

Advanced Resource Allocation and Scheduling for Non-Orthogonal Multiple Access

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I. SUMMARY OF PROGRESS

The main progress of our project in the past few months is to survey literature on the physical and MAC layer techniques for non-orthogonal multiple access (NOMA). Several research papers have been found and carefully studied. In the following, we first briefly describe some of the papers surveyed, and then we organize our findings into *physical layer* and *MAC layer* aspects in Section I-A and Section I-B respectively.

Among the papers that we have surveyed, the authors in [1] compare the performance between orthogonal frequency-division multiple access (OFDMA) and NOMA. They in particular investigate successive interference cancellation (SIC) and state that SIC receivers should follow the rule that the optimal order for decoding is in the order of the increasing $\frac{|h|^2}{N}$. An NOMA/Multiple-Input Multiple-Output (MIMO) scheme is proposed to achieve further capacity gain. In [2], the authors investigate the enhancement of the cell-edge user throughput by using SIC in the cellular downlink. They propose an optimization method that can balance the throughput of cell-edge users and interior users. The work in [3] is the extension of [2], where the authors investigate the use of FFR and weighted PF-based multi-user scheduling with SIC in the cellular downlink. They show that NOMA can indeed help achieve user fairness. Contrary to [1]–[3], related work [4] not only considers the ideal channel capacity but also analyzes SIC performance with respect to modulation schemes and packet error rate (PER). A resource allocation algorithm is proposed to leverage the spatial gain and the simulation results show their proposed algorithm to achieve more than 100 percent throughput gain compared to OFDMA-based systems. In [5], the authors investigate SIC and propose an iterative SIC receiver architecture with combined pilot/date based channel estimation for efficient decoding of NOMA signals. The simulation results show that the proposed iterative SIC receivers can reach low PER for users with weak SNR without incurring high complexity.

A. PHY Layer Aspects

To allow non-orthogonal access from multiple users over the same radio resource, successive interference cancellation (SIC) or superposition coding has been popularly considered in the literature [1]–[3]. To understand how SIC works, take the two-user downlink communication in Fig. 1 as an example. The transmitted signal from the base station is a linear combination of the signals intended for UE1 and UE2. To decode individual signals, SIC needs to be performed at each

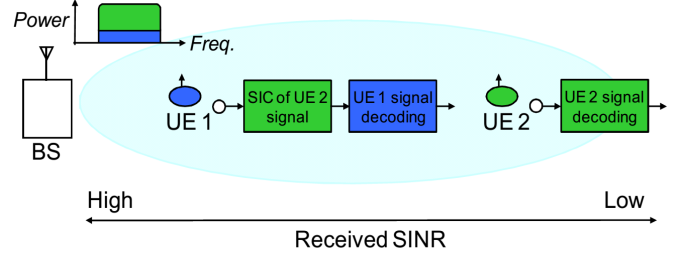


Fig. 1: Two-user SIC in the downlink

receiving UE. The optimal order for decoding is the order of the increasing channel gain normalized by the noise and inter-cell interference power. Assuming that the channel gain of UE1 is better than UE2, if UE2 can decode its signal, then UE1 must also be able to decode the UE2 signal. Therefore, as shown in Fig. 1, UE1 first decodes the signal of UE2 and then decodes its signal after the decoded UE2 signal has been subtracted. For UE2, it can simply go ahead and decode its own signal without decoding the signal for UE1 first. The case for SIC among K UEs can be performed similarly, and ideally for any UE the optimal decoding is to remove the signal components of UEs with worse channel gains. As shown in [1], the achievable rate $R_b^{(sic)}(k)$ for UE k in resource b can be represented as follows:

$$R_b^{(sic)}(k) = W_b \log_2 \left(1 + \frac{|h_{k,b}|^2 P_{k,b}}{\sum_{\substack{i=1 \\ \frac{|h_{k,b}|^2}{N_{k,b}} < \frac{|h_{i,b}|^2}{N_{i,b}}}}^K |h_{i,b}|^2 P_{i,b} + W_b N_{k,b}} \right), \quad (1)$$

where $|h_{i,b}|^2$ is channel gain between UE i and the base station, W_b is the bandwidth of resource b , $P_{i,b}$ is the transmission power allocated to UE i , and $N_{i,b}$ is the noise and inter-cell interference power for UE i .

In practice, it might not be possible to achieve perfect interference cancellation. The authors in [4] have shown simulation results for SIC with respect to modulation schemes and SNR

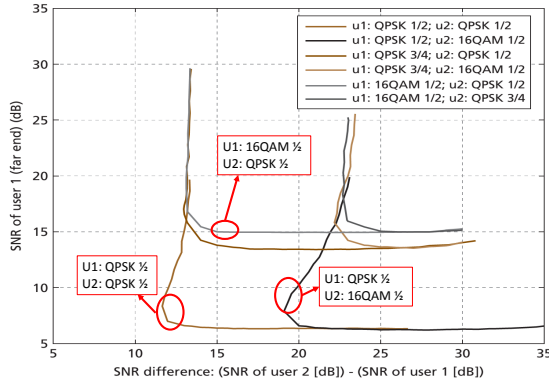


Fig. 2: Modulation and PER vs. SNR difference

TABLE I: Modulation curve in Fig. 2

U1 Modulation	U2 Modulation	SNR of U1	SNR Difference
QPSK 1/2	QPSK 1/2	6-15	12-20
QPSK 1/2	16QAM 1/2	6-15	≥ 20
16QAM 1/2	QPSK 1/2	≥ 15	12-20

