ACCESS TECHNOLOGY PERFORMANCES OF A V2X SYSTEM FOR 5G TELECOMMUNICATIONS NETWORKS

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ABSTRACT

Today’s wireless networks allocate radio resources to users based on the orthogonal multiple access (OMA) principle. Nevertheless,as the number of users increases, OMA based approaches may not meet the stringent emerging requirements including very high spectral efficiency, very low latency, and massive device connectivity. Nonorthogonal multiple access (NOMA) principle emerges as a solution to improve the spectral efficiency while allowing some degree of multiple access interference at receivers. In this tutorial style paper, we target providing a unified model for NOMA, including uplink and downlink transmissions, along with the extensions tomultiple inputmultiple output and cooperative communication scenarios. Through numerical examples, we compare the performances of OMA and NOMA networks. Implementation aspects and open issues are also detailed.

Keyword: *IOT, V2X , NOMA, FD-NOMA,OMA , CAPACITY ANALYSIS, 5G, MIMO*

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1. INTRODUCTION

Wireless mobile communication systems became an indispensable part of modern lives. However, the number and the variety of devices increase significantly and the same radio spectrum is required to be reused several times by different applications and/or users. Additionally, the demand for the Internet of Things (IoT) introduces the necessity to connect every person and every object [1]. Besides the aforementioned techniques, a new radio access technology is also developed by researchers to be used in communication networks due to its capability in increasing the system capacity. Recently, nonorthogonality based system designs are developed to be used in communication networks and have gained significant attention of researchers. Hence, Multiple Access (MA) techniques can now be fundamentally categorized as Orthogonal Multiple Access (OMA) and Non Orthogonal Multiple Access (NOMA). In OMA, each user can exploit orthogonal communication resources within either a specific time slot, frequency band, or code in order to avoid Multiple Access interference.The previous generations of networks have employedOMAschemes, such as Frequency Division Multiple Access (FDMA) of first generation (1G), Time Division Multiple Access (TDMA) of 2G, code division multiple access (CDMA) of 3G, and orthogonal frequency division multiple access (OFDMA) of 4G. In NOMA, multiple users can utilize nonorthogonal resources concurrently by yielding a high spectral efficiency while allowing some degree of multiple access interference at receivers [6, 7].

In otherwords, the insufficient performance ofOMAmakes it inapplicable and unsuitable to provide the features needed to be met by the future generations of wireless communication systems. Consequently, researchers suggest NOMA as a strong candidate as an MA technique for next generations. Although NOMA has many features that may support next generations, it has some limitations that should be addressed in order to exploit its full advantage set. Those limitations can be pointed out as follows. In NOMA, since each user requires to decode the signals of some users before decoding its own signal, the receiver computational complexity will be increased when compared to OMA, leading to a longer delay. Moreover, information of channel gains of all users should be fed back to the base station (BS), but this results in a significant channel state information (CSI) feedback overhead. Furthermore, if any errors occur during SIC processes at any user, then the error probability of successive decoding will be increased. As a result, the number of users should be reduced to avoid such error propagation. Another reason for restricting the number of users is that considerable channel gain differences among users with different channel conditions are needed to have a better network performance.

This article, focused on NOMA technique, along with its usage in MIMO and cooperative scenarios. Practice implementation aspects are also detailed and besides an overview about the standardizations of NOMA in 3GPP LTE and application in the 5G scenarios is provided.

In addition, unlike previous studies, this paper includes performance analyses of MIMO-NOMA and cooperative NOMA scenarios to make the NOMA concept more understandable by researchers. The remainder of this paper is organized as follows. Basic concepts of NOMA, in both downlink and uplink networks, are given in Section 2. In Sections 3 and 4, MIMO-NOMA and cooperative NOMA are described,respectively. Practical implementation challenges of NOMA are detailed in Section 5.This article is concluded in Section 6.

1.1 RELATED WORK

The number of studies that target realtime implementation of NOMA is very limited. To the best of the authors' knowledge, beyond three main studies, such content is not included in any other study at the time of preparation of this paper. In [4], single user-(SU-) MIMO is integrated to downlink and uplink NOMA, and extensive computer simulations provide detailed rate evaluation between OMA and NOMA methods. Moreover, a comprehensive testbed is created to experiment downlink NOMA with SU-MIMO setup under real-time impairments. Turbo encoding is also utilized in the implementation and a SIC decoding structure, which also includes turbo decoding and MIMO detection, is proposed. Due to usage of a wider bandwidth, NOMA provides data rate improvement of 61% in this experiment scenario. Reference [5] targets improper power allocation issue, which is seen as a performance limiting factor in conventional NOMA models. By exploiting the physical layer network coding (PNC) in NOMA, the authors propose network-coded multiple access (NCMA). Adaptation of PNC provides an additional transmission dimension, and the received signals via two different dimensions increase the throughput significantly when compared to the conventional NOMA systems. It is validated by experimental results that the proposed NCMA variations provide noticeable performance improvements under the powerbalanced or near power-balanced scenarios. As the final study, software defined radio (SDR) implementation of downlink NOMA is realized to evaluate the performance differences between NOMA and OMA techniques.Moreover, protocol stack of LTE is modified to propose a suitable protocol stack forNOMA. Besides thesemultilayermodifications, detailed experiments are also carried out.Measurement results demonstrate the performance advantages of NOMA over OMA. Since superposition coding and NOMA are very similar in context, studies on superposition coding also contain the same valuable outcomes. In [14], advantages of superposition coding over time division multiplexing approach in terms of improving the quality of the poor links are validated via an SDR platform. Accordingly, the packet error rate is measured and need of a joint code optimization is shown.Moreover, an improved packet error rate performance that is obtained with superposition coding, when compared to the results of time division multiplexing utilization, is demonstrated. Similarly in [13], the authors propose a scheduler based on superposition coding and it is demonstrated that superposition coding based resource allocation can provide a data rate improvement up to 25% when compared to the orthogonal access techniques.These studies provide significant insights about realtime implementation aspects of NOMA.

