Bidirectional resource scheduling algorithm for advanced long term evolution system

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Abstract
The 5G long term evolution-advanced (LTE-A) system aims to offer unprecedented data rates, user experience, and minimal latency amongst the end users with the introduction of carrier aggregation (CA) technology. Radio resource management (RRM) with scheduler is responsible for satisfying the user quality of service (QoS) requirements through resource allocation. Due to the need for an uninterrupted bidirectional communication between the eNodeB and user equipment (UE) in LTE-A, the joint scheduling algorithm is acknowledged as a central research prospect. In this article, a modified joint uplink/downlink (UL/DL) user carrier scheduling algorithm satisfying demand service requests UE, is proposed. The joint optimization of the subcarrier assignment in an orthogonal frequency-division multiplexing-based network is utilized to balance the resource coupling between the UL/DL directions. CA is used to determine the weight factors required for the bandwidth allocation within the mobile users based on the QoS class identifier. These weight factors are employed as probability functions for resource allocation. The proposed algorithm will reduce the computational complexity arised in the conventional joint UL/DL scheduling algorithm based on the suboptimal solutions via probability functions. The simulation results show that the packet loss rate and packet delay among the mobile users are substantially reduced for both real-time and nonreal-time services.

KEYWORDS
downlink, LTE-A, QoS class identifier, resource blocks, UEs, uplink

1 | INTRODUCTION

Long term evolution-advanced (LTE-A) is intended to support higher spectral efficiency, intensified experience and integrity in terms of resource allocation for real-time (RT) and nonreal-time (NRT) services for user equipment (UE). The exponential growth of wireless devices and associated data services, it is not hypothetical to meet on demand service requests from the users. To mitigate the shortfall of transmission capacity of the conventional cellular technology, carrier aggregation (CA) technology is adopted along with the existing LTE system. The available bandwidth for the mobile communication can be optimized up to 100 MHz with the aid of aggregation of the carrier components (CCs) of the CA technology.1,2 This technology will give full contentment to new generation cellular network peak data rates with minimum packet loss and delay among the users. Radio resource management (RRM) acts as a packet scheduler for the
allocation of resource blocks (RBs) to the UE in an efficient manner so as to meet the quality of service (QoS) requirements in the LTE-A system. The scheduler assigns these RBs to the selected users to carry out scheduling either in uplink (UL) and downlink (DL). Effective utilization of the available bandwidth to the mobile users and fairness among the users are highly dependent on the type of scheduling algorithm employed.

RRM is the most challenging and complex process, which incorporates solution ascertain for the users experience for different QoS requirement among them. Resources are self-reliantly allocated for the UE in UL and DL. Advent of mobile services, online gaming, live data streaming, and video conferencing with identical quality requirement in multimedia applications, unidirectional scheduling algorithms will not fulfill all the QoS requirements for the users. Exponential increase in the mobile internet usage in the current cellular network, unidirectional scheduling algorithms will experience higher constraints to meet on demand service requests in terms of battery power of the UE and frequency band allocations.

Many recent contributions on scheduling scheme for resource allocation manifest better user satisfaction in terms of fairness, throughput, and spectral efficiency. Mobile to mobile packet scheduling algorithm surpasses the resource starvation problem optimizing framework. It minimizes the frequency band usage along with satisfying users QoS provisions. In Reference 4 the delay based and QoS aware scheduling scheme exhibits efficient solutions for the heterogeneous traffic RT and NRT services to maintain the balance between delay and throughput. The new dragonfly algorithm will optimizes resource assignment for QoS requirements with higher level of energy efficiency. Experimental results prove that the proposed scheme improves overall system performance along with users QoS satisfaction.

The existing scheduling schemes mainly concentrate on optimizing the user accomplishment either UL or DL. QoS provision is the basic objective in LTE-A radio access networks. In multi traffic type, conventional scheduling scheme does not a guarantee the good QoS performance due to the delay bound. For example, in video conferencing where end-to-end interaction is needed and joint optimization of the user performance is required for both the directions along with desired data rates.

To meet the bidirectional requirements, scheduling must be done for UL and DL at the same time. In this scheduling scheme RBs to the UEs are allocated simultaneously for the UL and DL in accordance with QoS requirements of the users. Most of the existing work in the resource allocation policies concentrates only on DL direction. Investigation on the joint UL/DL resource allocation is limited. Some of the work on joint UL-DL scheduling is implemented for other wireless technologies such as WLAN, but due to the difference in access mechanism between LTE and WLAN, these opportunistic algorithms cannot be used directly. Similar work is done in Reference 10, with an extension of traditional resource allocation algorithms for joint UL-DL scheduling with frequency-division duplexing (FDD) but it introduces computational complexity in calculation of the weight factors for resource allocation for both UL and DL. In References 12,13, a simultaneous UL and DL resource allocation strategy is used UL CCs, which are made available for DL data delivery. A theoretical game model for orthogonal frequency-division multiplexing (OFDM)-based networks better performs for joint optimization on symmetric applications with increased delay at the scheduler. In Reference 12, intermode interference in wireless links is alleviated through successive approximate scheduling policies for asymmetric applications.

