Power Domain-NOMA

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Contributor: Naureen Farhan ,

In the current era of exponentially growing demand for user connectivity, spectral efficiency (SE), and high throughput, the performance goals have become even more challenging in ultra-dense 5G networks. The conventional orthogonal frequency division multiple access (OFDMA) tech-niques are mature but have not proven sufficient to address the growing user demand for high data rates and increased capacity. Therefore, to achieve an improved throughput in an ultra-dense 5G network with an expanded network capacity, the unified non-orthogonal multiple access (NOMA) technique is considered to be a more promising and effective solution. Throughput can be im-proved by implementing PD-NOMA, as the interference is managed with the successive inter-ference cancellation (SIC) technique, but the issue of increased complexity and capacity with compromised data rate persists.

heterogeneous network power domain NOMA

1. Introduction

5G networks are widely deployed with the orthogonal frequency division multiple access (OFDMA) technique to achieve efficient resource allocation and user association. This multi-access technique is more commonly implemented with fractional frequency reuse, multi-cell architectures, clustering techniques, etc. However, considering a proficient multi-tier dense heterogeneous network deployment, clustering has proven to be a noticeable way to manage the linkages among the randomly deployed base stations with reduced network overhead; multi-tier HetNets consist of macro base stations (MBS) and small cell base stations (SBS) [1][2][3]. In addition, for efficient user association in such ultra-dense heterogeneous networks, the conventional OFDMA techniques have not proven to be sufficient enough to accommodate users' ever-increasing high data rate demand. Eventually, this results in poor data rates and underprovided network performance and capacity. As shown in [2], the author has improved user association and data rate with increased density but with a highly complex solution using the cluster-based OFDMA technique.

Moreover, in OFDMA, each sub-channel can serve only one user at a definite time slot, frequency band, or code to avoid interference and enable single-user detection under a simple receiver scheme. Ultimately, it is not expected to provide an adequate spectrum efficiency. Therefore, a less complex mechanism is required with which efficient spectrum use can be achieved along with improved fairness, high data rate, increased capacity, and enhanced user connectivity. This could be achieved by simultaneously serving multiple receivers with various channel conditions as with the non-orthogonal multiple access (NOMA) technique.

Researchers have widely used NOMA schemes because of their competence in increasing the system capacity and accommodating the network requirement of increased spectral efficiency (SE) and throughput with low complexity measures. NOMA is implemented as either a power domain (PD-NOMA) scheme or a code domain (CD-NOMA) scheme; researchers considered PD-NOMA. In PD-NOMA, different users are assigned different power coefficients under the respective channel conditions to attain improved system performance. This scheme has a simple implementation, does not require considerable changes to the existing network architecture, and does not require additional bandwidth to improve the SE [4].

In addition, according to some researchers, within the ultra-dense heterogeneous networks, the incorporation of the power domain non-orthogonal multiple access (PD-NOMA) technique, orthogonal multiple access (OFDMA) techniques has been identified to provide an improved solution to achieve proficient resource allocation with enhanced capacity and load balancing in ultra-dense heterogeneous networks [5]. The PD-NOMA scheme superposes coding at the transmitter, and the base stations transmit superposed signals to multiple users in the power domain. In addition, PD-NOMA does not require significant alterations to the existing 3GPP LTE architecture, which helps in achieving the implementation of low-complexity solutions.

PD-NOMA implements successive interference cancellation (SIC) [6] to decode the signal one by one and concurrently yield a high SE while allowing some degree of multiple access interference at the receivers. The downlink PD-NOMA with SIC enhances the network performance, but the complexity associated with both the capacity and user throughput still continues with the increased network densities, as each user has to decode the neighboring user signal, which increases the computational complexity and leads to longer delays with increased channel state information feedback overhead at the BS. Thus, the PD-NOMA scheme also shows several challenges requiring mitigation through efficient solutions [7].

