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ORIGINAL ARTICLE

A Computational Power Allocation Scheme for Fair NOMA Downlink System

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ABSTRACT

Representing the next generation wireless network, non-orthogonal multiple access (NOMA) has become crucial multiple accessing techniques in recent times. In this article, the core issue of NOMA system, allocating power to multiple users has been addressed. In NOMA, the increment in the power of one user increases the interference of other users because all the users utilize the same frequency band but distinguish by their power level. To cancel the signals of other users at reception, users must perform successive interference cancellation (SIC) by handling other users' signals as noise and finally decode its own signal. Incompetent power allocation could upturn the interference greatly, which decreases the data rate and user fairness, the result is degradation of the system capacity and unfair user data rate. Simulation results showed that power allocation of each user has a great impact on other users' data rate and total system capacity. In this article computational approach has been used to propose an optimum power allocation scheme for multiuser NOMA that valuable for optimizing the power and user fairness along with ergodic sum capacity of the system. We further compute the fairness index, the data rate of individual users and the entire system. Numerical finding and simulation results show that the suggested approach will be essential in power allocation.

Keywords: Optimum power allocation, Successive interference cancellation (SIC), Non-orthogonal multiple access (NOMA), Power division multiple access (PDMA), Computation and mathematical model.

Author`s Contribution	Address of Correspondence	Article info.
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***Cite this article:** Hussain M, Rasheed H. A Computational Power Allocation Scheme for Fair NOMA Downlink System J. Inf. commun. technol. robot. appl.2018; 9(1):73-79.*

***Funding Source:** Nil*
***Conflict of Interest:** Nil*

INTRODUCTION

With the speedy development of the Internet of things and intelligent terminals (intelligent terminals include memory and a processor), the number of devices upheld by the next generation network (NGN) will be exponentially increased, compared with the current generation network, it will grow 100 times. Next generation network expected to be competent of handling greater network efficiency and high data rates. NGN will propose adaptable and scalable services, it guarantees a faster, smarter and efficient network. The next generation networks will be skilled in managing 10 times more simultaneous connections. It will offer remote access to many real-time services and ultra-high definition multimedia experience. The next/future generation network, in the emergency conditions, any user is generally able to get more data rate as it allows in a normal condition such as emergency vehicles, high definition medical image transmission services and other special needs of users. One of the examples is Wireless Phone Emergency Response (WIPER) system, an emergency response management tool at this time under development will emerge very soon. [1-2].

However, as wireless networks carry on improving our lives, it is truly restricted by limited network resources, in terms of frequency, time and power. It is of great importance to distribute resources smartly to improve the performance of wireless networks. As the next generation network need to improve the resources to fulfill the requirement of large users, large scale, large business volume, high traffic, and other innovative technology. To attain effective allocation with limited network resources and, to fulfill the demands in communication networks, optimization models and techniques are often used. The goal of optimization is to maximize resources. In resources, allocation maximizes multiple users, cognitive users, cooperatives node, data rate, channel reuse, etc. Whereas constraints could be power, capacity, cooperative users, subcarrier and spectrum [3].

Recently, a new promising technique non-orthogonal multiple access has also been accepted by means of capable contender not only for the next generation but also beyond next-generation cellular networks. In comparison with traditional orthogonal multiple access technique (OMA), where every single user is served by the dedicated allocation of the frequency band, NOMA offered to every user, utilized entire bandwidth. The key idea is at the cost of marginal inter-user interference (IUI), NOMA utilizes the same radio resources for simultaneously serving the multiple users, it also permits setting up more users than the vacant resources. In the NOMA system, the information signals of different users with dissimilar power are superposed by taking advantage of their different corresponding channel gain. For multi-user detection and decoding, successive interference cancellation (SIC) is utilized by the receiver. For NOMA downlink, the information signals of different users are transmitted with dissimilar power levels which are allocated by BS in such a way that multiple users utilize the same radio resources. Every user equipment (UE) utilizes SIC and detects its preferred signal after multiple iterations by utilizing the power differences. However in uplink, before detecting the information signals of weak users with less power the BS continuously detect and subtract the information signals of users with greater power [4-5].

