NOMA: Emerging Radio Access Technique for Next Generation Wireless Networks

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Abstract: The next generation of wireless networks demands for the massive and heterogeneous connectivity, larger bandwidth, ultra-low latency, and ubiquitous connectivity to facilitate higher data rate in new technologies like self-driven vehicles, virtual reality and Internet of Things. With prominence towards 5G and beyond technologies, new research directions are to be explored to achieve the latency to be less than one millisecond and data rate up to 1 Gbps. A crucial challenge for 5G networks is to implement effective radio access technique which can improve the spectral efficiency to cope with the increasing network densification. In order to meet these challenges, various fundamental technologies have been proposed and examined such as massive multiple-input multiple-output (mMIMO), M2M communication, millimeter-wave (mmWave) communications, beamforming and non-orthogonal multiple access (NOMA). One of the key solution to increase the spectral efficiency is Non-orthogonal Multiple Access (NOMA). NOMA has great potential as it is able to serve multiple users simultaneously at same frequency/code resource and going to outperform the usual orthogonal Multiple Access (OMA) technique in future cellular networks. As per the resource allocation scheme in NOMA based system, it has to deal with the inter user interference. In this paper we have focused on Power domain NOMA and to alleviate interference among the users scheme of Successive interference cancellation (SIC) is implemented and simulated both for uplink and downlink channels. This article shows the complete mathematical model for unordered and ordered power domain NOMA and the system level simulation results shown to compare the performance on the basis of outage probability with different power allocation schemes. It is identified that the capacity of the system increases with the application of optimum power allocation. NOMA is proved to improve the spectral efficiency and transmission latency, by supporting massive users with enhancing user-fairness.

Keywords: Non-orthogonal Multiple Access (NOMA), Massive MIMO, Successive Interference cancellation (SIC).

1. INTRODUCTION

As the fifth generation (5G) wireless networks has been evolved which has to support three important fields of applications, including enhanced mobile broadband (eMBB), massive machine type communications (mMTC) and ultra-reliable and low-latency communications (URLLC) [1]. In order to meet the demand of above mentioned application, next generation wireless networks has to cope with various challenges in order to support extensive heterogeneous traffic and users, So new modulation and multiple access (MA) schemes are need to be developed. In next generation cellular communications, the design of the radio access technology (RAT) is essential factor for improving spectral efficiency and the system capacity in a cost effective way. Radio access technologies are mainly characterized by the radio frame design, waveform design, multiple inputs and multiple output (MIMO) transmission scheme, multiplexing and multiple access scheme. Specifically the design of the multiple access schemes is needed from a system performance improvement, as it facilitates multiple users to access and share the radio resources efficiently and simultaneously. In literature we have various multiple access techniques like frequency division multiple accesses (FDMA), time division multiple access (TDMA), code division multiple Access (CDMA). Multiple access techniques are broadly categorized into two different approaches, that are orthogonal multiple access (OMA) and non-orthogonal multiple access (NOMA). In orthogonal technique of access scheme, a perfect receiver is used to separate completely unwanted signals from the desired signal using orthogonal basis functions [2].

In 4G mobile communication systems such as Long Term Evolution (LTE) and LTE-A, standardized by the 3rd Generation Partnership Project (3GPP), orthogonal multiple access based on orthogonal frequency division multiple access (OFDMA) which is used in combination with scheduled FDMA and TDMA techniques for downlink and single carrier (SC) FDMA for uplink are acquired [3]. In OFDM the spectrum can be divided into a large number of orthogonal narrow-band sub-channels which avoids putting guard-bands between adjacent subcarriers as a result it achieved an increased spectral efficiency in comparison to FDMA. To meet many new demands required for 5G networks it may be very challenging to achieve a threefold enhancement in the spectrum efficiency compared to the LTE baseline. OMA is able to support restricted numbers of users due to limitations in the numbers of orthogonal resources blocks, which limits the spectral efficiency and the capacity. Also it suffers from the high peak-to-average power-ratio (PAPR). To overcome this drawback, it requires highly linear power amplifier [4]. This increases the power consumption of the user and degrades the power efficiency and it shortens the battery life. Thus the gain in the total capacity beyond 500 fold can be achieved if some new ways of spectrum extension using new and higher frequency bands and network densification can achieve a capacity gain of 50 fold.

In contrast to OMA, NOMA introduces a new method of multiplexing within one of the time/frequency/code domains. NOMA allows allocating one frequency channel to multiple users simultaneously within the same cell and helps to improve spectral efficiency (SE), higher throughput, easy channel feedback, support massive connectivity, enhanced user fairness, minimal wireless network and low transmission latency [5]. Generally, NOMA techniques can be divided into two schemes, namely, power domain NOMA and code domain NOMA. In this paper we proposed power domain NOMA where multiple users of different channel conditions are multiplexed in the power domain on the transmitter side and multiuser signal separation on the receiver side is conducted.

2. MOTIVATIONS AND FEATURES OF NOMA

Researchers are attracting towards NOMA to meet 5G requirements and putting a lot of efforts in NOMA including various performance analysis methods, fairness analysis, energy efficiency, and user pairing. NOMA is the promising technique as a cellular multiple access scheme according to the following key features:

1) NOMA provides high spectral efficiency, which is attributed to the fact that it allows time/frequency/code all the resource block to be exploited by multiple users.

2) NOMA can support massive connectivity as it supports multiple users within one resource block approximately for billions of smart devices. This feature is most essential for Internet of Things (IoT) scenarios with users that need very low data rates with massive number of end users.

