

Rate Performance and Spectral Efficiency of Non-Orthogonal Multiple Access for 5G Communication



R. Prameela Devi, N. Prabakaran

Abstract: Multiple access is a key procedure which is used from 1G to 4G communication. Different multiple access techniques in different generations create difference in data rate, connectivity, outage performance etc. 5G is the recent technology in which a new multiple access technique must be used to increase the outage performance, massive connectivity and data rate for next generation. This paper gives clear idea about the Non-Orthogonal Multiple Access (NOMA) technique and different challenges to overcome in NOMA and also a brief description of different power allocation techniques is mentioned. The data rate performance of OFDMA and NOMA are evaluated and shown how spectral efficiency can be increased using NOMA.

Index Terms: NOMA, Single carrier NOMA, Multicarrier NOMA, Power domain.

I. INTRODUCTION

NOMA is the technique which can drastically improve the performance of the next generation wireless communication by increasing the data rate, capacity and decrease the round-trip delay.

Earlier to NOMA i.e. from first generation to fourth generation all the multiple access techniques are of orthogonal type of resource allocation like Frequency Division Multiple Access (FDMA), which is used in initial generation of communication, Time Division Multiple Access (TDMA) which is used in second generation, Code Division Multiple Access is used after 2nd generation and Orthogonal Frequency Division Multiple Access (OFDMA) used in current generation of communication i.e. 4th generation. Even in 4th generation OFDMA is used for downlink and for uplink SC-FDMA is used. For the next generation communication NOMA technique is chosen by many researchers of all over the world. Furthermore, NOMA is considered for the layered division Multiplexing (LDM) for TV standards (ATSC3.0) [11]. That is the spectrum of TV broadcast can also be increased by using NOMA.

NOMA has many markable advantages compared to orthogonal Multiple Access as follows.

1. Spectral efficiency: In orthogonal multiple access the resource is dedicated to a Particular user where there is no possibility of reusing the resource. If such reusing is possible where the same resource can be allocated to different users based on the channel conditions, then more spectral efficiency can be achieved, and so throughput increases.
2. User resource fairness and Low latency: Latency can be reduced in 5G using NOMA since the same resource can be allotted to different user and no user need to wait for the other user's completion of accessing, i.e. all the users are allocated to the same spectrum can use the resources parallelly without blocking the other user's data. Interference may occur due to this procedure but can be taken care by implementing an appropriate process at receiver. Therefore, fairness among users can be achieved and at the same time latency can be reduced.
3. Compatibility: Compared to OMA, NOMA is compatible to the current and next generation systems as there are no much changes required to do in the same existing system [12,13]. Even though there are many limitations in NOMA like decoding other user signals before its own signal, applying Successive interference Cancellation at receiver in case if there are many users, channel state information overhead etc. NOMA is considered as a best multiple access technique in fifth generation as many of the techniques used in NOMA is compatible with the next generation technologies as per 3GPP LTE Release 15. The main Aim of this paper is to present NOMA principles and innovations. Section II is about types of NOMA for future generation and in section III NOMA implementation challenges are discussed. In section IV, how to allocate the resources optimally is discussed and the performance metrics which are to be improved in NOMA are discussed in section V. Section VI concludes the paper.

II. TYPES OF NOMA

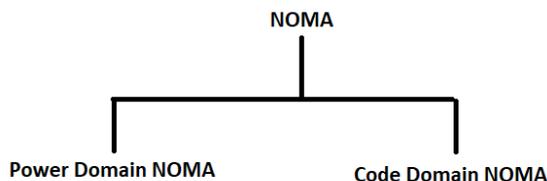


Figure.1 Classification of NOMA

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1. Power domain NOMA

In power domain NOMA power is shared to the users based on the channel conditions and at transmitter all the users' data is added up and then transmitted using superposition coding and at receiver side [21] the superimposed signal is used to retrieve the information of user based on the SIC method which depends on channel conditions. But the power control at transmitter side and receiver side in uplink is different to that of in downlink. Downlink transmission power has only one constraint that the maximum power used in the base station. The signals of different users' equipment have the same channel gain which forces the receiver to create more difference among the different users' equipment for better signal. The two-user equipment signals separation at receiver are superimposed as

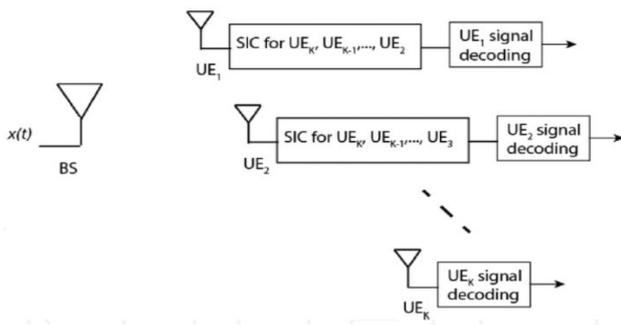


Figure.2 Downlink NOMA with K users

$$x = p_1x_1 + p_2x_2$$

i.e. this is the transmitted signal and the received signal is as follows

$$Y = h_i x + w_i$$

Here h_i decides how much signal x is efficiently received from the base station and w_i is AWGN. At receiver side multiuser separation must be performed to separate the signals. The same technique can be applied for multiple number of users where it is clearly shown in the above Fig.2.