Because of the lack of a central processing unit and restricted processing capacity of mobile users, interference cancellation schemes and the realization of suitable multiuser detection, the downlink is more challenging than uplink in NOMA. In the downlink, the intra-cluster interference is effecting strong users than weak users. In the uplink, however, intra-cluster interference is effecting more likely to be effecting weak users than strong users.

A technique known as Fair-NOMA is planned for multiple user's fairness for upcoming wireless mobile networks. In Fair-NOMA, users will all the time be confirmed to manage a minimum capacity as much as OMA. To take the user's fairness into consideration is the key feather of NOMA system. In order to reorganize an improved tradeoff, concerning user fairness and system throughput, NOMA allotted greater power to users using inferior channel conditions to those using good channel conditions, as compared to the conventional water-Filling power allocation. Consequently, all users utilize the same spreading code, frequency, and time slot that guarantees an improved spectral efficiency. In this article proposed a model for improvement in user fairness with capacity for NOMA by using optimum power allocation [6].

The rest of the article is organized as follows as; the proposed scheme with detail information is provided in Section 2. The performance comparisons and results of the proposed schemes are specified in section 3. As a final point, Section 4 concludes the article and presents some guidelines for upcoming research.

SYSTEM MODEL

In NOMA the entire transmit power is split up into multiple power subdivisions, just like the sub-bands/time-slots in FDMA/TDMA. Let a group of k^{th} users/user equipment's (UEs) are located under the same base station (BS) [7]. Each user utilizes a fraction of total power P. Power allocated to the kth user by BS is $\alpha_k P = P_k$.

Where $\alpha_1 + \alpha_2 + \alpha_3 \cdots \alpha_k = 1$. A typical NOMA system model is shown in Fig 1.

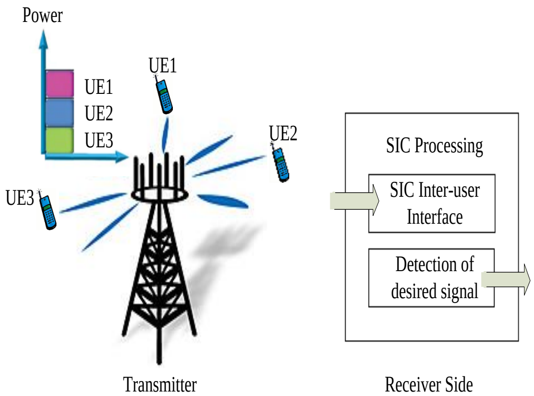

Fig. 1 System model of NOMA with SIC

- **NOMA downlink**

In NOMA downlink, less power is allotted to the user/user equipment (UE) which is closest to the BS and highest power is allotted to UEs which are located at largest distant from the BS. First, each UE work out for the strongest signal to decode it, and after that subtracts the strongest make out signal from the actual signal received at the receiver. Until the SIC receiver finds its own signal, it iterates the subtraction continuously [8] as illustrated in Fig 2.

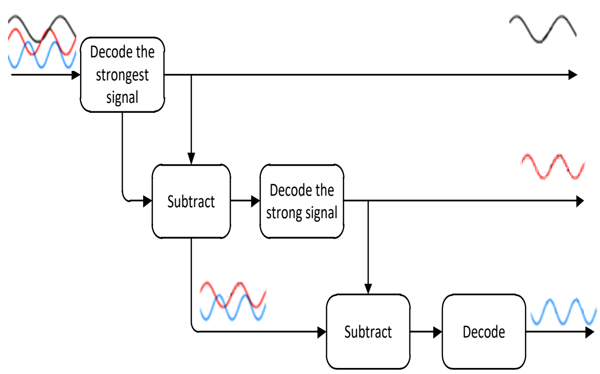

Fig. 2 Successful Interference Cancellation

The UE placed nearby to the BS subtracts the signals of other UEs, located at a distant from the BS. Meanwhile, the signal of the farthest UE will decode its own signal first because it contributes the most to the received signal [8] as shown in Fig 3.

