Multiuser Scheduling in 3GPP LTE-A Uplink Non-Stand-Alone Cellular Network with Virtual MIMO

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Abstract—New 5G architecture gives access to New Radio (NR) with co-exist LTE. 3GPP LTE-A transition towards NR is a wireless technology that is widely employed in the cellular mobile network to support significantly high volume traffic. In this paper, we propose the best N-subset reduction and a modified RME algorithm (BNSRME) as an uplink multiuser scheduler. It is responsible for allocating resources among the active users in the most effective manner. The N-subset reduction method selects the best chunk of continuous resource blocks from the available system bandwidth. Users are assigned chunks based on channel-dependent selection and utility function. The BNSRME scheduling algorithm aims to optimize performance, spectral efficiency, and allows multiuser scheduling where multiple active users are allocated the same time-frequency resources. We consider the threshold cap $\text{SNR}_T$ to improve sensitivity quality for satisfactory users. The approach is MU scheduling which will be the most commonly deployed in non-stand-alone (NSA) 5G uplink cellular network. The result shows that the system spectral efficiency improves by 32.55 % by using the proposed multiuser algorithm compared to single user scheduling in an uplink. It has been shown that its performance can be further improved by using the MU-MIMO system.

Keywords LTE, Minimum Mean Square Error (MMSE), resource block allocation, Single Carrier Frequency Division Multiple Access (SC-FDMA), single-user scheduling, spectral efficiency, uplink multi-user scheduling, subcarrier spacing (SCS).

1 Introduction

3GPP standard will contribute towards the roll out of 5G mobile communication to enhance the dynamic capacity of LTE. It utilizes maximum resource blocks (RBs) and spectral bandwidth. Today, almost every community and industry have interest to use 5G revolution. A 5G NR technology is anticipated to high data rate, reliability, low latency, online gaming and number of heterogenous connections. It supports connectivity in coordinate multipoint (COMP) transmission and heterogeneous network. It improves QoS and inclusion at a cell edge which can benefit to the user experience.

Wireless 4G/5G, LTE employs localized single carrier frequency division multiple access (SC-FDMA) as air interference for uplink (UL) transmission and is referred to as the DFT-Spread-OFDMA which is a modified form of OFDMA [1],[2]. OFDMA has been opted in downlink (DL) transmission since it is robust in nature to handle multipath fading. It is also adopted in several wireless generations due to multiuser (MU) diversity gain and frequency diversities [3]. A majority of the cellular operators in the world have deployed LTE standards, most recently referred to as release16. 5G NR employs 15, 30, 60 KHz subcarrier spacing (SCS) in frequency range1 (FR1) band. SCS 60 KHz and 120 KHz are used as mmWave FR2 bands [4]. Thus, LTE can easily migrate to NR at 15 KHz subcarrier spacing. The total available bandwidth is divided into multiple subcarriers that can be allocated to different users, depending on the time-varying channel condition. Each Resource Block (RB) contains 12 consecutive subcarriers and 6-7 symbols which represent a minimum basic allocated unit for data transmission. The scheduler assigns RBs to the individual user at every scheduling interval. The NR and LTE both transmits 14 symbols in 1 ms slot for 15 KHz subcarrier spacing.

5G remote access involves 5G NR and LTE evaluation. The SCS options are close to 15 KHz as given in Table III. This is considered as a baseline for 5G NR by 3GPP. As NR waveform is scalable so it allows subcarrier spacing ranging from at least 3.75 KHz ($n = -2$) to 480 KHz ($n = 5$). The current (2G/3G/4G) cellular system operates blow 6GHz. 5G new radio (NR) is addressing new spectrum allocation on global and regional countries. The technology necessity will unleash new frequencies range from 1 GHz to 100 GHz. The integration of LTE and 5G NR evolution will be used to fulfill high load traffic requirement.

Although most of the work has been focused on the downlink in the past, the SC-FDMA in uplink is used to maximize spectral efficiency (SE) and throughput by considering the continuous RB constraint. SC-FDMA is preferred due to low characteristics of PAPR. It is the lower value of PAPR that helps to save the battery life of a mobile. Multiuser (MU) diversity gain is activated due to special multiplexing over high-quality transmission channel conditions [5], [6]. At deep fade channel conditions, the RBs are not allocated to users. An opportunistic scheduling system should be designed in such a way, so as to maximize the overall throughput of the user. It may be biased and unsymmetrical for different users. The level of satisfaction and efficiency among users is not the same. The scheduling methodology has increased benefits that are similar to base station (BS) and have a higher channel status. The Heuristic
algorithm allows the allocation of resources for each user is based on user requirements, current satisfaction status, and channel quality status [7]. The estimation of data rate to be transmitted, the number of resources needed, and the priority given to each user. At a current travel time interval ($TTI_{curr}$), these are needed to satisfy the users professional fair (PF) allocation. This form of fairness may not be adequate for latency constraint applications. In such cases, the largest weighted delay first (LWDF) is updated, which is especially appropriate for real-time services without delay.

In this paper, a novel best N-subset reduction and modified recursive maximum expansion (BNSRME) algorithm is used for MU uplink scheduling. In channel time variation condition, MU scheduling has a flexible allocation of all continuous RBs to a user as a chunk. The scheduling also ensures, that at most one chunk is assigned to an SU. In relation to the sum rate utility maximization, the constraints are considered which maximize the allocation of RBs. It helps to improve sensitivity quality for satisfactory users. This is a central function in LTE data transmission traffic handling. Each RB comprises a collection of adjacent sub-carriers and constitutes a minimum allocation unit. The SU transmit data streams on assigned RBs are point-to-point single or multiple antenna links between base station (BS) and a single UE. The MU BNSRME scheduling algorithm provides an essential degree of freedom for the resource selection to users. The resources are RBs, power levels, modulation and coding (MCS). The users are assigned chunks based on channel-dependent selection and also the utility function to allocate chunks of RBs to the users. The BNSRME scheduling algorithm focuses on maximizing throughput, and optimizing spectral efficiency. However, the multiple users are permitted in the same time-frequency resources. In MU scheduling, the best users are selected based on low-level interference calculation and SINR.

