Aerial Spectral Efficiency of Non Orthogonal Multiple Access (NOMA) for 5G Wireless Communications through Successive Interference Cancellation and Superposition Coding

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Abstract - *Non Orthogonal Multiple Access (NOMA) is a candidate multiple access technology for the Fifth Generation (5G) wireless communication systems. NOMA allows two different users to transmit signals over the same subcarrier and at the same time but with orthogonal phases to avoid interference. NOMA multiplexes multiple users on each subcarrier which achieves better performances on power efficiency and user fairness than conventional Orthogonal Multiple Access (OMA) schemes. In non-orthogonal access all the users are served at the same time, with same frequency and code. A pair of users can be served simultaneously I their corresponding channel gains are spatially different. NOMA exploits the Power Domain Multiplexing (PDM) to allocate less power to users with good channel conditions and requisite amount of power to users with slightly bad channel condition. Power spectral density enhancement uses techniques with efficient power allocation strategies. Although NOMA does not employ Multiple Input Multiple Output (MIMO) antenna systems, however NOMA with MIMO antenna systems proves to be game changing combination for spectral efficiency and capacity scaling. In this paper we have proposed a simulation environment to address the achievable spectral efficiency of NOMA through successive interference cancellation at the receivers and superposition coding at the transmitter side. We have also proposed various state of the art methods for efficient Bit Error Rate (BER) analysis, efficient power allocation and outage probability. All the simulation works have been carried out using Matlab 2016a through 5G communication toolbox.*

Key Words: Non Orthogonal Multiple Access (NOMA), Aerial Spectral Efficiency, Successive Interference Cancellation (SIC), Superposition Coding.

1. LITERATURE SURVEY

Towards the generation history of the cellular mobile communication technologies, different wireless communication schemes have been deployed from the first generation (1G) systems to the fourth generation (4G) systems. According to [1] and [2], these schemes are Frequency-Division Multiple Access (FDMA) for first generation, Time-Division Multiple Access (TDMA) & Code-Division Multiple Access (CDMA) for second generation (2G) [3], Code-Division Multiple Access (CDMA) for third generation (3G) and Orthogonal Frequency-Division Multiple Access (OFDMA) for fourth generation [4]. The currently adopted multiple access scheme for 4G communication systems is the orthogonal frequency-division multiple access (OFDMA). According to [5] [6], in OFDMA systems, a wideband signal has been divided into many narrowband subcarriers, and each user is assigned with an orthogonal subcarrier separated in frequency, and a base station can communicate with each user on the subcarriers associated to the users. Although 4G systems provide a higher achievable data rate than the previous generations, the high latency sometimes cannot satisfy the requirement of IoT. As the statistical researches from “Fierce Wireless” website show that the 4G LTE systems have the latencies about 75 milliseconds in 2015 [7]. As [8] mentioned, the IoT devices will not only be remotely controlled and managed by people, but can also communicate with each other. Therefore, some multimedia applications of IoT requires lower transmission latencies that at least less than the human visual delay constraint 10 milliseconds. 5G will provide a latency of 2 milliseconds, which can meet this requirement. As [9] [10] mentioned that 5G will play an important role in growing the Internet of things. Apart from the problem on latencies, OFDMA system also has problems on the user fairness. The conventional power allocation strategies such as water filling strategy cause distinct data rates for the users depending on their different channel conditions [11], [12]. As mentioned in [13] and [14], users with the best channel conditions are always selected to maximize the system throughput, and which makes the channel quality of users with poor channel conditions critical. Moreover, with the increasing amount of Internet traffic, 4G systems cannot meet the requirement of power efficiency, it costs too much power and wastes many resources as the orthogonal multiple access requires the individual user to use a single subcarrier. Consider these problems of 4G systems, it will be challenging to improve the cellular mobile communication on the upcoming 5G systems [15], [16]. The targeted requirements for the new generation are to develop a new wireless communication system to accommodate a large amount of Internet traffic and to achieve power efficiency and user fairness. A new appropriate scheme will be proposed to satisfy these requirements.

In this work, non-orthogonal multiple access (NOMA) will be presented as a promising candidate that might be used in the future 5G systems. There are some other potential candidates that have been proposed [17], such as Energy harvesting [18][19], massive MIMO [20][21], millimeter wave communications [22][23] and ultra-dense network [24][25].

