International Journal of Electronics

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tetn20

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INTERNATIONAL JOURNAL OF ELECTRONICS
https://doi.org/10.1080/00207217.2021.1939434

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ABSTRACT

In a non-orthogonal multiple access (NOMA) system, most crucial function at the transmitter is power allocation followed by superposition coding and at the receiver end successive interference cancellation (SIC). The overall system throughput and performance of the system depends on user clustering, power allocation scheme and SIC at receiver, which is expected to have minimal error. In this paper, we compare the performance of different power allocation algorithms through symbol error rate versus signal to noise ratio plot randomising Rayleigh channel conditions. Simulations are done for the power-domain NOMA system. We propose Eigenvalue-based power allocation in NOMA, which performs better than the traditional counterparts. The simulation is carried out for two-user system using MATLAB.

ARTICLE HISTORY

Received 4 January 2021
Accepted 25 April 2021

KEYWORDS

NOMA; FTPA; OPA; PSO; GPA

I. Introduction

There is a growing demand for a wireless communication system with increased data rate, low latency, effective spectrum utilisation and ability to provision higher number of users. One of the promising technologies that meet these demands is non-orthogonal multiple access (NOMA). It allows users to share the same time-frequency resource by distinguishing them based on power domain or code domain or a combination of them (Balasubramanya et al., 2018). The power domain NOMA exploits different power levels allocated to multiple users to distinguish and separate them using successive interference cancellation (SIC) at the receivers.

Power allocation in NOMA can be done in different ways. It can be based on channel gain, signal to noise ratio (SNR), distance from transmitters, fairness index, or so as to maximise energy efficiency (EE). Effective power allocation scheme used at the transmitter leads to nearly perfect SIC. At the transmitter after power allocation, signal intended to be sent to the users are multiplied by the power index, combined or superimposed and sent as a signal. This signal being received by multiple users sharing the same resource, detects the signal and decodes it as a strong user signal. If that is not the intended signal, then the strongest user signal is regenerated and cancelled from the received signal. This process is repeated until all users can decode their respective signals (Lin et al., 2019). This is the basic principle behind SIC.

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Power allocation (PA) impacts the performance of a system, such as interference management and rate distribution among users. If it is inappropriate, then it may lead to unfair rate distribution and outage. Important parameters that are needed to design PA schemes are CSI availability, channel conditions, maximising objective function, quality of service (QoS) requirements, total power constraint and many more. Some of the performance metrics used for PA schemes are sum rate, fairness, EE, number of admissible users, etc. (Islam et al., 2019). Some of the conventional power allocation schemes used in NOMA include fixed power allocation (FPA), waterfilling based and fractional transmit power allocation (FTPA). Some of the proposed schemes exhaustively presented in literature include adaptive power allocation, generalised power allocation (GPA), full search, improved fractional transmit power allocation (I-FTPA), optimum power allocation (OPA), particle swarm optimisation (PSO) algorithm based, salp particle swarm optimisation, fuzzy logic, dynamic power allocation based on reinforcement learning (RL) and many others. The mentioned techniques differ in terms of throughput, error rate, sum rate, outage probability, complexity, fairness index, etc.

The overall performance of Multiple Input Multiple Output (MIMO)-NOMA system is superior over MIMO-OMA in terms of ergodic sum rate both for two user case as well as multiple users wherein two users are grouped in a cluster sharing same transmit beam (Zeng et al., 2017). This is because, MIMO-NOMA allocates unequal power levels to the users sharing same time-frequency resource unlike same power levels for all users in case of OMA. Downlink sum rate can further be maximised by optimising beamforming and transmit power sequentially. Fraction programming (FP) is proposed in (Feng et al., 2020), which is sub-optimal iterative PA algorithm. Closed form expression for PA is derived via Karush-Kuhn-Tucker (KKT) conditions. This algorithm performs good in terms of throughput. FP-based algorithm converges to optimal point and in case of non-convex problem may converge to local optima. Given the existing literature related to PA algorithms in NOMA, the contributions of this paper towards optimal power allocation in NOMA is listed as below:

- We have compared the performance of different PA algorithms namely, waterfilling algorithm, FPA, FTPA, I-FTPA, GPA, OPA and PSO-based power allocation schemes in terms of symbol error rate (SER) versus SNR. The inference is drawn from the simulation results as to which PA scheme is better for Rayleigh fading channel.
- We propose Eigenvalue-based PA where Eigenvalues are obtained from the diagonal matrix after singular value decomposition of channel matrix. These values characterise the channel and reflects the channel fading, this allows us to better distinguish the users in a cluster. This method is found to maximise the capacity of the system.
- The simulation results show that the proposed PA algorithm achieves considerably low SER values with respect to different SNR compared to above-mentioned PA schemes and performs close to optimal PA under varying channel conditions.

This paper is organised as follows. Section II briefs about the related work carried out in the domain of PA in NOMA. Section III describes the system model used for simulation. Section IV presents the proposed Eigenvalue-based PA. Section V provides NOMA system parameters used for simulation. In Section VI, we provide the simulation results and discussions on the same. Conclusion and future scope are outlined in Section VII.

II. Related work

There are a lot of related works regarding power allocation to users within a cluster in MIMO-NOMA system. In this section, we reproduce the concepts of Waterfilling, FPA, FTPA, I-FTPA, GPA, OPA, PSO-based, Channel gain and target SNR-based power allocation with their advantages and limitations.

A. Waterfilling algorithm for PA

Unlike the earlier equal PA, in this method, PA is done based on channel coefficients. The amount of power allocated or the level of water filled is proportional to the SNR. It also depends on total power available, interference power levels and channel gain matrix. Channel gain is arranged in descending order, their inverse is taken. Initial water level or power assigned is given as in Eq. (1) (Kumar & Goraya, 2012).

$$Power\ level = \frac{P_{tot} + \sum_{i=1}^{n} \frac{1}{H_i}}{\sum channels} - \frac{1}{H_i} \tag{1}$$

where P_{tot} is the total available power, H is the channel gain, n is number of users. This process is continued until the power value becomes negative. It is observed that by this process higher power is allocated to user with greater channel gain. Joint iterative waterfilling-based PA is proposed in (Youssef et al., 2017). Mean capacity determined for the system with waterfilling is more compared to when there is no waterfilling and successive waterfilling algorithm. This method is better than equal power allocation, but is not good in terms of fairness index and has variations in terms of outage probability.

B. Fixed PA

Different but fixed power is allocated to users based on channel gain. User with poor channel gain is assigned more power (0.6P/0.7P) and user with good channel gain is allocated a lesser power (0.4P/0.3P) (Bai et al., 2019). Where P is the total power available for allocation. Using this scheme, there is less signalling overhead and simple but does not have definite formula to calculate power allocation based on channel gain.

C. Fractional Transmit Power Allocation

This scheme is better than fixed PA, and it is a suboptimal solution. The power allocation is done as per the Eq. (2) based on channel gain.

$$P_i = \frac{|h_i|^{-2\beta} * P_{tot}}{\sum_{i=1}^{n} |h_i|^{-2\beta}} \tag{2}$$

where β is value between 0 and 1, it is fractional value of power. If it is equal to zero then equal power is allocated to the user pair. If it is increased, greater fraction of power is allocated to user with poor channel condition. It is more complex and involves signalling overhead compared to FPA (Algashmari & Nassef, 2020). In Eq. (2) $|h_i|^2$ is the magnitude square of channel gain and n is the total number of users in the cluster. P_{tot} is the total power available for allocation. Here, since there is a single decay factor used for all the users, it doesn't change for varying channel conditions of the users though it is a dynamic PA scheme. The performance may worsen if one of the users encounters bad channel conditions. FTPA is better than FPA as it considers the channel conditions for assigning power levels.