1.1. Prior Work

In [8], the authors implemented the OFDMA scheme and proposed a joint user association and power allocation algorithm to obtain an energy-efficient HetNet environment. The authors achieved an energy-efficient solution with compromised performance and smaller power constraints for the sub-channel allocations. In OFDMA, a frequency resource is allocated to each user, even to a receiver with relatively low SE and throughput. In addition, with conventional methods that introduce scheduling, a receiver with a fair channel condition has a higher chance of being considered than one with a diminished channel condition. This leads to fairness problems with increased latency. PD-NOMA assigns the same frequency resource to multiple users to improve the SE. In addition, multiuser detection (MUD) with SIC is implemented at the user end to manage interference. However, in [9] the researchers presented a resource-allocation scheme under distributed clustering with OFDMA and PD-NOMA schemes. The authors have worked on various cluster sizes and analyzed with numerical and simulation results that large clusters can provide better performance in terms of better spectral efficiency. In addition, considering user association, they discussed the importance of both schemes in achieving improved gains for both uplink and downlink communication, though more work could also be performed to show the overall improvement in the system capacity and throughput with the proposed cluster formations and user association under the PD-NOMA scheme.

PD-NOMA has gained considerable research interest in HetNets and has been implemented as an efficient resource allocation strategy compared to the conventional OFDMA technique. As in [10], a distributed resource allocation is presented for a self-backhauled small-cell network in full-duplex mode. The authors contributed to joint user scheduling, mode selection, and power allocation in a two-tier network, intending to maximize the network sum rate and the quality of service (QoS) and capacity constraints by implementing PD-NOMA over the small-cell network in the full-duplex mode. However, the authors did not study increased capacity with ultra-dense random user deployments.

In [11], PD-NOMA is utilized for user association and resource allocation in a dense heterogeneous network and improved connectivity in 5G systems. This work is presented by considering various case studies to demonstrate the effectiveness of PD-NOMA in ultra-dense networks. It emphasizes that the development of techniques that offer robust connectivity of massively deployed devices to improve energy efficiency with managed user deployments through increased network capacity with various distant user allocations has not been taken under consideration. In [12], PD-NOMA was implemented with beamforming to gain energy-efficient resource allocation and user association. The network is considered to be an ultra-dense user-centric heterogeneous network. In addition, in [13], the authors deemed multi-access edge computing and worked on offloading techniques to improve the performance in heterogeneous networks by reducing delays and achieving user association and resource sharing through a game-based algorithm.

Moreover, in [14], the complete details of the PD-NOMA scheme and its practical implementation are discussed in detail. In [14], the analysis and discussion of PD-NOMA were mainly performed as an efficient future radio multi-access technique. In [15], the author conducted a comprehensive survey on PD-NOMA and analyzed it as a proficient scheme to enhance the network capacity with efficiency and ultimately improve the network performance along with a few future research directions in the said domain by combining PD-NOMA with other schemes.

Moreover, in [5], Cirine Chaeib et al. utilized PD-NOMA for user association and sub-channel assignment to accomplish an effective radio resource management strategy. In addition, the authors implemented OFDMA and NOMA in a hybrid manner, and the results proved that the hybrid technique outperformed the results achieved with standalone OFDMA or NOMA for efficient user association.

Similarly, in [16], the author considered the gained sum rate of NOMA over OFDMA for uplink transmission with a single antenna, multiple antennas, and massive multiple antennas and proved with analytical results the accuracy of the gain achieved with the proposed technique. In [17], the authors showed with simulation results that NOMA can be a solution to increase the cell capacity without compromising the network performance for 5G networks, eventually satisfying users' ever-increasing data rate demands.

The benefits of both OFDMA and NOMA schemes cannot be ignored for 5G ultra-dense heterogeneous networks. PD-NOMA has been suggested for user association as a technique for achieving a reliable and efficient solution with improved network capacity.

Therefore, it can be concluded from the above-discussed literature that PD-NOMA has gained great significance in radio resource management and user association in heterogeneous networks. However, it still has to mitigate a few challenges with ultra-dense heterogeneous network deployments.

