# NOMA Made Practical: Removing the Receive SIC Processing through Interference Exploitation

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**Abstract**

Non-orthogonal multiple access (NOMA) is a powerful transmission technique that enhances the spectral efficiency of communication links, and is being investigated for 5G standards and beyond. A major drawback of NOMA is the need to apply successive interference cancellation (SIC) at the receiver on a symbol-by-symbol basis, which limits its practicality. To circumvent this, in this paper a novel constructive multiple access (CoMA) scheme is proposed and investigated. CoMA aligns the superimposed signals to the different users constructively to the signal of interest. Since the superimposed signal aligns with the data signal, there is no need to remove it at the receiver using SIC. Accordingly, SIC component can be removed at the receiver side. In this regard and in order to provide a comprehensive investigation and comparison, different optimization problems for user paring NOMA multiple-input-single-output (MISO) systems are considered. Firstly, an optimal precoder to minimize the total transmission power for CoMA subject to a quality-of-service constraint is obtained, and compared to conventional NOMA. Then, a precoder that minimizes the CoMA symbol error rate (SER) subject to power constraint is investigated. Further, the computational complexity of CoMA is considered and compared with conventional NOMA scheme in terms of total number of complex operations. The results in this paper prove the superiority of the proposed CoMA scheme over the conventional NOMA

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technique, and demonstrate that CoMA is an attractive solution for user paring NOMA MISO systems with low number of BS antennas, while circumventing the receive SIC complexity.

**Index Terms**

NOMA, constructive interference, successive interference cancellation.

## I. Introduction

Non-orthognal multiple access (NOMA) technique has received significant attention very recently as a viable multiple access technique for communication networks [1]–[3]. In NOMA the transmitter superimposes the users signals in same frequency, time, and code domains while being able to resolve the signals in the power domain. The users with poor channel conditions (weak users) are allocated with high transmission power levels, while the users with strong channel conditions (strong users) are allocated with low power levels. At reception, the weak users detect their signals by treating the other users' signals as noise. On the contrary, the strong users first decode the signals of the weaker users, then they detect their own signals by removing the weaker users' signals using successive interference cancellation (SIC) [1]. This is a significant known limitation of NOMA, which poses impractical symbol-by-symbol complexity.

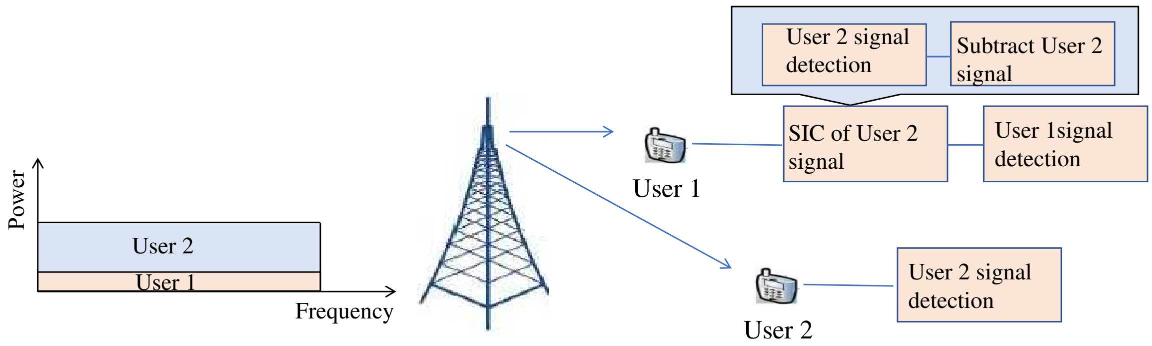
The efficiency of NOMA technique has been extensively investigated in the literature. For instance, the results in [4] showed that NOMA can achieve superior performance comparing with orthogonal multiple access (OMA) schemes. The performance of NOMA was analyzed in [5] based on the availability of the channel state information (CSI) at the transmitter. In [6] a power minimization problem for two-users multiple-input-single-output (MISO)-NOMA systems was formulated and solved. The results in this work showed that the proposed NOMA approach can enhance the performance of MISO systems. To maximize the fairness among the users in NOMA systems, an optimal power allocation scheme has been considered in [7].

Furthermore, in NOMA systems when number of users is large, the interference in the system might be strong. This interference will lead to increase the complexity and the processing delay at the receivers. More relevant to this work, in order to reduce the interference, complexity and processing delay, user pairing scheme has been proposed and considered in the literature [8]–[11]. In this scheme, each two users (pair) share a specific orthogonal resource slot and NOMA technique is implemented among the users in each pair. User pairing scheme has been widely investigated in the literature. The authors in [9] proposed a user pairing scheme in which the network area is divided into two regions, near and far regions, and each far user is paired with a near user. The results in [9] explained that, the performance gain performed by NOMA over OMA can be further improved by paring the users whose channel conditions are more distinctive. In [10] MU-MIMO NOMA systems was considered, in which the users are paired and share the same transmit beam-forming vector. Under this scenario, the superiority of MIMO-NOMA over MIMO-OMA has been proved for a two-user paring scenario. The authors in [11] proposed a greedy-search based user pairing scheme in order to maximize the achievable sum rate of NOMA system.

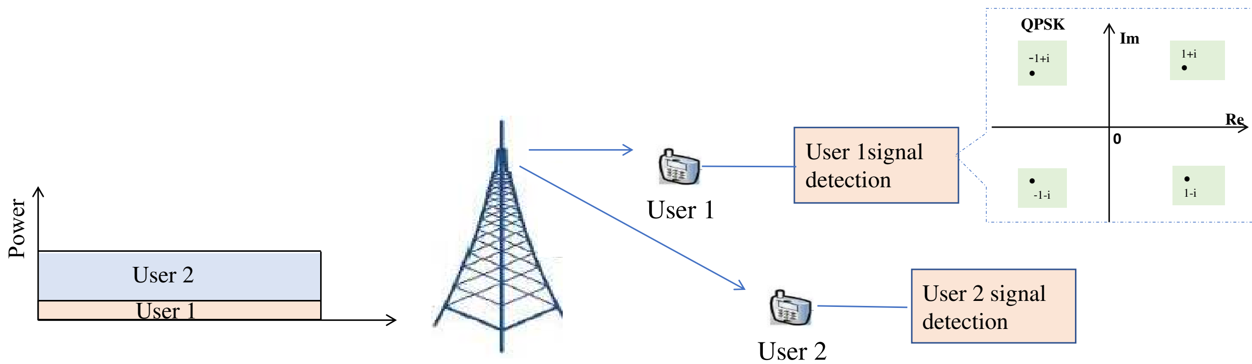
In parallel, constructive interference (CI) precoding has received research interest in the last few years [12]–[15]. CI precoding is also a non-orthogonal transmission approach which exploits the known interference to improve the system performance. Based on the knowledge of the CSI and the users messages, the BS can classify the multi-user interference as constructive and destructive. The constructive interference can be defined as the interference that can move the received symbol deeper in the detection region of the constellation point of interest. Accordingly, a constructive precoder can be obtained to make the known interference in the system constructive to the received symbols. The CI concept has been widely studied and investigated in the literature. This line of research introduced in [12], where the CI precoding technique has been proposed for downlink MIMO systems, showing significant performance improvements over conventional precoding. The first optimization based CI approach was introduced in [13] where a modified vector-perturbation technique was proposed, in which the search of perturbing vectors was limited to a specific area where the distances from the decision thresholds are increased with respect to a distance threshold. In [14], [15], a symbol-level precoding scheme for downlink MU-MISO system has been proposed. In these works the authors used the knowledge of the CSI and data symbols to exploit the constructive interference in the system. Further work in [16], [17], a general category of CI regions has been considered, and the features of this region have been studied. Different convex alphabet relaxation schemes for vector precoding in MIMO broadcast channels have been proposed in [18] to achieve interference-free communication over singular channels. It has been shown in [19] that vector precoding can be implemented to reduce the transmission power of MIMO systems. The authors in [20], [21] implemented CI precoding scheme in wireless power transfer scenarios to minimize the total transmit power. Recently in [22], [23] closed-form expressions of CI precoding scheme for phase-shift keying (PSK) and quadrature amplitude modulation (QAM) have been derived. These expressions have derived based on optimal performance, thus its performance is equivalent to the optimization-based CI schemes presented in the literature. Based on these closed form expressions, in our previous works in [24]–[27] analytical expressions of the achievable sum-rate and error probability of CI precoding have been derived for different scenarios. For more details, the reader is referred to [28] where the concept of the CI precoding scheme and its practical implementation have been presented and discussed in details.