The fundamental functionality of the scheduling scheme is to meet the user expectations with efficient allocation of available resources. However, 3GPP specification is not well defined for the choice of scheduling approach but network operators are free to select, design, configure, and implement their own algorithm based on the priority of services on their network. Satisfying all the needs of the users with single scheduling approach is difficult. Solution for each problem of the scheduling process will lead to another problem and depends on several network parameters. Therefore, trade-offs to be made while designing the scheduling approach between the network parameters with respective of spectral efficiency, throughput, end-to-end delay, and packet loss rate (PLR). To support effectively the current real RT and NRT service types, effective use of shared spectrum is necessary.

This research article proposes modified joint UL/DL user carrier scheduling (MJUCS) algorithm as an optimization problem. In this solution, network resources can be allocated for UL and DL based on the QoS provision of the users with reduced delay and computational complexity. The following key novelties and contributions of the proposed work summarized.

- **Weight factors**: We determine the weight factors for each service by using CA technology based on the network traffic and amount of data transferring through each traffic class.

- **Resource allocation**: Joint optimization of resource allocation scheme in OFDM network is derived through probability functions, where nonlinear behavior of the each service request is utilized for the resource allocation scheme.

- **Users response**: Prioritizing users in response to probability function and scheduling each user from higher rank of the priority queue. This scheme is highly flexible and can be used for advanced spectrum utilization in 5G networks.
Performance analysis: Performance of the proposed MJUCS algorithm is compared with conventional joint scheduling approach with respect to computational complexity, throughput, fairness, and end-to-end delay for each traffic class.

2 RELATED WORK

On demand service request of UE is satisfied with available RBs, by the assimilation of minimal energy consumption algorithm in discontinuous reception switching. This algorithm achieves increased QoS request along with reduced overall energy consumption in the LTE-A system. However, this method does not guarantee all the traffic class users of the system. Investigation of delay and energy over the QoS prioritization resource management approach shows that, matching theoretic flow prioritization improves the user utility function for on demand services. In improved joint user carrier scheduling algorithm for orthogonal frequency-division multiple access (OFDMA) resource allocation, user level service weight factors are calculated adaptively for RBs assignment in the RRM of the LTE-A system. This proposed algorithm outperforms the joint user carrier scheduling policies. However, the designed algorithm suits only for DL scheduling scheme. In Reference 13, the author describes standard group partitioning and dynamic algorithms for allocation of resources to unicast and multicast services in standard LTE-A environment. Allocation of resources in terms of subframes instead of RBs will reduce the computational complexity of the system utility functions. The modified GDP suits well for unicast and multicast applications.

Joint optimization of resource allocation and power control are studied and analyzed in Reference 16 for heterogeneous networks (HetNets). This scheme minimizes the end-to-end delay in the HetNets particularly in dense users for round robin scheduling approach. Simulation results show that proposed scheme outperforms conventional schemes in terms of end-to-end delay among the users. Channel aware and queue aware RB allocation for LTE DL for buffer overflow estimation provide lower delay and maximum throughput. The proposed methodology derives novel service curves to measure the buffer overflow probability. Simulation results show that better performance in comparison with other scheduling algorithms such as QoS aware, particle swarm optimization and maximum carrier to interference ratio schemes. There are various discrepancies exist in this method while evaluating the spectral components of the RBs.

Most of the existing scheduling policies in LTE-A system aims to optimize the throughput, end-to-end delay, and spectral efficiency among the mobile users but all these schemes performs well for unidirectional resource allocation schemes. Due to the exponential increase in the multimedia communication, online gaming over the internet and data rates of the UL has not satisfied the user expectations. UL scheduling algorithms plays an important role in throughput and delay requirements of the users in multimedia applications. Current cellular technology intends to offer uninterrupted services to the mobile users in response to their QoS provision. In Reference 9, author described different scheduling algorithms together with network parameters in LTE system. Game theoretical model is proposed for radio resource distribution for the joint UL and DL requirements to accomplish UEs symmetric services in Reference 19. The proposed algorithm maximizes the user utility function for both UL and DL directional simultaneously to meet the QoS requirements of each user even in the absence of channel state information of transmitter. Limited amount of feedback is required for centralized and distributed resource management that produce higher level of fairness among the UEs. Coupling constraints of joint UL/DL in the absence of CSI will results in delay at the base station during the resource assignment and allocation of subcarriers for the users. Moreover, evaluation of the utility function on behalf each user will yield computational complexity at scheduler.