Other popular techniques are used with PD-NOMA, including the cooperative NOMA and cognitive radio with the NOMA technique. In cooperative NOMA, the relaying function is performed by the near user to reduce the outage probability and can virtually extend the coverage area of the base station, and the relaying function can be performed under various techniques to achieve the desired results of improved network performance [18]. Further, in [19] the author presented a detailed critical overview of current research methods in cooperative PD-NOMA (PD-CNOMA) and also discussed the implementation of PD-CNOMA with other techniques such as cognitive radio, energy harvesting, and full duplex 5G technologies. Further, in [20], the author has explored energy harvesting assisted cooperative NOMA with underlay cognitive radio networks. The presented methodology has high complexity, and the impacts of power transmission, energy harvesting co-efficient, and imperfect SIC was also analyzed with simulation and analytical results. Thus, it can be concluded that by using cooperative PD-NOMA, the performance of 5G networks can further be improved, i.e., by implementing better techniques for deploying relays and by selecting significant values of transmission power, SIC strategies, and other performance parameters.

In cognitive radio with NOMA, on the other hand, the far user is considered the primary user if the target rate conditions are satisfied with the far user. Thus, more power is allocated to the far user, and remaining power is allocated to the secondary user; the coverage probability can be improved with this scheme, but with high signal to noise ratio (SNR) values, the system performance declines [21].

Hence, with the above-mentioned schemes, the user association can be improved, but still the complexity of the SIC process at the receiver's end persists. With clustering, the complexity of the SIC process can be reduced, and thus the chances of errors during the SIC process can be reduced [22][23]. Researchers proposed the clustered PD-NOMA technique and implemented it with the previously applied interference managed hybrid clustering (IMHC) scheme [1] and found that with the proposed PD-NOMA scheme, the interference among the users was further reduced because with the clustered PD-NOMA, the frequency band was shared with a lower number of users due to clustering. Hence, researchers could achieve improved throughput and channel capacity with the proposed scheme due to effectively reduced interference among the associated users and high channel gain differences.

The literature analyzed in **Table 1** and discussed above shows that the performance of PD-NOMA with massive deployments, specifically if the nodes are deployed over more considerable distances, needs to be addressed. However, despite the remarkable capabilities of PD-NOMA, only a few studies has been performed to address this issue with clustering methods to achieve improved user association, system capacity, and sum rate in ultra-dense heterogeneous networks.

Table 1. Existing literature performed with PD-NOMA.

Research Work	Contribution	Sum Rate	Capacity	Clustering	Ultra-Dense HetNet	User Association
[11]	Proposed a unified NOMA framework for user association and resource allocation to achieve massive connectivity.				✓	✓
[12]	Energy efficiency maximization is achieved by proposing a joint optimization framework of PD-NOMA and beam forming.					✓
[17]	System level performance analysis with hybrid PD-NOMA and OFDMA schemes.		✓		✓	
[24]	PD-NOMA, game theory algorithms are proposed based on QoS threshold to improve user association and power allocation.	✓			✓	✓
[22]	Proposed a cluster specific beam-forming algorithm to maximize sum-throughput.	✓		✓	✓	

1.2. Challenges of PD-NOMA

NOMA faces a few challenges with the increased number of users; considering an ultra-dense network deployed with the PD-NOMA scheme, energy consumption at the user end becomes high due to extensive SIC calculations. As each user has to decode all other users' information associated with the same BS, if an error occurs in decoding any one user's information, then all additional decoding will therefore have an impact and eventually will harm the system level performance, specifically in achieving an efficient sum rate and capacity [23]. Thus, the computational complexity and power consumption will be increased at the receiver's end. The channel gain information is sent back to the BS, resulting in remarkable channel state information overhead. In addition, in downlink NOMA, for an arbitrary user 'k', it decodes the user signals with lower channel gain and processes the user signals with a relatively high channel gain as noise [25][26].