In this work, we exploit the CI concept to address a major limitation of NOMA systems. This is the need to apply SIC on a symbol-by-symbol basis at the receiver, which introduces impractical complexity. Accordingly, we propose an approach to entirely circumvent SIC, based on the concept of CI. We introduce a new constructive multiple access NOMA (CoMA) precoding technique that aligns the superimposed signals to the different user equipments (UE) constructively to the signal of interest. The key principle is shown in Fig. 1b, contrasting it with the classical NOMA approach in Fig. 1a. Since for CoMA the superimposed signal aligns with the data signal, the received symbol appears at the correct constellation region, it does not require channel equalization and there is no need to remove the interfering symbol at the receiver using SIC technique. Critically, this new scheme allows the following key gains that make NOMA practical:

1) A low complexity UE - by removing SIC from the receiver, CoMA allows minimal receive signal processing as shown in Fig. 1b.
2) Since channel equalization is not required, this removes the need for channel state information (CSI) at the UE, which in turn
   - Removes the overheads associated with collecting and sharing CSI.




(a) Conventional NOMA.




(b) CoMA (Invention)

Figure 1: Conventional NOMA and CoMA schemes.

• Removes the quantization and noise-related errors in the CSI shared from the BS to each UE.

3) Reduces the latency in processing the received signal on a symbol-by-symbols basis at each UE.

Due to the above key advantages, the proposed approach makes NOMA more practical and fits different practical scenarios. In this regard and in order to provide a comprehensive comparison, based on the CoMA concept, two new optimal precoders are designed, one to minimize the total transmit power and one to minimize the symbol error rate (SER) for a given NOMA pair. In addition, the receiver complexity of CoMA scheme is investigated and compared with conventional NOMA scheme.

For clarity we highlight the main contributions of this work as follows.

1) CoMA scheme is proposed and introduced for the first time to remove receive SIC and reduce the complexity of user pairing NOMA MISO systems.
2) New CoMA precoder that minimizes the transmit power for a given system performance is designed.
3) We further adapt CoMA concept to design new precoder that is able to minimize the system error rate subject to total power constraint.
4) The complexity analysis of the proposed CoMA scheme is considered and investigated.
5) The performance of CoMA scheme is compared with OMA and conventional NOMA precoders.

The results in this work show that CoMA scheme consumes much less power than conventional NOMA and OMA techniques to achieve similar target rates. In addition, CoMA scheme has lower error rate than OMA and conventional NOMA schemes. Furthermore, our results confirm that the new proposed CoMA scheme has very low computational receiver complexity compared to conventional NOMA technique.

Next, Section II describes the MU-MISO system model. Section III, introduces the new proposed CoMA scheme. Section IV considers power minimization problems of CoMA and NOMA subject to QoS constraint. Section V, studies the error rate minimization problems for CoMA and NOMA subject to total power constraint. The computational receiver complexity of NOMA and CoMA are presented in Section VI. Numerical results are presented and discussed in Section VII. Finally, Section VIII concludes this paper.

## II. System Model

We consider a down-link MU-MISO system, in which a BS equipped with $N$ antennas transmits information signals to $2K$ single antenna users using user-pairing NOMA technique [8]–[11]. In this system, each two users are paired to form a cluster, and hence, there are $K$ pairs/clusters in the system as shown in Fig. 2. Block fading channel model is assumed, in which each channel coefficient includes both small scale fading and large scale fading. The

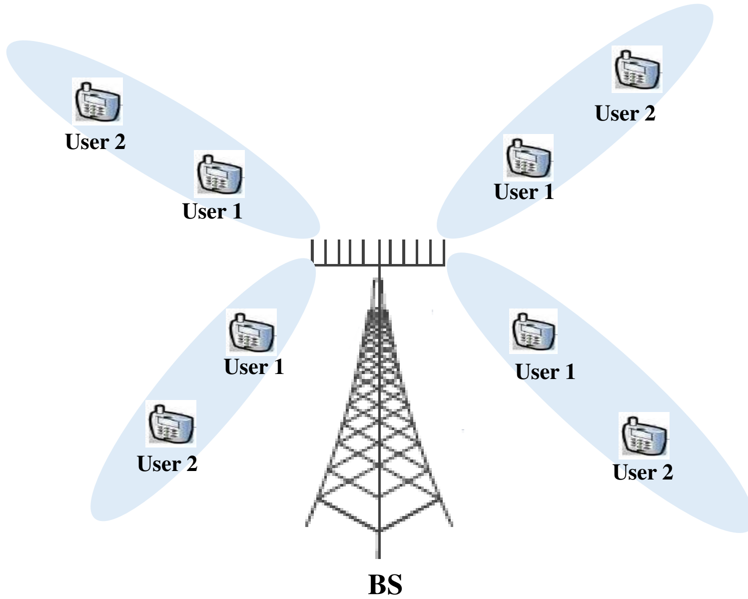



Figure 2: A multiuser NOMA system with $K$ pairs.

$N \times 1$ channel vector between the BS and user $i$, $i \in \{1, 2\}$ in pair $k$, $k \in \{1, ...., K\}$, is $\mathbf{h}_{k,i} \sim \mathcal{CN}\left(0,\, \mathbf{I}_N \sigma_{k,i}^2\right)$.

Following the principle of NOMA, the BS broadcasts a superimposed message of the two users in each pair. For pair $k$, the BS transmits $\mathbf{x}_k = \mathbf{w}_{k,1} x_{k,1} + \mathbf{w}_{k,2} x_{k,2}$, where $x_{k,1}$ and $x_{k,2}$ are the data symbols for user 1 $(u_{k,1})$ and user 2 $(u_{k,2})$ with unit variance, $\mathbf{w}_{k,i}$ is the precoding vector of user $i$. In user-pairing NOMA scheme the two users in each pair are ordered based on their CSI. Without loss of generality, user 1, is assumed to has better channel than user 2, hence, the power allocated to user 2 should be higher than the power allocated to user 1. The received signals at user 1 and user 2 in pair $k$ can be written as

$$y_{u_{k,i}} = \mathbf{h}_{k,i}^T \sum_{l=1}^{2} \mathbf{w}_{k,l} x_{k,l} + n_{u_{k,i}}, \tag{1}$$

where $n_{u_{k,i}}$ is the additive white Gaussian noise (AWGN) at user $i$ with variance $\sigma_{u_{k,i}}^2$, $n_{u_{k,i}} \sim \mathcal{CN}\left(0,\, \sigma_{u_{k,i}}^2\right)$.

Based on NOMA, the stronger user, user 1, adopts a SIC, in which user 1 first detects user 2 signal, and then removes the detected signal term from the received signal to decode its own message. Thus, the received SINR at user 1 to detect user 2 signal, $x_{k,2}$, can be written as,

$$\gamma_{x_{k,2}\rightarrow u_{k,1}} = \frac{\left|\mathbf{h}_{k,1}^T \mathbf{w}_{k,2}\right|^2}{\left|\mathbf{h}_{k,1}^T \mathbf{w}_{k,1}\right|^2 + \sigma_{u_{k,1}}^2}, \tag{2}$$

The data rate for user 1 to detect user 2 signal, $R_{x_{k,2}\rightarrow u_{k,1}}$, should be larger than the target rate of user 2 and thus $\gamma_{x_{k,2}\rightarrow u_{k,1}}$ should be higher than the target SINR at user 2 $(r_2)$. The received signal at user 1 after using SIC is given by

$$y_{u_{k,1}} = \mathbf{h}_{k,1}^T \mathbf{w}_{k,1} x_{k,1} + \epsilon + n_{u_{k,1}}, \tag{3}$$

where $\epsilon$ is the SIC error with variance $\sigma_\epsilon^2$. This error may occur due to incorrect detection of $x_{k,2}$ , incorrect CSI knowledge, or incorrect knowledge of the power allocation at the BS. Consequently, the received SINR at user 1 and user 2, to detect $x_{k,1}$and $x_{k,2}$, respectively, can be written as

$$\gamma_{u_{k,1}} = \frac{\left|\mathbf{h}_{k,1}^T \mathbf{w}_{k,1}\right|^2}{\sigma_\epsilon^2 + \sigma_{u_{k,1}}^2}, \tag{4}$$

$$\gamma_{u_{k,2}} = \frac{\left|\mathbf{h}_{k,2}^T \mathbf{w}_{k,2}\right|^2}{\left|\mathbf{h}_{k,2}^T \mathbf{w}_{k,1}\right|^2 + \sigma_{u_{k,2}}^2}. \tag{5}$$

However, as we have explained earlier, NOMA scheme suffers from a key challenge. The need to perform SIC at the receiver on a symbol-by-symbol level, i.e. for an LTE frame on the order of 0.1msec. This implicates:

- Large complexity at the UE receiver that makes the practical application challenging.
- Increased latency in the signal detection.
- Overheads in obtaining/feedback of CSI.
- Increased transmit power when the SIC errors increase.

In order to overcome all these challenging points CoMA technique is proposed and presented in the next Section.