Optimization problem in OFDMA for joint UL/DL resource allocation is used for the total sum rate maximization in Reference 12 is focused on the balancing the data rates in both UL and DL. The time gap between the UL and DL rates per UE is minimized to maximize the overall weighted sum rate of the LTE-A network. This proposed work concentrates and suits better for symmetric services in the LTE-A system. Optimization problem for joint allocation techniques satisfies bandwidth allocation in FDD environment. It mainly focused on the QoS outage of the different traffic class of users for on demand service request of LTE-A system. The results of the modified opportunistic scheduling algorithm are used to derive the UL-DL QoS metric for coupling UL-DL along with the outage probability. The simulation results exhibits favorable behavior in comparison to the conventional unidirectional scheduling policies. The allocation of RBs based on the utility function, introduces a certain degree of computational complexity due to the sum rate maximization.

Modified opportunistic scheduling algorithm for optimization problem of joint UL/DL scheduling scheme in OFDM system is proposed in the study. The proposed outage probability expression for the joint UL/DL demonstrates that QoS outage is decreased in the bandwidth allocation among the users. However, the proposed solution does not account for...
for all the traffic class users in the LTE-A system. Joint optimization of carrier assignment, resource allocation among UL DL pair and power in OFDMA network are considered to maximize the average throughput of the network for self-interference and internode interference problems. The dual methodology is used to solve optimization problem through sequential convex approximations results in improved throughput with comparison with the existing techniques. Dual concave convex procedure causes degradation in fairness level among the UEs for the resource allocation in UL and DL direction for LTE-A system.

Some of the works carried on bidirectional scheduling algorithms, presented in the article gives an existence to various degrees of discrepancy in these algorithms, with respect to methodology, environment, scenario usage, and simulation setup. These algorithms fail to maintain balance between the UL and DL data rates and QoS requirement of the UEs. Therefore, in this article suboptimal solutions for the resource allocation policies involved in joint scheduling process is considered. Initially optimization problem of the joint scheduling process is framed and suboptimal problem is derived to find the best resource allocation policies with reduced computations and increased throughput of the network. The following section represents system model for the proposed algorithm.

3 | SYSTEM MODEL AND PROBLEM FORMULATION

3.1 | System model

We consider an eLTE based 5G network configuration with single eNodeB in nonstandalone NR mode. In this configuration a new radio base station can support connectivity to evolved packet core (EPC). This needs LTE eNodeB as an anchor for control plane connectivity to existing core network. It consists of set of UEs (UE1, UE1, ..., UEN), in which each user requesting bandwidth can be shared for their applications. The available bandwidth will have CCs of CA as \( C = \{C_1, C_2, \ldots, C_M\} \) and \( \alpha = \{\alpha_1, \alpha_2, \alpha_3, \ldots, \alpha_N\} \). Each user \( \alpha_n \in \alpha \) may have different CA accessibility depending on the capabilities of the UE. \( \alpha_n \) denotes the maximum number of component carriers that user \( n \) can aggregate. For example, for the \( i \)th UE without having CA capability will have \( \alpha_i = 1 \). \( \beta = \{\beta_1, \beta_2, \ldots, \beta_M\} \) represents the amount of RBs on carriers and \( \beta_m \) denotes number of RBs on the \( m \)th carrier. \( \beta_m \in \beta \) have different number of RBs and has \( \gamma = \{\gamma_m|\gamma_m \in \{270, 273, 135, 127\}\}^{1 \times M} \) where \( \gamma_m \) represents the number of RBs in given \( \beta_m \) and modulation order. These RBs depend on the subcarrier spacing. The QoS of each traffic class flow is represented by the QoS class identifier (QCI). The total bandwidth at each TTI is divided into BWUL, BWDL, and BWsh for UL, DL, and shared bandwidth, respectively. The utility function of every user is regenerated based on the QoS provisions in subcarriers of the channel bandwidth. However, for each service set of carriers for UL and DL are represented as \( S^U = \{S^0, S^1\} \) and \( S^D = \{S^0, S^1\} \), respectively. \( S = S^U \cup S^D \) is the set of available subcarriers at base station. Noncontiguous CA with different band is used for shared bandwidth. Since traffic class for first nine services in 5G network is same as that of 4G network, we have used the same notation for traffic flow of each users QCI indicated as qci\( ^j_i \) and load as \( \ell^i_j, i \in \{1,2,3,\ldots,9\} \).

