İSTANBUL TİCARET ÜNİVERSİTESİ
FEN BİLİMLERİ DERGİSİ

İstanbul Commerce University Journal of Science

http://dergipark.org.tr/ticaretfbd

Research Article / Araştırma Makalesi

NON-ORTHOGONAL MULTIPLE ACCESS WITH V-BLAST UNDER OPTIMUM ORDERING

OPTİMUM SIRALAMALI V-BLAST KULLANAN DİKGEN OLMAYAN ÇOKLU ERİŞİM

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https://doi.org/10.55071/ticaretfbd.1116164

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Received / Geliş Tarihi
13.05.2022

Accepted/ Kabul Tarihi
17.10.2022

Abstract

Non-orthogonal multiple access (NOMA) is expected to be one of the fundamental technologies of the upcoming 6G standard. This is mainly due to NOMA's potential in enabling all the users to utilize the same frequency band and the same time slot. In this paper, NOMA is implemented in a multiple-input multiple-output wireless communication system. By implementing zero-forcing V-BLAST algorithm into NOMA, spectral efficiency is improved, and successive interference cancellation is carried out. To perform optimum ordering, receive antennas' signatures are compared and which signal to be decoded first is determined. Outage probability results of the system with optimum ordering and the same system without ordering are compared. In this way, a 3 dB gain is shown to be attained in terms of signal-to-noise ratio.

Keywords: Multiple-input multiple-output, non-orthogonal multiple access, optimum ordering, Wireless communications, V-BLAST**.**

Öz

Dikgen olmayan çoklu erişimin (DOÇE), yaklaşmakta olan 6G standardının temel teknolojilerinden biri olması beklenmektedir. Bu, esas olarak DOÇE'nin tüm kullanıcıların aynı frekans bandını ve aynı zaman aralığını kullanmasını sağlama potansiyelinden kaynaklanmaktadır. Bu çalışmada, DOÇE çoklu girişli çoklu çıkışlı kablosuz iletişim sisteminde uygulanmaktadır. DOÇE'ye sıfıra-zorlamalı V-BLAST algoritması uygulanarak, spektral verimlilik arttırılmış ve ardışık girişim iptali gerçekleştirilmiştir. Optimum sıralama yapmak için, alıcı antenlerin imzaları karşılaştırılmış ve ilk önce hangi sinyalin çözüleceği belirlenmiştir. Optimum sıralama uygulanan sistem ile uygulanmayan sistemler kesinti olasılığı sonuçları açısından karşılaştırılmıştır. Bu sayede işaret-gürültü oranı açısından 3 dB'lik bir kazancın elde edildiği görülmektedir.

Anahtar Kelimeler: Çoklu giriş çoklu çıkış, dikgen olmayan çoklu erişim, kablosuz haberleşme, optimum sıralama, V-BLAST.

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1. INTRODUCTION

Following the successes of Nikola Tesla and Guglielmo Marconi in the field of wireless communications, scientists have continued to develop this technology. More communication devices are developed and adapted to our everyday lives. Most recent technological developments are concentrated on fifth generation (5G) and beyond communication systems (Ding et al., 2017).

In wireless communication, there are several types of multiple access techniques to accommodate multiple users. Each has its own characteristics and is implemented into mobile communication generation by generation. First and second-generation communication systems respectively use frequency division multiple access (FDMA) and time division multiple access (TDMA). In FDMA and TDMA technologies, transitions respectively between different frequencies and time slots exist in an orthogonal fashion. To provide high data rates to users, code division multiple access has later been implemented in the third-generation systems. In the fourth-generation long-term evolution systems, orthogonal frequency division multiple access (OFDMA) has been utilized, where distinct squares on the available time-frequency grid are used for multiple access. OFDMA is a multi-user extension of OFDM technique which provides a highly effective way of combating frequency-selective fading (Lan et al., 2014; Rahman et al., 2021).

On the other hand, recent reports show that mobile traffic needs will experience a 500-fold increase in the next decade (NTT DoCoMo, 2012). There are also some other necessities such as delay-sensitive communication, high-volume of services, and more communication devices in existence. This is where we come across the 5G communication. The usage of real-time remote sensing technologies, smart factories and home applications, smart cities, traffic management systems, and Internet of Things (IoT) adoption in real life suggests that the required data rates will skyrocket in a short time (Bariah et. al., 2020).

In order to address these issues, several approaches have been recommended by scientists. Using higher frequency bands to obtain higher bandwidths and spectrum extension, utilizing channel state information (CSI) at the transmitter and/or receiver (user) sides, which has also been used in previous generations, employing multiple-input multiple-output (MIMO) to enhance spectral efficiency by spatial multiplexing or to improve transmission reliability through spatial diversity are some of the most prominent ones (Agiwal et. al., 2016; Li et al., 2020). The maximum achievable diversity gain in a t transmit and r receive antenna system (known as a $t \times r$ MIMO system) is tr. The achievable diversity order depends on the detection method employed at the receiver side (Zheng & Tse, 2003). In addition to these technological advancements, millimeter-wave communications, comprehensive network architectures, massive MIMO systems, and non-orthogonal multiple access (NOMA) are developed and have been implemented together to overcome challenges in the upcoming telecommunications generations (Rahman et al., 2021).

