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Design of dynamic resource allocation scheme for real-time traffic in the LTE network

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Abstract

The 5G wireless technology is recently standardized for meeting intense demand. The Long Term Evolution (LTE) technology provides an easy, time-saving, and low-cost method for deploying a 4G/5G network infrastructure. To support multimedia service and higher bandwidth data delivery, an LTE MAC layer has Quality of Service (QoS) support with several QoS class indicator (QCI) levels. Based on LTE current QCI priority and QoS requirements in UEs, the original Max-Rate scheduler, Proportionally Fair (PF) and Modified Largest Weighted Delay First (M-LWDF) algorithms could not achieve their goal owing to the UE's dynamic physical capacity with a different Channel Quality Indicator (CQI) at run time. For better QoS service than LTE networks, per UE's CQI state for each resource block (RB) must be considered simultaneously in LTE MAC layer resource allocation with cross-layer support. As downlink real estimated capacity is dynamic owing to a UE's periodic CQI reporting, the CQI state in LTE scheduling must be considered. This study proposes a smart and flexible scheme for Enhanced Utilization Resource Allocation (EURA) including three novel mechanisms that can dynamically fit UEs' CQI states. The simulation results in this study demonstrate that the proposed EURA scheme outperforms the contrast schemes (Max-Rate, EXP/PF and M-LWDF), can save more rare radio capacity, and improve the utilization of radio resource assignment.

Keywords: 4G/5G, Scheduling, Cross-layer QoS, EURA, Resource allocation

1 Introduction

Mobile networks are rapidly evolving and evident in the transitioning from *fourth generation (4G)* to the fifth generation (5G). Following the blooming markets of cellular phone networks and popular Internet services, mobile high-bandwidth data communication is becoming a new and promising business niche. For many network connection requirement users, it is the basic target for advanced wireless technology venders to provide wireless network services anytime and anywhere. Therefore, wireless technology for the *fourth generation (4G)* of wireless broadband communications has been standardized in recent years. *Long Term Evolution (LTE) and LTE-Advanced (LTE-A)* [1–6] is commercially deployed in many countries. LTE offers traditional voice telephone service and provides a cost-effective broadband communication service. The *Third Generation Partnership Project (3GPP)* formally recognizes the LTE platform as the technology standard for wireless communications. Since LTE standard is defined by telecom vendors and is backward compatible with the GSM or UMTS cellular systems, its deployment is much easier than with traditional IEEE wireless network technology. Moreover, the latest *fifth-generation (5G)* combined with *Device-to-Device (D2D)* communication technology is used to improve transmission quality for users, and it achieves better performance even in high-speed movement. Therefore, the 5G *new radio (NR)* 3GPP standard has already regarded D2D as an extremely important application scenario in the communication technologies of *release 15* [7, 8] and *16* [9, 10]. At present, 4G LTE networks and 5G NR cooperate with each other and provide mobile network services. MAC layer data scheduling in 4G LTE and 5G NR has many technologies in common. This study first discusses how to design a mechanism to allow data transmission scheduling to concurrently support *Quality of Service (QoS)* within a MAC layer in an LTE architecture when the real radio capacity of multiple mobile users changes dynamically.

Based on *GPRS (2.5G)* and UMTS network technologies, both the core network (Evolved Packet Core, EPC) and radio access (Evolved Universal Terrestrial Radio Access Network, E-UTRAN) in LTE are completely packet-switched models. Moreover, LTE is designed to work with different bandwidths and provide a peak data rate at 100 Mbps in a downlink and 50 Mbps in an uplink. To support multimedia services and high-bandwidth data delivery, an LTE MAC layer supports QoS with different *QoS class indicator (QCI)* levels. Therefore, some researchers have tried to adopt the *maximum throughput (MT)* [11, 12] as Max-Rate scheduler or *Proportionally Fair (PF)* [13] or *Modified Largest Weighted Delay First (M-LWDF)* [14] algorithm as LTE MAC scheduling scheme in *Evolved Node B (eNB)* to maximize throughput or allocate a fairness bandwidth or delay budget with weight consideration for many mobile users. However, based on LTE current QCI priority and QoS requirement in UEs, the original MT scheduler cannot achieve maximization throughput due to a run-time UE's dynamic capacity with a variation *Channel Quality Indicator (CQI)*. In addition, although the traditional PF algorithm can achieve the fairness of the rate between different UEs, and the reference of rate corresponds to the number of sub-*resource blocks (RBs)*, in a wireless network environment, the same number of RBs may occur owing to changes in CQI over time. However, an actual UE's assigned rate cannot reflect an actual situation.

To identify the real RBs' resource state in wireless network, some researches [15–17] had proposed the dynamic resource allocation schemes to calculate both PHY and MAC layer resources simultaneously. For providing better QoS service over LTE networks, per UE's CQI state for each RB should be considered simultaneously in LTE MAC layer resource allocation (Fig. 1). It is necessary to consider the CQI state in LTE eNB scheduling. The *Enhanced Utilization Resource Allocation (EURA)* scheme has been proposed in this study. Furthermore, three novel mechanisms in the proposed EURA scheme can dynamically fit UEs' CQI state. The proposed EURA scheme with three mechanisms can improve the utilization of an LTE radio resource. The main contributions of the paper are summarized as follows.

- We propose the idea of considering both the UE's CQI states in each RB and overall RBs resource allocation for real-time traffic flows.

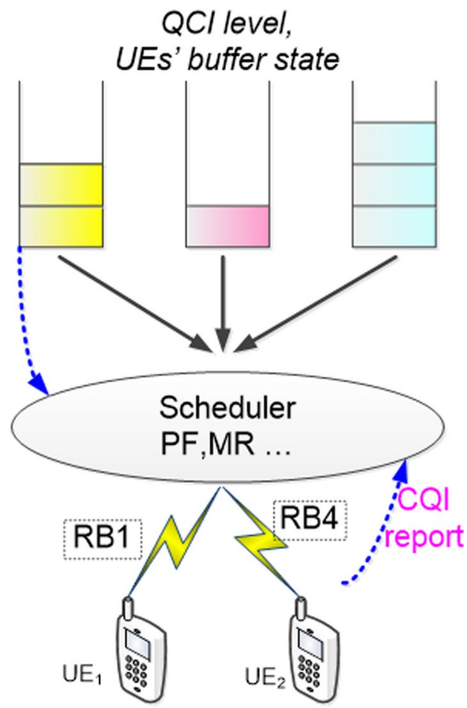

Fig. 1 Diagram of LTE scheduler; Per UE's CQI state for each RB should be considered simultaneously in LTE MAC layer resource allocation

- We propose the idea of Dynamic QCI level adopting policy to aggregate as one QoS group when the total requirement of transmitted data is smaller than total of the RB capacities.
- To allocate RB resources by our proposed EURA scheme with some policies will improve the total utilization of RBs allocation in LTE networks.

This study is organized as follows. LTE MAC technology and some scheduling in an LTE network are briefly introduced in Sect. 2. Method of the proposed EURA scheme for LTE is presented in Sect. 3. Results, simulation study, performance comparison and discussion are listed in Sect. 4. Finally, we will conclude this study in Sect. 5.

2 Related work

2.1 LTE MAC layer

The basic time unit for packet scheduling and transmission in LTE network is called a *transmission time interval (TTI)* with a length of 1 ms. Thus, TTI is the time unit for LTE resource allocation [18]. In each TTI, a scheduling decision is made, in which each scheduled UE is assigned a certain number of radio resources in the time and frequency domain. In the time domain, a TTI is split into two slots (one slot is 0.5 ms). Each slot comprises seven OFDM symbols in the case of the normal cyclic prefix length. In the frequency domain, resources are grouped in units of 12 subcarriers, such that of one unit of 12 subcarriers for a duration of one slot is called an RB, which is the smallest element of resource allocation. The smallest unit of a resource is a *resource element (RE)* that consists of one subcarrier for a duration of one OFDM symbol. Therefore, an RB is comprised of 84 (7×12) REs in the case of the normal cyclic prefix length in Fig. 2.

The channel capacity was assumed to be static for traditional MAC scheduling, and it was revised for LTE network environments. In LTE, an eNB typically selects the *modulation and coding scheme (MCS)* depending on a prediction of the *downlink (DL)* channel condition, which is according to the UE's CQI report transmitted (Fig. 1). The 3GPP LTE has given a table of references for the efficiency of each CQI index [19] (CQI ranges from 1 to 15 by the modulation type of 64QAM, 16QAM, and QPSK) as Table 1.

2.2 Related research

In the field of 4G/5G wireless network research, the research on the scheduling of various MAC layer networks has always been the focus of many researchers, such as the research on handover scheduling in homogeneous or heterogeneous mobile networks [20, 21] and research on multimode QoS guarantee [22–28]. In the LTE mobile network scheduling research field, some research focus on the discussion of uplink scheduling [29, 30], but most of the research focused on downlink scheduling. In addition, to allow mobile users to allocate resources within the limited wireless network bandwidth, it is necessary to incorporate QoS considerations in scheduling.

