Research on key technologies of overlay multiple access based on deep learning

Ronglan Huang*
Guangxi Colleges and Universities Key Laboratory of Image Processing and Intelligent Information System, Wuzhou University, Wuzhou, Guangxi, 543002, China
*Corresponding author. Email: 283685512@qq.com

Abstract. NOMA (Non-Orthogonal Multiple Access), as one of the candidate technologies of 5G, can improve the spectrum efficiency and system capacity, and has attracted wide attention. The essence of NOMA is multi-user overlay transmission in power domain, and multiple users will schedule on the same sub-band. The fundamental principle and key technologies of NOMA technology, such as power multiplexing superposition coding technology and SIC (Successful Interference Cancellation) technology, are described. The BER performance of NOMA communication system based on power domain in downlink is studied, and the appropriate power allocation ratio range is obtained. From the overall point of view of the system, users are grouped with the goal of maximizing the channel gain difference of all matched users, and then the problem of maximizing the weighted sum rate is transformed into the problem of minimizing the weighted sum mean square error by using the deep learning algorithm. By updating each optimization parameter iteratively in turn, it converges to the local optimum of the objective function. This method can improve the weighting and rate performance of the system with fewer iterations.

1. Introduction
In order to meet the increasing number of users' access and service demands, MA(Multiple Access) has been continuously researched and innovated to meet more users' access on limited spectrum resources. For example, FDMA (Frequency Division Multiplexing Access) technology is adopted in 1G system, TDMA (Time Division Multiplexing Access) technology is mainly adopted in 2G system, CDMA (Code Frequency Division Multiplexing Access) technology is adopted in 3G system, and OFDMA (Orthogonal Frequency Division Multiplexing Access) technology is adopted in 4G system.

At present, the key technologies of 5G research [1-3] include large-scale antenna array, ultra-dense networking, full spectrum access, new network and new multiple access technology. With the rapid development of the Internet of Things, the 5th generation mobile communication (5G) urgently needs to solve the problem of simultaneous and reliable access of massive terminals.

Due to the limitation of spectrum resources, it is an inevitable trend for a large number of users to communicate at the same time and frequency in future wireless communication systems [4]. NOMA (Non-Orthogonal Multiple Access) technology can ensure a large number of users to communicate at the same time and frequency, and has attracted more and more attention. Aiming at the problem that NOMA overlay multiple access user grouping and power allocation scheme affect system performance, a dynamic grouping scheme is proposed, and the weighted sum mean square error algorithm in broadcast interference channel is used to solve the non-convex power allocation problem. The algorithm can
guarantee convergence to at least one local optimum after less iterations, and improve the weighting and rate performance of the system.

2. Traditional random access mechanism

In traditional mobile communication LTE / LTE-A (long term evolution / long term evolution advanced) system, random access is divided into two modes: competitive random access and non-competitive random access. In noma system, multi-user overlay transmission is used on the same time-frequency resources, so multiple users in each subband will be scheduled [5], which will inevitably increase the interference between users. Different users are sorted according to power, and then interference cancellation is carried out to realize correct demodulation of multi-user information and achieve the purpose of distinguishing multi-users [6-7]. Combined with advanced multiuser detection technology, NOMA can effectively improve spectrum efficiency and accommodate more access users.

Traditional random access mechanism requires that only one terminal can send scheduling information in the same time-frequency code resource; Otherwise, the base station thinks that the terminal has collided, which limits the number of terminals accessing the network in a certain period of time. Although the performance advantage is obvious, the user iteration complexity of the algorithm is high. Different users allocate different powers according to channel conditions, and after superposition coding, they reach the receiving end through the channel for multi-user signal detection. Multiple access technology is of vital significance in the field of wireless communication, and its technical means are constantly updated with the development of communication industry.

3. Overlay multiple access mechanism

3.1. Random user selection algorithm

In the literature [6], SC (Superposition Coding) is the earliest technology to transmit information to multiple receivers through a single source. In other words, it allows the transmitter to transmit multiple user information at the same time. Using overlapping subcarriers to improve spectrum efficiency, it is still difficult to reach the maximum Shannon capacity bound, and it is necessary to allocate non-orthogonal waveforms to different users on the same time-frequency resources to achieve greater capacity [8]. In the worst case, it is necessary to decode all users' signals in turn for users with the largest channel gain. With the increase of the number of superimposed transmission users, the complexity of the user receiver also increases, and the signal processing delay becomes more serious, which cannot meet the low delay requirement of future mobile communication.

