Non Orthogonal Multiple Access Based Interference Mitigation Schemes in the Emerging 5G Cellular Mobile Networks

Ndagi Muhammad Hassan, Habeeb Bello-Salau, Caroline Omoanatse Alenoghena, and Bala Alhaji Salihu
Department of Telecommunication Engineering,
Federal University of Technology Minna, Nigeria
ndagi@futminna.edu.ng, habeeb.salau@futminna.edu.ng, carol@futminna.edu.ng, salbala@futminna.edu.ng

ABSTRACT— ***The emerging 5G mobile cellular network is envisaged to accommodate the increasing data traffic growth from the unprecedented proliferation of smart devices. The developments in the internet of things (IoT) have also led to the emergence of radio access technologies that can only be handled by a network with ultra-reliable low latency. The non- orthogonal multiple access (NOMA) technology is being proposed by 3GPP for 5G network because of its high spectrum efficiency. But interference management remains a major challenge in deploying NOMA techniques. This paper studies the working principles of NOMA techniques, reviews existing NOMA based interference mitigation schemes and proposes multi antenna zero-forcing beamforming vector, two user NOMA clustering algorithm and formulates an optimization problem for power allocation to mitigate inter-cluster and inter user interference in a NOMA based 5G mobile network.***

KEYWORDS— ***Non orthogonal multiple access; 5G network; interference mitigation; Zero-forcing beamforming; power allocation; successive interference cancellation***

I. INTRODUCTION

The increasing demand for higher data rates and capacity of wireless communication systems led to evolution from the first generation (1G) to the present fourth generation (4G) and Long term Evolution (LTE) networks. Multiple access techniques have been the major technology distinguishing these different generations. The frequency division multiple access (FDMA) used in 1G, time division multiple access (TDMA) mostly for 2G, code division multiple access (CDMA) in 3G and orthogonal frequency division multiple access (OFDMA) for 4G are primarily orthogonal multiple access (OMA) schemes [7]. However, the fast growth of mobile internet propelled by unprecedented proliferation of smart devices has given rise to anticipated 1000-fold data traffic by 2020 for the fifth generation (5G) networks [6]. Moreover, due to developments in the internet of things (IoT), the 5G is envisioned to support massive connectivity of users and devices. According to the standard organizational partners; the 3rd generation partnership project (3GPP), 5G network should support three key families of applications; enhanced mobile broadband networks, massive machine type communication, and ultra-reliable low latency communications [1].

The OFDMA in 4G supports heterogeneous networks informs of femtocells and picocells but will be unable to meet new demands for massive machine type communication in 5G due to the limitation in its orthogonal resource blocks [5]. Non orthogonal multiple access (NOMA) is being introduced as an effective approach to increasing spectrum efficiency and providing the massive connectivity required in 5G. Power domain NOMA superposes multiple user signals at the transmitter over same channel (same time-frequency resources) and uses multiuser detection algorithms known as successive interference cancellation (SIC) at the receiver to detect desired signal [13].
Although NOMA offers higher spectrum efficiency and ensures massive connectivity of devices, it is prone to more signal interference because users share same spectrum at different power levels. Interference mitigation remains a major challenge in the implementation of multiple access technologies to realize 5G mobile networks. Recent research works on interference mitigation tends towards the actualization of NOMA for 5G networks. Power domain NOMA is believed to be a promising multiple access scheme for 5G. Specifically, a downlink version of NOMA known as multiuser superposition transmission (MUST) has been approved by 3GPP LTE Release 14 to identify techniques that will enable LTE support MUST. A downlink NOMA with two superposed user signals is shown in Figure 1.