2. SYSTEM MODEL

In this section, an overview of NOMA in downlink and uplink networks is introduced through signal-tointerference-and-noise ratio (SINR) and sum rate analyses.Then, high signal-to-noise ratio (SNR) analysis has been conducted in order to compare the performances of OMA and NOMA techniques.

2.1 Downlink NOMA Network.

At the transmitter side of downlink NOMA network, as shown in Figure 1, the BS transmits the combined signal, which is a superposition of the desired signals of multiple users with different allocated power coefficients, to all mobile users. At the receiver of each user, SIC process is assumed to be performed successively until user's signal is recovered. Power coefficients of users are allocated according to their channel conditions, in an inversely proportional manner. The user with a bad channel condition is allocated higher transmission power than the one which has a good channel condition. Thus, since the user with the highest transmission power considers the signals of other users as noise, it recovers its signal immediately :

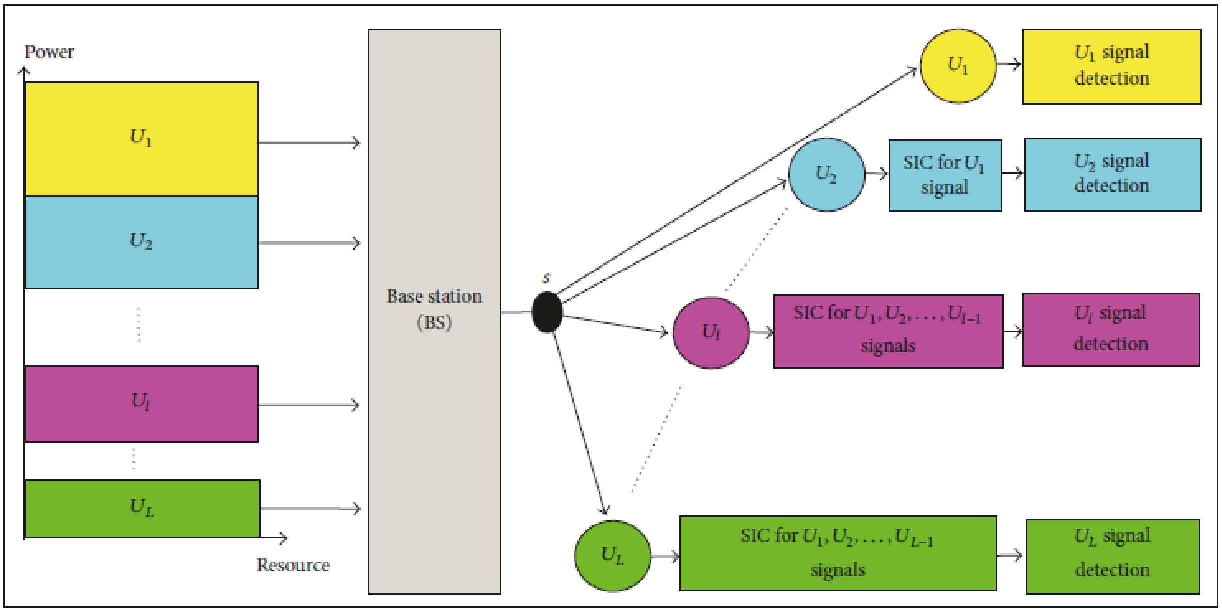

Figure 1: Downlink NOMA network.

without performing any SIC process. However, other users need to perform SIC processes. In SIC, each user's receiver first detects the signals that are stronger than its own desired signal. Next, those signals are subtracted from the received signal and this process continues until the related user's own signal is determined. Finally, each user decodes its own signal by treating other users with lower power coefficients as noise.
The transmitted signal at the BS can be written as follows:

$$S=\sum_{l=1}^{l}\sqrt{a_i P_s x_i} \quad (1)$$

x_i : is the information of user U_i with unit energy.,

P_s : is the transmission power at the BS

a_i : is the power coefficient allocated for user i subjected $\sum_i a_i = 1$ et $a_1 \geq a_2 \geq \cdots \geq a_L$,
$s \geq a_2 \geq \cdots \geq a_L$ since without loss of generality the channel gains are assumed to be ordered as$|h_1|^2 \leq |h_2|^2 \leq \cdots \leq |h_L|^2$ where h_l is the channel coefficient of lth user, based on NOMA concept.
The received signal at l-th user can be expressed as follows:

$$y_l = h_l s + n_l = h_l \sum_{l=1}^{l}\sqrt{a_i P_s x_i} + n_l \quad (2)$$

Where n_l is zero mean complex additive Gaussian noise with a variance ofσ^2 that is $n_l \sim \aleph(0, \sigma^2)$.