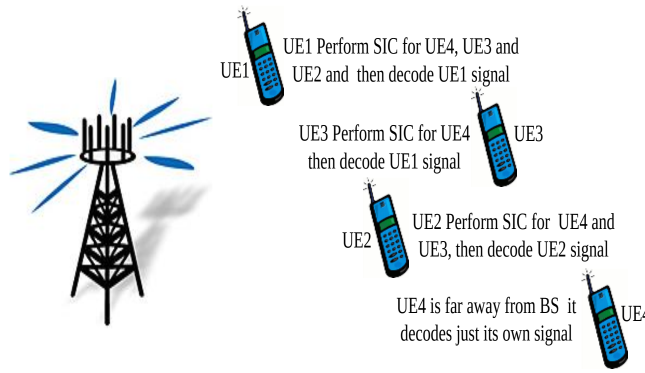

Fig. 3 NOMA downlink

Assuming perfect successive interference cancellation for the most nearby user, UE1, the signal is decoded in last, will be its own signal, the SNR for UE1 can be written as;

$$SNR_1 = \frac{P_1|h_1^2|}{N}$$

Where $|h_k|$ is the channel attenuation factor for the link between the BS and UE_k, N_o is the noise density *(W/Hz)*, W is the bandwidth, P_k is power allocated to UE_k, $N = N_o W$ and $K = 1,2,3 \cdots k$ Similarly, SNR for UE_2 can be written as;

$$SNR_2 = \frac{P_2|h_2^2|}{P_1|h_2^2| + N}$$

SNR for UE_k which is located far away from BS, the signal SIC receiver decodes it initially will be its required signal because it is allotted the greatest power in comparison of others. Other user's signal will be considered as interference. SNR for the k_{th} user can be written as;

$$SNR_k = \frac{P_k|h_k^2|}{\sum_{i=1}^{K-1} P_i|h_k^2| + N} \qquad (1)$$

The throughput (bps) for the k_{th} user at downlink can be written as;

$$R_k = W \log_2\left(1 + \frac{P_k|h_k^2|}{\sum_{i=1}^{K-1} P_i|h_k^2| + N}\right) \qquad (2)$$

Total downlink system capacity for k number of users can be written as;

$$R_T = W \sum_{k=1}^{K} \log_2\left(1 + \frac{P_k|h_k^2|}{\sum_{i=1}^{K-1} P_i|h_k^2| + N}\right) \qquad (3)$$

Here, least power allocated to the closest user and highest power allocated to the user which is located at the largest distance from BS [9].

- **Optimum Power Allocation for fair NOMA**

Power allocation is needed for all practical NOMA systems. Optimum power allocation is possible when all UEs are received its signal with the same signal-to-noise ratio (SNR). Otherwise, a UE with a less SNR leads the BER of the system. When SIC is utilized, it is also required that each UE experiences the similar SNR at the stage of decoding. On the other hand, interference is being canceled out at the receiver such as the closest UE has to cancel the most interference and the farthest UE the least. To achieve fair data rate for all users;

$$SNR_1 = SNR_2 = SNR_3 = \cdots = SNR_k$$

$$SNR_1 = SNR_2$$

$$\frac{P_1|h_1^2|}{N} = \frac{P_2|h_2^2|}{P_1|h_2^2|+N}$$

$$P_2 = \frac{P_1|h_1^2|}{|h_2^2|}\left(\frac{P_1|h_2^2|+N}{N}\right)$$

$$SNR_2 = SNR_3$$

$$\frac{P_2|h_2^2|}{P_1|h_2^2|+N} = \frac{P_3|h_3^2|}{P_1|h_3^2|+P_2|h_3^2|+N}$$

$$P_3 = \frac{P_2|h_2^2|}{|h_3^2|}\left(\frac{P_1|h_3^2|+P_2|h_3^2|+N}{P_1|h_2^2|+N}\right)$$

