

## The impact of user mobility into non-orthogonal multiple access (NOMA) transmission systems

Antonino Masaracchia<sup>1,\*</sup>, Van-Long Nguyen<sup>2</sup>, Minh T. Nguyen<sup>3</sup>

<sup>1</sup>Queens University Belfast, Belfast BT7 1NN, UK

<sup>2</sup>Graduate School, Duy Tan University, Da Nang, 550000, Vietnam

<sup>3</sup>Thai Nguyen University of Technology, Thai Nguyen 24000, Vietnam

### Abstract

Non-orthogonal multiple access techniques (NOMA) have been recognized as a paradigm shift for the design of multiple access techniques for the next generation of wireless networks. Many existing works on NOMA have focused on scenarios with low-mobility users (static), where users with different channel conditions or quality of service (QoS) requirements are grouped together for the implementation of NOMA. However, when increased, user mobility can strongly impacts on the performance of a NOMA systems, especially in the context of downlink perceived throughput, network fairness and QoS fulfilment of each users. This paper presents some of the main drawback which can be obtained if the user mobility is not taken into account in the design of NOMA communication systems. Future direction and challenges to address these issues are also discussed.

Received on 02 October 2020; accepted on 16 October 2020; published on 21 October 2020

**Keywords:** downlink throughput, network fairness, NOMA, power allocation, user aggregation, user mobility

Copyright © 2020 Antonino Masaracchia *et al.*, licensed to EAI. This is an open access article distributed under the terms of the Creative Commons Attribution license (<http://creativecommons.org/licenses/by/3.0/>), which permits unlimited use, distribution and reproduction in any medium so long as the original work is properly cited.

doi:10.4108/eai.21-10-2020.166669

### 1. Introduction

In accordance with Cisco forecast, during the last few years has been outlined how the standardization process of the 5G wireless communications and beyond must be performed by considering the tremendous surge of mobile data traffic for the upcoming years [1]. For example, it is envisioned that 5G will provide a 15 times increase in spectral efficiency compared to 4G [2]. In order to meet these requirements, the design of a suitable radio access technology (RAT) represents an important aspect for improving the performance of a cellular mobile communication system in a cost-effective manner.

Power-domain non-orthogonal multiple access (PD-NOMA) technology offers a number of advantages which permit to label it as a promising multiple access scheme for future RAT [3–5], gaining a great attention from both academia research and industry.

By using superposition coding (SC) multiplexing at transmitter and successive interference cancellation (SIC) at receiver, the PD-NOMA paradigm permits to serve multiple users in the same resource block (RB) multiplexing them within the power domain. More in details, a transmitter which serves a set of  $N$  users within its coverage area, transmit a linear superposition of  $N$  users' data by allocating a fraction  $\beta_i$  of the total available power  $P$  to each user, i.e., the power allocated for the  $i_{th}$  user is  $P_i = \beta_i P$  with  $\sum_{i=1}^N \beta_i = 1$ . Then, each user is able to decode its own data by deleting the interfering users' signals through the SIC principle [6].

Since the power allocated to each user strongly depends on their channel conditions, power allocation strategies play a crucial role in PD-NOMA communication systems. Indeed, based on users' channel conditions, the transmitter needs to carefully choose the proper amount of power which should be assigned to each user in order to satisfy network service requirements, i.e., Quality-of-Service (QoS), user-perceived data throughput and maximum throughput. Under this perspective, several studies have been carried out in order to propose power allocation schemes aimed to

\*Corresponding author. Email: [A.Masaracchia@qub.ac.uk](mailto:A.Masaracchia@qub.ac.uk)  
Antonino Masaracchia is with the School of Electronics, Electrical Engineering and Computer Science, Queens University Belfast, Belfast BT3 9DT, U.K

optimize some network metrics, either for terrestrial base station (BS) or unmanned aerial vehicle (UAV) communication [7–16].

On the other hand, has been recently outlined how the user aggregation process and user to sub-band pairing represent another important aspects for improving the performance of NOMA communication systems [17–20]. In particular, has been illustrated how, respect to the conventional orthogonal multiple access (OMA) systems, the performances of a fixed power allocation NOMA (F-NOMA) can be further enlarged by multiplexing users carefully, accordingly to their channel condition.