2 Related work

In recent times, resource allocation in uplink is a part of extensive research due to less exposure in past literatures. The efficient allocation of resources among the UEs under good channel conditions with a max-min and delay-fairness algorithm was presented in [8]. In [9], author introduced a 5G NR physical layer framework. He applied the idea of effective short packet communication and bandwidth for meeting the resource allocation and UE QoS constraint targets. The comparative tradeoff for energy efficiency, spectral efficiency and queue size was proposed in [10]. The scheduler framework where ensures the guaranteed QoS for joint traffic under ergodic capacity in densely 5G network was proposed in [11]. Employing beam-forming optimization and resource allocation problems to optimize the minimum transmission rate for downlink and uplink. Although to match the demand of users in poor channel conditions were addressed in [12], [13]. The performance of the system was measured on the SU and MU by employing the differential feedback-based higher layer-configured subband scheme which was proposed in [14]. The transmission path assignment in full-duplex, user pairing and power allocation was considered in [15], which was formulated as a joint max-min fairness rate. The maximization problem is NP-hard. In [16], the author investigated the possible combination of an antenna selection and user scheduling sets to maximize the weighted sum rate with Bernoulli random process probability. In [17], the ergodic achievable rate was observed during the full-duplex mode of DL and UL. It used the conventional half-duplex data transmission based on the channel state indicator (CSI) feedback [18]. In [19], the author demonstrated the radio resource management which plays an important role in increasing spectral efficiency capacity in joint multi-cell reception over single-cell reception. A novel resource allocation scheme based on the bidding mechanism was proposed in [20], [21], to accomplish maximum network utility. Here, the packet drop rate was minimized under the Lyapunov optimization method. A multi-cell cooperation technique was used in [22]-[24], with a joint resource allocation algorithm to achieve overall system throughput with MMSE equalization for dynamic user grouping. Considering better channel conditions, the authors prioritized a few users and tried to achieve fairness amongst the users but consequently, the overall performance degraded as mentioned in [25], [26]. In [27], the author demonstrated that all the users were first grouped in a cell and scheduled after precoding based on the low dimension effective channel. To improve resource allocation efficiency and user satisfaction based on a chunk-based frequency domain, a packet scheduling algorithm was described in [28]. In [29], the authors proposed adaptive proportional fair scheduling algorithms, where all the users achieved fairness. The base station dynamically adjusted subscribers’ scheduling priorities in a real-time-service.

All of these works validate the significant improvement in SE, throughput and they eventually improve the overall performance of UL scheduling system.

2.1 Contribution

In this paper, we investigated different scheduling algorithms and subsequently compared these algorithms with the proposed novel algorithm. Specifically, our main contributions are as follows:

1) To perform the MU uplink scheduling, we proposed the best N-subset reduction method and modified RME algorithm (BNSRME). The best N-subset reduction method helps to identify the best of best large size
continuous chunk of RBs. It is called the best model $M_{\text{best}}$. Then we find the subsequent next best chunk of RBs until the last available RB. These RBs are used in the modified RME algorithm to select the best RB by using a searching method. So, all searched models are arranged as RB-UE mapped pairs in a linear matrix with a Utility function. This allocates the best chunk of RBs to the highest priority predicator UE and so on.

2) A utility function as an optimization model is considered for scheduling. A fixed power is allocated to the UE. To improve users satisfaction and system performance, we considered a threshold limit (BNSRME-TH) which is based on SNR values. The sum rate utility maximization constrains are considered to optimize the RBs allocation and to increase the level of sensitivity for satisfactory users.

3) The simulation is accomplished with $2 \times 4$ and $2 \times 8$ MMSE - receiver antenna models and it compared with the proposed method with different scheduling algorithms. The simulation is also performed for different numerology ($\mu = 1, 2, 3$) taking NSA architecture into account. The NSA demonstrates the transition from LTE-A to NR. New 5G architecture gives access to NR with co-exist LTE in the case of NSA.

2.2 Structure

The remainder of this paper is organized as follows. Section 3 describes system model, problem formulation is discussed in Section 4, Section 5 describes the existing scheduling scheme, the proposed scheduling algorithm with RB allocation methods is described in Section 6, the simulation of the proposed algorithm and its discussions are presented in Section 7. The conclusions are drawn in Section 8.

3 System model

A UL cellular system is considered as shown in Fig. 1. It has total $N$-RBs of available spectrum bandwidth. Each RB unit consists of 12 subcarriers and 6-7 symbols in the frequency-time domain. The allocation of RBs to UE is based on channel conditions. Assume $K$ independent users in an uplink MU-MIMO system. Consider that each base station has $R_{b}$ receiver antennas and each UE has $T_{x}m \geq 1$ transmit antennas. In a cell, more users are latched onto base stations as active members. Therefore, the received signal from the $k$th UE to a base station is processed with $M$-point DFT on each UL. Let $x_{k} \in \mathbb{C}^{T_{x}m \times 1}$ be the transmit signal from $k$th user, $k = \{1, 2, \cdots, K\}$. In cell, $Y_{A} \in \mathbb{C}^{R_{b} \times 1}$ based on a wireless channel which represents the UL received signal at $BS_{A}$. The channel gain between the $k$th UE and BS is denoted by $H_{k}^{UL} \in \mathbb{C}^{T_{x}m \times R_{b}}$. The received UL signal $Y_{A}$ at $BS_{A}$ can be modeled as:

$$Y_{A} = \sum_{k=1}^{K} H_{k}^{A} x_{k} + z_{A},$$

(1)

$$Y_{A} = \sum_{k=1}^{K} H_{k}^{A} x_{k} + \sum_{l=1}^{L} \sum_{q=1}^{K_{l}} H_{lq}^{A} x_{lq} + z_{A},$$