The random user selection algorithm does not depend on other constraints, and randomly selects candidate superimposed users in the candidate user set. When the instantaneous rate of a randomly selected user is greater than the threshold value $R_0$, the user will use OMA (Orthogonal Multiple Access) to access and monopolize the time-frequency resources. When the user rate does not meet the threshold value, it will be superimposed with other users, and finally realize NOMA transmission with $N$ users superimposed. The specific algorithm flow is shown in Figure 1. The algorithm is relatively simple to implement, and only needs to consider whether the rate of a single user meets the predefined rate threshold, and does not need to consider the channel differences and interference between superimposed users.
The total transmission power of the base station is constant, and the users with good channel performance are called strong users, and the transmission power allocated by the base station is small. On the contrary, users with poor channel performance are called weak users, and the base station allocates a large transmission power to them. After receiving the information, the non-group leader terminal checks whether the identity information of the user equipment is included in the terminal identity list. Each access user uses complex domain multi-code spreading sequence with low cross-correlation which is easy to be received by serial interference cancellation, and expands its modulation symbol; Therefore, the more user information needs to be decoded, the subsequent decoding errors will accumulate and deteriorate, which will affect the system performance. However, if the number of superimposed transmission users is limited, the error probability of subsequent decoding caused by this error propagation is also low, which can be compensated by coding with better performance.

3.2. Dynamic user grouping scheme
The exhaustive search algorithm obtains the optimal solution by traversing all candidate user combinations. However, through the research of many scholars, it is found that the system throughput is related to the fair performance of users and the asymmetry of matching user channels. Literature [9] shows that when the channel gain difference between two users is larger, the non-orthogonal multiple access system with SIC can achieve greater performance improvement. The extended symbols of each user can be sent in the same time-frequency resources. Finally, the receiving side uses linear processing and block-level SIC (Successful Interference Cancellation) to separate the information of each user. After decoding one user signal, it is subtracted from the superimposed signal before the next user signal is decoded. In this way, it is more convenient to separate user information at the receiving end. Based on this feature, overlay users can be selected according to the channel differences of candidate users.

The channel state difference of users in the same group decreases, and the co-channel interference increases for users with weaker channels. That is, the number of users allowed to access at the same
time (that is, the number of sequences) is greater than the length of sequences, and then the system is equivalent to working in an overload state. When SIC is applied, if one user is decoded, the signals of other users should be regarded as interference, and then the next user should be decoded. It is necessary to subtract the decoded signal from the original received signal and decode it again. Repeat the above process until all user signals are decoded.

Combined with the influence of the channel gain difference of matching users on the system performance, this paper considers improving the fairness of users and the system performance as a whole, and chooses the standard that maximizes the channel gain difference among all matching users to group the users of dynamic grouping algorithm.

For simplicity, this paper considers that the number of users accessing each group is equal, that is, \( K_g = K/G \) is satisfied. The specific process is as follows:

1. Ordering all users according to channel gain from low to high;
2. Users are divided into \( G \) categories from the position of users \( j = n(K/K_g) \), \( n = \{1,2,\cdots\} \), \( 1 < j < K \);
3. Search for users of different categories to match according to grouping basis. When \( K_g = 2 \), the basis of the proposed user grouping scheme is expressed as:

\[
\max_k \sum_{i=1}^{j} \sum_{j+1}^{K} |h_j|^2 - |h_i|^2
\]

When \( j \) is a decimal, the user in the middle of the ranking does not perform matching, and occupies a subband transmission alone. In other cases, the process performs matching grouping as described above. It should be pointed out that when only two users are allowed to overlay in each group, the time complexity of the algorithm is \( k \) in order to search the matching scheme that maximizes the grouping criteria. With the increase of the total number of users \( O(K!) \), the number of candidate user sets traversed also increases obviously.

### 3.3. Access capacity analysis

In OFDMA system, a single user will monopolize the time-frequency resources and transmission power on the resource block, without considering the interference between users [10]. However, in NOMA system, sub-bands are shared by superimposed users, and multiple users share the time-frequency resources of sub-bands. Compared with the basic NOMA system, the NOMA communication system based on Turbo code needs to carry out Turbo coding on the user information at the transmitting end, and then carry out QPSK modulation and power allocation on the coded signal. When designing the coding domain pattern, the channel coding with different delays will be considered based on the coding matrix. At the receiving end, SIC algorithm with low complexity and high performance is used to realize multiuser detection. The main idea is that the design problem of the linear transceiver can be transformed into the covariance minimization problem of the power at the transmitting end and the equalization coefficient at the receiving end by fixing the structure of the receiver as a linear receiver.

Assuming that \( q \) is the number of terminals initiating access, \( p(r,\theta) \) is the two-dimensional probability density of terminals initiating access, and \( N_p \) is the number of available preamble sequences, the probability that one preamble sequence will not collide is:

\[
P_s = P(B = 1) = \binom{q}{1} \left( \frac{1}{N_p} \right) \left( 1 - \frac{1}{N_p} \right)^{q-1}
\]

In which: event \( B \) indicates the number of terminals selecting the same preamble sequence, and \( q \) can be predicted according to the load forecasting algorithm [11].