For the QoS supporting issue, Ali et al. [31] and Jang et al. [32] had proposed different policies for different QoS data traffic types to improve QoS performance, better delay guarantee, and high throughput. Biernacki et al. [33] proposed some fairness algorithms to find a balance between different QoS types traffic to avoid starvation at lower QoS level traffic flows. Considering the scheduling algorithm and QoS support at the same time, Aminu et al. [34] conducted a survey on many scheduling algorithm mechanisms for the LTE MAC layer scheduling mechanism and characteristics of QoS considerations. Some comparative analyses have been performed on their

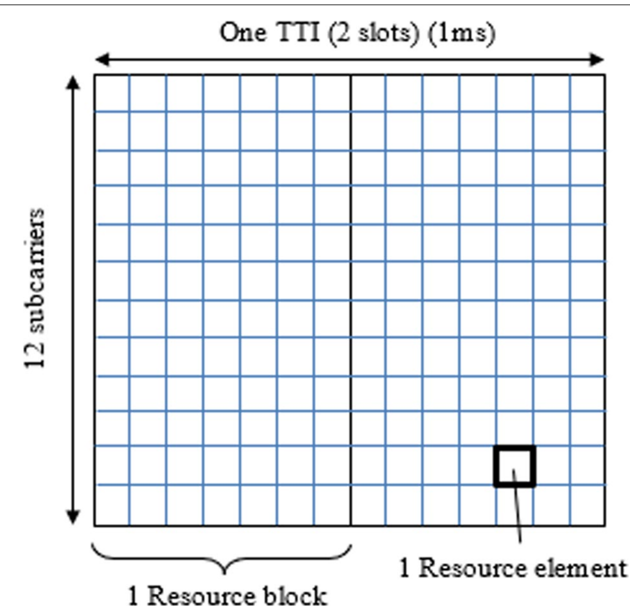

Fig. 2 Basic time–frequency resource structure of LTE TTI [18]; An RB is comprised of 84 REs in the case of the normal cyclic prefix length

Table 1 CQI table by 3GPP [19]

CQI index	Modulation	Approximate code rate	Efficiency (bits/RE)
0	No Tx	–	–
1	QPSK	0.076	0.1523
2	QPSK	0.12	0.2344
3	QPSK	0.19	0.3770
4	QPSK	0.3	0.6016
5	QPSK	0.44	0.8770
6	QPSK	0.59	1.1758
7	16QAM	0.37	1.4766
8	16QAM	0.48	1.9141
9	16QAM	0.6	2.4063
10	64QAM	0.45	2.7305
11	64QAM	0.55	3.3223
12	64QAM	0.65	3.9023
13	64QAM	0.75	4.5234
14	64QAM	0.85	5.1152
15	64QAM	0.93	5.5547

research results to explore the various parameters of the various downlink scheduling algorithms for resource allocation. Deniz et al. [35] mainly used the *mobile user (UE)* role at the edge to further explore different resource allocation scheduling algorithms. In the consideration of throughput and fairness, the advantages and disadvantages of each are discussed. The mechanism proposed by the author can simultaneously consider two performance parameters and have fairly good performance results. Nasralla et al. [15] discussed and analyzed many current QoS-aware downlink scheduling algorithm mechanisms in LTE networks and divided these mechanisms into four main classes, namely, delay aware, queue aware, target bit rate aware, and hybrid aware. They also proposed to use the hybrid aware category as a conceptual mechanism to design a resource allocation scheduling algorithm that considers QoS while also taking into account fairness. In doing so, there can be a certain degree of scheduling fairness in the face of real-time and non-real-time traffic.

On top of that, for the UEs' location and radio link channel conditions to be time-varying in practice, the MAC layer and PHY layer state should be considered simultaneously. Chang et al. [16] proposed an adaptive cross-layer packet scheduling to guarantee real-time high-speed packet service for LTE-Advanced network. The proposed scheduling can apply both radio resource allocation at the PHY layer and adaptive packet scheduling at the MAC layer simultaneously. Moreover, the proposed scheduling can outperform the compared approaches in system capacity, packet dropping probability, average packet delay. Liu [36] developed a dynamic resource allocation algorithm for the downlink transmission which involves RBs, component carriers, modulation and coding schemes, and frequency partitions with an overall consideration. Author considered not only to determine the multiple kinds of resources at each transmission time interval, but also to enforce the constraints specific to the LTE-A network. In addition, a Lyapunov optimization framework with submodular-based greedy algorithm to resolve the high dimensional NP-hard allocation problem had been designed in this article. It can make a good performance tradeoff between throughput and stability for in the multi-tier heterogeneous wireless network environment. Zhang et al. [17] focused on physical layer resource and power allocation for *non-orthogonal multiple access (NOMA)* in heterogeneous network. Authors investigated the resource optimization problem of NOMA heterogeneous small cell networks with simultaneous wireless information and power transfer. A power optimization algorithm was proposed using Lagrangian duality to maximize the energy efficiency. Zhang et al. [37] considered both the physical and MAC layers resource with power allocation for NOMA in *Unmanned aerial vehicles (UAVs)* network. Authors designed for maximizing energy efficiency with dynamic adjusting based on radio link *channel state information (CSI)* in the limited resource and power UAV network. A suboptimal power allocation algorithm was proposed using with *successive convex approximation (SCA)* method to have better performance than existing algorithm. Selim Demir et al. [38] provided a cross-layer resource management mechanism for an indoor multiuser *visible light communication (VLC)* access network. Authors had formulated and investigated a stochastic cross-layer optimization problem to optimize the network resources under the constraints of queue stability and power. Moreover, the proposed scheme with admission control, GA-based resource allocation and power control can maximize the total system throughput and have better performance than other algorithms. Fang et al. [39] focused on energy-efficient resource allocation for a NOMA and *multi-access edge computing (MEC)* network with imperfect CSI. In addition, each user can upload its tasks to multiple *base stations (BSs)* for remote executions. Authors had investigated the one-user two-BS case and derived the optimal closed-form expressions of task assignment and power allocation via the bilevel programming method. The proposed algorithm can have better performance than the conventional OMA schemes.

The relation between QoS level and UE's CQI state is quite important for QoS supporting. How to improve the LTE overall system performance under fairness, channel state, and bandwidth constraints is a complicated job for the eNB allocates the appropriate resources for many UEs in each TTI. Many dynamic resource allocation and cross layer resource management schemes have been proposed for wireless networks. To consider cross QoS level UEs' resource allocation is also necessary to provide better QoS service and improve total radio resource utilization over LTE networks. Per UE's CQI state for all RBs should be considered simultaneously in LTE MAC layer resource allocation (Fig. 1). Nevertheless, each RB only can be allocated for one UE in a TTI scheduling, inter-UEs for inter-RBs resource allocation should be considered at the same time. So far the effective use of scarce radio resources for many UEs' allocation has not been further discussed in detail on previous studies. This study will further explore and focus on this point.

3 Methods: enhanced utilization resource allocation (EURA) scheme

Estimation of the channel capacity depends on the CQI reports from a UE, meaning that different UEs would have different views of the channel capacity (e.g., RB1 to RB6, as bottom part of *Part 0 of* Fig. 3). Since current per RB capacity via each