D. Improved FTPA

The decay factor β used as an exponent in the case of FTPA is varied based on channel gain in I-FTPA.

$$P_i = \frac{P_{tot} * \left(|h_i|^2 / N_{0,i} \right)^{-\beta_i}}{\left(|h_1|^2 / N_{0,1} \right)^{-\beta_1} + \cdots + \left(|h_i|^2 / N_{0,i} \right)^{-\beta_i}} \tag{3}$$

where P_i is the power allocated to i[th] user, β_i is chosen based on channel gain and N is noise variance. When power allocation factors of all users are summed, it should be equal to 1 (Bai et al., 2019). This method outperforms orthogonal frequency division multiple access (OFDMA), NOMA-FPA, and NOMA FTPA in terms of Bit Error Rate (BER). It has improved adaption to channel conditions but the choice of the different decay factors should be done carefully. Different decay factors influence each user's detection accuracy. This can be changed to meet the needs of user based on application. Decay factor can be changed according to varying channel as compared to FTPA where it is not done. Thus, I-FTPA performs better than FTPA in NOMA.

E. Generalised Power Allocation

This is a simple algorithm used to allocate power in NOMA. Eq. (4) represents the concept of GPA (Ahmed et al., 2018).

$$P_i = \frac{n!}{i! \times (n-i)!} \times C^i \tag{4}$$

where C is the choice factor given by $C = P^{1/n} - 1$, $P = \sum_{i=1}^{n} P_i$.

GPA-based PA is a simplified approach but its performance is comparable with other conventional PA schemes. It is to be noted that none of the parameters are optimised for the calculation of power. However, the performance of GPA is consistent with different modulation techniques.

F. Optimal Power Allocation

This scheme maximises the overall system throughput and sum rate with certain fairness index constraint. Firstly, power matrix is initialised with all possible values and target fairness index is set. Iteratively for every possible combinations of PA, fairness index and capacity are calculated. If fairness index is less than the target value then capacity is set to zero. Every calculated value of capacity is compared with maximum capacity, which is initially set to zero. If the capacity value is greater than maximum capacity, then maximum capacity value is changed to the present calculated value of capacity.

$$maximizesumcapacity = \sum_{i=1}^{n} BW \times log_2\left(1 + \frac{P_i \times |h_i|^2}{N + \sum_{k=1}^{i-1} P_k \times |h_k|^2}\right) \quad (5)$$

where $\sum_{i=1}^{n} P_i \leq P_{tot}, P_i > 0$ and fairness index F is given by $F = \frac{\left(\sum R_i\right)^2}{n \times \sum R_i^2}$, where R is the sum capacity, N is the noise variance (Manglayev et al., 2016). The sum capacity is evaluated for different fairness index and its performance with respect to throughput is found to be superior over orthogonal multiple access (OMA). But as the fairness index is increased the sum capacity reduces and so there is no significant difference in the performance of both OMA and NOMA. OPA does an exhaustive search to provide best performance under fairness constraint.

G. Particle Swarm Optimisation (PSO) based PA

PSO is optimised scheme where large population of particles randomly initialised positions are moved in search space until optimised solution is attained. Inputs to PSO algorithm are population size and channel gain. It is an iterative procedure where all particles are initialised to random positions (position which indicates the possible PA values of user pair), particle's best position and swarm's global best position. Iterations are either carried out for certain number times or until a satisfying condition is met. In every iteration, particle's velocity and its position are updated to maximise/minimise fitness function. Fitness function in the case of PA in NOMA is energy efficiency (ratio of data rate to transmission power) which is maximised. Finally, swarm's best position is updated as the optimal power allocation to the users. The output of PSO algorithm is thus vector of final allocated powers (Pliatsios & Sarigiannidis, 2019). Fitness function is given by Eq. (6).

$$f = \sum_{s=1}^{S} log_2\left(1 + \frac{h_s^2 P_s}{\frac{B}{S} N_0}\right) - 100 * max\left(0, \sum_{s=1}^{S} (P_s - P_{max})^2\right) \quad (6)$$

where S is the number of channels, B is bandwidth and N_0 is noise variance. It is an optimal PA scheme for obtaining high energy efficiency as it has faster convergence and global optima. In addition, it is also to be noted that there are lot of parameters which need to be initialised carefully before applying the algorithm such as swarm size, number of iterations, inertia, particle velocity, correction factor, particle and swarm best value and many more. It gives the optimal power allocation coefficients based on the number of subcarriers, the population size, and the channel gain of each user. A fitness function is used in order to enforce the constraints of the optimisation problem. It is an iterative procedure hence time consuming but yields good results.