QCIUL \( \) is the user utility function for the UL, which represents the bearer services for the end users. The aim of the proposed joint UL/DL scheduling in 5G networks is to maximize the resource utility functions while minimizing the difference between the UL and DL data rates. There are nine bearer services are listed in the LTE-A system over the RT and NRT services. LUL \( \) is the traffic load exerted into the network at each TTI. The following weight factors for the UL are calculated:

\[
W_{UL}^{UL} = \sum_j QCI_{UL} \sqrt{L_{UL}^j} = \sum_{i=1}^{N} \sum_{j=1}^{9} qci_{UL,i}^{j} \ell^i_j. \quad (1)
\]

Similarly the weight factors for the DL are calculated. Sum rate maximization of these weight factors are used for the bandwidth allocation. If the available bandwidth in each direction is not sufficient then shared bandwidth is used. The bandwidth portion for UL and DL is calculated from the shared bandwidth as,

\[
BW_{sh}^{UL} = W_{UL}^{UL} / (W_{UL}^{UL} + W_{DL}^{UL}) \times BW_{sh}. \quad (2)
\]

\( \rho_{UL}^{j} \) is the SINR of the UEs are used for the optimization of the weight factors in (3).

\[
w_{UL,i,UL}^{j} = \rho_{UL}^{j} \left( qci_{UL,i}^{j} \sqrt{\ell^i_j} \right). \quad (3)
\]
The RBs for UL and DL is calculated based on Equations (1) to (3) as follows,

$$\text{RBs}_{i,UL}^j = \text{floor} \left( \frac{w_{UE,i,UL} \times BW_{sh}^{UL} / \sum_{j=1}^{N} \sum_{i=1}^{9} w_{UE,i,UL}}{N} \right),$$  

$$\text{RBs}_{i,DL}^j = \text{floor} \left( \frac{w_{UE,i,DL} \times BW_{sh}^{DL} / \sum_{j=1}^{N} \sum_{i=1}^{9} w_{UE,i,DL}}{N} \right),$$  

$$\text{RBs}_{\text{rem}} = BW_{sh}^{UL} - \sum_{j=1}^{N} \sum_{i=1}^{9} (\text{RBs}_{i,UL}^j + \text{RBs}_{i,DL}^j).$$

These weight factors are further used for the MCS index assignments to determine data rates for each direction. This is a crucial step in scheduling process, since data rates for each service will directly affects throughput and end-to-end delay of UEs. Therefore, analysis of the throughput and end-to-end delay of the mobile users based on the above procedure is done by considering optimization problem.

### 3.2 Optimization problem formulation

In this article, proportional fair scheduling algorithm is employed to optimize throughput of $j$th user over the traffic flow $i$. Therefore, optimized throughput is formulated as.

$$\text{Maximize} \left( \sum_{j=1}^{N} \sum_{i=1}^{9} qc_i^j \times \sqrt{I_i^j} \times \text{RBs}_{i,UL}^j \times \text{MCS}_{i}^j \right).$$

Maximum supported MCS index of all UEs in the different RBs is modeled as

$$K = \{ k_{m,p,n} | k_{m,p,n} \in \{0, 1, \ldots, h\} \} \text{M x } p \times N,$$

where $k_{m,p,n}$ represents maximum MCS-index of $\alpha_n$ on $\beta_m$ in $p$th RB. Its value depends on channel quality ranges between 0 and $h$. The value of $h$ for the UL is 68, DL is 120, and $\rho = \text{max}[\gamma_m]$. The proposed system considers 3GPP TS 38.306 specifications for the MCS and transport block size mapping.

The resource allocation in terms of CA capability for all UEs can be represented in binary matrix as,

$$A = \{ a_{m,p,n} | a_{m,p,n} \in \{0, 1, \ldots, h\} \} \text{M x } p \times N,$$

where $a_{m,p,n} = 1$ if and only if $p$th RB allocated in $\beta_m$ is allocated to $\alpha_n$ uniquely and $a_{m,p,n} = 0$ otherwise. To represent allocated MCS-index to each $\alpha_n$ for given TTI, weight factors needs to be mapped to throughput of the system as follows,

$$V = \{ v_{m,p,n} | v_{m,p,n} \in \{0, 1, \ldots, h\} \} = \sum_{m=1}^{M} \sum_{j=1}^{N} \sum_{i=1}^{9} (\text{RBs}_{i,UL}^j + \text{RBs}_{i,DL}^j).$$

To formulate the CC selection and RB assignment for both UL and DL, throughput is calculated as follows

$$R_{j,\text{total}}(t) = \sum_{m=1}^{M} \sum_{j=1}^{N} \sum_{i=1}^{9} (v(t)_{m,n} \times a_{m,p,n}(t) \text{ MB/s}),$$
where \( v(t)_{m,n} \) and \( a_{m,p,n} \) are \( v_{m,p,n} \) and \( a_{m,p,n} \) into \( t \)th TTI, respectively. The utility function of the proportional fair for \( a_n \) up to \( t \)th time slot is referred as \( Z(t) \) and is represented as,

\[
Z(t) = \frac{R_{j,\text{total}}(t)}{T_n(t)}.
\] (12)

This utility function is used for the resource allocation during the TTI for different traffic class users of the LTE-A system. The optimization of the \( R_{j,\text{total}}(t) \) will results different scheduling policies based on the utility function. The detailed explanation of JUCS and MJUCS algorithms along with flow diagram is depicted in the following sections.