## III. Constructive NOMA (CoMA) Scheme

The main idea of CoMA scheme is to align the superimposed signals that is known to the BS to increase the useful signal power at the receiver. As we mentioned earlier, the interference signal is constructive if it can move the received symbol towards the detection/constructive region. The basic concept of CI precoding for QPSK constellation is summarized in Fig. 3. Briefly, the constructive interference pushes the received symbol deeper in the detection/constructive region, this represents the green areas in the constellation of Fig. 3, and thus enhances the detection. Additionally, the constructive areas for BPSK, QPSK and 8PSK are shown in Fig. 4. For more details, the reader is referred to [28] where the interference exploitation scheme has been discussed and the practical implementation of CI precoding has been presented.

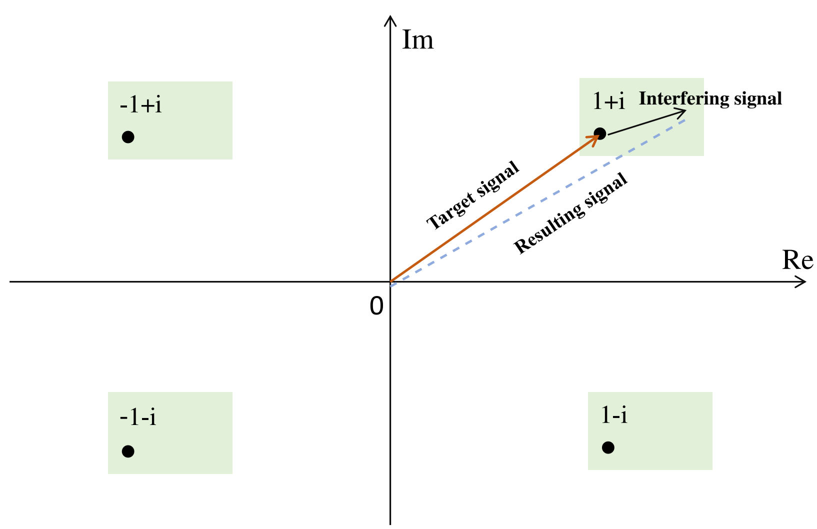



Figure 3: The basic concept of CI in QPSK, the constructive regions are represented by the green areas.

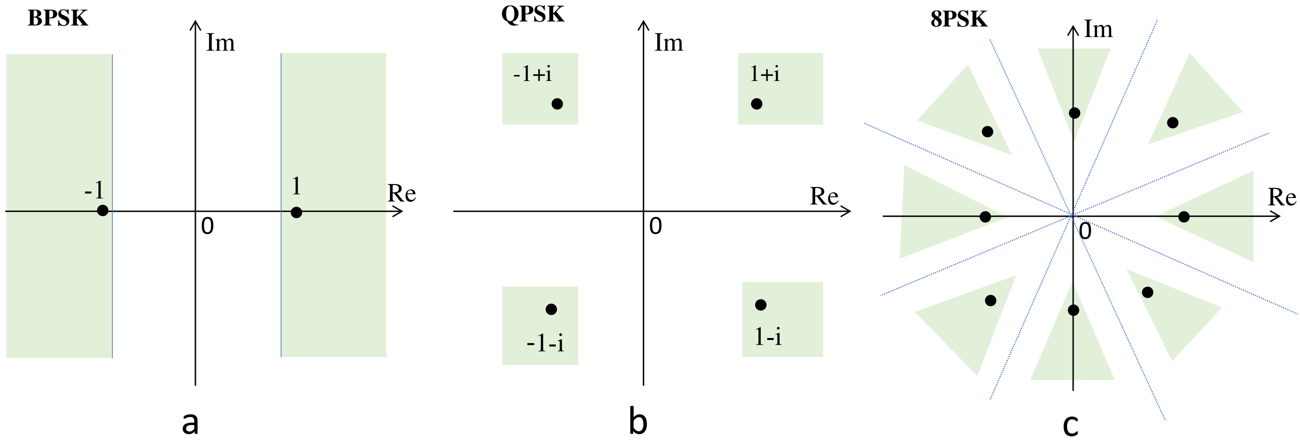



Figure 4: Constructive interference in a) BPSK, b) QPSK and c) 8PSK, the constructive regions are represented by the green areas.

Therefore, following the CI principle [28] the transmit precoding can be designed to impose constructive interference to the desired symbol. When the interference is aligned by means of precoding vectors to overlap constructively with the signal of interest, all interference contributes constructively to the useful signal and thus the SINR expressions can be modified to take the constructive interference into account. For the example of PSK signaling, the modulated symbols of the users in pair $k$ can be expressed as $x_{k,i} = x\, e^{j\phi_i}$, where $x$ denotes the constant amplitude and $\phi_i$ is the phase. Thus, the received signals at user 1 and user 2 presented in (1) can be represented as

$$y_{u_{k,i}} = \mathbf{h}_{k,i}^T \sum_{l=1}^{2} \mathbf{w}_{k,l} e^{j(\phi_l - \phi_i)} x + n_{u_{k,i}}, \tag{6}$$

In CoMA scheme the interference at the strong user is designed to be constructive to the desired symbol, thus the interference at user 1 contributes in the useful received signal power. Therefore, the received SINRs at users 1 and 2 in pair $k$ are given, respectively, by [14], [20]

$$\gamma_{u_{k,1}} = \frac{\left|\mathbf{h}_{k,1}^T \left(\mathbf{w}_{k,1} x_{k,1} + \mathbf{w}_{k,2} x_{k,2}\right)\right|^2}{\sigma_{u_{k,1}}^2}, \tag{7}$$

$$\gamma_{u_{k,2}} = \frac{\left|\mathbf{h}_{k,2}^T \mathbf{w}_{k,2}\right|^2}{\left|\mathbf{h}_{k,2}^T \mathbf{w}_{k,1}\right|^2 + \sigma_{u_{k,2}}^2}. \tag{8}$$

The block diagram of the user 1 receiver for conventional NOMA and CoMA can be shown as in Fig. 5. By comparing the two receivers we can notice that by implementing CI, there is no need to use SIC and channel equalization, and thus this simplifies the signal processing procedure at the receiver side.

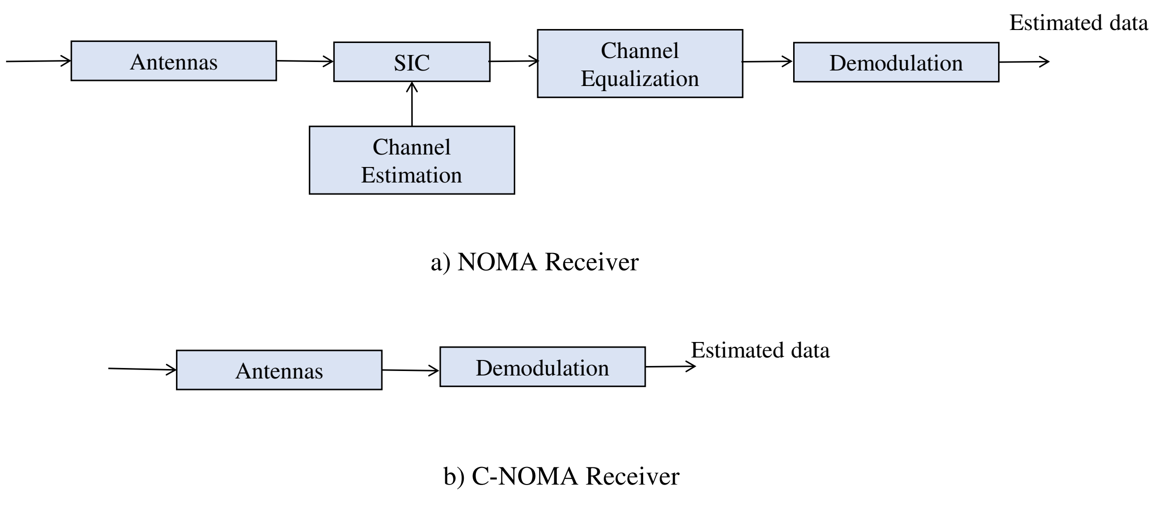



Figure 5: Receivers of conventional and constructive NOMA schemes.

In the following Sections different precders are designed to minimize the transmit power and the error rates of MU-MISO NOMA systems.

## IV. Power Minimization

In this Section we design prcoder vectors that minimize the total transmission power subject to a quality-of-service (QoS) constrains. For sake of comparison, CoMA and NOMA are considered in this Section.