However, as far as the authors are aware, most of the works about power allocation NOMA do not take into account the mobility of users and its impact for channel condition. Indeed, due to the nature of mobile wireless communications, mobility needs to be considered for practical applications of NOMA. The initial power allocation may not satisfy SIC and/or outage probability constraints. Furthermore, as each user may have different channel gain at the new position, the initial power allocation may not achieve the best network performance. Therefore, dynamic power allocation (DPA) policies result essential to serve moving users.

Under this perspectives, this paper presents an overview about the importance of considering the user mobility in designing power allocation strategies and user aggregation policies for NOMA communication systems. In particular it is highlighted how the adoption of static power allocation (SPA) can negatively affect the network performance.

The rest of the paper is organized as follow. The system model considered to analyse the effect of user mobility is presented in Section 2. The results from simulation are presented and discussed in Section 3. Finally, conclusion and future directions are provided in Section 4.

## 2. System Model

As illustrated in Fig. 1, let us suppose to have a set of  $N$  users, randomly distributed into a circular area of radius  $R$  according to a Poisson point process (PPP) and served by a BS which is placed at the center of the cell and performs NOMA transmissions with a maximum transmitting power  $P_{max}$ . It is supposed that the total bandwidth  $B$  is equally divided into  $\frac{N}{2}$  slot each of them used to multiplex one cell-centre user (best channel condition) with one cell-edge user (worst channel condition) with a maximum transmitting power  $P = \frac{2P_{max}}{N}$ . In particular, indicating with  $g_i$  the channel gain of user  $i$ , it is multiplexed with the user  $j$  if their

channel gain ratio respects the following condition:

$$0.4 \leq \frac{g_i}{g_j} \leq 0.5 \quad (1)$$

This condition, as illustrated in [19], guarantees

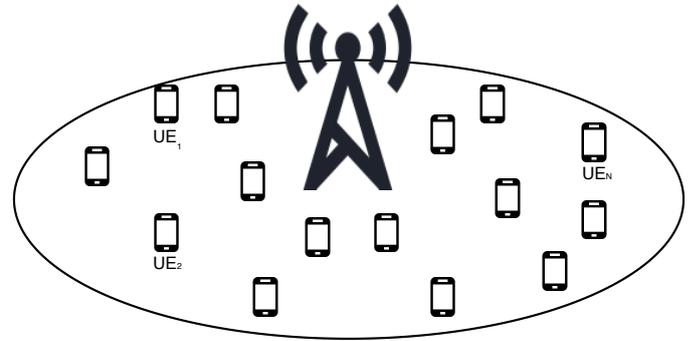


Figure 1. System model.

the minimum power requirements at the transmitter to maintain the minimum quality-of-service (QoS) requirements  $R_{th}$  to each user multiplexed within the same RB. Then, according with the SC multiplexing principle, the signal received by user  $i$  along the sub-band  $j$  can be expresses as:

$$y_{i,j} = h_i \times \sum_{k=1}^2 \sqrt{P_k} s_k + \omega_j; \quad (2)$$

where  $h_i$  represents the channel coefficient of user  $i$ ,  $P_k = \beta_k \frac{2P_{max}}{N}$  is the amount of transmitting power allocated to user  $k$ ,  $s_k$  with  $\|s_k\|^2 = 1$  is the signal transmitted to user  $k$  and  $\omega_j$  is the received noise.

Regarding the channel coefficient  $h_k$ , it is modelled as  $h_k = d_k^{-\alpha/2} \times \delta$ , where  $d_k$  represents the distance between user  $k$  and the transmitter,  $\delta$  is the complex Gaussian channel gain with distribution  $\mathcal{CN}(0, \sigma_{ch})$  and  $\alpha$  is the path loss exponent. The noise power at the receivers in the whole bandwidth is  $N_0 = 290 \cdot k_B \cdot B \cdot NF$ , where  $k_B$  and  $NF$  are the Boltzmann constant and noise figure at 9 dB, respectively. Then the noise power along each sub-band is  $N_B = \frac{2N_0}{N}$ .