2. Power Domain-NOMA

Generally, PD-NOMA has achieved improved spectral efficiency (SE), enabling users to share resources efficiently. More commonly, a basic two-user downlink NOMA scheme is considered in much of the research, where two users are allocated such that the user U1 is deployed near the base station with high channel gain and U2 is far from the base station, experiencing a relatively low channel gain. Different powers are superimposed upon each other at the transmitter's end for users U1 and U2 as shown in **Figure 1**. The transmitter assigns high power to the weak user due to its high path loss component and comparatively low power to the strong user. The strong signal receiver will have a higher signal-to-noise ratio than the weak user, implying that the strong user can decode and subtract its signal more efficiently. The robust user's signal at the weak side is considered noise, as its transmission power is lower than the weak user's signal. Therefore, the weak user can decode its signal without performing SIC.

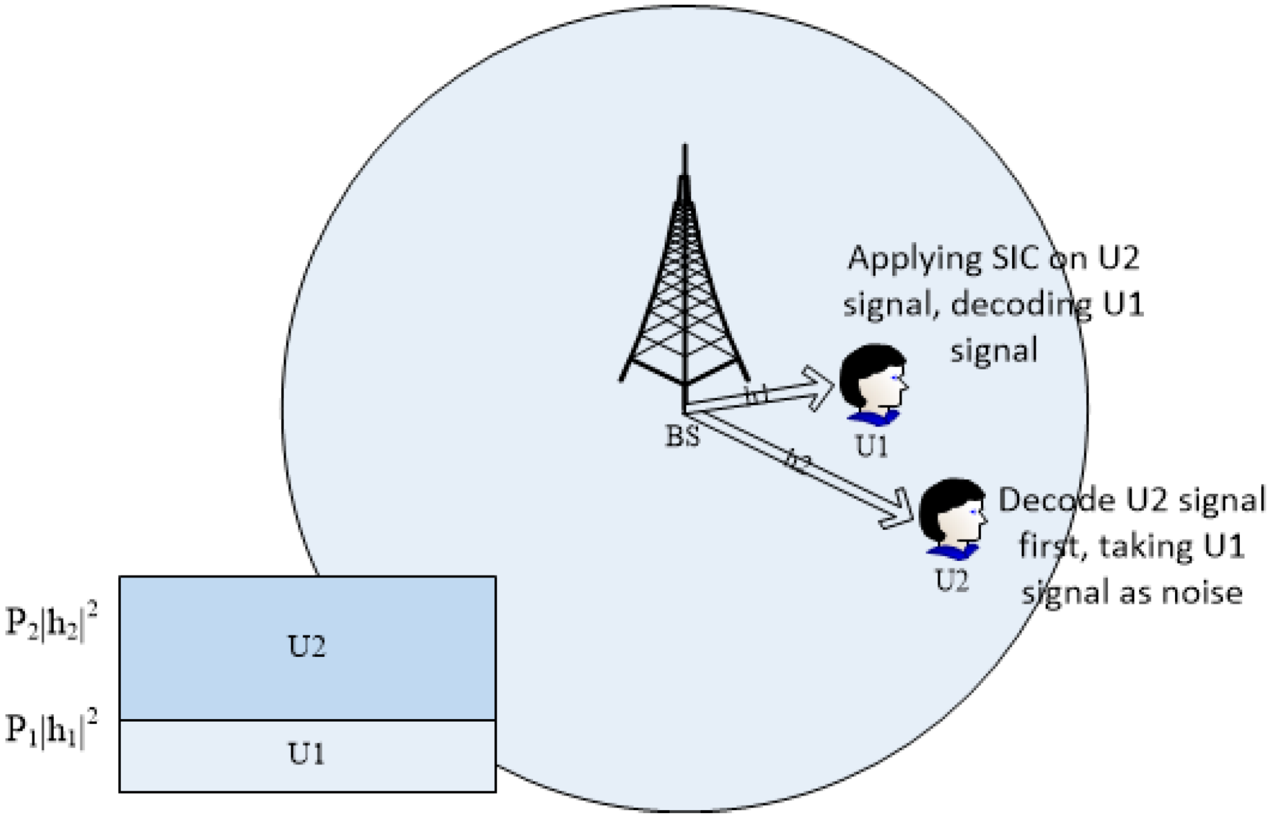

Figure 1. PD-NOMA with 2 users.

