Power Control Scheme for NOMA Random Access with Imperfect SIC

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***Abstract*— In this paper, power control is considered to improve the performance of uplink random access 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.**

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

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][3].

In NOMA, since several received signals overlap and share a subband in the power domain, successive interference cancellation (SIC) is required for the base station (BS) to decode the messages of each terminals. In order for the SIC to work well, an appropriate difference between received powers at the BS is required [4]. 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 [5].

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 performance of our proposed scheme 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.

II. System Model

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 k^{th} UE and the target received power at eNodeB, respectively. d_k is the distance between the eNodeB and the k^{th} UE. The channel (power) gain h_k^2 is given by $h_k^2 = d_k^{-\alpha} u_k^2$, where $d_k^{-\alpha}$ 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.

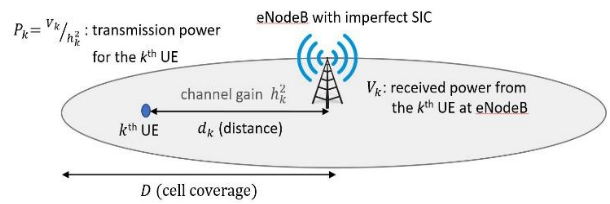

Fig. 1. System model for uplink NOMA random access with imperfect SIC .

In the case of imperfect SIC, the interference after cancellation remains in the next cancellation stage, and the effect can be expressed as [6][7]

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

where β_i represents the remaining interference term after the i^{th} cancellation.

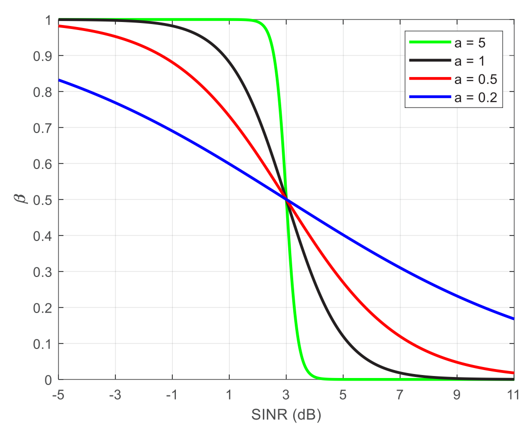

Fig. 2. Modeling the effect of imperfect SIC (when $\Gamma_{SIC} = 3[\text{dB}]$).

In previous studies [6][7], 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

$$\beta_k = \frac{1}{1 + e^{a \times (SINR_{k(Perfect\ SIC)} - \Gamma_{SIC})}}, \quad (2)$$

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 a in (2) depends on the actual performance of implemented SIC.

III. Proposed Power Control Scheme

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} [8] as.

$$P = min\{P_{MAX}, P_{target\_power} + PL\}. \quad (3)$$

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

On the other hand, a power control scheme for multichannel ALOHA is investigated in [9], 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. However, since this power control discretely determines the received power level, the same received power at eNodeB may occur, which causes performance degradation.

A. Proposed Scheme I

In this paper, we propose two power control schemes that can allocate the received power level to an arbitrary value according to the distance from the eNodeB. In the first proposed 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 k^{th} UE is proposed as

$$V_k = min\{\eta^{D/_{0.1D}}, \ \eta^{D/d_k}\}, \quad (4)$$

where the peak transmission power is limited as $\eta^{D/_{0.1D}}$ because V_k diverges to infinity when d_k approaches zero. The parameter η determines the degree of inverse proportionality of V_k.

B. Proposed Scheme II

In the second power control scheme, the received power from the k^{th} UE is proposed as

$$V_k = \eta^{\kappa(1-\frac{d_k}{D})}, \quad (5)$$

where the power difference among UEs according to d_k is relatively constant when compared to the proposed scheme I. In (5), V_k does not diverge according to d_k, so the peak power limit is not required. Also, in (5), the parameter κ is considered to represent a more comprehensive inverse proportional function.

Fig. 3 shows the received power distribution according to each UE locations for several power control schemes. It can be seen that the amount of power consumption is different for each power control schemes, implying that in order to properly compare the performance of several power control schemes, the average power consumption by the all UEs should be considered together.

