Simple Power Adjustment Scheme for Uplink NOMA Based Random Access

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***Abstract*— In this paper, Uncoordinated power control is considered to improve the performance of uplink random access (RA) in non-orthogonal multiple access (NOMA) employing imperfect successive interference cancellation (SIC). First, the effect of imperfect SIC is modeled exploiting the sigmoid function. Then, in order to improve the performance of the NOMA SIC receiver, we propose an uncoordinated power control method that makes the power received from each terminal different. Based on the simulation results, it is shown that the proposed scheme results in performance improvement compared to the conventional power control method in the orthogonal multiple access (OMA) or other power control schemes in NOMA. Also, the effect of imperfect SIC on RA performance is shown.**

Keywords—Random Access, Power Control, Imperfect SIC, NOMA

I. INTRODUCTION

6G aims to provide ultra-massive machine-type communications (umMTC) service in which numerous MTC devices successfully communicate with each other. In order to achieve this goal, it is essential to support random access (RA) technology for increasing the maximum number of MTC-type devices that can be connected in an ultra-high density environment. In order to increase the number of devices that can be supported, non-orthogonal multiple access (NOMA) based RA, which allows users to attempt access by sharing frequency resources, is more advantageous than traditional orthogonal multiple access (OMA) based RA [1][2].

In NOMA, since several received signals overlap and share a subband in the power domain. Therefore successive interference cancellation (SIC) is required for the base station (BS) to decode the messages of each UEs. In order for the SIC to work well, an appropriate difference between received powers at the BS is required. In the meanwhile, it is difficult to expect perfect SIC performance in practical environments. Therefore, it is desirable to establish an imperfect SIC model and optimize NOMA RA performance accordingly[3].

In this paper, the impact of imperfect SIC is first modeled exploiting the sigmoid function. Then, an uncoordinated power control method for each terminal is proposed to improve RA performance in NOMA. Based on the simulation results, we compare the proposed schemes with the existing power control method for RA, and show that the proposed power control method yields significant performance improvement in terms of throughput normalized by average transmission power. In addition, in order to examine the effect of imperfect SIC on NOMA RA, the NOMA RA performance of power control schemes are compared by applying imperfect SIC reflecting two different environments.

II. SYSTEM MODEL

A. *Cell Environment*

In this paper, we consider an uplink NOMA random access system as shown in Fig. 1. P_k and V_k are the transmission power of the kth UE and the target received power at eNodeB, respectively. d_k is the distance between the eNodeB and the kth UE. The channel (power) gain h_k^2 is given by $h_k^2 = d_k^{-a} u_k^2$, where d_k^{-a} is the path loss and u_k^2 indicates the multipath fading. We assume the channel is reciprocal in this paper, implying the channel gain h_k^2 can be obtained at UE via downlink reference signal etc.

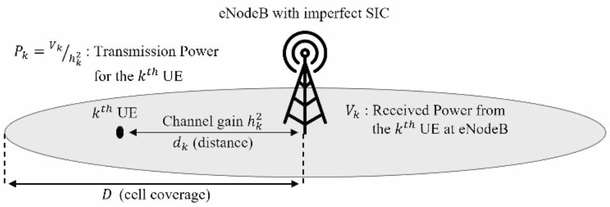

Fig. 1. System model for uplink NOMA random access with imperfect SIC .

B. *Imperfect SIC*

In the case of imperfect SIC, the interference after cancellation remains in the next cancellation stage, and the effect can be expressed as [4]

$$SINR_{k(Imperfect\ SIC)} = \frac{P_k |h_k|^2}{\sum_{i=1}^{k-1} \beta_i P_i |h_i|^2 + \sum_{i=k+1}^{K} P_i |h_i|^2 + n}, \quad (1)$$

where β_i represents the remaining interference term after the ith cancellation.

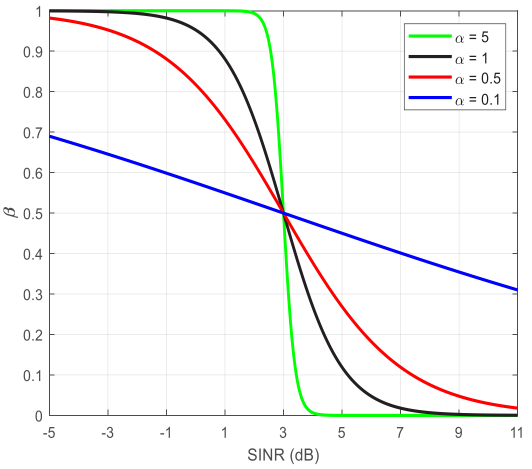

Fig. 2. Modeling the effect of imperfect SIC (when $\Gamma_{SIC} = 3$[dB])