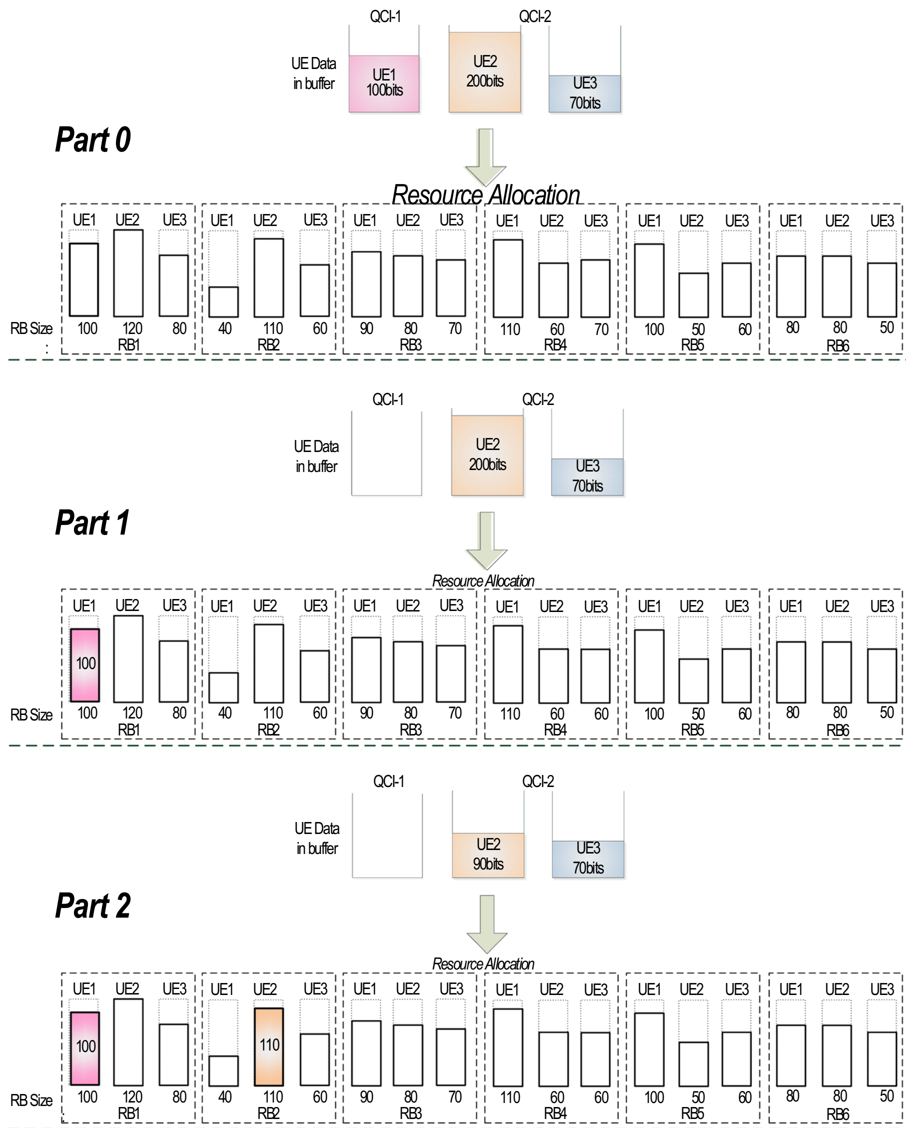

Fig. 3 Example of traditional resource allocation with QCI priority consideration; Example case of LTE resource allocation in the MT scheduler with the priority queue scheme

UE is dynamic, it is important to schedule these DL RBs for meeting a UE's requirement appropriately. For LTE resource allocation in the MT scheduler with the priority queue scheme, the higher priority level of QCI-1 data (UE1 in Fig. 3) must be scheduled first. For example, the ideal capacity of the dotted line of RB is 120 bits; however, the real RB capacity depends on each UE's CQI report, which is the solid line of RB as illustrated blocks in Fig. 3. Therefore, the 100 bits capacity of RB1 is allocated to the UE1's data requirement as *Part 1 of* Fig. 3. Then, to fit the respective UE2 200 bits and UE3 70 bits data (in Fig. 3) will require the lower priority level, QCI-2. All the remaining RBs (RB2, RB3, RB4, RB5, and RB6) also must be assigned as *Parts 2-6 of* Fig. 3. Finally, the case of three UEs' resource allocation scenario is shown in Fig. 3. In the

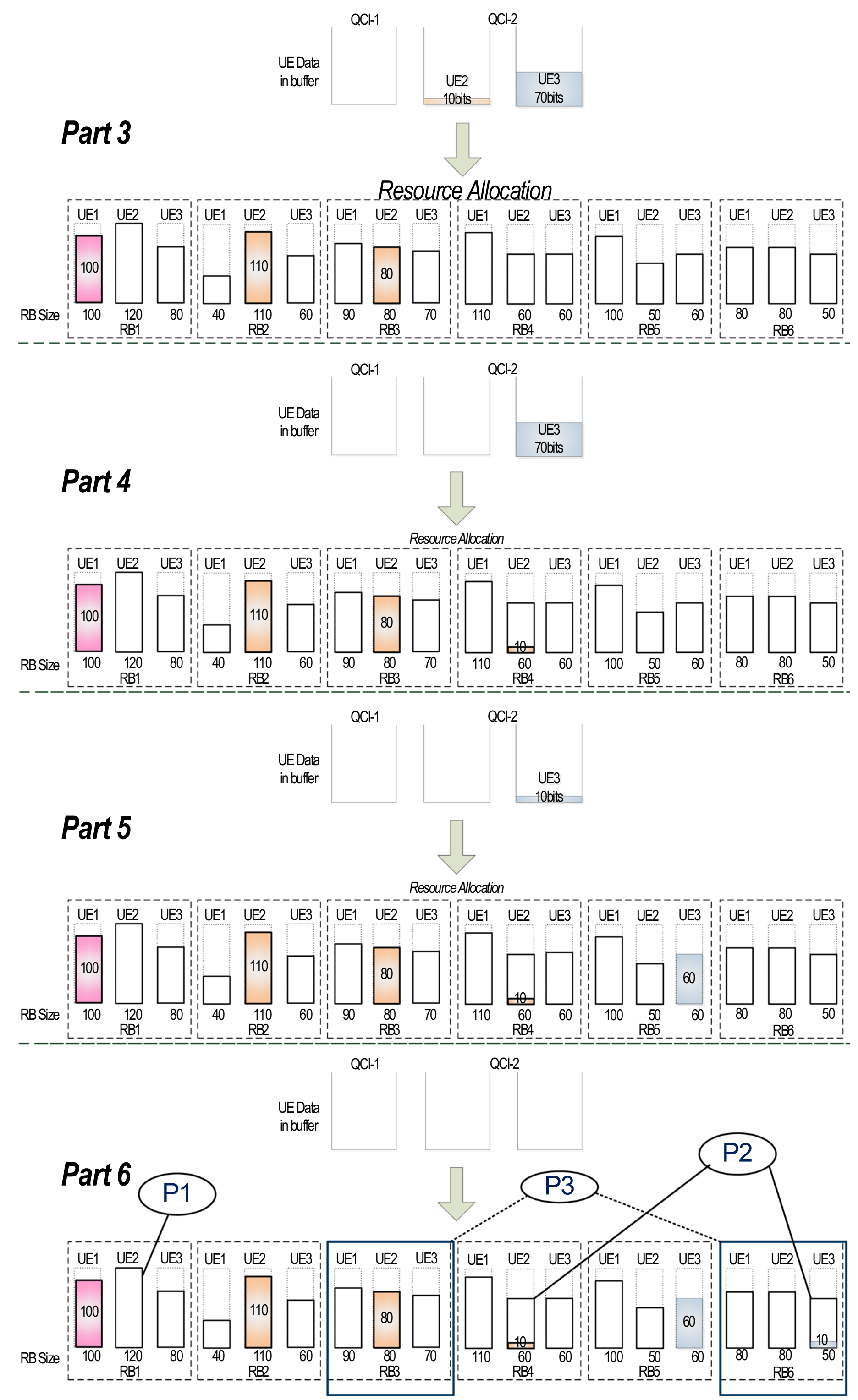

Fig. 3 continued

example, there are six assigned RBs at the adopting scheme of the MT scheduler with a priority queue. Some problems are listed as *P1*, *P2*, and *P3* in *Part 6 of* Fig. 3. The highest capacity size RB (RB1 for UE2) cannot be allocated as *P1 problem*, no choosing policy when assigning RB3 or RB6 for UE2 as *P3 problem*, it might save one free RB5 when assigning RB6 for UE2, and RB3 for UE3's total 70 bits data requirement; moreover, some remaining useless capacities can be found in RB4 with UE2 and RB6 with UE3 as *P2 problem*. To allocate RB resources with some policies will improve the utilization of RBs allocation in LTE networks.

3.1 Basic idea

Since each UE DL real capacity is dynamic owing to UE's periodical CQI reporting, it is necessary to consider state in LTE scheduling. Our proposed EURA scheme can dynamically fit UEs' CQI state to improve the performance of LTE wireless capacity. Initially, if the total UE requirement data is not in heavy load state, the QCI priority queue rule will not need to be adopted as *Dynamic QCI level adopting* checking policy in our proposed EURA scheme. For RBs allocation, the better UE CQI state in RBs should be assigned in advance to prevent the *P1 problem* in Fig. 3. The first idea of the proposed mechanism is *Larger RB capacity first*. Second, if there are two or more RB candidates for assignment, fitting the UE's data requirement should be assigned first, which might decrease occurrence rate as *P2 problem* in Fig. 3. The second idea of the proposed mechanism is *Lower remaining RB space first*. Finally, if there are more than one suitable RBs for selection, a lower combined other available RB capacity (i.e., the lower total available space of other UEs in this RB) would be assigned first to reduce further side effect as *P3 problem* in Fig. 3. The third idea of the proposed mechanism is *Lower useless RB capacity first*. For regular LTE resource allocation, our proposed EURA scheme includes these one checking policy and three novel mechanisms in Figs. 4 and 5. The details of mechanisms are in the next section.