### A. CoMA Precoding

In this case we consider the power minimization problem for a given pair with target SINR levels $r_1$, $r_2$[1]. As per the above classification and discussion, the optimization problem can be formulated to take the constructive interference into account in the power minimization problem. The total power consumption in this case is $P = \left\|\sum_{i=1}^{2} \mathbf{w}_i e^{j(\phi_i - \phi_1)}\right\|^2$. Accordingly and based on basic geometry of the constructive interference regions [14], [20], the optimization problem for $M$-PSK signaling can be formulated as [14], [20]

$$\begin{aligned} &\min_{\mathbf{w}_i \succeq \mathbf{0}} \left\|\sum_{i=1}^{2} \mathbf{w}_i e^{j(\phi_i - \phi_1)}\right\|^2 \\ s.t.\ &\mathbf{C1}: \left|\mathrm{Im}\left(\mathbf{h}_1^T \sum_{k=1}^{2} \mathbf{w}_k e^{j(\phi_k - \phi_1)}\right)\right| \le \left(\mathrm{Re}\left(\mathbf{h}_1^T \sum_{k=1}^{2} \mathbf{w}_k e^{j(\phi_k - \phi_1)}\right) - \sqrt{r_1 \sigma_{u1}^2}\right) \tan\theta \\ &\mathbf{C2}: \left|\mathbf{h}_2^T \mathbf{w}_2\right|^2 \ge \left(\left|\mathbf{h}_2^T \mathbf{w}_1\right|^2 + \sigma_{u_2}^2\right) r_2 \end{aligned} \tag{9}$$

where $\theta = \pm\frac{\pi}{M}$. The first constraint in (9), **C1,** is constructive interference constraint for user 1 which is convex, please refer to [14] for more details. In addition, the second constraint in (9), **C2**, can be simplified using first order Taylor's approximation. After applying the first-order Taylor expansion on $\bar{\mathbf{w}}_i$, we can write

$$\left|\mathbf{h}_2^T \mathbf{w}_2\right|^2 = 2\mathrm{Re}\left(\bar{\mathbf{w}}_2^H \mathbf{h}_2 \mathbf{h}_2^T \mathbf{w}_2\right) - \mathrm{Re}\left(\bar{\mathbf{w}}_2^H \mathbf{h}_2 \mathbf{h}_2^T \bar{\mathbf{w}}_2\right) \tag{10}$$

and

$$\left|\mathbf{h}_2^T \mathbf{w}_1\right|^2 = 2\mathrm{Re}\left(\bar{\mathbf{w}}_1^H \mathbf{h}_2 \mathbf{h}_2^T \mathbf{w}_1\right) - \mathrm{Re}\left(\bar{\mathbf{w}}_1^H \mathbf{h}_2 \mathbf{h}_2^T \bar{\mathbf{w}}_1\right) \tag{11}$$

Therefore, (9) can be reformulated as

[1]From now and onward, for simplicity we omit the pair index $k$.

$$\min_{\mathbf{w}_i \succeq \mathbf{0}} \left\| \sum_{i=1}^{2} \mathbf{w}_i e^{j(\phi_i - \phi_1)} \right\|^2$$

$$s.t.\ \mathbf{C1}: \left| \mathrm{Im}\left( \mathbf{h}_1^T \sum_{k=1}^{2} \mathbf{w}_k e^{j(\phi_k - \phi_1)} \right) \right| \le \left( \mathrm{Re}\left( \mathbf{h}_1^T \sum_{k=1}^{2} \mathbf{w}_k e^{j(\phi_k - \phi_1)} \right) - \sqrt{r_1 \sigma_{u1}^2} \right) \tan\theta$$

$$\mathbf{C2}:\ 2\mathrm{Re}\left(\bar{\mathbf{w}}_2^H \mathbf{h}_2 \mathbf{h}_2^T \mathbf{w}_2\right) - \mathrm{Re}\left(\bar{\mathbf{w}}_2^H \mathbf{h}_2 \mathbf{h}_2^T \bar{\mathbf{w}}_2\right) \ge$$

$$r_2 \left(2\mathrm{Re}\left(\bar{\mathbf{w}}_1^H \mathbf{h}_2 \mathbf{h}_2^T \mathbf{w}_1\right) - \mathrm{Re}\left(\bar{\mathbf{w}}_1^H \mathbf{h}_2 \mathbf{h}_2^T \bar{\mathbf{w}}_1\right)\right) + \sigma_{u_2}^2 r_2 \tag{12}$$

Finally, the all steps to solve (12) and find the optimal precoding vectors using first-order Taylor expansion method is presented in Algorithm 1.

**Algorithm 1** Iterative Algorithm for (12).

1: Set the maximum number of iterations $Q$.
2: Randomly generate $\bar{\mathbf{w}}_i$.
3: Repeat
4: Using CVX to solve (12) as $\mathbf{w}_i^*$.
5: Update $\bar{\mathbf{w}}_i = \mathbf{w}_i^*$
6: $q = q + 1$.
7: Until $q = Q$.
8: Output $\mathbf{w}_i^*$ , $i \in K$.

*B. Review: Conventional NOMA Precoding*

The total power consumption in conventional NOMA is $P = \sum_{i=1}^{2} \|\mathbf{w}_i\|^2$. Consequently, from (2), (4) and (5) the power minimization problem can be formulated as

$$\begin{aligned} \min_{\mathbf{w}_i} \quad & \sum_{i=1}^{2} \quad \|\mathbf{w}_i\|^2 \\ s.t.\ \mathbf{C1}: \gamma_{u_1} \quad & \ge \quad r_1 \\ \mathbf{C2}: \gamma_{u_2} \quad & \ge \quad r_2 \\ \mathbf{C3}: \gamma_{x_2 \to u_1} \quad & \ge \quad r_2 \end{aligned} \tag{13}$$

The constraint **C3** to ensure the successful SIC for the strong user. The last expression in (13) can be presented in more detailed formula as

$$
\begin{aligned}
\min_{\mathbf{w}_i} \quad & \sum_{i=1}^{2} \quad \left\|\mathbf{w}_i\right\|^2 \\
s.t.\ \mathbf{C1}: \left|\mathbf{h}_1^T \mathbf{w}_1\right|^2 \quad & \geq \quad \left(\sigma_\epsilon^2 + \sigma_{u_1}^2\right) r_1 \\
\mathbf{C2}: \left|\mathbf{h}_2^T \mathbf{w}_2\right|^2 \quad & \geq \quad \left(\left|\mathbf{h}_2^T \mathbf{w}_1\right|^2 + \sigma_{u_2}^2\right) r_2 \\
\mathbf{C3}: \left|\mathbf{h}_1^T \mathbf{w}_2\right|^2 \quad & \geq \quad \left(\left|\mathbf{h}_1^T \mathbf{w}_1\right|^2 + \sigma_{u_1}^2\right) r_2
\end{aligned} \tag{14}
$$

Semidefinite relaxation (SDR) can be used to obtain the optimal precodrs in (14). The effectiveness of the SDR to solve this transmit beamforming problem has been widely considered in literature [29], [30]. The problem in (14) has been investigated and considered in details in [6], where the optimal and closed form solutions have been provided.

## V. SER Minimization

In this Section we design prcoder vectors to minimize the SER subject to total transmission power constraint. For sake of comparison, CoMA and NOMA are considered in this Section.

### *A. CoMA Precoding*

In this Section we consider SER for the proposed COMA scheme. According to [31] and [32], the symbol error rate, SER, can be expressed in the following form:

$$
\mathrm{SER} = \frac{1}{K} \sum_{k=1}^{K} f\left(\mathrm{SNR}_k\right) \tag{15}
$$

where $f\left(SNR_k\right)$ is a function of user k's SNR, which is determined by the modulation scheme. For example, if QPSK modulation is employed, $f\left(SNR_k\right)$ can be further expressed as

$$
f\left(SNR_k\right) = \frac{1}{\sqrt{2\pi}} \int\limits_{\mathrm{SNR}_k}^{\infty} e^{-\frac{1}{2}x^2}\, dx \tag{16}
$$

To minimize the SER of the proposed CoMA scheme, we construct the following optimization problem:

$$\mathcal{P}_1 : \min_{\mathbf{w}_1,\mathbf{w}_2} \max_{k} \{\text{SER}_k\}$$
$$s.t.\ \mathbf{C1}: \left\| \sum_{k=1}^{2} \mathbf{w}_k e^{j(\phi_k-\phi_1)} \right\|^2 < P$$
$$\mathbf{C2}: \left| \text{Im}\left( \mathbf{h}_1^T \sum_{k=1}^{2} \mathbf{w}_k e^{j(\phi_k-\phi_1)} \right) \right| \leq \left( \text{Re}\left( \mathbf{h}_1^T \sum_{k=1}^{2} \mathbf{w}_k e^{j(\phi_k-\phi_1)} \right) - \sqrt{\text{SNR}_1 \sigma_{u1}^2} \right) \tan\theta_t, \quad (17)$$

where $P$ is the total transmit power, **C1** represents the total transmit power budget and **C2** represents the constructive interference constraint for user 1, respectively. The objective function $\text{SER}_k$ is given by

$$\text{SER} = \frac{1}{\sqrt{2\pi}} \int_{\text{SNR}_k}^{\infty} e^{-\frac{1}{2}x^2}\, dx \quad (18)$$