(2)

$$Y_{A} = H_{k}^{A} x_{k} + \sum_{l=1}^{L} \sum_{q=1}^{K_{l}} H_{lq}^{A} x_{lq} + z_{A},$$

(3)

where, $z_{A} \sim \mathcal{C}\mathcal{N}_{0}(m_{A}, \sigma_{UL}^{2})$ is an independent additive noise in the receiver and it is modeled as a zero-mean complex Gaussian vector and variance $\sigma_{UL}^{2}$. Therefore, $a_{UL}^{2} I_{m A} \in \mathbb{C}^{T_{x}m \times R_{b}}$ represents a positive semi-definite spatial co-relation and covariance matrix due to zero mean. Therefore, inter-cell interference at BS is considered and denoted by $z_{A} + I_{0}$. Obtained interference as an additional source of noise in hardware can be optional in design. Potential interference from the received signal should be subtracted before processing of the desired signal.

![Fig. 1. UL Cellular system with NSA](image-url)
\[ D_{Ak}^H Y_A = D_{Ak}^H H_{Ak}^A x_{Ak} + D_{Ak}^H H_{Ak}^A x_{Ak} + \sum_{q \neq k} D_{Ak}^H H_{Ak}^A x_{Ak} + \sum_{l=1}^L \sum_{q=1}^{K_l} D_{Ak}^H H_{1q}^A x_{lq} + D_{Ak}^H z_A \]

\[
\sum_{\omega=1}^\infty D_{Ak}^H H_{Ak}^A x_{Ak} + \sum_{l=1}^L \sum_{q=1}^{K_l} D_{Ak}^H H_{1q}^A x_{lq} + D_{Ak}^H z_A
\]

Intra cell interference

Inter cell interference

Noise

The selection of the combining vector is based on the estimated channel and the corresponding uplink SEs. The UE \( E_k \) in cell \( A \), transmits a random data signal \( x_{Ak} \sim N_c(0, P_{Ak}) \) for \( A \in \{1, \cdots, L\} \). The variance \( P_{Ak} \) represents the transmit power i.e. the average energy per sample channel capacity of the MU-MIMO system.

### 3.1 Pilot reference model

UL pilots and ZC sequence are two cyclic shift sequences which are useful to reduce inter signal interference (ISI) in transmission. The MMSE estimation of the channel response \( H_{Bq}^A \) based on a received pilot signal \( X_A^P \) is \( \hat{H}_{Bq}^A \) which minimizes the mean-squared error (MSE) \( E\{\|H_{Bq}^A - \hat{H}_{Bq}^A\|^2\} \) and is given by:

\[
\hat{H}_{Bq}^A = \sqrt{P_{Bq}} F_{Bq}^A W_{Bq} X_A^P.
\]

where, \( X_A^P \) is that BS \( A \) use to estimate the channel response. Hence, \((B,q) \in P_{Ak}\) implies that UE \( E_q \) in cell \( B \) utilizes the same pilot as UE \( E_k \) in cell \( A \).

where,

\[
W_{Bq}^A = \left( \sum_{(b',q') \in P_{Bq}} P_{b'q'} \tau_{b'q'} F_{Bq} + \sigma_0^2 I \right)^{-1}.
\]

The channel error \( \hat{H}_{Bq}^A = H_{Bq}^A - \hat{H}_{Bq}^A \) has a correlation matrix \( C_{Bq}^A = E\{\hat{H}_{Bq}^A (\hat{H}_{Bq}^A)^H\} \) given by:

\[
C_{Bq}^A = F_{Bq}^A - P_{Bq} \tau_p F_{Bq}^A W_{Bq}^A F_{Bq}^A.
\]

This provides an MMSE estimator of the channel from any UE to BS \( A \). The good quality estimation represented by small MSE that is \( E\{\|H_{Bq}^A - \hat{H}_{Bq}^A\|^2\} = tr(C_{Bq}^A) \) for MMSE, where, \( W_{Bq}^A \) is an inverse normalized correlation matrix and \( F_{Bq}^A \) is a special correlation matrix of the channel to be calculated.

The interference vanishes and does not affect the channel error when the pilot sequences are orthogonal \( X_A^P X_A^P = 0 \).

### 3.2 Channel Model

The UL ergodic channel capacity of UE \( E_k \) in cell \( A \) is lower bounded by \( C_{lk}^U \) information rate that can be transmitted over the BW and is given by:

\[
C_{lk}^U = \Gamma E\{\log_2(1 + SINR_{lk}^U)\}
\]

The MMSE estimator minimizes the MSE of channel estimates and is given in (9).

In this equation \( SINR_{lk}^U \) is the UL instantaneous SINR. As shown in Figure 2, the random variance that takes a new independent realization in each coherence block \( \tau_e = T_C \times B_C \). The fraction of samples per coherence block in the UL data \( (r_u, \tau_e) \) is given as prelog factor \( \Gamma = \frac{r_u}{\tau_e} \). Since \( \tau_u = \tau_c - \tau_p - \tau_d \) where \( \tau_p \) is the pilot sequence which reduces the pilot overhead and \( \tau_d \) is the DL data. To increase the prelog factor, the length of \( \tau_p \) or the number of samples in DL can be reduced. Note that \( SINR_{lk}^U \) depends on \( D_{Ak}^H \) and therefore, each combining vector can be tailored to its related UE.

