Resource Allocation Scheme for LTE Uplink Transmission Based on Logical Channel Groups

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Abstract. It is still a difficult problem to allocate wireless resources for uplink transmission in LTE system. The main goals of previous researches aim at maximizing system throughput or fairness among UEs. However, the real requirements of UEs are not considered. The result is that Resource Blocks (RB) allocated by eNB are usually wasted and the requirements of UEs are not satisfied. We presented an AAG-2 scheduling scheme, which can ensure the QoS of GBR bearers, while at the same time efficiently distributes RBs to non-GBR bearers so as to improve resource utilization. However, in order to facilitate the management for many bearers, 3GPP suggested divide bearers into four Logical Channel Groups (LCG), rather than only two kinds of bearers mentioned above. So far, 3GPP has not specified how to map between LCG and bearers of different QoS Class Identifiers (QCIs), but left it to the operator for customization. As a result, it is an important issue about how to group bearers and how to guarantee QoS, while make good use of free RB. In this paper, we propose a new-version of AAG-2, named AAG-LCG, where bearers are classified into four LCGs with different priority levels. Especially, with the proposed scheme, eNB can efficiently allocate RBs to meet the QoS requirements of different LCG bearers, while also maintain sound overall system performance.

Keywords: AAG-LCG · Scheduling · Resource allocation

1 Introduction

For the LTE system, the importance of uplink resource allocation/scheduling in ensuring the Quality of Service (QoS) of guaranteed bit rate (GBR) bearers has led to the development of numerous resource allocation schemes. The criteria used in such schemes include maximizing system throughput [1, 2] or fairness [3, 4], or minimizing power consumption [5, 6]. However, the real requirements of UEs are neglected in these schemes. The result is that Resource Blocks (RB) allocated by eNB are usually wasted and the requirements of UEs are not satisfied. In our opinion, one of the most important objectives of resource allocation work is to meet the data rate granted by Radio Access Control (RAC), rather than maximizing system throughput or fairness. In [7, 8], we presented a scheme, named AAG-2 (Allocate As Granted-2), and show that it

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always provides GBR bearers with sufficient throughput (which is granted by RAC) and short delay, while at the same time achieves high resource utilization by efficiently providing RBs to non-GBR bearers. However, 3GPP has suggested divide bearers into four Logical Channel Groups (LCG) to alleviate signaling load induced by Buffer Status Reports (BSR) [9]. It raises new topics concerning how to divide bearers of different QCIs into four LCGs and how to allocate suitable resource to these LCGs. Based on AAG-2, in this paper, we present a new-version, named AAG-LCG, where eNB efficiently allocates RBs to meet the QoS requirements of different LCG bearers, while also maintains overall system performance.

This paper is organized as follows. The AAG-2 is described in Sect. 2 and the new version AAG-LCG is described in Sect. 3. The function of AAG-LCG is verified by comparing the performance with that of AAG-2 in Sect. 4. Finally, the conclusion and future works are drawn in Sect. 5.

2 Previous Work: AAG-2 Scheme

It could be quite normal for a UE to establish both GBR and non-GBR bearers at the same time. Because the QoS of non-GBR bearers is not guaranteed, they can be scheduled only if there are sufficient resources. The eNB may allocate RBs to all UEs according to priority sequence, so as to meet the requirement of all GBR bearers, and then allocate the rest of RBs to UEs which need to transmit non-GBR traffic. With this approach, however, the RBs allocated to a UE could often be discontinuous, which is not allowed for LTE uplink transmission.

To solve this problem, we proposed an AAG-2 scheme. It can allocate continuous RBs to meet the requirements of GBR bearers, and efficiently allocate the remaining RBs to transmit non-GBR traffic [7, 8]. The steps of AAG-2 are as follows:

(a) allocating RBs to meet the requirement of GBR and non-GBR traffic of high priority UEs,
(b) allocating the remaining RBs to meet the requirement of GBR traffic for the other UEs.

