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RESEARCH ARTICLE

User Selection Methods for Overcoming Growing Number of Served Users in Massive MIMO Systems

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ABSTRACT Massive MIMO is dominant in the current wireless communication systems. Massive MIMO system uses a massive number of antennas to serve multi-users simultaneously. The growth of served users in the system will increase the interference between them and affect the system's performance. To maintain the qualified service for the growing number of users, user selection techniques can be used to separate users into groups to be served well. This paper proposes three user selection methods named Mean Step User Selection (MSUS), Second Null User Selection (SNUS), and Interference Threshold User Selection (ITUS) methods. These three user selection methods aim to serve users with the best possible performance. The performance of these proposed user selection methods will be evaluated and compared with the performance of the system without selection and with the system using other user selection methods such as Random User Selection (RUS), Semi-orthogonal User Selection (SUS), and Inter-Channel Interference Based Selection (ICIBS) methods. The simulation shows that the proposed MSUS, SNUS, and ITUS methods provide an improvement in the spectral efficiency of 75.39%, 92.13%, and 153.71% when compared with the system without the selection method. The proposed user selection methods also improve performance compared to other user selection methods.

INDEX TERMS Downlink transmission, interference, massive MIMO, orthogonal locations, spectral efficiency, user selection methods.

I. INTRODUCTION

Massive Multi-input Multi-output (Massive MIMO) refers to a multi-user MIMO system that has a massive number of antennas at the base station (BS) and serves single antenna users. The massive MIMO has two transmission paths, downlink (DL) transmission and uplink (UL) transmission. The DL transmission means the transmission from the BS to the users, and the UL transmission means the transmission from the users to the BS [1], [2]. Beamforming in massive MIMO refers to signal processing procedures that aim to transmit and receive the signals through the system efficiently. Beamforming is a receive beamforming in the UL transmission and a transmit beamforming in the DL transmission. The receive beamforming (receive combining) in UL aims to separate the signals from the different users at the BS. The transmit beamforming (transmit precoding) in DL aims to direct the signals from the BS to the intended users' locations [1], [3], [4], [5].

The user selection methods act as promising techniques to improve the performance of the multi-user system. The user selection method aims to separate the users into groups to reduce the interference between the served users. Reducing the interference in each group will improve the performance of the system in terms of some metrics, such as the spectral efficiency (SE) and the sum SE [6], [7], [8], [9], [10]. So, the system performance can be evaluated based on the SE and the sum SE in the system. where SE refers to the number of bits transmitted by one-hertz bandwidth between the user and the BS, and the sum SE refers to the SE of all users in the system [11], [12].

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Several references present different user selection methods based on many different metrics. Ref. [13] presents two user scheduling algorithms named "Group Number Minimization and Degree of Freedom Maximization." The Group Number Minimization algorithm aims to minimize the number of user groups. Firstly, it selects the first user for each group based on the maximum Frobenius norm. Then the remaining users are selected with certain criteria to minimize the correlation and interference per group. The Degree of Freedom Maximization algorithm aims to use the total degree of freedom by initializing the group size with the number of transmit antennas. The first user is selected based on the maximum Frobenius norm. Then the remaining users are selected by criteria to cause the sum of channel ranks of the users per group larger than the remaining degree of freedom. Ref. [14] presents two user selection algorithms named "Semi-orthogonal User Selection and Random User Selection." The semi-orthogonal User Selection method selects users that are semi-orthogonal with each other based on a defined relation between their channels' norms. The random User Selection method selects users in groups randomly. Ref. [14] evaluates the performance based on the average sum rate with the SNR value using MR, ZF, MMSE schemes and without precoding.

Ref. [15] presents an optimal algorithm for dynamic user clustering and power allocation based on the joint exhaustive search. The dynamic user clustering algorithm divides the users into two multi-user clusters based on their received signal, named high power cluster (HPC) and low power cluster (LPC), where the HPC of strong channel users and the LPC of weak channel users. Ref. [15] also shows two stages of linear multi-user detection which are used to first estimate the HPC signals and then the LPC signals. This proposed dynamic user clustering aims to maximize the sum rate and attain user fairness. The performance here is evaluated based on the sum rate and the average user rate concerning the signal-to-noise ratio.

Ref. [16] presents the two-step user selection method and compares it with the chordal distance user selection and the proportional fair scheduling methods. The two-step user selection method selects users through two steps, the first step is based on user throughput at the last user selection, and the second step is based on the CSI feedback from the user to the BS. Ref. [16] evaluates its proposed method by the system throughput concerning the number of selected users and their azimuth angles. Ref. [17] presents Gram Matrix-based User Selection. It aims to minimize inter-user interference. It selects the first user based on the lowest historical spectral efficiency and selects other users based on the minimum inter-user correlation between the candidate user and the previously selected users. It compares its performance with the random selection user method in terms of the sum spectral efficiency of the system. Ref. [18] presents a low-complexity user selection algorithm in which the coverage area is divided into sectors. Then these sectors are divided into two semi-orthogonal groups to be served in separate coherence resources. It evaluates the performance based on the sum rate in the system.

Ref. [19] presents a circular user grouping technique that uses the semi-orthogonal algorithm. The circular user grouping method starts by dividing the users into groups with an equal number of users around the base station, then selects the users based on the semi-orthogonal algorithm. The performance here is evaluated based on the sum rate concerning the number of used antennas in the base station and the signal-to-noise ratio.

Ref. [20] presents two user selection algorithms for digital transceivers and hybrid transceivers. It discusses a decremental user selection algorithm for the digital transceiver and a sequential user selection for the hybrid transceiver. The decremental user selection selects the users based on the correlation between the users, and the sequential user selection selects the users based on the channel norm and the correlation. Ref. [20] evaluates the performance based on the achieved data rate.

Ref. [21] also presents the Semi-orthogonal User Selection and the Random User Selection methods, as Ref. [14]. But it evaluates the performance of the two methods based on the average sum rate with the number of used antennas using ZF and MMSE schemes.

Ref. [22] presents a two-stage precoding technique for multi-user MIMO based on an overlapping group approach. It shows the user grouping based on an overlapping method from the Greedy algorithm, which selects the users in a way to achieves the maximum capacity. The performance is evaluated here based on the overall sum rate and the bit error rate concerning the signal-to-noise ratio value.

Ref. [10] presents Norm based user selection algorithm, which is based on the Frobenius norm. The Norm based user selection algorithm selects the users based on the channel energy indicated by the Frobenius norm. The performance of this method is evaluated by the bit error rate concerning the signal-to-noise ratio value.

Ref. [23] presents the intra-group and inter-group semi-orthogonal user selections and the intra-group and inter-group random user selections. These two methods are based on a clustering algorithm that divides the users into predefined groups and then uses the semi-orthogonal selection or the random selection methods to find the best users in every group. The semi-orthogonal method selects the users that are semi-orthogonal with each other, and the random selection method selects the users randomly. Ref. [23] evaluates the performance of both methods based on the sum rate concerning the number of used antennas in the base station.