According with (2) and with the SIC principle, supposing that along each sub-band channel gains are ordered in a descending manner, i.e.,  $|h_1|^2 \geq |h_2|^2$ , the signal-to-noise ratio (SINR) at each user can be expressed as:

$$\gamma_{1,j} = \frac{|h_1|^2 P_1}{N_B}; \quad (3)$$

and

$$\gamma_{2,j} = \frac{|h_2|^2 P_2}{N_B + |h_2|^2 P_1}. \quad (4)$$

Then, the achievable rate for each user is:

$$R_{1,j} = B_j \cdot \log_2 \left( 1 + \frac{|h_1|^2 P_1}{N_B} \right); \quad (5)$$

and

$$R_{2,j} = B_j \cdot \log_2 \left( 1 + \frac{|h_2|^2 P_2}{N_B + |h_2|^2 P_1} \right). \quad (6)$$

At that point, supposing that both users have the same QoS requirements, i.e.,  $R_{k,j} \geq R_{th}$ ,  $k = 1, 2$ , the minimum amount of power required to transmit data to each user within the same sub-band will be:

$$P_{1,j} \geq \frac{A \cdot N_B}{|h_1|^2} \quad (7)$$

and

$$P_{2,j} \geq P_{1,j} \left( A + \frac{|h_1|^2}{|h_2|^2} \right). \quad (8)$$

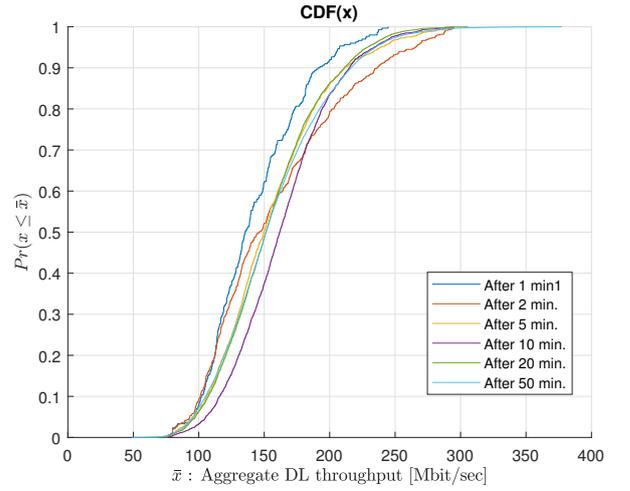
We suppose that SPA policy is adopted. This means that the amount of power of each user within the same RB are allocated according with (7)-(8) and are not changed for the all duration of the simulation.

### 3. Discussion

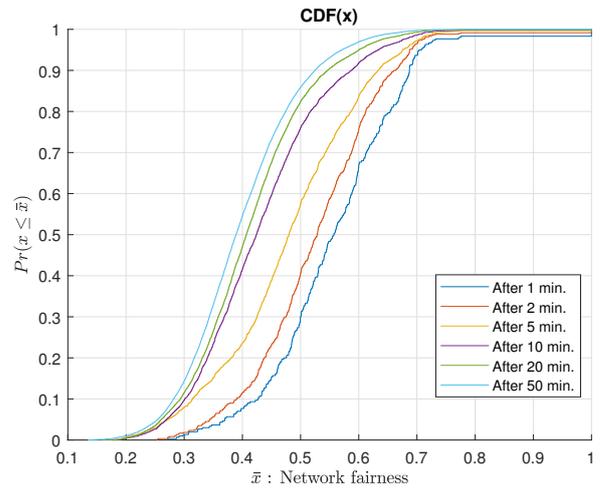
In this section we investigate how the user mobility impacts on network performances. In order to obtain the results illustrated below, we suppose that users are moving within the BS's coverage area according with a Random Way-point Mobility Model (RWMM). More in details, indicating with  $(x_k, y_k)_t$  the position of user  $k$  at time  $t$ , it is supposed that it moves toward a target position  $(\bar{x}, \bar{y})$ , randomly chosen within the coverage area, with a constant velocity  $v$  uniformly distributed within  $[v_{min}, v_{max}]$ . Once the target position is reached, the user stand in that position for a predefined amount of time  $T_p$ . Subsequently, another random position target position and velocity are chosen for that node, initiating then a new travel path. Positions of each node are updated after an amount of time of  $T_{step}$ . All the simulation parameters are listed in table 1.

**Table 1.** Simulation Parameter

Parameter	Value
Number of Users N	20
Cell Radius R	500 m
Bandwidth	40 MHz
$\sigma_{ch}$	1
Path loss exponent $\alpha$	4
$v_{min}$	1 m/s
$v_{max}$	2 m/s
Simulation time	3600 sec.
$T_p$	2 sec.
$T_{step}$	1 sec.



