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A Comprehensive Realization of Resource Spread Multiple Access / NOMA performances in 5G

Elayaraja C., Amali C., Sridevi D., Geetha.T. S.

Abstract: Since 4G has limited in capacity, restricted in resource utilization, reasonable latency and so on. In order to yield high performance factors of the above-said, a Non Orthogonal Multiple Access (NOMA) plays an important role in 5G communication networks. The NOMA is otherwise called as Resource Spread Multiple Access (RSMA), whose performance is quite fit while envisioned for the forthcoming communication (i.e., 5G and above), which fulfil the requirements of the current 5th Generation, in view of capacity improvement, power allocation, lower latency, outage probability for both uplink and downlink configurations. This paper gets into the analytical and simulation analysis of the power domain NOMA technique to two users case on sum capacity and outage power probability for conventional un-ordered (not fixed) and ordered (fixed). Based on the position of the users as near base stations and cell edges are analyzed, subjected not to compromise the quality of service (QoS), maximize the spectrum utilization, out-and-out resource allocation, good energy efficiency and so on. Here an interesting view on both the channel gain and SNR are possessed higher degree of consent on outage power and successive interference cancellation. When the channel gains are equal on both the users, correspondingly SNR and outage probability varies. On the other hand, when the gain of the weaker user channel is higher than the gain of the stronger user channel, then a cross over point arises significantly. Moreover, the Successive Interferences Cancellation (SIC) has increased by reducing the Signal to Noise ratio (SNR) and vice versa. This ideology is suited for the applications of 5G requiring asynchronous and grant-free access like IOT and mission critical control.

Keywords: unordered NOMA, fixed NOMA, SIC, SNR, outage probability, QoS, spectrum efficiency, power allocation.

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***** Correspondence Author

C.Elayaraja*, Research Scholar/Anna University and Assistant Professor, Department of Electronics and Communication Engineering, Dhaanish Ahmed College of Engineering, Anna University, Chennai, Tamil Nadu, India. Email: elayaraja.c@dhaanishcollege.in

Dr. C. Amali, Assistant Professor, Department of Electronics and Communication, SRM Valliammai Engineering College (Autonomous), Anna University, Chennai, Tamil Nadu, India. amalic.ece@valliammai.co.in

Dr.D.Sridevi, Assistant Professor, Department of General Engineering, SRM Valliammai Engineering College (Autonomous), Anna University, Chennai, Tamil Nadu, India. sridevid.mca@valliammai.co.in

Dr.T.S.Geetha, Associate Professor, Department of Electronics and Communication, Sriram Engineering College, Anna University, Chennai, Tamil Nadu, India. Email: geethakrishh@gmail.com

I. INTRODUCTION

History of the wireless communication evolution is as shown in Table 1. As if the generation grown in terms of data rates requirements, the corresponding techniques also suitably fixed till.

The researchers have been strived to achieve the 5G performances such as high data rates, lower latency, higher capacity, and high spectrum efficiency. In view of enhancing the spectrum utilization in 5G some of the inevitable techniques have been emerged, namely, MIMO, massive MIMO, mmWave MIMO, NOMA, FBMC, Device to Device and cooperative communication, and full duplex. The motivation of this paper is to achieve better performance than the conventional techniques of the 4G communication. A system that allows multiple users in non-overlapping time slots or frequency bands during transmission the so-called orthogonal multiple access (OMA). The conventional OMA techniques have TDMA, FDMA, CDMA and OFDMA. These serve a single user in each orthogonal resource block, where *n* users, n ∈ (1,...N) has scheduled over the transmission time period *T*. Therein, *T* is chosen as lesser than the coherence time of the channel. Then, each user transmits only T/N amount of the total transmission period with the entire transmit power Ps allocated to that user. Non-orthogonal multiple access (NOMA) initiates transmission by multiple users (MIMO) over the entire transmission period and bandwidth over the same frequency/time resources. These multiple users have generally classified in the Power domain and Code domain NOMA. Meanwhile, the total transmit power Ps to be shared between the 'n' users, a portion of n ∈ (0,1), has transmit power which is assigned to nth user n, and Ps. Herein NOMA, successive interference cancellation (SIC) employed at the receiver to eliminate the interference of the signals from the users with lesser channel gains[1].