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In previous studies, β_i is fixed to an arbitrary number, which makes it difficult to reflect the actual performance of imperfect SIC. In this paper, in order to reflect the practical case, the sigmoid function is exploited to determine the interference term β_i. That is, β_i of the imperfect SIC is modeled as

$$\beta_i = \frac{1}{1+e^{\alpha \times (SINR_{i(Perfect\,SIC)} - \Gamma_{SIC})}}, \tag{2}$$

where Γ_{SIC} is a reference SINR of the SIC operation. Fig. 2 depicts the proposed interference modeling in (2) when Γ_{SIC} is equal to 3 [dB]. The value of α in (2) depends on the actual performance of implemented SIC.

III. POWER CONTROL SCHEME

In this paper, we propose three power control schemes that can allocate the received power level to an arbitrary value according to the distance from the eNodeB as follows.

We compare the NOMA RA performance of our proposed power control schemes with the conventional power control scheme in OMA[5] as well as the NOMA SIC based PDMA with multichannel ALOHA in [6]. Therefore, in this section, we explain the power control schemes that has been proposed previously and the power control scheme that we propose.

A. Conventional

In OMA based RA, the transmission power P of the UE is adjusted so that the received power from each UE is maintained at a constant P_{target_power} [5] as

$$P = min\,\{P_{max},\ P_{target\_power} + PL\}. \tag{3}$$

However, since this method in the OMA keeps the received power at the eNodeB constant, it leads to performance degradation when applied to NOMA SIC based RA.

B. PDMA with Multichannel ALOHA

The power control method for multichannel ALOHA is investigated in [6], where the performance of NOMA SIC is improved by dividing a cell into L groups according to the distance and allocating L received power levels to each group.

$$V_L = \Gamma(\Gamma + 1)^{L-l}. \tag{4}$$

However, since this power control discretely determines the received power level, UEs received at the same power level may occur, which causes performance degradation.

C. Proposed Scheme I

In this power control scheme, we make a UE group close to the eNodeB has a large difference in their received power level, whereas a UE group far from the eNodeB has a small difference. Then, the received power from the kth UE is given by

$$V_k = min\,\{\eta^{D/_{0.1D}},\ \eta^{D/d_k}\} \tag{5}$$

where the peak transmission power is limited as $\eta^{D/_{0.1D}}$, since V_k diverges to infinity when d_k approaches zero.

D. Proposed Scheme II

In the second power control scheme, the received power from the kth UE is proposed as

$$V_k = \eta^{\kappa(1-\frac{d_k}{D})} \tag{6}$$

where the power difference among UEs according to d_k is relatively constant when compared to the proposed scheme I. In (6), V_k does not diverge according to d_k, so the peak power limit is not required. Also, in (6), the parameter κ is added to represent the inverse proportional function more generally.

E. Proposed Scheme III

In the third power control scheme, the received power from the kth UE is proposed as

$$V_k = 10^{\left(\frac{(V^{min} - V^{max})}{D^{\rho}} \times {d_k}^{\rho} + V^{max}\right)/10} \tag{7}$$

This power control scheme is continuous function with a PDMA with Multichannel ALOHA scheme gradient. The maximum and minimum values of this scheme are determined by V^{max} and V^{min}.