Under the condition of sufficient PUSCH(physical uplink shared channel) resources, the expected number of terminals accessed by orthogonal random process is expressed as:

\[
E(B_{\text{succ}}^{\text{oma}}) = N_p P_s = q \left( 1 - 1/N_p \right)^{q-1}
\]
For non-orthogonal random access, the number of non-orthogonal random access terminals with load $n$ is expected to be:

$$E(B_{\text{succ}}^{\text{non-orth}}) = q \left(1 - 1/N_p\right)^{q-1} \left(1 - P_f\right)$$

(4)

In which $P_f$ represents the failure probability of user pairing in the first step of non-orthogonal random access mechanism.

In the overlay multiple access mechanism, terminals may choose orthogonal multiple access or non-orthogonal multiple access randomly, and the expected number of access terminals is

$$E(B_{\text{succ}}^{\text{overlay}}) = \sum_{i=1}^{n_{\text{max}}} \sum_{p} q_i \left(1 - 1/N_{p}\right)^{q-1} \left(1 - P_{fi}\right)$$

(5)

The premise of formula (5) is

$$\sum_{i=1}^{n_{\text{max}}} \sum_{p} q_i N_{pi}$$

(6)

In which: $i$ represents the multiplexing load on the same resource multiplexed on PUSCH, that is, the number of multiplexed users, and the value range is $[1, n_{\text{max}}]$; $n_{\text{max}}$ is the maximum load of non-orthogonal access multiplexing, which is determined by the performance of SIC receiver. $i = 1$ represents orthogonal multiple access random access, and $i > 1$ represents non-orthogonal multiple access random access.

In the basic NOMA system model, the transmitter assumes that the number of access users is 2, and the allocated power $P_2$ of weak users is greater than the allocated power $P_1$ of strong users, and the user information modulation mode is QPSK modulation mode; In the downlink NOMA scheduling process, the base station equivalently processes the channel state information and power allocation information fed back by users, and then independently allocates MCS(Modulation and Coding Scheme) to different users in the subband. That is to say, in each iteration process, fix two of the three optimization variables and find the optimal value of the third parameter corresponding to the extreme point of the system function, so as to continuously reduce the weighted sum mean square error. The algorithm can converge to at least a local optimum with low complexity and high efficiency.

4. Simulation results

In this section, the improved power allocation algorithm is simulated and verified by MATLAB platform. Because NOMA is based on OFDMA system to realize multi-user superposition, NOMA system is closely related to OFDMA system, so we can use simulation parameters of OFDMA system [11] combined with NOMA power domain superposition principle to carry out NOMA simulation experiment.

Fig. 2 compares the cumulative distribution function curves of average capacity of far users under FTPA and improved power allocation strategy. First of all, we can see the performance advantages of NOMA over OMA access, which obviously improves the access capacity performance of far users.
Figure 2. Comparison of average capacity of distant users.

Fig. 3 is the error code curve of weak users. It can be seen from the figure that under the condition of small Signal-to-noise ratio (SNR), with the increase of power allocation ratio $\gamma$, the bit error rate of weak users gradually decreases. However, when SNR is large, especially when $\gamma > 5$, the bit error rate curve of weak users will produce a platform, which shows that the improvement of power allocation will no longer improve the reliability of the system. In order to continue to improve the system performance, it is necessary to start from other aspects, such as channel coding or changing the modulation mode.

Figure 3. Error code curves of weak users under different power allocation ratios.

In order to prove the effectiveness of the deep learning algorithm, this paper verifies the performance of the algorithm in two aspects. Firstly, the convergence of the algorithm is verified. Figure 4 shows the system and rate values under different iteration times, that is, the weighted values of all users are set to 1. It can be seen that only a dozen iterations are needed, and the sum rate value tends to be stable. Therefore, the deep learning algorithm can obtain stable system and rate performance with low complexity.
In this paper, sum rate is used to measure the performance of the system, and the weighted value of users in the proposed algorithm is set to 1, $\alpha_F = 0$ in FTPC algorithm, and the power of users in strong channel state and users in weak channel state under fixed grouping scheme is $(0.5P, 0.3P)$, where $P$ is the power constraint value of this group, and each group occupies the same power value, namely $P = P_{tot}/g$.

Fig. 5 shows the systems and rates corresponding to three power allocation algorithms under different total power constraints, in which each point in the figure is the average value obtained by random implementation of 1000 channels.