H. Target SNR-based PA

PA is performed in such a way that signal to interference plus noise ratio (SINR) is maximised for strong user and is above minimum level for weak user. It is also assumed that perfect channel state information (CSI) is known at both transmitter and receiver. PA is done based on noise variance, channel gain, target SNR and symbol power. Low power factor is allocated to the user with high gain and high-power factor is allotted to the user with low channel gain (Narengerile & Thompson, 2019). The advantage of this method is that it considers target SNR and channel gain to determine the PA factors, this ensures QoS.

III. System model

Uplink scenario of NOMA system is considered for a user pair. User data are modulated using quadrature phase shift keying (QPSK) technique. This modulated signal is multiplied with the square root of power factor as a scaling factor. Power factor assigned to a user depends on the power allocation algorithm used. Later, serial to parallel conversion, inverse fast Fourier transform (IFFT) is performed. Cyclic prefix is inserted to combat inter-symbol interference (ISI). Then, the signal is passed over the radio channel after performing parallel to serial conversion. The resulting user signals are added with Gaussian Noise.

At the receiver, operations opposite to that of transmitter is carried out. It is assumed that perfect CSI is available. Maximum likelihood (ML) detection is employed for signal detection. The detected symbols are compared with the actual transmitted symbols to estimate the SER, which is one of the important performance parameters of the system. The expression for received signal on subcarrier k is as given in Eq. (7)

$$R(k) = \sum_{i=1}^{M} \sqrt{a_i(k)P} H_i(k) S_i(k) + N(k) \tag{7}$$

where $R(k), H_i(k), S_i(k) and N(k)$ are received signal, FFT of channel impulse response, modulated signal and additive white Gaussian noise (AWGN), respectively. a_i, P are fractional value (ranging between 0 and 1) and total power available for the users. Sum of a_i for all subcarriers should be equal to 1. Multipath channel is modelled as Rayleigh channel.

The sequence of steps followed for simulation is in accordance with system model shown in Figure 1. Firstly, all the system parameters, data to be transmitted, pilot

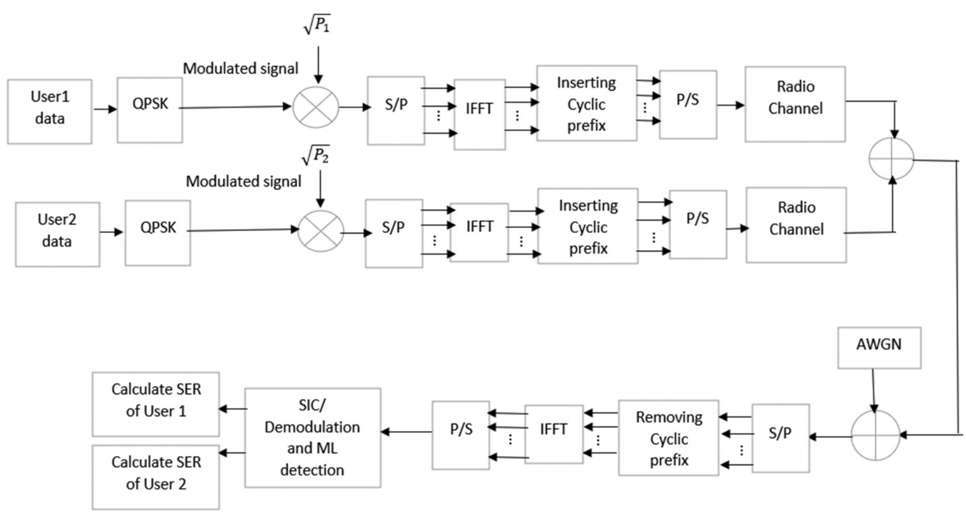

Figure 1. Block diagram of NOMA system.