**Figure 2.** CDF of aggregated DL throughput.



**Figure 3.** CDF of network fairness.

As illustrated in Fig. 2, which represents the CDF of the downlink (DL) aggregated throughput after different amount of time, the usage of the SPA does not strongly impacts the network, i.e., the average aggregate DL throughput does not change consistently along the time. However, even if the DL aggregated throughput can be considered constant in average, from Figs. 3-4 we can see how the usage of SPA policy results inefficient in maintaining other network performances like networks fairness and user's QoS fulfilment. In particular, in Fig. 3, which represents the CDF of the network DL fairness, one can note how the average value of network fairness decreases as the simulation time increases. In other words, allocate the same amount of power for long time will results in a decrease of the network fairness. This can be explained by the fact that as users starts

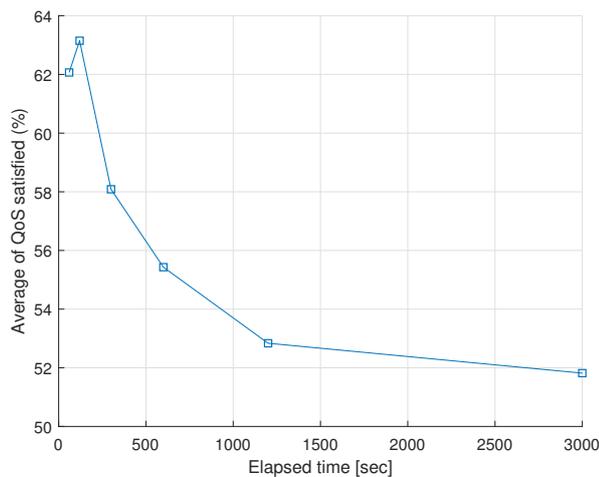


Figure 4. Percentage of QoS satisfied.

to move their channel gains change obtaining either higher channel gain or worst channel gain, resulting then in either an increase or a decrease of the DL achievable throughput, respectively. On the other hand, from Fig. 4, which represent the average percentage of percentage for which the QoS requirements are fulfilled over the time, one can also notice how the usage of a SPA dos not permits to fulfil with the QoS requirements of each user as the time during which the allocated power remain constant increases.

#### 4. Conclusions and Future Directions

In this paper, we illustrated the importance of considering user mobility in the design of NOMA communication systems. In particular, we illustrated how the usage of a SPA policy, even if it is able to maintain a "constant" average level of aggregate DL throughput, it negatively impacts on the DL throughput fairness and on the fulfilment of QoS constraint over the time. These effects are caused by the fact that SPA policies allocates a fixed amount of power to each user which depends on the particular channel gain experienced. However, due to the user mobility, the channel gain conditions can change consistently bringing to either better of worst network metric performances if the channel gain either increases or decreases, respectively.

As far as the authors are aware, the technical literature lacks works related to the design of dynamic power allocation and user clustering strategies for NOMA systems which takes into account the mobility of users. Then, due to the potentialities of NOMA technology in reaching the 5G and beyond 5G requirements, the design of dynamic power allocation and user clustering schemes, which considers users mobility, represents an

important future research direction. In particular, the adoption of recently advanced real-time optimization and artificial intelligence techniques represents a very promising direction towards the development of such dynamic allocation schemes.

#### Acknowledgement

This research is funded by the Global Challenges Research Fund under the DfE-GCRF 2020-21 scheme between Queen's University Belfast, UK and Vietnam National University, HoChiMinh City, Vietnam

