Investigation over NOMA with SIC in single antenna scheme

Ming Jie Yang

GICE, National Taiwan University
Taipei, R.O.C
R02942125@ntu.edu.tw
2014 May 9th

***Abstract*—The report shows progress on the project that explores non-orthogonal multiple access (NOMA) with successive interference cancellation (SIC). The short term objective of current phase is to build a simulation framework and examine the performance gain with SIC technique. The system is extended based on LTE architecture.**

I. Introduction

Briefly, by the previous effort in literature survey, we summarize related work as follows. In [1], the authors 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 help achieve user fairness.

Related work in [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 that proposed algorithm using NOMA with SIC achieves more than 100 percent throughput gain comparing OFDMA. In [5], the authors investigate SIC and proposed an iterative SIC receiver architecture with combined pilot/date based channel estimation for efficient decoding of NOMA signals. The simulation results show iterative SIC receivers reach low PER with weak SNR under a reasonable complexity.

II. System Model

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 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 by K UEs can be performed similarly, and ideally for any UE the optimal decoding is to remove the interference coming from UEs with worse channel gains. As shown in [1], the achievable rate $R_b^{(\mathrm{sic})}(k)$ for UE k in resource b can be represented as follows:

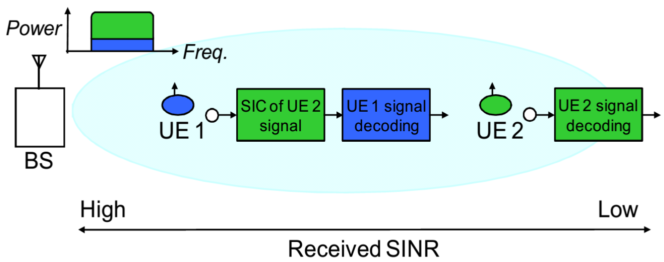

Fig. 1: Two-user SIC in the downlink

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

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. Equation 1 shows a simple version of SIC reception model, and the work in [6] investigate the design of a SISO SIC receiver operating on OFDM system