2.1.1 SINR Analysis.

By using (2), the instantaneous SINR of the lth user to detect the jth user, j $\neq L$.

$$SINR_{j\to l} = \frac{a_j\gamma|h_l|^2}{\gamma|h_l|^2\sum_{i=j+1}^{L} a_i+1} \quad (3)$$

Where $\gamma = \frac{P_s}{\sigma^2}$ denotes the SNR. In order to find the desired information of the lth user, SIC processes will be implemented for the signal of user j$\leq l$ Thus, the SINR of lth user can be given by :

$$SINR_{l} = \frac{a_l\gamma|h_l|^2}{\gamma|h_l|^2\sum_{i=l+1}^{L} a_i+1} \quad (4)$$

Then, the SINR of the Lth user is expressed as s :

$$SINR_l = a_L\gamma|h_L|^2 (5)$$

2.1.2 Sum Rate Analysis.

After finding the SINR expressions of downlinkNOMA, the sumrate analysis can easily be done.The downlink NOMA achievable data rate of lth user can be expressed as :

$$R_l^{NOMA-d} = log_2\,(1+SINR_l)$$

$$R_l^{NOMA-d} = log_2\left(1+\frac{a_l\gamma|h_l|^2}{\gamma|h_l|^2\sum_{i=l+1}^{L} a_i+1}\right) (6)$$

Therefore, the sumrate of downlinkNOMA can be written as :

$$R_{summ}^{NOMA-d} = \sum_{l=1}^{L} log_2\,(1+SINR_l)$$

$$R_{summ}^{NOMA-d} = \sum_{l=1}^{L-1} log_2\left(1+\frac{a_l\gamma|h_l|^2}{\gamma|h_l|^2\sum_{i=l+1}^{L} a_i+1}\right) + log_2\,(1+a_L\gamma|h_L|^2\ \ ) \ \ (7)$$

In order to figure out whether NOMA techniques outperform OMA techniques, we conduct a high SNR analysis. Thus, at high SNR, that is, $\gamma\to\infty$, the sum rate of downlink NOMA becomes :

$$R_{summ}^{NOMA-d} \approx \sum_{l=1}^{L-1} log_2\left(1+\frac{a_l}{\sum_{i=l+1}^{L} a_i}\right) + log_2\,(\gamma|h_L|^2\ \ )$$

$$R_{summ}^{NOMA-d} \approx log_2\,(\gamma|h_L|^2) \ \ (8)$$

2.2 *Uplink NOMA Network*.

In uplink NOMA network, as depicted in Figure 3, each mobile user transmits its signal to the BS.

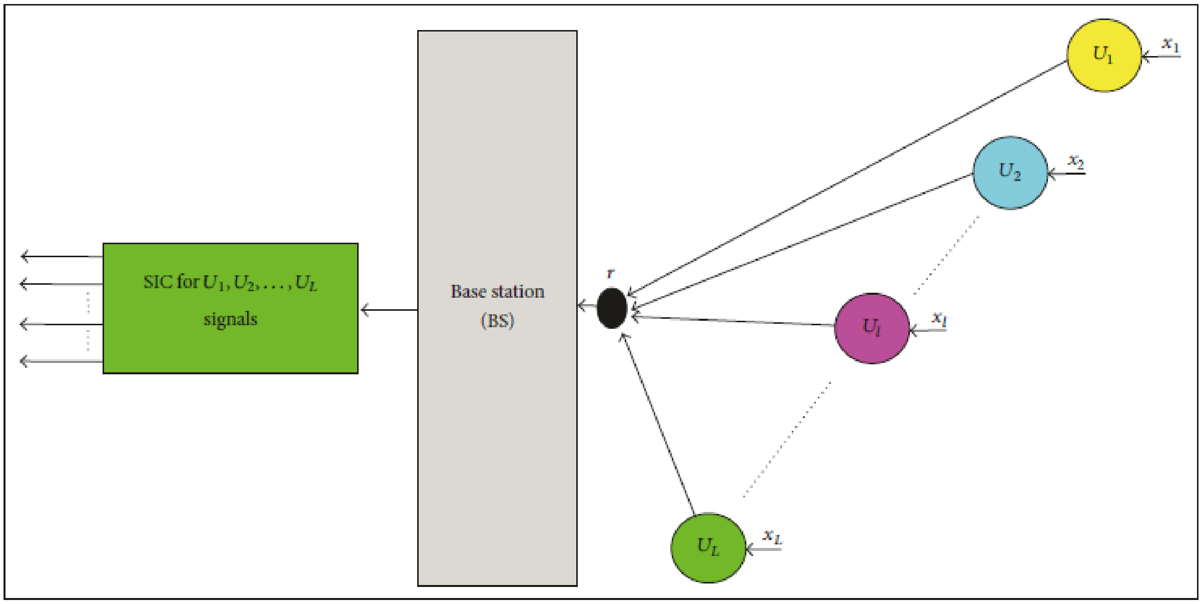

Figure 2 : Uplink NOMA network.

