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A QoS-Guaranteed Radio Resource Scheduling in Multi-User Multi-Service LTE-A Systems with Carrier Aggregation

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Abstract—**Carrier aggregation technology is introduced to improve the throughput by simultaneously data transmission on multiple component carriers (CCs) in the long term evolution advanced (LTE-A) system. Although many studies have been proposed to improve the throughput of single service in LTE-A system with CA configuration, challenging issues are unsolved for the multi-user multi-service network on the rsource management algorithms, such as the CC selection and the resource block (RB) allocation, in order to satisfy various requirements on quality of service (QoS) in different services. To solve these problems, the resource scheduling problem is formulated by considering service types, channel quality, buffer size and fairness factors and a novel approach is proposed to satisfy the QoS requirement of different services by maximizing the system utility. Simulation results show that the proposed scheme can significantly improve user's experience on the voice over LTE (VoLTE) service compared with existing schemes.**

Keywords-carrier aggregation (CA); long term evolution-advanced (LTE-A); qality of service (QoS)

I. INTRODUCTION

With the exponential growth of mobile data traffic demand and variety of mobile services, wireless networks are facing the challenge of explosive increasing trend of mobile data applications all over the world. Carrier Aggregation (CA) technology is regarded as one of key technologies in the long term evolution-advanced (LTE-A) system by aggregating multiple continuous or discontinuous licensed spectrum segments [1]. But a key issue in LTE-A system with CA configuration is how to manage the radio resources including multiple CCs and RBs on each CC to satisfy users with different QoS requirements. The resource allocation of LTE-A system with CA configuration is decomposed into CC selection and RB allocation to reduce the computational complexity.

The resource management problem is a challenging issue to improve the user's experience for different traffic types in the LTE-A system. The following problems should be considered in the resource management. 1) RB allocation and packet scheduling in multiple CCs, 2) QoS requirement for various traffic types, 3) buffer state of users, 4) fairness among users [2]. Serval greedy based radio resource allocation schemes have been proposed in [3]-[4] to improve the throughput in terms of the fairness among users by joint CC selection and RB allocation with the backlogged or finite buffer. In order to schedule the radio resource for data packet transmission in networks with CA configuration, two different scheduler structures of joint queue scheduler (JQS) and disjoint queue scheduler (DQS) are proposed in [5]. The performance of packet scheduling of poisson arrival is studied by the CC selection schemes of round robin (RR) and mobile hashing (MH) balancing schemes in [6]. However, these schemes ignored different types of services and QoS requirements. For instance, the throughput improvement may not effectively enhance the user's experience for the conversational service such as the voice over LTE (VoLTE) service. In order to improve the experience of real time services, a two-level scheduling scheme is proposed in [7] by cross-CC user migration (CUM) scheme assuming that only real time service is served. The user profile least load (UPLL) is proposed to improve the QoS of different users and reduce the band usage [8]. Considering multi-service QoS requirements and fairness among different services, the QoS-based separated random user scheduling (QSRUS) is proposed in [9]. The channel quality and bandwidth of CCs are not considered for the CC assignment and the length of queue in the buffer is ignored for the RB allocation in [8]-[9]. Obviously, no RB should be assigned to the user when the buffer of user is empty, otherwise the resource is wasted.

To solve the more challenging resource management problem in multi-user multi-service LTE-A system with CA configuration, a novel resource scheduling approach is proposed to meet different QoS requirements. Therefore, a CC selection scheme in terms of system bandwidth, channel quality and load of CCs is proposed in this paper to utilize the frequency diversity on CCs and balance the load on different CCs. And a novel RB allocation algorithm is proposed to guarantee the QoS requirements of different services by considering the queue length in a buffer, traffic types and fairness among users. Three typical services are considered in this paper which are the conversational service, the streaming media service and the best-effort (BE) service. Furthermore, system level simulation is performed and results show that the proposed scheme can significantly improve the user's experience in contrast to the existing schemes.

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The rest of this paper is organized as follows. In Section II, the traffic model and QoS requirements of different services are introduced and the resource scheduling problem with CA configuration is formulated. The resource scheduling approach including CC selection and RB allocation is presented in Section III. Section IV provides simulation results and conclusions are drawn in Section V.