Based on the SER expression in (16), the SER expression for the two users in the system can be obtained as

$$\text{SER}_1 = \frac{1}{\sqrt{2\pi}} \int_{\text{SNR}_1}^{\infty} e^{-\frac{1}{2}x^2}\, dx \quad (19)$$

$$\text{SER}_2 = \frac{1}{\sqrt{2\pi}} \int_{\text{SNR}_2}^{\infty} e^{-\frac{1}{2}x^2}\, dx \quad (20)$$

According to the monotonicity that the SER decreases with the increase of the received SNR, we transform the original optimization problem into the following form:

$$\mathcal{P}_2: \max_{\mathbf{w}_1,\mathbf{w}_2} \min_{k} \{\mathrm{SNR}_k\}$$
$$s.t.\ \mathbf{C1}: \left\| \sum_{k=1}^{2} \mathbf{w}_k e^{j(\phi_k-\phi_1)} \right\|^2 < P$$
$$\mathbf{C2}: \left| \mathrm{Im}\left( \mathbf{h}_1^T \sum_{k=1}^{2} \mathbf{w}_k e^{j(\phi_k-\phi_1)} \right) \right| \leq$$
$$\left( \mathrm{Re}\left( \mathbf{h}_1^T \sum_{k=1}^{2} \mathbf{w}_k e^{j(\phi_k-\phi_1)} \right) - \left| \left( \mathbf{h}_1^T \left( \mathbf{w}_1 e^{j\phi_1} + \mathbf{w}_2 e^{j\phi_2} \right) \right) \right| \right) \tan\theta_t$$
$$\mathbf{C3}: \mathrm{Im}\left( \mathbf{h}_2^T \mathbf{w}_2 \right) = 0,\ \mathrm{Re}\left( \mathbf{h}_2^T \mathbf{w}_2 \right) \geqslant 0 \tag{21}$$

where the additional constraint **C3** can guarantee that the received symbol for user 2 lies in the correct decision region, while the correct demodulation is guaranteed by the CI constraint, which is well known. $\mathcal{P}_2$ transforms the original "Max- SER" minimization problem into a "Min-SNR" maximization problem. By further introducing an auxiliary variable $(t)$, $\mathcal{P}_2$ can be further transformed into

$$\mathcal{P}_3: \max_{\mathbf{w}_1,\mathbf{w}_2,t} t$$
$$s.t.\ \mathbf{C1}: \left\| \sum_{k=1}^{2} \mathbf{w}_k e^{j(\phi_k-\phi_1)} \right\|^2 < P$$
$$\mathbf{C2}: \left| \mathrm{Im}\left( \mathbf{h}_1^T \sum_{k=1}^{2} \mathbf{w}_k e^{j(\phi_k-\phi_1)} \right) \right| \leq$$
$$\left( \mathrm{Re}\left( \mathbf{h}_1^T \sum_{k=1}^{2} \mathbf{w}_k e^{j(\phi_k-\phi_1)} \right) - \left| \left( \mathbf{h}_1^T \left( \mathbf{w}_1 e^{j\phi_1} + \mathbf{w}_2 e^{j\phi_2} \right) \right) \right| \right) \tan\theta_t$$
$$\mathbf{C3}: \mathrm{Im}\left( \mathbf{h}_2^T \mathbf{w}_2 \right) = 0,\ \mathrm{Re}\left( \mathbf{h}_2^T \mathbf{w}_2 \right) \geqslant 0$$
$$\mathbf{C4}: \left| \left( \mathbf{h}_1^T \left( \mathbf{w}_1 e^{j\phi_1} + \mathbf{w}_2 e^{j\phi_2} \right) \right) \right|^2 \geqslant \sigma_{u1}^2 t$$
$$\mathbf{C5}: \frac{\left| \mathbf{h}_2^T \mathbf{w}_2 \right|^2}{\left| \mathbf{h}_2^T \mathbf{w}_1 \right|^2 + \sigma_{u_2}^2} \geqslant t \tag{22}$$

where the auxiliary variable $t$ represents the minimum value of the received SNR for the two CoMA users. In order to deal with the non-convex fractional constraint **C5**, we propose to transform its numerator into a concave function [33] by employing the Taylor series expansion. More specifically, **C5** is re-expressed as the following form

$$\frac{\mathcal{A}\left(\mathbf{w}_2\right)}{\mathcal{B}\left(\mathbf{w}_1\right)} \geqslant t, \tag{23}$$

where the expressions for $\mathcal{A}\left(\mathbf{w}_2\right)$ and $\mathcal{B}\left(\mathbf{w}_1\right)$ are given by

$$\begin{aligned} \mathcal{A}\left(\mathbf{w}_2\right) &= 2\mathrm{Re}\left(\bar{\mathbf{w}}_2^H \mathbf{h}_2 \mathbf{h}_2^T \mathbf{w}_2\right) - \mathrm{Re}\left(\bar{\mathbf{w}}_2^H \mathbf{h}_2 \mathbf{h}_2^T \bar{\mathbf{w}}_2\right) \\ \mathcal{B}\left(\mathbf{w}_1\right) &= \left|\mathbf{h}_2^T \mathbf{w}_1\right|^2 + \sigma_{u_2}^2 \end{aligned} \tag{24}$$

where $\bar{\mathbf{w}}_2$ represents the initial feasible point of the Taylor series expansion. According to the Corollary 3 in [33], we introduce another auxiliary variable $y$ to transform the nonconvex constraint **C5** into a convex one:

$$2y\sqrt{\mathcal{A}\left(\mathbf{w}_2\right)} - y^2 \mathcal{B}\left(\mathbf{w}_1\right) \geqslant t, \tag{25}$$

Thus the corresponding optimization problem is further shown below:

$$
\begin{aligned}
&\mathcal{P}_4: \max_{\mathbf{w}_1,\mathbf{w}_2,t,y} t \\
&s.t.\ \mathbf{C1}: \left\| \sum_{k=1}^{2} \mathbf{w}_k e^{j(\phi_k-\phi_1)} \right\|^2 < P \\
&\mathbf{C2}: \left| \mathrm{Im}\left( \mathbf{h}_1^T \sum_{k=1}^{2} \mathbf{w}_k e^{j(\phi_k-\phi_1)} \right) \right| \leq \\
&\left( \mathrm{Re}\left( \mathbf{h}_1^T \sum_{k=1}^{2} \mathbf{w}_k e^{j(\phi_k-\phi_1)} \right) - \left| \left( \mathbf{h}_1^T \left( \mathbf{w}_1 e^{j\phi_1} + \mathbf{w}_2 e^{j\phi_2} \right) \right) \right| \right) \tan\theta_t \\
&\mathbf{C3}: \mathrm{Im}\left( \mathbf{h}_2^T \mathbf{w}_2 \right) = 0,\ \mathrm{Re}\left( \mathbf{h}_2^T \mathbf{w}_2 \right) \geqslant 0 \\
&\mathbf{C4}: 2\mathrm{Re}\left( \left( \bar{\mathbf{w}}_1 e^{j\phi_1} + \bar{\mathbf{w}}_2 e^{j\phi_2} \right)^H \mathbf{h}_1 \mathbf{h}_1^T \left( \mathbf{w}_1 e^{j\phi_1} + \mathbf{w}_2 e^{j\phi_2} \right) \right) - \\
&\mathrm{Re}\left( \left( \bar{\mathbf{w}}_1 e^{j\phi_1} + \bar{\mathbf{w}}_2 e^{j\phi_2} \right)^H \mathbf{h}_1 \mathbf{h}_1^T \left( \bar{\mathbf{w}}_1 e^{j\phi_1} + \bar{\mathbf{w}}_2 e^{j\phi_2} \right) \right) \geqslant \sigma_{u1}^2 t \\
&\mathbf{C5}: 2y\sqrt{\mathcal{A}\left(\mathbf{w}_2\right)} - y^2 \mathcal{B}\left(\mathbf{w}_1\right) \geqslant t,
\end{aligned} \tag{26}
$$

To solve $\mathcal{P}_4$, we adopt the block coordinate ascent algorithm. Firstly, for given $\mathbf{w}_1$, $\mathbf{w}_2$ and $t$, the optimal value of $y^*$ can be obtained in a closed form as

$$
y^* = \frac{\sqrt{\mathcal{A}\left(\mathbf{w}_2\right)}}{\mathcal{B}\left(\mathbf{w}_1\right)} \geqslant t, \tag{27}
$$