In uplink each user has different transmission power that is the power control is constrained by the maximum transmission powers of every user equipment.

Base station receives different UE signals and so the received power from different UES is already differentiated [17,18]. As all UEs are allowed to transmit simultaneously to the base station receiver, there are more chances of having inter channel interference (ICI) compared to that of ICI in downlink as there is fixed base station transmission power.

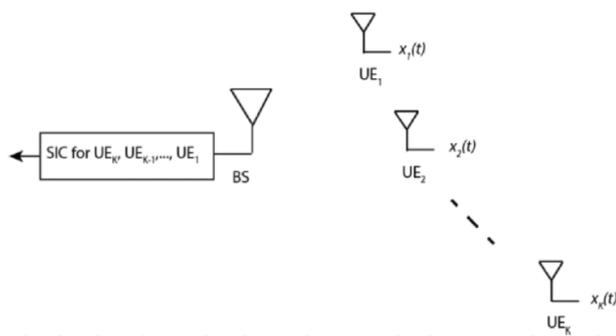


Figure.3 NOMA with multiple users in uplink

The transmission signal from the base station is

$$Y = N_i P_i X_i$$

Base station received signal from different users

(let x_1 and x_2) is as follows

$$Y = h_1 p_1 x_1 + h_2 p_2 x_2 + w$$

Where h_i represents the channel dependent parameter between user and the base station, w_i is the noise which is generally taken as additive white gaussian noise with ICI

2. Code domain NOMA:

NOMA can be achieved in code domain with better performance by user specific spreading sequences with low density and low correlation properties. This type of procedure was seen in CDMA [12] which was introduced in 90's only difference is receiver receives the superposed code and the receiver does not know the active key code until it has received. It must detect and receive the code using some algorithms like compression sensing, SCMA, LDS CDMA etc. Based on that NOMA in code domain is classified as shown in Fig.3.

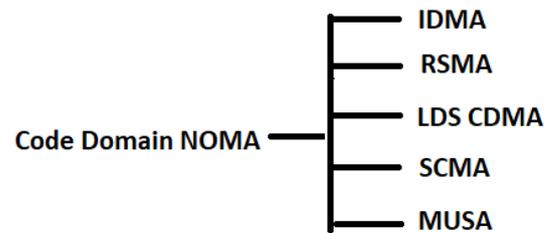


Figure.4 Classification of code domain NOMA

A. Interleave Division Multiple Access (IDMA)

It is similar to CDMA with low spreading gain and low rate forward error correction. IDMA reduces the Multiple access interference by assigning different interleavers to different users. All users use same sequence to spread is dispersed to producing chi-by-chip detection.

There are many advantages of IDMA as follows:

- IDMA allows different rates compared to other coding techniques and it has better BER performance even at less signal to noise ratio.
- Complexity of the receiver is less as it uses low data rate decoder with which most of the interferences can be reduced.

B. Multi User Shared Access (MUSA)

To distinguish different users in MUSA, non-binary complex values are used. As there is involvement of imaginary part in MUSA the total size of the spreading sequence can be reduced to reduce the correlation between the users. These complex values can be chosen from constellation of QAM along with origin i.e. the matrix which is expanded is a complex valued matrix with less size. That is each user symbol is spreaded by a spreading sequence which is collected randomly from a set of spreading sequences.

Same user may get different spreading sequences for different symbols which leads to better performance through interference averaging. All the set of spreading sequences have low cross correlation. At the receiver side a little complexity increases to perform SIC operation as it may not receive the symbols spreaded with the same sequence all the time. Compared to OMA systems MUSA can improve the performance of a system and reduce the overload.

C. Rate Splitting Multiple Access (RSMA)

This method is introduced by [11]. The process in this method is transmitting a stream which consists of a part of all messages. This combined stream is transmitted along with the remaining parts of each message as separate streams. At receiver side, combined message is decoded first and then all the other message streams are decoded by cancelling the effect of combined message.

D. Sparse Code Multiple Access (SCMA)

It is a technique where each sub carrier can be allotted to many users by assigning unique code book to each user. SCMA method achieve better sum rate performance compared to power domain NOMA [14] but the complexity of the receiver is more in SCMA method.