Even though OFDMA provides orthogonality in the frequency domain, in 5G technology there is a massive number of devices that should be connected to each other. This necessity has pushed on scientists to produce innovative ideas and consequently, they have developed a recent technology that uses the same frequency band for different users at a given time. The technique which is developed and implemented to improve spectral efficiency is called NOMA (Saito et al., 2013). In NOMA, the same frequency band is used at the same time, unlike OFDMA. To do this, the base station (BS) transmits signals with different power levels associated with distinct users. This is called superposition. At the receiver side, by using CSI, signals are decoded, and successive interference cancellation (SIC) is applied to separate the interference caused by the signals of other users (Mwakwata et al., 2021).

In NOMA, different power levels are used to ensure equal performance amongst the users. To do this, differences between the channel gains of users are considered. For some system models, CSI is supposed to be available at the transmitter. Then, the BS transmits the signals of the associated users with the purpose of reducing outage probability. However, this is not always practical in real life (Liu et al., 2016). In addition, in some MIMO-NOMA systems, the receiver is assumed to know the CSI and the number of the receive antennas is equal to or larger than the number of the transmit antennas (Ding et al., 2016; Özyurt & Torlak, 2019). With NOMA, the power coefficient arrangement requires the channel gain information of the users either in an instantaneous or statistical sense. In power-domain NOMA, the closer a user stands to the BS, the larger channel gain it attains and the less signal power it is allocated. Likewise, the channel gain of the furthest user is the lowest of all users, so it needs the highest signal strength.

With the purpose of explaining the NOMA technique in more detail, let us introduce a sample MIMO system with two users, where user 1 is much closer to the BS than user 2. Thanks to the difference in power coefficients and fairness between users, the signals sent to user 2 will have a much higher power level than the ones for user 1. In this way, even if the far user has worse channel conditions, it can detect and decode its associated signals as a result of the power allocation at the BS. While user 2 only deals with its own signals, user 1 must decode the signals of user 2 before detecting its own signals. This process is known as SIC. Since the signals of user 2 have much more power, user 1 applies SIC to the signals of user 2 and decodes them first. Then, user 1 cancels these signals from its received signal. At last, user 1 decodes its own signals in an inter-user interference (ISI) free fashion (Timotheou & Krikidis, 2015). Here, user 1 utilizes SIC to deal with two types of interference. One of them is the ISI caused by signals of user 2. The other interference is known as intra-user (inter-layer) interference (INSI) which originates from its own signals. On the other hand, user 2 directly decodes the received signal without regarding any interference signal.

In MIMO systems, multiple signals can be transmitted from the transmit antennas in a parallel and simultaneous fashion when the transmitter does not possess any kind of CSI. This is known as layered transmission, e.g., vertical Bell Labs layered space-time (V-BLAST). Therefore, multiple signals are needed to be detected at the receiver side. The order of this detection directly affects the system performance in terms of the outage probability. If the signals are transmitted through a Rayleigh channel, each transmitted signal is exposed to a different distortion at each receive antenna. Optimum ordering focuses on the outage probability results by using the maximum signal-to-noise ratio (SNR) on each distorted signal and rearranges the order of the detection accordingly. The CSI at the receiver is used to specify the order because the channel values have a direct effect on SNR. For zero-forcing (ZF) V-BLAST, it is shown that the optimum ordering has a 3 dB SNR gain beyond no ordering technique (Loyka & Gagnon, 2004).

In a MIMO system, the BS separates and combines the signals for different antennas properly, whereas the receiver may perform distinct linear and/or nonlinear processes to separate the entangled signal into its parts. Foschini (1999) showed a layered transmission block diagram and detected the received signals with V-BLAST technique. In a layered transmission algorithm, the transmitted signal is divided into different layers, with equal or unequal rates. These separated streams are coded in each layer and transmitted with multiple antennas in a parallel manner. In the V-BLAST technique, the interference signal is nulled out from the signal yet to be detected and the desired signal is decoded with no INSI at any layer. The V-BLAST provides a near-optimum solution in terms of performance and complexity (Kim & Lee, 2005). Özyurt et al. (2020) showed that ISI and INSI can be dealt with in MIMO-NOMA systems by applying a combination of ZF V-BLAST and SIC techniques at the users.