The scheme is briefly summarized as follows. Let's consider an eNB serving K UEs. For a UE$_m$, the total granted bit rate of the admitted h GBR bearers is expressed as $R_{m,GBR}^{grant} = \sum_{j=1}^{h} R_{m,j,GBR}^{grant}$. The $R_{m,j,GBR}^{grant}$ is the granted data rate of the j-th GBR bearer. Besides, we use $B_{m,MIX}^{grant} = B_{m,GBR}^{grant} + B_{m,AMBR}^{grant}$ to stand for the total data rate that is requested by both GBR bearers and Aggregate Maximum Bit Rate (AMBR) bearers. The $R_{m,AMBR}^{grant}$ is the AMBR of all non-GBR bearers of UE$_{m.}$ Then we convert data rates to the number of bits to be sent in a Transmission Time Interval (TTI, 1 ms). That is to say, $B_{m,GBR}^{grant} = R_{m,GBR}^{grant} \times 10^{-3}$ and $B_{m,MIX}^{grant} = R_{m,MIX}^{grant} \times 10^{-3}$ with unit bits/TTI.

Let $\bar{B}_m(n)$ denote the average number of bits per TTI that has been sent. It is defined based on Exponentially Weighted Moving Average (EWMA) as $\bar{B}_m(n) = (1-\alpha)\bar{B}_m(n-1) + \alpha B_m(n)$. For the n-th TTI, if the eNB intends to meet the requirement of UE$_m$, it should plan to allocate RBs for UE$_m$ to transmit the following number of bits

$$B_m^{plan}(n) = \min\left\{\max\left[\frac{B_m^{grant} - (1-\alpha)\bar{B}_m(n-1)}{\alpha}, 0\right], L_m(n-1)\right\}. \tag{1}$$

The $L_m(n-1)$, which is obtained through BSRs, is the total queue length of UE_m. This term is used to prevent wasting RBs when there are not so much data waiting in the buffer of UE_m. Because a UE may not transmit BSR in every TTI, the eNB may predict the value of BSR by subtracting the number of bits that has been scheduled for transmission. Whenever the eNB receives a new BSR, the total queue length is then updated. For the sake of ensuring the throughput of every UE, AAG allocates RBs to UEs based on the descending order of

$$P_m(n) = \frac{B_m^{grant} - \bar{B}_m(n-1)}{B_m^{grant}}. \tag{2}$$

This term, named priority metric, also indicates the current shortage ratio corresponding to the average data rate. UEs with higher priority metric is scheduled earlier.

The basic idea of AAG-2 is allocating RBs to firstly meet $B_{m,MIX}^{grant}$ for the UEs ranked in the top $x\%$ high priority, and then allocating the remaining RBs to meet $B_{m,GBR}^{grant}$ of the other UEs. The method for allocating RBs in each TTI is selecting free RBs with higher channel quality just like the AAG scheme described in [7, 8]. It is not easy to choose a fix value for x. If it is too small, more RBs are wasted by high priority UEs, and less non-GBR traffic is transmitted. On the contrary, with too large x, some high priority UEs may not get enough RBs to guarantee the quality of their GBR bearers. To prevent this problem, AAG-2 adjusts the value of x dynamically. For the n-th TTI we define the average satisfaction ratio associated with the GBR traffic as

$$S_{GBR}(n) = \frac{1}{K}\sum_{m=1}^{K} s_{GBR,m}(n-1). \tag{3}$$

The $s_{GBR,m}(n-1)$ is set to 1 if the queue length of the corresponding GBR predicted by eNB is 0, otherwise it is set to 0. At first, x is set to zero and then adjusted dynamically as follows:

$$x(n) = \begin{cases} \max(0, \min(100, x(n-1) + \Delta x_{raise})), & \text{if } S_{GBR}(n) \geq S_{th} \\ \max(0, \min(100, x(n-1) - \Delta x_{fall})), & \text{if } S_{GBR}(n) < S_{th}, \end{cases} \tag{4}$$

where S_{th} is a threshold for the average satisfaction ratio, while Δx_{raise} and Δx_{fall} are the step sizes for increasing and decreasing the value of x.

