms of NOMA with successive interference cancellation (SIC). Far-UEs and Near-UEs are co-scheduled as a group on the same resource block with different power allocation. To seek a good trade-off between computational complexity and system capacity, an improved method of proportional fair (PF) scheduling with joint Gray-mapping modulation is proposed. The results show that NOMA with SIC significantly enhances the system performance and spectral efficiency compared to conventional orthogonal multiple access (OMA), bringing 22.59% and 21.26% gain in cell average and cell edge throughput respectively. And using the Gray-mapped composite constellation and reducing signalling overhead with the improved pre-fixed power allocation method, which is promote to practical use, brings negligible performance loss.

Keywords: Non-orthogonal multiple access · Proportional fair · Power allocation · Successive interference cancellation

1 Introduction

With the advent of 5G communication system, the increasing demand of mobile data traffic poses challenging requirements for technological innovation. To address problems such as higher spectral efficiency, massive connectivity and lower latency, several companies in mobile communication industry proposed that non-orthogonal multiple access (NOMA) with successive interference cancellation (SIC) should be widely used in 5G, which achieves better system performance [1, 2].

There have been many related studies on key NOMA techniques. UE selection algorithm in [3] is proposed to reduce interference with certain computational complexity. The fixed power allocation (FPA) algorithm with reducing signalling overhead brings performance loss in [4, 5]. The paper in [6] just gives theoretical formulas to

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calculate proportional fairness factor in multi-UE transmission. And the paper in [7] introduces the multi-UE proportional fair (PF) scheduling method for uplink NOMA. In order to promote practical use of NOMA, [8–10] mainly tell how to implement SIC with low complexity at receiver side. The paper in [11] gives detailed descriptions of NOMA schemes under various realistic environments.

In this paper, we focus on key downlink NOMA techniques and propose improved schemes to promote better system performance and lower complexity with taking signalling overhead and practical use into consideration. The remainder of this paper is organized as follows. Section 2 introduces NOMA concept with SIC and signal model. Section 3 discusses several key algorithms and proposes improved methods. Section 4 gives the simulation parameters, system-level simulation results and analysis of different schemes. The conclusions are drawn in Sect. 5.

2 Descriptions of NOMA with SIC

For simplicity of presentation, we use two-UE system model to introduce the implementation of downlink NOMA. In this paper, we assume a multiple input multiple output (MIMO) system where the number of transmitter antennas is 2 ($N_t = 2$) and the number of receiver antennas is 2 ($N_r = 2$). The final transmitted signal and received signal at k-th UE can be described by:

$$\mathbf{x}(k) = \sqrt{\alpha_1}\mathbf{x_1}(k) + \sqrt{\alpha_2}\mathbf{x_2}(k), \mathbf{y}(k) = \mathbf{h_k}\mathbf{x}(k) + \mathbf{n_k} \tag{1}$$

where (α_1, α_2) denotes the power ratio for Near-UE (i.e. UE1) and Far-UE (i.e. UE2) respectively and $\alpha_1 + \alpha_2 = 1$. $\mathbf{x}(k)$ and $\mathbf{y}(k)$ represent the MIMO transmitted signal and received signal at k-th UE. $\mathbf{h_k}$ is the channel coefficient between k-th UE and its serving cell, and $\mathbf{n_k}$ is including white Gaussian noise and inter-cell interference.

Without loss of generality, we assume the channel condition of UE1 is better than that of UE2. At receiver side, in order to implement SIC to decode the original signals more effectively, it should be satisfied with $\alpha_1 < \alpha_2$. We first decode and reconstruct the original signal of UE2 with taking UE1 as interference. Then decode UE1 on the basis of knowing UE2 well, which means the signal of UE2 can be completely cancelled at the receiver of UE1. The formulas of SINR in NOMA mode are shown:

$$SINR_{1,NOMA} = \alpha_1 P_0 |h_1|^2 / N_1, SINR_{2,NOMA} = (\alpha_2 P_0 |h_2|^2)/(\alpha_1 P_0 |h_2|^2 + N_2) \tag{2}$$

where P_0 is the total transmission power at BS, and (N_1, N_2) is the noise power for UE1 and UE2 respectively. $SINR_{k,NOMA}$ and $SINR_{k,OMA}$ separately denote SINR in NOMA mode and OMA mode at k-th UE, which can be expressed by:

$$SINR_{1,NOMA} = \alpha_1 SINR_{1,OMA}, SINR_{2,NOMA} = \alpha_2/(\alpha_1 + 1/SINR_{2,OMA}) \tag{3}$$

3 Practical Scheduling Algorithms for Downlink NOMA

Detailed descriptions of each algorithm in practical scenarios are shown below, such as UE classification, power allocation and PF scheduling.