In this paper, a two-user MIMO-NOMA system that employs optimum decoding ordering at both users in order to improve the performance in terms of outage probability is proposed. The NOMA technique is implemented to expand the spectral efficiency and ensure fairness between two users. On the transmitter side, different power coefficients are assigned for each transmitted signal of the users. According to the closeness of the users to the BS, different channel gains are considered. On the receive sides, ZF V-BLAST algorithm is applied to reduce the complexity of the system by using CSI. When the BS does not have any CSI, the applicable performance metric is outage probability. Thus, the main purpose of the system designed in this paper is to make sure the received SNR level is above a predefined threshold rate value for the receiver. Since the SNR directly affects the outage probability of this system performance, the optimum ordering is implemented within the ZF V-BLAST. At the receiver sides, the ZF V-BLAST algorithm is applied with the optimum decoding ordering. The outage probability performance of the system is shown to be improved. The mentioned system is analytically explained with formulas.

The rest of the paper is organized as follows. In order to describe the proposed NOMA technique in detail, the system model and its fundamentals are introduced in the second section. The outage probability analysis method and formulations regarding the performance evaluation of the classical and proposed systems are presented in the third section. The simulation results are provided in the fourth section. The final section concludes the paper by mentioning the contributions of the proposed system.

2. SYSTEM MODEL

In this paper, a MIMO system with one transmitter/BS and two receivers/users is investigated. NOMA is applied at the transmitter side to provide fairness between the users. Different power levels to different users regarding their distances from the BS are allocated. The BS has two antennas while the receivers have equal to or more than two antennas. It is assumed that there are enough spaces between the BS antennas and within the antennas of each user to provide spatial diversity.

We initially consider a scenario where there is a BS with two transmit antennas ($t = 2$) and there are two users ($k = 2$) with two receive antennas ($r = 2$). It is assumed that there is no CSI at the BS, and the users know only their associated CSI.

The BS sends four modulated signals in every cycle (x_{ij}); two for each user in each time slot. The transmitted signals for user 1 are shown by x_{11} and x_{12} and the signals of user 2 are demonstrated as x_{21} and, x_{22}, respectively for the first and second transmit antennas. As discussed before, NOMA is applied with different power coefficients (P_{ij}) to each signal where P_{ij} represents the power allocation for the jth symbol of the ith user. It is assumed that user 2 is the far user. The BS transmits x_{11} and x_{21} from the first antenna ($\mathbf{x}_1$) and x_{12} and x_{22} from the second antenna ($\mathbf{x}_2$). Also, $\mathbf{x}$ is the column vector that includes the transmitted signals in which NOMA is applied (Benjebbovu et. al. 2013):

$$\mathbf{x} = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} x_{11}\sqrt{P_{11}} + x_{21}\sqrt{P_{21}} \\ x_{12}\sqrt{P_{12}} + x_{22}\sqrt{P_{22}} \end{bmatrix}, \tag{1}$$

where, $P_{2j} > P_{1j}$ for $j \in \{1,2\}$ is guaranteed in all conditions. H_k is the channel matrix which includes the independent and identically distributed (i.i.d.) zero-mean complex Gaussian random variables with unit variance, i.e., Rayleigh fading, for any k. Here, the subscript k imposes indices of the users and each user is affected by independent channels. Each channel (H_k) is a $r \times t$ matrix.

The ith row and jth column entry of H_k stands for the fading coefficient between the jth transmit antenna and the ith receive antenna at the kth user. Since user 1 is closer to the BS than user 2, the channel gain between the BS and user 1 is bigger than the channel gain between the BS and user 2. The overall system model is depicted in Figure 1.

The order of detection in the no ordering approach is as follows: user 2 does not perform SIC and detects x_{22} first and then x_{21}. Meanwhile, user 1 detects x_{22} and performs SIC to detect x_{12}. Then, x_{21} is detected and SIC is performed to detect x_{11}. Here, both users employ ZF V-BLAST where each user decomposes the channel matrix H_k with the QR decomposition method.