At the BS, SIC iterations are carried out in order to detect the signals ofmobile users. By assuming that downlink and uplink channels are reciprocal and the BS transmits power allocation coefficients to mobile users, the received signal at the BS for synchronous uplink NOMA can be expressed as :

$$r=\sum_{l=1}^{L} h_i\sqrt{a_i P x_i} + n \quad (9)$$

Where h_i is the channel coefficient of the ith user, P is the maximum transmission power assumed to be common for all users, and n is zero mean complex additive Gaussian noise with a variance of σ^2; that is, $n \sim \mathrm{CN}(0, \sigma^2)$.

2.2.1 SINR Analysis.

The BS decodes the signals of users orderly according to power coefficients of users, and then the SINR for lth user $l \neq 1$ can be given by [21] :

$$SINR_l = \frac{a_l \gamma |h_l|^2}{\gamma \sum_{i=1}^{l-1} a_i\, |h_i|^2 + 1} \quad (10)$$

where $\gamma = P/\sigma^2$. Next, the SINR for the first user is expressed as :

$$SINR_l = a_l \gamma |h_l|^2 \quad (11)$$

2.2.2. Sum Rate Analysis.

The sum rate of uplink NOMA can be written as :

$$R_{sum}^{NOMA-u} = \sum_{l=1}^{L} log_2\,(1 + SINR_l)$$

$$R_{sum}^{NOMA-u} = log_2\,(1 + a_l \gamma |h_l|^2\ ) + \sum_{l=2}^{L} log_2 \left(1 + \frac{a_l \gamma |h_l|^2}{\gamma |h_l|^2 \sum_{i=l}^{L-1} a_i |h_l|^2 + 1}\right)$$

$$R_{sum}^{NOMA-u} = log_2\left(1 + \sum_{l=1}^{L} a_i |h_l|^2\right) \quad (12)$$

When $\gamma \to \infty$, the sum rate of uplink NOMA becomes :

$$R_{sum}^{NOMA-u} \approx log_2\left(\gamma \sum_{l=1}^{L} |h_l|^2\right) \quad (13)$$

2.3. Comparing NOMA and OMA

The achievable data rate of the lth user of OMA for both uplink and downlink can be expressed as [21] :

$$R_l^{OMA} = \alpha_1 log_2\left(1 + \frac{\beta_1 \gamma |h_l|^2}{\alpha_1}\right) \quad (14)$$

where βl and αl are the power coefficient and the parameter related to the specific resource of Ul, respectively. And then, the sum rate of OMA is written as :

$$R_{sum}^{OMA} = \sum_{l=1}^{L} \alpha_1 log_2\left(1 + \frac{\beta_1 \gamma |h_l|^2}{\alpha_1}\right) \quad (15)$$

For OMA, for example, FDMA, total bandwidth resource and power are shared among the users equally; then using $\alpha_l = \beta_l = 1/L$ the sum rate can be written as :

$$R_{sum}^{OMA} = \sum_{l=1}^{L} \frac{1}{L} log_2(1 + \gamma |h_l|^2) \quad (16)$$

When $\gamma \to \infty$, the sum rate of OMA becomes :

$$R_{sum}^{OMA} \approx \sum_{l=1}^{L} \frac{1}{L} log_2(\gamma |h_l|^2) \quad (17)$$

Using

$$R_{sum}^{OMA} \approx \sum_{l=1}^{L} \frac{1}{L} log_2(\gamma |h_l|^2) \leq \sum_{l=1}^{L} \frac{1}{L} log_2(\gamma |h_L|^2) \quad (18)$$

$$R_{sum}^{OMA} = log_2(\gamma |h_l|^2) \approx R_{sum}^{NOMA-d}$$

Hence, we conclude :

$$R_{sum}^{OMA} \leq R_{sum}^{NOMA-d} \quad (19)$$

For the sake of simplicity, sumrates of uplinkNOMA and OMA can be compared for two users. Then, using (13) and
(17) the sum rate of uplink NOMA and OMA at high SNR can be expressed, respectively, as :

$$R_{sum}^{NOMA-u} \approx log_2\left(\gamma |h_1|^2 + \gamma |h_2|^2\right) \quad (20)$$

$$R_{sum}^{NOMA-u} \approx \frac{1}{2} log_2\left(\gamma |h_1|^2\right) + \frac{1}{2} log_2\left(\gamma |h_2|^2\right) \quad (21)$$

$$R_{sum}^{OMA} \leq log_2\left(\gamma |h_2|^2\right) \quad (22)$$

From (20) and (21), we notice $R_{sum}^{OMA} \leq R_{sum}^{NOMA-u}$.

Figure 4 shows that NOMA outperforms OMA in terms of sumrate in both downlink and uplink of two user networks using (7), (12), and (16).