Ref. [24] presents a user selection method named efficient system capacity user selection. It is based on a stored database that includes the capacity of users from previous allocation processes. This method selects users based on the best throughput stored in the database and evaluates the performance based on the total system throughput concerning group size during the selection process. Ref. [25] reviews the

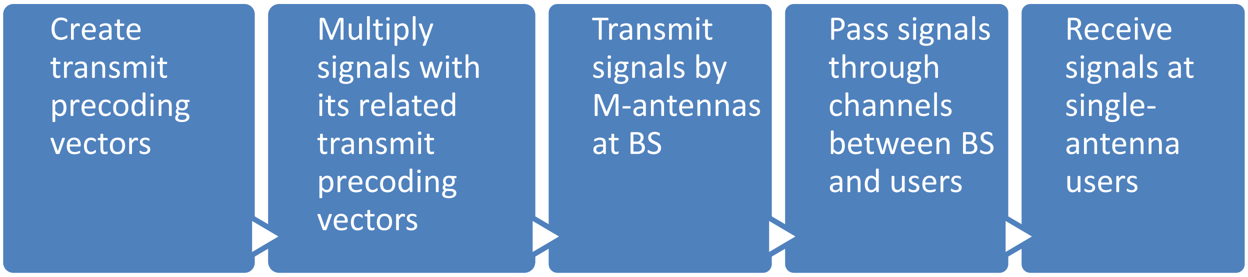

FIGURE 1. DL Transmission system model.

Semi-orthogonal Selection method and the Correlation-based Selection method. The Semi-orthogonal Selection chooses the user with the most semi-orthogonal channel with the other users. The Correlation-based Selection chooses pairs of users with a high correlation with each other and removes one of them that causes a high correlation with the selected users. Ref. [25] also presents a new user selection method named Inter-channel Interference-based Selection, which behaves as a generalization of the Correlation-based Selection method. It selects users in a way that leads to the highest overall SINR for all the selected users.

Ref. [26] presents two multi-user selection schemes: a user selection algorithm based on correlation and a user selection algorithm based on orthogonal matching pursuit. These two algorithms are based on some designed fixed reference frames, which act as a dictionary to be compared with the correlation between the user channel in both proposed algorithms. Ref. [26] compares the two proposed algorithms with the semi-orthogonal selection and the inter-channel interference-based user selection. The performance is evaluated based on the throughput versus the signal-to-noise ratio.

This paper proposes three user selection methods: the Mean Step User Selection (MSUS) Method, the Second Null User Selection (SNUS) Method, and the Interference Threshold User Selection (ITUS) Method. The MSUS and SNUS methods will be based on some orthogonal locations that will be deduced during the paper's analysis. The ITUS method will be based on a certain interference threshold level based on the system's requirements.

The performance of these proposed user selection methods will be compared with the system without the selection method and with the system using other selection methods that appeared in the surveyed part. The proposed methods will be compared with the Random User Selection (RUS) and the Semi-orthogonal User Selection (SUS) mentioned in Ref. [21] and also compared with the Inter-Channel Interference based Selection (ICIBS) mentioned in Ref. [25]. The performance is evaluated based on the SE and the sum SE concerning the number of separated groups in each user selection method.

The paper arranges as follows; section II presents the used system model and analyzes it to deduce the orthogonal locations required for the proposed methods. Section III discusses the idea of the user selection technique and discusses some user selection methods that will be used for comparison purposes. Section IV presents the proposed user selection methods. Section V presents the simulations and results of the proposed methods and compares them with other selection methods and the system without any selection method. Finally, the conclusions represent in Section VI.

II. SYSTEM MODEL AND ANALYSIS

This section will show the system model that is used in the paper to evaluate the system performance without and with the user selection methods. Also, it contains the required analysis that is used to discuss the proposed user selection methods in the paper.

The system model in this paper is the massive MIMO DL transmission with M-antennas at the BS and K-single antenna users. The BS uses the uniform linear array (ULA) as an antenna arrangement, assuming this ULA serves only a sector of 90°. The transmit precoding technique in this DL transmission is assumed to be the Maximum Ratio (MR) technique. Figure 1 presents the general DL transmission system used in the paper to investigate the performance of the proposed works in this paper.

As shown in Figure 1, the DL transmission starts by creating the transmit precoding vectors based on the used precoding technique, and these transmit precoding vectors will be used to direct the signals to the intended users' locations. Then these directed signals are transmitted by M-antennas at the BS through the channel between the BS and users. Finally, these signals will be received by the users.

The analysis of the used DL transmission system model can be explained as follows. By using the MR as a transmit precoding technique, the transmit precoding vector can be expressed as (1) [25], [27].

$$\boldsymbol{w}_i = \frac{\widehat{\boldsymbol{h}}_i}{\left\|\widehat{\boldsymbol{h}}_i\right\|} \tag{1}$$

where $\boldsymbol{w}_i$ is the transmit precoding vector related to the user equipment with index i (UE_i), $\widehat{\boldsymbol{h}}_i$ represents the estimated channel between the M-antennas BS and UE_i, and $\left\|\widehat{\boldsymbol{h}}_i\right\|$ represents its norm. For the analysis purposes, assuming an ideal channel estimation process, the estimated channel response is the same as the actual channel response $\left(\widehat{\boldsymbol{h}}_i = \boldsymbol{h}_i\right)$ and hence $\boldsymbol{w}_i = \boldsymbol{h}_i / \|\boldsymbol{h}_i\|$. Then, the channel vector can be represented with the help of the wave vector and the antennas' position in the ULA. For ULA, with antenna separation equal to half of the wavelength, the channel vector can be expressed as follows [28] and [29].

$$\boldsymbol{h}_i = \sqrt{\beta_i}\left[\mathrm{e}^{j1\pi\sin\Phi_i}\ \mathrm{e}^{j2\pi\sin\Phi_i}\ldots\mathrm{e}^{jM\pi\sin\Phi_i}\right] \tag{2}$$

And

$$\|\boldsymbol{h}_i\| = \sqrt{\beta_i+\beta_i+\ldots+\beta_i} = \sqrt{M\beta_i} \tag{3}$$

So,

$$\boldsymbol{w}_i = \frac{1}{\sqrt{M}}\left[\mathrm{e}^{j1\pi\sin\Phi_i}\ \mathrm{e}^{j2\pi\sin\Phi_i}\ldots\mathrm{e}^{jM\pi\sin\Phi_i}\right] \tag{4}$$

where β_i represents large-scale fading gain for the $\mathrm{UE_i}$, Φ_i is the azimuth angle of $\mathrm{UE_i}$, and M is the number of antennas at the BS.

After that, the signal of the user is multiplied by its related transmit precoding vector to be directed to that user, as in (5).

$$S_\mathrm{i}\mathrm{x}w_i = \frac{1}{\sqrt{M}}[S_i\mathrm{e}^{j1\pi\sin\Phi_i S_i}\ \mathrm{e}^{j2\pi\sin\Phi_i\ldots S_i}\mathrm{e}^{jM\pi\sin\Phi_i}] \tag{5}$$

Finally, the transmitted signals for all users are summed and transmitted through M antennas in the BS. On the receiver side, the signal reaches the intended user $\mathrm{UE_i}$ from all M BS antennas. The received signal at the user end contains the required signal plus the interference signals from other users in the system, as shown in (6) [27].

$$S_{UEi} = \frac{1}{\sqrt{M}}\sum_{k=1}^{K}\sum_{m=1}^{M} S_k\mathrm{e}^{jm\pi(\sin\Phi_\mathrm{k}-\sin\Phi_\mathrm{i})} \tag{6}$$

where K is the number of served users in the system, S_k is the transmitted signal of the user equipment with index "k" ($\mathrm{UE_k}$), and S_{UEi} is the received signal at the $\mathrm{UE_i}$.