II. System Model and Problem Formulation

A. Resource Scheduling Framework with CA

In this paper, the downlink CA scenario in a macrocell with u UEs is considered where there are multiple CCs with different frequency and bandwidth in licensed band. The coverage of CCs is different because of different frequency and radio propagation environment. Due to the backward compatibility with LTE user equipments (UEs), LTE UEs can only utilize a single CC and LTE-A UEs can aggregate multiple CCs using CA technology in Fig. 1.

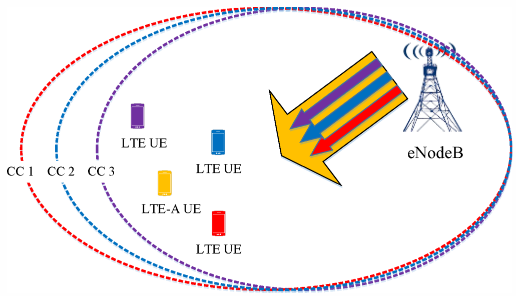

Figure 1. Downlink scenario of LTE-A network with CA

It is assumed that there are c CCs and N_j RBs of CC j ($j = 1,\ldots,c$). In each transmission time internal (TTI) of 1 ms, a couple of RBs of CCs are assigned to a single UE when there are traffic packets in buffer. The arrival packets for UEs are queued in the buffer in a FIFO manner, which are delivered to UEs when RBs are allocated. The joint queue scheduling (JQS) framework is adopted where a single queue of UE in buffer is served by multiple CCs. The resource scheduling framework of downlink CA scenario is shown in Fig. 2. For convenience, symbols and descriptions for the resource scheduling model are listed in Table I.

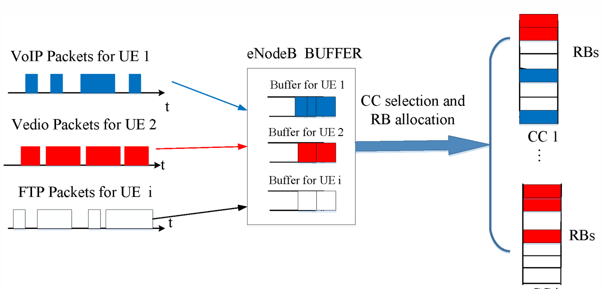

Figure 2. Resource scheduling framework of downlink CA

B. QoS Requirement and Utility Model

Base on 3GPP technology report [10], three typical services are considered in this paper, such as VoLTE as a conversational service, video streaming as a media streaming service, and FTP as a BE service. In the protocol stacks of LTE system, packets are transmitted by radio bears which are classified into guaranteed bit rate (GBR) bear for conversational service and non-GBR bear for media streaming service and BE service [11]. GBR bear can guarantee the minimum bit rate for conversational service regardless of wireless environment which can reduce the latency of conversational service.

TABLE I. Notations for Resource Scheduling Model.

Symbol	Description
$a_{i,j}$	$a_{i,j}$=1 indicates UE i can employ CC j, otherwise, $a_{i,j}$=0
$b_{i,j,k}$	$b_{i,j,k}$ =1 indicates RB k on CC j assigned to UE j, othewise $b_{i,j,k}$=0
$C=\{1,\cdots,c\}$	Set of CCs
i	$i \in U$, index of UEs
j	$j \in C$, index of CCs
k	$k \in K_j$, index of RBs
$K_j=\{1,\cdots,N_j\}$	Set of RBs on CC j, $j \in C$
$l_{i,j,k}$	The highest MCS of RB k on CC j to UE i
L_i	Length of queue in buffer for UE i
$\bar{r}_i$	Average rate of UE i
$r_{i,j,k}$	Transmission rate of RB k on CC j assigned to UE i with the highest MCS
$u_{i,j,k}$	Utility of RB k on CC j assigned to UE j
$U=\{1,\ldots,u\}$	Set of UEs attached to a BS
z_i	Number of CCs can be employed by UE i
τ_i	Waiting time of HOL packet of UE i