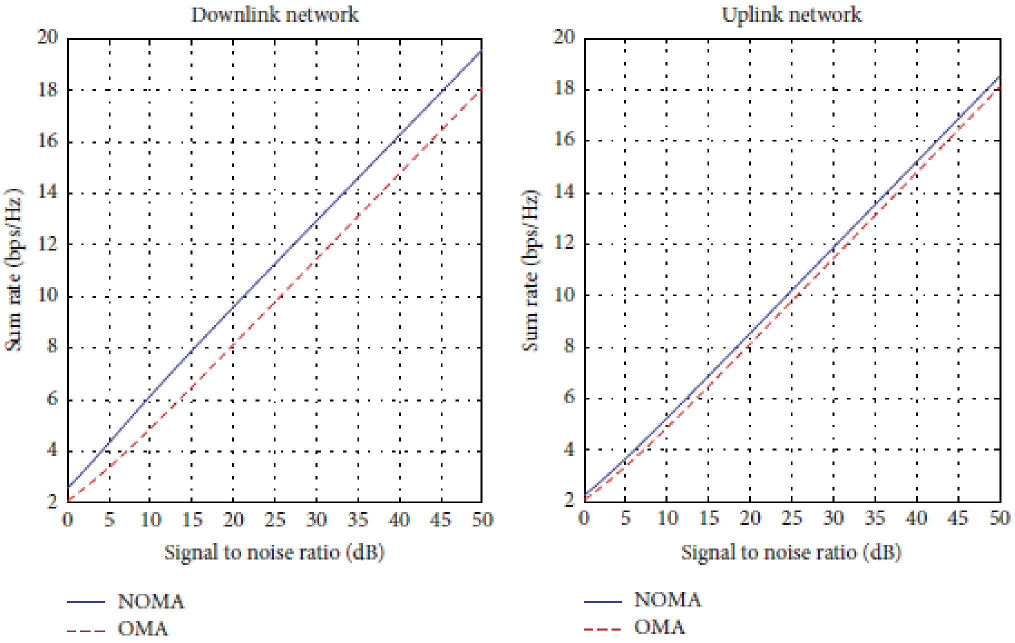

Figure 3: Sum rate of NOMA and OMA in both downlink and uplink networks with $\alpha1 = 0.6$, $\alpha2 = 0.4$, $|h1|2 = 0$dB, and $|h2|2 = 20$dB.

2.4 MIMO-NOMA

MIMO technologies have a significant capability of increasing capacity as well as improving error probability of wireless communication systems [19]. To take advantage of MIMO schemes, researchers have investigated the performance of NOMA over MIMO networks [20]. Many works have been studying the superiority of MIMO-NOMA over MIMOOMA in terms of sum rate and ergodic sum rate under different conditions and several constrictions. Specifically, the maximization problem of ergodic sum rate for two-user MIMO-NOMA system over Rayleigh fading channels is discussed. With the need of partial CSI at the BS and under some limitations on both total transmission power and the minimum rate for the user with bad channel condition, the optimal power allocation algorithm with a lower complexity to maximize the ergodic capacity is proposed. However, in order to achieve a balance between the maximum number of mobile users and the optimal achievable sum rate in MIMO-NOMA systems, sum rate has been represented through two ways. The first approach targets the optimization of power partition among the user clusters . Another approach is to group the users in different clusters such that each cluster can be allocated with orthogonal spectrum resources according to the selected user grouping algorithm. Furthermore, performances of two users per cluster schemes have been studied for both MIMO-NOMA and MIMO-OMA over Rayleigh fading channels. In addition, in accordance with specified power split, the dominance of NOMA over OMA has been shown in terms of sum channel and ergodic capacities.

MIMO-NOMA systems in terms of both OP and sum rate, as well as its superiority over MIMO-OMA, a special case, performance of single input multiple output- SIMO-NOMA network based on maximal ratio combining (MRC)
diversity technique in terms of both OP and ergodic sum rate is investigated in the following section.Moreover, closedform expression of OP and bounds of ergodic sum rate are derived.

2.4.1 *Performance Analysis of SIMO-NOMA.*

This network includes a BS and L mobile users as shown in Figure 5.

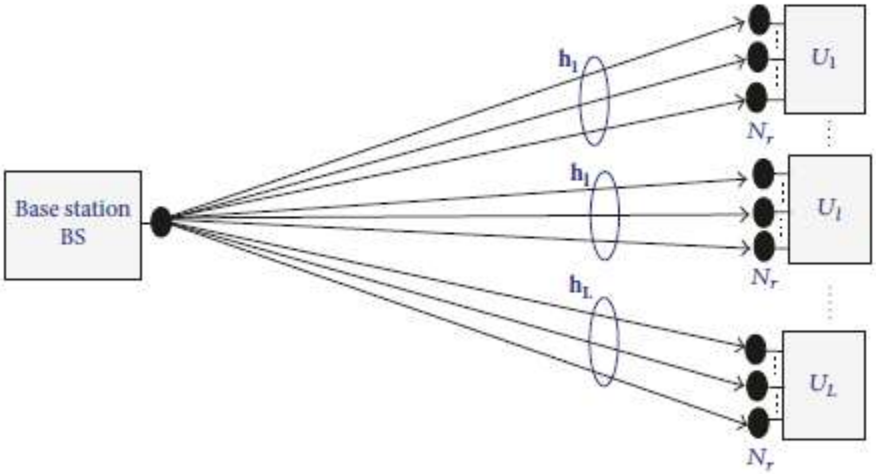

Figure 4: System model of the downlink SIMO-NOMA.