4 | JOINT UL/DL SCHEDULING ALGORITHM

Joint UL/DL scheduling\(^{10}\) is used for the allocation of resources in bidirectional for UEs during scheduling phase. During RRM process, eNodeB receives the service requests from UEs with respect to utility functions. Based upon traffic load of the network and QoS demands, CA is incorporated for shared allocation of resources. The incoming service request from the users is used to determine weight factors for UL, DL, and shared bandwidth for the resource allocation. Adaptive MCS is used for scheduling the resources using proportional fair algorithm. Conventional joint scheduling algorithm is represented as shown in the Figure 1. Equation (9) is used as sum rate maximization of the throughput of the network and used for the assignment of the MCS index values to the RB allocation process. This algorithm aims to maximize the throughput of the system along with minimum fairness among the mobile users.

Find number of users (N)

Read the measurements for each UE and Identify the traffic load on each directions (\( L^{UL}, L^{DL}, C^{UL}, \) and \( QC^{DL} \))

Resource available >
Service request

Yes

No

Determine bandwidth based on weight factors

Perform scheduling based on utility function

Stop

FIGURE 1 Joint UL/DL scheduling algorithm flow chart. UL, uplink; DL, downlink
5 | MODIFIED JOINT UL/DL USER CARRIER SCHEDULING ALGORITHM

A MJUCS algorithm for the RRM of the LTE-A is proposed in this article. Scheduling process is divided into two steps. In the first step, weight factors are calculated based on joint UL/DL scheduling algorithm. In the second step, resultant weight factors are used for packet scheduling based on JUCS Scheme. In this method, the weight factors of the utility function are transformed into priority function for each traffic class of users. In order to reduce the computational complexity of the calculation of weight factors, priority functions are introduced. This algorithm assures to accommodate the guaranteed and non-guaranteed QoS requirements of each user of the LTE-A system. Incoming service request from UE is divided into RT and NRT based on the QCI in the control packet received by eNodeB. During each FDD LTE air interface, RT, and NRT service requests are queued in response to arrival time of the service request, respectively. eNodeB is responsible for adapting the data rate of the users with respect to instantaneous channel capacity. During each TTI time interval link adaptation is carried at the base station based on the CSI information obtained from the UEs feedback channel. Base station selects the MCS values that are to be used for the next TTI. The weight factors of the UL and DL are then segregated for the RT and NRT services as follows.

The head of line (HOL) delay packet for the RT weight factors in queue for the RT user \( k \) in traffic flow \( i \) is calculated based on the current TTI and arrival time of the packet as,

\[
UL_{D_j}^{i,RT}(t) = T_{current} - T_{arrival}^{k,ij},
\]

where \( q_j(t) \) is the buffer size of the \( j \) UE at time \( t \). HD\( k \) highest bound is used for the normalization of the HOL in the \( j \)'s UE queue for RT and NRT services.

Direct usage of the weight factors for the RBs allocation leads to computational overhead for the scheduling process because of the dynamic nature of weight factors. Therefore, optimization of Equation (11), which needs higher number of computation in mapping of the RBs with MCS index, and that affects delay and throughput of the network during scheduling process. Adaptive modulation and coding scheme maximize the spectral efficiency subjected to maximum block error rate. Moreover, the optimization of Equation (11) for the RBs allocation based on the system model as,

\[
(A^*, V^*) = \arg\max_{A \in A_k, V \in V_k} U(A, V),
\]

\[
U(A, V) = \sum_{m=1}^{M} \sum_{j=1}^{N} \sum_{i=1}^{9} (v_{m,n} \times a_{m,p,n}/T_n ).
\]

Subjected to \( \sum_{n=1}^{N} a_{m,p,n} \leq 1 \),

where \( a_{m,p,n} \leq k_{m,p,n} \).
The problem in Equation (19) is linear, because of the product of $v_{m,n}, a_{m,p,n}/T_n$. To prevent predicament, the linear Equation (19) can be converted into suboptimal nonlinear by introducing an auxiliary variable called resource allocation indicator $b_{n,m,j} = \rho_{j,n}$ where $\rho_{j,n} = 1$ and $\rho_{k,n} = 0 \forall k \neq j$. $U(A,V)$ results as,

$$U(A,V) = \sum_{m=1}^{M} \sum_{j=1}^{N} \sum_{i=1}^{9} (b_{n,m,j} \times a_{m,p,n}/T_n)$$

(22)

Subjected to $b_{n,m,j} \leq k_{m,p,n}$

(23)