3) As in NOMA only the received signal strength needs to be estimated in the channel feedback. As a result perfect uplink channel state information (CSI) is not required at the base station.

4) In the uplink of NOMA, there is no need to schedule requests from users to the BS, which is normally required in OMA schemes. As a result, a grant-free uplink transmission can be established in NOMA, which reduces the transmission latency drastically [6]

5) To make NOMA promising, it should be used with advanced transmission/reception techniques such as dirty paper coding (DPC) or a SIC receiver [7-8], which is different from the techniques used in 3G systems. NOMA with a SIC receiver is the baseline scheme but it may be a drawback in terms of receiver complexity [10].

6) Utilization of additional domain for user multiplexing

For FRA (Future radio Access), good properties of 3.9/4G, i.e., LTE/LTE-Advanced, should be maintained as much as possible such as robustness against multipath interference, good affinity to MIMO technologies, and supportability for one-cell frequency reuse. Thus, we assume alternative waveforms such as a filter bank multicarrier (FBMC) [9] could be investigated especially for the higher frequency bands. NOMA is a scheme that utilizes an additional new domain, i.e., the power domain, which is not sufficiently utilized in 3.9/4G systems. The performance gain of NOMA compared to OFDMA increases when the difference in channel gains, i.e., path loss between UEs, is large [10].

7) In LTE/LTE-Advanced, many technologies are adopted to enhance the system performance. It is preferable for NOMA to take a receiver cancellation approach and to specify the basic cancellation mechanism so that NOMA with a SIC receiver can be a basic technology that provides a robust performance gain in practical wide area deployments [10].

3. SEQUENCING IN NOMA

A. Dynamic-ordered NOMA:

For the dynamic ordered scheme, the channel state information (CSI) is perfectly known at the BS. Before decoding, the receiver determines the decoding order based on the instantaneous received signal power of each user. The instant decoding order can be represented by a permutation v. Following the decoding order v, the users are decoded in the sequence of [v1,v2,· · ·,vN] with the instantaneous received signal power relation: pv1 > · · ·> pvN . When decoding the message of the user vn, the SIC receiver should decode all the prior (n−1) users' message first, then reconstruct and subtract regenerated multiuser interference from the superimposed signal. Meanwhile, the rest (N − n) users' signals are regarded as the inter-user interference [11].

B. Fixed-ordered NOMA:

For the fixed ordered scheme, it is assumed that the BS determines the decoding order only by considering the statistic CSI for each user, i.e. the average received power of each user. Therefore, the users are decoded in the sequence of 1, 2, · · ·, N based on their distance to the BS, i.e., d1 < d2 < dN.

4. WORKING PRINCIPLE for THE UPLINK AND DOWNLINK NOMA

Existing NOMA schemes can be classified into three categories: power-domain NOMA, code-domain NOMA, and NOMA multiplexing in multiple domains. We will introduce them subsequently with emphasis on power-domain NOMA. Power-domain NOMA is considered as a promising MA scheme for 5G networks [12]. Power-domain NOMA supports multiple users within the same time/frequency/code resource block by distinguishing them with different power levels.

(A) Illustration of the basic NOMA scheme applying SIC for UE receivers in the cellular downlink

This scheme considers a single-cell downlink scenario where there is a single base station (BS), and N users U_i , with iϵ N={1,2,3,....N} , and all terminals are equipped with a single antenna. Note that a similar uplink scenario can also be described and a NOMA scheme can equally be utilized there. The BS always sends data to all users simultaneously, subject to the constraint of total power P. It is assumed that the wireless links experience independent and identically distributed (i.i.d.) block Rayleigh fading and additive white Gaussian noise (AWGN).

The NOMA scheme allows simultaneous serving of all users by using the entire system Bandwidth (BW) to transmit data with the help of SC (Superposition coding) at the BS and SIC decoding techniques at the users. Here, user multiplexing is executed in the power domain. The BS transmits a linear superposition of N users' data by allocating a fraction of ρ_i , the total power to each U_i, i.e., the power allocated for the ith user is $P_i= \rho_i P$, to satisfy the total power constraint such that $\sum \rho i = 1$. On the receiving end, each user decodes the signals of the weaker users, i.e., U_i can decode the signals for each user.

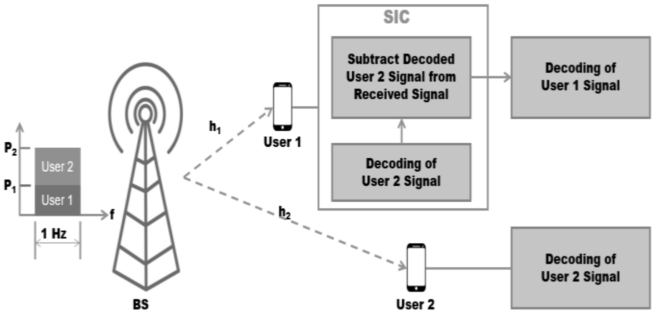

Figure 1: Decoding of user data in 2 user scenario

In downlink, the BS transmits the superimposed signal

$$X = \sum_{i=1}^{N} \sqrt{p_i} x_i \qquad \text{..............................(1)}$$

where xi is the unit power message signal intended for user i, pi denotes the power allocated for user i, and N denotes the total number of users in a NOMA cluster. The power allocated to a user depends on the powers of other users due to the BS total power constraint,

$$P = \sum_{i=1}^{N} \sqrt{p_i} \qquad \text{.............................(2)}$$

where P is the BS total power.

