MIMO Uplink NOMA with Successive Bandwidth Division

Soma Qureshi and Syed Ali Hassan

School of Electrical Engineering & Computer Science (SEECS)
National University of Sciences & Technology (NUST), Islamabad, Pakistan 44000
Email: {14mseesqureshi, ali.hassan}@seecs.edu.pk

***Abstract*—Non-orthogonal multiple access (NOMA) is a key enabling technology for fifth generation (5G) wireless networks because of its ability to provide greater spectral efficiency. However, a conventional NOMA scheme offers significant interference and higher outage probability especially when the number of users in the network is large. Therefore, in this paper, we propose a suboptimal algorithm which uses the concept of successive bandwidth division (SBD) in NOMA system, which not only reduces the complexity of the receiver side to a great extent, but also enhances the overall signal-to-interference plus noise ratio (SINR) of the uplink NOMA by supporting $2N$ users with just N base station (BS) antennas. The BS is assumed to have perfect channel state information (CSI) and uses a zero-forcing (ZF) postcoding matrix to recover the signals of different users. Numerical results show that the performance of the proposed scheme outperforms the conventional NOMA techniques in terms of receiver complexity and outage probability.**

***Index Terms*—NOMA, user-pairing, 5G, successive interference cancellation (SIC), outage probability, zero-forcing receiver.**

I. Introduction

For the past few years, the excessive usage of handheld devices for data transmission such as smart phones and tablets is becoming popular, which has motivated the researchers, both in academia and industry, to design the next generation wireless networks. The so-called fifth generation (5G) system will be designed to offer greater spectral efficiency as compared to the conventional 4G systems. While 5G systems provide a multitude of techniques to be used in future cellular systems including massive multiple-input multiple-output (MIMO), heterogeneous and small cell networks, and millimeter wave (mmWave) communications, the multiple access schemes also required to be designed critically [1], [2]. Generally, the multiple access schemes have been classified into two types, i.e., orthogonal multiple access (OMA) and non-orthogonal multiple access (NOMA). This classification is made on the basis of the exclusivity offered in resource allocation to the users [3]. The previous commonly OMA schemes include conventional time division multiple access (TDMA) and frequency division multiple access (FDMA) systems. In 4G wireless networks, the OMA is mainly based on orthogonal frequency division multiple access (OFDMA) [4]. OFDMA assigns each tone to at most one user such that each user gets disjoint set of subcarriers. Thus, each user experiences a different channel gain on each subcarrier. The transmitter of OFDMA systems can dynamically allocate power and rate on each tone to satisfy various quality of service (QoS) requirements of each user. The transmitter has the knowledge of perfect channel state information (CSI), which is required in multi-user communication systems. Thus, OMA techniques such as OFDMA and single carrier frequency division multiple access (SC-FDMA) have been adopted in various systems such as long term evolution (LTE) and LTE-advanced but all these techniques are user oriented and offer lack of user fairness while NOMA serves as a key enabling technology for 5G networks because of its greater spectral efficiency and user fairness [5], [6]. In NOMA, the signals from multiple users are superimposed in the power domain in such a way that they offer greater spectral efficiency. In NOMA, the users with poor channel conditions are allocated more transmission power while the one with better channel conditions are allocated less power. In this way, the users with poor channel condition can decode their own message easily while successive interference cancellation (SIC) is carried out for the users with better channel conditions [7].