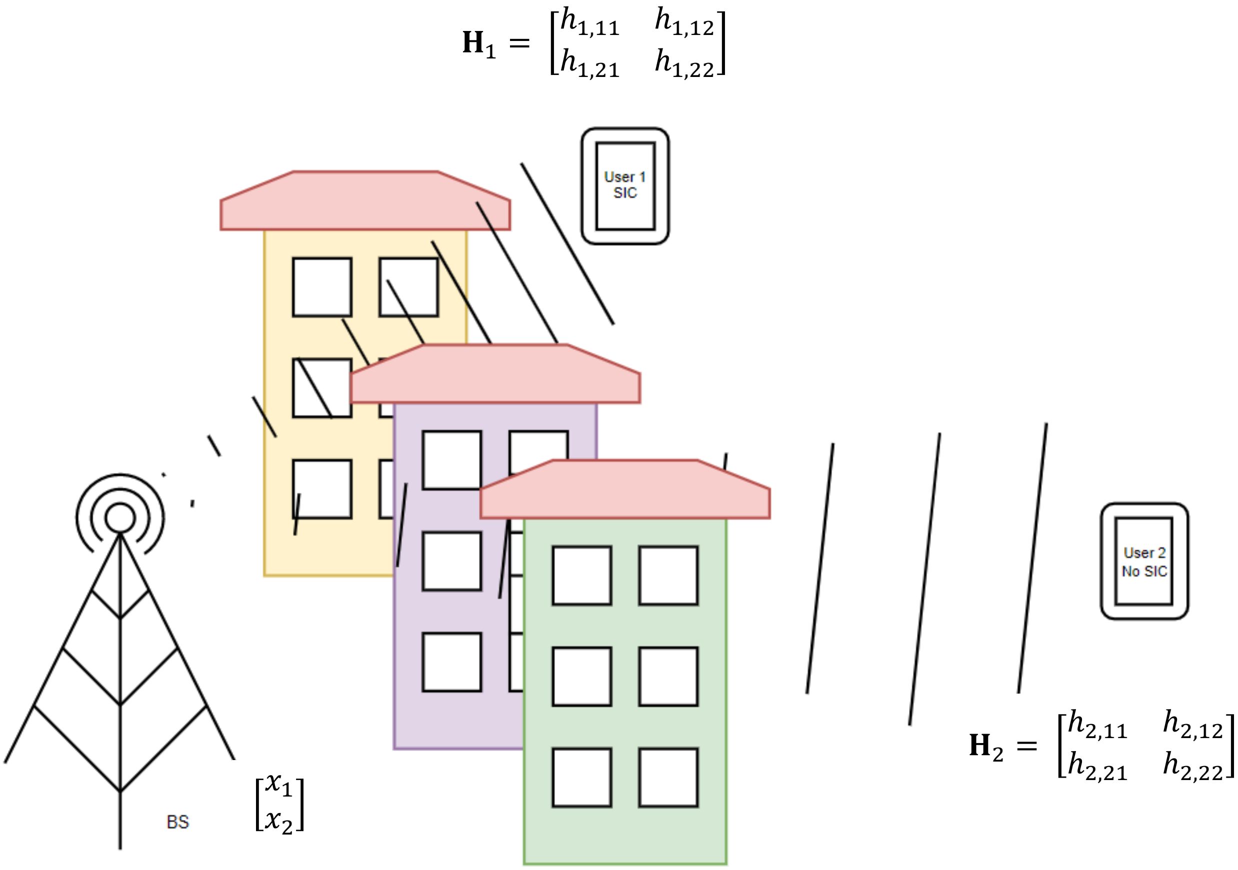

Figure 1. The System Model Consists of A BS and Two Users Each with Two Receive Antennas

The QR decomposition of H_k matrix results in $\mathrm{H}_k = \mathrm{Q}_k\mathrm{R}_k$. Here, Q_k is a $r \times t$ orthogonal matrix and R_k is a $t \times t$ upper triangular matrix. Let $r_{k,ij}$ denote the ith row and jth column element of R_k. The channel gains depend on $r_{k,ij}$ and we have $r_{k,21} = 0$. Besides, each user is affected by additive white Gaussian noise (AWGN).

For user 1, the received signal y_1 is given by:

$$\mathrm{y}_1 = \mathrm{H}_1\mathrm{x} + \mathrm{n}_1, \tag{2}$$

where, x is the 2×1 vector which includes the aggregate signal that is transmitted to all users, H_1 is the channel matrix of the first user, and n_1 is the 2×1 vector of the related AWGN term. For user 2, the received signal is y_2 can be written as:

$$\mathrm{y}_2 = \mathrm{H}_2\mathrm{x} + \mathrm{n}_2, \tag{3}$$

where, H_2 is the channel matrix of the second user and n_2 is the 2×1 vector of the related AWGN term. The vectors n_1 and n_2 are uncorrelated and all the entries in both vectors are independent and identically distributed zero-mean complex Gaussian random variables with unit variance.

By multiplying both sides of the equation with the Hermitian matrix of Q_k, it gives a 2×1 column vector (Özyurt et. al., 2020):

$$\mathrm{Q}_k^H\mathrm{y}_k = \mathrm{R}_k\mathrm{x} + \mathrm{n}_k, \tag{4}$$

where, $(.)^H$ represents the Hermitian transpose of a matrix. Since x is a 2×1 column vector and r_{21} equals zero in the upper triangular matrix of 2×2 R_k, the received signal at each user in (2) and (3) can be rearranged by using (4) as:

$$\mathrm{Q}_k^H\mathrm{y}_k = \begin{bmatrix} r_{k,11}x_1 + r_{k,12}x_2 + n_{k1} \\ 0 + r_{k,22}x_2 + n_{k2} \end{bmatrix}, \tag{5}$$

where, n_{k1} and n_{k2} are the first and second elements of the 2×1 column vector n_k, respectively.