symbols, target SNR are initialised. A multipath Rayleigh channel is defined, QPSK modulation and PA is performed on the user data. Later, the process followed in OFDM namely IFFT is performed on the product of transmit packet and square root of power scale. After IFFT, cyclic prefix is added whose length is greater than impulse response of channel to avoid inter-symbol interference. Parallel to serial conversion is done and signal is convolved with multipath channel. Superposition coding is carried out on signals from both the users. This is signal is added with Gaussian noise and random phase is also introduced to check for the robustness of the system. At the receiver end, serial to parallel conversion, removal of cyclic prefix, FFT, channel estimation and symbol detection are performed. Once the signal is detected, the amount of SER is calculated for different values of SNR.

IV. Proposed method of power allocation

We propose Eigenvalue-based power allocation as this better characterises the channel capacity. Since, Channel gain matrix is complex, its magnitude square is taken. Singular value decomposition is performed on this matrix. Later difference in channel gain between user1 and user2 is determined to know which of them is better in terms of channel. User pair is considered in a cluster, which shares the same channel. The following algorithm is used for the power allocation for both the users:

Algorithm:

Perform singular value decomposition (SVD) on the absolute square of the product of Hermitian of channel gain matrix and channel gain matrix to determine the diagonal matrix of singular values (S), which are non-negative and arranged in decreasing order.

Gain difference = channel gain vector of user2- channel gain vector of user 1

For each subcarrier initially check, if gain difference is greater than zero or less than zero. If it is greater than zero, then it means user 2 is better than user 1 in terms of channel and more power needs to be allocated to user 1.

Power allocation factor of user 2 = P_2

Power allocation factor of user 1 = P_1

$$P_2 = S_2^n / \left(S_1^m + S_2^n + N\right)$$

P_1 = 1- P_2

If gain difference is less than zero, it means user 1 is better than user 2 in terms of channel and more power needs to be allocated to user 2.

$$P_1 = S_1^m / \left(S_1^m + S_2^n + N\right)$$

P_2 = 1- P_1

Decoding matrix is created based on power factor matrix to determine the decoding order while performing SIC at the receiver.

Where *m* and *n* are integers chosen appropriately to minimise the error rate determined iteratively during signal detection and *N* is the noise variance. Eigenvalue powered by a certain integer upon the sum of trace of powered channel matrix and noise variance is employed.

The diagonal entries obtained after SVD are non-negative square roots of eigenvalues of matrix $H^H H$.

$$H^H Hy = \lambda y, y \neq 0 \tag{8}$$

where y is Eigenvector. singular values of H are given by $\sqrt{\lambda}$. Received signal component is given by Eq. (9).

$$r = \sqrt{\lambda}x + n \tag{9}$$

Where r is received signal, x is transmitted signal and n is noise component. Channel capacity is given by Eqs. (10) and (11) for weak user and strong user, respectively.

$$C_w = W \times log_2\left(1 + \frac{P_w \times |h_w|^2}{\sigma^2 + P_s \times |h_s|^2}\right) \tag{10}$$

$$C_s = W \times log_2\left(1 + \frac{P_s \times |h_s|^2}{\sigma^2}\right) \tag{11}$$

where W is bandwidth and second term within $\log_2$ is SINR. Power allocated to each user is in accordance with the algorithm described above. Total capacity of the system is maximised and signal detection accuracy is improved by this power allocation algorithm.

The purpose of using Eigenvalues is that it captures the key information and characteristics of the channel. They improve the efficiency by reducing the dimensions. They also characterise the channel capacity. Higher Eigenvalue of the channel matrix indicates higher received power and its value degrades with channel fading.

The reason that this method is better compared to its traditional counterparts is that Eigenvalues of channel matrix give important insights and characterises the channel and also distinguishes the different users well. This is dynamic as Eigenvalues change with time varying channel. The diagonal matrix obtained after singular value decomposition of the product of channel matrix and its Hermitian, is used to determine the power levels assigned to users in NOMA system. Improvement in detection is possible as there is reduced SER observed for both user 1 and user 2, and there is considerable difference in the SER versus SNR values between them.