The received signal in (6) can be rewritten in a simple form by a simple derivation. This derivation aims to simplify the exponential term in (6), and it starts by replacing the expression $[\pi(\sin\Phi_\mathrm{k}-\sin\Phi_\mathrm{i})]$ in (6) with the symbol (a) for simplicity and using the finite geometric series relation [30]. Then follow it with some mathematical simplification steps, so part of (6) can be simplified as shown below in equations [7:9].

$$\begin{aligned}\sum_{m=1}^{M}\mathrm{e}^{jma} &= \frac{\mathrm{e}^{ja(1)}-\mathrm{e}^{ja(M+1)}}{1-\mathrm{e}^{ja}}\frac{\mathrm{e}^{ja(1)}-\mathrm{e}^{ja(M+1)}}{1-\mathrm{e}^{ja}}\\ &= \frac{\mathrm{e}^{-ja(\frac{M}{2})}-\mathrm{e}^{ja(\frac{M}{2})}}{\mathrm{e}^{-ja(\frac{1}{2})}-\mathrm{e}^{ja(\frac{1}{2})}}\mathrm{x}\frac{\mathrm{e}^{ja(\frac{M+2}{2})}}{\mathrm{e}^{ja(\frac{1}{2})}}\\ &= \frac{\mathrm{e}^{ja(\frac{M}{2})}-\mathrm{e}^{-ja(\frac{M}{2})}}{\mathrm{e}^{ja(\frac{1}{2})}-\mathrm{e}^{-ja(\frac{1}{2})}}\mathrm{x}\frac{2j}{2j}\mathrm{x}\frac{\mathrm{e}^{ja(\frac{M+2}{2})}}{\mathrm{e}^{ja(\frac{1}{2})}} \qquad (7)\\ &= \frac{\sin\Phi(a\frac{M}{2})}{\sin\Phi(a\frac{1}{2})}\mathrm{x}\mathrm{e}^{ja(\frac{M+1}{2})} \qquad (8)\end{aligned}$$

So, the exponential part in (6) can be rewritten as shown in (9).

$$\sum_{m=1}^{M}\mathrm{e}^{\mathrm{jma}} = \frac{\sin(a\frac{M}{2})}{\sin(a\frac{1}{2})}\mathrm{x}[\cos\left(a\left(\frac{M+1}{2}\right)\right) + j\sin\left(a\left(\frac{M+1}{2}\right)\right)] \tag{9}$$

After that, the simplified part in (9) will be substituted in (6) to provide a new representation of the received signal, as shown in (10).

$$\begin{aligned}S_{UEi} = \frac{1}{\sqrt{M}}\sum_{k=1}^{K} S_k\frac{\sin(\frac{M}{2}\pi(\sin\Phi_k-\sin\Phi_i))}{\sin(\frac{1}{2}\pi(\sin\Phi_k-\sin\Phi_i))}\\ \mathrm{x}[\cos\left(\left(\frac{M+1}{2}\right)\pi\ (\sin\Phi_k-\sin\Phi_i)\right)\\ + j\sin\left(\left(\frac{M+1}{2}\right)\pi(\sin\Phi_k-\sin\Phi_i)\right)]\end{aligned} \tag{10}$$

According to (10), The received signal (S_{UEi}) appears as the Dirichlet Kernel function. Where the Dirichlet Kernel function presents a periodic version of the Sinc function [31], [32]. After that, the instantaneous received signal power at the user end will be estimated from (10) by multiplying the received signal with its conjugate, as shown in (11).

$$P_{S\_UEi} = \frac{1}{M}\sum_{k=1}^{K}(S_k\frac{\sin(\frac{M}{2}\pi(\sin\Phi_k-\sin\Phi_i))}{\sin(\frac{1}{2}\pi(\sin\Phi_k-\sin\Phi_i))})^2 \tag{11}$$

where, $P_{S\_UE_i}$ represents the instantaneous received signal power at the $\mathrm{UE_i}$. As shown in (11), the received signal power represents a squared periodic Sinc function. This periodic Sinc will be used to deduce the orthogonal locations, which are essential for the proposed user selection methods in this paper. The orthogonal locations can be calculated from the nulls of this periodic Sinc received signal power as follows. Only the symbols Φ_k and Φ_i in (11) will be replaced by $\Phi_{orthogonal}$ and Φ_{ref}, respectively.

$$\frac{M}{2}(\sin\Phi_{orthogonal}-\sin\Phi_{ref}) = \mp(1,2,3,\ldots,\frac{M}{2}) \tag{12}$$

$$\Phi_{orthogonal} = \sin^{-1}(\sin\Phi_{ref}\mp(1,2,3,\ldots,\frac{M}{2})\frac{2}{M}) \tag{13}$$

where $\Phi_{orthogonal}$ refers to the azimuth angle of the orthogonal locations, and Φ_{ref} is a reference angle used to initiate the creation of the orthogonal locations.

Equation (13) shows the available orthogonal locations in the system. As depicted in (13), the number of orthogonal locations is ($M/2$), which mainly depends on the number of used antennas at the BS. These orthogonal locations will be the basis of the proposed user selection methods. Figure 2 shows the deduced orthogonal locations' angles located on the received signal power.

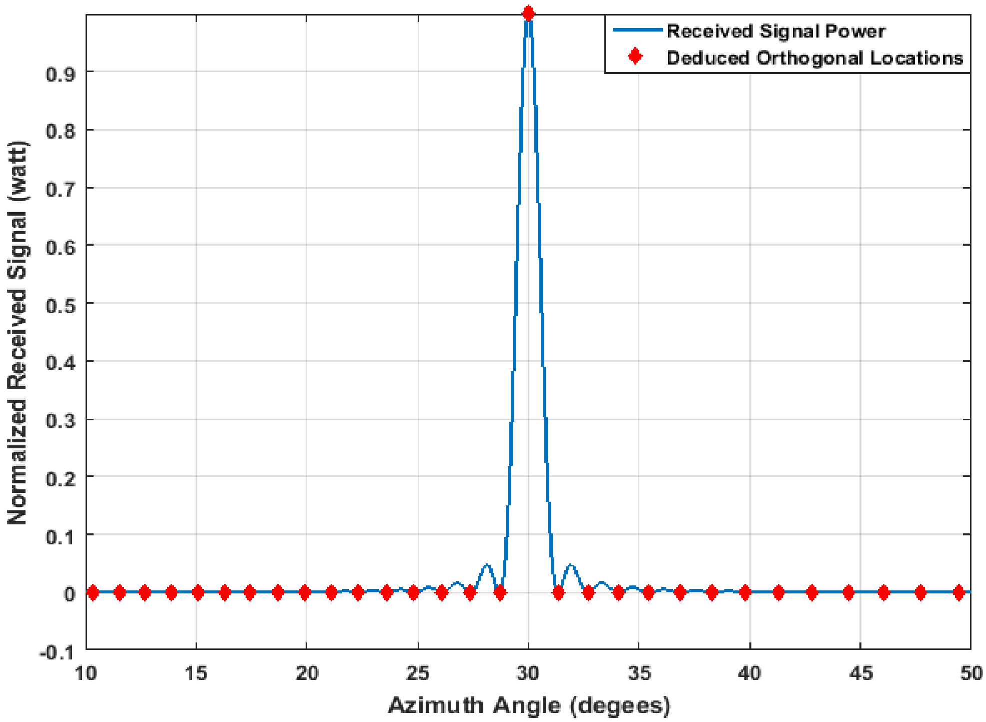

FIGURE 2. Orthogonal locations' angles located on the received signal power.