Resource Spread Multiple Access (RSMA or NOMA) has initiated for the theoretical analysis of two users. RSMA/NOMA gives prime guaranty that each user should achieve a minimum capacity, which is higher than OMA. Non-orthogonal multiple access/RSMA has been paying attention recently owing to its superior spectral efficiency. Specifically, at the transmitter side of NOMA employs Superposition Coding (SC) and at the receiver, Successive Interference Cancellation (SIC) employs as shown in Fig.1.

Table1. Evolution of wireless communication networks starts from before 1G, 1G, 2G, 3G, 4G and 5G

Generation	*Year*	*Data Services*	*Techniques*	*Applications*
Before 1G	<1983	Voice-centric	Analogue systems with (SSB) modulation	Voice transfer applications
1G	1983	Voice-centric.	Analogue systems for a high-capacity mobile system, Analogue system with FM radios.	AMPS (Advanced Mobile Phone Service)
2G	1990	Voice-centric.	Digital systems using TDMA multiplexing.	GSM was named 2G at the time when 3G was defined by ITU
2.5G	1995	High-capacity voice with limited data service	The CDMA system using 1.25 MHz bandwidth	GSM to GPRS and EDGE systems
3G	1999	Voice and data capability.	WCDMA (Wideband Code Division Multiple Access)	Frequency division duplex (FDD) and TDD modes.
4G	2013	High-speed data rate plus voice system	WiMAX system using OFDM, evolving from WiFi	The technology of LTE and that of WiMAX are very similar. Low data rates for Internet to high-speed data rates for mobile video.
5G	2021	System of super high-capacity and ultra-high-speed data with new design	*NOMA FBMC, Massive MIMO, D2D etc…	5G means a shift in design paradigm from a single-discipline system to a multi-discipline system

* Current requisite techniques.

This paper is structured as follows: Section II presents the related works on NOMA concepts. Section III describes the system model of power domain NOMA on unordered and fixed basis for both uplink and downlink using a successive interference cancellation (SIC) receiver and its power allocation scheme with some system-level evaluations. Section IV elaborates the results of power domain NOMA and the parametric simulations analysis on channel gain and SNR. Finally, Section-V concludes the NOMA reachability.

II. RELATED WORKS ON NOMA

Energy efficient based SIC decoding order with improved performance of outage probability in [2]. Thereafter, a new scheme for user admission through threshold difference based is explained in [3], and in resource block [4] contains all the related parameters like subcarriers, time slots and spreading codes with 5G requirements. Subsequently, NOMA with multiple antenna supports to resource control, cooperation transmission, coexistence has discussed in [5]. Device processing capabilities based on system level evaluation to improve the weaker user throughput and capacity has explained in [6]. General receiver complexities are inter cell and intra cell interferences, including SIC, which are approached on the uplink and downlink NOMA transmission in[7][8][9]. Ergodic capacity of MIMO-NOMA has approached on low complexity sub optimal and optimal power allocation schemes [10]. NOMA with cooperative communication and MIMO has explained which includes both transmissions and parameters [11]. Performance based key features of typical three NOMA schemes such as PDMA, MUSA, and SCMA [7]. Cluster based user approaches has done in[3][12].

The core point on this paper is to design, verify and analyze the performance of power domain NOMA in analytical and simulation methods. In order to get better sum rate capacity and outage power probability compared to conventional OMA of un-ordered (not fixed) and ordered (fixed). Therein, two users case has considered with different channel gains and allocations of power. Further, the system model is explored in the following sections.

III. SYSTEM MODEL

A. Power domain NOMA: Unordered-sum capacity:

In a single timeslot power domain, NOMA served to multiple users. Whereas spreading codes, OFDMA subcarriers and multiple access schemes are realized by allocating different power levels.