3.2 EURA

An optimal RBs allocation solution EURA is proposed in this study without using traditional QCI level option in the condition of which the total UEs data requirement is lower than radio deliver capacities. When the total data amount to be transmitted is smaller than the total of the RB capacities, QCI level is not necessary for LTE MAC scheduling as illustrated in *Part 0 of* Fig. 6. Using EURA, the largest amount of data in a UE buffer is allocated to one of the RBs. If the largest data in this UE is greater or equal to one of the RB that has the largest space, the data is sent to this RB; otherwise, it is sent to one of the smallest RBs that has enough space for data from a UE buffer. In *Part 0-1 of* Fig. 6, the largest amount data is 200 bits in UE2 and 120 bits of them are transmitted to RB1 that has 120 bits space, which is the largest one. The remaining 80 bits data are left in UE2. Further, the maximum amount of data is 100 bits in UE1. RB4 has 110 bits space for UE1, but it is not the smallest one. Therefore, data in UE1 is then transmitted to RB5 that has 100 bits capacity as shown in *Part 1-2 of* Fig. 6. To prevent other UEs from having the opportunity to use higher RB space in future so 80 bits in UE2 is sent to RB6 rather than RB3. Finally, the 70 bits in UE3 is transmitted to RB3.

The EURA algorithm is summarized as follows.

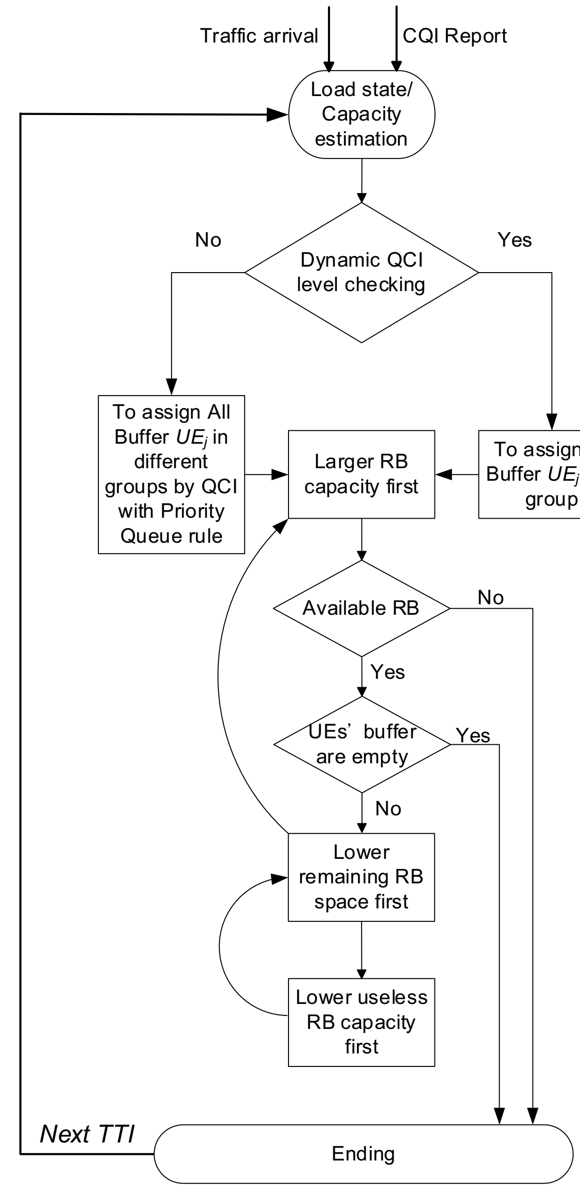

Fig. 4 Overview of EURA scheme algorithm; Diagram of our proposed EURA scheme includes these one checking policy and three novel mechanisms

- EURA can be applied without the priority of QCI level when the total data amount to be transmitted is smaller than total of the RB capacities based on the *Dynamic QCI level adopting* policy.
- The maximum amount of data in one of the UE buffers is allocated to one of the RBs in a group.
- If the largest data in this UE is more than or equal to one of the RB capacities that has the largest space, the data is sent to this RB in this TTI, and it is the *Larger RB capacity first* mechanism.

```
1. Load state / Capacity estimation: Estimate the current buffer data rate of each UE = λj.
2. Dynamic QCI level checking: Checking total buffer data rate with threshold Sch_Thr,
   if total buffer rate of UEs' λj ≤ Sch_Thr{
           to assign all UEj in a scheduling group
   }else{
           to assign all UEj in different groups based on UE's QCI level
   }
3. Large RB capacity first:
   for (K =1; K ≤ maximum number of groups; K++){
           3-1.
           while all group UEs' buffers are not empty and unassigned RB ≥ 1{
                   check all unassigned RB for each UE when its buffer is not empty and then
                   determine the highest radio quality UE as UEh
                   determine UEh's buffer data as Buffer_UE
                   for (i=1; i ≤ maximum unassigned RB; i++){
                           SpaceRBi = space of UEh's RBi
                           if the SpaceRBi ≤ Buffer_UE{
                                   FirstLevelRB = 1
                                   CandidateL1RBi = SpaceRBi
                           }else{
                                   SecondLevelRB = 2
                                   CandidateL2RBi = SpaceRBi
                           }
                   }
                   go to step 4
           }
   }
4. Lower remaining RB space first:
   descending sort CandidateL1RBi, ascending sort CandidateL2RBi
   if FirstLevelRB == 1{
           if the number of maximum CandidateL1RBi ≥ 2{
                   go to step 5
           }
           4-1.
           assign the space of RBi to UEK
           UEK = UEK - CandidateL1RB
           UEh's buffer data = Buffer_UE - CandidateL1RB
           go back to step 3-1
   }elseif SecondLevelRB == 2{
           if the number of minimum CandidateL2RBi ≥ 2{
                   go to step 5
           }
           4-2.
           assign the space of RBi to UEK
           UEh's buffer data = 0
           go back to step 3-1
   }
5. Lower useless RB capacity first:
   calculate the RB useless capacity of RBi of CandidateL1RBi or CandidateL2RBi (the RBi radio space
   for other UEs without UEh) as L1UselessRBi or L2UselessRBi
   if number of minimum L1UselessRBi ≥ 2{
           return the lowest RB serial number i and go back to step 4-1
   }elseif number of minimum L1UselessRBi == 1{
           return the serial number i of minimum L1UselessRBi and go back to step 4-1
   }elseif number of minimum L2UselessRBi ≥ 2{
           return the lowest RB serial number i and go back to step 4-2
   }else{
           return the serial number i of minimum L2UselessRBi and go back to step 4-2
   }
```

Fig. 5 Pseudo-code of EURA scheme; Pseudo-code of our proposed EURA scheme includes these one checking policy and three novel mechanisms

- If the largest data in this UE is less than or equal to at least one RB capacity, data is sent to the smallest unallocated RB, and it is the *Lower remaining RB space first* mechanism.
- If there are two or more available candidate RBs, to choose the RB that can fit the UE's data requirement with lower other UE's RB useless capacity should be assigned first, it is the *Lower useless RB capacity first* mechanism.