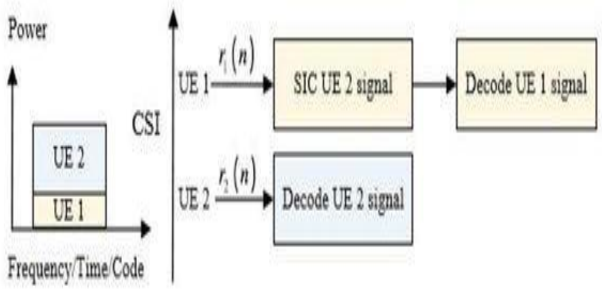

Figure 1: Downlink of a Non-orthogonal Multiple Access

The capacity gain of NOMA over conventional OMA can be illustrated by a simple SNR analysis. With OMA, two users A and B have achievable data rates as $\frac{1}{2}\log_2(1+\rho|h_A|^2)$ and $\frac{1}{2}\log_2(1+\rho|h_B|^2)$ respectively, where $\frac{1}{2}$ indicates a split of the bandwidth resources between users A and B. ρ is the SNR, h_A and h_B are channel gains for users A and B respectively. Assume $|h_A|^2 < |h_B|^2$, At high SNR $\rho \to \infty$, the sum rate can be approximated as $\frac{1}{2}\log_2(\rho|h_A|^2) + \frac{1}{2}\log_2(\rho|h_B|^2)$. While with NOMA, the achievable rates are $\log_2\left(1+\frac{\rho\alpha_A|h_A|^2}{1+\alpha_B\rho|h_B|^2}\right)$ and $\log_2(1+\rho\alpha_B|h_B|^2)$, respectively where α_A and α_B are the power alloaction coefficients. At SNR $\rho \rightarrow \infty$, the sum rate is approximated as $\log_2(\rho|h_B|^2)$, which is much more than the sum of OMA. The reason for the performance gain of NOMA over OMA can be attributed to the $\frac{1}{2}$ factor outside the logarithms of the sum rate for OMA which is due to the splitting of bandwidth resources between two users.

The basic operational principle of NOMA techniques entails multiple users been clustered and simultaneously served over the same time –frequency resources by either having their messages superposed in the power domain or code domain [7]. The inherent mutual intra-cluster and inter-cluster interference can only be managed with properly designed resource allocation techniques in conjunction with successive interference cancellation (SIC) schemes [7].
In this paper, the working principle of NOMA is described in section II, a review of NOMA based 5G interference mitigation techniques is in section III. The proposed interference aware NOMA multi antenna beamforming, two user clustering algorithm and optimized power allocation scheme is captured in section IV. Conclusions with recommendation for future works is in section V.

WORKING PRINCIPLE OF NOMA

A. Downlink NOMA Principle

The general principle of NOMA is to allow superposition of unique message signals at the BS of users in a NOMA cluster and decode desired message signal at the receiver by applying SIC. In downlink NOMA, BS transmits a superimposed signal

$$x = \sum_{i=1}^{U} \sqrt{p_i} x_i \qquad (1)$$

where x_i is the unit message signal intended for user i, p_i is power allocated to user i and U is total number of users in a NOMA cluster. The power allocated to a user depends on power of other users due to power constraint at BS,

$$p_t = \sum_{i=1}^{U} p_i \qquad (2)$$

where p_t is BS total power. The received i^{th} user signal is given by

$$y_i = h_i x + w_i \qquad (3)$$

where h_i is the channel gain between BS and user i, and w_i denotes Gaussian noise at the reciever for user i [16].

B. Uplink NOMA Principle

In the downlink, NOMA utilizes a power allocation and control mechanism to enable higher transmission power to be allocated to users with poor channel condition and low power to channels with higher gain [4]. Thus in a given cluster the strong interfering signals comes from the high power message signal of the relatively weak channel users. Subsequently, the user with the highest channel gain cancels all interferences while the lowest channel gain users receive all the interferences.
In the uplink NOMA, each user transmits x_i signal with p_i transmit power such that the received signal at BS can be defined by

$$y = \sum_{i=1}^{U} \sqrt{p_i} h_i x_i + w_i \qquad (4)$$

where w denotes reciever noise. The power transmitted per user is limited by their maximum battery power. Power control mechanism can be developed to enhance the performance of NOMA by allocating power coefficient to users mitigate intra-cluster interference.

C. Successive Interference Cancellation in NOMA

Successive interference cancellation (SIC) is one of the principles of NOMA implemented at the receiver terminal. The basic idea of SIC is that user signals are successively decoded. A user's signal is decoded and subtracted from the combined signals before the next user's signal is decoded. During SIC, one user's signal is decoded treating the other user's signal as an interferer, which can also be decoded with the help of the first having been already removed [11]. Prior to SIC implementation, the users are ordered according to their signal strength so that the receiver can decode stronger signals first, subtract it from the combined signals and isolate the weaker one from the residue. In brief the processes involved in decoding superposed messages can be mathematically expressed as follows: [18]. At user 1, single-user decoder g_1 decodes the message $S_1(n)$ by treating $S_2(n)$ as noise. User 2, performs the following steps to successfully recover its message from the receive signal $Y_2(n)$:

i. Decode user 1's message $S_1(n)$ by using single-user decoder g_1

ii. Subtract $\sqrt{p\beta_1} h_2 S_1(n)$ from the received signal $Y_2(n)$

$$Y'_2(n) = Y_2(n) - \sqrt{p\beta_1} h_2 S_1(n) \qquad (5)$$

a. Where h_2 is the complex channel gain at user 2

iii. Decode user's 2 messages $S_2(n)$ by applying another single user decoder on $Y'_2(n)$

SIC based receivers are prone to error propagation which may degrade the performance of some users. Therefore in designing SIC, some non-linear detection algorithms with higher detection accuracy can be considered to suppress the error propagation [7]. A typical NOMA based 5G network is illustrated in Figure 2.