The related steps regarding the decoding of the transmitted signals without optimum ordering at user 1 and user 2 are given below. Let $[\mathrm{A}]_{ij}$ denote the ith row and jth column entry of the matrix A. Also, assume that $x_{1,22}$ and $x_{1,21}$ represent the decisions respectively for x_{22} and x_{21} at user 1. User 1 initially decodes $x_{1,22}$ by using $[\mathrm{Q}_1^H\mathrm{y}_1]_{21}$. Then, by performing SIC, the contribution of $x_{1,22}$ is subtracted from $[\mathrm{Q}_1^H\mathrm{y}_1]_{21}$ and user 1 decodes its own symbol x_{12}. Subsequently, user 1 decodes $x_{1,21}$ by means of $[\mathrm{Q}_1^H\mathrm{y}_1]_{11}$ and the effect of $x_{1,21}$ is then eliminated from $[\mathrm{Q}_1^H\mathrm{y}_1]_{11}$ in order to carry out SIC. User 1 afterward decodes its other symbol x_{11}. On the contrary, at user 2 the procedure considering the decoding of the transmitted signals without optimum ordering is performed as follows. At first, user 2 decodes x_{22} by using $[\mathrm{Q}_2^H\mathrm{y}_2]_{22}$. Then, it decodes x_{21} by eliminating the contribution of x_{22} from $[\mathrm{Q}_2^H\mathrm{y}_2]_{21}$. It should be noted that, user 2 makes its decisions under interference from user 1's symbols. The stated steps are illustrated in Figure 2.

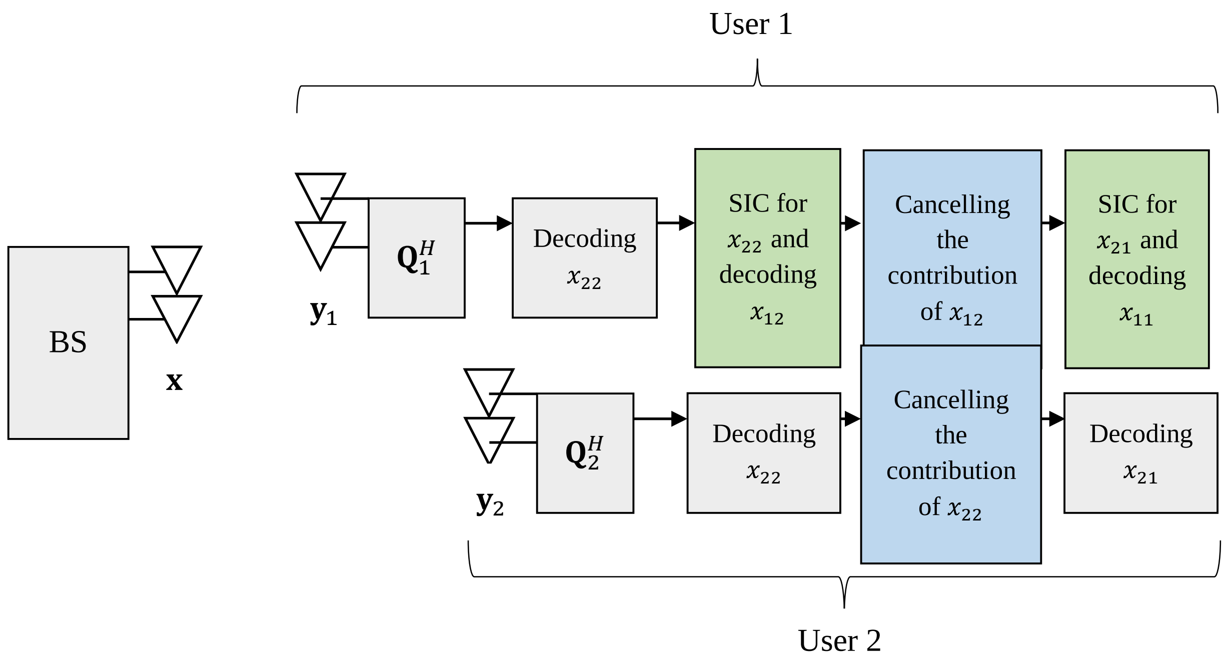

Figure 2. The Decoding Steps of Each Transmitted Signal at Two Users

In Figure 2, interuser interference cancellation is performed in green blocks whereas intrauser interference cancellation is conducted in blue blocks. Each channel matrix (H_k) consists of the signatures of the first (h_{k1}) and second (h_{k2}) transmit antennas for both users where h_{k1} and h_{k2} stand for the first two columns of H_k. While h_{k1} includes the channel coefficients between the first transmitter antenna and kth user, h_{k2} contains the channel coefficients between the second transmitter antenna and kth user. Both h_{k1} and h_{k2} are $2\ x\ 1$ column vectors.