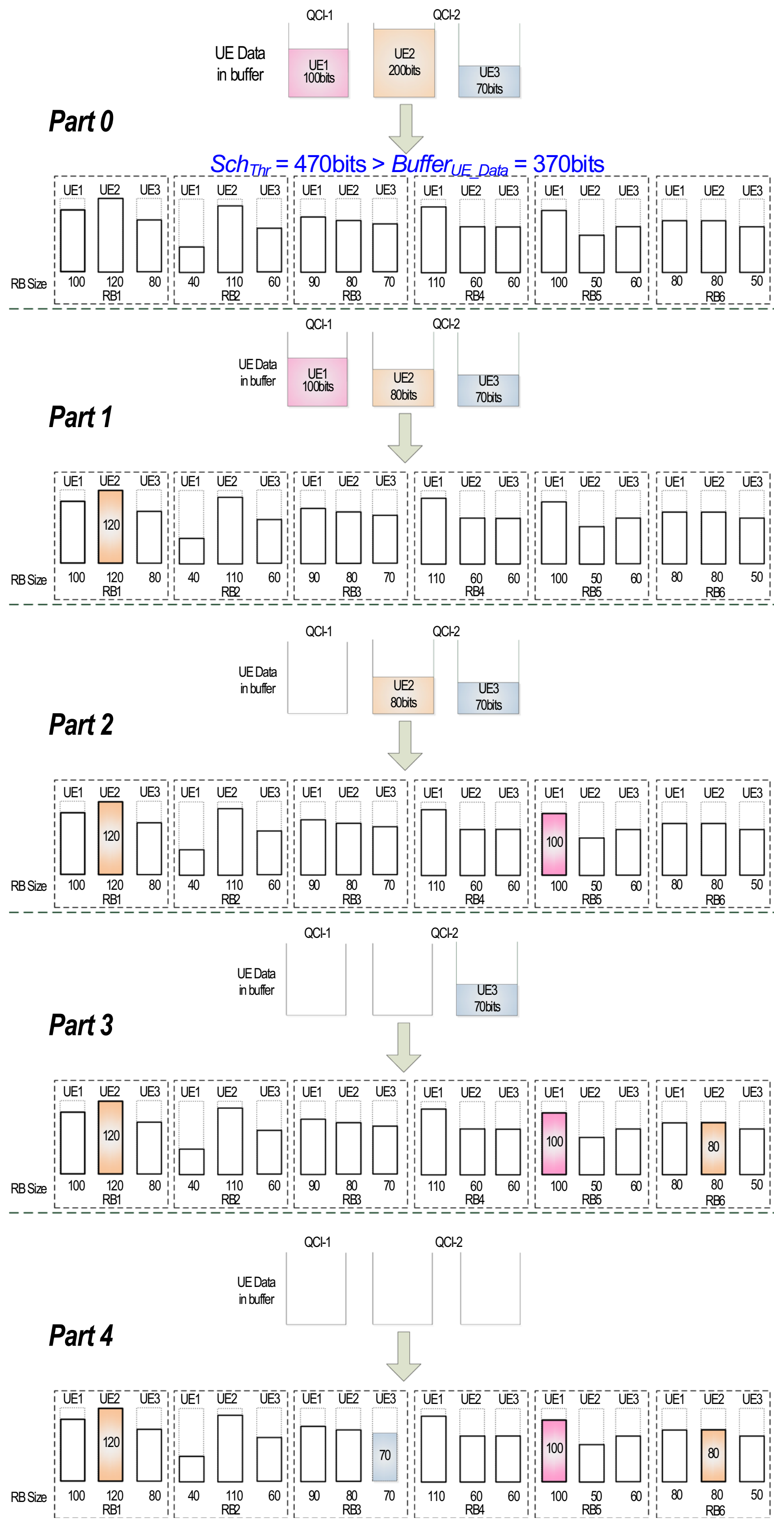

Fig. 6 Example of proposed EURA resource allocation scheme; Example case of our proposed EURA resource allocation scheme

Compared with the MT scheduler with the priority queue scheme (Fig. 3), our proposed EURA scheme with three mechanisms will have two more free RBs space for the abovementioned case (as shown in Fig. 6). Therefore, our proposed scheme can improve RBs utilization. It would also save more RB space for further resource allocation in 4G/5G networks.

3.2.1 Dynamic QCI level adopting

Since the channel capacity varies owing to the adaptively selected MCS for each UE. The estimation of the channel capacity for RB_i from UE_j*'s* CQI report as $CQI_{i,j}$. In CQI report, the UE reports a CQI value for each RB. Notations used in the estimation of the all RB capacity for UE_j are defined as follows and also illustrated in Fig. 7.

$N_{\mathrm{OFDM}}^{\mathrm{TTI}}$: The number of OFDM symbols (REs) in a TTI that are 14 in the case of the normal cyclic prefix length.
$N_{\mathrm{OFDM}}^{\mathrm{Ctrl}}$: The number of OFDM symbols used by the control channels in a TTI.
$N_{\mathrm{OFDM}}^{\mathrm{Resv}}$: The number of OFDM symbols reserved for reference signals in a TTI of 12 subcarriers.

Note that the two RBs in a TTI of 12 subcarriers are called the *RB group (RBG)* in the study. Therefore, the number of REs for the user data in an RBG, denoted by $N_{\mathrm{RE}}^{\mathrm{NTT}}$, is calculated as follows.

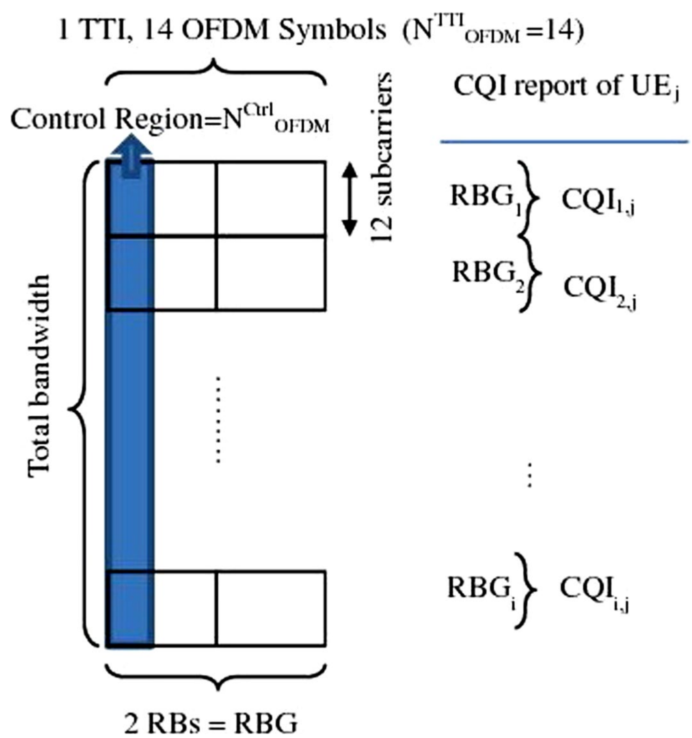

Fig. 7 Notations used in RB capacity estimation; Notations used in the estimation of the all RB capacity for UEs are defined and illustrated

$$N_{\text{RE}}^{\text{TTI}} = (N_{\text{OFDM}}^{\text{TTI}} - N_{\text{OFDM}}^{\text{Ctrl}}) \times 12\,(\text{subcarriers}) - N_{\text{OFDM}}^{\text{Resv}} \tag{1}$$

For the CQI report, each RB channel capacity estimated for UE_j in an RBG_i, denoted by $C_{i,j}^{\text{RBG}}$, is calculated as follows.

$$C_{i,j}^{\text{RBG}} = N_{\text{RE}}^{\text{TTI}} \times \text{Eff}(\text{CQI}_{i,j}) \tag{2}$$

The function of $Eff(CQI_{i,j})$ in Eq. (2) returns the efficiency value for the given CQI value $CQI_{i,j}$ according to Table 1 in the system. Based on this, N_{RBG} is the total number of RBG in the system.

For the case of the full-Sub-band report, note that $CQI_{i,j}^{S_k}$. is the CQI value for Sub-band S_k, the channel capacity estimated for UE_j. in a TTI, denoted by C_j^{Report}, is calculated as follows.

$$C_j^{\text{Report}} = \sum_{\forall S_k} \left(N_{\text{RE}}^{\text{TTI}} \times \text{Eff}\left(CQI_{i,j}^{S_k} \right) \times N_{RBG} \right) \tag{3}$$

As the estimation of the traffic load for a UE, the estimation of the current channel capacity for UE_j, denoted by C_j, is calculated by exponentially averaging the samples of each calculation. The channel capacity for all UEs is calculated by combing the channel capacity estimated by each UE with the ratio of the UE's traffic load in the group. The channel capacity (bits/TTI) f all UEs, denoted by $C_{Channel}$, is calculated as follows:

$C_{\text{Channel}} = \sum_{\forall UE_j} \left(C_j \frac{\lambda_j}{\lambda} \right)$, where λ is the total DL load, and λ_j. is the current load of UE_j. Because we can use Eq. (4) to calculate the average data rate that all RBs of the current TTI can provide, and through a weighted value β in the formula, we can make dynamic adjtments.

$$Sch_{Thr} = \beta \times C_{\text{Channel}} \tag{4}$$

Thus, we can refer to the first step *"Load state/Capacity estimation"* in our proposed EURA scheme, as shown at the top of Fig. 4. We compare the current usable bandwidth space calculated using Eq. (4) with the amount of all UE buffer data in each TTI period in the eNB. If the bandwidth is sufficient (Fig. 4, *"Dynamic QCI level checking"* and *"Yes"*) as the result of Eq. (5). In fact, at this time, not necessary to consider the QCI weights between different UEs, i.e., all UEs are regarded as the same priority group so that the overall radio resources can be used most effectively.

$$Sch_{Thr} \geq \text{Buffer}_{\text{UE\_Data}} \tag{5}$$

3.2.2 Larger RB capacity first

If there are more than one UEs groups after the dynamic QCI level adopting procedure, the allocated sequence based on group priority. In a UEs group, we will schedule according to the amount of UE buffer data, and the largest amount of buffer data will give priority to the allocation of RB radio resources. When the highest priority

UE has many RB candidates can be selected for resource allocation at the same time, the largest RB will be effectively allocated to achieve the goal of high-quality RB space allocation in advance in *Part 1 of* Fig. 6.