The next section will introduce the user selection technique and discuss some selection methods that will be used in the comparison with the proposed methods.

III. USER SELECTION TECHNIQUE

The user selection technique is used to separate the served users into groups as a way to serve the users in the system with improved performance. The users in each group will be serviced at the same resource block, and the users in the separated groups will be serviced in different resource blocks at different times or frequencies. The user selection methods divide the users into groups to reduce the interference between the served users in the same group so the system can serve all users with better performance.

The user selection method acts as an important technique in massive MIMO systems due to the continuously growing number of served users. The growing number of served users will lead to performance degradation in the system due to increased interference between the users. So, the user selection method is required to separate the users to be able to serve with the required good performance. The user selection method will improve the system performance but at the cost of some complexity due to the required multiplexing processes between groups [6], [7], [8], [9], [10], [27].

In general, the user selection method divides the users into groups based on some constraints related to the requirement in the system.

This section shows the principles of the RUS, SUS, and ICIBS methods that are used for comparison purposes with the proposed methods.

A. RANDOM USER SELECTION (RUS) METHOD

The Random User Selection (RUS) method divides the users into groups in a random manner. This method is only based on the maximum allowable number of users in each group. Algorithm 1 shows the RUS method [21].

Algorithm 1 The RUS Metho

% Set the maximum number of allowed users in each group
While (number of users in the group $<$ maximum number of allowed users)
% Select this user for this group
End while

B. SEMI-ORTHOGONAL USER SELECTION (SUS) METHOD

The Semi-orthogonal User Selection (SUS) method separates the users into groups based on the orthogonality level between the users. The orthogonality level between every two users will be based on the correlation between their channel vectors, as shown in (14). The orthogonality level between the users indicates the expected interference level between them. The users will be orthogonal when the orthogonality level equals zero. While the users will be semi-orthogonal when the orthogonality level equals a small value, as shown in equation (15). The users that act semi-orthogonal to each other will be served in the same group. Algorithm 2 shows the SUS method [21].

$$L_{ij} = \frac{\left|\boldsymbol{h}_i^* \boldsymbol{h}_j\right|}{\|\boldsymbol{h}_i\| \left\|\boldsymbol{h}_j\right\|} \tag{14}$$

Algorithm 2 The SUS Method

% Set the required semi-orthogonal level ($\propto$)
For all users do
% get the orthogonality level between the users
$L_{ij} = \frac{|h_i^* h_j|}{\|h_i\|\|h_j\|}$
% Select the users in each group
% Test this orthogonality level with the selected $\propto$
If ($L_{ij} \leq \propto$)
Serve this user in this group
Else
Serve this user in another group or another resource block
End If

Algorithm 3 The ICIBS Method

% Select the maximum allowable number of users in each group
While (number of users in a group > maximum number of users)
% do for all users
% test the ICI for the users
$\text{ICI} = \frac{1}{K-1} \sum_{\forall j \backslash i} \frac{|h_i^H h_j|}{\|h_i\|_2 \|h_j\|_2}$
$j^* = argmax$ (ICI)
*% Remove the user with indexj**
End while

$$L_{ij} \leq \propto \quad (15)$$

where, L_{ij} is the orthogonality level between users with indexes i and j. h_i and h_j is the channel vectors for users with indexes i and j. And $\propto$ is the required semi-orthogonality level between the users which will be selected with a small positive value.

C. INTER-CHANNEL INTERFERENCE BASED SELECTION (ICIBS) METHOD

The Inter-Channel Interference Based Selection (ICIBS) method separates the users into groups by removing the user with the maximum Inter-Channel Interference (ICI) from this group and servicing it in another suitable group. Separating the users with high ICI will reduce interference and improve spectral efficiency and overall system performance. The ICIBS is based on the ICI relation, as shown in (16). The ICIBS method starts by indicating the maximum number of required users in each group and then separating the users into groups based on the ICI relation, as explained in algorithm 3 [25].

$$\text{ICI} = \frac{1}{K-1} \sum_{\forall j \backslash i} \frac{|h_i^H h_j|}{\|h_i\|_2 \|h_j\|_2} \quad (16)$$

where ICI is the inter-channel interference.

IV. PROPOSED USER SELECTION TECHNIQUES

This section shows the three proposed user selection methods in this paper. Two of them, named MSUS and SNUS, depend mainly on the azimuth angles of the users and are based on some orthogonal locations that were deduced in the analysis part, and the third method, named ITUS based on a certain accepted interference threshold level.

Algorithm 4 The proposed MSUS Method

For all users do
% get the orthogonal locations
$\Phi_{orthogonal} = \sin^{-1}(\sin\Phi_i \mp (1, 2, 3, \ldots, \frac{M}{2})\frac{2}{M})$
% get the mean step value
$\Delta_i = \left|\Phi_{orthogonal}(i) + \Phi_{orthogonal}(i \pm 1)\right|$
$\Delta_{mean\ step} = \frac{\sum_{i=1}^{\left(\frac{M}{2}\right)} \Delta_i}{\left(\frac{M}{2}\right)}$
% Select the users in each group
% Select the users to be served with the intended user in the group
If $|\Phi_{user} - \Phi_{intended}| \geq \Delta_{mean\ step}$ Serve this user in this group
Else
Serve this user in another group or another resource block
End If

A. PROPOSED MEAN STEP USER SELECTION METHOD

The proposed Mean Step User Selection (MSUS) method separates the users into groups based on their azimuth angles. The selection in MSUS depends on the orthogonal locations in the system, which are deduced in the analysis part in (13). The MSUS method is based on the mean value of the steps between all orthogonal locations. This mean step value is calculated in two steps: first, by measuring the steps between all available orthogonal locations, then by getting the mean of all steps, as shown in (17) and (18).

$$\Delta_i = \left|\Phi_{orthogonal}(i) + \Phi_{orthogonal}(i \pm 1)\right| \quad (17)$$

$$\Delta_{mean\ step} = \frac{\sum_{i=1}^{(M/2)} \Delta_i}{(M/2)} \quad (18)$$

where Δ_i is the step between the adjacent orthogonal locations, and $\Delta_{\text{mean step}}$ is the mean of all steps.

The MSUS method will base on the mean step value ($\Delta_{mean\ step}$) to separate the users into groups. The users in each group will be separated from each other by an angular gap greater than or equal to the mean step value ($\Delta_{mean\ step}$). The MSUS method separates users into groups based on the condition in (19).

$$\left|\Phi_{user-i} - \Phi_{user-j}\right| \geq \Delta_{\text{mean step}} \quad (19)$$

where Φ_{user-i} and Φ_{user-j} are the azimuth angles of two users in the same group.

The separation of users into groups and the suitable gap between the users in each group will reduce the interference between the users and improve the performance of the system. Algorithm 4 shows the proposed MSUS method.