NOMA allocates less power for the users with better downlink CSI, to guarantee overall fairness and to utilize diversity in time/frequency/code domains. SIC is used for signal detection at the receiver. The user with higher transmit power, that is, the one with smaller downlink channel gain, is first decoded while treating another user's signal as noise. In practice, for a particular system setting, P_t is predefined and is thus divided among UEs according to the adopted power allocation (PA) scheme.

The user with higher transmit power, that is, the one with smaller downlink channel gain, is first decoded while treating another user's signal as noise. Once the signal corresponding to the user with higher transmit power is detected and decoded, its signal component will be subtracted from the received signal to facilitate the detection of subsequent users. It should be noted that the first detected user suffers from the highest inter-user interference and also the detection error in the first user will pass to the other users, which is why we have to allocate sufficient power to the first user to be detected.

The received signal at the i-th user is given by

$y_i = h_i\ x + w_i$, where h_i represents the channel gain between the BS and user i, and w_i denotes the Gaussian noise (with power spectral density $N_{0,i}$ zero mean and variance σ_n^2) at the receiver for user i.

If signal superposition at the BS, and SIC at U_i , are carried out perfectly, the corrponding SNR for user U_i for 1 Hz system BW is given by

$$\gamma_{u_i}^{x_i} = \frac{\rho_i P |h_i|^2}{P |h_i|^2 \sum_{k=i+1}^{N} \rho_i + \sigma_n^2} \qquad \text{............(3)}$$

Where $P|h_i|^2 \sum_{k=i+1}^{N} \rho_i$ interference is power and σ_n^2 is noise.

The data rate achievable for user U_i for 1 Hz system BW is given by:

$$R_i = \log_2 (1 + \gamma_{u_i}^{x_i}) = \log_2 \left(1 + \frac{\rho_i P |h_i|^2}{P |h_i|^2 \sum_{k=i+1}^{N} \rho_i + \sigma_n^2}\right) \qquad (4)$$

Note that the data rate of user is R_N, as this user successively decodes and cancels all other users' signals prior to decoding its own signal. Also note that a strong user experiences a better channel condition, but that does not mean the signal strength is stronger. In fact, a lower transmit power is assigned to a strong user, and a weak user is assigned more power. Thus, the weak user's signal is the strongest one. Therefore, NOMA does not contradict the basic concept of SIC, that decoding of the strongest signal should be performed first.

The optimal order for decoding is in the order of the increasing channel gain normalized by the noise and inter-cell interference power, $|h_i|^2/N_{0,i}$. Based on this order, any user can correctly decode the signals of other users whose decoding order comes before that user for interference cancellation. Thus, UE-*i* can remove the inter-user interference from the *j*-th user whose $|h_j|^2/N_{0,j}$ is lower than $|h_i|^2/N_{0,i}$.

In a 2-UE case, assuming that $|h_1|^2/N_{0,1} < |h_2|^2/N_{0,2}$, (and hence $P_1 > P_2$), UE-1 does not perform interference cancellation since it comes first in the decoding order. UE-1 first decodes x_1 and subtracts its component from received signal y1. Therefore, UE-2 can decode x_2 without interference from x_1. Assuming the error-free detection of x_1 at UE-1, the throughput of UE-i $C_{u_1}^{x_1}$, is represented as

$$C_{u_1}^{x_1} = \log_2 (1 + \gamma_{u_1}^{x_1}) = \log_2 \left(1 + \frac{a_1 P |h_1|^2}{P |h_1|^2 a_2 + \sigma_n^2}\right) \qquad (5)$$

After decoding first user and cancelling interference

$$Y_2 = h_2 \sqrt{\rho_2 P}\ x_{2/} \sigma_n \qquad \text{......................(6)}$$

SNR for decoding user 2 at source 2 is:

$$\gamma_{u_2}^{x_2} = \frac{\rho_2 P |h_2|^2}{\sigma_n^2} \qquad \text{..................(7)}$$

And

$$C_{u_2}^{x_2} = \log_2 \left(1 + \frac{\rho_2 P |h_2|^2}{\sigma_n^2}\right) \qquad \text{..........................(8)}$$

it can be seen that power allocation for each UE greatly affects the user throughput performance and thus the modulation and coding scheme (MCS) used for data transmission of each UE. By adjusting the power allocation ratio, *P*1/*P*2, the BS can flexibly control the throughput of each UE. Clearly, the overall cell throughput, cell-edge throughput, and user fairness are closely related to the power allocation scheme; therefore, a flexible radio interface needed to utilize the potential gain of the NOMA [13].

3.1. Probability of Outage Analysis for fixed NOMA in Downlink:

In this section, we present an exact analysis of the outage probability for user-1 under the considered network setting. Let ω_1 and $\widetilde{R_1}$ represent the target SINR, and the rate for user 1, respectively, where $\omega_1 = 2^{\widetilde{R_1}} - 1.$

For given quality of service (QoS) constraints:

$\log_2 (1+ \gamma_{u_1}^{x_1}) < \widetilde{R_1}$

$$\gamma_{u_1}^{x_1} = \frac{a_1 P |h_1|^2}{P|h_1|^2 a_2 + \sigma_n^2} < 2^{\widetilde{R_1}} - 1 = R_1 \quad \text{....................(9)}$$

$\rho_s = \frac{P}{\sigma_n^2}$, where P= Total transmit power

$a_1 \rho_s$ = Fraction of total power allotted to user 1.