3.2.3 Lower remaining RB space first

To find an appropriate RB assignment rule is very important for improving RB resource allocation in our proposed EURA scheme. When it is necessary to allocate the highest UE buffer data volume, if there are multiple RBs whose capacity is greater than or equal to the space requirement of the UE buffer, we should give priority to one sufficient RB space to avoid leftovers. The main reason is that one RB can only be allocated to one UE in the same TTI, and this mechanism is called *Lower remaining RB space first*. Through this mechanism, the precious RB radio space can be used very effectively. In *Part 1 and Part 2 of* Fig. 6, the RB5 will be allocated for UE1 to avoid 10 bits useless space for RB4 allocation; furthermore, the remaining data of UE2 will be assigned to RB3 or RB6 as there would be 30 bits useless space for RB2 assignment.

3.2.4 Lower useless RB capacity first

A better allocation decision for LTE MAC scheduling could increase DL utilization when there are two or more free RB candidates for resource allocation. Our proposed *Lower useless RB capacity first* mechanism would reduce the issue of wasted RB resource in the next schedule. When UE buffer data needs to be allocated, if there are more than two RBs with the same RB capacity to choose from, we will give priority to the RB that is poor in quality compared to other UEs because it has less capacity. This will avoid the need to use more RBs when scheduling in future. Moreover, according to the 80 bits in UE2 to be transmitted, there are four RBs candidates as RB2, RB3, RB4, and RB6 (*Part 2 of* Fig. 6) can be chosen. According to the principle of "lower remaining RB space first" in Sect. 3.2.3, we will only consider RB3 and RB6. When it is all 80 bits, each RB cannot be used by other UEs after it is selected for one UE. Therefore, the least unusable space, in theory, is allocated by RB6 (RB3 90+70, RB6 80+50) as shown in *Part 3 of* Fig. 6. However, if we do not adopt this mechanism, suppose RB3 is allocated to UE2 instead, and when the subsequent UE3 is to be allocated, two of RB2, RB4, and RB6 must be selected to transmit all the data of UE3.

4 Results and discussion

4.1 Experiment setup and performance criteria

In Fig. 8, the simulated network environment consists of one LTE-A eNB and maximum 20 UEs. Each UE traffic flow contains audio and video and has different packet sizes for different types of traffic flows. Different UEs present the level of a traffic load. In this simulation environment, the theoretical load value is $\rho = 0.25$, number of UEs is 20, and each RB can provide the optimal ideal value capacity of CQI-15 in Table 1 for calculation. However, the load in the actual simulation environment will be higher than usual. The main reason for this is that each RB will be calculated based on the changes in the actual reported CQI due to the different locations of the UEs. Therefore, the RB capacity that can be actually used must be much smaller

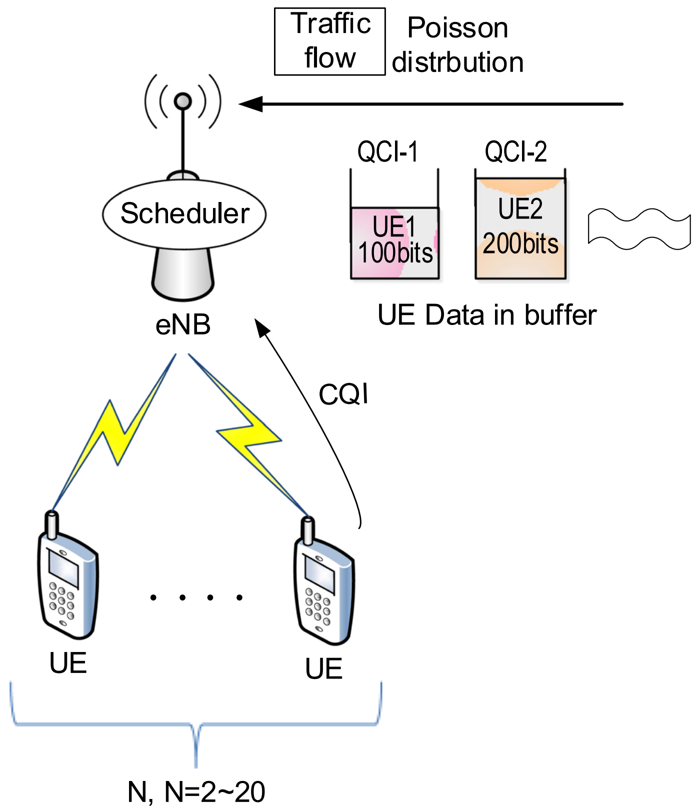

Fig. 8 Simulation architecture; The simulated network environment consists of one LTE-A eNB and 20 UEs

than the ideal value. In the simulation results, we can find that traffic load $\rho > 0.9$ in the heavy load situation when UE = 20. In the dynamic QCI level adopting mechanism in Sect. 3.2.1, we set the parameter β in the threshold of Sch_{Thr}, and what would be a better value for parameter β? Estimation it in a simulated experimental environment, we assume that β is *1-2*. When β is *1*, it means that there is a *50%* theoretical probability that Eq. (5) is found, and when β is *1.2*, it is *60%*, when β is *1.4*, it is 70%, and when β is *1.6*, it is *80%*. When β is *1.8*, it is *90%*, and when β is *2*, it is 100%. By estimating the experimental hit rate results as shown in Fig. 9, we found that setting β to *1.8* yields the highest success rate; therefore, in our experiment, we will use $\beta = 1.8$. Other simulation parameters are shown as Table 2. A simulation study is conducted to evaluate the performance of our proposed EURA scheme, the Max-Rate scheduler [12] can have MT feature, the EXP/PF [33] can have fair allocation schedule with lower delay and the M-LWDF can achieve delay budget with fair weight consideration as two-way resource allocation schedule that the three contrast schemes are also simulated. For the EURA algorithm we proposed, we mainly hope to improve the utilization of the entire RB and prevent the delay of the UE from increasing considerably. Therefore, in the simulation, the main goal is to understand the use of RB capacity in the entire resource allocation. In addition, delay and

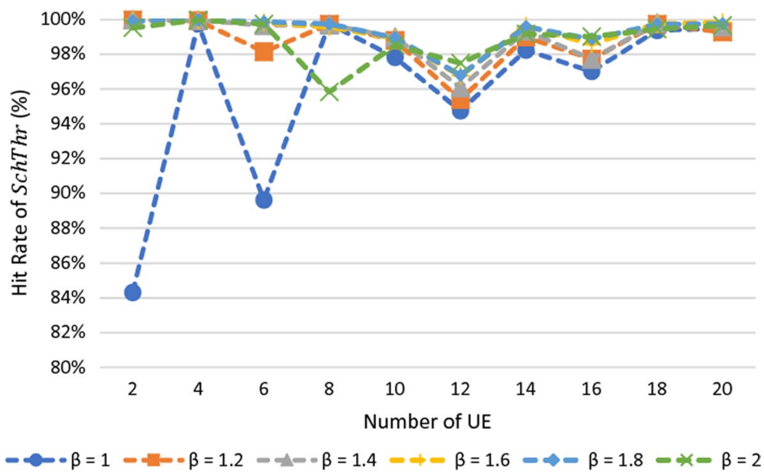

Fig. 9 Hit rate of Sch_{Thr} larger than $Buffer_{UE\_Data}$; Estimating the experimental hit rate results for different values

Table 2 Simulation parameters

Parameter	Value
System capacity	19.3 MHz
# UE	2–20 (equal load)
QCI type	QCI-1–QCI-4
# RB in a TTI	100
CQI value of RB	Uniform distribution
The value of β	1.8
CQI reporting type	All feedback
Packet size of audio traffic	180 bits
Packet size of video traffic	8000 bits

throughput for commonly used traffic flow are also topics that we need to discuss. The five parameters in the simulation experiment are described as follows.

- *Residual RB (%)* that is the average percentage of unallocated number of DL RB in a TTI.
- *Residual Capacity (bits)* that is the average of total unallocated DL RBs' bits in a TTI.
- *Rate of waste capacity (%)* that the average percentage of allocated DL RB's useless bits in a TTI is also defined as the difference between RB real capacity and an assigned UE's data. Furthermore, it is also the P3 problem (a case of Part 6 of Fig. 3 for the RB4 and RB6).
- *Delay (ms)* that is the average system time of a UE's DL traffic data at eNB buffer.
- *Total Throughput (kbps)* that is the receive traffic flow bit rate for all UEs in the simulation.