3.1 UE Classification

For NOMA system model of UE classification, we use coupling loss including all power loss between k-th UE and its serving BS to divide UE groups with simplicity, which can be represented by PL_k. Assuming the threshold of coupling loss is PL_T, if $PL_k < PL_T$, the k-th UE is Near-UE, otherwise, the k-th UE is Far-UE. Then all UEs can be divided into two groups, which is shown in Fig. 1 below:

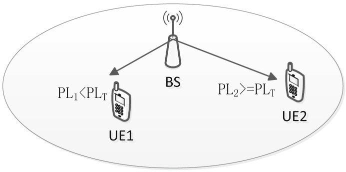

Fig. 1. Illustration of UE classification in NOMA system

3.2 Power Allocation

For NOMA system, one key is how to allocate power for pairing UEs with better performance and less signalling overhead. The best performance can be achieved by searching all possible UE pairs [4]. And it will inevitably bring high computational complexity and huge resource consumption for granted, which is very difficult to practical use. There are some practical methods of power allocation as below.

3.2.1 Pre-fixed Power Ratio Set Method

Considering different channel conditions between UEs and to facilitate the demodulation at receiver, it should be satisfied with $\alpha_1 < \alpha_2$. Pre-fixed power ratio set is one method that can be easy to implement with performance loss and less network signalling overhead which is provided to inform power ratios to the pairing UEs [12].

3.2.2 Adaptive Power Ratio Method with Independent Modulation

Based on the pre-fixed power ratio set method, we can get some power ratios as a candidate set. Searching all available ratios and choosing the best one with taking system performance into consideration, in which way, both requirements of resource consumption and system performance could be satisfied to a certain degree.

This adaptive method is proposed on the basis of condition that two UEs are independent in the process of coding, non-Gray mapping and modulating [13], and they are only combined in the power domain without taking other details into consideration, which is shown in Fig. 2.

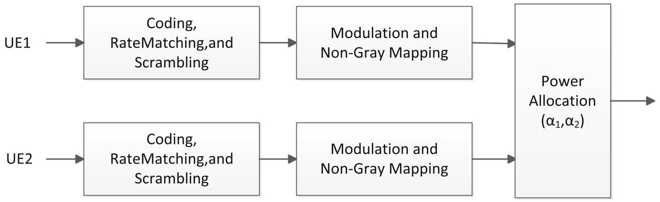

Fig. 2. Illustration of transmitter processing of independent modulation of NOMA system

3.2.3 Improved Adaptive Power Ratio Method with Joint Modulation

Above two methods do not take the legacy constellation and joint modulation for co-scheduled NOMA UEs into consideration. In order to reduce changes to the existing OMA system and facilitate to practical promotion, this improved adaptive power allocation method with joint Gray-mapping modulation [13] is proposed and shown in Fig. 3.

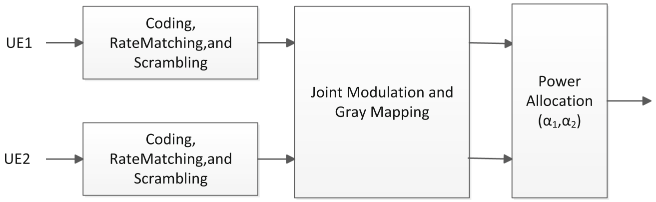

Fig. 3. Illustration of transmitter processing of joint modulation of NOMA system

Generally speaking, most Far-UEs with worse channel conditions are modulated by QPSK. Then we can set Far-UEs as QPSK fixedly with less network signalling overhead. To implement joint Gray-mapping modulation, the configuration of power ratios should be altered to applicable use.

- If Near-UE is QPSK, then the power ratio is configured with 2:8, which followed by co-modulated 16QAM perfectly.
- If Near-UE is 16QAM, then the power ratio is configured with 5:16, which followed by co-modulated 64QAM correspondingly.
- If Near-UE is 64QAM, then the power ratio is configured with 21:64, which followed by co-modulated 256QAM with low probability of appearance.

The power ratio is calculated by energy allocation and the composite constellation. Use the traditional constellation to find position (i_1, q_1) for UE1 and position (i_2, q_2) for UE2, and the composite constellation to find (i, q), where i and q denote the real and imaginary parts in the constellation respectively. It is satisfied with:

$$\sqrt{\alpha_1}(i_1, q_1) + \sqrt{\alpha_2}(i_2, q_2) = (i, q) \tag{4}$$

Then the power ratios can be set with evaluating potential system-level gain and complexity under realistic deployment scenarios. Take an example of the composite constellation (64QAM) of Far-UE with QPSK and Near-UE with 16QAM to illustrate details, as shown in Fig. 4.