E. Low Density CDMA (LDS-CDMA)

LDS-CDMA is a low-density spreading sequence is used to spread the symbols of a user time domain, then to maintain the same processing gain zero padding is attached. Compared to conventional CDMA this method uses less complex multiuser detection.

F. Multi Input Multi Output NOMA. (MIMO): MIMO-NOMA technique is used to improve the capacity. Many research studies are going on MIMO-NOMA to improve the performance with more capacity.

In MIMO NOMA [10] many users are arranged as a group and sharing the same transmitted beamforming vector with Zero forcing precoding and alignment of the signals are used at the base station and the users which are in the same group gives the same performance as that of single user and single base station.

III. CHALLENGES TO OVERCOME

Some challenges which are to be faced during implementation of NOMA from survey are,

In [2] uplink and downlink implementation explained along with their differences. downlink NOMA is more complex because of using iterative detection process at many users. It also shown that SIC receiver implementation is different in uplink with that of downlink is more in uplink as many users' signals are superimposed and transmitted. But it is not that much effective in downlink. The above mentioned complexity of decoding of the received signals and error propagation is explained in paper [1].

In [10] the following challenges are mentioned. Firstly, due to some hardware and the offset frequency used in the carrier and offset in time, NOMA systems cannot estimate the channel directly. Challenges in error propagation in SIC implementation is discussed. This can be improved by improving the estimation quality of the impairment is shown as an effective method to obtain the desired level of

performance. Secondly, there are many signals overlapped so there is more probability of degrading the error performance of NOMA. To improve the performance of the system CSI must be maintained good in such a way that the pilot bit positions and number of pilot's information is very much important in design considerations like tracking the channel characteristics efficiently and then allocating the pilots. Thirdly, assigning the frequency bands to the current user which are already allocated to a user creates a serious problem. CSI of current user must be estimated with transmissions which are done orthogonally. For future NOMA this problem needs to be considered.

IV. OPTIMAL RECOURSE ALLOCATION

In [2] using non convex optimization method, total transmission power is reduced by designing a new power allocation, rate allocation and at decoding place using successive interference cancellation method, even if there is no channel state information. But the complexity of the computations is more. To improve the system performance and reduce the complexity of computations a suboptimal resource allocation is designed. In [3], optimization is done by separating the object function into two convex functions and then achieve optimization globally and thus system performance can be improved. In [4] power allocation solution is optimized by treating each user separately for SIC implementation and which ever get low power computations that is chosen as optimal solution.

Proportional fairness: In [5] user pairing must be done as a prior requirement and then optimal solution is chosen for power allocation. Max-min and min-max method is used to get user fairness. Power allocation from fairness point of view by increasing the minimum achievable user rate with instantaneous Channel state information (CSI) and reducing the maximum outage with average CSI.

In [6] studied outage balancing problem of downlink joint power allocation and decoding order selection. Power allocation can be done in many ways like Arbitrary Power allocation technique (APA), Fractional transmit power allocation (FTPA), negative power adjustment of water filling power allocation, Generalized power allocation.

In arbitrary power allocation method [7,8] the total available power P is arbitrarily assigned to all the users of the system. Let there are 2 users u_1 and u_2 , then the power allocation will be 20% to 80% of total power allocation respectively. For this no specific logic is used to divide the power. It is fixed allocation of power. This process will become difficult to assign powers for the application of many users. In such case this method is not worthy.

In FTPA, depending on the channel gains of each user fractional coefficient is assigned to every user i.e. the total available power is fractionally divided to every user. But fairness index is chosen arbitrarily while assigning the fractional points. Another method of power allocation is water filling method with small negative power adjustment. This method runs faster than the water filling method.

If number of channels increased, running time of water filling technique increases and such increase in execution time is reduced in negative power adjustment method. This method eliminates the need to perform iterative search process of classic water filling method, i.e. computational complexity is reduced.

In Generalized power allocation method (GPA) [8] power allocation is done using a choice factor in which there is no arbitrary selected values present. Choice factor is selected based on the total power and the number of users. Power to each user is allotted based on a simple formula consisting of choice factor and total number of users. Even the GPA is simple it is yielding similar results compared to all other power allocation methods. i.e. even with simple calculation the desired results can be obtained.

V. PERFORMANCE METRICS

Performance of NOMA can be measured in three aspects like outage probability, bit error probability and spectral efficiency. For instance, power which is allotted to a near-user to the power which is allotted to a far-user is 1:4. Then the outage performance at high SNR values shows best performance compared at low SNR values. The data rate of far-user is always better than the data rate of near-user as the assigned gain of far-user is better than near-user all these rate performances is evaluated in the paper [1]. the following figure shows the rate performance of two users considering the far-user and near-user having same distance from the base station. From the below figure it shows that NOMA has higher rate pair compared to OFDMA.