In our system model, the optimum ordering technique is applied at each user to determine which signal is decoded initially. The optimum ordering is chosen such that the outage probability is minimized (Loyka & Gagnon, 2004). To decide the decoding order of the transmitted signals, CSI is utilized at each user. To this end, the signatures of the transmit antennas are used. At the kth user, the squared gains of the first and second layers under optimum ordering (the squared channel gains during the kth user decodes its own symbols) are respectively given by (Özyurt & Torlak, 2019),

$$\max \{\mathrm{h}_{k1}^H \mathrm{P}_{\mathrm{h}_{k2}}^{\perp} \mathrm{h}_{k1}, \mathrm{h}_{k2}^H \mathrm{P}_{\mathrm{h}_{k1}}^{\perp} \mathrm{h}_{k2}\}, \tag{6}$$

and

$$\min \{ \|\mathrm{h}_{k1}\|^2, \|\mathrm{h}_{k2}\|^2\}. \tag{7}$$

Here, $\mathrm{P}_{\mathrm{h}_{k1}}^{\perp}$ and $\mathrm{P}_{\mathrm{h}_{k2}}^{\perp}$ are the projection matrices onto the null spaces of the vectors h_{k1} and h_{k2}, respectively (Loyka & Gagnon, 2004):

$$\mathrm{P}_{\mathrm{h}_{k1}}^{\perp} = \mathrm{I} - \mathrm{h}_{k1}(\mathrm{h}_{k1}^H \mathrm{h}_{k1})^{-1} \mathrm{h}_{k1}^H, \tag{8}$$
$$\mathrm{P}_{\mathrm{h}_{k2}}^{\perp} = \mathrm{I} - \mathrm{h}_{k2}(\mathrm{h}_{k2}^H \mathrm{h}_{k2})^{-1} \mathrm{h}_{k2}^H, \tag{9}$$

where I stands for the $r \times r$ identity matrix.

At the kth user, if $\mathrm{h}_{k1}^H \mathrm{P}_{\mathrm{h}_{k2}}^{\perp} \mathrm{h}_{k1}$ is larger than $\mathrm{h}_{k2}^H \mathrm{P}_{\mathrm{h}_{k1}}^{\perp} \mathrm{h}_{k2}$, the decoding order is set such that the symbols transmitted from the second transmit antenna are first decoded and then, the symbols transmitted from the first transmit antenna are decoded. Otherwise, the decoding order is reversed.

The decoding order of the transmitted signals when optimum ordering is applied may change according to (12) and (13). If the decoding order changes, the columns of H_k are switched accordingly. It is important to note that the similar SIC processes as above under no ordering scenarios are also applicable with optimum ordering.

The system mentioned so far is designed when the receiver has two antennas. It should be noted that, the preceding steps defined above can also be used when the MIMO system has more than two receive antennas. As H_k is a $r \times t$ matrix, after the QR decomposition of H_k, the derived matrices Q_k and R_k are $r \times t$ and $t \times t$ matrix, respectively. The element $r_{k,21}$ of R_k is still equal to zero. The effect of optimum ordering can easily be seen when it is applied at users with more than two receive antennas. We also investigate the case where the users have three and four receive antennas in the numerical results section. In this way, the outage probability results are improved significantly compared to the case with two receiver antennas.

3. OUTAGE PROBABILITY ANALYSIS

The proposed system is designed to improve the outage probability performance by applying optimum ordering. To accomplish this, the BS transmits the signals with various power levels which are determined by NOMA whereas the users employ ZF V-BLAST for detection. CSI is used to rearrange the order of detection and in this way, outage probability performance can be enhanced.

If optimum ordering is not applied at user 1, after performing SIC, x_{12} is decoded initially. Next, x_{11} is decoded following SIC. Signal-to-interference-plus-noise ratio (SINR) is used to quantify the upper bounds of a wireless communication system. As it is assumed that optimum ordering does not affect the SIC performance at users, related SINR values are not affected by $x_{2,21}$ and $x_{2,22}$ (Özyurt et. al., 2020):

$$\mathrm{SINR}_{12} = r_{1,22}P_{12}, \tag{10}$$
$$\mathrm{SINR}_{11} = r_{1,11}P_{11}, \tag{11}$$

where, $\mathrm{SINR}_{\mathrm{ij}}$ represents the corresponding SINR values of the jth symbol of the ith user. The upper triangular R_1 matrix consists of the elements $r_{1,11}$, $r_{1,12}$, and $r_{1,22}$ which are used to calculate SINR:

$$r_{1,11} = \|\mathrm{h}_{11}\|^2, \tag{12}$$
$$r_{1,12} = \frac{\|\mathrm{h}_{11}^H\ \mathrm{h}_{12}\|^2}{\|\mathrm{h}_{11}\|^2}, \tag{13}$$
$$r_{1,22} = \mathrm{h}_{12}^H \mathrm{P}_{\mathrm{h}_{11}}^{\perp} \mathrm{h}_{12}. \tag{14}$$