difference as given in Fig. 2. All points enclosed in the upper right area of each curve are in the desired operating region with $\text{PER} \leq 10^{-2}$. Table I further shows the relationship between modulation and SNR for three marked points in the figure. We can find that the simulation result does not strictly follow (1). For example, if the SNR of U1 becomes 8 times (i.e. 9 dB) larger, the modulation of U1 can upgrade from QPSK to 16QAM, which has only 2 times larger capacity. Fig. 2 motivates our further investigation on the practical performance of SIC for MAC layer design.

B. MAC Layer Aspects

To leverage the benefits of NOMA, MAC layer techniques such as resource allocation, scheduling, and power control need to be properly redesigned for performance optimization. In the following, we describe two related work for allocating resources to NOMA users.

1) *Two-user resource allocation*: The authors in [4] consider the problem of choosing the best pair of UEs for sharing each resource unit. An algorithm called variable multi-user resource allocation as shown in Algorithm 1 is proposed. Specifically, UEs are sorted in the descending order of their channel gains. For each candidate UE, the algorithm first finds the other UE that can use the same resource based on the simulation model in Fig. 2. The set of UEs that can pair with the candidate UE is obtained as group \mathcal{A} . Then, group \mathcal{B} is obtained from \mathcal{A} , where the multi-user data rate $R_b^{(\text{sic})}(z)$ of the far user z should reach at least half of its single-user data rate $R_b(z)$. Finally, group \mathcal{C} is obtained from group \mathcal{B} by the rule of fair scheduling. The algorithm allocates the resource to the pair (x, y) whose sum rate is the highest in group \mathcal{C} .

2) *Optimization of multi-user resource allocation*: In [2], the authors investigate an optimization problem that can dynamically control the worst data rate and the maximum data rate in the cellular system. Ideally, the total user sum rate is

Algorithm 1 Variable multi-user resource allocation algorithm

Sort users in descending order by their channel gains
for each user x in the sorted list **do**
 $\mathcal{A} = \{(x, y) | (x, y) \text{ both fulfill NOMA constraint with } y \text{ being the far user}\}$
 $\mathcal{B} = \{(x, y) | (x, y) \in \mathcal{A} \text{ and } R_b^{(\text{sic})}(z) \geq \frac{1}{2}R_b(z), \text{ where } z = \arg \min_{i=x,y} |h_i|^2\}$
 $\mathcal{C} = \{(x, y) | (x, y) \in \mathcal{B} \text{ and } y \text{ is less scheduled}\}$
 Select $(x, y) \in \mathcal{C}$ that has the highest sum rate
 Allocate one resource to (x, y)
end for

maximized when each resource is assigned to a user with the highest signal-to-interference plus noise power ratio (SINR) among candidate users. Specifically, if there are K users and B resources, the maximum sum rate R_{\max} can be represented as

$$R_{\max} = \sum_{b=1}^B W_b \log_2 \left(1 + \frac{\max_k \left(\frac{|h_{k,b}|^2}{N_{k,b}} \right) P_{k,b}}{BW_b} \right). \quad (2)$$

Notice that base station can transmit maximum power P/B per resource unit.

Based on (1) and (2), the problem to maximize the worst user data rate with total rate constraint is written as

$$\begin{aligned} & \text{maximize} && \min_{k \in K} R^{(\text{sic})}(k) \\ & \text{subject to} && P_{k,b} \geq 0, \forall k, b, \\ & && \sum_{k=1}^K P_{k,b} = P/B, \forall b, \\ & && \sum_{k=1}^K R^{(\text{sic})}(k) \geq \alpha R_{\max}, \end{aligned} \quad (3)$$

where $R^{(\text{sic})}(k) = \sum_{b=1}^B R_b^{(\text{sic})}(k)$. The parameter α is adjustable, where a larger value of α favors the total user rates while a smaller value of α favors user fairness. For example, if $\alpha < 1$, the base station does not need to fulfill the strict constraint of R_{\max} and can allocate resources to other users.

Problem (3) is not a convex optimization problem; therefore, the solution obtained using the interior-point method depends on the initial setting of parameters $P_{k,b}$. In view of (2), the authors use the following for initial setting of $P_{k,b}$ in the evaluation:

$$P_{k,b} = \begin{cases} \frac{P}{B}, & k = \arg \max_i \left(\frac{h_{i,b}}{N_{i,b}} \right) \\ 0, & \text{otherwise.} \end{cases} \quad (4)$$

Still, due to the complexity of the problem, the solution of (3) obtained by the interior point method through (4) is local optimal but not global optimal. Further investigation on formulation and optimization of multi-user resource allocation is needed.

II. PLAN FOR THE NEXT MONTH

In the next month, we plan to continue investigation of NOMA on physical and MAC layers to better equip ourselves with state-of-the-art research advances on NOMA. In addition to theoretic, ideal models for NOMA, we also plan to investigate more closely the simulation models presented in [4] to lay a more solid ground for the resource allocation and scheduling techniques to be investigated in this project.

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