The performance of AAG-2 would be compared with the new version proposed in this paper in Sect. 4.

3 Proposed New Version: AAG-LCG Scheme

3.1 Motivation

As specified in 3GPP specification [9], a UE notifies eNB with "how many data is pending for uplink transmission" through different kinds of BSR. 3GPP has defined nine QoS Class Identifier (QCI) to classify bearers of different characteristics. A UE could establish many bearers especially when it acts as a WiFi access point. If BSR messages are sent in a per-bearer mode, these messages could be a heavy burden of PUCCH (Physical Uplink Control Channel). As a result, in order to facilitate the management for many bearers, 3GPP suggested divide bearers into four LCGs, LCG 0–LCG 3. Then, BSRs are reported per-LCG, rather than per-bearer. That means, for a UE, the queue lengths of all bearers of the same LCG are added together and then reported. So far, 3GPP only designates signaling channels to LCG 0, while hasn't specified how to map the other QCI bearers to the other LCGs, but left it to the operator for customization. As a result, it is an important issue about how to group bearers and how to ensure the corresponding data rate so as to guarantee QoS.

3.2 The Operation of AAG-LCG

Because the QoS of non-GBR traffic is not guaranteed, in this paper, we suggest divide GBR bearers into two groups, GBR1 and GBR2. As a result, bearers are mapped to four LCGs as illustrated in Fig. 1, where the priority of GBR1 is higher than that of GBR2. The operator can decide which QCIs are treated as LCG1 and which are regarded as LCG2. For example, operator may treat the bears with QCI = 5, whose typical service is non-conventional video, as LCG2.

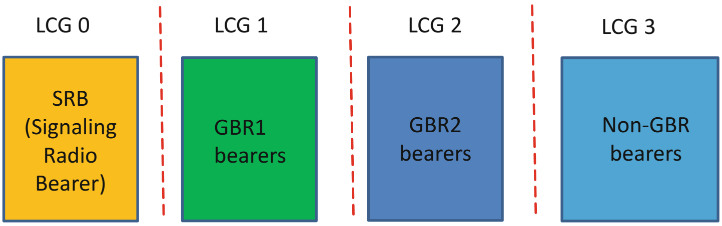

Fig. 1. The mapping between LCGs and bearers of different QCIs

In order to provide differential QoS to bearers of different LCGs, it is necessary to design a new scheme which can deal with the four LCGs. As a result, in this paper, we propose a new version AAG-LCG. For convenience, signaling traffic is excluded in the following discussion because it has been classified as LCG 0 with highest priority. Besides, in order to clearly express the corresponding characteristics of different LCGs, we use GBR1, GBR2, and non-GBR to stand for LCG 1, LCG 2, and LCG 3, respectively. The design principle is described as follows based on Fig. 1.

If the throughput of all GBR1 bearers reaches a threshold, eNB can allocate RBs for GBR2 bearers. If both GBR1 and GBR2 reach their respective thresholds, eNB can allocate RBs for non-GBR. As a result, we define two kinds of satisfactory degrees for GBR1 and GBR2, respectively. For GBR1,

$$S_{GBR1}(n) = \frac{1}{K}\sum_{m=1}^{K} s_{GBR1,m}(n-1), \tag{5}$$

where K is the number of UEs under service, while

$$s_{GBR1,m}(n-1) = \begin{cases} 0, & \textit{if } L_{m,GBR1} \neq 0 \\ 1, & \textit{if } L_{m,GBR1} = 0 \end{cases} \tag{6}$$

is the satisfactory degree corresponding to the UE_m. And $L_{m,GBR1}$ is the predicted queue length corresponding to the GBR1 of the UE_m.

The satisfactory degree of GBR2 is also defined in the similar way as follows.

$$S_{GBR2}(n) = \frac{1}{K}\sum_{m=1}^{K} s_{GBR2,m}(n-1) \tag{7}$$

$$s_{GBR2,m}(n-1) = \begin{cases} 0, & \textit{if } L_{m,GBR2} \neq 0 \\ 1, & \textit{if } L_{m,GBR2} = 0 \end{cases}. \tag{8}$$

We should keep in mind that the RBs allocated to a UE must be contiguous. That means, if the eNB want to allocate RBs for a UE to transmit its GBR1, GBR2, and non-GBR traffic, these RBs should be contiguous and had better to be allocated at a time. The same is for allocating the requirement for GBR1 and GBR2.