Algorithm 5 The proposed SNUS Method

For all users do
% get the orthogonal locations
$\Phi_{orthogonal} = \sin^{-1}(\sin\Phi_i \mp (1, 2, 3, \ldots, \frac{M}{2})\frac{2}{M})$
% get the second null azimuth angle
$\Phi_{second\ null} = \sin^{-1}(\sin\Phi_i \mp \frac{4}{M})$
% Select the users in each group
% Select the users to be served with the intended user
If $\Phi_{user} \geq \Phi_{second\ null}$
Serve this user in the same group
Else
Serve this user in another group or another resource block
End If

B. PROPOSED SECOND NULL USER SELECTION METHOD

The proposed Second Null User Selection (SNUS) method is also based on the users' azimuth angles, and the selection process depends on the deduced orthogonal locations. The SNUS method separates the users into groups based on the second null value, where the second null value means the second null from the user according to the received signal power curve. The second null value can be explained from the received signal power curve in Figure 2, where it means the second null or moving two nulls away from a certain user. The second null value will be measured from the relation of the orthogonal location in (13), as explained in (20).

$$\Phi_{second\ null} = \sin^{-1}(\sin\Phi_i \mp \frac{4}{M}) \tag{20}$$

where $\Phi_{second\ null}$ is the second null azimuth angle value.

The SNUS method separates the users into groups where the users in each group are selected with azimuth angles greater than or equal to the second null azimuth angle ($\Phi_{second\ null}$), as the condition in (21).

$$\Phi_{user} \geq \Phi_{second\ null} \tag{21}$$

The angular gap between users in the same group will reduce the interference between users and enhance the system's performance. Algorithm 5 presents the SNUS method.

C. PROPOSED INTERFERENCE THRESHOLD USER SELECTION METHOD

The proposed Interference Threshold User Selection (ITUS) method is based on a chosen interference threshold value. The ITUS method divides the users into groups, where the users in each group will affect each other by an interference value less than the chosen interference threshold value.

The interference threshold in the ITUS method can be chosen based on the system's requirements, such as keeping a suitable SE value. As the threshold value indicates the maximum accepted interference level in the system, it must be chosen as a small value to achieve a suitable required SE value. In this paper, the threshold value is chosen to be (P_S/M), where P_S is the normalized received signal power and M is the number of used antennas at the BS. With the large number of used antennas for massive MIMO, the threshold level is ensured to be a small value. The chosen threshold will achieve a better SE value compared with the other used selection methods, as shown in the simulation section.

Algorithm 6 The proposed ITUS Method

% assign the reference interference threshold value
$I_{threshold} = \frac{P_S}{M}$
For all users do
% get the interference power from other users
$I_{user} = \frac{1}{\sqrt{M}} \sum_{m=1}^{M} S_{user} e^{jm\pi(\sin\Phi_{user} - \sin\Phi_i)}$
$I_{user} = I_{user} * conjugate(I_{user})$
% Select the users in the group
% Select the users to be served with the intended user
If $I_{user} \leq I_{threshold}$
Serve this user in the same group
Else
Serve this user in another group or another resource block
End If
Where, $I_{threshold}$ is the interference threshold and I_{user} is user interference.

The separation of users into groups, where the users in each group have an interference level less than the chosen interference threshold value, will reduce interference between the users and improve the system's performance. Algorithm 6 presents the ITUS method.

The proposed user selection methods are evaluated through the massive MIMO system. The system performance is evaluated in terms of the SE and the sum SE of the system concerning the number of separated groups in each proposed method.

$$SE = \log_2(1 + \frac{P_s}{N + I_{user}}) \tag{22}$$

$$Sum\ SE = \sum_{i=1}^{K} SE_i \tag{23}$$

where N is additive white gaussian noise power.

V. SIMULATIONS AND RESULTS

This section shows the simulations and the results of the massive MIMO system with and without user selection methods. During the simulations, the massive MIMO is assumed with (M =100) antennas at the BS, which will be used to serve single-antenna users. The number of users will be changed during the simulations, and the locations of users will be randomly chosen. The simulations start by evaluating the system performance with a growing number of served users in the system and show the resulting performance degradation. Then the system performance is evaluated when using the proposed user selection methods. The performance of the proposed user selection methods (MSUS, SNUS, and ITUS) will be compared with the system without using a selection method and with other user selection methods: RUS, SUS, and ICIBS methods. The simulations will prove that the

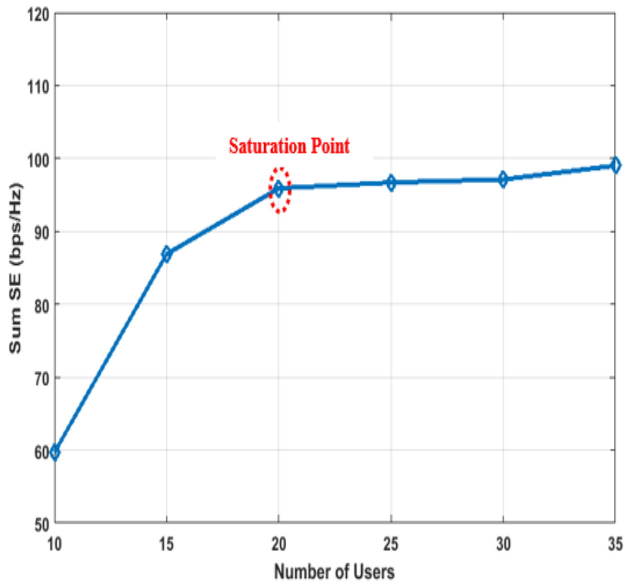

FIGURE 3. System performance with an increasing number of served users.

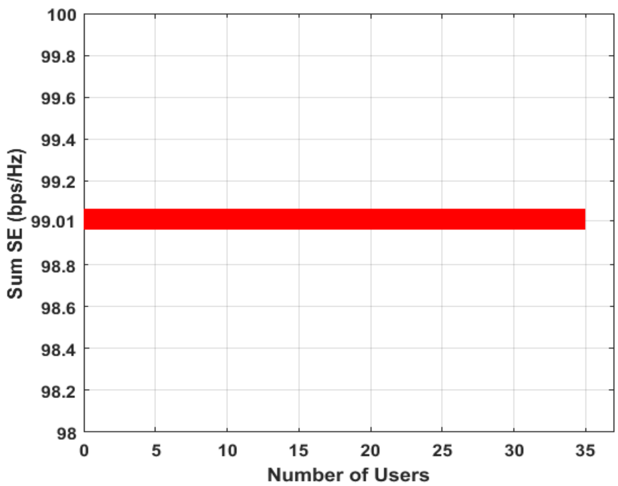

FIGURE 4. The system performance without using any selection method.

proposed user selection methods will improve the system performance as a function of the sum SE. Each user selection method will divide the users into separated groups, while each group will be served in a different resource block in a way to reduce the interference between users in the same group and enhance the system performance. Each method makes a tradeoff between the number of separated groups and the system's performance. The simulations and the results are performed using the MATLAB R2016a software package.

A. SYSTEM PERFORMANCE WITH GROWING SERVED USERS' NUMBER

This section shows the performance of a massive MIMO system when increasing the number of users in the system.