2. INTRODUCTION

The NOMA scheme is different from the conventional orthogonal multiple access (OMA). The basic concepts and the applications of NOMA are studied in [26]. According to [27] users are divided into some groups, each group is assigned with an orthogonal subcarrier. The users in each group are allocated with different power depending on their channel conditions in order to reach the perfect balance between system throughput and user fairness. Multiple users in one subcarrier are served by one base station in the same time slot, at the same frequency and code channel. The users with different channel conditions have different ways of decoding their messages. For the users with better channel conditions, they will decode the poorer channel users' messages first, and then employ the successive interference cancellation (SIC) to get their own messages by removing others' information. On the other hand, users with poorer channel condition are unable to employ SIC, and they can treat other users' messages as noise to get their own.

3. SYSTEM MODEL

Based on the proposed schemes, a system model is shown in Figure 1. To elaborate how the NOMA users receiving and decoding messages. Assume that user m and user n are assigned in one subcarrier. When receiving messages at the same time, both of users should receive a combined signal that have both users' messages inside. User n is closer to the base station, and its channel condition is better than user m, so it employs successive interference cancellation (SIC) to cancel the user m's signal and decode its own messages. User m is farther from the base station, and it is allocated with more power than user n. With a poor channel condition, user m is unable to employ SIC, so it decodes its own messages by treating the signal of user n as noise.

As an improved system for 4G, 5G should have a better performance. The simulation results will demonstrate the performance comparison between NOMA and conventional OMA. We choose one of the proposed schemes for both NOMA and OMA. For OMA, we use TDMA scheme that users share the subcarrier, but they can only communicate at different time periods. But for NOMA, users can receive messages at the same time with different decoding methods.

Recall from the proposed schemes:

- Random user pairing with targeted data rates.
- User pairing with targeted data rates depending on channel conditions.
- User pairing with targeted data rates depending on channel conditions and privileges.

The three designed schemes are based on target data rates, so the comparison of their performances can be analyzed by keeping target data rate as a constant value. However, the performances with different pairing orders and different allocated power to users are distinct.

For different pairing orders, depending on the pairing criteria, users with high priority are supposed to pair with users with low priority in the case when the pairing criterion is only the channel condition according to the literature review. So some of the methods for pairing orders are analyzed for comparison with the traditional way (pairing the highest priority user with the lowest priority user). Particularly, the other pairing orders can be stated as following:

- Highest priority user with 2nd highest priority user
- Lowest priority user with 2nd lowest priority user
- 2nd highest priority user with 2nd lowest priority user
- The two users in the middle of priority order

For different power allocation, similar to the pairing orders. According to [28], the user with poorer channel condition is supposed to be allocated with more power. In this design, some more power allocation methods are developed for the performance comparison. These methods are shown as following:

- Equal power allocation for both users.
- Allocating 1/3 power to the user with high priority and 2/3 power to the user with low priority.
- Allocating 1/4 power to the user with high priority and 3/4 power to the user with low priority.
- Allocating 1/5 power to the user with high priority and 4/5 power to the user with low priority.

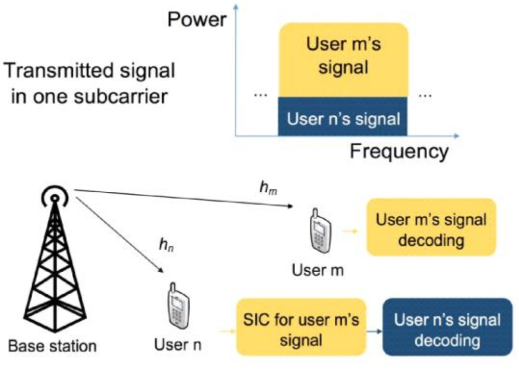

Figure 1: The system model of user pairing for NOMA System

The throughput for NOMA scheme can be considered as the achievable data rate for each user in one subcarrier. The data rates for NOMA users are calculated in different ways. Take the user pairing as an example, for two downlink users in the single subcarrier, depending on the channel conditions, the user M is pairing with user N, where N has a better channel condition than M. Then M can treat user N's messages as noise. According to [29], the data rate for user M can be represented as following:

$$R_m = log_2\left(1 + \frac{a_m^2|h_m|^2}{|h_m|^2 a_n^2 + \frac{1}{\rho}}\right) \qquad (1)$$

In the above equation, *h*⍰⍰ and *h*⍰⍰ are the channel gain for user M and user N, where |*h*⍰⍰|² ≤ |*h*⍰⍰|². Also ⍰⍰⍰⍰ and ⍰⍰⍰⍰ are the power allocation coefficients for the two users. Normally, ⍰⍰⍰⍰ ≥ ⍰⍰⍰⍰ since the user with poorer channel condition is usually allocated with more power for user fairness. Constant ρ denotes the transmit signal to noise power ratio (SNR).