In order to keep the RBs allocated for a specific UE contiguous, we adopt an approach illustrated in Fig. 2. The objective is to meet the requirements of GBR1 and GBR2 traffic for the UEs with priority metric ranked in the top $x_1\%$, and also meet the requirements of GBR1, GBR2, and non-GBR traffic for the $x_2\%$ of them with higher priority. It is not good to set fix values for $x_1\%$ and $x_2\%$. With too small values, eNB may waste too many RBs, and less low-priority traffic is served. On the contrary, if $x_1\%$ and $x_2\%$ are too large, high-priority UEs may occupy too many resources, and the RBs for the low-priority UEs would be insufficient. Thus, we dynamically adjust the value of x as the following.

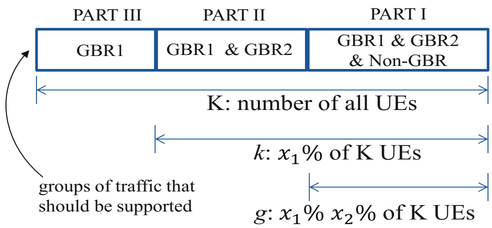

Fig. 2. Illustration for how many UEs should be supported with different groups

$$x_1 = \begin{cases} \max(0, \min(100, x_1 + \Delta x_{raise})) & \text{if } S_{GBR1}(n) \geq S_{th1} \\ \max(0, \min(100, x_1 - \Delta x_{fall})) & \text{if } S_{GBR1}(n) < S_{th1} \end{cases} \quad (9)$$

$$x_2 = \begin{cases} \max(0, \min(100, x_2 + \Delta x_{raise})) & \text{if } S_{GBR2}(n) \geq S_{th2} \\ \max(0, \min(100, x_2 - \Delta x_{fall})) & \text{if } S_{GBR2}(n) < S_{th2} \end{cases}. \quad (10)$$

3.3 Flow Chart for Resource Allocation

The principle of AAG-LCG is described with the help of the flow chart shown in Fig. 3. For the allocation work of each TTI, eNB updates the values of parameters and

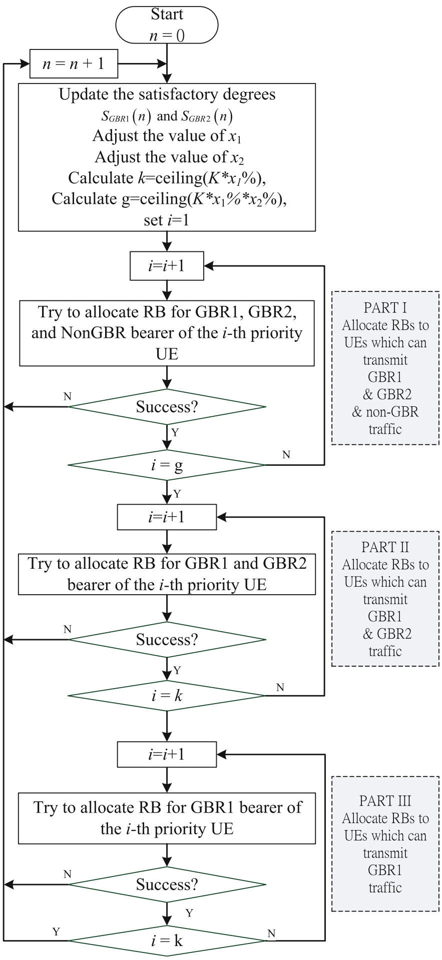

Fig. 3. Flow chart of AAG-LCG

Table 1. Parameters of simulation environment

Number of users	10, 20, 30, 35, 40, 50
System bandwidth	20 MHz
Simulation duration	20 s
Channel quality	MCS index = 28 (TBS index = 26) for all RBs
α of EWMA	0.01
Threshold of average satisfaction ratio S_{th1}	90%
Threshold of average satisfaction ratio S_{th2}	90%
Δx_{raise}	10
Δx_{fall}	1
Bearers of each UE	one GBR1 bearer; one GBR2 bearer one non-GBR bearer
Traffic pattern of each bearer (independent and identically distributed)	Near Real Time Video (NRTV), Truncated Pareto distribution, average data rate: 640 Kbps
Extra ratio	15%