TABLE I. SIMULATION PARAMETER

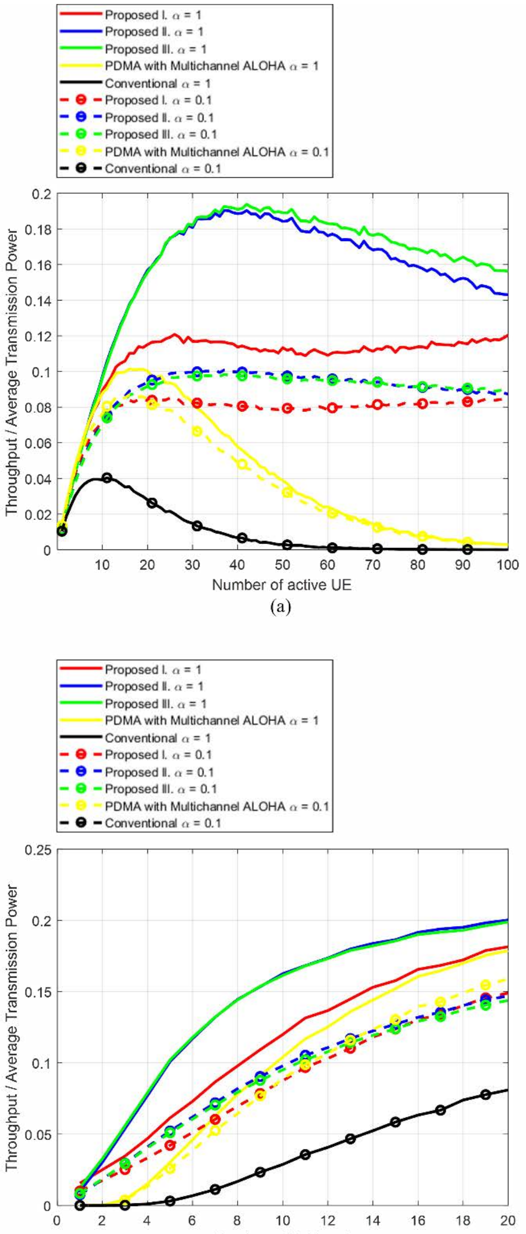
Simulation Parameter	
Parameter	***Value***
Target SINR	3 dB
D (cell radius)	100
a (path loss exponent)	3
Number of Active UE	20
Number of subband	10
η for Proposed scheme I	10
η for Proposed scheme II	8
κ	9
ρ	0.8
V^{max}	100 dB
V^{min}	3 dB

IV. SIMULATION RESULTS AND DISCUSSIONS

In this paper, NOMA RA simulation was performed to verify the performance of our proposed power control scheme. For objective performance verification, as described in Section Ⅲ, the conventional[5] and PDMA with Multichannel ALOHA[6] schemes are simulated together with the three power control schemes we propose. In order to reflect the different average power consumption mentioned in the previous section, we consider our performance measure as the throughput normalized by the average transmission power, where the throughput is defined as the number of success UEs in uplink RA. Moreover, the RA success is defined as $SINR_{k(Imperfect\,SIC)}$ in (1) exceeds the target SINR. The values of parameters used for simulation are shown in Table Ⅰ.

As shown in Fig. 3, NOMA RA performance was analyzed according to Number of active UE and Number of subbands in two situations where $\alpha = 1$ and $\alpha = 0.1$. In Fig.3 (a) (b), when both $\alpha = 1$ and $\alpha = 0.1$, the proposed power control schemes show generally higher performance than the existing methods. In particular, the cases of proposed scheme Ⅰ and Ⅱ show much higher performance than other power controls. This is because the proposed scheme I and II place a large power difference according to the distance for all UEs.

It is shown in Fig. 3 (a) that the performance of PDMA with multichannel ALOHA in decreases rapidly with the increased number of UEs. This is because the number of UEs attempting RA using the same power level increases as the number of received power level is limited. it can be seen that the performance peaks when the number of active UEs is equal to 10, where the ratio of the number of subband to the number of UEs is equal to 1:1. In Fig.3 (b) as the number of subband increases up to the number of active UEs, the performance of all power control schemes get better.



(a)

(b)

Fig. 3. Throughput per average transmit power for different value

In Fig.3 (a) (b), power control schemes show higher performance when $\alpha = 1$ than $\alpha = 0.1$. This means that an environment in which interference term β is more differently allocated according to the SINR of each UE is advantageous to NOMA RA performance. On the other hand, in the case of the conventional method, it can be seen that the performance is quite similar to each other when $\alpha = 1$ and $\alpha = 0.1$. This is because the conventional method controls the power of UEs received from the eNodeB to be constant, so SIC shows significantly low performance regardless of the value of β.

V. CONCLUSION

In this paper, we modeled a more practical imperfect SIC by generalizing the interference term β. Then, we proposed uncoordinated power control schemes and showed the performance gain provided by the proposed schemes via simulations. Through the simulation, it is shown that it is advantageous to improve NOMA based RA performance to design the power of each UEs received from the eNodeB continuously rather than discretely. Also, it is advantageous to adjust each UE's transmission power such that the received power at eNodeB has appropriate power difference for the NOMA SIC. In addition, we observed and analyzed the effect of imperfect SIC in different environments on the performance of NOMA RA. However, since the proposed schemes may not be the optimal power control, a generalization of the inverse function in the proposed scheme and the optimum power control function for maximizing system performance will be further examined.

ACKNOWLEDGMENT

This work was supported by Institute for Information & communications Technology Planning & Evaluation(IITP) grant funded by the Korea government(MSIT) (No. 2021-0-00368, Development of the 6G Service Targeted AI/ML-based autonomous-Regulating Medium Access Control (6G STAR-MAC)).

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