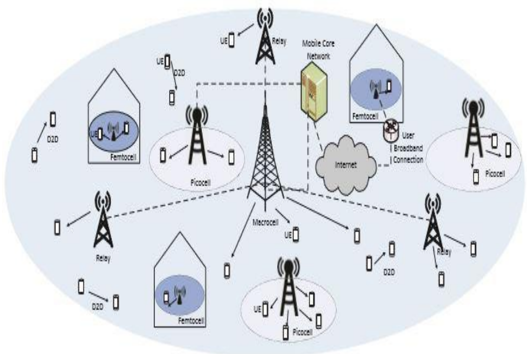

Figure 2: A proposed NOMA based multi-tier 5G mobile network.

II. REVIEW OF NOMA BASED INTERFERENCE MITIGATION SCHEMES

In [14] an uplink power control (PC) scheme for NOMA users was proposed, the scheme makes use of evolutionary game theory to dynamically adjust the transmitted power level of users which helps in mitigating user interference. The adaptive PC scheme was effective in increasing spectral and network efficiency but incurred higher complexity due to the SIC at the user end. In order to evaluate the outage performance of NOMA due to interference, [8] derived expressions for the ergodic sum rate and outage probability to demonstrate the effectiveness of NOMA with fixed power allocation. The fairness among multiple users in NOMA was considered by [17]. They developed low-complexity polynomial for adapting power allocation coefficients to control interfering users. The solution was only optimal with instantaneous and average CSI.

In [3] joint subcarrier and power allocation assignment in downlink NOMA was addressed. The solution uses matching theory by assuming equal power split and applying user subchannel matching algorithm that converges to a stable matching followed by a water-filling phase for power allocation. In order to strike a balance between computational complexity and optimality, [10] employed monotonic optimization to develop the optimal joint subcarrier and power allocation policy. Simulation results reveals the suboptimal algorithm achieves a close to optimal performance and provided substantial throughput improvement when compared to conventional multicarrier orthogonal multiple access (OMA). [9] assuming a perfect knowledge of CSI at the BS proposed a low complexity sub-optimal algorithm for energy efficient channel assignment and power proportional factors determination for subchannel multiplex users.

Using the channel gain difference among users in NOMA cluster, [2] derived the optimal power allocation policy that maximizes sum throughput per NOMA cluster and in turn maximizes the overall system throughput. Numerical compared the performance of NOMA over orthogonal multiple access and indicates significant improvement. In [8] an opportunistical user pairing model by statistically allocating transmission powers among NOMA users was proposed. Simulation results shows the scheme significantly improved system throughput when compared with conventional OMA.

In [19] multi-input multi-output (MIMO) technology with zero-forcing beamforming and minimum mean square error (MMSE) SIC scheme in NOMA to mitigate interference between clusters was applied. They proposed an interference predicted minimum mean square error (IPMMSE) SIC by modifying the MMSE weight factor using interference signals. The simulation results shows that the bit error rate (BER) is degraded putting into consideration the performance of practical SIC schemes. [21] investigated system level throughput performance of NOMA with minimum mean square error based linear filtering (MMSE-SIC) in the uplink NOMA. They employed a weighted proportional fair (PF)-based multiuser scheduling scheme to achieve a good tradeoff between total user throughput and cell-edge user throughput. The simulation results reveals significant enhancement in system level throughput compared to the orthogonal access which widely used in 3.9 and 4G mobile communication systems. [12] applied genetic algorithm (GA) for cluster user pairing and iterative gradient ascent method (IGAM) as an optimal power allocation technique for each user group in NOMA downlink systems. Simulation results shows that GA based NOMA achieves the same performance with the conventional exhaustive search methods with slightly lower complexity.

[19] developed a joint user association and power control optimization algorithm to determine the traffic load in energy corporation enabled Helnets. The algorithms achieved higher energy efficiency than existing OMA schemes but the computation complexity contributes to the overhead that may not be realizable for practical applications. [10] investigated zero-forcing beamforming and random beamforming making use of the imperfect CSI feedback with semi-orthogonal user selection algorithm to reduce the interference between NOMA users. Numerical results shows NOMA systems with limited CSI still gains larger rate over OMA schemes but only suitable with random beamforming which is not good in mitigating inter-beam interference. [20] proposed a novel receiver design for NOMA systems. The advantage of the receiver is that it has less complexity when compared with ideal SIC, although the complexity is still high for practical applications.