Then, for given, $y^*$, $\mathbf{w}_1$, $\mathbf{w}_2$ and $t$ can be obtained via solving $\mathcal{P}_4$ by substituting $y^*$ into the constraint **C5** and solve the following optimization problem $\mathcal{P}_5$:

$$\mathcal{P}_5: \max_{\mathbf{w}_1,\mathbf{w}_2,t} t$$

$$s.t.\ \mathbf{C1}: \left\|\sum_{k=1}^{2} \mathbf{w}_k e^{j(\phi_k-\phi_1)}\right\|^2 < P$$

$$\mathbf{C2}: \left|\mathrm{Im}\left(\mathbf{h}_1^T \sum_{k=1}^{2} \mathbf{w}_k e^{j(\phi_k-\phi_1)}\right)\right| \leq$$

$$\left(\mathrm{Re}\left(\mathbf{h}_1^T \sum_{k=1}^{2} \mathbf{w}_k e^{j(\phi_k-\phi_1)}\right) - \left|\left(\mathbf{h}_1^T\left(\mathbf{w}_1 e^{j\phi_1} + \mathbf{w}_2 e^{j\phi_2}\right)\right)\right|\right)\tan\theta_t$$

$$\mathbf{C3}: \mathrm{Im}\left(\mathbf{h}_2^T \mathbf{w}_2\right) = 0,\ \mathrm{Re}\left(\mathbf{h}_2^T \mathbf{w}_2\right) \geqslant 0$$

$$\mathbf{C4}: 2\mathrm{Re}\left(\left(\bar{\mathbf{w}}_1 e^{j\phi_1} + \bar{\mathbf{w}}_2 e^{j\phi_2}\right)^H \mathbf{h}_1 \mathbf{h}_1^T \left(\mathbf{w}_1 e^{j\phi_1} + \mathbf{w}_2 e^{j\phi_2}\right)\right) -$$

$$\mathrm{Re}\left(\left(\bar{\mathbf{w}}_1 e^{j\phi_1} + \bar{\mathbf{w}}_2 e^{j\phi_2}\right)^H \mathbf{h}_1 \mathbf{h}_1^T \left(\bar{\mathbf{w}}_1 e^{j\phi_1} + \bar{\mathbf{w}}_2 e^{j\phi_2}\right)\right) \geqslant \sigma_{u1}^2 t$$

$$\mathbf{C5}: 2y^* \sqrt{\mathcal{A}\left(\mathbf{w}_2\right)} - y^{*2}\mathcal{B}\left(\mathbf{w}_1\right) \geqslant t, \tag{28}$$

It has been shown that the iterative algorithm converges within only a few iterations. For clarity, we summarize the algorithm in Algorithm 2 below.

**Algorithm 2** Block Coordinate Ascent Algorithm for solving $\mathcal{P}_5$.

Initialization : $\bar{\mathbf{w}}_1 = 0$, $\bar{\mathbf{w}}_2 = 0$, $t = 0$
Repeat
Update $y$ based on (27);
Update $\mathbf{w}_1$, $\mathbf{w}_2$ and $t$ by solving $\mathcal{P}_5$
Until Convergence

*B. Review: Conventional NOMA Precoding*

Similarly, in order to minimize the SER of conventional NOMA scheme, we can consider the following optimization problem:

$$\mathcal{P}_1 : \max_{\mathbf{w}_1,\mathbf{w}_2} \min_{k} \{\mathrm{SNR}_k\}$$
$$s.t.\ \mathbf{C1}\text{:}\ \|\mathbf{w}_1\|^2 + \|\mathbf{w}_2\|^2 \leq P$$
$$\mathbf{C2} : \gamma_{x_2 \to u_1} \geq r_2 \tag{29}$$

The constraint **C2** to ensure the successful SIC for the strong user. To deal with the non-convex objective function, an auxiliary variable $t$ is introduced to equivalently convert the original problem $\mathcal{P}_1$ into a new problem as follows

$$\mathcal{P}_2 : \max_{\mathbf{w}_1,\mathbf{w}_2,t} t$$
$$s.t.\ \mathbf{C1}\text{:}\ \|\mathbf{w}_1\|^2 + \|\mathbf{w}_2\|^2 \leq P$$
$$\mathbf{C2} : \left|\mathbf{h}_1^T \mathbf{w}_2\right|^2 \geq \left(\left|\mathbf{h}_1^T \mathbf{w}_1\right|^2 + \sigma_{u_1}^2\right) r_2$$
$$\mathbf{C3}\text{:}\ \left|\mathbf{h}_2^T \mathbf{w}_2\right|^2 \geqslant t \left|\mathbf{h}_2^T \mathbf{w}_1\right|^2 + t\sigma_{u_2}^2 \tag{30}$$

Note that the objective function and the constraint **C1** in $\mathcal{P}_2$ are convex, and the challenge is only in the constraints **C2** and **C3**. However, we would like to mention that, similar problem has been considered and solved in the literature using bisection-based method, we refer the reader to [34]–[37] for more details.

## VI. Receiver Complexity

In this section we focus our attention on the receiver complexity, which impacts the user equipment where the computational resources are scarce. To compare the computational receiver complexity of CoMA with conventional NOMA, we provide here the complexity analysis for the detection process. In the complexity analysis, the number of complex operations is used as the complexity metric. The complexity of SIC can be divided into two parts: decoding and subtraction.

For classical NOMA, the weak user needs to detect its signal, while the powerful user, first detects the weak user's signal, then subtracts it from the received signal, before finally detecting its own signal. Assuming an ML detector, the complexity of NOMA for pair $k$ can be obtained as [38], [39]

$$\mathcal{C}_{NOMA-pair,k} = \sum_{i=1}^{2} \underbrace{\left(4NM_k + 2M_k^N\right)}_{ML \text{ detection}} \times (2-i+1) + \underbrace{\mathcal{O}\left(M_k^2\right)}_{\text{Subtraction}} \tag{31}$$

where $M_k$ is the modulation order of pair $k$. The total complexity of NOMA for all pairs can be written as

$$\mathcal{C}_{NOMA} = \sum_{k=1}^{K} \left( \sum_{i=1}^{2} \underbrace{\left(4NM_k + 2M_k^N\right)}_{ML \text{ detection}} \times (2-i+1) + \underbrace{\mathcal{O}\left(M_k^2\right)}_{\text{Subtraction}} \right) \tag{32}$$

where $K$ is number of pairs.

On the other hand, for CoMA, the weak user needs to apply classical detection for its signal, while the powerful user detects its signal without the need to remove the interference. Accordingly, the complexity of CoMA for pair $k$ can be written as [38], [39]

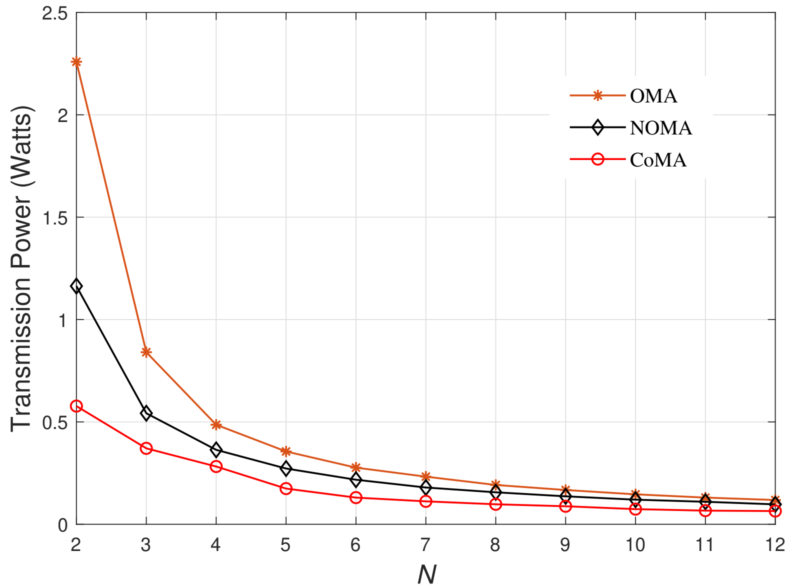
$$\mathcal{C}_{CI-NOMA-pair,k} = \underbrace{\left(4NM_k + 2M_k^N\right)}_{ML \text{ detection}} + \underbrace{D_k\left(M_k\right)}_{CI \text{ detection}} \tag{33}$$

where $D_k\left(M_k\right)$ is the complexity of decision operation upon the received signal for pair $k$ which depends on the modulation order. The total complexity of CoMA for all pairs can be obtained as