The transmitter of BS is equipped with a single antenna and the receiver of each mobile user is equipped with Nr antennas. The received signal at the lth user after applying MRC can be written as follows:

$$r_l = \|h_l\| \sum_{l=1}^{L} h_i \sqrt{a_i P_s x_i} + \frac{h_l^H}{\|h_l\|} n_1 \quad (23)$$

where h_l is Nr × 1 fading channel coefficient vector between the BS and lth user and without loss of generality and due to NOMA concept they are sorted in ascending way; that is, **‖h1‖2** ≤ **‖h2‖2** ≤ · · · ≤ **‖hL‖**, and n_l is Nr × 1 zero mean complex additive Gaussian noise with $E[n_l n_l^H] = I_N \sigma_l^2$ at the lth user, where $E[\cdot]$, $(\cdot)H$, and **I**r denote the expectation operator,Hermitian transpose, and identity matrix of order r, respectively, and $\sigma 2$ l = $\sigma 2$ is the variance of **nl** per dimension.

From (23), instantaneous SINR for lth user to detect jth user, $j \le l$, with $j \ne L$ can be expressed as follows:

$$SINR_{j\to l} = \frac{a_j \gamma \|h_l\|^2}{\gamma \|h_l\|^2 \sum_{i=j+1}^{L} a_i + 1} \quad (24)$$

Now, nonordered channel gains for MRC can be given as follows:

$$\left\|\widetilde{h_l}\right\|^2 = \sum_{\mathrm{i=1}}^{\mathrm{N}} \left|\mathrm{h_{l,i}}\right|^2, \mathrm{l} = 1,2 \ldots\ldots\ldots.. \mathrm{L} \quad (25)$$

where $h_{l,i}$ denotes the channel coefficient between the BS and ith antenna of the lth user and are independent and identically distributed (i.i.d.) Nakagami-$m$randomvariables. By the help of the series expansion of incomplete Gamma function [72, eq. (8.352.6)], the cumulative distribution function (CDF) and probability density function (PDF) of Gamma random variable X, square of Nakagami-m random variable can be defined as follows:

$$F_X(x) = \frac{\gamma(m, mx/\Omega)}{\Gamma(m)} = 1 - e^{-mx}/_{\Omega} \sum_{k=0}^{m-1} \left(\frac{mx}{\Omega}\right)^k \frac{1}{k!}$$

$$f_X(x) = \left(\frac{m}{\Omega}\right)^m \frac{x^{m-1}}{\Gamma(m)} e^{-mx}/_{\Omega} \quad (26).$$

3. NUMERICAL RESULTS

In the literature, power allocation and user clustering are generally considered as the main problems in NOMA systems, and several strategies are proposed to provide efficient solutions to these issues. As also considered in [9–10], these problems are formulated as an optimization problem and the corresponding solution procedures are also proposed.Besides these, studies, propose approaches that are suitable to real-time applications. Imperfect CSI is assumed in the corresponding system models. However, real-time implementation challenges are not considered in most of the studies and the associated implementation design, which may provide effective solutions to these challenges, is not mentioned. In this section, these challenges are highlighted and important design components are explained. In the following subsection, some studies that include real-time implementation of NOMA are mentioned and challenges of such real-time implementations will be detailed.

- *Outage Probability of SIMO-NOMA*

The OP of the lth user can be obtained as follows:

$$P_{out,l} = P_r\left(SINR_{j\to l} < \gamma_{th_j}\right)$$

$$=P_r\left(\frac{a_j\gamma\|h_l\|^2}{\gamma\|h_l\|^2\sum_{i=j+1}^{L}a_i+1} < \gamma_{th_j}\right)$$

$$=P_r\left(\|h_l\|^2 < \frac{\gamma_{th_j}}{\gamma\left(a_j-\gamma_{th_j}\sum_{i=j+1}^{L}a_i\right)}\right)$$

$$P_{out,l}=P_r(\|h_l\|^2 < \eta_l^*) = F_{\|h_l\|^2}(\eta_l^*)=\frac{L!}{(L-l)!(l-1)!}\cdot\sum_{t=0}^{L-l}\sum_{r=0}^{l+t}\sum_{s=0}^{r(mN_r-1)}\frac{(-1)^{t+r}}{(l+t)}\cdot\binom{L-l}{t}\binom{l+t}{r}\vartheta_s(r,mN_r){\eta_l^*}^{s}e^{-rm\eta_l^*/\Omega} \quad (27)$$