The major advantages of NOMA over conventional OMA techniques is its high spectral efficiency and user fairness, however, it offers significant interference due to which multi-user detection (MUD) is required to retrieve the signal at the receiver side. NOMA outperforms the conventional OMA schemes with randomly deployed users as characterized in [6]. On the other hand, the conventional opportunistic schemes prefer to give all power to the users with better channel condition, which improves the overall capacity of the system but deteriorates fairness [7]. Thus, NOMA techniques are getting attention and are a promising enabler to improve the spectral efficiency for 5G wireless networks. The optimal scheme for NOMA is to allow all the users to share the subcarrier and resources but it will increase the receiver complexity to a great extent. There are some other techniques that allow NOMA such as code division multiple access (CDMA), low density spreading (LDS) but they add redundancy to facilitate the users separation at the receiver. Some other existing work on the design of uplink NOMA for 5G wireless network has been proposed in [8], [9]. The combination of NOMA with cooperative communications and the impact of user pairing in NOMA has been characterized in [10], [11]. Other work on downlink NOMA has been proposed in [12]. However, these techniques are not capacity approaching. These techniques are more channel oriented. They degrade the overall spectral efficiency of the system. We could not adopt the existing capacity approaching techniques because they are limited to very small number of users, which is not practically required. Therefore, in this paper, to achieve the throughput gain of NOMA with capacity approaching techniques, we propose an algorithm successive bandwidth division (SBD) in which the users are divided into orthogonal groups with limited number of users in each group. Because of the orthogonality among the users, no joint processing is required at the receiver side to retrieve the users signals. In order to further reduce the inter-set interference, the users within the same sub-band are paired. The users paired within the same sub-band are members of two distinct sets, namely strong set and weak set. The sets are classified on the basis of the channel conditions. The members of weak set should be chosen in a way that it offers very little or no interference to the other user within the same sub-band. As the proposed system is formed by combining OMA and NOMA techniques, so it inherits the advantages of both techniques.

The paper is organized as follows. In Section II, we present the system model of the proposed SBD NOMA scheme with multiple antennas. In Section III, we discuss the impact of different parameters on the performance and also described the algorithm for strong and weak sets formation and subchannel allocation. Simulation results and discussion is provided in Section IV. Concluding remarks are drawn in Section V.

II. System Model

Consider the uplink of a multi-user MIMO communication system, where the base station (BS) is equipped with N antennas while the users are equipped with a single antenna each. The total number of users in a cell is K where $K \geq 2N$. For a conventional uplink system with multiple antennas at the BS, only N users can be supported simultaneously without any interference. In the proposed uplink scheme, the BS can support K users by superposition coding. Let ξ denotes the set of all K users. In a conventional NOMA scheme, the set ξ is divided into two sets A and B, such that $A \cup B = \xi$ and $A \cap B = \phi$. The sets A and B are defined on the basis of the channel gains that the users experience. The users with relatively high channel gains are considered as strong and are members of set A while the ones with relatively weak channel gains are considered to constitute the weak set, B.

For the case of conventional OMA, the channel is divided into K identical sub-bands to allow access from K different users. All the users are allocated separate frequency bands and the other users cannot use the frequency band other than the one allocated to them. Hence the signals can be decoded independently at the receiver side and ideally no interference arises. However, the bandwidth assigned to each user is reduced to $1/K$ in this case, which reduces the overall spectral efficiency of the OMA system. In conventional NOMA systems, the users are squeezed in the same frequency band. In this particular case, users in both the sets A and B are allocated to the same frequency band. As multiple users are admitted at the same frequency, the interference offered to them by other users within the sub-band is quite high. We will show later that the users in set B are a constant source of inter-set interference to the users in set A. Thus, the signals of the users in the strong set are decoded first with interference, and then the user signals in the weak set are decoded without interference. As a result, the decoding complexity at the receiver side is very high even aided by SIC or joint decoding. However, for both extremes, it can be seen that the capacity and reliability are affected for OMA and NOMA schemes, respectively. A possible alternative to reduce the interference, receiver complexity, outage probability and to enhance the sum capacity, is to use the proposed SBD NOMA described in the following section.

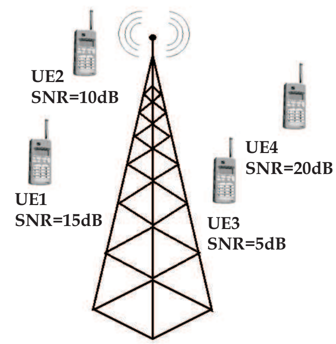

Fig. 1. Uplink NOMA with multiple users and N receive antennas.

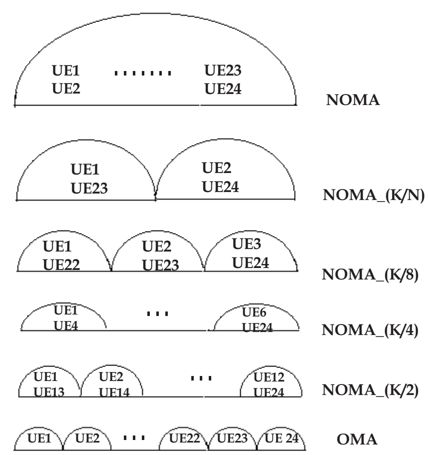

Fig. 2. OFDMA vs. NOMA and proposed SBD scheme, K=24 for this particular example.