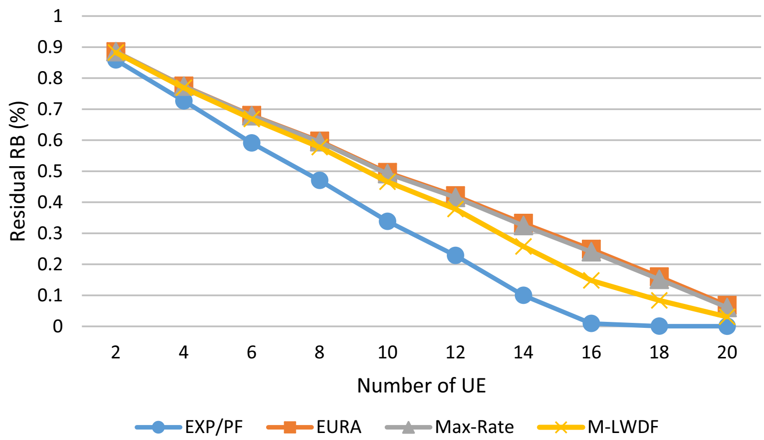

Fig. 10 Simulation result of residual RB's rate; The performance comparison of residual RB's rate for our proposed scheme and the contrasts

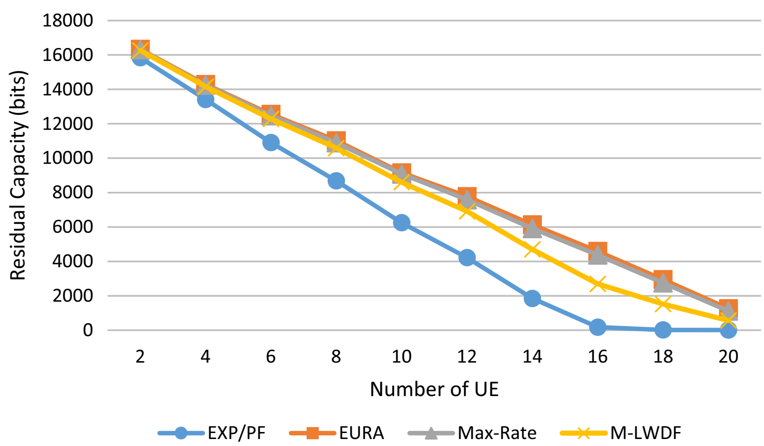

Fig. 11 Simulation result of residual capacity; The performance comparison of residual capacity for our proposed scheme and the contrasts

4.2 Experiment results

There are three parts for performance evaluation. Initially, the simulation must identify performance and resource allocation utilization among our proposed EURA and three contrast schemes, and there are five criteria are defined for comparison as Sect. 4.2.1. Next, our proposed EURA includes three novel mechanisms, and the effect of three mechanisms is analyzed for utilization improvement in Sect. 4.2.2. Finally, the effect of different traffic packet size is discussed in Sect. 4.2.3.

4.2.1 Performance of the proposed EURA scheme

In Figs. 10, 11 and 12, the Max-Rate scheduler might have a better RB utilization due to the concept of maximum value UE's allocation for each RB in a TTI; however, our proposed EURA scheme would have better utilization than the Max-Rate scheduler owing to our proposed EURA scheme that can dynamically use Eq. (4) for different

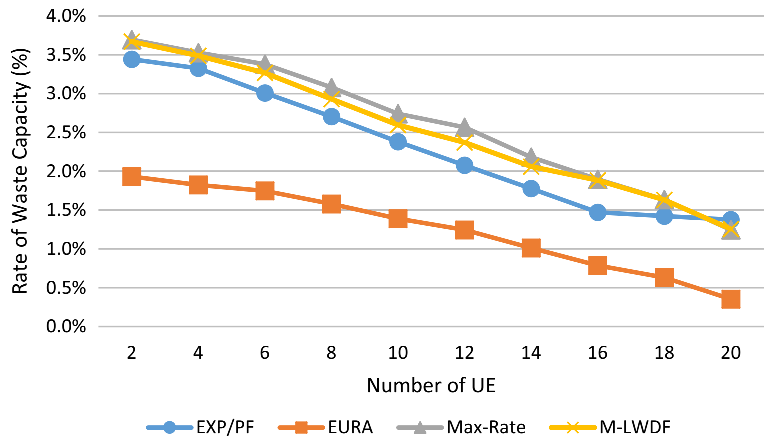

Fig. 12 Simulation result of waste capacity rate; The performance comparison of waste capacity rate for our proposed scheme and the contrasts

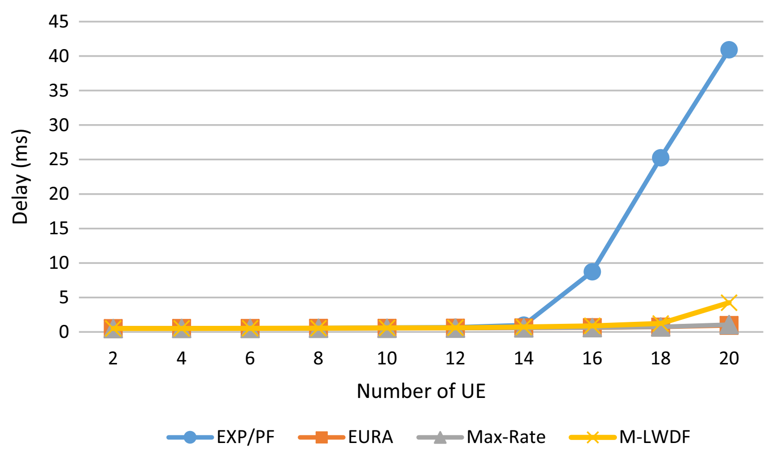

Fig. 13 Simulation result of delay; The performance comparison of delay for our proposed scheme and the contrasts

QCI priority UEs' traffic allocation. The three novel mechanisms can improve the utilization of RB resource allocation. Moreover, our proposed EURA scheme outperforms the M-LWDF and EXP/PF schemes owing to the both M-LWDF and EXP/PF schemes focusing on UEs resource allocation fairness. In Figs. 13 and 14, as our proposed EURA scheme has higher utilization, the criteria of delay and total throughput can also have better performance than the other three contrast schemes.

4.2.2 Effect of three mechanisms

Based on Sect. 4.2.1 simulation results, our proposed EURA scheme outperforms the other two contrasts. We use the gain analysis for the three novel mechanisms (*Larger RB capacity first* mechanism as *Larger RB*, *Lower remaining RB space first* mechanism as *Lower remaining RB*, *Lower useless RB capacity first* mechanism as *Lower useless RB* in Figs. 15 and 16), the gain comparison base is Max-Rate scheduler. To improve the RB

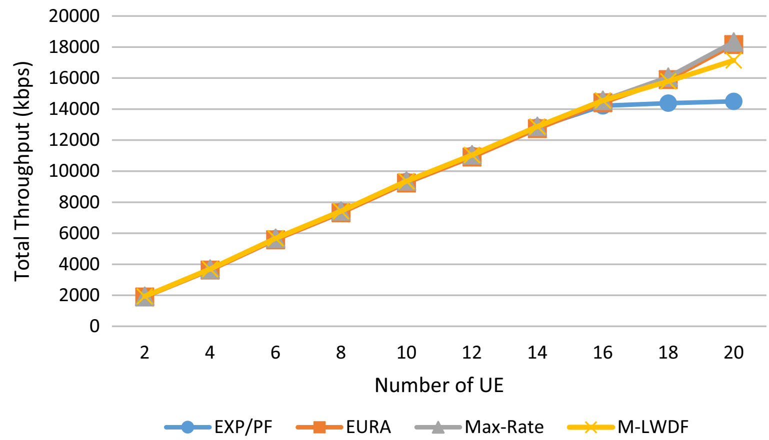

Fig. 14 Simulation result of total throughput; The performance comparison of total throughput for our proposed scheme and the contrasts

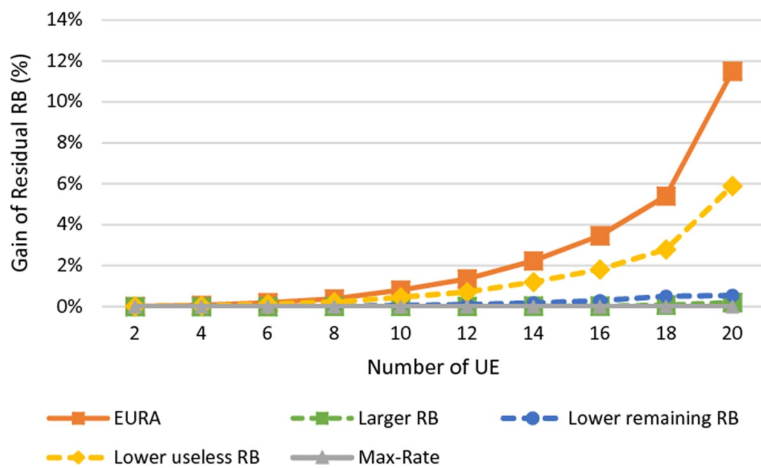

Fig. 15 Gain of residual RBs between EURA with three mechanisms and Max Rate; The performance gain of residual RBs between EURA with three mechanisms and Max Rate

utilization allocation, the *Lower useless RB capacity first* mechanism might be the main influencing factor for our proposed EURA scheme owing to inter-UEs resource allocation. It can also save more RBs' space for the next UE schedule.