III. PROPOSED NOMA BASED INTERFERENCE MITIGATION SCHEMES

The proposed interference aware and mitigating schemes comprise algorithms that will be developed for a multi antenna zero-forcing beamforming technique at the transmitter to mitigate inter-cluster interference. A two user per cluster selection algorithm to reduce inter-user interference. An optimized power allocation method for the selected users in a cluster.

A. AMulti-Antenna Array Zeroforcing Beamforming (ZFBF)

In order to mitigate inter-cluster interference with the ZFBF in a two users per cluster NOMA based system, the stronger channel gain (h) user will be used to generate the BF vector. Assuming a perfect CSI, and based on channel matrix of the stronger user in the cluster the BF-vector (w_k) must satisfies the conditions in equation 7.

$$\frac{H_{n,1}}{|H_{n,1}|}.w_k = \{0, \text{ for } n \neq k1, \text{ for } n = k(7)$$

Assume $H = [h_{1,1}{}^T \ldots h_{1,N}{}^T]^T$ where $(.)^T$ means transpose of a matrix.
Then

$$w = H^+ = H^*(HH^*)^{-1} \qquad (8)$$

Where $(.)^{+}$ and $(.)^{*}$ are the pseudo-inverse and conjugate transpose of H

B. User Clustering Algorithm

In developing a user clustering algorithm, two users will be considered per cluster; a strong channel user k_1 and weak channel user k_2. Strong users in a cell will be distributed into different NOMA clusters. Key point of the proposed clustering algorithm is to pair highest channel gain user with lowest channel gain user in a cluster. Second highest channel gain user with second lowest channel gain user in the same cluster and so on. Based on these guidelines, users will be grouped into two sets: Group A and Group B, the users in group A denoted will have much higher channel gains compared to users in group B.

C. Optimized Power Allocation Algorithm

Based on the two user per cluster downlink NOMA, the channel gains of users k_1 and k_2 can be assumed to be γ_1 and γ_2 respectively. while $P_1$and P_2 are the transmission powers of γ_1 and γ_2 respectively. The NOMA principle gives higher power allocation to the weaker channel users, therefore an algorithm for optimal power allocation problem can be formulated by allocating $\frac{2}{3}$ of total power P_t to the weak user.

$$\max \omega B \sum_{i=1}^{2} \quad \log_2\left(1+\frac{P_i\gamma_i}{\sum_{j=1}^{i-1} \quad P_j\gamma_i+\omega}\right) (9)$$

Subject to: C_1: $\sum_{i=1}^{2} \quad P_j = \frac{2}{3}P_t$

Where ω is the resource block each of bandwidth B allocated to a cluster.

IV. CONCLUSION

Although NOMA techniques is being proposed as a candidate for 5G network, its advantage of having very high spectrum efficiency can only be harnessed with careful interference aware resource allocation design. In this paper we reviewed some of the NOMA interference aware designs and proposed a multi antenna zero-forcing beamforming array with a two user cluster algorithm and an optimized power allocation scheme.

References

[1] G. A. Akpakwu, B. J. Silva, K. P. Hancke, and A. M. Abu-Mahfouz, "A Survey on 5G Network for Internet of Things: Communication Technologies and Challenges" IEEE ACCESS, vol.1, No.4, pp. 3619-3647, 2018.

[2] M. S. Ali, E. Hossain, M. J. Hossain, T. Tabassum, and D. I. Kim, "Non-orthogonal multiple access (NOMA) in cellular Uplink and Downlink: Challenges and Enabling Techniques" http://128.84.21.199/abs/1608.05783. 2016.

[3] L. S. Bayat, and Y. Li, "Radio Resource Allocation for Downlink Non-orthogonal Multiple Access (NOMA) Networks Using Matching Theory," IEEE Global Communication Conference, Vol 2. No.6, pp. 1205-1225, 2015.

[4] K. Benjebbour, K. Saito, A. Li, Y. Kishiyama, and T. Nakamura, "Non-orthogonal muiltiple access (NOMA): Concept Performance Evaluation and Experimental trials" IEEE International Conference on Wireless Networks and Mobile Communication, 2016.