![Fig. 2. Coherence block](image)

### 4 Problem formation

The optimization problem of resource allocation scheduling for each user in the frequency domain is considered. It is a utility maximization problem constraints in single-cell uplink SC-FDMA for a given scheduling interval. Intern, it is subject to rate constraints. Let \( N_{bb} \) be the total number of resource blocks in the cell to be assigned to \( k \) users. Considering \( K \) is the number of UEs in the given cell \( A \), the \( N_{RB(s)} \) is the chunk subset of resource blocks in the system. Here, \( N_{RB,s,k} \) subset RBs is assigned to the \( k^{th} \) user and \( P_k \) is the instantaneous transmission power of user \( k \in K \). The utility-based optimization is modeled as:

\[
SINR_{lk}^U = \frac{P_{lk}(D_{Ak}^H H_{Ak}^A)^2}{\sum_{l=1}^L \sum_{q=1}^{K_l} P_{lq} \left( \| (D_{Ak}^H H_{Ak}^A) \|^2 \right) - D_{Ak}^H D_{Ak} \left( \sum_{l=1}^L \sum_{q=1}^{K_l} P_{lq} \left( \hat{H}_{lq}^A (\hat{H}_{lq}^A)^H \right) \right) + \sigma_{UE}^2 l_{mA}^2}}
\]
subject to:

\[
S_{nk}^n - S_{nk}^{n+1} + s_{nk}^{N_{RBs}} \leq 1 \quad n = \{1, 2, \ldots, N_{RB}\},
\]

The optimization problem can be minimized by the proposed BMSRME algorithm.

5 Scheduling scheme

5.1 Modified Largest Weighted Delay First (MLWDF)

The MLWDF scheduling algorithm is especially appropriate for real-time services without delays. The PF satisfies user requirements fairly but does not perform satisfactorily in the latency constraint applications. In such cases, the MLWDF is used [30]. In MLWDF user \( k \) selects to transmit resources in \( RB_k \) in \( TTI_n \) as shown in (14):

\[
i = \arg \max_{k=1}^{K} \left\{ \frac{r_{lk,N_{RB,k}}[n]}{R_k[n-1]} d_{nk}^h[n] \right\},
\]

where, \( d_{nk}^h[n] \) is a current delay i.e. head of line of the oldest packet for user \( k \).

5.2 Heuristic resource allocation

The heuristic framework is an optional solution based on the "partition to overcome thought". It considers the users channel quality status, their requirements, and current satisfaction status for resource allocation. To satisfy maximum users, it has done the proper estimation of the transmitted data rate and required resources allocation at the time of each scheduling. The number of resources \( N_{RB,k} \) and data rate \( \Delta r_k[n] \) for each user \( k \) in \( TTI_{cur} \). It is calculated based on channel quality condition, user requirement, traffic conditions and QoS requirements. If the resource block assignment \( N_{RB,k}[n] \) is higher, the data rate of the user is higher [31], [32].

We define \( P_k \) as a priority list of users; \( k \) is calculated according to the users satisfaction status. Finally, the scheduler selects the first or highest priority \( k \) user from the priority list. It also checks that the sum of estimated assigned resources should not exceed the total number of available resources, \( N_{RB} \). The RBs selected by the scheduler are assigned to the user in an opportunistic round-robin manner. The first user chooses resources that have the best channel conditions among all other users. Then the second-best channel condition is selected by the second user and so on. The users are assigned resources until it gets to \( N_{RB,k}[n] \).
resources in every round of iterations. Each user calculates the data rate \( \Delta r_k[n] \) that related to adequate number of resource assignments. The data rate to be transmitted to each user \( k \) at \( TTI_{cur} \) is given by:

\[
\Delta r_k[n] = r_k^{req} \cdot (t_k[n] + 1) - r_k^{req} [n - 1] \cdot t_k[n - 1]
\]

The number of resources \( N_{RB,k} \) required at \( TTI_{cur} \) is given as

\[
N_{RB,k} [n] = \frac{\Delta r_k [n]}{\sum_k r_k}
\]

where, \( r_k \) is the data rate to user \( k \). Hence, \( N_{RB,k} \) calculates the required number of resources to achieve a data rate \( \Delta r_k[n] \).

5.3 Opportunistic scheduling

Many users have a strong channel condition and therefore the network allows such users to share resources most efficiently. This in turn increases the sum throughput in the system. Opportunistic scheduling utilizes channel conditions to allocate time slots for users. It gives a higher system throughput in case of flexible service quality of all the users [33]. An opportunistic system should be designed in such a way so that to maximize the overall throughput of the user. It may be biased and not symmetrical for different users. The level of satisfaction and efficiency among users is not the same. The scheduling methodology has increased benefits that are similar to base station and have a higher channel status (SINR). In single BS, the data rate for the \( k^{th} \) user over \( N_{RB,k} \) resource block is given as:

\[
r_{k,A} = w_{k,A,N_{RB}} \log_2 (1 + SINR_{k,A,N_{RB}}).
\]

where, \( w_{k,A,N_{RB}} \) is the bandwidth of the \( k^{th} \) RB \((N_{RB,k})\) at the \( A^{th} \) base station.

\[
SINR_{k,A,N_{RB}} = \frac{RSRP_{k,A,N_{RB}}}{\sum_{b=m} \sum_{j=f} RSRP_{m,k,l} + w_{k,A,N_{RB}}}
\]

6 Up-link scheduling scheme

Scheduling can significantly improve user capacity with efficient allocation of radio resources utilization in NSA. The maximization throughput among users in a cellular system can be decomposed by the flexibility of resource allocation and management into several problems like antenna selection, resource assignment, time-frequency sharing, precoding, and power allocation. The traffic model for each link from a cell to the UE is assumed to be dependent on typically rapid variation in instantaneous channel conditions. Due to frequency selective fading at the receiver, the spontaneous and rapid variation in the channel can significantly affect the average signal intensity. The quality radio link can be assessed in a cell along with shadow fading path loss by measuring the signal power.