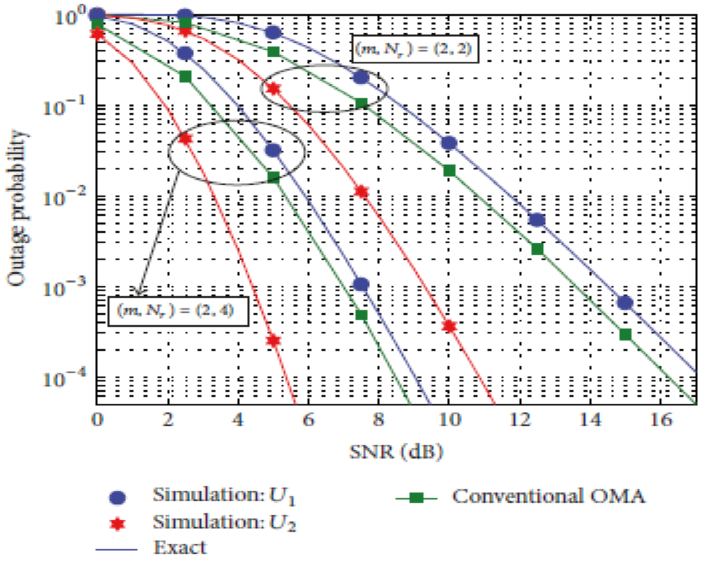

Figure 5: Outage probability of MIMO-NOMA system versus SNR for $L = 2$, $a1 = 0.6$, $a2 = 0.4$, γth1 = 1, γth2 = 2, and γth = 5.

- ***Ergodic Sum Rate Analysis of SIMO-NOMA***

Ergodic sum rate can be expressed as :

$$R_{sum} = \sum_{l=1}^{L} E\left[\frac{1}{2}\log_2(1+SINR_l)\right]$$

$$R_{sum} = \underbrace{\sum_{l=1}^{L-1} E\left[\frac{1}{2}\log_2(1+SINR_l)\right]}_{R_{\bar{L}}} + \underbrace{E\left[\frac{1}{2}\log_2(1+SINR_l)\right]}_{R_L} \quad (28)$$

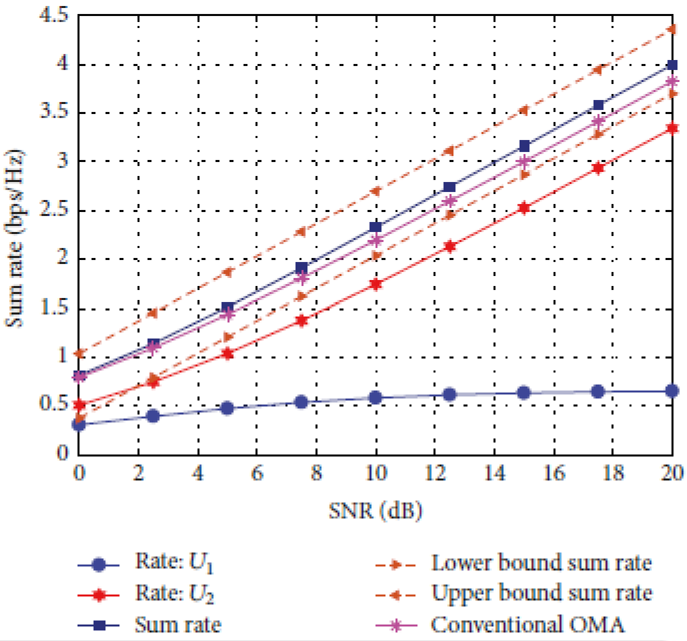

Figure 6: Ergodic sum rate of MIMO-NOMA system versus SNR for $L = 2$, $\alpha_1 = 0.6$, $\alpha_2 = 0.4$, $\gamma_{th1} = 1$, $\gamma_{th2} = 2$, $\gamma_{th} = 5$, and $(m, N_r) = (2,2)$.

- Cooperative NOMA

Cooperative communication, where the transmission between the source and destination is maintained by the help of one or multiple relays, has received significant attention of researchers since it extends the coverage area and increases system capacity while reducing the performance deteriorating effects of multipath fading [16, 17]. In cooperative communication systems, relays transmit the received information signals to the related destinations by applying forwarding protocols, such as amplify-and-forward (AF) and decodeand- forward (DF). In addition, in the last decade, the relays can be fundamentally categorized as half-duplex (HD) and full-duplex (FD) according to relaying operation. Differing from HD, FD relay maintains the data reception and transmission process simultaneously in the same frequency band and time slot [18]. Thus, FD relay can increase the spectral efficiency compared to its counterpart HD [18]. Therefore, the combination of cooperative communication and NOMA has been considered as a remarkable solution to further enhance the system efficiency of NOMA. Accordingly, in [13], a cooperative transmission scheme,where the userswith stronger channel conditions are considered as relays due to their ability in the decoding information of other users in order to assist the users with poor channel conditions, has been proposed to be implemented in NOMA. In [14], by assuming the same scenario in [13], Kim et al. proposed a device-to-device aided cooperativeNOMAsystem,where the direct link is available between the BS and one user, and an upper bound related to sum capacity scaling is derived. In addition, a new power allocation scheme is proposed to maximize the sum capacity. On the other hand, in [11], the authors analyze the performance of NOMA based on user cooperation, in which relaying is realized by one of the users, operating in FD mode to provide high throughput, by applying power allocation.