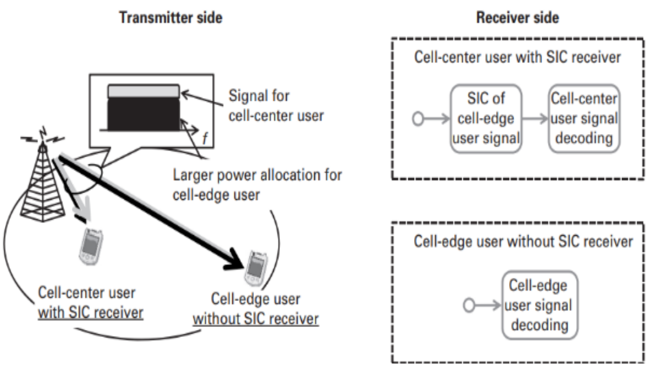

Fig.1. Example of NOMA downlink

In NOMA, the base station communicates to all the users simultaneously as shown in Fig1. Therein, power assigned to the cell-center user with SIC receiver and cell-edge user without SIC receiver. The model for the above-said is as follows. NOMA denotes the two user's channel gains by h_i, $i \in \{1,2\}$, and $|h_1| \leq |h_2|$. The BS overlays the user's messages by allotting corresponding power coefficients, indicated by α_i, $i \in \{1,2\}$.

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Assigning more power to the user with weaker channel conditions is the idea of power-domain NOMA, i.e., $\alpha_1 \geq \alpha_2$ and $\alpha_1 + \alpha_2 = 1$; if $|h_1| \leq |h_2|$. As shown in fig.1, by considering User 2's message as noise, User 1 decodes its own message directly using Shannon- fano coding theorem. An achievable rate for user 1, as indicated in equation 1,

$$\log_2(1+\gamma_{u1}^{x1}) = \log_2(1+\frac{a1\rho_s\beta1}{a2\rho_s\beta1+1}) \text{ bits/s/Hz}, \qquad (1)$$

$|h_1|^2 = \beta_1$, where ρ_s denotes the total transmit signal-to-noise ratio (SNR) $\rho_s = \frac{Ps}{\sigma^2}$, Ps is the total transmit power, γ_{u1}^{x1} is SINR is for decoding x_1 at u_1. At user 2 NOMA downlink performance exhibits Signal to Interference Cancellation, i.e., it first decodes user 1's message and then cancelling the interference from its observation as in equation 2, 3 and 4.

$$y_2 = h_2(\sqrt{a_1\rho_s}x1 + \sqrt{a_2\rho_s}x2) + n_2 \qquad (2)$$

$$\gamma_{u2}^{x1} = \frac{a1\rho_s|h_2|^2}{a2\rho_s|h_2|^2+1} = \frac{a1\rho_s\beta_2}{a2\rho_s\beta_2+1} \qquad (3)$$

$|h_2|^2 = \beta_2$;

So the sum-rate of NOMA for ($\beta_2 \geq \beta_1$), can be evaluated as

$$C_{u1}^{x1} + C_{u2}^{x2}$$

$$= \log_2\left(1+\frac{a1\rho_s\beta1}{a2\rho_s\beta1+1}\right) + \log_2(1+a_2\rho_s\beta_2) \qquad (4)$$

$$C_{u1}^{x1} + C_{u2}^{x2} \geq \log_2(\rho_s\beta_2) \qquad (5)$$

Whereas OMA sum rate is

$$C_{u1}^{x1} + C_{u2}^{x2} \approx \frac{1}{2}\log_2(\rho_s\beta_2) \qquad (6)$$

$\beta_2 \gg \beta_1$. By comparing equation 5 and 6, concludes the clarity of sum rate achieved by NOMA is very much greater than that of sum rate achieved by OMA.