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**Figure 2** Modified joint user scheduling algorithm flow diagram
Therefore, linear optimization of the function $U(A,V)$ needs to be mapped to suboptimal solution through probability function to have minimal complexity of scheduling process. This is justified for each TTI, once the packets are segregated and queued in RT and NRT, dynamic nature of the weight factor computations will not impacts the further scheduling process and also due to enhanced number of users in the network, suboptimal exponential sum rate maximization will results in minimum delay among the end users along with higher spectral efficiency via logarithmic scale. Therefore, at each TTI, the resources are allocated based on the priority functions with respect to the average weights for the RT and NRT services using Equations (14) and (17) as follows,

$$P_{j,i,n}(t) = \log \left( \frac{R_{j,i,n}(t) * D_k(t)}{(T_{PF} - 1)R_{j,\text{total}}(t) + \sum_{n=1}^{N} P_{j,n} * R_{j,i,n}(t)} \right), \quad (24)$$

$R_{j,i,n}(t)$ is calculated as data rate for user $j$ at the $n$th RB group of the $i$th CCs at time slot $t$, $D_k(t)$ is HOL sum packet delay for the $j$th UE. $\sum_{n=1}^{N} P_{j,n} * R_{j,i,n}(t)$ is overall throughput of the $j$th user at the time $t$, $T_{PF}$ the average proportional window length. $R_{j,\text{total}}(t)$ is average user throughput for all CCs. $R_{j,\text{total}}(t)$ is average throughput for all the RT and NRT is updated every time for each CCs and is maintained minimum of 240 kbps.

$$k_{i,n} = \arg_{k=1,2,3,\ldots,N} \max \{ P_{j,i,n}(t) \}, \quad (25)$$

where $k_{i,n}$ is the selected user $k$ at ith CC of the $n$th RBs. This priority function is repeated until all available RBs are allocated for all the users and $R_{j,\text{total}}(t)$ is updated. The detailed scheduling process of the modified joint scheduling algorithm is depicted as shown Figure 2.

### 6 | COMPUTATIONAL COMPLEXITY ANALYSIS

In order to analyse computational complexity of the proposed algorithm, we compare the proposed algorithm with JUCS.\(^{15}\) We have assumed CC of the CA will have same number of RBs for the resource allocation. In JUCS algorithm, weight factors estimated for UL and DL during each TTI needs to be mapped to the MCS index for the RBs assignment. For each UE per CC, $\rho \times N$ complex multiplications and comparisons are required to accomplish MCS index assignment and $(h + 1)$ different combinations of MCS index assignments are possible. Therefore, the total number of complex multiplications and comparisons needed for all the UEs for the assignment of MCS index required is $(2\rho NM (1 + h)^N)$ for each cell. In overview, the total computational complexity (multiplications and comparisons) of JUCS can be written as,

$$C_{\text{JUCS}} \approx 2\rho NM(1 + h)^N. \quad (26)$$

Modified joint user UL/DL scheduling algorithm will transform the weight factors for the RT and NRT service request into probability functions, which in turn used for MCS index. For each UE, $(h + 1)$ different combinations of MCS index assignments are possible as in case of JUCS but the number of complex multiplications and comparisons required for both directions is $(2\rho NM(1 + h))$. Therefore, the total number of complex multiplications and comparisons needed for all the UEs in each cell for the assignment of MCS index is.

$$C_{\text{MJUCS}} \approx 2\rho NM \log (1 + h)^N. \quad (27)$$

In the proposed algorithm, probability functions will average the weight factors of the RT and NRT services for each UE. Since throughput of the network is a linear function with respect to network parameters, when the number of users in the network increases, computations of the weight factors results in overhead which will affects the delay and throughput of the network. However, MJUCS algorithm transforms linear dependency into suboptimal nonlinear behavior for throughput with respect to the network. Therefore, throughput and delay of the UEs will be achieved in accordance with QoS provision of the users even in the presence of network congestion. Table 1 highlights the computational complexity of the JUCS with the MJCS for the different values of $N,P,$ and $M$. We have assumed $P = 100$ and $h$ is average value for UL and DL as 68 and 120, respectively.
### Table 1 Complexity comparisons

| Complexity | \(N = 4, M = 3\) | \(N = 9, M = 6\) |
|------------|----------------|----------------|
| JUCS       | \(1.2755 \times 10^9\) | \(8.2356 \times 10^9\) |
| MJUCS      | \(3.1640 \times 10^9\) | \(3.2036 \times 10^9\) |

Abbreviation: MJUCS, modified joint uplink/downlink (UL/DL) user carrier scheduling.

### 7 Simulation Results and Performance Evaluation

#### 7.1 Simulation parameters

Modified joint UL/DL scheduling algorithm is designed based on the OFDM 5G network to support multimedia applications with diverse QoS requirements. The proposed OFDM network uses multiple subcarriers to avoid interchannel interference and intersymbol interference. To meet the peak data rates, an adaptive MCS is incorporated with RRC antenna configuration. Joint proportional fair scheduling algorithm is utilized for resource allocation in combination with load and desired fairness levels so as to maintain balance among throughput maximization and minimum fairness as per user requirements.