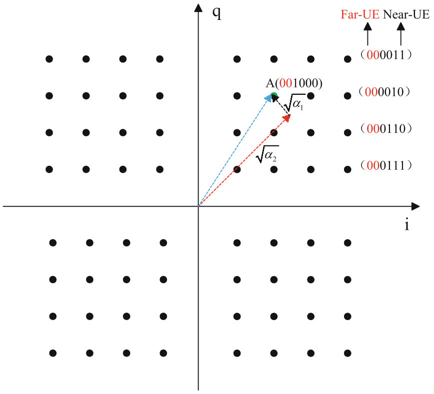

Fig. 4. An example of the composite constellation (64QAM) of Far-UE with QPSK and Near-UE with 16QAM

3.3 Proportional Fair Scheduling Method with Constraints

3.3.1 Conventional PF Scheduling Method in Downlink NOMA

For orthogonal frequency division multiplexing (OFDM) based system, the system bandwidth can be divided into multiple sub-bands. The BS scheduler can decide for each subband on whether to work in NOMA or OMA mode based on PF factor to trade off system capacity and UE fairness. The set of candidate UEs that maximizes PF factor is approximated as follows [4]:

$$PF_U(s) = \sum_{k \in U} (PF_k(s)) = \sum_{k \in U} \left(\frac{R_k(s,t)}{T_k(t)} \right) \tag{5}$$

$$U_s^* = \underset{U}{\operatorname{argmax}} (PF_U(s)) \tag{6}$$

The term U denotes the set of pairing UEs including Far-UEs and Near-UEs. And $PF_s(U)$ is the set of PF factors of candidate UEs. Choose the maximum of PF factors to decide final scheduling UE pairs in subband s. The PF factor of k-th UE in subband s is represented by $PF_k(s)$. $R_k(s, t)$ denotes the instantaneous throughput of k-th UE in subband s at time t and $T_k(t)$ is the already successfully delivered throughput of k-th UE at time t.

And the throughputs are updated as follows [6]:

$$T_k(t+1) = \begin{cases} (1 - 1/t_c)T_k(t) + 1/t_c R_k(t), & k = k^* \\ (1 - 1/t_c)T_k(t), & k \neq k^* \end{cases} \tag{7}$$

where k^* is the scheduled UE and t_c defines the time horizon in which we want to achieve fairness, generally the value is set to 200 TTI.

3.3.2 Improved PF Scheduling Method with MIMO Fusion and Joint Modulation

To further improve potential system gain under practical situations, we propose the improved PF scheduling method with MIMO fusion and joint modulation. We define the coefficient of PF factor to promote NOMA potential gain as below:

$$\beta = PF_{OMA} / PF_{NOMA} \tag{8}$$

where β is a parameter for adjusting NOMA and OMA scheduling priority and has influence on the cell average and cell edge throughput with typical values between 1 and 2, which needs to be determined by system-level simulations. In conventional NOMA scheduling method, the value of β is 1.

In MIMO transmission system, pairing UEs in NOMA scheduling mode should have the same PMI index [14]. Specifically, if the rank of transmission mode is larger than 1, the same PMI index should be at least guaranteed in one layer. Due to the improved adaptive power ratio method with joint Gray-mapping modulation, it has better system robustness and stability compared to the adaptive power ratio method with independent non-Gray-mapping modulation.

4 Simulation Results and Analysis

To evaluate the performance gain of the improved method under realistic scenarios, the system-level simulation for downlink NOMA is conducted. The simulation parameters are listed in Table 1 below.

Table 1. System-level simulation parameters

Cell layout	Hexagonal grid, 19 sites, 3 cells per site
ISD	500 m
Carrier frequency	2 GHz
Number of RB	50
System bandwidth	10 MHz
Traffic mode	Full buffer
Receiver mode	MMSE-IRC
Number of BS antennas	2
Number of MS antennas	2
BS antenna gain	17 dBi
HONET max attenuation	25 dB
BS antenna height	25 m
MS antenna Height	1.5 m

(*continued*)

Table 1. (*continued*)

Antenna tilt angle	12°
Scenario	ITU Urban Macro [15]
Thermal noise	−174 dBm/Hz
Coupling loss	Path-loss, shadowing, small scale fading, penetration and antenna gain
Penetration loss	9 dB
UE speed	3 km/h

This part presents the system-level simulation results for downlink NOMA system and detailed analysis of different methods for comparison.

The impact of the threshold of coupling-loss PL_T on UE candidate sets is shown in Table 2. The larger value of PL_T means more UEs are defined as Near-UE. To minimize the different ratios between Near-UEs and Far-UEs, we choose 85 dB as the suitable PL_T to make better potential performance of NOMA scheduling.