The other user N will decode M's information and remove them by SIC. The data rate is calculated differently:

$$R_n = log_2(1 + \rho a_n^2|h|^2) \qquad (2)$$

The performance of NOMA system can be indicated by the outage probability [30]; the outage probability is defined as the probability that user's achieved data rate has not reached the targeted data rate required from the users' Quality of Service (QoS). Statistically, shown as P (⍰⍰⍰⍰ < ⍰⍰⍰⍰), which is a probability formula where P denotes the probability, ⍰⍰⍰⍰ is the achievable user data rate, and ⍰⍰⍰⍰ is the targeted data rate.

There are some benefits for NOMA system compared with conventional OMA system, they are displayed as following [30]:

- High achievable data rate
- Large capacity
- Energy efficiency
- User fairness

There are some existing designs employing NOMA system. One of the schemes in [29] it stated is the impact of user pairing with fixed power allocation (F-NOMA). In this situation, the total transmit power is a fixed number. The scheme pairs the users with the best channel condition with the users with the worst channel condition. The results from the paper show that this scheme has a higher throughput compared with the conventional OMA. Also, this difference will become larger when the gap between the channel gains of the paired users is increasing. Another scheme from [30] represents a randomly deployed method for NOMA users with targeted data rate. The simulations and analytical results show that the randomly deployed users can achieve a lower outage probability than the conventional OMA under well-chosen values of targeted data rate and allocated power.

4. RESULTS

The performance comparison for different communication systems is shown in Figure 1.

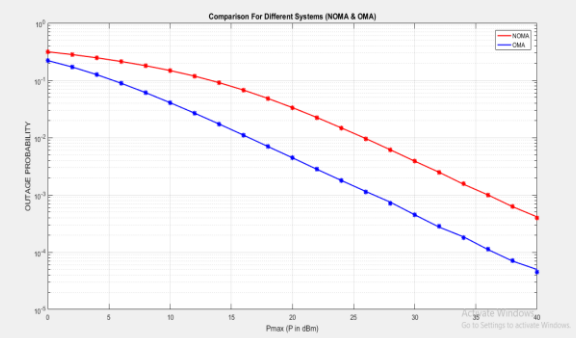

Figure 1. Simulation graph for different systems (OMA & NOMA).

In this simulation, the path loss realization and multipath realizations are set to be 100 and 10000 correspondingly. For NOMA, the priority for user pairing is channel gain over weight, and the paired users have the largest priority and lowest priority in equal power allocation. For OMA, only one user is chosen in single subcarrier, and the outage probability calculation is the figure1 above.

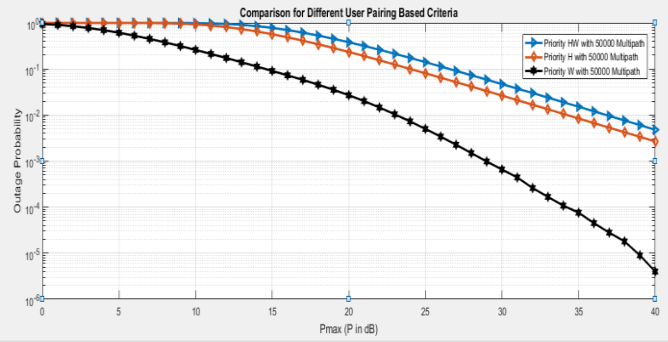

Figure 1: Simulation graph of user pairing based on different criteria.

For this case of simulation, the path loss realization and multipath realizations are set to be 100 and 50000 correspondingly. The selected users are two users with the largest priority and lowest priority. Each user is allocated with equal power. The curves in Figure 2 show that user pairing based on channel conditions has the highest sum rate, and the random pairing has the lowest sum rate among the three curves. It is shown by the outage probability on the same power domain 18 dBm. The lowest outage probability means the best performance. On the same outage probability level, pairing based on channel condition and weights costs a bit more power than the one based on channel condition only. However, as the design section stated, the weights are suggested to be considered as another pairing criterion in practice even though it may cost more power than the existing one. The performances can be different if selecting different users based on the values of their priority. Two schemes on the pairing orders have been proposed in Table 1.