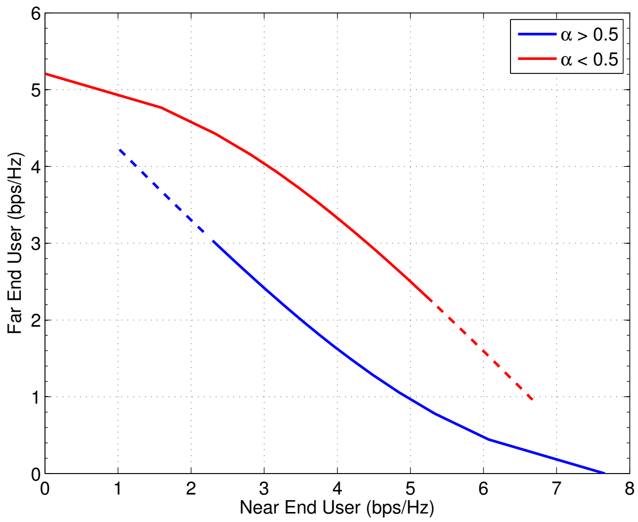

Fig. 2: Upper boundary of rate in two users scheme

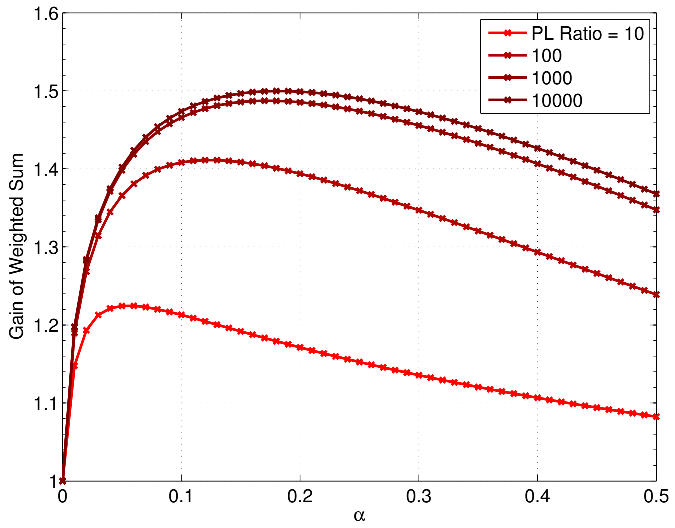

Fig. 3: Gain in Weighted sum of throughput for different PL ratio

considering ICI cause by time variations in channel. In the downlink scenario, the transmission power of the base station is limited and denotes as P. Assume there are two users that are served by the base station. The power of the signal sent to near-end user, indexed as user 1, is $P_1 = \alpha P$, and far-end user, user 2, is $P_2 = (1 - \alpha)P$. The channel is AWGN with pass loss exponent coefficient set to be 4.5. Consider the capture effect in receiving two signal in the same frequency, one with stronger signal power will be demodulated. Thus as shown in Fig. 2, when the power allocation factor α is greater than 0.5, giving more power resource to near-end user, the curve is convex. On the contrary, the curve is concave, which also indicates that there is gain in weighted sum of throughputs. The weighted sum rate [4] as a function of power allocation factor is defined as follows,

$$Gain = \frac{1}{R_1(P)} R_1(\alpha P) + \frac{1}{R_2(P)} R_2((1 - \alpha)P) \qquad (2)$$

where R_1, R_2 are functions denotes channel capacity with given power allocated. The measure for the system performance is enhanced by weighted sum rate, since optimizing the sum rate of all users in the system results in serving specific user with good channel condition. In Fig. 3 the gain in weighed sum changes by different power allocation factor selected, and an optimal allocation varies for different pass loss ratio of user 1 and user 2. As the difference of the PL ratio increase the gain in weighted sum increase also. However, we've observed that the maximum of the gain is limited and possibly converges.

III. SIMULATION

To analyse how well the theoretical gains can be realized in practice, a more sophisticated simulation is done to extend our investigation in NOMA with SIC. The simulation is set up by following description.

A. *system architecture*

The system architecture is shown in Fig. 4. In this system, the receiver can only extract two layer of multiplexed data. The values of the parameters for related blocks are listed below.

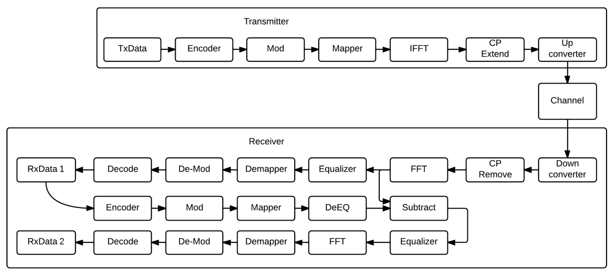

Fig. 4: Simulation system architecture block diagram

- FFT size : 2048
- Cyclic prefix length : 144 samples
- Carrier frequency : 2.6 GHz
- Bandwidth : 20MHz
- Modulation : BPSK, QPSK, 16QAM
- Coding rates : 1/2
- Channel : AWGN, multipath fading channel
- Path loss model: Hata, medium sized city
- Equalizer : MMSE

B. *numerical results*

In this section, extensive simulations are carried out to examine the analytical results derived above. $1M$ bits of data is transmitted in following simulations.