4.2.3 Effect of schedule assignment schemes

We discuss the impact of changing λ and *packet size* on *waste capacity rate*, *delay*, and *total throughput* when the number of traffic load UEs is the same, i.e., the same ρ. We simulated the original packet size as *Medium PKT*, half of the original packet size as *Small PKT*, and 1.5 times of the original packet size as *Large PKT*. In Fig. 17 we can find that when packet size value is small, the number of packets in the UE buffer under the same load situation will be high, and the amount of data will be average, i.e., the traffic burstiness is small. Therefore, RB allocation may be required for each TTI. For this reason, as the RB allocation opportunity increases, more

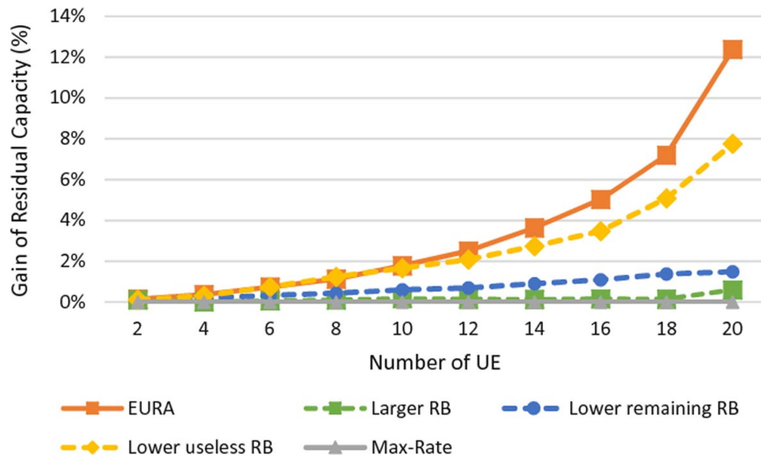

Fig. 16 Gain of residual capacity between EURA with three mechanisms and Max Rate; The performance gain of residual capacity between EURA with three mechanisms and Max Rate

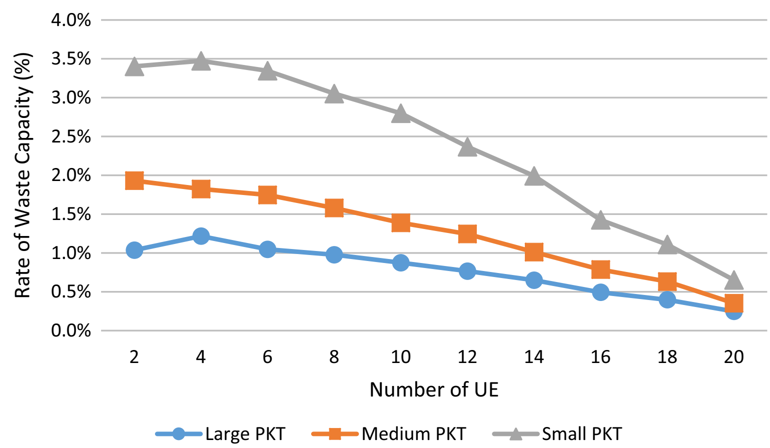

Fig. 17 Analysis of waste capacity rate in different packet size situations; The performance analysis of waste capacity rate in different packet sizes for our proposed EURA scheme

remaining space occurs in each allocation RB. When the packet size is large, it will increase traffic burstiness and at the same time, reduce the need to allocate RB so there is a lower waste capacity rate. However, as the traffic load increases, almost every TTI and RB have a chance to allocate UE traffic so the influence of different packet sizes is relatively insignificant.

In Fig. 18, we can find that when the packet size value is small, i.e., the traffic burstiness characteristic is small, delay value will also be small; on the contrary, when the packet size value is large, i.e., the traffic burstiness characteristic is larger, and the delay value will also be larger.

In Fig. 19, although different packet sizes have a slightly different effects on waste capacity rate and delay, the difference is relatively small so there is no obvious difference in total throughput.

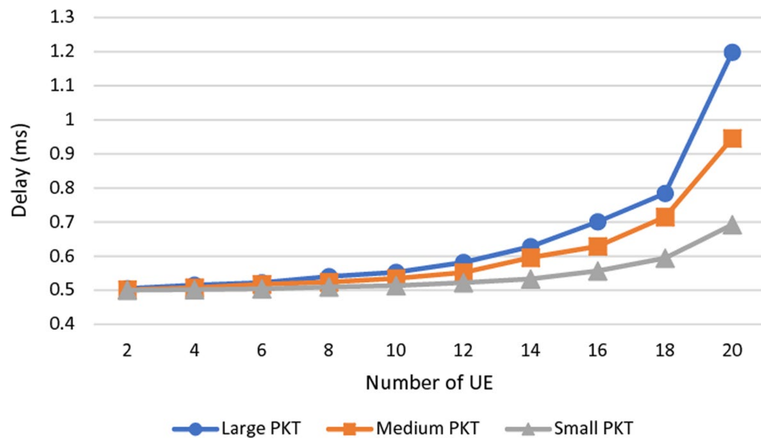

Fig. 18 Analysis of delay in different packet size situations; The performance analysis of delay in different packet sizes for our proposed EURA scheme

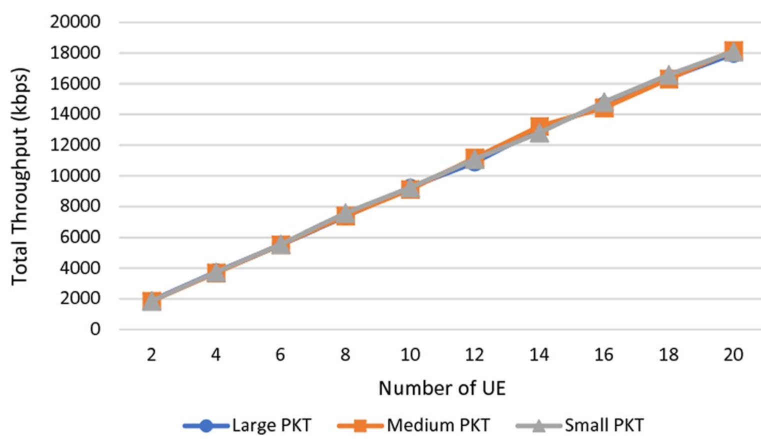

Fig. 19 Analysis of total throughput in different packet size situations; The performance analysis of total throughput in different packet sizes for our proposed EURA scheme

5 Conclusion

For 4G/5G mobile wireless network providers, the LTE network has attracted tremendously attention in the world. To increase the efficiency of MAC scheduling in LTE network is still an important and hot issue, and some traditional scheduling schemes have been discussed in some research articles. To improve further mobile network utilization, LTE radio channel capacity is assumed to be dynamic, and eNB can typically select the modulation scheme and code rate depending on a prediction of the DL channel condition, which is based on the UE's CQI report. We propose an EURA scheme with three novel mechanisms, which is considering both radio resource capacity of UE's CQI states in each RB and overall RBs resource allocation with QoS requirements. The experiment simulation study shows that the RB utilization performance at our proposed scheme is better than the contrasts of EXP/PF, M-LWDF and Max-Rate scheduler schemes. Moreover, our EURA scheduling scheme can not only be adopted for cellular LTE network, but also be achieved for *Machine-to-Machine (M2M)* LTE network. It might increase computing loading due to large machine devices as UEs and have different traffic patterns due lower bandwidth requirement for machine devices. In future, researchers can corporate with other 4G/5G scheduling schemes to fit mobile users' requirements for different purposes (e.g., fairness, delay guarantee, etc.). These might improve the flexibility of LTE MAC scheduling. Moreover, our proposed three mechanisms can also be applied to other MAC scheduling schemes to improve the utilization of MAC layer resource allocation.

Abbreviations

LTE: Long Term Evolution; QoS: Quality of Service; QCI: QoS class indicator; PF: Proportionally Fair; CQI: Channel Quality Indicator; RB: Resource block; EURA: Enhanced Utilization Resource Allocation; LTE-A: LTE-Advanced; 3GPP: Third Generation Partnership Project; 5G: Fifth-generation; D2D: Device-to-Device; NR: New radio; EPC: Evolved Packet Core; E-UTRAN: Evolved Universal Terrestrial Radio Access Network; MT: Maximum throughput; eNB: Evolved Node B; TTI: Transmission time interval; RE: Resource element; MCS: Modulation and coding scheme; QoS: Quality of service; UE: Mobile user; RBG: RB group; M-LWDF: Modified Largest Weighted Delay First; DL: Downlink; NOMA: Non-orthogonal multiple access; UAVs: Unmanned aerial vehicles; CSI: Channel state information; SCA: Successive convex approximation; VLC: Visible light communication; MEC: Multi-access edge computing; BSs: Base stations.

Authors' contributions

All authors read and approved the final manuscript.

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Availability of data and materials

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

Declarations

Competing interests

There are no potential competing interests in our paper. And all authors have seen the manuscript and approved to submit to this journal. We confirm that the content of the manuscript has not been published or submitted for publication elsewhere.

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