$$SNR_3 = SNR_4$$

$$\frac{P_3|h_3^2|}{P_1|h_3^2|+P_2|h_3^2|+N} = \frac{P_4|h_4^2|}{P_1|h_4^2|+P_2|h_4^2|+P_3|h_4^2|+N}$$

$$P_4 = \frac{P_3|h_3^2|}{|h_4^2|}\left(\frac{P_1|h_4^2|+P_2|h_4^2|+P_3|h_4^2|+N}{P_1|h_3^2|+P_2|h_3^2|+N}\right)$$

Power allocation for the k_{th} user;

$$P_k = \frac{P_{k-1}|h_{k-1}^2|}{|h_k^2|}\left(\frac{\sum_{i=1}^{K-1}P_i|h_k^2|+N}{\sum_{i=1}^{K-2}P_i|h_{k-1}^2|+N}\right) \quad (4)$$

The fraction of total power allocation can be written as;

$$P_{k(frac)} = \frac{P_k}{\sum_{k=1}^{K}P_k}$$

$$P_{k(frac)} = \frac{P_{k-1}|h_{k-1}^2|}{\sum_{k=1}^{K}P_k|h_k^2|}\left(\frac{\sum_{i=1}^{K-1}P_i|h_k^2|+N}{\sum_{i=1}^{K-2}P_i|h_{k-1}^2|+N}\right) \quad (5)$$

Where;

$$\sum_{k=1}^{K}P_{k(frac)} = 1$$

- **User fairness in NOMA**

Fairness index is used in wireless communication to confirm whether users are getting a fair share of system resources. Considering one of the most important resources, user data rate, multiuser NOMA downlink system required a fair access scheme. In NOMA the furthest user from BS always has low data rate. It performs less SIC iteration because its own signal is much stronger than most of the other signals. On the other hand, the closest user performs most SIC iteration and subtract all strong use' signals to decode its own signal [10]. Fairness index is define as;

$$F = \frac{\left(\sum_{k=1}^{K}R_k\right)^2}{K\sum_{k=1}^{K}R_k^2}$$

$$F = \frac{\left(W\sum_{k=1}^{K}\log_2\left(1+\frac{P_k|h_k^2|}{\sum_{i=1}^{K-1}P_i|h_k^2|+N}\right)\right)^2}{K\sum_{k=1}^{K}\left(W\log_2\left(1+\frac{P_k|h_k^2|}{\sum_{i=1}^{K-1}P_i|h_k^2|+N}\right)\right)^2} \quad (6)$$

To get the capacity for each UE becomes similar to each other, F should get close to 1.

RESULTS AND DISCUSSION

In NOMA downlink individual allocated power greatly effect the performance of the whole system. Power increase of one user produces more interference for other users. Fig 4 illustrated the effect of power allocation of User 1 on system capacity and other users' data rate. Similarly Fig 5, Fig 6 and Fig 7 are shown the effect of power allocation of User 2, User 3 and User 4, respectively. Optimum power allocation for fair NOMA is shown in Fig 8. It is observed that the power of the nearest user should be as low as possible if not, the farthest user needs much more energy to keep the fairness index close to unity, which is challenging. If increasing the power of the nearest user by 1watt causes a 35watt increment in the power of the farther user, and

2watt causes 175watt increment, in order to maintain user fairness as shown in Fig 8. The optimum fraction of power allocation with different power level {1-3watt} of the nearest user is shown in Fig 9. In Fig 10 individual user data rate clarified that optimum power allocation offer fair data rate among the users. Variation in user data rate is minimum and fairness index close to unity when optimum power allocation is utilized. Also, other power allocation schemes are shown in Fig 10. NOMA has better capacity in contrast to traditional OFDMA because in NOMA each user utilizes complete bandwidth of the system. NOMA capacity does not increase linearly with a number of users because each new user has to face interference of already existing users. Fig 11 illustrated the total system capacity vs a number of users with different power scheme. If a number of users are more than three, system capacity is not effected by optimum power allocation.