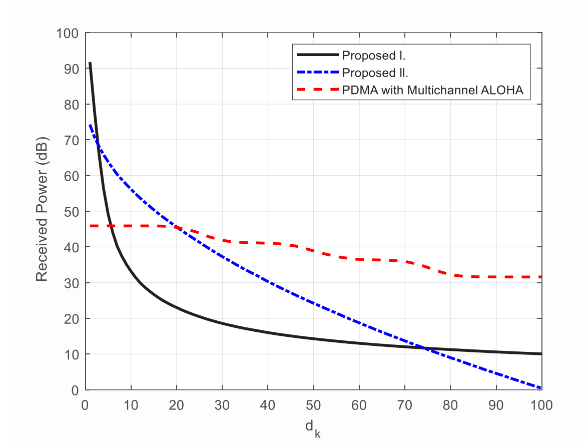

Fig. 3. Received power V_k versus d_k (The cell radious D = 100, the number of power level for PDMA = 4)

IV. Simulation Results and Discussions

We compare the performance of our proposed power control schemes with the conventional power control scheme (3) in OMA as well as the NOMA SIC based PDMA with multichannel ALOHA in [9]. For the simulation, the radius of the cell is set to D = 100. Also, we choose η = 10 in (4) and η = 8, κ = 9 in (5), respectively. 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. In our simulations, the target SINR is set to 3 [dB]. The multipath fading and the path loss exponent are assume to be Rayleigh distributed and α=3, respectively.

As shown in Fig. 4, the performance of all power control methods degrades as the target SINR increases. Furthermore, as the target SINR increases, the performance difference among several power control schemes decreases. It is shown in Fig. 5 that the performance of PDMA with multichannel ALOHA in [9] 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. On the other hand, our proposed scheme I and II result in significant performance improvement because the received power level of the UEs is determined as a continuous and unrestricted value. In the case of the conventional power control method, 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. 6, as the number of subband increases up to the number of active UEs, the performance of all power control schemes get better. In Fig. 4, 5 and 6, it can be seen that the our proposed power control schemes show higher performance than the existing power control method, and the proposed scheme II is better than the proposed scheme I. This indicates that keeping the appropriate power difference at eNodeB is more effective for NOMA RA with imperfect SIC.

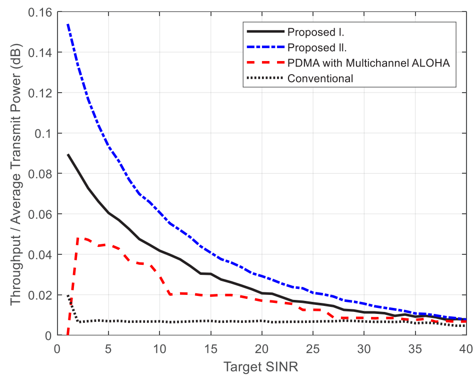

Fig. 4. Throughput per average transmit power versus different target SINR (The number of subbands = 10, the number of active UE = 20)

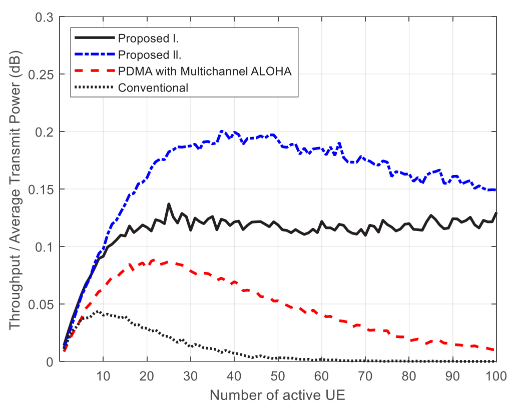

Fig. 5. Throughput per average transmit power versus the number of active UE (The number of subbands = 10)

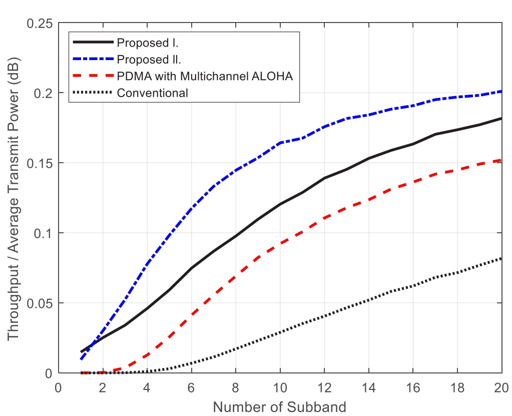

Fig. 6. Throughput per average transmit power versus the number of subband (The number of active UE = 20)

V. Conclusion

In this paper, we first formulated the interference term β in the imperfect SIC in terms of the sigmoid function. Then, we proposed uncoordinated power control schemes for NOMA based RA and showed the performance gain provided by the proposed schemes via computer 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. 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

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