A. Proposed SBD Scheme

In SBD NOMA, first the bandwidth resources are split orthogonally into several identical sub-bands. The sub-bands to be formed depends on a number P where $\{P \in \mathbb{N} \mid 1 \leq P \leq K\}$, where $\mathbb{N}$ is a set of natural numbers. For example, in Fig. 2, let the total number of users $K = 24$.

We now define a set ϕ which is the set of factors of K. For $K = 24$, $\phi = \{1, 2, 3, 4, 6, 8, 12, 24\}$. Since we assume even number of users, hence all even elements from ϕ are chosen except $P = 1$. The $P = 1$ is a special case where SBD NOMA specifies to orthogonal multiple access. Then the users are grouped into K/P sub-bands via OMA techniques, e.g., OFDMA with P users in each sub-band. The P users are chosen from the sets A and B whose channel coefficients are pairwise orthogonal so that they offer minimum or no interference to each other. The number P changes the number of sub-bands, the number of interferers, the dimensions of channel and detection matrices, dimensions of the received signal and the number of users in each sub-bands. However, the total number of users remains the same. The number P divides the strong and weak sets A and B into K/P smaller sets such that $\sum_{i=1}^{K/p} A_i \cup B_i = \xi$ where the cardinality of A_i and B_i, $\forall_i$ is $P/2$. The number of interferers in each sub-band is $P/2$ while the number of users in each sub-band is P. The total number of received signals at the BS is K/P. The system bandwidth and the corresponding noise variance becomes BW$/P$, $\sigma^2 P/K$ where BW is the total bandwidth of the system and σ^2 is the noise variance.

Let $P = 1$. In this case the SBD NOMA has K sub-bands, specializing the case to OMA. Each user from both sets, gets a separate frequency band. When $P = 2$, SBD NOMA has $K/2$ sub-bands. When $P = 4$, SBD NOMA has $K/4$ sub-bands. Similarly, for $P = 8$, SBD NOMA has $K/8$ sub-bands. In order words, we define NOMA$_P$ to be the access scheme where K/P sub-bands are formed, with K/P users use one sub-band and a conventional NOMA scheme works in each sub-band.

To illustrate the main concept of the proposed SBD NOMA, consider the example shown in Fig. 2. Suppose that the number of users is, $K = 24$. The set ξ is divided into two sets A and B, such that $A = \{u_1, u_3, ..., u_{K-1}\}$ and B= ξ-A. The number of users in the two sets A and B are assumed to be equal and even. For $P = 2$ the access scheme is NOMA$_2$, the number of users in each sub-band is 2. Each A_i, B_i from the sets A and B has cardinality of 2. The number of interferer is 1 in this case. Similarly, for $P = 4$, SBD NOMA has 4 users in each sub-band. Each A_i, B_i from the sets A and B has cardinality of 4. The number of interferer is 2 in this case. $P = K$ specialize to the case of conventional uplink NOMA, with only one sub-band and N interferers.

As only P users can transmit their signals simultaneously within each sub-band, hence the received signal is the superposition of the signals from P users. The other users are decoded independently without any interference. Furthermore, as the number of superimposed users is only P, the construction and decoding complexity of the proposed scheme is much lower than that of direct-superimposition scheme, in which the number of superimposed users is K. Hence, this proposed scheme offers greater spectral efficiency and reduces the number of multi-user detection at the receiver side.

B. Received Signal Model

The signal received at the BS from the entire group of users within the K/P sub-bands in this scenario is given by

$$\mathbf{y} = \mathbf{H}_1\mathbf{s}_1 + \mathbf{H}_2\mathbf{s}_2 + \mathbf{n}, \tag{1}$$

where $\mathbf{y}$ is an $N \times 1$ uplink received signal vector, $\mathbf{H}_1$ and $\mathbf{H}_2$ are $N \times P/2$ channel matrices of strong and weak sets, respectively. The $\mathbf{n}$ is an $N \times 1$ additive white Gaussian noise (AWGN) vector with zero mean and unit variance. The channel matrices $\mathbf{H}_1$, $\mathbf{H}_2$ of strong and weak sets are given by