$a_2 \rho_s$ = Fraction of total power allotted to user 2.

$$|h_1|^2 = \beta_1$$

$$\gamma_{u_1}^{x_1} = \frac{a1\, \rho s\, \beta_1}{a2\, \rho s\, \beta_1 + 1} < 2^{\widetilde{R_1}} - 1 = R_1$$

$R_1 (a_2 \rho_s \beta_1 +1) > a_1 \rho_s \beta_1$

$R_1 a_2 \rho_s \beta_1 + R_1 > a_1 \rho_s \beta_1$

$R_1 > a_1 \rho_s \beta_1 - R_1 a_2 \rho_s \beta_1$

$(a_1 - R_1 a_2) \rho_s \beta_1 < R_1$

For Probability of outage user 1 <1

$a_1 - R_1 a_2 > 0$

$R_1 < \frac{a_1}{a_2}$

Probability of outage for User 1 is:

$\Pr \{(a_1 - R_1 a_2) \rho_s \beta_1 < R_1\}$

$= \Pr \{ \beta_1 < \frac{R_1}{(a1 - R1\, a2)\rho s}\}$

Let $\beta_1 = |h_1|^2$

$E\{\beta_1\} = \delta_1^2$

PDF of β_1 is

$$= f_{\beta 1}(\beta_1) = \frac{1}{\delta_1^2} e^{-\frac{\beta_1}{\delta_1^2}}, \ \beta_1 \geq 0$$

$$= \int_0^{\frac{R_1}{(a1 - R1\, a2)\rho s}} f\beta 1 (\beta 1) d\beta 1$$

$$= \int_0^{\frac{R_1}{(a1 - R1\, a2)\rho s}} \frac{1}{\delta_1^2} e^{-\frac{\beta_1}{\delta_1^2}} d\beta 1$$

$$= 1 - \exp\left(-\frac{R_1}{(a1 - R1\, a2)\delta_1^2 \rho s}\right) \quad \text{.....................(10)}$$

Probability of outage for User 2 is:

$\Pr \{ C_{u_2}^{x_1} < \widetilde{R_1} \ \cup \ C_{u_2}^{x_2} \widetilde{R_2}\}$

$C_{u_2}^{x_1} < \widetilde{R_1} \ \Rightarrow \log_2 (1+ \gamma_{u_2}^{x_1}) < \widetilde{R_1}$

$\Rightarrow \frac{a1\, \rho s\, \beta_2}{a2\, \rho s\, \beta_2 + 1} < 2^{\widetilde{R_1}} - 1 = R_1$

$\Rightarrow (a_1 - R_1 a_2) \rho_s \beta_2 < R_1$

$\Rightarrow \beta_2 < \frac{R_1}{(a1 - R1\, a2)\rho s}$

$C_{u_2}^{x_2} < \widetilde{R_2} \ \Rightarrow \log_2 (1+ \gamma_{u_2}^{x_2}) < \widetilde{R_2}$

$\Rightarrow a2\, \rho s\, \beta_2 < 2^{\widetilde{R_2}} - 1 = R_2$

$\Rightarrow \beta_2 < \frac{R_2}{a2\, \rho s}$

Therefore, outage occurs if

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

Let $\beta_2 = |h_2|^2$

$E\{\beta_2\} = \delta_2^2$

PDF of β_2 is

$$f_{\beta 2}(\beta_2) = \frac{1}{\delta_2^2} e^{-\frac{\beta_2}{\delta_2^2}}, \ \beta_2 \geq 0$$

The probability of outage for decoding at user-2 is given as follows:

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

$$= \int_0^{\max \{\frac{R_1}{(a_1 - a_2 R_1)\rho_s}, \frac{R_2}{a_2 \rho_s}\}} f\beta 2 (\beta 2) d\beta 2$$

$$= \int_0^{\max \{\frac{R_1}{(a_1 - a_2 R_1)\rho_s}, \frac{R_2}{a_2 \rho_s}\}} \frac{1}{\delta_2^2} e^{-\frac{\beta_2}{\delta_2^2}} d\beta 2$$

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

3.2. Probability of Outage Analysis for Ordered NOMA in Downlink:

In ordered NOMA the weaker channel is decoded first and stronger channel is decoded later.. Let the channel gain of user-1 is:

$\widetilde{\beta_1} = |\widetilde{h_1}|^2 = \min \{|h_1|^2, |h_2|^2\}$

System model for Ordered NOMA is given as:

$Y_i = \widetilde{h_i}(\sqrt{a_1 \rho_s}\, \widetilde{x_1} + \sqrt{a_2 \rho_s}\, \widetilde{x_2}) + n_i$

PDF of β_i is

$\beta_i = |h_i|^2$

$E\{\beta_i\} = \delta_i^2$

$$f_{\beta i}(\beta i) = \frac{1}{\delta_i^2} e^{-\frac{\beta_i}{\delta_i^2}}, \ i=\{1,2\}$$

CDF of ordered NOMA for user-1:

$F\widetilde{B_1}(\widetilde{\beta_1}) = \Pr(\widetilde{B_1} \leq \widetilde{\beta_1})$