6.1 SU / MU scheduling

SU has point-to-point multiple antenna channel links between BS and a single UE. In spatial multiplexing (SM) independent user data are transmitted over each transmit antenna. Adding the number of antenna ports which increasing data capacity in SM. It can increase SE, bandwidth efficiency, system performance, and channel capacity. The resulting device becomes a virtual MU-MIMO when the data streams of different users are multiplexed on different antennas. The scheduling of RBs to multiple users is shown in Algorithm 1. The obtained data rate for the \( k^{th} \) user would be the function of RBs allocated at that instant. The algorithm enables MU scheduling. It supports the most of the user capacity in multi-dimensional by opting adaptive MCS and transmit antenna selection. The proposed algorithm, promises a rate gain to cater multiple UEs for increasing demand on traffic. A SU-MIMO raises the data rate for the single user. However, MU-MIMO system increases the total ability of the cell to accommodate multiple users. Each UE has \( t \) antennas in the MU-MIMO system, so simultaneous transmission over the same frequency-time-domain is possible. The MU-MIMO diversity antenna system can also achieve a maximum sum rate for each user. All these benefits depend on the level of CSI the BS receives from each UE. The channel estimation and CSI feedback play an important role in making this technique effective.

UL MU Scheduling in BS takes the feedback input synchronously or asynchronously from the UE. This helps to calculate the RBs needed for each UE. If all UEs reports very accurate channel feedback to the BS, which estimates the total number of UL resources available for users and the higher throughput is achieved by using MU-MIMO.

6.2 Proposed best N-subset reduction RME scheduler

Most of the available scheduling algorithms that consider different parameters for the allocation of RBs to the UE. They cogitate channel conditions, buffer size, the current satisfaction level of the UE, QoS, etc. But in these algorithms, the tradeoff between computational complexity and system performance has been identified, especially in the uplink.
direction where power is limited. We have proposed the BNSRME algorithm to reduce the computational complexity and to classify the best RB-UE pair. In this algorithm, the best RB subset is identified based on the SNR of the UE using the N-subset reduction method. Their rate is calculated and the RB-UE pair is placed into the utility matrix. Here, the minimum user constraint is considered where each user should be allocated at least one RB. The modified RME algorithm is used to find the best utility matrix when it performs a rigorous search and identifies the maximum matrix. The search is again divided into the left and right sides of the maximum matrix to identify the best matrix. This method eventually reduces the computational time. In algorithm 2, we considered the threshold limit based on SNR to increase the system performance further. The system performance did go up using this technique.

6.2.1 Best N subset reduction

The selection of the user is a permutation and combination problem in MU scheduling. MU selection shows high complexity in a large MU MIMO system. Considering 12 users are selected from 30 users, it is calculated up to
\[
\frac{30!}{(30-12)!} = 4.143e^{16}.
\]

The size of the user sub-channel matrix also increases as the number of users increases. As a result of this, the computational complexity of the algorithm also increases. A greedy algorithm reduces complexity and maximizes throughput in an MU selection. To obtain the best selection, we fit a separate list stress test regression for each combination feed predictor. Here \( P = K, P = (x_1, x_2, \cdots, x_K) \) is considered. In every combination feed predictor, the best separate list stress test regression is identified and placed into the predictor model. From every stress test regression list, one best model is identified among \( \{M_1, M_2, \cdots, M_K\} \). At the end of one complete cycle, the best of best model \( (M_{BB}) \) is identified from all the predictors. This \( M_{BB}(M_{BB} \approx N_{RB}) \) is the best RB allocated to the UE. We can find the best subset by using the following steps:

Step 1: Let \( M_0 \) be the null model i.e. \( y = B_0 \). It doesn’t have a predictor since no user is scheduled.

Step 2: For \( k = 1, 2, 3, \cdots, K \), it all \( \binom{P}{k} \) possible into a model that contains exactly \( k \) predictor users. When \( k = 1 \), the predictor also equals to 1. When \( p \) and \( k \) are both 1, we need to model them as, \( \binom{P}{k} \). It can be \( y = B_0 \), thus over and above this all models should be filled. Hence, the following models that come up with 1 predictor is:

\[
y_1 = B_0 + B_1 x_1
\]

Step 3: Choose the best model and call it \( M_{RB} \), from \( y_1, y_2, \cdots, y_K \). Since it uses linear modeling, \( R^2 \) (lowest) or \( R^2 \) (highest) would be the best model. It is called \( M_{RB} \). Assume \( M_{RB} \) is the best.

when \( k = 2 \), fill all models containing 2 predictor users. So the following possible models that come up with 2 predictor users are:

\[
y_1 = B_0 + B_1 x_1 + B_2 x_2 \quad \text{(20)}
\]

\[
y_2 = B_0 + B_1 x_1 + B_2 x_3
\]

\[
y_3 = B_0 + B_1 x_1 + B_2 x_4
\]

\[
y_k = B_0 + B_1 x_1 + B_2 x_K.
\]

Choose the best model amongst all the possible models. Consider that \( M_2 \) is the best.

When \( k = 3 \), then the following are the possible models that come up with 3 predictors:

\[
y_1 = B_0 + B_1 x_1 + B_2 x_2 + B_3 x_3 \quad \text{(21)}
\]

\[
y_2 = B_0 + B_1 x_1 + B_2 x_3 + B_3 x_4
\]

\[
y_3 = B_0 + B_1 x_1 + B_2 x_4 + B_3 x_5
\]

\[
y_k = B_0 + B_1 x_1 + B_2 x_2 + B_3 x_K.
\]

The best models with respective predictor users are:

\[
k = 1 \quad k = 2 \quad k = 3 \quad \ldots \quad k = 9 \quad k = K
\]

\[
M_1 \quad M_2 \quad M_3 \ldots \quad M_9 \quad M_K
\]