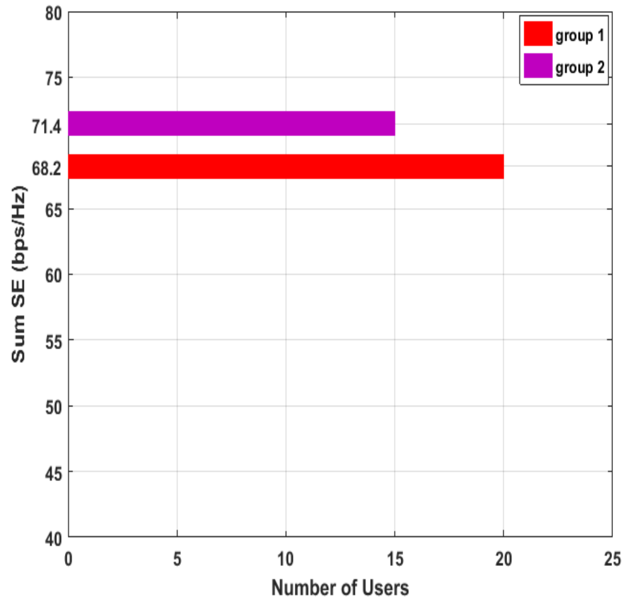

FIGURE 5. System performance with RUS method.

The performance here is evaluated based on the sum SE as a function of the number of served users, as shown in Figure 3. As shown in Figure 3, firstly, the sum SE increases with increasing the number of served users. Then at a certain number of users, approximately 20 served users, the sum SE starts to stabilize around a certain level, as shown in the figure. This stable region refers to the saturation region, where the saturation region refers to the region of stabilization of sum SE around a certain level regardless of growing the served users' number, and the starting point of this region is referred to as a saturation point. The saturation point here is at 20 users, and the sum SE stills near 100 bps/Hz through the saturation region. The sum SE is still near the value of 100 with increasing the number of users from 20 to 35, which means a high degradation of the system performance.

As dedicated in Figure 3, the system performance begins to degrade when the number of users exceeds the saturation point, exceeding 20 users. Any increase in the number of served users after this saturation point will cause degradation in the performance of each user and the whole system performance.

After this saturation point, a certain user selection method must be used to separate the users into groups to avoid performance degradation and serve the users with better performance.

The next subsections show the performance of the system when using different user selection methods. It starts by evaluating the performance when using RUS, SUS, and ICIBS methods, then evaluates the performance using the proposed selection methods. The results of the proposed methods will be compared with the case without selection and with the RUS, SUS, and ICIBS methods.

For the comparison, assume there are 35 users at some random locations and evaluate the performance of each case

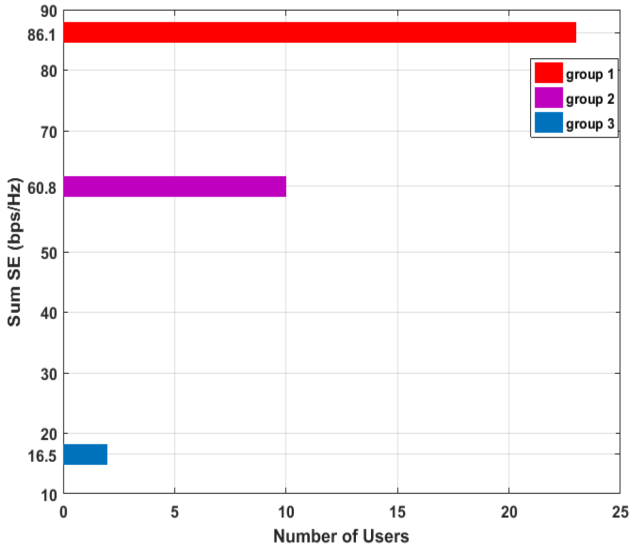

FIGURE 6. System performance with the SUS method.

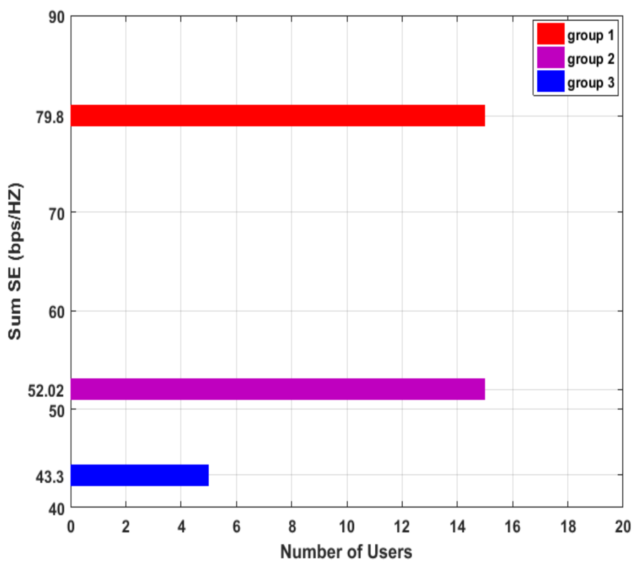

FIGURE 7. System performance with ICIBS method with 15 selected. Users.

based on the number of separated groups and the resulting sum SE.

For the case without using any selection method, all users will be served as one group without separation but with degraded performance. Figure 4 shows that the case without selection method serves all 35 users as one group with a sum SE of 99.0160 bps/Hz.

B. SYSTEM PERFORMANCE WITH RUS METHOD

This section shows the system performance when using the RUS method. The RUS method separates the users into groups randomly based only on the required number of users in each group. Here, the RUS method is based on

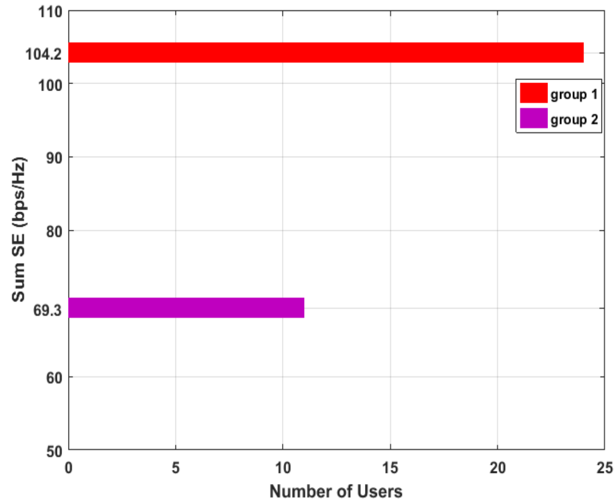

FIGURE 8. System performance with the proposed MSUS method.

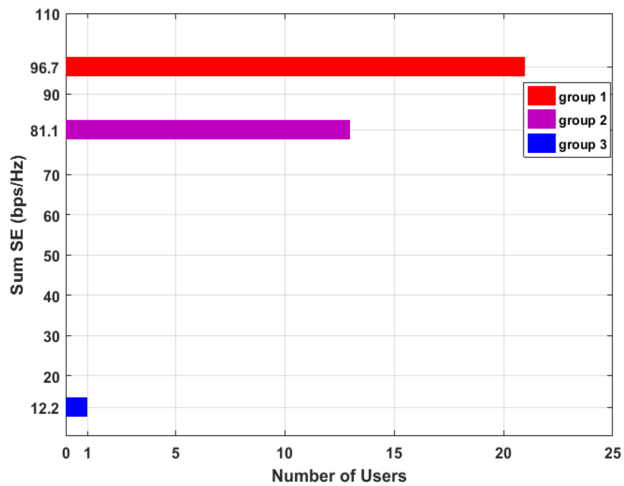

FIGURE 9. System performance with the proposed SNUS Method.

the saturation value of 20 users, as explained previously in Figure 3. It separates the users into groups with a constraint that each group user's number is equal to or less than 20 users.