$= 1 - \Pr(\widetilde{B_1} \leq \widetilde{\beta_1})$

$= 1 - \Pr(\min\{B_1, B_2\} > \widetilde{\beta_1})$

$= 1 - \Pr(B_1 > \widetilde{\beta_1}, B2 > \widetilde{\beta_1})$

$= 1 - \Pr(B_1 > \widetilde{\beta_1}) \Pr(B2 > \widetilde{\beta_1})$

Remember,

$\Pr(B_1 > \widetilde{\beta_1}) = \int_{\beta_1}^{\infty} \frac{1}{\delta_1^2} e^{-\frac{\beta_1}{\delta_1^2}} d\beta 1 = e^{-\frac{\widetilde{\beta_1}}{\delta_1^2}}$

Similarly, $\Pr(B2 > \widetilde{\beta_1}) = e^{-\frac{\widetilde{\beta_1}}{\delta_2^2}}$

$F\widetilde{B_1}(\widetilde{\beta_1}) = \Pr(\widetilde{B_1} \leq \widetilde{\beta_1}) = 1 - e^{-\frac{\widetilde{\beta_1}}{\delta_1^2}} \times e^{-\frac{\widetilde{\beta_1}}{\delta_2^2}}$

To get PDF we have to differentiate

the expression of CDF:

d/dβ (CDF) = PDf

$$f_{\widetilde{B_1}}\left(\widetilde{\beta_1}\right) = \left(\frac{1}{\delta_1^2} + \frac{1}{\delta_2^2}\right) e^{-\widetilde{\beta_1}\left(\frac{1}{\delta_1^2}+\frac{1}{\delta_2^2}\right)}$$

Let us say $\left(\frac{1}{\delta_1^2} + \frac{1}{\delta_2^2}\right) = \frac{1}{\delta_s^2}$

$$= \frac{1}{\delta_s^2} e^{-\widetilde{\beta_1}\left(\frac{1}{\delta_s^2}\right)}$$

P_{out} = Pr ($C^{u1} < \widetilde{R_1}$)

$= \Pr\left(\frac{a1\ \rho s\ \widetilde{\beta_1}}{a2\ \rho s\ \widetilde{\beta_1}\ +1} < 2^{\widetilde{R_1}} - 1 = R_1\right)$

$= \Pr\left(\widetilde{\beta_1} < \frac{R_1}{(a1 - R1\ a2\ )\rho s}\right)$

$$\mathbf{P_{out}} = \int_0^{\frac{R_1}{(a1-R_1\ a2\ )\rho s}} \frac{1}{\delta_s^2}\ e^{-\frac{\widetilde{\beta_1}}{\delta_s^2}}\ d\widetilde{\beta_1}$$

$$= 1-\exp\left(-\frac{R_1}{(a1-R1\ a2\ )\delta_s^2 \rho s}\right) \quad \text{....................................(12)}$$

It indicates that if δ_3 is smaller than the probability of outage increases.

Channel Gain of User 2

$$\widetilde{\beta_2} = \left|\widetilde{h_2}\right|^2 = \max\{|h_1|^2, |h_2|^2\}$$

CDF of ordered User-2:

$$F_{\widetilde{\beta_2}}\mathrm{F}\left(\widetilde{\beta_2}\right) = \Pr\left(\widetilde{B_2} \leq \widetilde{\beta_2}\right)$$

$= \Pr(\max\{|h_1|^2, |h_2|^2\} \leq \widetilde{\beta_2})$

$= \Pr(B_1 \leq \widetilde{\beta_2})\ \Pr\left(B2 \leq \widetilde{\beta_2}\right)$

$$\Pr(B_1 > \widetilde{\beta_2}) = \int_{\widetilde{\beta_2}}^{\infty} \frac{1}{\delta_1^2}\ e^{-\frac{\beta_1}{\delta_1^2}}\ d\beta 2 = 1- e^{-\frac{\widetilde{\beta_2}}{\delta_1^2}}$$

Similarly, $\Pr\left(B2 > \widetilde{\beta_2}\right) = 1 - e^{-\frac{\widetilde{\beta_2}}{\delta_2^2}}$

$$F_{\widetilde{\beta_2}}\left(\widetilde{\beta_2}\right) = \left(1- e^{-\frac{\widetilde{\beta_2}}{\delta_1^2}}\right)\left(1 - e^{-\frac{\widetilde{\beta_2}}{\delta_2^2}}\right)$$

$$= 1- e^{-\frac{\widetilde{\beta_2}}{\delta_1^2}} - e^{-\frac{\widetilde{\beta_2}}{\delta_2^2}} + e^{-\frac{\widetilde{\beta_2}}{\delta_s^2}}$$

Where $\left(\frac{1}{\delta_1^2} + \frac{1}{\delta_2^2}\right) = \frac{1}{\delta_s^2}$

$$P_{out} = 1-\Pr\left(\frac{a1\ \rho s\ \left|\widetilde{h_2}\right|^2}{a2\ \rho s \left|\widetilde{h_2}\right|^2 + 1} \geq R_1, a2\ \rho s \left|\widetilde{h_2}\right|^2 \geq R_2\right)$$

$= 1-\Pr\left(\widetilde{\beta_2} \geq \frac{\varphi}{\rho_s}\right)$

$= \Pr\left(\widetilde{\beta_2} < \frac{\varphi}{\rho_s}\right)$

$= F_{\widetilde{\beta_2}}\left(\frac{\varphi}{\rho_s}\right)$

$$\varphi = \max\left\{\frac{R_1}{(a_1 - a_2 R_1)}, \frac{R_2}{a_2}\right\}$$

$$=1-\exp\left(-\frac{\varphi}{\rho_s \delta_1^2}\right) - \exp\left(-\frac{\varphi}{\rho_s \delta_2^2}\right) + \exp\left(-\frac{\varphi}{\rho_s \delta_s^2}\right) \quad \text{.....(13)}$$