Step 4: Select the best (\( M_{RB} \)) mode out of \( \{M_1, M_2, \cdots, M_K\} \). From the cross-validation error \( C_p \) or adjusted \( R^2 \) methods, any one method can be used because \( \{M_1, M_2, \cdots, M_K\} \) have different variables or lengths. Considering \( k = 3 \) the best model is:

\[
M_{BB3} = y = B_0 + B_1 x_1 + B_2 x_7 + B_3 x_{10} \quad \text{(23)}
\]

\[M_3\] is the highest subset module. The best \( N \) allocation is \( M_{BB3} \approx N_{RB} \) allocation for UE. This is computed in (23) and represented in matrix \( A_i \) that denoted in matrix \( Q_i \) :

\[
\min b^T X
\]

subject to:

\[
Q_X \leq 1_M, \; Q_{eq} X = 1K, \; x_j \in [0,1] \forall j \in X \quad \text{(24a)}
\]
Where, \( b \) is the real value vector, \( X \) is the vector allocation selection. A constraints matrix of \( M \) rows is represented as \( Q \) and \( Q_{eq} \) is the quality constraint matrix of UEs. Each non-zero vector of the solution vector \( X \) which corresponds to select the respective column allocation in \( Q \). The matrix \( Q \) is found as:

\[
Q = [Q_1, Q_2, ..., Q_k]
\]

(25)

where entries \( Q_i \) are given as:

\[
Q_i = \begin{bmatrix}
\bar{Q}_{i1} & 0 & 0 & 0 \\
0 & \bar{Q}_{i2} & 0 & 0 \\
0 & 0 & \bar{Q}_{i3} & 0 \\
0 & 0 & 0 & \bar{Q}_{i4}
\end{bmatrix}
\]

(26)

Matrix \( Q_i \) is the set of the best RB allocations. The matrix \( \bar{Q}_i \) is the set of the best \( n^{th} \) RB allocation of \( i \). The quality constraint matrix is given as:

\[
Q_{eq} = \begin{bmatrix}
1^T \bar{c}_1 & \cdots & 0^T \bar{c}_k \\
\vdots & \ddots & \vdots \\
0^T \bar{c}_1 & \cdots & 1^T \bar{c}_k
\end{bmatrix}
\]

(27)

where, \( \bar{c}_i \) denotes the number of columns in \( Q_i \). The UE to RB subset metric mapping is as follows:

\[
\begin{bmatrix}
R_{B_1} & R_{B_2} & \cdots & R_{B_{N(RB)}} \\
U_{E_1} & M_{11} & M_{12} & \cdots & M_{1N(RB)} \\
U_{E_2} & M_{21} & M_{22} & \cdots & M_{2N(RB)} \\
\vdots & \vdots & \vdots & \ddots & \vdots \\
U_{E_N} & M_{N1} & M_{N2} & \cdots & M_{NN(RB)}
\end{bmatrix}
\]

(28)

An RB subset is a chunk of continuous RBs that are scheduled for UE in TTI. Continuous RBs in all subsets in matrix \( A \) of size \( M_{RB} \times M_{C} \). \( N_{RB} \) are the total number of RBs in a cell and \( M_{C} \) is calculated as \( M_{C} = 0.5M_{RB} + 0.5M_{RB} + 1 \). \( M_{C} \) is the number of several possible RB subsets in \( C \).

### 6.2.2 BNSRME algorithm

We proposed the best N-subset reduction and modified the RME algorithm (BNSRME) as an uplink multiuser scheduler. It performs resource allocation among the active users in cellular networks. Algorithm 1 shows the mathematical working of the modified RME scheduler. The scheduler searches for the first maximum (\( M_{L,j} \)) metric in each iterative. Once located, the scheduler expands the RB search on both sides till the scheduler finds a metric whose size is more than \( M_{L,j} \). It assigns the searched RB subset to UE. Later the UE is removed from unscheduled UE list and is marked as a served UE. The RME performs the same steps for each UE recursively in a manner, where, either the UEs are served or all RBs are scheduled. The computational complexity of the BNSRME algorithm is given in equation (31).

\[
1 + \sum_{i=1}^{K} i \times (N - (K - i)) \\
\approx O(1 + NK)
\]

(29)

(30)

**Algorithm 1: BNSRME**

\( k = \{1,2,\cdots,K\} \)

\( M_{L,j} = \Psi_{L,j} \) represents utility matrix value based on SINR/channel condition for scheduling \( U_i \) and \( RB_j \) for the \( k^{th} \) user in TTI.

1. While \( k \neq 0 \) and \( N_{RB} \neq 0 \) do
2. Find \( U_i \cap E \in K \) and \( RB_j \in N_{RB} \)

With maximum matrix in \( M \) i.e. \( M_{L,j} \in \Psi_{L,j} \)

3. \( k' = \arg \max \sum_{k=1}^{K} U'(S_k)\alpha_r r_{k[n]} \)

4. Let \( C \) be the set of RBs or chunks to be allocated to UE \( i \)
5. \( C = 0 \)
6. \( C = C \cup \{j\} \) allocated RBs sequentially from both the sides of \( RB_j \)
7. Let \( j_i = j - 1 \)
8. \( j_r = j + 1 \)
9. while (adjacent RBs is not allocated and \( M(i,j_i) = \max(M(\cdot,j_i)) \) and \( j_i \geq 1 \)

10. do
11. \( C = C \cup \{j_i\} \)
12. \( j_i = j - 1 \)
13. end while
14. while (adjacent \( RB_j \) is not allocated and \( M(i,j_r) = \max(M(\cdot,j_r)) \) and \( j_r \leq N_{RB} \)

15. do
16. \( C = C \cup \{j_r\} \)
17. \( j_r = j_r + 1 \)
18. end while
19. if no RBs in \( C \) then break
20. End if
21. Allocate subset \( C \) to \( U_i \) (i.e. \( C \) contains continuous RBs)
22. \( N_{RB} = N_{RB} - C \) \( (N_{RB} = N_{RB}/|k|) \)
23. \( K \leftarrow K\backslash[k]\) remove the element \( k^{th} \) from \( K \)
24. \( M_{L,j} \leftarrow 0 \)
25. \( k' = \arg \max \sum_{k=1}^{K} U'(S_k)\alpha_r r_{k[n]} \)
26. end while

In the first iteration, the modified RME algorithm identifies the highest UE-RB matrix. In the second iteration, the search is divided into two parts from the identified highest UE-RB pair and so on to identify the next highest UE-RB pair. Hence
a parallel search starts from the second iteration and the execution time reduces given in equation (31).

\[ \approx O \left( 1 + \frac{NK}{2} \right) \quad (31) \]

It has a linear complexity in terms of UE and RB respectively. Thus, the real time implementation of this algorithm is simple.