$$\mathbf{H}_i = \begin{bmatrix} \mathbf{h}_{i,1} & \mathbf{h}_{i,2} & \dots & \mathbf{h}_{i,P/2} \end{bmatrix}, \tag{2}$$

where $i \in \{1, 2\}$. The $\mathbf{h}_{i,n}$ is the $N \times 1$ uplink channel vector of the n^{th} user i.e., $\mathbf{h}_{i,n} \sim \mathbb{CN}$ (0,1). The transmitted symbols from each user can be given as

$$\mathbf{s}_1 = \begin{bmatrix} \sqrt{\alpha_{1,1}}x_{1,1} & \dots & \sqrt{\alpha_{1,P/2}}x_{1,P/2} \end{bmatrix}^{\mathsf{T}}, \tag{3}$$

$$\mathbf{s}_2 = \begin{bmatrix} \sqrt{\alpha_{2,1}}x_{2,1} & \dots & \sqrt{\alpha_{2,P/2}}x_{2,P/2} \end{bmatrix}^{\mathsf{T}}, \tag{4}$$

where $(.)^{\mathsf{T}}$ denotes the transpose, $\alpha_{i,j}$ represents the NOMA power allocation coefficient of strong and weak users, $j = \{1, 2, ..., P/2\}$ and $x_{i,j}$ represents the symbol transmitted by the user i to the BS antenna j. The $\mathbf{s}_1$ and $\mathbf{s}_2$ represent the $P/2 \times 1$ signal vector of strong and weak sets, respectively. The number of interferers in each sub-band is $P/2$ while the number of users in each sub-band is P. The total number of received signals at the BS is K/P.

The received signal of the n^{th} user in the strong set is the superimposed signal given by

$$\mathbf{y}_n = \mathbf{h}_{1,n}\sqrt{\alpha_{1,n}}x_{1,n} + \sum_{j=1}^{P/2} \mathbf{h}_{2,j}\sqrt{\alpha_{2,j}}x_{2,j} + \mathbf{n}, \tag{5}$$

where $\mathbf{h}_{1,n}$ and $\mathbf{h}_{2,n}$ are the $N \times 1$ uplink channel vectors of the n^{th} user from both sets to the BS having N antennas and $\mathbf{n}$ is the $N \times 1$ AWGN vector. Since the BS receives superimposed signals, a SIC scheme is required at the receiver side for decoding. The signals of the strong set are decoded first, with interference from weak set while the users in the weak set are decoded without interference. As there are only P users in each sub-band so interference comes only from the users with relatively weak channel gain. The remaining users are orthogonal and offer no inter-set interference.

At the receiver side, a zero-forcing (ZF) postcoded or detection matrix is used to decode the signals of strong and weak sets. The BS generates the detection matrix by using the CSI of all the users. The corresponding postcoded matrix of the channel matrices $\mathbf{H}_1$ and $\mathbf{H}_2$ are given by

$$\mathbf{Z}_i = \begin{bmatrix} \mathbf{z}_{i,1}^{\mathsf{T}} & \mathbf{z}_{i,2}^{\mathsf{T}} & \dots & \mathbf{z}_{i,P/2}^{\mathsf{T}} \end{bmatrix}^{\mathsf{T}} = (\mathbf{H}_i)^*((\mathbf{H}_i)(\mathbf{H}_i)^*)^{-1}, \tag{6}$$

where $(.)^{-1}$ and $(.)^*$ denotes the inverse and complex conjugate of a matrix. In the above equation $\mathbf{Z}_1$ is the $P/2 \times N$

postcoded matrix of users in the strong set and $\mathbf{z}_{n,1}$ is the $1 \times N$ uplink channel vector of the n^{th} user, respectively.