(B) *Illustration of the Uplink ordered NOMA scheme*

NOMA can equally be applied in an uplink scenario. In the uplink, SIC is performed at the BS. For a two-user NOMA, the received signal at the BS is represented as

$$Y = h_1 \sqrt{Pa_1}\, x1 + h_2 \sqrt{Pa_2}\ x2 + w$$

Here, user U_i transmits the signal x_i , with $P_i = \sqrt{P}a_1$ being the transmission power. Also, w is the AWGN with zero mean and variance. With the help of SIC, the BS decodes the signals of U_1 and U_2 in two stages. In the first stage, the signal of U_2 is decoded, treating the signal U_1 as noise. In the next stage, the receiver subtracts the decoded signal x_2 from the received signal and then decodes the signal of U_1 [14].

Corresponding SINR of user-1 for decoding x_1 at BS is written as:

$$\gamma_{BS}^{x_1} = \frac{a1\ \rho s\ \beta_1}{a2\ \rho s\ \beta_2\ +1}$$

Where, $\beta_1 = |h_1|^2$, $\beta_2 = |h_2|^2$

Achievable rate for user 1:

$$\log_2(1+\gamma_{BS}^{x_1}) = \log_2\left(1+\frac{a1\ \rho s\ \beta_1}{a2\ \rho s\ \beta_2\ +1}\right) \quad \text{..............(14)}$$

After decoding and removing the signal component corresponding to x_1 , the resulting signal is:

$$Y_2 = h_2 \sqrt{a_2 \rho_s}\ x2 + n_{BS}$$

And the SINR for user-2 is:

$$\gamma_{BS}^{x_2} = a2\ \rho s\ \beta_2$$

3.3. Probability of outage for Uplink NOMA:

Outage condition for user-1 can be written as follows:

If the maximum achievable rate is less than the desired rate, than outage occurs.

$$\log_2(1+\gamma_{BS}^{x_1}) < \widetilde{R_1}$$

$$\gamma_{s_1}^{x_1} = \frac{a1\ \rho s\ \beta_1}{a2\ \rho s\ \beta_2\ +1} < 2^{\widetilde{R_1}} - 1 = R_1 \quad \text{..............(15)}$$

It implies that, $\beta_1 < \frac{R_1(1+a_2\rho_s\beta_2)}{a_1\rho_s}$

The probability of outage can be evaluated as

$\Pr\left\{\beta_1 < \frac{R_1(1+a_2\rho_s\beta_2)}{a_1\rho_s}\right\}$

$$= \int_0^{\infty} F_{B_1}\left(\frac{R_1(1+a_2\rho_s\beta_2)}{a_1\rho_s}\right) f_{\beta_2}(\beta_2) d\beta_2$$

$$= F_{B_1}(x) = \Pr(B_1 \leq x)$$

Gives $\int_0^x f_{B_1}(\beta_1) d\beta_1 = \int_0^x \frac{1}{\delta_1^2}\ e^{-\frac{\beta_1}{\delta_1^2}}\ d\beta 1 = 1- e^{-\frac{x}{\delta_1^2}}$

So we can write

$$= \int_0^{\infty}\left(1 - e^{-\frac{R_1(1+a_2\rho_s\beta_2)}{a_1\rho_s\delta_1^2}}\right) f_{\beta_2}(\beta_2) d\beta_2$$

$$= 1-\frac{e^{-\frac{R_1}{a_1\rho_s\delta_1^2}}}{1+\frac{R_1 a_2 \delta_1^2}{a_1 \delta_1^2}} \quad \text{........(16)}$$

Outage does not occur for user 2 when

$\log_2(1+\gamma_{BS}^{x_1}) \geq \widetilde{R_1}$ and

$\log_2(1+\gamma_{BS}^{x_2}) \geq \widetilde{R_2}$

$$\frac{a1\,\rho s\,\beta_1}{a2\,\rho s\,\beta_2 + 1} \geq R_1 \text{ and } a2\,\rho s\,\beta_2 \geq R_2$$

$$=\beta_1 \geq \frac{R_1(1+a_2\rho_s\beta_2)}{a_1\rho_s}$$

$$=\beta_2 \geq \frac{R_2}{a_2\rho_s}$$

Therefore , probability of outage for user-2 is

$$P_{out} = 1 - \Pr\left\{\beta_1 \geq \frac{R_1(1+a_2\rho_s\beta_2)}{a_1\rho_s}, \beta_2 \geq \frac{R_2}{a_2\rho_s}\right\}$$

$$=1-\int_{\frac{R_2}{a_2\rho_s}}^{\infty} F_{B_1}\left(\frac{R_1(1+a_2\rho_s\beta_2)}{a_1\rho_s}\right) f_{\beta_2}(\beta_2)d\beta_2$$

$$=1-\int_{\frac{R_2}{a_2\rho_s}}^{\infty} e^{-\left(\frac{R_1(1+a_2\rho_s\beta_2)}{a_1\rho_s}\right)} f_{\beta_2}(\beta_2)d\beta_2$$

$$=1-\frac{e^{-\left(\frac{R_1}{a_1\rho_s\delta_1^2}+\frac{R_2}{a_2\rho_s\delta_2^2}+\frac{R_1R_2}{a_1\rho_s\delta_1^2}\right)}}{1+\frac{R_1a_2\delta_2^2}{a_1\delta_1^2}} \quad \text{..............(17)}$$

This is the required expression for Probability of outage in Uplink ordered NOMA.