[5] Y. Cai, Z. Qin, F. Cui, G. Ye Li, and J. McCann "Modulation and Multiple Access for 5G Networks" IEEE Survey and Tutorials Vol. 20 No.1 pp. 629-645, 2018.

[6] T. Dateki, H. Seki, and M. Minowa" From LTE -Advance to 5G : Mobile Access system in progress" Journal of fujitsu Science and Technology, Vol. 52 No.2 pp. 92-108, 2016.

[7] L. Dai, B. Wang, Y. Yuan, S. Hen, I. Chih-Lin and W. Zhaocheng "Non-orthogonal Multiple Access for 5G: Solutions, Challenges, Opportunities, and future Reseach" IEEE Communication Magazine, Vol. 9 No.53 pp. 74-81, 2015.

[8] Z. Ding, P. Fan, and H. V. Poor " Impact of User Pairing on 5G non orthogonal Multiple Access downli nk Trans mission" IEEE Transaction Vehicular Technology Vol. 65, No.8 pp. 1-12, (2014).

[9] F. Fang Z. Haijun, and C. M. Victor, "Energy Efficient Resource Allocation fpr Downlink Non-Orthogonal Multiple Access Network" IEEE Transactions on communications, Vol. 64, No. 9, 2016.

[10] S. Liu, and C. Zhang, "Non orthogonal Multiple Access in A Downlink Multiuser Beamforming system with Limited CSI Feedback" EURASIP Journal on communications and Networking, pp. 236, 2016.

[11] N. I. Mirikidis, and D. D. Vergados, " A Survey on Successive interference Cancellation Performabce frp Single-antenna and Multiple-antenna OFDMA systems" IEEE Communication surveys Tutorials Vol.15 No.1 pp. 312-335, 2013.

[12] F. G. Omer, K. Fatih, H. Ibrahim, and K. K. Gunes, "Resource Allocation for Downlin k NOMA System: Genetic Algorithm Approach" IEEE International Conference on Telecommunication and Signal Processing, **ISBN:** 978-1-5090-3982-1, 2017.

[13] S. M. Riazul Islam, N. Avazov, O. A. Dobre, and K. Kwak, "Power Domain Orthogonal Multiple Access (NOMA) in 5G Systems:Potentials and Challenges" IEEE communication Surveys and Tutorials, (2016) (2016) Vol. 19, No.2 pp.721-742, 2016.

[14] S. Riaz, and U. Park, " Power Control for Interference mitigation by evolutionary game theory in Uplink NOMA for 5G Networks" Journal of Chineese Institute of Engineers, Vol. 41, No.1 pp. 18-25, 2018.

[15] X. Su, , H. Yu, W. Kim, C. Choi, and D. Choi, " Interference Cancellation for Non –orthogonal Multiple access used in Future Wireless mobile Networks" Journal on wireless Communications and Networking, Issue 232 pp. 1-12, 2016.

[16] H. Tabassum, M. Shipon, E. Hossain, M. J. Hossain, D. I. Kim, "Non orthogonal Multiple Access (NOMA) in Uplink and Downlink: Challenges and Enabling Techniques" IEEE Transacions in Communications, Vol. 65, No.8 pp. 3555-3570, 2016.

[17] S. Timotheou and I. Krikidis "Fairness for Non-orthogonal Multiple Access in 5G Systems" IEEE Signal Processing Letters, Vol. 22 No.10 pp.1647-1651, 2015.

[18] S. Vanka, S. Srinivasa, Z. Gong, P. Vizi, K. Stamatiou, and M. Haenggi, "Superposition Coding Strategies: Design and Experimental Evaluation" IEEE Transaction on Wireless Communications, Vol.11, No.7, pp. 2628-2639 2012.

[19] B. Xu, Y. Chen, C. J. Riquena, and T. Zhang "Resource Allocation IN Energy Corporation Enabled Two- Tier

NOMA Helnets Towards Green 5G" IEEE Journal on Selected Areas in Communications, Vol. 35, No.12, pp. 2758-2770, 2017.

[20] C. Yan, A. Harada, A. Benjebbour, L. Yang, A. Li, and H. Jiang, "Receiver Design for Downlink Non orthogonal Multiple Access (NOMA)" IEEE 81st Vechicular Technology Conference (VTC Spring), **ISBN:** 978-1-4799-8088-8, 2015.

[21] E. Yuki, K. Yoshihita, and H. Kenichi "An Uplink Non orthogonal Access with MMSE-SIC in the Presence of Inter-cell interference" IEEE International Symposium on Wireless Communication Systems (ISWCS), **ISSN:** 2154-0225, 2012.