The feature of VoLTE service is that the packet size S_{VoLTE} and arrival internal T_{VoLTE} are fixed. T_{VoLTE} = 20 ms and S_{VoLTE} = 976 bits for voice packets and T_{VoLTE} = 160 ms and S_{VoLTE} = 536 bits for silence packets [10]. The minimum bit rate of GBR bear for VoLTE is

$$r^{\min} = \frac{S_{VoLTE}}{T_{VoLTE}} \tag{1}$$

which guarantees that the packets in buffer can be delivered to UEs before the next VoLTE packet arrival. The voice packets need bigger bite rate than silence packets and the minimum bite rate r_i^{min} = 976/20 kbps = 48.8 kbp*s* when the queue is not empty and r_i^{min} = 0 when the queue is empty.

Compared with FTP service, the tough packet loss ratio (PLR) result from the network congestion is required for video streaming service. In order to achieve the trade-off among throughput, fairness of users and PLR, the utility model is utilized to evaluate the profit of radio resource allocation and is defined as

$$u_{i,j,k} = \frac{r_{i,j,k}}{\bar{r}_i} f\left(\tau_i\right) \tag{2}$$

where τ_i is the waiting time of head-of-line (HOL) packet in the queue of UE i and $f(\tau_i)$ defined in (3) is used to distinguish the priority of video streaming service from FTP service in order to satisfy the delay and PLR requirement of video streaming service.

$$f(\tau_i)=\begin{cases}\exp\left(\dfrac{\tau_{\max}}{\tau_{\max}-\tau_i}\right), & \tau_i<\tau_{\max} \\ 0, \quad \tau_i=\tau_{\max}\end{cases}, i\in U_{video} \quad (4)$$

where τ_{max} is the maximum waiting time that video packets can tolerate and the packet will be discarded when waiting time reaches the τ_{max}. Then, the second packet in the queue of UE i becomes the HoL packet and $f(\tau_i)$ is recalculated. Due to the GBR bear for VoLTE and no delay requirement of FTP, $f(\tau_i)=1$ for $i \in U_{VoLTE} \cup U_{FTP}$. The sets of users with service of VoLTE, video streaming and FTP are denoted as U_{VoLTE}, U_{video} and U_{FTP} respectively.

C. QoS Requirement and Utility Model

In each TTI, the objective of scheduling scheme is to maximize the total utility of all RBs. And the resource scheduling problem with CA can be formulated as:

$$\max\sum_{i=1}^{u}\sum_{j=1}^{c}\sum_{k=1}^{N_j}a_{i,j}b_{i,j,k}u_{i,j,k} \quad (4)$$

$$s.t. \quad \sum_{j=1}^{c}a_{i,j}\le z_i, a_{i,j}\in\{0,1\}, i\in U \quad (5)$$

$$\sum_{i=1}^{u}b_{i,j,k}=1, b_{i,j,k}\in\{0,1\}, j\in C, k\in K_j \quad (6)$$

$$r_i=\sum_{j=1}^{c}\sum_{k=1}^{N_j}b_{i,j,k}r_{i,j,k}\ge r_i^{\min}, i\in U_{GBR} \quad (7)$$

$$r_i=\sum_{j=1}^{c}\sum_{k=1}^{N_j}a_{i,j}b_{i,j,k}r_{i,j,k}\le L_i, i\in U \quad (8)$$

The constraint in (5) restricts that UE i can employ at most z_i CCs and $z_i = 1$ for LTE UEs. The constraint in (6) ensures that each RB can only be assigned to a single UE. The constraint in (7) guarantees the minimum bite rate for VoLTE users and the constraint in (8) shows that the total transmission bits cannot exceed the length of queue in the buffer. Let U_{GBR} and U_{nonGBR} are sets of GBR users and non-GBR users respectively.

III. QoS-Guaranteed Resource Scheduling Approach

QoS-Guaranteed resource scheduling approach (QoS-RSA) is proposed with two steps: CC selection and RB scheduling.

A. CC Selection

The CC selection for LTE users is performed when the users attach to the eNodeB. For VoLTE users, the resource of a single CC is enough for user's requirement because the transmission rate of VoLTE service is very small. If multiple CCs are allocated to VoLTE users, the power consumption of terminal will increase without improving user experience dramatically.