It can be seen from the figure that with the increase of the total power constraint, the sum rate of the three algorithms is increasing. Among them, the fixed power allocation algorithm only occupies a fixed power proportion according to the different channel gains, which has the lowest complexity and therefore the worst sum rate performance. However, FTPC's power allocation algorithm corresponds to the second lowest system and rate, and different users occupy a corresponding proportion of transmission power according to their specific channel gain, which increases the complexity and improves the performance. The algorithm proposed in this paper can converge to the local optimal value with fewer iterations, and this value can obtain better system and rate performance.

According to the basic characteristics of NOMA power domain superposition and SIC principle at the receiving end, with the increase of power factor, the power obtained by UE 1 increases, while the power of UE 2 decreases gradually, so the SINR of interference information UE 2 decreases during
CWIC interference cancellation at the receiving end of UE 1, which increases the difficulty of interference cancellation and causes the error code propagation to affect the decoding performance of UE 1. At the same time, with the increase of power factor, the power difference between users becomes smaller and the mutual interference between users becomes larger. However, since all users use QPSK, the modulation order is small. When SNR is large enough (15dB), the receiver can eliminate the influence of interference between users on the reception performance and ensure the reception performance.

![Figure 6. Throughput performance of each modulation scheme combination.](image)

Fig. 6 shows that with the increase of the modulation order of superimposed users, the SNR required for receiving increases. When the SNR reaches 22dB, the CWIC performance achieves the ideal interference cancellation performance.

5. Conclusion

In this paper, the error performance of NOMA communication system in power domain is analyzed and compared. Firstly, the optimal power ratio range is obtained through the basic NOMA system, and then the influence of channel coding on system performance is studied. Then, the problem of maximizing weighted sum rate is transformed into the problem of minimizing weighted sum mean square error by using deep learning algorithm. By updating each optimization parameter iteratively in turn, it converges to the local optimum of the objective function. This method can improve the weighting and rate performance of the system with fewer iterations. In the non-orthogonal random access mechanism, the method of power backoff is adopted to ensure that the base station receives multi-user superposition signals with different arrival powers. Simulation results show that, with the same access resources, the access quantity of overlay multiple access mechanism is higher than that of single multiple access random access mechanism.

Acknowledgements

This work was supported in part by the Natural Science Foundation of Guangxi Province under Grant 2020GXNSFBA297037, and in part by the Wuzhou University Key Scientific Research Project under Grant 2020b001.

References

[1] X. Jia, S. Ji, Q. Fan, et al. Research on backhaul scheme and performance of multi-layer full-duplex heterogeneous network based on non-orthogonal multiple access. Journal of Electronics and Information Technology, vol. 41, pp. 945-951, (2019).

[2] P. Sharma, P. Upadhyay, D. Costa, et al. Performance Analysis of Overlay Spectrum Sharing in Hybrid Satellite-Terrestrial Systems with Secondary Network Selection. IEEE Trans. Wireless Commun., vol. 16, pp. 6586-6601, (2017).
[3] M. Chen, H. Li, Y. Yang. A non-orthogonal multiuser detection method based on IDMA. Journal of Guangxi University: Natural Science Edition, vol. 42, pp. 2223-2229, (2017).

[4] T. Ding, Y. Liu, N. Zhang, et al. Hybrid multiple access random access in 5G large connection scenario. Journal of Beijing University of Posts and Telecommunications, vol. 41, pp. 1-6, (2018).

[5] M. Jelena, B. Vojislav, N. Khan. Sharing It My Way: Efficient M2M Access in LTE/LTE-A Networks. IEEE Trans. Veh. Technol., vol. 66, pp. 696-709, (2017).

[6] S. Wen. Non-orthogonal multiple access technology for 5G. University of Science and Technology, (2018).

[7] Y. Li, B. Li, M. Yang, et al. A spatial aggregation group multiple access protocol associated with multiple cells. Journal of Northwestern Polytechnical University, vol. 37, pp. 174-180, (2019).

[8] C. Jiang, Z. Wu. A new uplink non-orthogonal multiple access scheme based on low density superposition coding modulation. Journal of Beijing University of Posts and Telecommunications, vol. 41, pp. 14-19, (2018).

[9] A. Bastami, P. Kazemi. Cognitive Multi-Hop Multi-Branch Relaying: Spectrum Leasing and Optimal Power Allocation. IEEE Trans. Wireless Commun., vol. 18, pp. 4075-4088, (2019).

[10] M. Chen, J. Ding, Y. Yang. A non-orthogonal multiuser detection method under overload system. Journal of Southwest University (Natural Science Edition), vol. 40, pp. 140-145, (2018).

[11] M. Feng. Analysis of NOMA for 5G. China Science and Technology Investment, (2018).

[12] A. Alfitouri, K. Hamdi. Multiple-Access Capabilities of a Common Gateway. IEEE Trans. Veh. Technol., vol. 66, pp. 5148-5159, (2017).