Table 2. Ratios of UE categories with the different threshold of coupling loss

PL_T (dB)	Near-UE (%)	Far-UE (%)
82	41.23	58.77
84	47.54	52.46
85	50.10	49.90
86	52.28	47.72
88	58.25	41.75

The overall cell throughput for different numbers of UEs per cell is summarized in Fig. 5. Take 20 UEs per cell with $\beta = 1.5$ for example, the gains of cell average and cell edge throughput are up to 22.59% and 21.26%. With the increasing number of UEs, the gain is roughly increased with more NOMA scheduling mode into use.

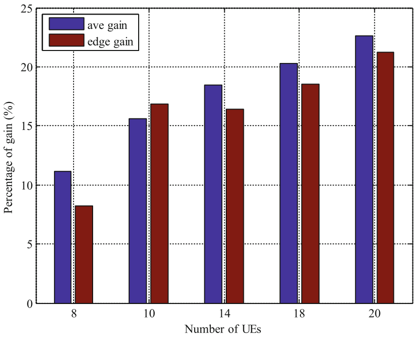

Fig. 5. Gain of cell average and cell edge throughput with different numbers of UEs per cell

The NOMA gain for different numbers of subbands is summarized in Fig. 6. The number of subband is 1 means wideband scheduling. With the increasing numbers of subbands, the gains for cell average and cell edge throughput are reduced in general. The reason is that power allocation and scheduling is implemented for subband, while MCS selection remains wideband. In addition, the baseline OMA with more subbands achieves better performance with frequency selective scheduling.

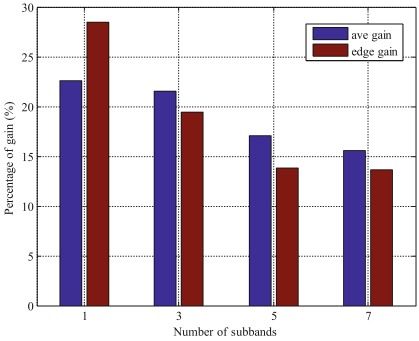

Fig. 6. Gain of cell average and cell edge throughput with different numbers of subbands

The improved PF scheduling method makes good use of the coefficient of PF factor to achieve system gain. The figure in Fig. 7 is drawn to evaluate the impact of β on the system performance. In general, with the increase of coefficient of PF factor, the cell average throughput has a rising tendency with fully exploiting NOMA superiority, and the gain of cell edge throughput is first up and down later. Taking a good trade-off between cell average and cell edge throughput, we choose 1.5 as the suitable coefficient of PF factor with 15.58% and 16.87% gain respectively in cell average and cell edge throughput with the situation of 10 UEs per cell and 9 subbands. Compared to the conventional NOMA scheduling with $\beta = 1$, the additional achieved gains are 7.54% and 2.9% for cell average and cell edge throughput.

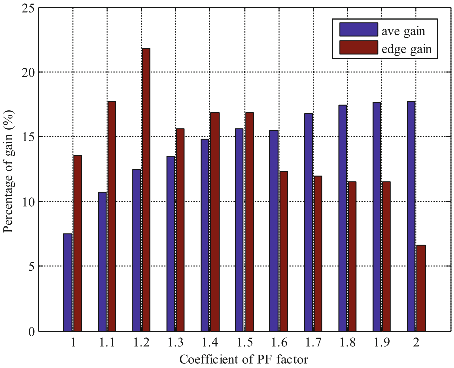

Fig. 7. Gain of cell average and cell edge throughput with different coefficients of PF factor

It is obvious that NOMA brings better performance than OMA. Compared the improved PF scheduling method with joint Gray-mapping modulation to the adaptive NOMA scheme with $\beta = 1.5$, there is 1.2% and 3.52% loss for cell average and cell edge throughput respectively as shown in Table 3. For Far-UEs, the ratios of QPSK and 16QAM are 83.36% and 16.64%, giving the convincing evidence to implement the proposed adaptive power ratio method with joint Gray-mapping modulation. The proposed scheduling method brings negligible performance loss with less signalling overhead and implementation complexity, which can be better practical use.

Table 3. Comparison between different schemes for 10 UEs per cell

Schemes	Ave throughput (bps/Hz)	Edge throughput (bps/Hz)	Ave/edge gain (%)
OMA	1.7868	0.0479	0/0
Adaptive NOMA	2.0652	0.0560	15.58/16.87
Improved NOMA	2.0405	0.0540	14.2/12.76

5 Conclusion

The results show that NOMA with SIC significantly enhances the system performance and spectral efficiency compared to the conventional OMA, even taking practical conditions and joint Gray-mapping modulation into consideration. The proposed PF scheduling method achieves noticeable gain with less signalling overhead and implementation complexity.

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