The CC selection is decided upon the bandwidth of CCs, channel condition of users on CCs, and load of CCs as follows

$$j^*=\arg\max_j\frac{\sum_{k=1}^{N_j}B_k\log\left(1+\Gamma_{i,k}\right)}{L_j^{user}} \quad (9)$$

where B_k is 180 kHz, the bandwidth of each RB is composed of 12 subcarriers, and the duration of a time slot is 0.5 ms. L_j^{user} is the total queue length of users with the same service on CC j. If CC j^* is selected by LTE UE i, $a_{i,j^*}=1$ and $a_{i,j^*}=0, j\in C\backslash j^*$. For LTE-A UEs except for the VoLTE service, $a_{i,j}=1, j\in C$. In Eq. (9), $\Gamma_{i,k}$ is the signal-to-interference and noise ratio (SINR) of UE i on RB k.

B. RB Allocation

After CC selection, RB allocation is performed to maximize the total system utility with constraints of (6)-(8). The RB allocation consists of following two steps.

1) RB Allocation for GBR users: The problem of RB allocation for GBR users is a sub-problem of (4). In the process of RB allocation to UE i in U_{GBR}, the basic principle is that the fewest RBs are used to satisfy the minimum bit rate requirement of GBR users in order to preserve more RBs for nonGBR users. So, the sub-problem can be formulated as

$$\min\sum_{k=1}^{N_j}a_{i,j}b_{i,j,k} \quad (10)$$

$$s.t. \quad r_i=\sum_{k=1}^{N_j}a_{i,j}b_{i,j,k}r_{i,j}\ge r_i^{\min}, i\in U_{GBR} \quad (11)$$

In order to solve the problem (10), the channel condition of all unallocated RBs for UE i is checked and the RBs with the best channel condition is allocated to UE i until the constraint in (11) is satisfied.

2) RB Allocation for non-GBR users: After the users in U_{GBR} are allocated with RBs, the users in U_{nonGBR} begin the allocation. During the process of RB allocation for non-GBR users, the constraint in (7) need not to be considered. The Cross-CC PF can achieve the optimal solution without constraint of (8) which has been proved in [13].

In our algorithm, UE i^* in U_{nonGBR} is selected to maximize the utility of each RB without considering the constraint in (8) as shown in (12)

$$i^*=\arg\max_{i\in U_{nonGBR}}\frac{a_{i,j}\cdot r_{i,j,k}}{\bar{r}_i}f(\tau_i) \quad (12)$$

Then, iterative adjustment process of RB allocation is performed to satisfy the constraint in (8). Users in U_{nonGBR} are classified into U_{nonGBR}^{over} and U_{nonGBR}^{less} based on whether the total bits of RBs allocated to user are over the queue length in the buffer. In each iteration, one of RBs allocated to users in U_{nonGBR}^{over} will be released to be allocated to users in U_{nonGBR}^{less}

until the constraints in (8) is met. The reallocation of RBs follows the principle of minimizing system utility loss.

$$(j^*,k^*)=\text{argmin}\ \Delta u_{i^*j,k}^{min} \tag{13}$$

$$\Delta u_{i^*,j,k}^{\min}=\min_{i\in U_{nonGBR}^{less}}\left(u_{i^*,j,k}-u_{i,j,k}\right) \tag{14}$$

After RB k^* on CC j^* is released, the RB is reassigned to user in U_{nonGBR}^{less} based on (12). The procedures of RB allocation are shown in **Algorithm I**.

IV. Simulation Results

System level simulation experiments are conducted to verify the user experience performance of the proposed QoS-RSA algorithm. Key parameters, such as delay, PLR, and throughput are adopted to evaluate the performance of algorithms.