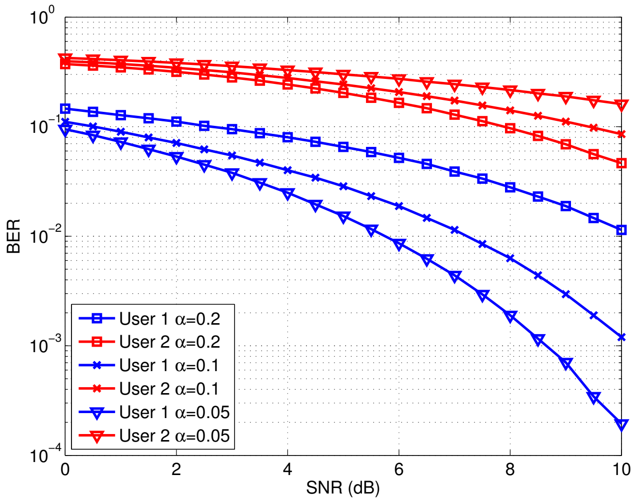

Fig. 5: BER performance of two users with identical channel condition

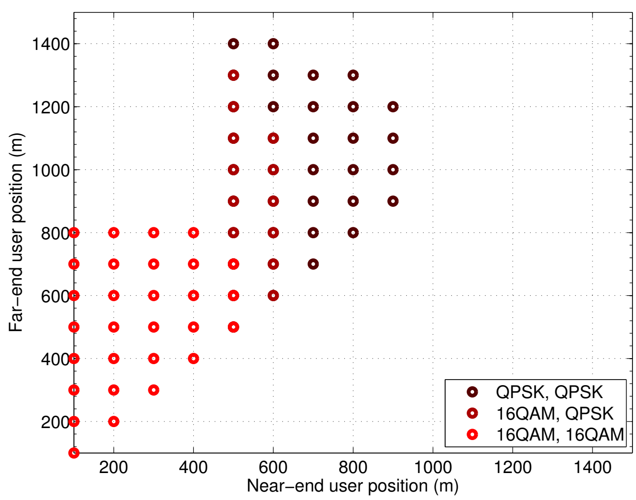

Fig. 7: Modulation supported by given BER threshold 10^{-2} in two user case

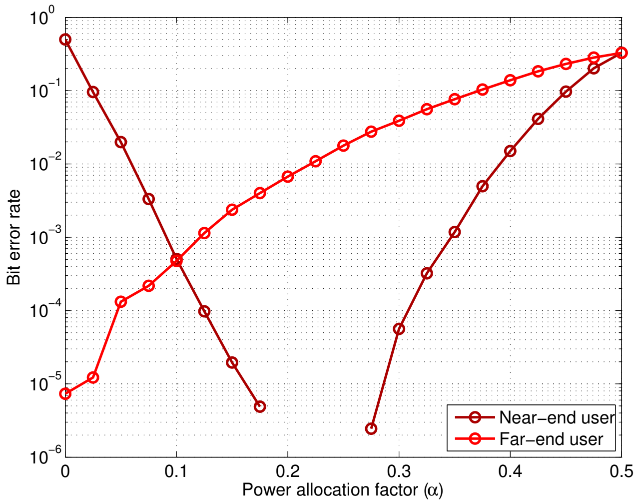

Fig. 6: BER for different power allocation factor

1) power allocation: As in the previous mathematical model, whether or not the desired transmission signal can be demodulated is not taken into account. When the base station allocates similar power resources on both users' signals, the receiver may not be able to extract any of the original data. In other words, the region where alpha is set near 0.5 have to be checked. Also, we would like to see the performance of SIC when user 1 and user 2 have identical channel condition when served by the same base station.

In Fig. 5 shows BER curve for 2 users served in same BS with same channel condition. The data stream is multiplexed by power allocation factor α with 0.2 0.1 and 0.05. The SNR value is defined as $fracPN_0$ at receiver end, value P is the constraint of transmission power of BS as mentioned above.

To investigate in the optimal strategy of power allocation, i.e. optimal α value, when serving two users. In Fig. 6 shows the BER to different α settings. The BS transmission power is set to be $5mW/MHz$, and background noise is $-144dBm$. Near-end user, indexed as user 1, is position at a distance of $150m$, and far-end user, user 2, is at $220m$. The channel loss exponent is 4.5 and thus the PL ratio is about 5.6. Supposed that the system requires BER no greater than 10^-2, α can be set in the range between 0.06 and 1.17 in this case.

2) pair selection: It is shown that the channel conditions of users has significant impact to the gain in Fig. 3 according to the mathematical model of SIC. Obviously, the greater difference of channel gain, the more capacity gain can be reached theoretically.

In Fig. 7, two user equipments is served by single base station and for each point in the figure is a test case of combination of position. Users in this simulation can choose its modulation, QPSK or 16QAM, if there exists an feasible solution of power allocation factor that guarantees the BER of both users is less than a given threshold. The figure plots only the highest possible order of modulation user can reach. Here, the BER threshold is set to be 10^{-2}. Fig 7 also shows that to maintain a certain level of QOS in BER, the position of the users is constrained by the far-end user. This is fine by principle that to prevent error propagation in multi-phase decoding, the error rate of the data decoded previously (far-end user's data) has to be controlled.

Moreover, it is verified that the greater difference of distance, the more capacity gain can be reached by simulation. Since the channel gain is a monotonically decreasing function of distance, greater difference in distance indicates greater difference of channel gain. For example, assume the far-end user is positioned at a distance of 800 meter. Near-end user can only operates at QPSK modulation if it's positioned at 700 or 800, where the channel condition is close to near-end user. As the near-end user move close to the base station, higher order of modulation is possible for both users.