Schemes	Description
Proposed scheme 1	Largest priority user pairing with lowest priority user
Proposed scheme 2	Largest priority user pairing with 2nd largest priority user
Baseline 1	Pairing two users in the middle of priority order
Baseline 2	Lowest priority user pairing with 2nd lowest priority user

Table 1. Different schemes in Figure 1.

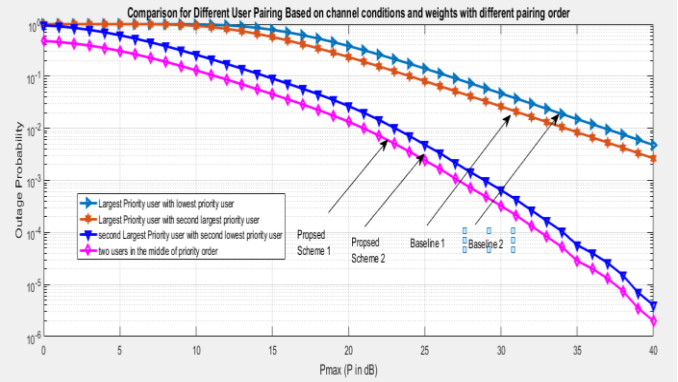

Figure 3: Simulation graph for user pairing with different pairing orders.

Figure 3 shows the simulation results. The path loss realization and multipath realizations are set to be 100 and 10000 correspondingly, and the pairing priority is channel gain over weight. The performance of proposed scheme 1 for user pairing is the best, and the curve coincides with the proposed scheme 2 for the pairing for largest priority user and 2nd largest priority user. Actually, if the largest priority user is chosen, the outage probability will not change too much for which user is selected to pair with it. In other word, the total sum rate mainly depends on the users with good channel conditions (the higher channel gain can achieve higher sum rate), but changes slightly when the other user is selected differently. In the simulation, both of these pairing orders can be applied because they have the similar performances, and only two users are considered each time. While in the reality, these two orders are different because any of the other 8 users should not be ignored.

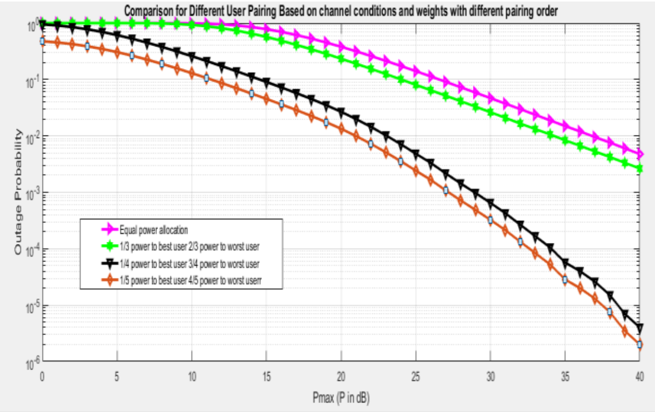

Figure 7: Simulations for per user pairing with different power allocations

The path loss realization and the multipath realizations are set to be 100 and 1000 correspondingly, and the pairing criterion is channel gain. In Figure 4, the performances for different power allocations are very similar, which means the total sum rates will be the same no matter what power allocation is used in this case. When the total allocated power is a constant value, the total sum rate will not change much if the power allocated to the user with better channel condition is less than or equal to the user with poorer channel condition. However, the users in the same subcarrier will have different data rates if the power allocations are different. Different power allocations are applied depending on the users' requirements.

5. CONCLUSION

In conclusion, the simulation results show that the user pairing based on channel conditions can achieve a higher sum rate as well as a larger capacity than conventional OMA. In other word, this design scheme can accommodate much more users to meet the huge demand of internet traffic for the following years, and it also saves more power than the conventional OMA when the required data rates are same. 3 proposed NOMA schemes based on user pairing have been studied as well, and their performances are shown in the simulation. The scheme of pairing the users with the best and the worst channel conditions achieves the best performance among the 3 proposed schemes and its performance has been verification via analytical results. Although the scheme of considering social weights achieves a bit lower sum rate than the method of user pairing based on users' channel conditions, considering users' importance in the society is the feature of this design, which makes NOMA system more realistic.

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