The elements of R_1 are modified granted that decoding order is applied. If $\mathrm{h}_{11}^H \mathrm{P}_{\mathrm{h}_{12}}^{\perp} \mathrm{h}_{11}$ is greater than $\mathrm{h}_{12}^H \mathrm{P}_{\mathrm{h}_{11}}^{\perp} \mathrm{h}_{12}$.for user 1, then $r_{1,11}$, $r_{1,12}$, and $r_{1,22}$ changes as:

$$r_{1,11} = \|\mathrm{h}_{12}\|^2, \tag{15}$$
$$r_{1,12} = \frac{\|\mathrm{h}_{11}^H\ \mathrm{h}_{12}\|^2}{\|\mathrm{h}_{12}\|^2}, \tag{16}$$
$$r_{1,22} = \mathrm{h}_{11}^H \mathrm{P}_{\mathrm{h}_{12}}^{\perp} \mathrm{h}_{11}. \tag{17}$$

At user 2, the SINR formulas can be given as:

$$\mathrm{SINR}_{22} = \frac{r_{2,22}P_{22}}{r_{2,22}P_{12}+1}, \tag{18}$$
$$\mathrm{SINR}_{21} = \frac{r_{2,11}P_{21}}{r_{2,11}P_{11}+|r_{2,12}|^2 P_{12}+1}. \tag{19}$$

Considering the classical approach at user 2, firstly $x_{2,22}$ is decoded and $x_{2,12}$ is treated as an interference signal given in (24). Then, $x_{2,21}$ is decoded and $x_{2,11}$ and $x_{2,12}$ become the interference signals shown in (25). The term ‘1’ in the denominators of (24) and (25) refers to the average AWGN power.

The upper triangular R_2 is composed of the elements $r_{2,11}$, $r_{2,12}$, and $r_{2,22}$ which are used to calculate the SINR:

$$r_{2,11} = \|\mathrm{h}_{21}\|^2, \tag{20}$$

$$r_{2,12} = \frac{\left\|\mathrm{h}_{21}^{H}\ \mathrm{h}_{22}\right\|^{2}}{\|\mathrm{h}_{21}\|^{2}}, \tag{21}$$
$$r_{2,22} = \mathrm{h}_{22}^{H}\mathrm{P}_{\mathrm{h}_{21}}^{\perp}\mathrm{h}_{22}. \tag{22}$$

In optimum ordering, since the columns of H_2 are swapped, the elements of R_2 also changes. If $\mathrm{h}_{21}^{H}\mathrm{P}_{\mathrm{h}_{22}}^{\perp}\mathrm{h}_{21}$ is larger than $\mathrm{h}_{22}^{H}\mathrm{P}_{\mathrm{h}_{21}}^{\perp}\mathrm{h}_{22}$.for user 2, then $r_{2,11}$, $r_{2,12,}$ and $r_{2,22}$ are adjusted as:

$$r_{2,11} = \|\mathrm{h}_{22}\|^{2}, \tag{23}$$
$$r_{2,12} = \frac{\left\|\mathrm{h}_{21}^{H}\ \mathrm{h}_{22}\right\|^{2}}{\|\mathrm{h}_{22}\|^{2}}, \tag{24}$$
$$r_{2,22} = \mathrm{h}_{21}^{H}\mathrm{P}_{\mathrm{h}_{22}}^{\perp}\mathrm{h}_{21}. \tag{25}$$

When dealing with the high SINR regime, the effect of optimum ordering is not significant enough because the power of AWGN and the elements of R_k becomes negligible. Furthermore, SIC operation is assumed to be perfect at both users, as the optimum ordering does not affect the performance of the SIC.

4. NUMERICAL RESULTS

In this section, various simulation results considering the outage probability performance of the proposed system under different scenarios are demonstrated. For both no ordering and optimum ordering cases, the same target rates are used in order to guarantee fairness. The simulation results are obtained by ensuring SIC stability conditions given by $P_{2j} > P_{1j}$. Also, user 1 which is closer than user 2 to the BS has a larger average channel gain than user 2. The outage probability results are acquired by using the desired achievable rates for both users. Furthermore, the only additional complexity needed with the optimum ordering is the comparison of the columns of H_k channel matrix at each user. Besides, the BS does not need CSI and all the required calculations are performed at the users.

The outage probability performance of the proposed system with two transmit and two receive antennas is shown in Figure 3. It can be clearly seen that when the outage probability is equal to 10^{-4}, an SNR gain of 3 dB is achieved when optimum ordering is applied at each user.