Thus, grouping or clustering active users in the same resource block is necessary in PD-NOMA and is usually performed as two or multiple users per cluster. The selection in the basic NOMA scheme, with single-antenna BS and users, depends on the rapid channel gains, and the users are ranked accordingly to allow proper SIC decoding, which tends to improve as the channel gain increases, unless the channel gain of the weak user is minimal [27]. Overall, the optimal user clustering requires a thorough search and might not be reasonable for practical systems and networks with many users [28]. Therefore, researchers resort to low complexity solutions to solve the user clustering problem through heuristic algorithms, leading to unexpected results. Instead, the NOMA clustering problem includes the following [27]: A large number of user decoding is considered to be complex, and therefore it is required to limit the exhaustive search to a much smaller region of the achievable set; this will simplify the problem and can lead to the optimum result.

References

1. Farhan, N.; Rizvi, S. An Interference-Managed Hybrid Clustering Algorithm to Improve System Throughput. Sensors 2022, 22, 1598.
2. Zhu, L.; Yang, L.; Zhang, Q.; Zhou, T.; Hua, J. Cluster-based energy-efficient joint user association and resource allocation for B5G ultra-dense network. Phys. Commun. 2021, 46, 101311.
3. Farhan, N.; Rizvi, S.; Shabbir, A.; Memon, I. Clustering Approaches for Efficient Radio Resource Management in Heterogeneous Networks. Vfast Trans. Softw. Eng. 2021, 9.
4. Aldababsa, M.; Toka, M.; Gökçeli, S.; Kurt, G.K.; Kucur, O. A tutorial on nonorthogonal multiple access for 5G and beyond. Wirel. Commun. Mob. Comput. 2018, 2018, 9713450.
5. Chaieb, C.; Abdelkefi, F.; Ajib, W. Joint user association and sub-channel assignment in wireless networks with heterogeneous multiple access and heterogeneous base stations. In Proceedings of the 2020 IEEE 31st Annual International Symposium on Personal, Indoor and Mobile Radio Communications, London, UK, 31 August–3 September 2020; pp. 1–6.
6. Saito, Y.; Kishiyama, Y.; Benjebbour, A.; Nakamura, T.; Li, A.; Higuchi, K. Non-orthogonal multiple access (NOMA) for cellular future radio access. In Proceedings of the 2013 IEEE 77th Vehicular Technology Conference (VTC Spring), Dresden, Germany, 2–5 June 2013; pp. 1–5.
7. Sadat, H.; Abaza, M.; Mansour, A.; Alfalou, A. A Survey of NOMA for VLC Systems: Research Challenges and Future Trends. Sensors 2022, 22, 1395.
8. Fang, F.; Ye, G.; Zhang, H.; Cheng, J.; Leung, V.C. Energy-efficient joint user association and power allocation in a heterogeneous network. IEEE Trans. Wirel. Commun. 2020, 19, 7008–7020.
9. Celik, A.; Tsai, M.-C.; Radaydeh, R.M.; Al-Qahtani, F.S.; Alouini, M.-S. Distributed user clustering and resource allocation for imperfect NOMA in heterogeneous networks. IEEE Trans. Commun. 2019, 67, 7211–7227.
10. Forouzan, N.; Rabiei, A.M.; Vehkaperä, M.; Wichman, R. A distributed resource allocation scheme for self-backhauled full-duplex small cell networks. IEEE Trans. Veh. Technol. 2021, 70, 1461–1473.
11. Qin, Z.; Yue, X.; Liu, Y.; Ding, Z.; Nallanathan, A. User association and resource allocation in unified NOMA enabled heterogeneous ultra dense networks. IEEE Commun. Mag. 2018, 56, 86–92.
12. Zhang, L.; Zhang, G.; Zhao, X.; Li, Y.; Huang, C.; Sun, E.; Huang, W. Resource allocation for energy efficient user association in user-centric ultra-dense networks integrating NOMA and beamforming. AEU-Int. J. Electron. Commun. 2020, 124, 153270.
13. Zhou, J.; Zhang, X.; Wang, W. Joint resource allocation and user association for heterogeneous services in multi-access edge computing networks. IEEE Access 2019, 7, 12272–12282.