In the next section, we provide an overview of the cooperative NOMA system which is investigated in [12] to provide an example of cooperative NOMA.

Consider a dual hop relaynetworkbasedondownlinkNOMAas given in Figure 8(b)which consists of one BS (S),oneAFHDrelay (R), and L mobile users. In the network, all nodes are equipped with a single antenna, and direct links between the BS and mobile users can not be established due to the poor channel conditions and/or the mobile users are out of the range of BS. We assume that all channel links are subjected to flat Nakagami-m fading.

In the first phase, the superimposed signal s given in (1) is transmitted from the BS to the relay and then the received signal at R can be modeled as :

$$y_R = h_{SR}\sum_{i=1}^{L}\sqrt{a_iP_s}\,x_i + n_R, \qquad (29)$$

- ✓ **Outage Probability of Cooperative NOMA**

By using the approach given in [89], the OP of the lth user can be written as :

$$P_{out,l} = 1 - \Pr\left(\left|h_{RU_l}\right|^2 > \eta_l^*, |h_{SR}|^2 > \frac{\eta_l^*\left(1+\gamma\left|h_{RU_l}\right|^2\right)}{\gamma\left(\left|h_{RU_l}\right|^2 - \eta_l^*\right)}\right) \qquad (30)$$

The OP expression given in (30) can be mathematically rewritten as :

$$P_{out,l} = \underbrace{\int_0^{\eta_l^*} f\left|h_{RU_l}\right|^2(x)}_{j_1} + \underbrace{\int_{\eta_l^*}^{\infty} f\left|h_{RU_l}\right|^2(x)F_{|h_{SR}|^2}\left(\frac{\eta_l^*(1+\gamma x)}{\gamma(x-\eta_l^*)}\right)dx}_{J_2} \qquad (31)$$

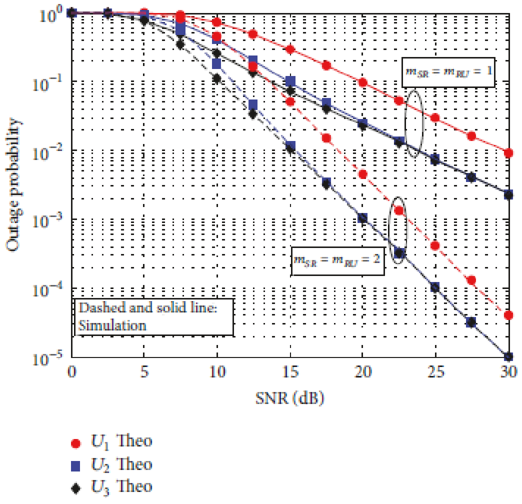

Figure 7: Outage probability of NOMA versus SNR in case dSR =0.5 and different Nakagami-m parameters.

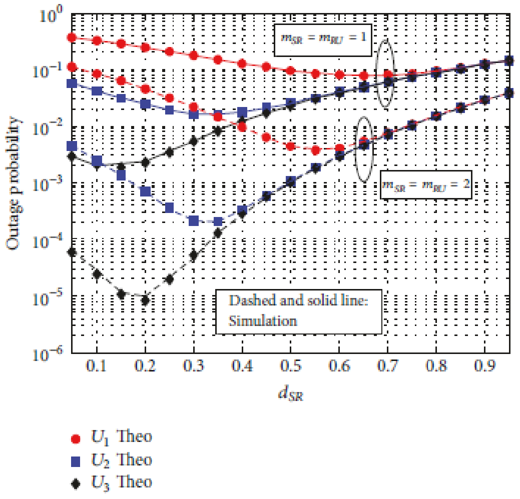

Figure 8: Outage probability of NOMA versus dSR in case γ =20 dB and different Nakagami-m parameters.

4. CONCLUSIONS

In conclusion , NOMA schemes are proposed to improve the efficient usage of limited network sources. OMA based approaches that use time, frequency, or code domain in an orthogonal manner cannot effectively utilize radio resources, limiting the number of users that can be served simultaneously. In order to overcome such drawbacks and to increase themultiple access efficiency, NOMA technique has been recently proposed. Accordingly, users are separated in the power domain. Such a power-domain based multiple access scheme provides effectivethroughput improvements, depending on the channel conditions. In OMA, differences between channels and conditions of users cannot be effectively exploited. It is quite possible for a user to be assigned with a large frequency band while experiencing deteriorating channel conditions. Such user cases limit the effectiveness of OMA based approaches. However, according to the NOMA principle, other users who may be experiencing better channel conditions can use these bands and increase their throughput. Moreover, corresponding users who are the primary users of these bands continue to use these bands. In such deployments, power level of users is selected in a way to target a certain maximum error rate. Furthermore, the performance of NOMA can be significantly improved using MIMO and cooperative communication techniques.

In this article , we provide a unified model system model for NOMA, including MIMO and cooperative communication scenarios. Implementation aspects and related open issues are detailed.

A comprehensive literature survey is also given to provide an overview of the state-of-the-art.

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