### 6.2.3 Multiuser Satisfaction Function

The satisfaction of users in data utilization depends on the type of services that the MU received in the offloading services. The received transmission rate quality varies with the difference in SINR and assigned resources. The MU is satisfied if BER is equal to the threshold \( SNR_{T,k}^r[n] \) given in (33). \( SNR_{T,k}^r \) depends on the channel conditions and the type of receiver. Let, \( \Psi_k \) be the utility matrix associated with SINR. The largest \( \Psi_k \) is the higher \( k^{th} \) user satisfaction for which higher quality of services is preferred. The MU satisfaction function during offloading is given in (32). This method is BNSRME-TH described mathematically in Algorithm 2.

\[
k[t] = \ln(1 + \Psi_k r_k[n]),
\]

\[
k[t]^{\text{threshold}}_{RB,k} = \arg \max \sum_{k=1}^{K} U'(S_k) \alpha_k r_k[n] \in \Psi,
\]

#### Algorithm 2: BNSRME-TH

1. Considering steps 1 to 20 from algorithm 1
2. Allocate subset C to UE, if \( C \geq \text{threshold} SNR_{T,k}^r[n] \)
3. \( N_{RB} = N_{RB} - C \) (\( N_{RB} = N_{RB}/\{k\} \))
4. \( K \leftarrow K \backslash \{k\} \), remove the element \( k^{th} \) from \( K \)
5. \( M_{l,j} \leftarrow 0 \)
6. \( k[t]^{\text{threshold}}_{RB,k} = \arg \max \sum_{k=1}^{K} U'(S_k) \alpha_k r_k[n] \in \Psi \)
7. end if

### 7 Simulation results and discussions

This section illustrates the performance of the proposed BNSRME and BNSRME-TH scheduler algorithm which shows increased system performance. This explicitly evaluates the tradeoff between the satisfaction of users and resource utilization. The simulation is carried out using MATLAB with the parameters given in Table 1.

LTE specified with 15KHz subcarrier spacing with 4.69μSec duration CP overhead. According to 3GPP, it was straight forward to keep similar OFDM numerology for NR. The SCS options are close to 15KHz as given in Table 2. This is considered as baseline for 5G NR by 3GPP. The SCS of OFDM subcarrier spacing can be opted as per \( 15 \times 2^n \) KHz. Where, \( n \) is an integer value of design parameter and can be optimized for different cases.

| Parameter                  | Value                  |
|----------------------------|------------------------|
| Number of cells            | 3                      |
| Cell area                  | 500m × 500m            |
| System bandwidth           | 20MHz                  |
| No. of users per cell      | 30                     |
| Channel gain at 1KM        | -148.1 dB              |
| Pathloss                   | 3.76                   |
| Shadow fading (Standard deviation) | 10                   |
| Received Noise Power       | -94dBm                 |
| UL transmit power          | 23dBm                  |
| Maximum eNodeB transmission power | 30dBm                |
| Carrier frequency          | 2GHz                   |
| Total number of subcarriers | 2048                  |
| Subcarrier bandwidth       | 15KHz                  |
| Number of RBs              | 100                    |
| Noise figure at UE         | 10dB                   |
| Noise figure at eNodeB     | 5dB                    |
| Transmission time interval | 1ms                    |
| Multiple antenna configuration | MU-MIMO 2 × 4, 2 × |

| Parameter                  | Value                  |
|----------------------------|------------------------|
| OFDM numerology            | 15 KHz, 30 KHz, 60 KHz |
| \( \mu = 0 \)              |                         |
| \( \mu = 1 \)              |                         |
| \( \mu = 2 \)              |                         |
| \( \mu \geq 3 \)           |                         |
| Frequency band             | 0.45–6 GHz, 0.45–6 GHz  |
| Supported BW               | 50MHz, 100MHz          |
| OFDM symbol duration       | 66.67μs, 33.33μs       |
| Cyclic prefix duration     | 4.69μs, 2.34μs         |
| OFDM symbol with CP        | 71.35/2^n μs           |
| Slot duration μs           | 1000 μs, 500 μs, 250 μs |
| OFDM symbols               | 14, 28, 56             |

The performance of the proposed scheduling algorithms compared with existing algorithms is shown in Fig.3, where \( N_{tm}(G,i) \times N_{rb}(i) = 2 \times 4 \) antenna configuration is used. The base station employs an MMSE receiver. In a simulation, the interference from other cells is considered. Here, each user and BS is modeled with fading channel coefficient matrix H. The users are assigned the resources in time-frequency and the transmit power is equally distributed amongst the RBs. The proposed algorithm uses an efficient way of utilizing RBs by
using the N-subset reduction and RME approach in UL. By using the proposed algorithm better SE is achieved than the opportunistic, MDF, and heuristic algorithms given in Table 3.

Table 3. Average sum SE of different algorithms

| SNR (dB) | MLW DF | Heuristic | Opportunistic | BNSRME | BNSRM E-TH |
|----------|--------|-----------|---------------|--------|------------|
| 20       | 8.01   | 10.09     | 10.93         | 11.84  | 14.39      |
| 25       | 8.79   | 11.19     | 12.04         | 12.96  | 15.83      |

For example, in the proposed BNSRME-TH and BNSRM algorithms have the average sum SE is 15.83 bits/s/Hz and 14.39 bits/s/Hz respectively for 20 dB SNR, which is higher than the existing algorithm. The BNSRME-TH algorithm has significant SE as compared to other users. Once it exceeds $C \geq \text{threshold}\text{SNR}_{T,R}[n]$, the highest satisfied user has higher gain throughput. The SE has improved by 31.65 % than the existing opportunistic algorithm at 20dB SNR. The advantage of this algorithm is that it can be applied in any channel condition and can achieve better SE.