Number of requests from UEs for RT and NRT services required for the simulation scenario is assumed to be equal. We have considered that eNodeB is connected to the EPC and each UE is connected to the base station via FDD air interface nonstandalone NR mode. Subcarrier spacing of 240 kHz along with normal cyclic prefix is used. Each frame is divided into 10 subframes with total 224 slots with minimum 25 RBs. All the users are uniformly distributed over the cell radius with traffic volume for each user in the range \([0.2, 0.8]\). We have considered 3GPP extended typical urban (EPA) model within the LTE-A specification. All the users are uniformly distributed around the centrally placed eNodeB over the single cell. The available channel bandwidth is divided into 55 subbands. TTI duration is 1 ms consists of 14 OFDM symbols along with cyclic prefix. 2X2 MIMO physical layer deployment with transmit and receive correlation effects ISI and ICI reduction in OFDM-based system. Feasibility of the proposed algorithm is evaluated in 5G network along with simulation parameters as listed in Table 2. In order to measure the performance of the MJUCS algorithm, we compare with JUCS algorithm with respect to throughput, end-to-end delay, and spectral efficiency.

### Table 2 Simulation parameters

| Parameters                  | Simulation values                        |
|-----------------------------|------------------------------------------|
| Cell radius                 | 2 km                                     |
| Carrier frequency           | 2 GHz                                    |
| Multipath model             | 3GPP model                               |
| Modulation and coding scheme| Adaptive modulation and coding            |
| Duplexing mode              | FDD                                      |
| Antenna types               | 2X2 MIMO                                 |
| eNodeB                      | Max. Tx power 40 W/43 dBm                |
| User equipment              | Max. Tx power 200 mW/23 dBm              |
| Scheduling algorithm        | Joint proportional fair                  |
| Number of eNodeB            | 1                                        |
| Number of users per sector  | 30, 40, 50, 65, 75, 80, 95, 100          |
| Modulation                  | 16, 64QAM                                |
| Channel bandwidth           | 100 MHz                                  |
| Bearer type                 | Vary (QCI 1 to QCI 9)                    |
7.2 Result analysis

The MJUCS algorithm based on OFDM system is designed and simulated using MATLAB LTE tool box. Initially performance of the proposed algorithm is evaluated with conventional unidirectional scheduling scheme in 5G networks and later MJUCS performance is compared with JUCS. The average throughput of the MJUCS scheme as a function of the number of active users is presented in Figure 3A. MJUCS algorithm uses joint PF scheduler, which provides best throughput performance because of the exploitation of the multicarrier diversity.

The average throughput for RT and NRT services satisfy all the traffic class users. However, when the number of users increases, the PF scheduler sacrifices throughput to provide best fairness among the users. In a dense network, due to the favorable channel propagation condition, the scheduler allocates all available RBs with highest MCS to meet the desired data rates. Figure 3B,C represents the average delay per user and the service coverage, respectively. When the arrival rate is low irrespective of the service type, the delay and service coverage graphs behave as constant lines due to CA. As traffic arrival rate increases, all the traffic class cannot be serviced completely and some of the users are fed into queues thus increases the delay. MJUCS explore MIMO diversity effectively as compared with conventional scheme, which results in reduced slope over the average delay per traffic class. Users with NRT service requests are the sufferers due to the RT service delay and QoS provisions. Since the priority of the RT services will be high for all the QCI traffic class, the slope of the delay and service coverage are moderate when compared with best and NRT service users. The advantage of the MJUCS algorithm is noticeable in service the coverage graph. All the RT and NRT services for the users using MJUCS have average throughput 3.6 and 3.3 Mbps, respectively. This plays important factors in QoS provision for dynamic traffic services when the arrival rate is high.

The average throughput of the MJUCS algorithm for different traffic classes is depicted in Figure 4. We have considered the first nine QCI traffic classes for the simulation, are categorized as RT and NRT services. The application of higher modulation scheme for each traffic class results in the improved throughput. OFDM-based physical layers have to transmit on MIMO multipath model transforms and spectral components with higher SNIR, which result in significant performance gain in terms of throughput per flow for all the traffic classes.

The combination of higher spectral confinement and low powered payload transmission will provide brute spectral efficiency which in turn improves the CC allocation during scheduling phase. Figure 5A,B represent the throughput and spectral efficiency as the function of different SINR. Since the ETA channel model is characterized by low MIMO correlation profile, maximum SINR obtained for the given configuration is 25 dB. QCI traffic classes for 7, 8, and 9, the
desired code rate needs higher modulation index. Therefore, for such traffic classes 64QAM modulation is used. However, for lower QCI traffic classes we use 4QAM modulation.