Figure 5 shows that the RUS separates the users into two groups. The first group contains 20 users with a sum SE of 68.2203 bps/Hz, and the second group contains 15 users with a sum SE of 71.4772 bps/Hz. So this RUS method yields a sum SE of 139.6974 bps/Hz for the system.

C. SYSTEM PERFORMANCE SUS METHOD

This section shows the system performance using the SUS method. The SUS separates the users into groups based on the semi-orthogonal levels between the users, as explained previously in Algorithm 2. Here, the semi-orthogonal level ($\propto$) is used at 0.1.

Figure 6 shows that the SUS separates the users into three groups. The first group contains 23 users with a sum SE of

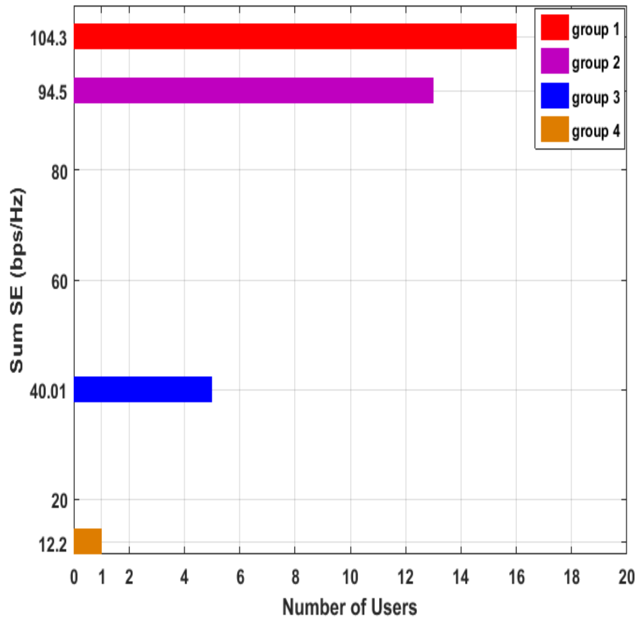

FIGURE 10. System performance with the proposed ITUS method.

86.1729 bps/Hz, the second group contains 10 users with a sum SE of 60.8214 bps/Hz, and the third group contains 2 users with a sum SE of 16.5739 bps/Hz. So, the SUS method results in a sum SE of 163.5682 bps/Hz for the system.

D. SYSTEM PERFORMANCE WITH ICIBS METHOD

This section shows the system performance using the ICIBS method. The ICIBS method divides the users into groups by separating the user with the high ICI effect on other users, according to Algorithm 3.

Here, the maximum number of users in each group is used to be equal to 15 users. Figure 7 shows that the ICIBS separates the users into three groups. The first and second groups contain 15 users with a sum SE of 79.8581 bps/Hz and 52.0268 bps/Hz, respectively, and the third group contains 5 users with a sum SE of 43.3109 bps/Hz. So, the ICIBS yields a sum SE of 175.1957 bps/Hz for the system.

E. SYSTEM PERFORMANCE WITH PROPOSED MSUS METHOD

Here, the system performance is evaluated when using the proposed MSUS method. The MSUS method separates the users into groups based on algorithm 4. The MSUS method divides the served users into two groups, as shown in Figure 8. The first group has 24 users with a sum SE of 104.2872 bps/Hz, while the second group has 11 users with a sum SE of 69.3774 bps/Hz. The MSUS method yields a sum SE of 173.6645 for the whole system.

F. SYSTEM PERFORMANCE WITH PROPOSED SNUS METHOD

Here, the system performance is evaluated when using the SNUS method. The SNUS method separates the users into groups based on algorithm 5. The SNUS method separates the users into three groups, as shown in Figure 9. The first group has 21 users with 96.7573 bps/Hz, the second group has 13 users with 81.1970 bps/Hz, and the third group has one user with 12.2880 bps/Hz. So the SNUS provides a sum SE of 190.2422 bps/Hz for the system.

G. SYSTEM PERFORMANCE WITH PROPOSED ITUS METHOD

Here, the system is evaluated when using the proposed ITUS method. The ITUS method separates the users into groups based on the chosen threshold value. The threshold value is used equally (P_S/M)., where is P_S the normalized received signal power and M is the number of used antennas which equals 100.

The ITUS method separates the users into four groups, as explained in Figure 10. The first group has 16 users with a sum SE of 104.3369 bps/Hz, and the second group has 13 users with a sum SE of 94.5799 bps/Hz. The third group has 5 users with a sum SE of 40.0162 bps/Hz, and the fourth group has one user with a sum SE of 12.2880 bps/Hz. The ITUS method provides a sum SE of 251.2210 bps/Hz for the system.

H. COMPARISON BETWEEN THE PROPOSED USER SELECTION METHODS WITH OTHER DIFFERENT SELECTION METHODS AND WITHOUT SELECTION METHOD CASE

This subsection compares the results of the three proposed user selection methods with the case without using a user selection method and with different selection methods: RUS, SUS, and ICIBS. This comparison is shown in Figure 11 and also in Table 1. Figure 11 shows the comparison as a function of the sum SE of the whole system in each case. Table 1 shows the comparison in terms of the number of separated groups in each case, the sum SE of the system in each case, and the sum SE improvement of each selection method case from the case without selection.

According to the comparison in Table 1, the system, without using any user selection method, serves all the users as one group and has less performance with a sum SE of 99.0160 bps/Hz. The system with the RUS method divides the users into two groups and provides a sum SE of 139.6974 bps/Hz, with a 41.08% improvement from the case without selection. The system with the SUS method divides the users into three groups and provides a sum SE of 163.5682 bps/Hz, with a 65.19% improvement from the case without selection. The system with the ICIBS method divides the users into three groups and provides a sum SE of 175.1957 bps/Hz, with a 76.94% improvement from the case without selection.

The MSUS divides the users into two groups as a way to reduce the number of served users and the interference strength in each group. The MSUS yields a sum SE of 173.6645 bps/Hz, with a 75.39% improvement from the case without selection. The SNUS separates the users into three

TABLE 1. Comparison of the proposed user selection methods with the case without selection and with the RUS, SUS, and ICIBS methods.

	Number of Separated Groups	Sum SE of System (bps/Hz)	SE Improvement than without Selection Method
Without Selection Method	1	99.01	-
RUS Method	2	139.69	41.08%
SUS Method	3	163.5682	65.19%
ICIBS Method	3	175.1957	76.94%
Proposed MSUS Method	2	173.66	75.39%
Proposed SNUS Method	3	190.24	92.13%
Proposed ITUS Method	4	251.22	153.71%