The algorithm targets maximizing the SE and allows MU scheduling where multiple users are assigned resources at the same time. The MMSE receiver is used at BS for SU and MU MIMOs with a high transmit correlation to investigate the proposed scheduling algorithm in the uplink cellular network. Fig. 4 and 5 illustrate the performance of the SU and MU-MIMOs with different antenna configurations for the proposed algorithms. In Fig.4 $N_{T,m}(G,i) \times N_{R,b}(i) = 2 \times 4$ and in Fig.5 $N_{T,m}(G,i) \times N_{R,b}(i) = 2 \times 8$ antenna configurations are used respectively.

In both the antenna configurations, $s(u,i) = 2$, two data streams are employed per user. Therefore, in $2 \times 4$ and $2 \times 8$ antenna configurations at most two and four users can be spatially multiplexed respectively. The interference from the surrounding cell, UEs can be suppressed in the MMSE estimator when using other pilots. Hence, in this simulation, the pilot reuse factor of 4 is used. In order to evaluate the performance of the SU and MU-MIMOs for the proposed algorithm, it can be seen that the SE for $2 \times 4$ and $2 \times 8$ MU-MIMO is 12.50 bits/s/Hz and 25.30 bits/s/Hz respectively. Using the BNSRME-TH algorithm the SE which is double in case of the $2 \times 8$ MU-MIMO as expected. The average sum SE of the proposed algorithm with different antenna configurations are given in Table 4.
Table 4. Average sum SE of proposed algorithm

| Antenna Configurations | SNR | SU-BNR (SU-BNSRM) | ME-TH | SU-BNR (SU-BNSRM) | ME-TH | MU-BNR (MU-BNSRM) | ME-TH |
|------------------------|-----|-------------------|-------|-------------------|-------|-------------------|-------|
|                        | 20dB| 5.95              | 8.90  | 9.89              | 11.58 |                   |       |
|                        | 30dB| 6.68              | 9.43  | 10.48             | 12.50 |                   |       |

\[N_{tm}(G,i) \times N_{br}(i) = 2 \times 4\]
\[N_{tm}(G,i) \times N_{br}(i) = 2 \times 8\]

In the SU and MU-MIMO, there is a 56.88 % and 86.89 % rise in the case of 2 \times 4 and 2 \times 8 antenna configurations for 30dB SNR. The use of more antennas improves the performance of the proposed algorithms. It is also observed that the MU-MIMO has greater SE than the SU-MIMO. As the MU-MIMO effectively reduces the transmission rank of the SU-MIMO by reducing sensitivity. It changes the balance of the singular value of the SU channel and restricts the rank of SU-MIMO. Also, the capability of the transmitter restricts the multiplexing gain of the MU-MIMO compared to the SU-MIMO. Hence, small and inexpensive UEs can be developed.

The computational complexity per coherence block of MMSE receiver is \(O(\tau_u R_{x,A} K_A)\), where, \(\tau_u\) is the UL data samples per coherence block, \(R_{x,A}\) is the number of BS antennas in cell A, \(K_A\) is the number of UEs in cell A.

SE of network is evaluated with different SCS selection for available allocated BW to multiuser. The maximum data is reached for UE when spectral efficiency improves. The SNR at MU is a function of the BS transmission power, receiver noise, channel effects, and the spectral efficiency for the FR1 band. From Fig. 6 it is observed that the spectral efficiency is increased with higher values of SNR. Table III depicts the 14, 28 and 56 symbols transmission in 1ms slot for 15 KHz, 30 KHz and 60 KHz subcarrier spacing respectively. It is observed that the SE is higher for the 60 KHz SCS compared to 30 KHz and 15 KHz SCS.

Fig. 7 presents the cumulative distribution function (CDF) of the SE per UE under the SU and MU-MIMOs for the proposed algorithm considering a 2 \times 4 antenna system. It is observed that the SE of the MU-MIMO substantially outperformed that of the SU-MIMO. The throughput of the SU and MU MIMO for the proposed algorithm using different antenna schemes is shown in Fig. 8. It should be noted that the proposed N-subset reduction method identifies the compressed set of RBs to be allocated to the users results in an improved throughput.
7 Conclusion

The focus of this paper is on the exploration of an uplink MU technique in 3GPP standard networks. We have proposed an uplink MU scheduling BNSRME algorithm. The users are allocated chunk resources in the frequency-time domain based on strong SINR values range. For the selection of RBs, the N-subset reduction method is proposed. It identifies the best chunk of RBs and feeds it into the utility matrix. The BNSRME algorithm identifies the maximum matrix $M_{ij}$ and assigns RBs to the UE. Further, the SINR threshold $SNR_{T,k}[n]$ value is considered for the user to get maximum throughput. The proposed BNSRME and BNSRME-TH algorithms are simulated for the SU and MU environments. Based on the simulation results it can be concluded that the system capacity is dependent on instantaneous channel conditions. Therefore the SE rises in the case of the MU-MIMO and performance increases significantly compared to the existing algorithms. By using the given scheduler, the MU-MIMO gives the best performance. It also provides higher gain when uplink resource allocation is flexible. The threshold consideration of the algorithm which increases the SE by 31.65% as compared to the opportunistic algorithm. The simulation is performed for the MU-MIMO 2x4 and 2x8 antenna systems to show that the proposed algorithm can achieve high efficiency. Here it is observed that the SE doubles in the case of the 2x8 MU-MIMO system as analyzed theoretically. Also simulation for the different numerology shows that the SE increases with the increase in SCS. For future work, we will develop a computationally efficient scheme for latest release NR UL scheduling with a massive MIMO system in a standalone NR architecture.

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