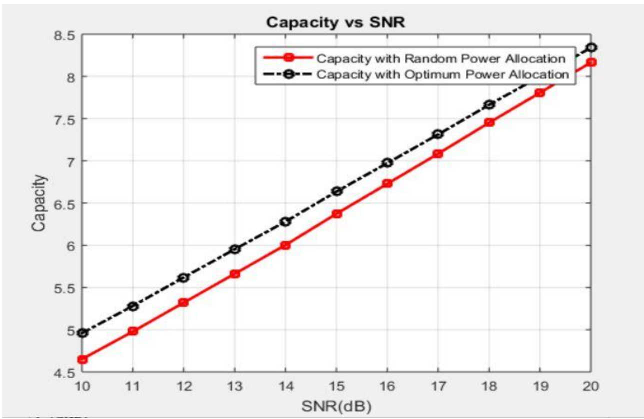

Fig.2. Capacity with random power allocation (SNR) for 0 to 20 dB

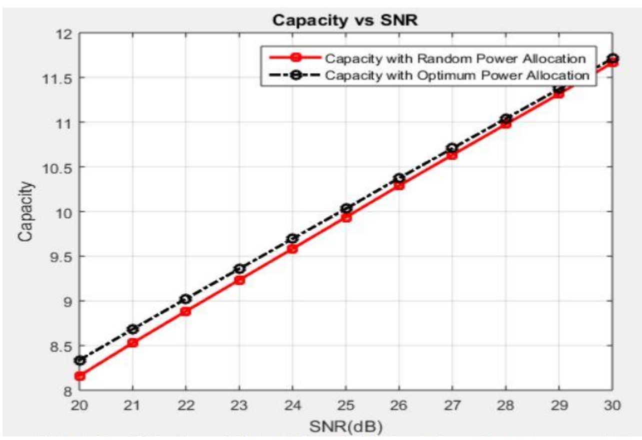

Fig.3. Capacity with random power allocation (SNR) for 20 to 30 dB.

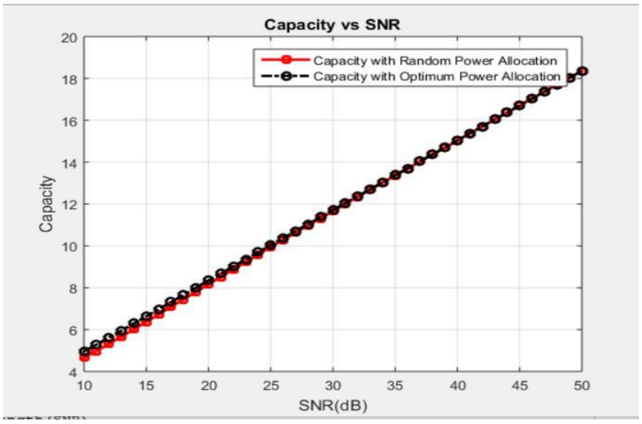

Fig.4. Capacity with random power allocation (SNR) for 10 to 50 dB.

The Sum capacity (bits/Hz) has calculated with varying SNR for the ordered and unordered NOMA and the same is compared with OMA as in equation 6. Different values of SNR from 0dB to 20 dB as shown in Fig 2. Here the capacity with random power allocation and optimum power allocations are increasing with suitable difference in bits/Hz in linear manner. Once the SNR is increased from 20dB to 30dB, the capacity is also increased linearly. But, random and optimum power allocations are closer to each other as shown in Fig.3. Further, increasing the SNR from 10 dB to 50 dB as in Fig.4, the capacity is increased linearly up to 18 to 20 bits/Hz. And the same is compared with OMA techniques, as in equation 6, therein the sum capacity is half-reduced. Whereas, the NOMA has produced better result than the OMA based on the capacity improvement concerns.

Outage probability for ordered and unordered NOMA schemes are discussed in the following section.

B. Power allocation for ordered and unordered:

In this section, different power allocation to the multi users and the corresponding outage probability are analyzed in mathematical model and the same has simulated in MATLAB. Fig.5 illustrates the scheme of power allocation and its procedure. Stronger user and weaker users are considered upon on the position of user1 and user2 respectively.

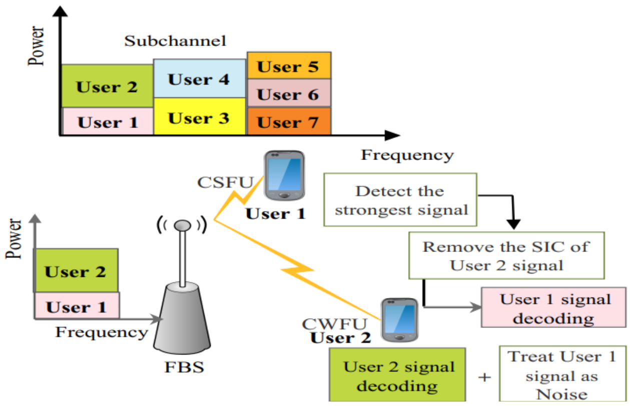

Fig.5. NOMA superposition and Power allocation.