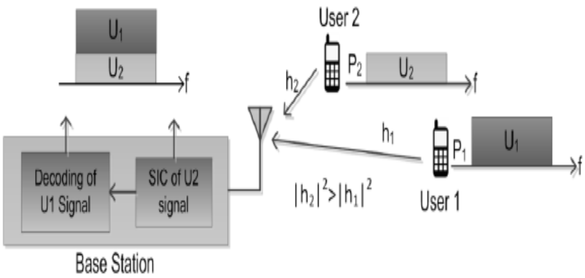

Figure 2: NOMA in Uplink Scenario

5. SIMULATION RESULTS

In this section, to achieve more insights of the analytical results, we provide the theoretical evaluations for a 2-user NOMA system. with the increase of SNR, the theoretical curves match better with the simulation ones, which corroborates the validity of the theoretical analysis. The outage probabilities of the dynamic-ordered and fixed ordered SIC receivers are presented in Fig.3. It can be observed that the dynamic ordered scheme outperforms the fixed one in terms of the outage probability.

To illustrate the performance gains, this section provides numerical results for Fixed and ordered NOMA setups both for downlink and uplink. The primary performance matrix outage probability is considered for this purpose. The above mentioned system is simulated in MATLAB with the following parameters:

Simulation Table

Parameter	Value
Desired Data rate for user 1 and 2	$\widetilde{R_2} = 1$
	$\widetilde{R_1} = 1$
Power ratio	$a_1 = 0.9$, $a_2 = 0.1$
Channel property	$\delta_1^2 = 1, \delta_2^2 = 5$
Algorithm	SIC
NOMA Techniques	Ordered and Fixed NOMA