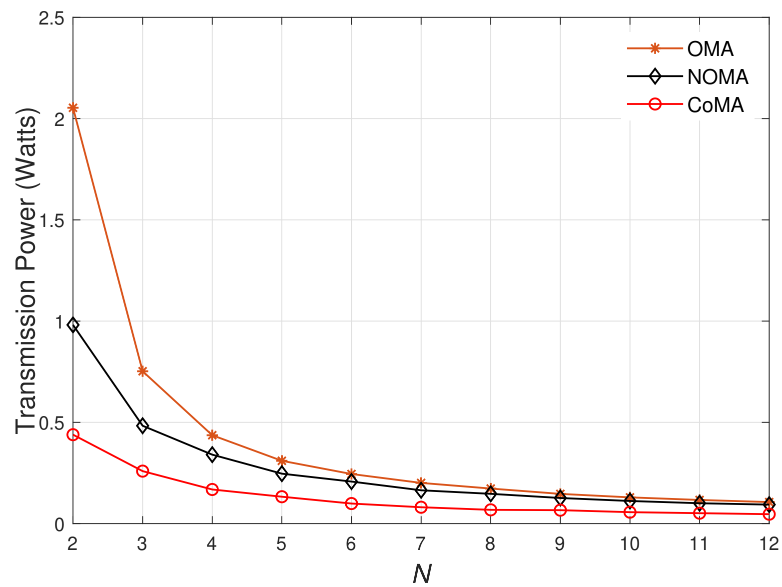
$$\mathcal{C}_{CI-NOMA} = \sum_{k=1}^{K} \left( \underbrace{\left(4NM_k + 2M_k^N\right)}_{ML \text{ detection}} + \underbrace{D_k\left(M_k\right)}_{CI \text{ detection}} \right). \tag{34}$$

## VII. Numerical Results

To evaluate the performance of the proposed CoMA technique, in this Section several numerical results for CoMA are presented and compared with conventional NOMA and OMA




(a) Power consumption versus number of BS antennas when $(r_1, r_2, \sigma_1, \sigma_2) = (1, 1, 2, 1)$.

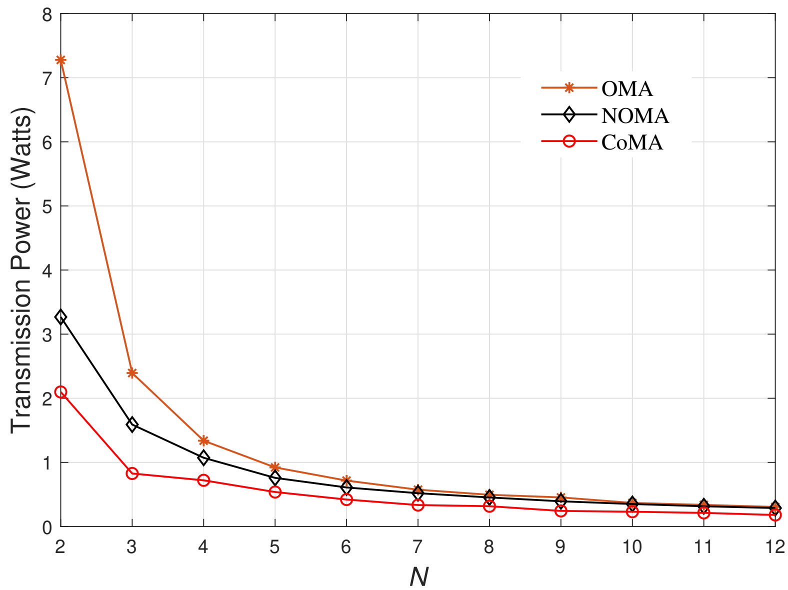



(b) Power consumption versus number of BS antennas when $(r_1, r_2, \sigma_1, \sigma_2) = (1, 1, 3, 1)$.

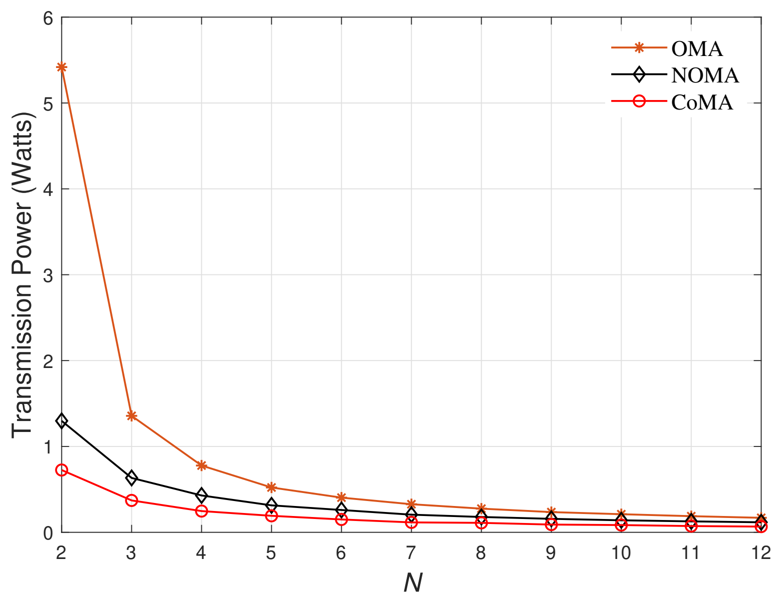
Figure 6: Power consumption for OMA, NOMA and CoMA versus number of BS antennas for different channel variance.

using Monte Carlo simulations. In these results we assume the users have same noise variance, $\sigma_{u_1}^2 = \sigma_{u_2}^2 = \sigma^2$.

To measure the performance of CoMA technique in terms of total power consumption for MU-MISO systems, in Fig. 6 we plot the power consumption versus number of BS antennas $N$ for OMA, conventional NOMA and CoMA with QPSK signaling using the power minimization




(a) Power consumption versus number of BS antennas when $(r_1, r_2, \sigma_1, \sigma_2) = (1, 3, 2, 1)$.




(b) Power consumption versus number of BS antennas when $(r_1, r_2, \sigma_1, \sigma_2) = (3, 1, 2, 1)$.

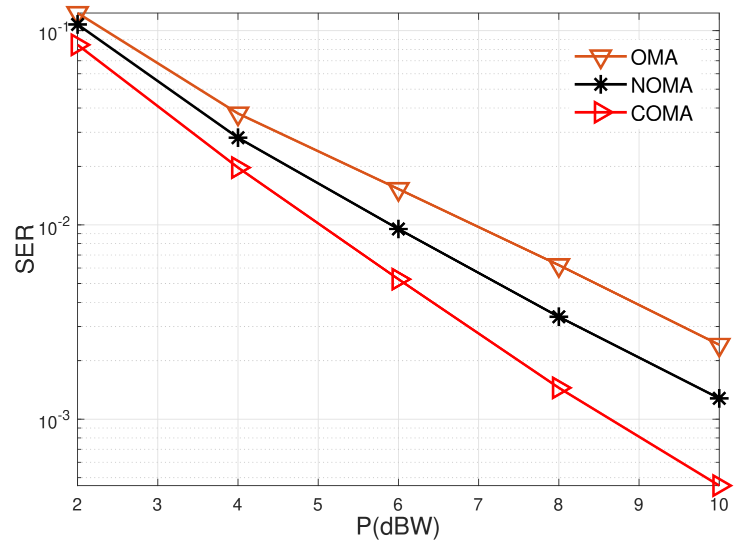
Figure 7: Power consumption for OMA, NOMA and CoMA versus number of BS antennas for different target rates.

approaches in (14), and (12). The case when $(r_1, r_2, \sigma_1, \sigma_2) = (1, 1, 2, 1)$ is presented in Fig. 6a and when $(r_1, r_2, \sigma_1, \sigma_2) = (1, 1, 3, 1)$ is shown in Fig.6b. Several observations can be extracted from these results. Firstly it can be observed that, CoMA scheme has a significant enhancement in terms of power consumption in comparison with the conventional NOMA and OMA schemes. It is also noted that the proposed CoMA scheme yields a significant performance gain in the symmetric scenario when $N = 2$. On the other hand, it is worth pointing out that the difference between the considered schemes becomes negligible when $N$ is large. Nevertheless, the complexity gains of CoMA by removing the SIC operation persist. In addition, the total transmission power decreases when the channel variance of user 1 increases or if there is a notable disparity of channel strengths among users, as shown in Figs. 6a and 6b. This is because the strong user, user 1, in this case needs small power to achieve its target rate, $r_1$.