Let us investigate the signal-to-interference plus noise ratio (SINR) of the users within the strong and weak sets. After applying the postcoded matrix $\mathbf{Z}_1$ to the users of strong set, the resulting received signal becomes

$$\mathbf{r}^{(1)} = \mathbf{Z}_1\mathbf{H}_1\mathbf{s}_1 + \mathbf{Z}_1\mathbf{H}_2\mathbf{s}_2 + \mathbf{Z}_1\mathbf{n}, \tag{7}$$

where $\mathbf{r}^{(1)}$ is an $(N/(K/P)) \times 1$ received signal vector. From (7) , the signal of the n^{th} user in the strong set is as follow

$$r_{1,n}^{(1)} = \mathbf{z}_{1,n}\mathbf{h}_{1,n}\sqrt{\alpha_{1,n}}x_{1,n} + \sum_{j=1}^{P/2}\mathbf{z}_{1,n}\mathbf{h}_{2,j}\sqrt{\alpha_{2,j}}x_{2,j} + \mathbf{z}_{1,n}\mathbf{n}, \tag{8}$$

In (8), the signal $\mathbf{z}_{1,n}\mathbf{h}_{1,n}\ \sqrt{\alpha_{1,n}}x_{1,n}$ represents the desired signal of strong user while the signal $\sum_{j=1}^{P/2}\mathbf{z}_{1,n}\mathbf{h}_{2,j}\sqrt{\alpha_{2,j}}x_{2,j}$ represents the inter-set interference from the weak user. The number of interferers is N for conventional uplink NOMA system with $P = K$. The number of interferers reduces as P decreases in the proposed SBD scheme with no interferer for $P = 1$. The received instantaneous SINR is given as

$$SINR_{1,n} = \frac{||\mathbf{z}_{1,n} \odot \mathbf{h}_{1,n}||^2\alpha_{1,n}}{\sum_{j=1}^{P/2}||\mathbf{z}_{1,n} \odot \mathbf{h}_{2,j}||^2\alpha_{2,j} + \sigma_n^2}, \tag{9}$$

where $||.||$ and $\odot$ denotes the modulus and point to point multiplication. Before decoding its own message, each user in the strong set needs to decode the message of the user in the weak set. After successful decoding of the message the strong user decodes its own message. For decoding of weak user signal, SIC is carried out so there will be no interference in this case. Hence, after applying ZF matrix, the signals of weak set become

$$\mathbf{r}^{(2)} = \mathbf{Z}_2\mathbf{H}_2\mathbf{s}_2 + \mathbf{Z}_2\mathbf{n}, \tag{10}$$

The received signal and corresponding SINR of n^{th} weak user is given by

$$r_{2,n}^{(2)} = \mathbf{z}_{2,n}\mathbf{h}_{2,n}\sqrt{\alpha_{2,n}}x_{2,n} + \mathbf{z}_{2,n}\mathbf{n}, \tag{11}$$

$$SINR_{2,n} = \frac{||\mathbf{z}_{2,n} \odot \mathbf{h}_{2,n}||^2\alpha_{2,n}}{\sigma_n^2} \tag{12}$$

In (12), the inter cluster and inter-set interference has been completely minimized. This is done by choosing orthogonal signal as part of a strong and weak sets. The sum capacities of all the users in a strong and weak set is given by

$$R_i = BW/P\sum_{n=1}^{N}log_2\left(1 + SINR_{i,n}\right); \quad i \in \{1, 2\}, \tag{13}$$

where BW is the system bandwidth.

Since we assume N antennas and $2N$ users, the strong users are only affected by inter-set interference from the weak users. In this case, each channel vector and the ZF postcoding vector satisfies the following condition.

$$\mathbf{z}_{1,j} \odot \mathbf{h}_{1,n} = 0; \forall j \neq n, \quad j \in \{1, 2, ..., P/2\}, \tag{14}$$

However, if the number of antennas and users is such that the resultant matrix is rectangular then the strong and weak users get interference from other strong and weak users, respectively. The received SINR of the n^{th} user in the strong and weak sets becomes

$$SINR_{1,n} = \frac{||\mathbf{z}_{1,n} \odot \mathbf{h}_{1,n}||^2\alpha_{1,n}}{I + \sigma_n^2}, \tag{15}$$

where I represents the interference and is given by

$$I = \sum_{j=1}^{P/2}||\mathbf{z}_{1,n} \odot \mathbf{h}_{2,j}||^2\alpha_{2,j} + \sum_{j=1, j\neq n}^{P/2}||\mathbf{z}_{1,n} \odot \mathbf{h}_{1,j}||^2\alpha_{1,j}, \tag{16}$$

$$SINR_{2,n} = \frac{||\mathbf{z}_{2,n} \odot \mathbf{h}_{2,n}||^2\alpha_{2,n}}{\sum_{j=1, j\neq n}^{P/2}||\mathbf{z}_{2,n} \odot \mathbf{h}_{2,j}||^2\alpha_{2,j} + \sigma_n^2}. \tag{17}$$