variables at first. Then the PART I of the flow chart shows the steps that try to allocate RBs to the UEs which are entitled to transmit GBR1, GBR2 and non-GBR traffic. These are the g UEs as shown in Fig. 2. Then, PART II tries to allocate for the next (*k*-*g*) UEs. The last PART III deals with the rest UEs.

4 Performance Evaluation

4.1 Simulation Environment

We will compare the performance between AAG-2 and AAG-LCG based on the simulation parameters listed in Table 1. In order to clearly observe the difference, we set all RBs with the same channel quality. However, when we average the data rate of a variable bit rate traffic patterns based on EWMA, the obtained values would vary over time. For example, whenever a big burst appears, the EWMA value at that instant would be higher than the long-term mean data rate of the pattern. The larger the burst is, the larger the instant EWMA value is obtained. Thus, B_m^{grant} in (1) and (2) should be set a little bit higher than the long term mean data rate. In this paper, we set $B_m^{grant} =$ (long term mean data rate) $\times$ (1 + extra ratio). The suitable value for the extra ratio depends on how smooth the input traffic pattern is. With too small extra ratio, the corresponding bearer would get insufficient RBs, and lots of the traffic would be blocked. On the contrary, with too large extra ratio, the eNB would allocate too many RBs for the bearer, thus less bearers can be accommodated. We set the extra ratio as 15% in this paper.

The parameters for AAG-2 are almost the same with that for AAG-LCG. For AAG-2, however, there is only one threshold value S_{th}, which is set as 90%, the same as the values of the two thresholds for AAG-LCG. Besides, the GBR traffic for AAG-2 is the combination of GBR1 and GBR2 traffic used for AAG-LCG because there is only one group of GBR traffic for the AAG-2. For a UE, when the number of LCGs of traffic (volumes/data rate) is changed, not only the B_m^{grant} in (1) and (2) should be changed, but also the $\bar{B}_m(n-1)$ should be changed to the same as B_m^{grant} at the same time. Otherwise, the instantaneous transmission rate would be unstable.

4.2 Numerical Results

Let’s take a glance at Fig. 4. The utilization of RBs is 90% when the eNB is loaded with 50 UEs. According to the slope of the curve, the utilization would exceed 100% if there are 60 UEs. However, overloading is not allowed by the RAC. As a result, the maximum number of UEs is set as 50 UEs for the simulation scenario.

Figure 5 shows the throughput comparison between the AAG-2 and AAG-LCG. The throughput of GBR increases linearly to the load (the number of UEs). When there are 50 UEs, the throughput of non-GBR approaches zero for both schemes. For the AAG-LCG scheme, the throughput of GBR1 and GBR2 coincides and increases linearly with the number of UEs. That means the throughput of GBR1 and GBR2 traffic is ensured with high priority.

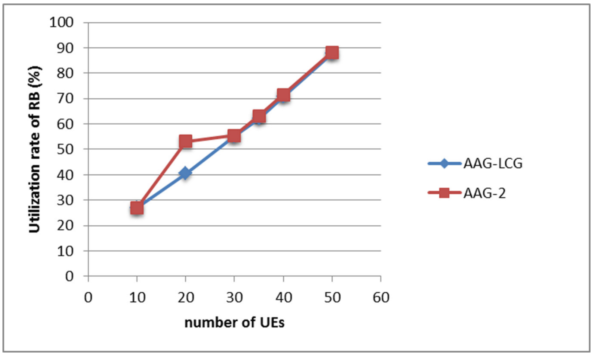

Fig. 4. Comparing the utilization for different schemes.