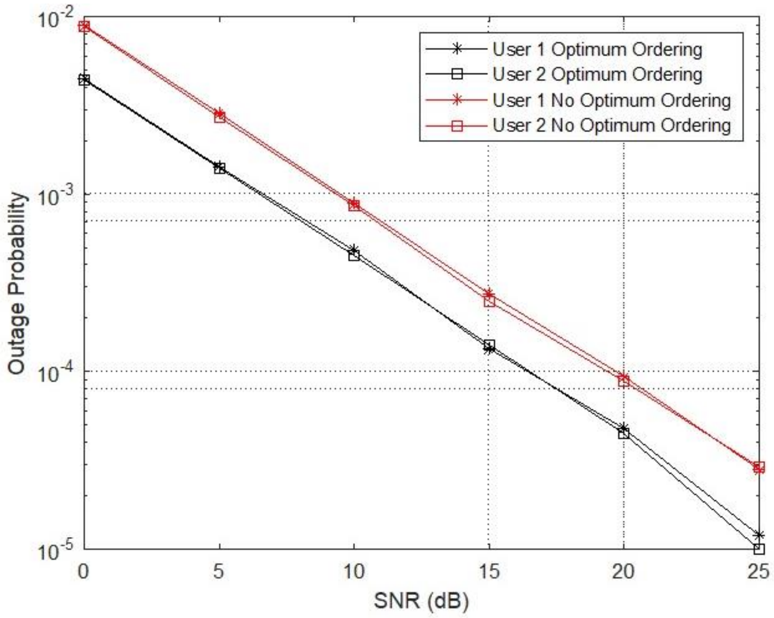

Figure 3. Outage Probability for The System with Two Transmit and Two Receive Antennas When Optimum Ordering is Applied at Each User

Moreover, we compare the cases where both users have two, three, and four antennas in Figure 4. To determine the outage probability results, the same achievable rate is targeted for in all these systems to make a fair comparison. Expectedly, as the number of antennas at the receiver side increases, the outage probability significantly decreases. It can be clearly seen that, in the high SNR region (SNR > 20 dB), the effect of optimum ordering becomes prominent. For example, a 3dB SNR gain is attained when the outage probability is 10^{-4} under all the inspected scenarios.

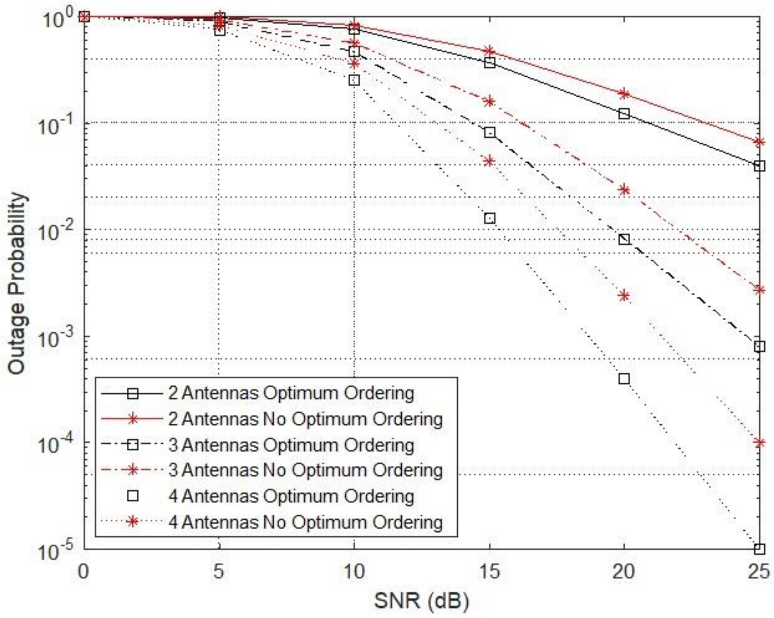

Figure 4. Outage Probability Results When Optimum Ordering is Applied at Both Users with Two, Three, and Four Receiver Antennas

5. CONCLUSION

In this study, MIMO is combined with the spectral efficient NOMA architecture which has been used frequently in current wireless technologies. For this purpose, ZF V-BLAST technique with its low processing complexity is integrated into the system. By considering the outage probability concerns, optimum decoding ordering is implemented for ZF V-BLAST. Starting with a scenario where a BS with two antennas communicates with two users each with two antennas, we describe the related steps in a detailed fashion. Then, the system model is extended to cover more than two antennas at both users. It turns out that the introduced system model achieves a 3 dB SNR gain as compared to a similar scenario with no decoding ordering. As the optimum ordering technique utilizes CSI at only the receiver sides, the suggested system model can be considered a practical choice without any significant additional complexity.

Contribution of The Authors
The authors confirm that they equally contributed to this paper.

Conflict of Interest
The authors declare that there is no conflict of interest.

Statement of Research and Publication Ethics
Research and publication ethics were observed in the study.

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