V. NOMA system parameters

NOMA is used in a two user OFDM system. The two users share the same time frequency resource to transmit data. They use different power levels for transmission hence SIC is performed at the receiver (Base station- uplink scenario). Perfect CSI is assumed to be available at both transmitter and receiver. Multipath Rayleigh channel is considered along with AWGN. An OFDM system with 64 subcarriers is chosen and one packet consisting of 3 symbols. Two symbols are used for pilot sequences and 1 symbol for the actual data. Baseband modulation scheme chosen is QPSK. Random QPSK symbols are generated for data and fixed pilots are used. The base station receives packets from both the users superposed with AWGN. Random phase shift is also applied to each channel and packet to

Table 1. Parameters used for simulation.

Parameters	Value
Number of Subcarriers	64
Number of Pilot Subcarriers	64
Length of Cyclic prefix	20
Number of channel paths	20
Number of NOMA users	2

check for the robustness of the system. SER is measured per subcarrier iteratively for different SNR. Other parameters used for simulation are as given in Table 1.

VI. Simulation results and discussion

The performance results of a NOMA system are compared for nine different power allocation schemes. There are many ways to evaluate the performance of a system namely SER versus SNR plot, throughput, outage probability, system capacity etc. We have evaluated the performance of NOMA system after signal detection by means of plotting SER versus SNR (dB). The simulation is carried out in MATLAB for two users sharing same time frequency resource. A multipath Rayleigh channel with 20 paths is used.

The simulation parameters used for fixed PA is 0.7P and 0.3P for users with poor channel and good channel gain, respectively (Bai et al., 2019). β of 0.4 is chosen as the exponent for channel gain in Eq. (2) that represents PA formula of FTPA (Algashmari & Nassef, 2020). The varying decay factors, which is the objective of I-FTPA, β_1 is chosen to be 0.8 and β_2 is chosen to be 0.2 depending on which user is better in terms of channel gain (Bai et al., 2019). The initial parameters chosen for PSO-based PA (Pliatsios & Sarigiannidis, 2019) are 20 iterations, inertia of 1, swarm size of 100.

Figure 2 shows the SER versus SNR plot comparing all the power allocation schemes mentioned in Sections II and IV. It can be observed from the simulation results that GPA

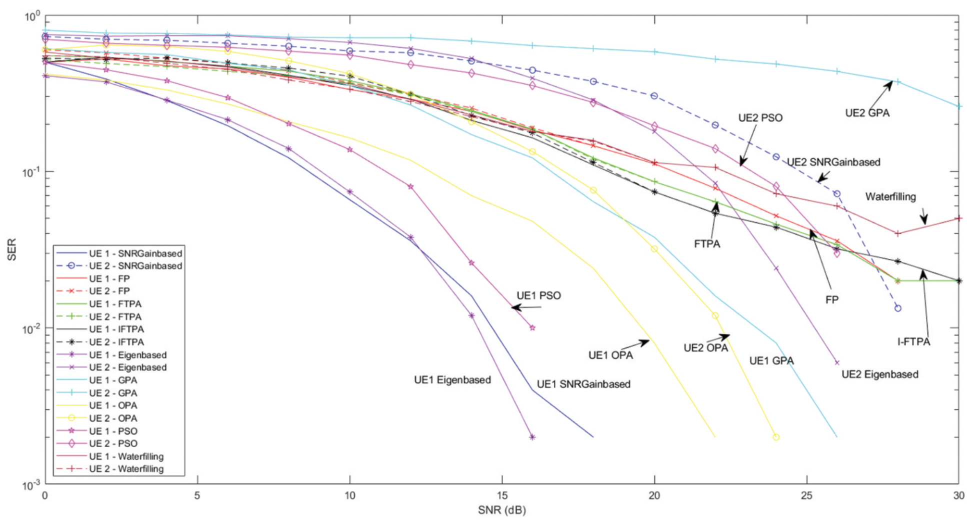

Figure 2. SER versus SNR plot comparing different PA schemes.