Uplink and downlink scenarios are mathematically modelled for unordered NOMA power allocation schemes as in equation 9 and 11.

B.1.Probability of outage for user 1 (unordered):

Sum rate capacity of user1 is less than the desired rate of user 1 as in equation 7, 8 then,

$$C_{u1}^{x1} = \log_2(1 + \gamma_{u1}^{x1}) < R_1 \quad (7)$$

$$\log_2(1 + \frac{a_1\rho_s\beta_1}{a_2\rho_s\beta_1+1}) < 2^{R_1} - 1 = R_1 \quad (8)$$

where $\beta_1 < \frac{R_1}{(a_1 - a_2 R_1)\rho_s}$, the probability of outage for the user 1 and user 2 are as in equation 9,10,11 respectively.

$$Pr\left\{\beta_1 < \frac{R_1}{(a_1 - a_2 R_1)\rho_s}\right\} = 1 - \exp\left(-\frac{R_1}{(a_1 - a_2 R_1)\delta_1^2\rho_s}\right) \quad (9)$$

B.2.Probability of outage for user 2 (unordered):

User 2 decoding fails if either decoding of x_1 or x_2 fails.

$$Pr\{C_{u2}^{x1} < R_1 \ added \ with \ C_{u2}^{x2} < R_2 \ \} \quad (10)$$

$$Pr\left\{\beta_2 < \max\left\{\frac{R_1}{(a_1 - a_2 R_1)\rho_s}, \frac{R_2}{a_2 \rho_s}\right\}\right\}$$

$$= 1 - \exp\left(-\frac{1}{\delta_2^2} max\left\{\frac{R_1}{(a_1 - a_2 R_1)\rho_s}, \frac{R_2}{a_2 \rho_s}\right\}\right) \quad (11)$$

Probability of outage Vs SNR for Unordered NOMA has shown in Fig. 6. With different user, gain has calculated in theoretical and simulation, the values has been drew in graph. If the gains are equal then Pout varies between 10e-02 and 10e-03, if the weaker user has higher gain than stronger user, then also it has vast variation with lesser outages. By increasing the SNR values, the resultant becomes better in NOMA compared to the conventional OMA techniques.

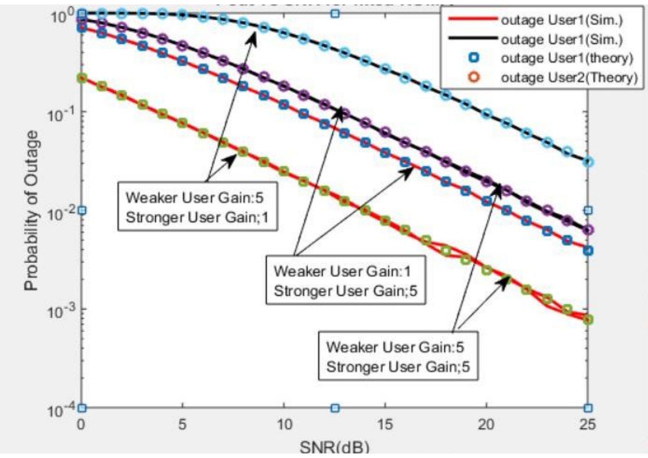

Fig.6. Pout vs SNR for unordered NOMA for different gain between 1 to 5.

In unordered NOMA, the gain variation as well as power factor amplitudes variation facilitate a reasonable probability of outage as shown in Fig.7.