#### References

- [1] CISCO, Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2016-2021 White Paper. URL <https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/mobile-white-paper-c11-520862.html>.
- [2] BOCCARDI, F., HEATH, R.W., LOZANO, A., MARZETTA, T.L. and POPOVSKI, P. (2014) Five disruptive technology directions for 5g. *IEEE Communications Magazine* 52(2): 74–80.
- [3] DAI, L., WANG, B., YUAN, Y., HAN, S., I, C. and WANG, Z. (2015) Non-Orthogonal Multiple Access for 5G: Solutions, Challenges, Opportunities, and Future Research Trends. *IEEE Communications Magazine* 53(9): 74–81. doi:10.1109/MCOM.2015.7263349.
- [4] ISLAM, S.M.R., AVAZOV, N., DOBRE, O.A. and KWAK, K. (2017) Power-Domain Non-Orthogonal Multiple Access (NOMA) in 5G Systems: Potentials and Challenges. *IEEE Communications Surveys Tutorials* 19(2): 721–742.
- [5] SAITO, Y., KISHIYAMA, Y., BENJEBBOUR, A., NAKAMURA, T., LI, A. and HIGUCHI, K. (2013) Non-Orthogonal Multiple Access (NOMA) for Cellular Future Radio Access. In *Proc. IEEE 77th Vehicular Technology Conf. (VTC Spring)*: 1–5. doi:10.1109/VTCSpring.2013.6692652.
- [6] VANKA, S., SRINIVASA, S., GONG, Z., VIZI, P., STAMATIOU, K. and HAENGGI, M. (2012) Superposition Coding Strategies: Design and Experimental Evaluation. *IEEE Transactions on Wireless Communications* 11(7): 2628–2639. doi:10.1109/TWC.2012.051512.111622.
- [7] DING, Z., SCHÖBER, R. and POOR, H.V. (2016) A general mimo framework for noma downlink and uplink transmission based on signal alignment. *IEEE Transactions on Wireless Communications* 15(6): 4438–4454.
- [8] ZHANG, Y., WANG, H., ZHENG, T. and YANG, Q. (2017) Energy-efficient transmission design in non-orthogonal multiple access. *IEEE Transactions on Vehicular Technology* 66(3): 2852–2857.
- [9] NGUYEN, V., TUAN, H.D., DUONG, T.Q., POOR, H.V. and SHIN, O. (2017) Precoder design for signal superposition in mimo-noma multicell networks. *IEEE Journal on Selected Areas in Communications* 35(12): 2681–2695.
- [10] ZHU, J., WANG, J., HUANG, Y., HE, S., YOU, X. and YANG, L. (2017) On optimal power allocation for downlink non-orthogonal multiple access systems. *IEEE Journal on Selected Areas in Communications* 35(12): 2744–2757.

- [11] DO, T.N., DA COSTA, D.B., DUONG, T.Q. and AN, B. (2018) Improving the performance of cell-edge users in miso-noma systems using tas and swipt-based cooperative transmissions. *IEEE Transactions on Green Communications and Networking* 2(1): 49–62.
- [12] LIU, F. and PETROVA, M. (2018) Dynamic power allocation for downlink multi-carrier noma systems. *IEEE Communications Letters* 22(9): 1930–1933.
- [13] NASIR, A.A., TUAN, H.D., DUONG, T.Q. and POOR, H.V. (2019) Uav-enabled communication using noma. *IEEE Transactions on Communications* 67(7): 5126–5138.
- [14] NASIR, A.A., TUAN, H.D., DUONG, T.Q. and DEBBAH, M. (2019) Noma throughput and energy efficiency in energy harvesting enabled networks. *IEEE Transactions on Communications* 67(9): 6499–6511.
- [15] MASARACCHIA, A., NGUYEN, L.D., DUONG, T.Q., YIN, C., DOBRE, O.A. and GARCIA-PALACIOS, E. (2020) Energy-efficient and throughput fair resource allocation for ts-noma uav-assisted communications. *IEEE Transactions on Communications* : 1–1.
- [16] MASARACCHIA, A., NGUYEN, L.D., YIN, C., DOBRE, O.A. and GARCIA-PALACIOS, E. (2020) The concept of time sharing noma into uav-enabled communications: An energy-efficient approach. In *2020 4th International Conference on Recent Advances in Signal Processing, Telecommunications Computing (SigTelCom)*: 61–65.
- [17] MASARACCHIA, A., HA, D.B. and LE, N.P. (2019) On the optimal user grouping in noma system technology. *EAI Endorsed Transactions on Industrial Networks and Intelligent Systems* 6(20). doi:10.4108/eai.13-7-2018.159802.
- [18] DING, Z., FAN, P. and POOR, H.V. (2016) Impact of user pairing on 5g nonorthogonal multiple-access downlink transmissions. *IEEE Transactions on Vehicular Technology* 65(8): 6010–6023.
- [19] MASARACCHIA, A., DA COSTA, D.B., DUONG, T.Q., NGUYEN, M. and NGUYEN, M.T. (2019) A PSO-Based Approach for User-Pairing Schemes in NOMA Systems: Theory and Applications. *IEEE Access* 7: 90550–90564. doi:10.1109/ACCESS.2019.2926641.
- [20] MASARACCHIA, A., NGUYEN, L.D., DUONG, T.Q., DA COSTA, D.B. and LE-TIEN, T. (2019) User-pairing scheme in noma systems: A pso-based approach. In *International Conference on Industrial Networks and Intelligent Systems (Springer)*: 18–25.