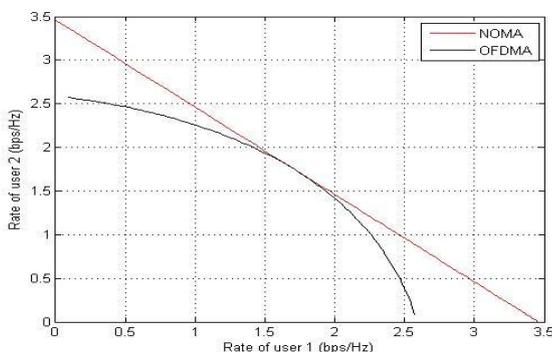


Figure.5(a) Rate pairs for downlink of OFDMA and NOMA.

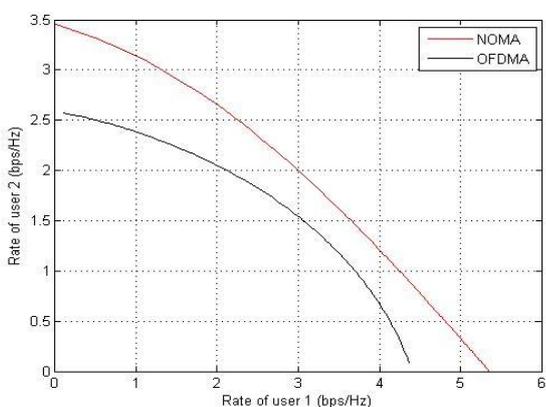


Figure.5(b). Rate pairs for downlink of OFDMA and NOMA.

Table.I Symmetric and Asymmetric channel for OFDMA and NOMA

users	Symmetric channel rate in (bps/Hz)		Asymmetric channel rate in (bps/Hz)	
	OFDMA	NOMA	OFDMA	NOMA
With SNR 10				
User1	3	3	4	4
User2	1.2	1.4	0.8	1.4
With SNR 20				
User1	2.5	2.5	3	3
User2	0.4	1	1	1.4

From the above Table it is understood that there is no much difference in the performance of NOMA with OFDMA even the power resource is taken for multiple accessing for both symmetric and asymmetric channels.

Energy Efficiency (EE) is calculated as ratio of sumrate to the total power consumption [19,20] of a base station. The total transmission power of the base station is given as

$$P_{total} = P_{signal} + P_{static}$$

i.e. it is the sum of power consumed by the signal and the static power which is consumed by the circuitry.

$$EE = R_T / P_{total} \text{ (bits/joule)}$$

Spectral efficiency (SE) is given as

$$SE = R_T / W \text{ (bps/Hz)}$$

From the Fig.6 it is shown that as EE increases SE increases for half of the curve as shown in the figure. After certain point the SE increases there will be decrease in the EE. From the figure it is clear that the NOMA has higher EE compared to OFDMA.

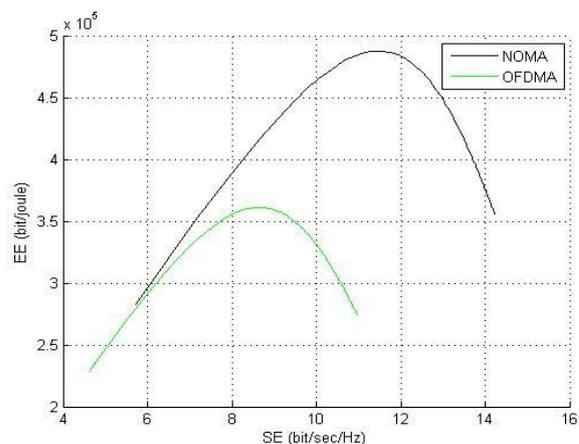


Figure.6 EE-SE curves for OFDMA AND NOMA

VI. CONCLUSION

Orthogonal Multiple Access techniques use time, frequency or code as a resource for multiplexing orthogonally, which is not used efficiently. The available radio resources can be utilized efficiently when Non-Orthogonal Multiple Access techniques are used. Some of the limitations like a smaller number of users are served parallelly using the same technique, poor channel conditions etc., can be overcome by NOMA with less error rate compared to OMA.

In this paper the key challenges, performance metrics are detailed in which data rate performance of NOMA is better than OFDMA in case of two users was evaluated and how the spectral efficiency is better than that of NOMA is shown. An in-depth literature survey is provided for further research to improve the spectral efficiency. Near future NOMA plays an important role in next generation wireless communications.

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