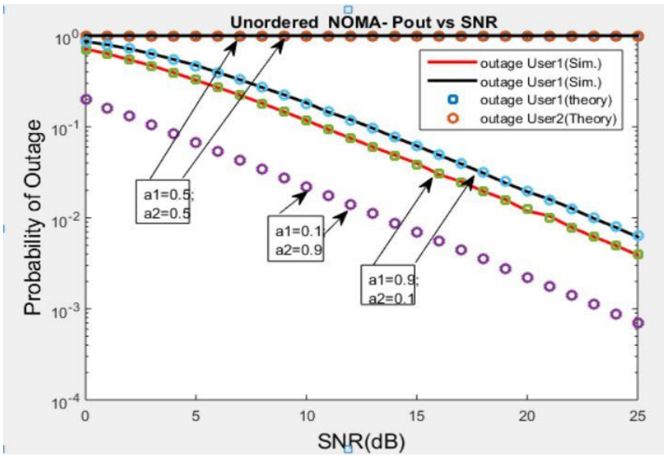

Fig.7. Pout vs SNR for unordered NOMA for different power factors values.

Ordered NOMA - probability of outage is investigated for both uplink and downlink scenarios, which are explained in the next section.

C. Probability of outage of fixed NOMA (Ordered):

Minimum value of channel gain is considered for the user1 as in equation (12) to determine the probability of outage, accordingly maximum value of channel gain is considered for the user 2 as in equation (13) and equation (14) to find out the probability of outage.

For user1, $\beta_1 = |h_1|^2 = \min(|h_1|^2, |h_2|^2)$ (12)

$$P_{out} = 1 - \exp\left(-\frac{R_1}{(a_1 - a_2 R_1)\delta_1^2\rho_s}\right) \quad (13)$$

For user2, $\beta_2 = |h_2|^2 = \max(|h_1|^2, |h_2|^2)$ (14)

Uplink fixed NOMA, probability of outage is clearly indicated in Fig.8 and Fig.9, as the value of SNR increases then Pout decreased exponentially.

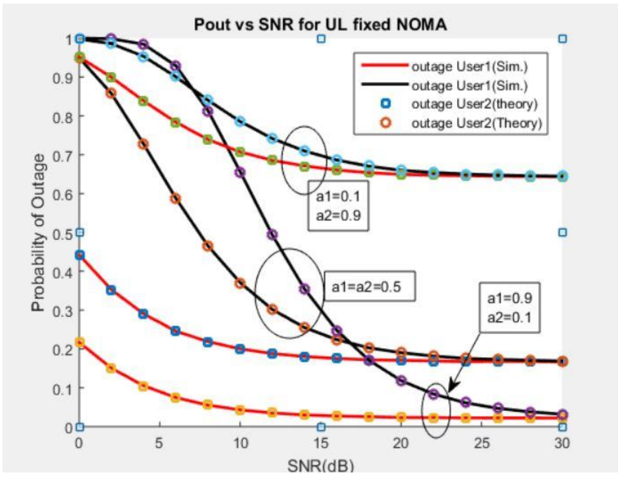

Fig.8 Pout vs SNR for uplink ordered NOMA for different power factors between 0.1 and 0.9

If the power factor amplitude are equal (a1=a2= 0.5) then the outage probability is also equal at 22.5dB for both the users as shown in Fig. 8. The probability of outage is improved by increasing gain as well as increasing SNR as shown in Fig.9. There is no cross over point exists on the channel gain concern in uplink ordered NOMA.

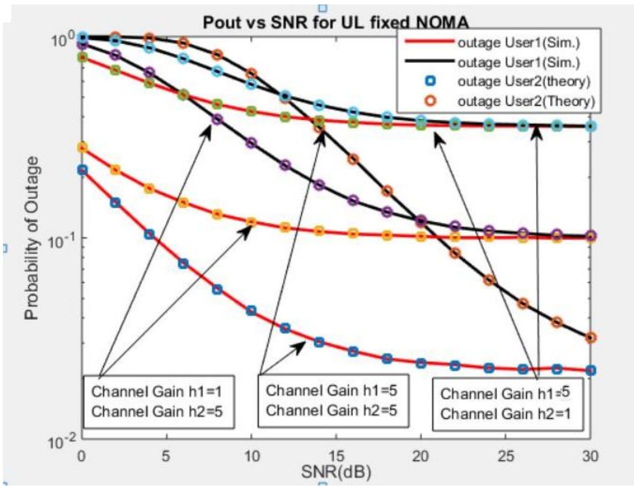

Fig.9. Pout vs SNR for uplink ordered NOMA for various values of channel gains.