14. Benjebbour, A.; Saito, Y.; Kishiyama, Y.; Li, A.; Harada, A.; Nakamura, T. Concept and practical considerations of non-orthogonal multiple access (NOMA) for future radio access. In Proceedings of the 2013 International Symposium on Intelligent Signal Processing and Communication Systems, Naha, Japan, 12–15 November 2013; pp. 770–774.
15. Islam, S.R.; Avazov, N.; Dobre, O.A.; Kwak, K.-S. Power-domain non-orthogonal multiple access (NOMA) in 5G systems: Potentials and challenges. IEEE Commun. Surv. Tutor. 2016, 19, 721–742.
16. Wei, Z.; Yang, L.; Ng, D.W.K.; Yuan, J.; Hanzo, L. On the performance gain of NOMA over OMA in uplink communication systems. IEEE Trans. Commun. 2019, 68, 536–568.
17. Marcano, A.S.; Christiansen, H.L. Impact of NOMA on network capacity dimensioning for 5G HetNets. IEEE Access 2018, 6, 13587–13603.
18. Vu, T.-H.; Nguyen, T.-V.; Kim, S. Cooperative NOMA-enabled SWIPT IoT networks with imperfect SIC: Performance analysis and deep learning evaluation. IEEE Internet Things J. 2021, 9, 2253–2266.
19. Liaqat, M.; Noordin, K.A.; Abdul Latef, T.; Dimyati, K. Power-domain non orthogonal multiple access (PD-NOMA) in cooperative networks: An overview. Wirel. Netw. 2020, 26, 181–203.
20. Wang, Z.; Yue, X.; Peng, Z. Full-duplex user relaying for NOMA system with self-energy recycling. IEEE Access 2018, 6, 67057–67069.
21. Le, C.-B.; Do, D.-T.; Zaharis, Z.D.; Mavromoustakis, C.X.; Mastorakis, G.; Markakis, E.K. System performance analysis in cognitive radio-aided NOMA network: An application to vehicle-to-everything communications. Wirel. Pers. Commun. 2021, 120, 1975–2000.
22. Song, D.; Shin, W.; Lee, J.; Poor, H.V. Sum-throughput maximization in NOMA-based WPCN: A cluster-specific beamforming approach. IEEE Internet Things J. 2021, 8, 10543–10556.
23. Higuchi, K.; Benjebbour, A. Non-orthogonal multiple access (NOMA) with successive interference cancellation for future radio access. IEICE Trans. Commun. 2015, 98, 403–414.
24. Wang, K.; Liu, Y.; Ding, Z.; Nallanathan, A.; Peng, M. User association and power allocation for multi-cell non-orthogonal multiple access networks. IEEE Trans. Wirel. Commun. 2019, 18, 5284–5298.
25. Zeng, H.; Zhu, X.; Jiang, Y.; Wei, Z.; Sun, S.; Xiong, X. Toward UL-DL Rate Balancing: Joint Resource Allocation and Hybrid-Mode Multiple Access for UAV-BS Assisted Communication Systems. IEEE Trans. Commun. 2022, 70, 2757–2771.
26. Sun, J.; Wang, Z.; Huang, Q. Cyclical NOMA based UAV-enabled wireless network. IEEE Access 2018, 7, 4248–4259.

27. Maraqa, O.; Rajasekaran, A.S.; Al-Ahmadi, S.; Yanikomeroglu, H.; Sait, S.M. A survey of rate-optimal power domain NOMA with enabling technologies of future wireless networks. IEEE Commun. Surv. Tutor. 2020, 22, 2192–2235.
28. Kimy, B.; Lim, S.; Kim, H.; Suh, S.; Kwun, J.; Choi, S.; Lee, C.; Lee, S.; Hong, D. Non-orthogonal multiple access in a downlink multiuser beamforming system. In Proceedings of the MILCOM 2013–2013 IEEE Military Communications Conference, San Diego, CA, USA, 18–20 November 2013; pp. 1278–1283.