Figure 6A,B show the UL and DL data rates for the proposed MJUCS algorithm with classical independent unidirectional resource allocation scheme, respectively. For simple analysis we have considered 20 users, each user is having separate utility functions with equal rate in UL and DL. We can observe in Figure 6B that, DL data rates is larger than the UL data rates and there is no bound on each direction. For example, user 6, the UL achieved data rates is 6.2 Mbps whereas DL data rates is about 42.3 Mbps. This is completely different in case of MJUCS Figure 6A, the DL data rate is decreased by approximately half whereas UL data rate is doubled. The difference between the DL and UL is

**FIGURE 4** Average throughput of different QCI traffic classes vs number of active users. QCI, QoS class identifier

**FIGURE 5** Effect of SINR on throughput and spectral efficiency of the system. A, Average throughput vs SINR. B, Spectral efficiency vs SINR
FIGURE 6  UL and DL rates. A, MJUCS algorithm. B, Classical independent resource allocation scheme. UL, uplink; DL, downlink; MJUCS, modified joint uplink/downlink (UL/DL) user carrier scheduling

considerably large in conventional scheduling scheme compared with MJUCS algorithm. Although, the classical independent scheduling scheme achieves higher data rate, it might not suitable for multimedia services, where the desired data rate for both the directions are required.

Next, we compare the performance of the MJUCS algorithm with conventional joint scheduling scheme in terms of network parameters. Figures 7 and 8 shows performance of the spectral efficiency and PLR of the proposed system. The MJUCS outperforms the JUCS in terms of spectral efficiency, because of the higher multiple CCs in both directions. In JUCS bandwidth components are allocated in unidirectional and more over they are fixed.

However, in case of MJUCS, bandwidth is dynamically allocated in both directions to the user requirements. One of the major components in measuring the performance of the joint scheduling algorithm is packet loss ratio. PLR plays an important role in QoS provision for the mobile user. Figure 8 represents average PLR of the RT services of the UE for various traffic classes.

Based on the weight factors, MJUCS adaptively updates the priority of the RT users, because of this condition, there is a 16.8% of reduction in the mean PLR for the RT services. MJUCS produces throughput 0.342 Mbps as compared with the JUCS algorithm 0.286 Mbps, because of shared bandwidth in each direction for the resource allocation. Proposed simulation scenario with user’s range 10 to 120, as shown in the Figure 9, throughput meets the designed QoS requirements for the NRT applications.

FIGURE 7  Spectral efficiency
Throughput of the NRT users is directly proportional to the amount of bandwidth allocated during the RRM. The MJUCS performs better when compared with the conventional joint scheduling algorithm in terms of throughput and minimum delay. The simulation results show 36% increase in throughput due to the probability functions of the weight factors.

Figure 10 represents the complexity analysis for the computational time of the MJUCS and JUCS. As the number of UEs increases in particular cell, computational time for both the algorithm will gradually increases. The proposed algorithm has 5.6% central processing unit spent on the scheduling process and JUCS has 16.8%. The average weight
factors will reduce the number of complex multiplications and comparisons performed during transformation of weights into probability functions. Scheduler needs to account only once in the TTI, for the priority of the service requests of UEs for the resource allocation. Therefore, the proposed algorithm not only reduces the complex computations but also minimizes the processing time of the scheduler. End-to-end delay of the real-time services of the LTE-A will be improved from the scheduler.

8 CONCLUSION

A modified joint UL/DL scheduling algorithm is simulated in OFDM-based FDD air interface LTE-A system. This algorithm is focused on bidirectional allocation of radio blocks among the mobile users based on weight factors under the consideration of 5G networks in nonstandalone NR mode. These weight factors will adaptively allocate radio resources to the different traffic class users of RT and NRT service requests for the UEs. For each TTI, weight factors are transformed into probability function for resource allocation based on the QoS requirements from the mobile users. Linear optimization problem of the resource allocation policy is solved using suboptimal logarithmic functions. The proposed algorithm will effectively utilizes the probability functions of the user’s utility functions to perform radio resource allocation for the RT and NRT services, which results in increased spectral efficiency, reduced delay among the end users of the LTE system. Simulation results show that, the MUJCS algorithm balances the allocation of resources to maximize the user utility metric for multimedia applications. Optimization of priority functions improves the performance of the network in terms of throughput along with reduced computational complexity of the joint scheduling process. In future bidirectional scheduling schemes will play an important role in satisfying the QoS provision of users in HetNets. In this network architecture small radius femto cells are overlaid on existing macro cell to improve the indoor communications. Most of the traffic generated from the upcoming 5G networks will be indoor communication. Bidirectional scheduling policies provide better solutions to indoor communication but also exhibit more challenges to the scheduler due to the different access mechanism, strategies, power constraint among macro and femto base stations.

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