III. Impact of User Pairing on SBD

The user pairing has the potential of reducing the complexity at the receiver side. Therefore, in the proposed SBD scheme, both conventional OMA and NOMA are implemented simultaneously. The grouping is done on the basis of the channel gains between the users. The users which are pairwise orthogonal are grouped together in the same sub-band with different channel gains to get full benefit of the NOMA within each sub-band. The user pairing strategy affects the overall throughput of the proposed scheme.

The detailed algorithm for choosing members of strong and weak set is presented in Algorithm 1. The algorithm aims to minimize the interference offered by the weak user to the strong user.

In step 5 of the above algorithm, the user pairing is critical. It will affect the overall sum capacity of the proposed SBD scheme. This is because the performance of SBD is much dependent on the way the users are paired. Careful user pairing not only improves the sum rate, but also has the potential to improve the individual user rates.

IV. Results and Discussion

In this section, computer simulations are used to evaluate the performance of the proposed SBD NOMA schemes. We investigate the performance of the SBD schemes and compare it with the conventional OMA and NOMA techniques. The cell radius is assumed to be 1000m in which all the users are randomly distributed. The channel coefficients are assumed to be independent and identically distributed (i.i.d) Rayleigh flat faded. The transmission power allocated to all users is 24dBm. The noise is assumed to be zero mean circular-symmetric complex Gaussian having a noise density of -174dBm/Hz. The overall system bandwidth is 4.32MHz. The path loss is calculated by using the following model.

Algorithm 1 Strong and Weak Sets Formation and Subchannel Allocation Algorithm

Initialization

1) A set ξ of K users, where $K = \{1, ..., k\}$.
2) $\mathbf{H}_1$ and $\mathbf{H}_2$
3) Number of antennas, N.

Iteration

1) All K users feedback their CSI to the BS. The BS creates a set M of channel matrix, $\mathbf{M}$=$0_{(K \times N)}$, $\mathbf{M} = \{\mathbf{h_1}, \mathbf{h_2}, ..., \mathbf{h_k}\}$.
2) The transmitter then calculates the frobenius norm of all users and arrange it in descending order.

$$\mathrm{M}_{ord} = \{|\mathbf{h_1}|^\mathbf{2}, |\mathbf{h_2}|^\mathbf{2}, ..., |\mathbf{h_k}|^2\} \text{ where } |\mathbf{h_K}|^\mathbf{2} > |\mathbf{h_{K+1}}|^\mathbf{2} \text{ and } K \in \{1, 2, ..., k\}.$$

3) The transmitter then separates two sets $\mathbf{H}_1$ and $\mathbf{H}_2$ from M_{ord} on the basis of the channel gains that the user experience i.e., $\mathbf{H}_1 \cup \mathbf{H}_2 = \mathrm{M}_{ord}$ and $\mathbf{H}_1 \cap \mathbf{H}_2 = \phi$.

$$\mathbf{H}_1 = \{|\mathbf{h_1}|, |\mathbf{h_2}|, ...|\mathbf{h}_{\lfloor \mathbf{K/2} \rfloor}|\},$$
$$\mathbf{H}_2 = \{|\mathbf{h}_{\lfloor \mathbf{K/2} \rfloor + \mathbf{1}}|, |\mathbf{h}_{\lfloor \mathbf{K/2} \rfloor + \mathbf{2}}|, ...|\mathbf{h_K}|\},$$

$\lfloor . \rfloor$ denotes the floor function. In $\mathbf{H}_1$, the N users having the higher channel gains are selected as the members of strong set A, while the remaining users are selected as the members of the weak set, B. The respective channel gains of strong and weak users are $\mathbf{H}_1$ and $\mathbf{H}_2$. The users with channel gains $\mathbf{H}_1$ are members of set A and users with channel gains $\mathbf{H}_2$ are members of set$B$.