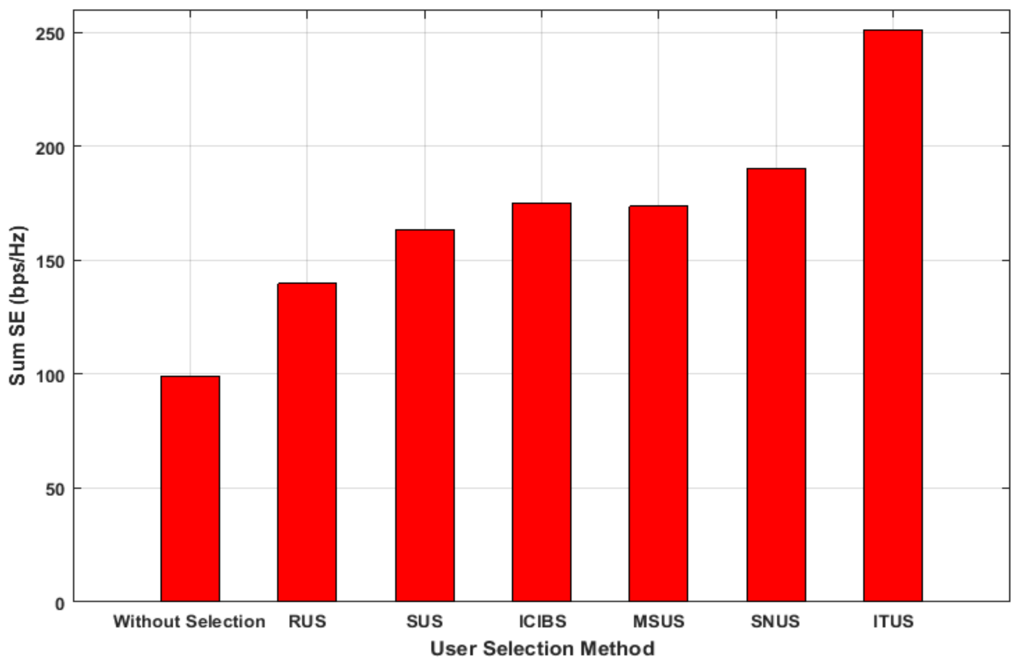

FIGURE 11. System performance for the comparison between the proposed methods and other methods.

groups to reduce the number of users and interference in each group. The SNUS yields a sum SE of 190.2422 bps/Hz, with a 92.13% improvement from the case without selection. The ITUS separates the users into four groups, and it also aims to reduce the number of users and interference in each group. The ITUS yields a sum SE of 251.2210 bps/Hz, with a 153.71% improvement from the case without selection.

As explained from the comparison, all cases using the user selection method provide better performance than the case without the user selection method. All proposed user selection methods provide better performance than the RUS and SUS methods. The ICIBS method provides better performance than the proposed MSUS method due to the greater number of separated groups. But the ICIBS provides less performance than the proposed SNUS and ITUS methods. For the proposed user selection methods, the ITUS method has the best performance among the others, followed by the SNUS method, and finally the MSUS method. On the other side, the MSUS method has the fewest groups compared to the others, followed by the SNUS method, and finally the ITUS method. As a result, the proposed methods trade off the number of separated groups and the resulting sum SE.

For another random users case to be discussed, assuming there are 40 randomly located users and examining their performance using the different presented selection methods.

TABLE 2. Comparison of the proposed user selection methods with the case without selection.

	Number of Separated Groups	Sum SE of System (bps/Hz)
Without Selection Method	1	81.4
RUS Method	2	148.2934
SUS Method	3	158.4922
ICIBS Method	3	192.2406
Proposed MSUS Method	3	214.159
Proposed SNUS Method	4	247.0729
Proposed ITUS Method	4	274.7822

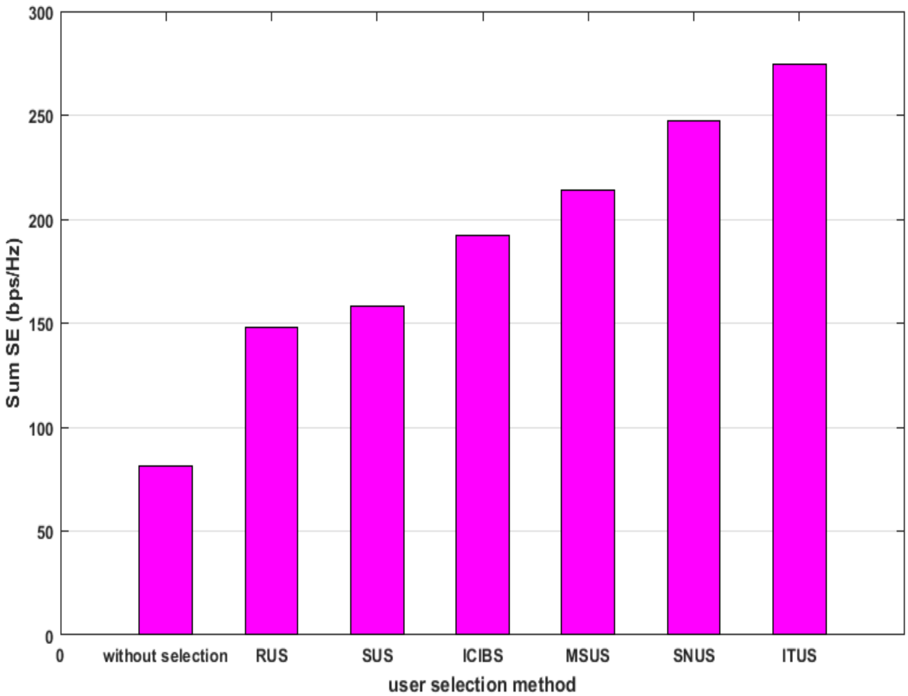

FIGURE 12. System performance for the comparison of the newly discussed case.

Table 2. and Figure 12 show the performance of this newly discussed case with a comparison with the different user selection methods. As shown, there is a tradeoff between the number of separated groups and the sum SE in the different user selection methods. The proposed selection methods still provide better performance than the case without selection and the case of RUS and SUS methods. The proposed SNUS and ITUS methods provide better performance than the ICIBS method. Also, here the MSUS provides a better performance than the ICIBS because the MSUS, in this case, divides the users into the same number of groups as the number of groups in the ICIBS method.

VI. CONCLUSION

This paper discussed the importance of using user selection methods in case of growing the number of users in the system to enhance the system performance. It proposed three user selection methods named "MSUS, SNUS, and ITUS," all aimed to separate the users into groups to be served with a better performance. The performance of these three proposed user selection methods was compared with the case without any selection method and with other user selection methods: RUS, SUS, and ICIBS. With 100 antennas at the BS, the system performance was evaluated when growing the number of served users, and the saturation region was started at 20 users where the sum SE remained near 100 bps/Hz regardless of any more increases in the number of users, so the user selection methods were essential to be used. The system performance with the proposed user selection methods was evaluated based on the resultant sum SE and compared with the RUS, SUS, and ICIBS methods and the case without any selection method. The results showed that all proposed user selection methods enhanced the system performance. The proposed MSUS, SNUS, and ITUS methods improved the sum SE with ratios of 75.39%, 92.13%, and 153.71% than the case without selection, respectively. The proposed SNUS and ITUS methods enhanced the sum SE more than the compared RUS, SUS, and ICIBS selection methods. And the MSUS method improves the performance more than the RUS and SUS methods, but the MSUS method provides better performance than the ICIBS only if the MSUS divides the users into groups more than or equal to the number of groups in the ICIBS method.

The proposed methods made a tradeoff between the number of separated groups and the sum SE, so they traded off between the multiplexing complexity and the system performance. The MSUS has fewer groups than the SNUS and ITUS methods, and the ITUS has more groups. On the other side, the ITUS has the best performance enhancement than the MSUS and SNUS methods, while the MSUS has less performance enhancement than the two other methods.

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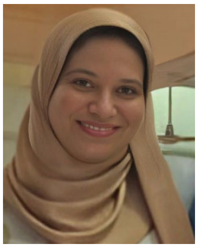

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