Algorithm 1 RB allocation algorithm of QoS-RSA

Input: $\bar{r}_i$, $f(\tau_i)$, $l_{i,j,k}$ and r_i^{min}
Initialization: $b_{i,j,k}=0$ for $\forall i\in U$, $\forall j\in C$ and $\forall k\in K_j$
Calculate the $r_{i,j,k}$ according to $l_{i,jk}$
Divide U into U_{GBR} and U_{nonGBR}
for each $j\in C$ **do**
    for $i\in U_{GBR}$ and $a_{i,j}=1$ **do**
        while $r_i^{min}>0$ and $K_j\neq\emptyset$ **do**
            $k^*=\arg\max_{k\in K_j} r_{i,j,k}$
            $r_i^{min}\leftarrow r_i^{min}-r_{i,j,k^*}$, $b_{i,j,k^*}=1$ and $K_j\leftarrow K_j\backslash\{k^*\}$
        end while
    end for
    for $k\in K_j$ **do**
        $i^*=\arg\max_{i\in U_{nonGBR}}\frac{a_{i,j}\cdot r_{i,j,k}}{\bar{r}_i}f(\tau_i)$ and $b_{i^*,j,k}=1$
    end for
end for
$U_{nonGBR}^{over}\leftarrow\emptyset$ and $U_{nonGBR}^{less}\leftarrow\emptyset$
for $i\in U_{nonGBR}$ **do**
    if $\sum_{j=1}^{c}\sum_{k=1}^{N_j}a_{i,j}b_{i,j,k}r_{i,j,k}\geq L_i$ **do**
        $U_{nonGBR}^{over}\leftarrow U_{nonGBR}^{over}\cup\{i\}$
    else
        $U_{nonGBR}^{less}\leftarrow U_{nonGBR}^{less}\cup\{i\}$
    end if
end for
for $i\in U_{nonGBR}^{over}$ **do**
    while $\sum_{j=1}^{c}\sum_{k=1}^{N_j}a_{i,j}b_{i,j,k}r_{i,j,k}\geq L_i$ **do**
        (j^*,k^*)=argmin $\Delta u_{i^*j,k}^{min}$ and $b_{i,j,k^*}=0$
        $i^*=\arg\max_{i\in U_{nonGBR}^{less}}\frac{a_{i,j}\cdot\min\left(r_{i,j^*,k^*},L_i\right)}{\bar{r}_i}f(\tau_i)$ and $b_{i^*j,k}=1$
        if $\sum_{j=1}^{c}\sum_{k=1}^{N_j}a_{i,j}b_{i^*,j,k}r_{i^*,j,k}\geq L_i$ **then**
            $U_{nonGBR}^{over}\leftarrow U_{nonGBR}^{over}\backslash\{i^*\}$
        end if
    end while
end for

A. Simulation Setup

The physical layer parameters are mainly based on [12] and all simulation parameters are listed in Table II. The VoLTE service is modeled by on-off model, where the self-transition probability and inter-state transition probability are 0.99 and 0.01. H.264 video streaming source with average arrival 128 kbps is used in the simulation where the frame rate is 25 frames per second and each frame consists of 8 slices. The maximum tolerant latency of VoLTE and video packets is 50 ms and 300 ms. FTP service is modeled as a sequence of file downloads. The file size is modeled as a truncated log-normal distribution where the mean is 2 MB, the standard deviation is 0.722 MB and the maximum is 5 MB. The number of users varies from 40 to 280 and 50% users are LTE-A users using CA technology. Each simulation experiment lasts 2 seconds (i.e., 2000 TTIs) for different number of users.

The performance of proposed QoS-RSA scheme is compared with two other algorithms by simulations, i.e., the cross-CC-PF algorithm with least load (LL) CC selection (cross-CC-PF+LL) [14] and QSRUS proposed by [9].

TABLE II. Key Parameters of System Level Simulation.