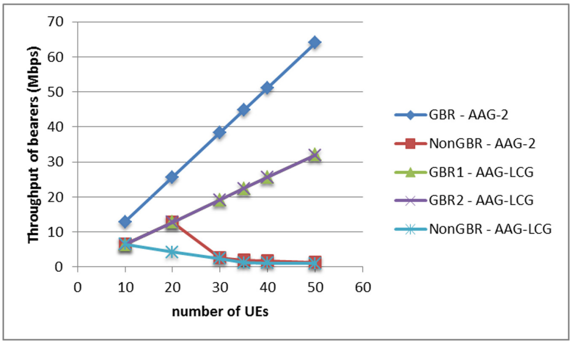

Fig. 5. Comparing the throughput of different LCGs for different schemes

For the AAG-2 scheme, when there is no more than 20 UEs, the throughput of non-GBR traffic keeps increasing linearly with the number of UEs. However, it decreases dramatically when there are more than 30 UEs because almost all of the RBs are allocated for GBR traffic.

For the AAG-LCG scheme, the throughput of non-GBR traffic is worse than that with AAG-2 scheme; it always decreases linearly with the increase of the number of UEs. So far, it seems that the AAG-LCG scheme does not differentiate the QoS of GBR1 and GBR2 traffic. However, let's observe the QoS in terms of packet delay shown in Fig. 5. For the AAG-LCG scheme, the delay of high priority GBR1 is always shorter than that of GBR2. While the delay of GBR bearer for AAG-2 is between them. That means the AAG-LCG scheme does differentiate the QoS of GBR1 and GBR2 traffic in terms of delay.

As for the delay of non-GBR traffic with AAG-LCG scheme, even though it is as short as 9 ms when the eNB is light loaded with 10 UEs, it diverges when the load increases. As a result, it is not shown in the figure. The delay of non-GBR traffic with AAG-2 scheme is better, it is as short as 30 ms when the eNB is light loaded with 20

UEs. However, when there are 30 UEs, because most of the RBs are occupied by GBR traffic, the delay of non-GBR traffic diverse and is not shown in the figure.

Let's return to Fig. 4, which illustrates the utilization of RBs. The two curves of AAG-2 and AAG-LCG almost coincide except when there are 20 UEs. The reason is that AAG-2 transmits more non-GBR traffic when there are 20 UEs as shown in Fig. 4.

The figures illustrated above reveal that the AAG-LCG scheme can divide the user traffic into GBR1, GBR2, and non-GBR traffic with different QoS in terms of throughput or delay. It meets the requirement that bears can be divided into four LCGs and scheduled with different QoS (Fig. 6).

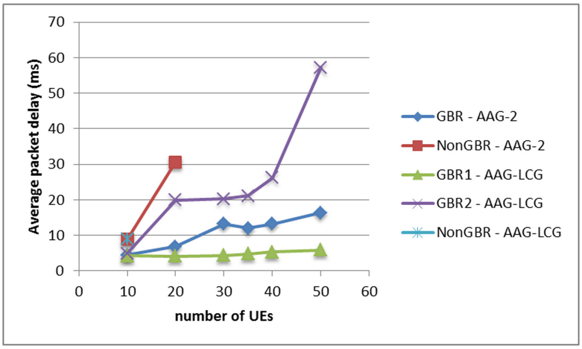

Fig. 6. Comparing the average delay of different LCGs for different schemes

5 Conclusion and Future Works

The 3GPP has suggested divide bearers into four LCGs to alleviate the signaling load of BSR. In this paper, based on the specification, we present an AAG-LCG scheme. This scheme classifies user traffic bearers into different LCGs according to the specification. Simulation results reveal that AAG-LCG can provide bearers of different LCGs with different QoS in terms of throughput and/or delay. Because there is always tradeoff between the QoS of GBR (including GBR1 and GBR2) traffic and RB utilization (and also the QoS of non-GBR traffic), the future work is investigating how to adjust the parameters so as to balance these performance metrics.

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