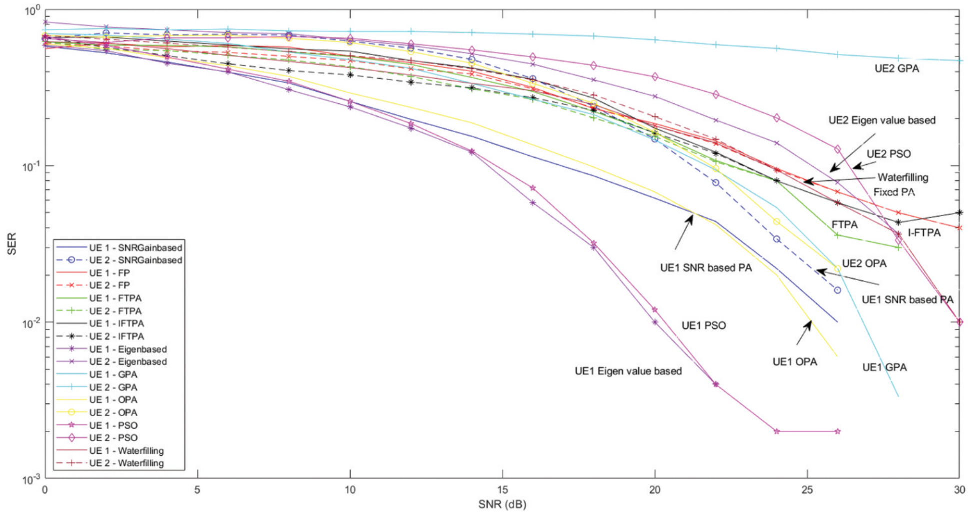

Figure 3. SER versus SNR plot comparing different PA schemes with channel randomised.

performs poor in case of user 2. The conventional PA algorithms such as waterfilling, FPA, FTPA and I-FTPA also do not have appreciably low levels of SER. The performance of PSO-based and SNR-channel gain-based (Narengerile & Thompson, 2019) algorithms are considerably good. The proposed Eigenvalue-based PA achieves an SER of the order 10^{-3} at an SNR of 16 dB for user 1 and 26 dB for user 2. Comparing the PA schemes, fixed SER of 0.002 is achieved at an SNR of 16 dB for Eigen-value-based PA, 18 dB for target SNR-based PA, 19 dB for PSO-based PA, 22 dB for OPA, 26 dB for GPA, above 30 dB for FP, waterfilling, FPA, FTPA and I-FTPA for user 1. In case of user 2, SER of 0.002 is achieved for SNR of 24 dB for OPA, 26 dB for Eigenvalue-based PA, 29 dB for PSO-based PA and even worse for other PA schemes. The reason for not having SER in the orders of 10^{-4} or 10^{-5} is that we have considered Rayleigh fading channel in the presence of Gaussian and random phase noise in order check the robustness of the algorithm. When SER of both users are considered for comparison, Eigenvalue-based PA clearly shows to have low levels of SER, this is because it gives clear picture about characteristics of the channel and distinguishes the two users well. The proposed algorithm however steps back to generalise with the dynamic channel, and it needs to be iterated to converge to best power allocation, however it is intermediate in terms of complexity.

Figure 3 shows SER versus SNR plot for Rayleigh channel with randomisation applied. It can be inferred from the plots that proposed Eigenvalue-based PA gives an SER of the order of 10^{-3} below 25 dB, which is better than other methods. PSO-based PA, SNR and channel gain-based PA performs in par with the proposed scheme. The traditional methods like waterfilling, fixed PA and FTPA have poor performance. SER versus SNR curves for User1 (UE1) and User2 (UE2) is clearly marked in both the semilogy plots.

VII. Conclusion

Power Allocation Schemes in NOMA for next generation wireless networks is investigated and Eigenvalue-based PA is proposed in this paper. The simulation results show that for a Rayleigh channel, Eigenvalue-based PA performs well compared to other state-of-art PA schemes and close to optimal PA. Future research can be carried out for different types of channel models of MIMO-NOMA system and joint code-power domain NOMA can be considered. For a practical scenario, randomisation in terms of mobility of users and their distance with respect to Base station can be chosen as parameters for PA. Joint optimisation of clustering, PA and SIC could also be worked.