To provide quality service in wireless multiple access network, it's essential to make proper scheduling between users when the resources is limited. To exploit the properties of

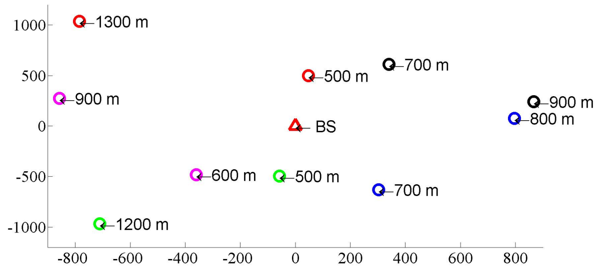

Fig. 8: Topology of 10 randomly scattered users

TABLE I: Schedule results for each resource block

RB #1	RB #2	RB #3	RB #4	RB #5
QPSK-1300	QPSK-700	QPSK-900	QPSK-1200	16QAM-600
16QAM-500	QPSK-800	QPSK-700	16QAM-500	QPSK-900
α value				
0.1	0.3	0.3	0.075	0.025

SIC we've observed in previous simulation, we further make a experimental scheduling algorithm in a simple scenario.

In Fig. 8 shows the topology we use in the simulation. 10 users are randomly scattered in 1400 square meter plane. Each user has to transmit at least once, and the base station allows at most 2 users to scheduled in a single resource block. The BER threshold is 10^{-2} here. In short, we have to schedule all users in 5 resource blocks with 2 users in each with no overlapping. By the properties of SIC, we would like to put two user with sufficient difference in channel gain.

First, we sort all 10 users by the distance in decreasing order, and start scheduling form the farthest one, then scan the rest and find the best one with the highest spectrum efficiency. Next, remove the pair of users form the scheduling set of users, perform the same process iteratively. Finally, we get a schedule and the corresponding power allocation factor α shown in Table I. The alpha listed below each pair is a single point of solution in feasible region. The simulation shows possible strategy for pair selection in scheduling users with SIC functionality.

IV. Conclusion

It is positive that SIC can enhance user fairness for users in relatively bad channel condition. Further experiment is done to prove that scheduling is necessary to reach better performance gain. It's as expected that scheduling users in great difference of path loss may reach our objective.

V. Future Work

First of all, in practice the base station cannot get the position information of users, thus the algorithm to decide SIC pairs in single RB has to be designed depends on the channel feedback. Second, the simulation parameter settings should set as the same as 3GPP specification's regulation to evaluate the performance. The future simulation will refer to report in series 36. Third, The scheduling algorithm in the report is a simple greedy one. To exploit SIC in scheduling, a full search should be done for reference. Fourth, The unit test of FDE module (equalizer) is done, should replace the old one. The channel is static 3-taps TDL, a time-vary version should be build.

Finally, Project of uplink SISO-SIC simulation launches right after the the downlink part is finished.

References

[1] Y. Saito, Y. Kishiyama, A. Benjebbour, T. Nakamura, A. Li, and K. Higuchi, "Non-Orthogonal Multiple Access (NOMA) for Cellular Future Radio Access," *Proceedings of IEEE Vehicular Technology Conference (VTC Spring)*, pp. 1–5, June 2013.

[2] S. Tomida and K. Higuchi, "Non-orthogonal Access with SIC in Cellular Downlink for User Fairness Enhancement," *Proceedings of IEEE Intelligent Signal Processing and Communications Systems (ISPACS)*, pp. 1–6, Dec 2011.

[3] J. Umehara, Y. Kishiyama, and K. Higuchi, "Enhancing User Fairness in Non-orthogonal Access with Successive Interference Cancellation for Cellular Downlink," *Proceedings of IEEE Communication Systems (ICCS)*, pp. 324–328, Nov 2012.

[4] Joerg Schaepperle and Andreas Regg, "Enhancement of Throughput and Fairness in 4G Wireless Access Systems by Non-orthogonal Signaling," *Bell Labs Technical Journal*, vol. 13, no. 4, p. 5977, 2009.

[5] A. Ruegg and A. Tarable, "Iterative SIC Receiver Scheme For Non-orthogonally Superimposed Signals on Top of OFDMA," *Proceedings of IEEE Personal Indoor and Mobile Radio Communications (PIMRC)*, pp. 156–161, Sept 2010.

[6] E. Leung and P. Ho, "A successive interference cancellation scheme for an odfm system," in *ICC 98, IEEE International Conference on Communications*, vol. 1, Jun 1998, pp. 375–379 vol.1.

[7] K. Higuchi and Y. Kishiyama, "Non-orthogonal access with random beamforming and intra-beam sic for cellular mimo downlink," in *78th Vehicular Technology Conference (VTC Fall)*, Sept 2013, pp. 1–5.

[8] O. Goussevskaia and R. Wattenhofer, "Scheduling wireless links with successive interference cancellation," *ICCCN*, pp. 1–7, July 2012.