Parameter	Setting/Description
Simulation scenario	3GPP Macro-cell case #1 (19 sites)
Cell size	500 m
Transmit power of eNB	43 dBm
Macrocell pathloss model	Cost 231 urban model
Shadow fading	Logarithmic normal distribution, σ =3
Fast fading	Doppler fading
Thermal noise density	-174 dBm/Hz
CC configuration	5 MHz @ 800MHz 10 MHz @ 2.6 GHz
RB number	25 for 10 MHz, 50 for 10 MHz
Modulation and coding schemes	QPSK (78,120,193,308,449,602)/1024 16QAM (378,490,616)/1024 64QAM (464,567,666,772,873,948)/1024
User type distribution	LTE-A CA 50%, LTE 50%,
User service distribution	VoLTE 30%,video streaming 40%, FTP 30%
User position distribution	Uniformly-distributed
Speed of users	3 km/h

B. VoLTE Performance

Packet delay and PLR are vital evaluation indexes for conservational service as the VoLTE service. The average packet delay of VoLTE packets is shown in Fig.3. It can be observed that the performance of QoS-RSA is more preferable than other algorithms. Furthermore, the performances of other algorithms are very poor when the number of users is large. Fig.3 shows that the average delay is beyond 10 ms and Fig.4 shows that the PLR is beyond

5% using two other algorithms when the number of users is over 250.

C. *Video Streaming Performance*

PLR is adopted to evaluate the QoS of video streaming service. Fig.4 shows that the PLR performance of QoS-RSA is better than two other algorithms. More RBs will be allocated users when the waiting time of users' packets is closer to τ_{max} (i.e.300ms) for delay factor. Compared with LL, the carrier quality is considered in the proposed CC selection scheme which can improve the transmission rate of LTE users because of the better channel condition. Therefore, the QoS-RSA scheme can provide video streaming service with less PLR to users

D. *FTP Performance*

Throughput of users with FTP service is adopted to evaluate the user experience. Fig.5 shows the total FTP throughput of QoS-RSA is bigger than QSRUS for the reason that the channel quality of CCs is considered in CC selection which utilizes the frequency diversity of CCs sufficiently.

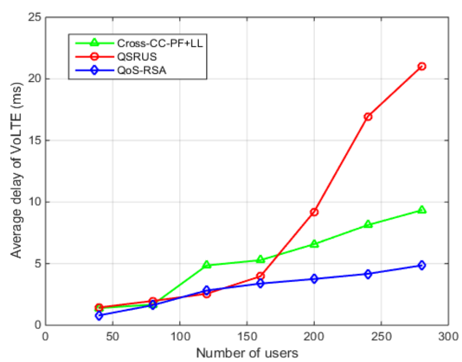

Figure 3. Average delay of VoLTE packets

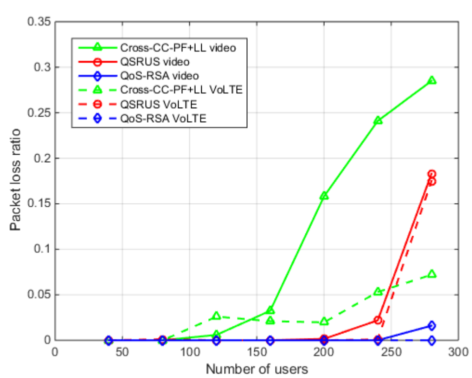

Figure 4. Packet Loss probability of video packets and VoLTE packets

V. CONCLUSION

In this paper, a QoS-guaranteed resource scheduling approach has been proposed for multi-user multi-service LTE-A system with CA configuration. A novel CC selection scheme considering the bandwidth, channel quality and load of CCs is proposed for users with single CC and VoLTE users. Then, a novel RB allocation algorithm is proposed to maximize the total system utility to guarantee QoS requirement of different service and satisfy the constraint of finite buffer. System level simulation results demonstrate that the proposed scheme can provide better user experience in LTE-A system with CA configuration, where PLR is blow 1% and throughput is improved by about 15% compared with the QSRUS.

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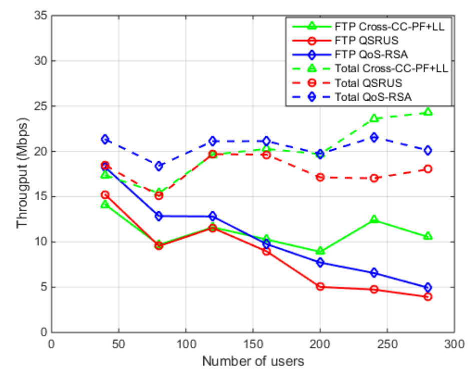

Figure 5. Throughput of all users and FTP users

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