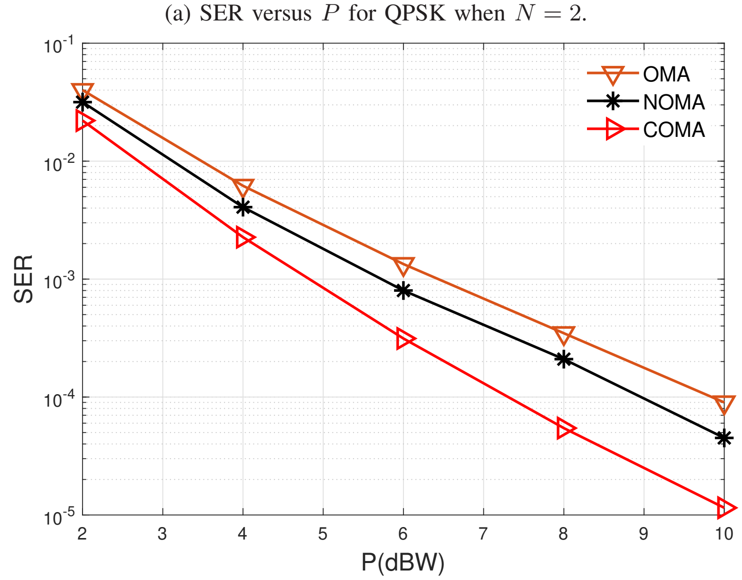
Furthermore, Fig. 7 shows the power consumption for OMA, NOMA and CoMA versus number of BS antennas for different target rates. Fig. 7a presents the case when $(r_1, r_2, \sigma_1, \sigma_2) = (1, 3, 2, 1)$ while Fig. 7b shows the case when $(r_1, r_2, \sigma_1, \sigma_2) = (3, 1, 2, 1)$. It can be clearly seen in these results that, increasing the target rates of the two users leads to boost the transmission power, and this increasing in the power is essential when the target rate of the second user, $r_2$, is higher.

To evaluate the error rate performance of the proposed CoMA scheme, Fig. 8 illustrates the SER versus the the total transmit power, $P$, for OMA, conventional NOMA and COMA with different values of number of BS antennas and modulation order. Fig. 8a and Fig. 8b show the SER versus the total transmit power when $N = 2$ and $N = 4$, respectively, for QPSK, while Fig. 8c represents the SER versus the transmit power when $N = 4$ for 8PSK scheme. Several interesting features can be noted in this figure. Firstly, it is evident from these results that the SER reduces with increasing the transmit power, and CoMA scheme always outperforms OMA and conventional NOMA techniques in the all power levels. Looking closer at Fig. 8a and Fig. 8b we can observe that, increasing number of BS antennas reduces the SER, and the gain attained by CoMA over conventional NOMA is almost fixed with the transmit power. Finally, from Fig. 8b and Fig. 8c it is clear that COMA has better performance than the other two schemes and this superiority is major when the total transmit power is high.

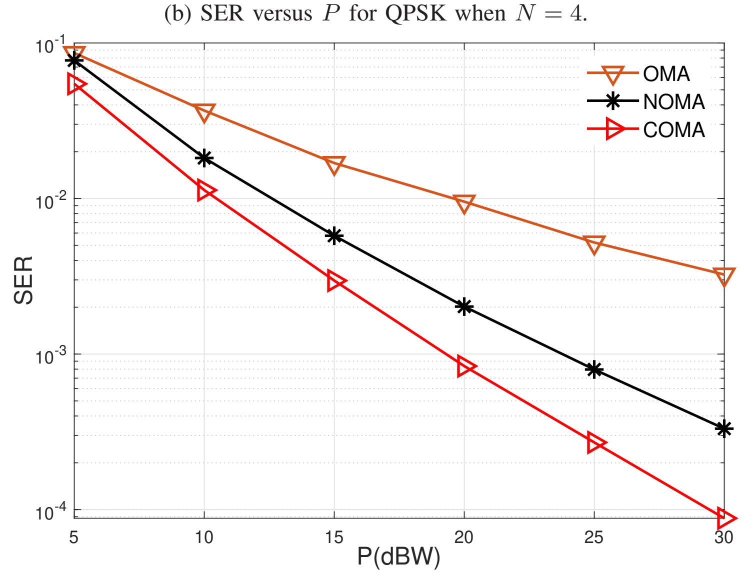
The computational receiver complexity of CoMA and conventional NOMA versus number of BS antennas $N$ is presented in Fig. 9. It can be observed from these results that, CoMA substantially reduces the computational complexity, which is desirable in hardware-limited networks. In addition, the computational complexity gap between the two schemes is much wider when number of BS antennas $N$ is high.




(a) SER versus $P$ for QPSK when $N = 2$.




(b) SER versus $P$ for QPSK when $N = 4$.




(c) SER versus $P$ for 8PSK when $N = 4$.

Figure 8: SER for OMA, NOMA and CoMA versus $P$ for different number of antennas and modulation order.

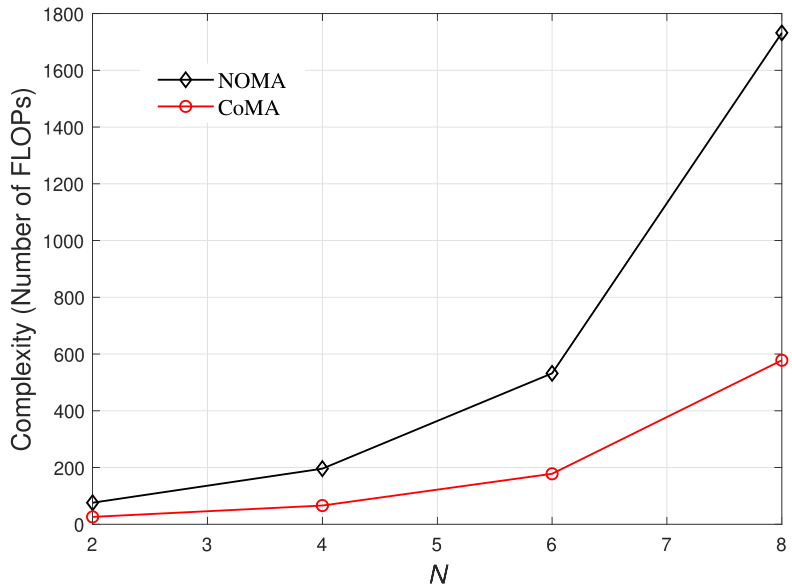



Figure 9: Computational complexity versus number of BS antennas for BPSK.

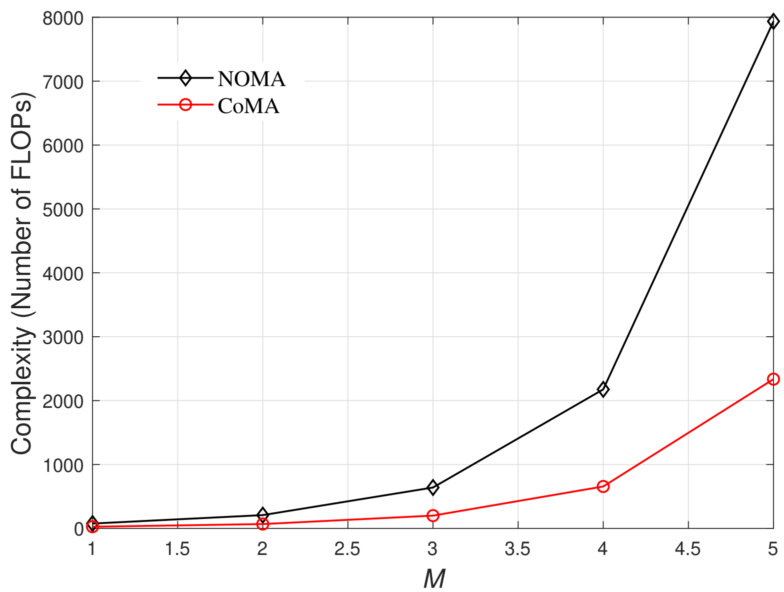



Figure 10: Computational complexity versus modulation order.

Finally, Fig. 10 shows the computational receiver complexity of CoMA and conventional NOMA versus the modulation order $M$ when $N = 2$. As shown in the figure, conventional NOMA scheme has higher computational complexity than CoMA. In addition, the conventional NOMA becomes computationally expensive for higher modulation orders.

## VIII. Conclusions

In this paper a CoMA scheme for user pairing NOMA systems was proposed and investigated. Firstly, for a given pair of users, the minimum transmission power and the optimal precoding vectors of CoMA scheme has been obtained. Then, optimal precoding vectors that minimizing the symbol error rate subject to total power constrains for CoMA scheme has been considered. Further, the complexity of CoMA has been studied and compared with conventional NOMA scheme in terms of the total number of complex operations. Simulation results have been provided to show that, CoMA scheme consumes much less power than conventional NOMA and OMA schemes to achieve similar target rates. In addition, CoMA scheme produces lower error rate than conventional NOMA technique over the all transmit power values. Furthermore, the proposed CoMA scheme implicates very low computational receiver complexity compared to conventional NOMA technique.

## Acknowledgment

This work is supported by the U.K. Engineering and Physical Sciences Research Council (EPSRC) under grant EP/R007934/1.

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