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

Ahmed, T., Yasmin, R., Homyara, H., & Hasan, M. A. F. M. (2018). Generalized Power Allocation (GPA) Scheme for Non-Orthogonal Multiple Access (NOMA) based wireless communication system. *International Journal of Computer Science, Engineering and Information Technology*, *08*(06), 01–09. https://doi.org/10.5121/ijcseit.2018.8601

Algashmari, W., & Nassef, L. (2020). Power allocation evaluation for Downlink Non-Orthogonal Multiple Access (NOMA). *International Journal of Advanced Computer Science and Applications*, *11*(4). https://doi.org/10.14569/IJACSA.2020.0110417

Bai, W., Yao, T., Zhang, H., & Leung, V. C. M. (2019). Research on channel power allocation of fog wireless access network based on NOMA. *IEEE Access*, *7*, 32867–32873. https://doi.org/10.1109/ACCESS.2019.2901740

Balasubramanya, N. M., Gupta, A., & Sellathurai, M. (2018). *Combining code-domain and power-domain NOMA for supporting higher number of users* [Paper presentation]. 2018 IEEE Global Communications Conference (GLOBECOM), Abu Dhabi, United Arab Emirates. 1–6. https://doi.org/10.1109/GLOCOM.2018.8647770 .

Feng, W., Zhao, N.,Ao, S., Tang, J., Zhang.X., Fu, Y., So, D.K.C., & Wong, K-K . (2020). Joint 3D trajectory and power optimization for UAV-aided mmWave MIMO-NOMA networks. *IEEE Transactions on Communications*. 369–375. https://doi.org/10.1109/TCOMM.2020.3044599

Islam, S. R., Zeng, M., Dobre, O. A., & Kwak, K. S. (2019). Non-Orthogonal Multiple Access (NOMA): How it meets 5g and beyond. *Wiley 5G Ref The Essential 5G Reference Online,* Hoboken, N J, USA: Wiley. 1–28.

Kumar, K., & Goraya, D.-Manwinder. (2012). Proposed water filling model in a MIMO system. *ijetae*. 1 (2), 127-132. ISSN 2250-2429

Lin, C., Chang, Q., & Li, X. (2019). A deep learning approach for MIMO-NOMA downlink signal detection. *Sensors (Basel, Switzerland)*, *19*(11), 2526. https://doi.org/10.3390/s19112526

Manglayev, T., Kizilirmak, R. C., & Kho, Y. H. (2016). Optimum power allocation for non-orthogonal multiple access (NOMA) [Paper presentation]. 2016 IEEE 10th International Conference on Application of Information and Communication Technologies (AICT), Baku. 1–4. https://doi.org/10.1109/ICAICT.2016.7991730 .

Narengerile, & Thompson, J. (2019). Deep learning for signal detection in non-orthogonal multiple access wireless systems [Paper presentation], 2019 UK/China Emerging Technologies (UCET), Glasgow, United Kingdom. 1–4. https://doi.org/10.1109/UCET.2019.8881888 .

Pliatsios, D., & Sarigiannidis, P. (2019). Resource allocation combining heuristic matching and particle swarm optimization approaches: The case of downlink non-orthogonal multiple access. *Information*, *10*(11), 336. https://doi.org/10.3390/info10110336

Youssef, M., Farah, J., Nour, C. A., & Douillard, C. (2017). Waterfilling-based resource allocation techniques in downlink Non-Orthogonal Multiple Access (NOMA) with single-user MIMO [Paper presentation]. 2017 IEEE Symposium on Computers and Communications (ISCC), Heraklion. 499–506. https://doi.org/10.1109/ISCC.2017.8024578 .

Zeng, M., Yadav, A., Dobre, O. A., Tsiropoulos, G. I., & Poor, H. V. (2017). On the sum rate of MIMO-NOMA and MIMO-OMA systems. *IEEE Wireless Communications Letters*, *6*(4), 534–537. [7938651]. https://doi.org/10.1109/LWC.2017.2712149