$$\mathbf{H_1} = \begin{bmatrix} \mathbf{h}_{\mathbf{1},1} & \mathbf{h_{1,2}} & \dots & \mathbf{h}_{\mathbf{1},\mathbf{N}} \end{bmatrix}^\mathsf{T},$$
$$\mathbf{H_2} = \begin{bmatrix} \mathbf{h}_{\mathbf{2},1} & \mathbf{h_{2,2}} & \dots & \mathbf{h}_{\mathbf{2},\mathbf{N}} \end{bmatrix}^\mathsf{T},$$

4) Do head to tail pairing of users from both sets to get minimum interference.
5) For SBD NOMA, each Rayleigh fading channel matrix divides itself into smaller matrices with dimension $N \times P/2$, where P denotes the access scheme. The smaller channel matrices and the corresponding user indexes of strong and weak sets satisfy the condition $\sum_{i=1}^{K/p} A_i \cup Bi = \xi$. The users from the two sets are paired in different sub-bands to reduce interference.
Go to 1).

End When all the N users from the two sets are paired in sub-bands.

$$PL_{dB} = 30 + 10\beta \log_{10}(d), \tag{18}$$

where d is the distance between the BS and the MS and β is the path loss exponent, which is kept at 4 in this study. The working SNR is assumed to be $10dB$.

Fig. 3 compares the sum capacity of OMA, NOMA and proposed SBD schemes. The primary observation of this section is comparing the sum capacity of all multiple access schemes with the number of users and examining the effect of number of users. The sum capacity improves with the increase in the number of users but that improvement in not substantial

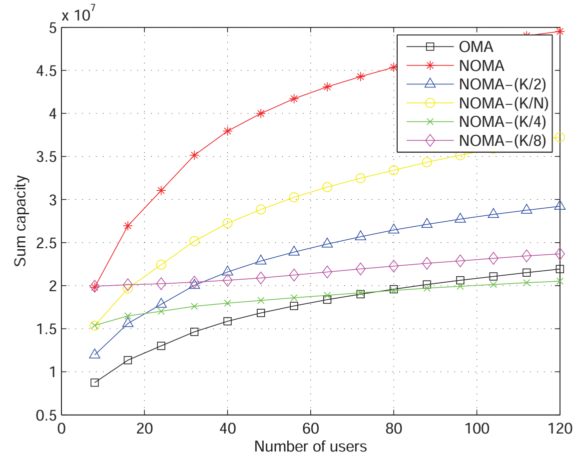

Fig. 3. Comparison of sum capacity of OMA, NOMA and proposed SBD scheme.

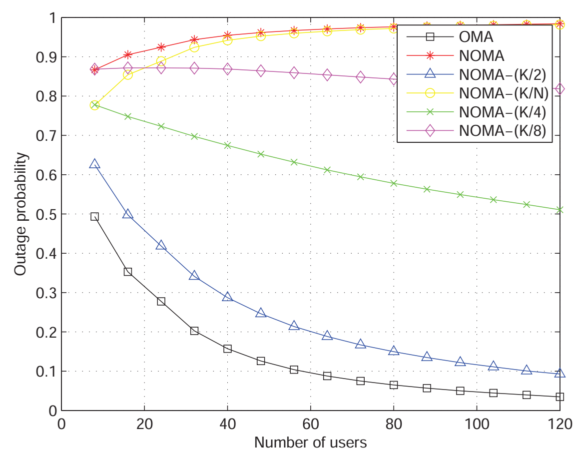

Fig. 4. Outage analysis of OMA, NOMA and proposed SBD scheme.

for NOMA_4 and NOMA_8 schemes after the number of users exceeds a certain limit. However, the complexity offered by them is much less than the conventional uplink NOMA system. The NOMA_N scheme outperforms the OMA and conventional NOMA techniques in terms of receiver complexity, decoding and offer better throughput and fairness.