For the ordered NOMA – downlink, probability of outage has derived for both the theory and simulation. Fig.10 depicts that the existence of probability of outage upon the variation of channel gain and power factor amplitudes. Here, it is found that a cross over point occurs when the weaker channel gain is greater than the stronger channel gains as h_1=1dB and h_2= 10dB. Very low outage probability has reached for both the users at 13dB SNR and cross over point has occurred at 3dB as well. Different values of channel gain and power factor amplitudes has applied to the fixed NOMA and unordered NOMA for the uplink and downlink cases and analyzed their performances. These parameter variations and performance results, which are suitable to meet the requirement of the present requisite communication technology.

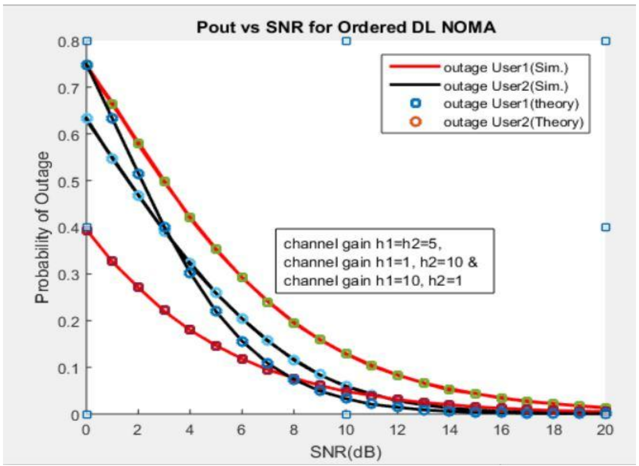

Fig.10. Pout vs SNR for downlink ordered NOMA for various values of channel gains.

IV. RESULT AND DISCUSSION

In the rayleigh fading channel sum capacity depends on the SNR and channel gain. As if the SNR increases from 10dB to 20 dB and further, the sum capacity also found increased. In Table.2, depicts the sum-capacity calculations with different SNR dB values, and comparison of conventional OMA with NOMA. As a result, it has interestingly shown that NOMA performs extremely better in sum-capacity calculation with increasing SNR in dB.

Table.2 NOMA sum-capacity calculations

Sl.No.	***NOMA - capacity with random power allocation***		***NOMA-capacity with optimum power allocation***	***OMA capacity***	***Inferences***
	SNR (dB)	*Capacity (bits/Hz)*	*Capacity (bits/Hz)*	*Capacity (bits/Hz)*	NOMA sum capacity is very much greater than the OMA sum capacity.
1	10	4.6	5	2.5	
2	20	8.2	8.4	4.2	
3	30	11.6	11.75	5.8	
4	40	15.2	15.6	7.8	
5	50	18.2	18.5	9.2	

This implied that NOMA has great credential in placing 5G techniques as massive connectivity, fairness to the user and maximum sharing of resources. In addition, the sum capacity is calculated and simulated in MATLAB. Result of outage probability is completely depends upon the user1 desired rate R1, power factor amplitudes a_1,a_2 and total power SNR.

Table.3 Outage probability of NOMA

NOMA Analysis	*Operation*	*Power factor*		*User gain*		*SNR (dB)*	*Outage Probability*		*Inferences*
		a1	*a2*	*delta1*	*delta2*		*User1*	*User2*	
Unordered NOMA	uplink	0.9	0.1	5	1	10	0.995	0.156	Based on the Fig.6 ,and Fig.7.
		0.9	0.1	5	5	20	0.06564	0.0766	
Ordered or fixed NOMA	uplink	0.5	0.5	1	9	20	0.2986	0.2667	Based on Fig.8
		0.5	0.5	9	1	25	0.0045	0.0086	
	downlink	0.9	0.1	1	10	3	0.38	0.38	Based on Fig.9
		0.9	0.1	10	1	20	0.0015	0.0016	