Power Allocation	Random Vs Optimum

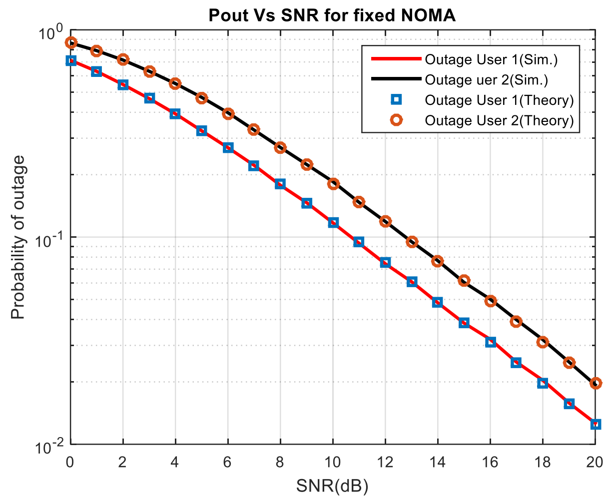

Figure 3: Fixed NOMA in Downlink Scenario

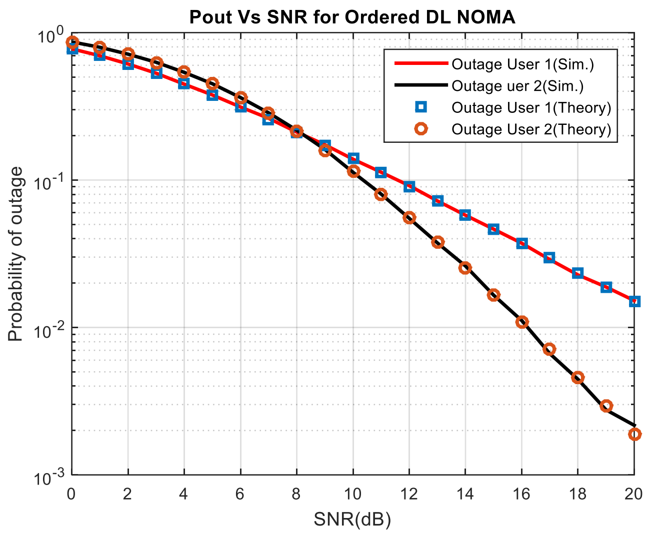

Figure 4: Ordered NOMA in Downlink Scenario

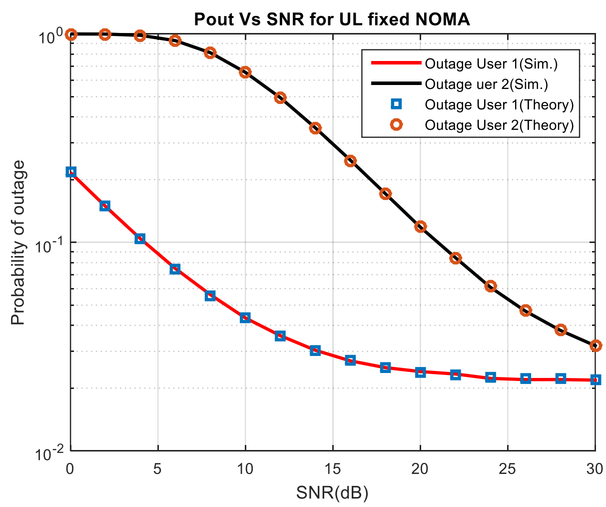

Figure 5: NOMA in Uplink Scenario

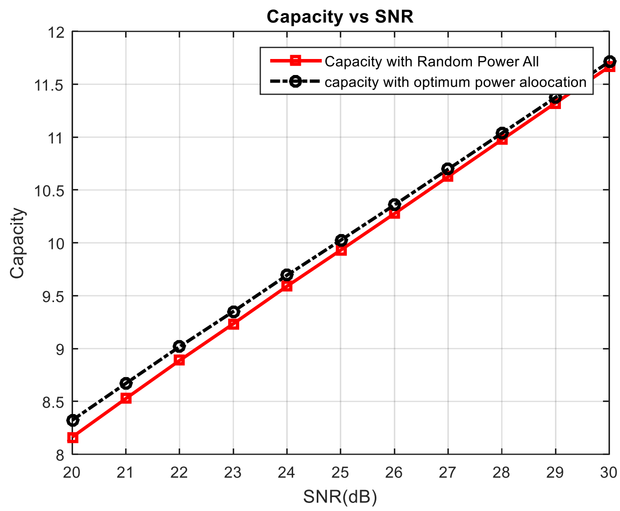

Figure 6: Capacity for NOMA with random and optimum power allocation

6. CONCLUSION

In this paper, we propose and investigate the performance of NOMA for Fixed as well as ordered users in Downlink and Uplink. The technique of Successive interference cancellation is proved to be very efficient and it has been concluded that the probability of outage decreases with increasing SNR. The dynamic ordered scheme outperforms the fixed NOMA scheme because the dynamic strategy could guarantee the smallest multiuser interference for each user by adjusting the decoding order based on the instantaneous receiving power dynamically. Also we have applied this dynamic ordered NOMA approach in Uplink. The mathematical outage probability expressions are derived for each user under the Rayleigh fading environment for both types of SIC receivers. The numerical results show that the dynamic ordered scheme can achieve better outage performance than the fixed one. Also the capacity for NOMA can be improved with optimum power allocation.

For future work, we plan to investigate power and rate allocation strategies to further enhance NOMA performance in next generation wireless Networks.

REFERENCES

[1] "Study on scenarios and requirements for next generation access technologies 3GPP, Sophia Antipolis, France, Tech. Rep. 38.913", June 2017.

[2] P. Wang, J. Xiao, and L. P, "Comparison of orthogonal and non-orthogonal approaches to future wireless cellular systems," IEEE Veh. Technol. Mag., vol. 1, no. 3, pp. 4-11, Sep. 2006.

[3] 3GPP TS36.300, Evolved Universal Terrestrial Radio Access (EUTRA) and Evolved Universal Terrestrial Radio Access Network (EUTRAN); Overall description, Dec. 2008.

[4] T. Jiang, and Y. Wu, "An Overview: Peak-to-Average Power Ratio Reduction Techniques for OFDM Signals," in IEEE Transactions on Broadcasting, vol. 54, no. 2, pp. 257–268, June 2008.

[5] L. Dai, B. Wang, Y. Yuan, S. Han, C. l. I, and Z. Wang, "Non-orthogonal multiple access for 5G: solutions, challenges, opportunities, and future research trends," in IEEE Communications Magazine, vol. 53, no. 9, pp. 74–81, September 2015.

[6] Yunlong Cai, Zhijin Qin, Fangyu Cui, Geoffrey Ye Li, "Modulation and Multiple Access for 5G Network" IEEE Communications Surveys & Tutorials, Vol. 20, No. 1, First Quarter 2018 pp. 629-646.

[7] D. Tse and P. Viswanath, Fundamentals of Wireless Communication, Cambridge University Press, Cambridge, U.K., 2005.

[8] O. Somekh and S. Shamai, "Shannon-theoretic approach to a Gaussian cellular multiple-access channel with fading," IEEE Trans. Inf. Theory, vol. 46, no. 4, pp. 1401–1425, July 2000.

[9] Yuya Saito, Yoshihisa Kishiyama, Anass Benjebbour, Takehiro Nakamura, Anxin Li, and Kenichi Higuchi, "Non-Orthogonal Multiple Access (NOMA) for Cellular Future Radio Access"

[10] K. Higuchi and Y. Kishiyama, "Non-orthogonal access with successive interference cancellation for future radio access," APWCS2012, Aug. 2012.

[11] Jinglun Wang, Bin Xia, Kexin Xiao, Yichen Gao and Shaodan Ma , "Outage Performance Analysis for Wireless Non-orthogonal Multiple Access Systems", IEEE Access · January 2018 DOI: 10.1109/ACCESS.2018.2789581

[12] K. Higuchi and Y. Kishiyama, "Non-orthogonal access with random beamforming and intra-beam SIC for cellular MIMO downlink," in *Proc. IEEE Veh. Technol. Conf. (VTC Fall)*, Las Vegas, NV, USA, Sep. 2013, pp. 1–5.

[13] Annass Benjebour et. Al., "NOMA: from concept to standardization", Proceedings in IEEE Conference on Standards for Communications and Networking (CSCN) 2015.

[14] S.M. Riazul Islam, Nurilla Avazov, Octavia A. Dobre, and Kyung-Sup Kwak, "Power-Domain Non-Orthogonal Multiple Access (NOMA) in 5G Systems: Potentials and Challenges", National Research Foundation of Korea, Ministry of Science, ICT and Future Planning)-NRF-2014K1A3A1A20034987, as well as the Natural Sciences and Engineering Research Council of Canada (NSERC)-2014.