Fig. 4 shows the outage performance of OMA, NOMA and proposed SBD schemes. It can be easily observed that the proposed SBD schemes can achieve better outage performance as compared to conventional NOMA especially NOMA_2 and NOMA_N schemes. The decreasing trend of outage probability in SBD scheme is because of the fact that we are dividing the bandwidth and noise variance accordingly which increases the individual SINR of users. We can derive an interesting result by combining Fig. 3 and 4 that although the conventional uplink NOMA achieves maximum sum capacity but it increases the receiver complexity and outage probability to a great extent, which is practically not desired especially if the number of users is very large. Hence in the situations where the

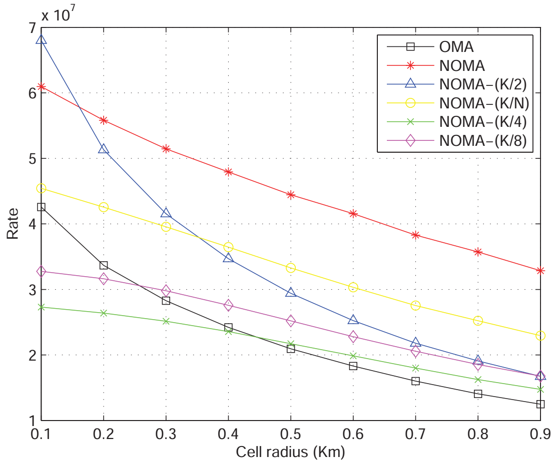

Fig. 5. Impact of cell radius on SBD scheme (N=2, K=40).

TABLE I
PERCENTAGE DECREASE IN SUM CAPACITY BY CHANGING SYSTEM BANDWIDTH

System Bandwidth	OMA	NOMA	NOMA-(K/2)
2.16 MHz	39.1 %	45.7 %	39.7 %
1.08 MHz	63.90 %	70.50 %	64.80 %
System Bandwidth	NOMA-(K/N)	NOMA-(K/4)	NOMA-(K/8)
2.16 MHz	43.10%	42.14 %	41.25 %
1.08 MHz	67.60 %	67.20 %	66.72 %

TABLE II
PERCENTAGE INCREASE IN SUM CAPACITY BY REDUCING PATH LOSS EXPONENT

Path loss Exponent	OMA	NOMA	NOMA-(K/2)
3.76	34.1 %	41.9%	29.2 %
3.1	70 %	59.0 %	58.7 %
Path loss Exponent	NOMA-(K/N)	NOMA-(K/4)	NOMA-(K/8)
3.76	27.9%	27.3 %	18 %
3.1	57.39%	46.9 %	39.7 %

user priority is reduced complexity, cost and enhanced QoS, SBD NOMA schemes should be preferred over conventional uplink NOMA, which provide better rate and a fairly reliable transmission scheme.

In Fig. 5, the impact of cell radius on the performance of OMA, NOMA and SBD NOMA is demonstrated. It can be seen that SBD NOMA performs better than the conventional NOMA if the cell radius is assumed to be very small. However, NOMA outperforms at other values, but as the cell radius increases, the inter-set interference offered to NOMA by weak set also enhances, which increases the decoding complexity at the receiver side.

Finally, the effect of changing system bandwidth and path loss exponent on the performance of SBD NOMA has been evaluated for $K = 40$. Decreasing the system bandwidth to 2.16MHz and 1.08MHz reduces the sum capacity as compared to 4.32MHz. The percentage decrease for each SBD NOMA scheme is shown in Table I. Reducing the system bandwidth to one half almost decreases the sum capacity to 40% for each scheme. Similarly, decreasing the system bandwidth to one quarter reduces the sum capacity in a range of 60 to 70%. The percentage decrease in sum capacity is highest for NOMA, as the number of interferers is large for NOMA. Similarly, decreasing the path loss exponent increases the sum capacity as shown in Table II. The percentage increase in sum capacity is not substantial for NOMA_8 scheme. However, it can be observed that NOMA_2 dominates NOMA_N at path loss exponent of 3.1.

V. CONCLUSIONS

5G wireless networks require high spectral efficiency to meet the ever increasing demand of traffic in mobile communication for which NOMA is a very promising solution. However, it offers enhanced system complexity especially in massive access scenarios. Therefore, in this paper we have investigated the performance gap between NOMA, OMA and proposed SBD scheme. The proposed SBD scheme reduces the number of interferers at the receiver side, which not only reduces the multi-user detection algorithms required to retrieve the signal but also offers better outage and user fairness as compared to conventional NOMA scheme. Therefore, the system that demands reduced outage and complexity can use SBD NOMA. The results suggest that SBD NOMA with proper path loss exponent, cell radius and bandwidth can significantly outperform non-orthogonal multiple access in terms of system spectral efficiency and user fairness.

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