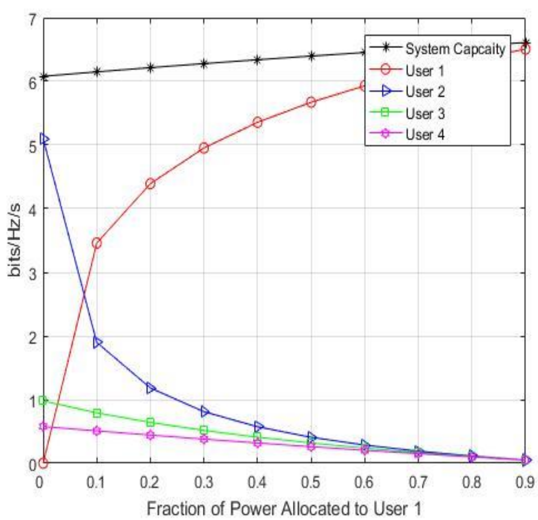

Fig. 4 Effect of power allocation of User-1 on system capacity and other users

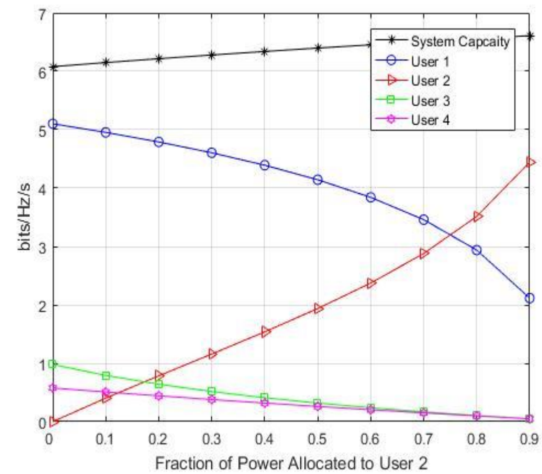

Fig. 5 Effect of power allocation of User-2 on system capacity and other users

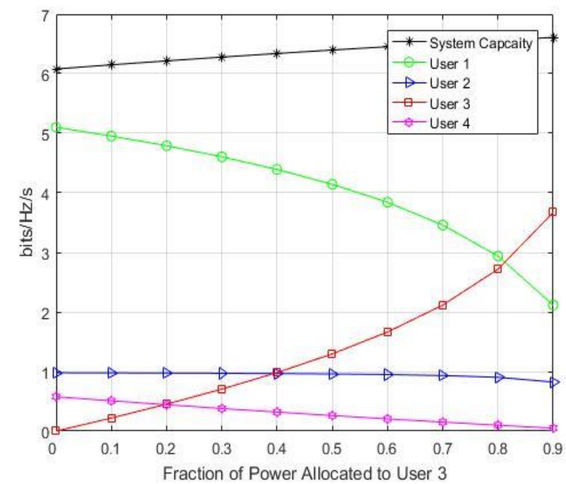

Fig. 6 Effect of power allocation of User-3 on system capacity and other users

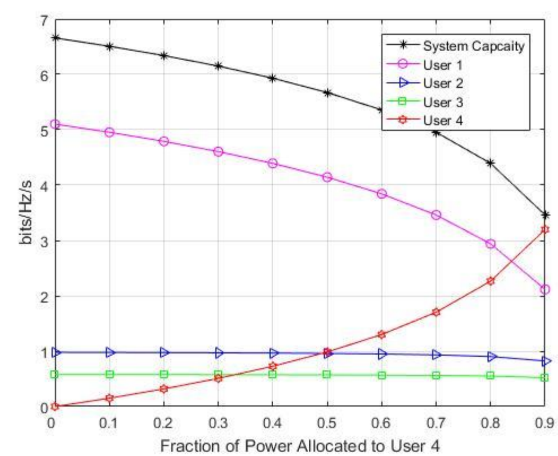

Fig. 7 Effect of power allocation of User-4 on system capacity and other users

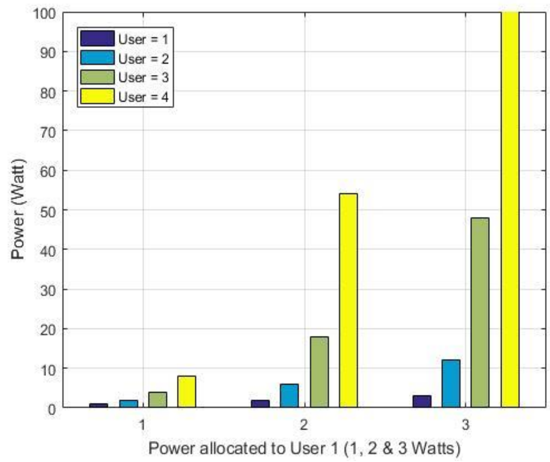

Fig. 8 Optimum power allocation

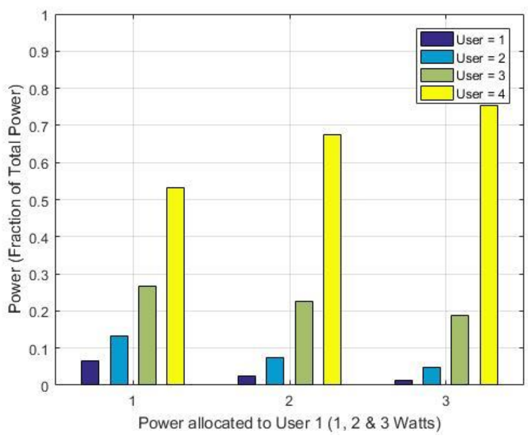

Fig. 9 Optimum fraction power

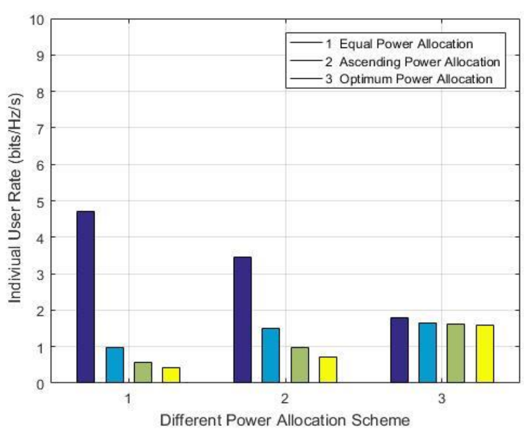

Fig. 10 User fairness

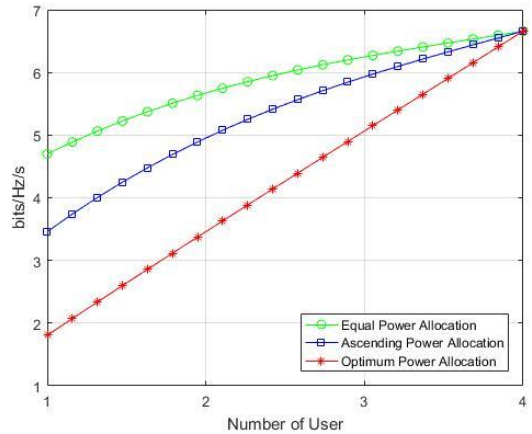

Fig. 11 Total system capacity vs number of users

CONCLUSION

In this article, the fundamentals of power allocation for NOMA downlink system and its effect have been discussed, in terms of data rate, system capacity and effect of individual power allocation on the total system capacity and other users. An optimum power allocation scheme has been proposed to avoid unfair user data rate which degraded the performance of NOMA system. We provided mathematical justification for optimal power allocation scheme and derived a closed form expression. Our computational approach and its simulation results validated our claims which will be significant in power allocating for next-generation wireless communication. For future work, with mathematical modification, the proposed scheme can be formulated for NOMA uplink system or some other power-based multiple access schemes like code division multiple access schemes.

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