To achieve the better performance using NOMA, the above-said parameters has to be reconfigured dynamically. Outage probability of NOMA calculations with different SNR values are shown in Table.3. Outage probability has decreased by increasing SNR as in Fig.6, and Fig.7.for the unordered NOMA. For the ordered NOMA outage probability has found equal for both the weaker and stronger users from SNR from 20dB onwards as in Fig.8. In fixed NOMA outage probability has still decreased for both the users SNR at 3dB, where the cross over point exist as in Fig.9.subsequently,equal outage probability has been exist for both the users SNR from 13dB onwards as in Fig.9. Furthermore, weaker user probability of outage is increased in such a way that increasing desired rate of user1, decreasing the square of the harmonic mean of the transmit SNR in the ordered NOMA. Overall, it has found that the probability of outage performance has so better for NOMA than OMA.

V. CONCLUSION

The power domain NOMA has presented, which permits two users to reach the capacity much greater than the capacity of conventional OMA techniques used in 4G. Based on the power allocation methods, sum capacity has derived and investigated to different users. Therein, a random power allocation and optimum power allocation methods are used to compare various SNR values and sum-capacities for each user. And outage probability has also derived for unordered and ordered basis for both uplink and downlink scenarios. Moreover, the ordered power domain analysis has proven that the channel gain of weaker user (h_1) even smaller than that of the stronger user channel gain (h_2), the outage performance of the weaker user has significantly improved compared to stronger user. Most importantly, in NOMA, resources are equally shared to all the users in the cell, as a result, latency is reduced at a maximum level, outage probability is improved, sum capacity is increased, and also interference is minimized as well. Finally, the above-said performance factors are aptly fits to the current 5G communication networks, as a result, NOMA can be used in many more applications like mission critical control, IOT, drone communication and so on.

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AUTHORS PROFILE

Elayaraja Chinnathambi, received his bachelor’s degree in Electronics and Communication Engineering from Vellore Engineering College, Vellore, India, ME degree in Applied Electronics from Coimbatore Institute of Technology , Coimbatore, Tamil Nadu, India in 2004. He is doing PhD degree in Anna University, Chennai, Tamil Nadu, India. He is working as an Assistant Professor in Dhaanish Ahmed College of Engineering, Padappai, affiliated to Anna University, Chennai, Tamil Nadu, India. He has more than 14 years of teaching experience in Engineering Colleges. He is a Life member of ISTE. His research interest towards 5G Wireless Communication Networks, Signal processing for wireless communication, Image Processing, Antenna and Filter design.

Dr. Amali Chinnappan, received her bachelor’s degree in Electronics and Communication Engineering from Government College of Technology, Coimbatore, India. ME degree in Applied Electronics from College of Engineering, Guindy, India, in 2007. She received her PhD degree from SRM University, Chennai, Tamil Nadu, India, in 2016. She is working as an Assistant Professor in SRM Valliammai Engineering College (Autonomous) Affiliated to Anna University, Chennai. She has 18 years of teaching experience in Engineering Colleges. She is a member of ISTE, IAENG, IAE, ISRD and ISC. Her research interest in Wireless Networks, Resource Management, and Mobility and Interference Management in Wireless Networks.

Dr.D.Sridevi, has Completed Masters in Computer Application from the Annamalai University in the year 2004 and Completed M.E in CSE from Anna University in the year 2008. She successfully completed her research from Gandhigram Rural University, Dindugal in the year 2019. She is life member of ISTE and CSI. She has published around 10 International Journals and 3 International Conferences. Currently working as a Assistant Professor (Senior Grade) in Department of General Engineering at SRM Valliammai Engineering College, Chennai. Her research interests are Data Mining, Big Data, IoT etc. She is having 11 years of teaching experience.

Dr.T.S.Geetha, working as Associate Professor in Sriram Engineering College, Chennai. She has completed her bachelor's degree in Electronics and Communication Engineering at MIT campus, Anna University, Chennai then completed Master’s degree in Communication systems at Crescent Engineering College under Anna University. She completed her doctorate in Renewable Energy at Vels University Chennai. She has 9 years of industrial experience and 13 years of academic experience. She published around 12 international Journals and 5 International Conferences. Her research interests include Medical Electronics, Mobile networks, Digital communication, computer networks, and optical communication.