Research on Scheduling Algorithms in Uplink of LTE System

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Abstract. Downlink scheduling of LTE packet scheduling has been widely studied, while uplink scheduling is rarely studied. Aiming at the problem that uplink scheduling can not guarantee the transmission of real-time traffic packets within the delay period, a new uplink scheduling algorithm is proposed, we establish the target integer linear programming model by the delay constraints of real-time traffic. And aiming at the problem that the bandwidth of low priority traffic is insufficient and the overall QoS is affected when multi-class traffic is processed, a new scheduling algorithm for multi-class traffic is proposed, which includes multi-class traffic scheduling algorithm for eNodeB and priority adjustment algorithm for UE. Through our algorithm, emergency UE is always scheduled first, the algorithm can also maximize MAC throughput and satisfy the minimum QoS constraints. It can also improve the problem that the bandwidth of low priority traffic is insufficient. The experimental results show that the proposed algorithm can significantly improve LTE uplink performance.

1. Introduction

With the rapid development of mobile Internet and the popularity of intelligent terminals, it inspired the urgent desire of the people of wireless transmission rate. Meanwhile, as the representative of 2G and 3G mobile communication system can not meet user of the data rate requirements, more and more people’s attention have been bought to the LTE/ LTE-Advanced as the next generation standard for 4G mobile communications technology. In order to achieve higher transmission rate to meet the traffic needs of users, how to improve the utilization of resources in a limited radio resources system, namely how to design an effective scheduling strategy for efficient management of radio resources has became one research points in LTE/LTE-A system [1-4].

Orthogonal frequency division multiple access (OFDMA) is used for LTE downlink, single carrier frequency division multiple access (SC-FDMA) is used for LTE uplink. Data rate can be improved through OFDMA and SC-FDMA, because OFDMA and SC-FDMA can provide better interference management [3]. The channel is divided into multiple sub-carriers by OFDMA and SC-FDMA. The evolved nodeB (eNodeB) is responsible for packet scheduling, eNodeB can allocate a certain group of sub-carriers for transmitting packets. In groups of 12 sub-carriers of 15 kHz each for a duration of 1 ms (the time duration of 1 ms is a transit time interval (TTI)), Sub-carrier allocation is done. And the unit of allocation is called the physical resource block (PRB). Currently, Downlink scheduling of LTE packet scheduling has been widely studied, while uplink scheduling is rarely studied [5-8].

At present, most of the algorithms do not consider the delay constraints of real-time traffic, packets cannot be transmitted within the delay period, and there are many dropped packets [9-12]. In this...
paper, we have provided an optimization algorithm for LTE uplink scheduling, the algorithm considers the delay constraints of real-time traffic, and packets can be transmitted within the delay period, there are fewer dropped packets, as a result, fairness is improved.

Furthermore, Different classes of real-time traffic have different delay requirements. we have provided the other optimization algorithm for multi-class traffic, the algorithm can solve the problem of insufficient resources of low priority traffic when there are many high priority traffic. We have also provided a priority adjustment algorithm to improve QoS of low priority traffic and maintain minimum QoS requirements of high priority traffic.

2. Uplink Scheduling Algorithm
DHAM is suitable for best-effort traffic. While DHAM may influence the QoS of real-time traffic, such as voice and video. DHAM is for scheduling the UEs with better channel quality. When packets of real-time traffic couldn’t be transmitted within the delay period, the packets will be dropped and the QoS of real-time traffic will be influenced. In this paper, We optimize DHAM [13] and get a new algorithm called USCH. In order to describe the algorithm, $N_U$ is used to indicate the number of active UEs, $M$ is used to indicate the number of RCs, $\Omega$ is used to indicate set of delay violating users, $N_D$ is used to indicate $|\Omega|$. We use the same traffic matrix $W$, $W$ is made up of $w_{i,j}$, $w_{i,j}$ is the flow generated when the $i$th UE sends data through the $j$th RC. Firstly, we establish the integer linear program model, the model includes objective function, delay constraint of real-time traffic, the first constraint and the second constraint.

The objective function is given by:

$$\text{Maximize} \sum_{i,j} \alpha_{i,j} w_{i,j}$$

Where $\alpha_{i,j}$ is a binary variable, if the $i$th UE is allocated to the $j$th RC, then $\alpha_{i,j} = 1$, otherwise, $\alpha_{i,j} = 0$.

The delay constraint of real-time traffic is given by:

$$\delta \left( 1 - \sum_j \alpha_{i,j} \right) \leq D_h - t, \forall i$$

Where $\delta_i$ indicates the delay of the head of the line packet of the $i$th UE, if the $i$th UE has been scheduled in the current TTI then $\left( 1 - \sum_j \alpha_{i,j} \right) = 0$; otherwise $\left( 1 - \sum_j \alpha_{i,j} \right) = 1$. $D_h$ indicates the delay deadline for real-time traffic, $t$ is the length of the TTI.

The first constraint is given by:

$$\sum_i \alpha_{i,j} \leq 1, \forall j$$

The first constraint (3) indicates that an RC can be allocated to at most one UE.

The second constraint is given by:

$$\sum_j \alpha_{i,j} \leq 1, \forall i$$


3. Scheduling Algorithm for Multi-class Traffic

For multi-class of traffic, the existing methods also use strict priority scheduling, namely, the voice queue is emptied first, followed by the video queue and the data queue respectively [14]. As a result, the lower priority traffic suffer from bandwidth starvation, and the overall service quality is affected. So we can choose lower priority traffic to be transmitted first when the transmission of higher priority traffic can be safely delayed without violating its delay constraints in a certain TTI. In this paper, We have provided multi-class traffic scheduling algorithm for eNodeB, in the algorithm, emergency UE is always scheduled first, MAC throughput can be maximized, and the minimum QoS constraints can be satisfied. We have also provided a priority adjustment algorithm for UE to improve the problem that the bandwidth of low priority traffic is insufficient.

3.1. Multi-class Traffic Scheduling Algorithm for eNodeB

In practice, UE may generate many traffic packets with different priority, The higher the delay requirement, the higher the priority. Multi-class traffic have different QoS requirements. For example, the delay bounds of voice is less than 50 ms, the delay bounds of video is less than 150 ms, while data has no delay constraints [14], namely, priority of voice traffic is higher than priority of video traffic, priority of video traffic is higher than priority of data, As a result, when real time traffic load is high, data packets may suffer from bandwidth starvation. To solve the problem, we provide a new algorithm, we structure a single parameter, the parameter can ensure the delay bounds of each class traffic.

Firstly, we build a objective function and constraints, the objective function is given by (5), the constraints are given by (6), (7) and (8).

Maximize \[ \sum_{i} \sum_{j} \alpha_{ij} \gamma_{ij} \]  
\[ \sum_{j} \alpha_{ij} = 1, \forall j = 1, 2, ..., M, (M+1), ..., N_{U} \]  
\[ \sum_{j} \alpha_{yj} = 1, \forall i \]  
\[ \alpha_{ij} = 0 \text{ or } 1 \]  

Where \( \alpha_{i,j} \) is a binary variable, if the \( i \) th UE is allocated to the \( j \) th RC then \( \alpha_{i,j} = 1 \), otherwise, \( \alpha_{i,j} = 0 \). \( N_{U} \) indicates the number of active UEs. 1, 2, ..., \( M \) indicate the identification of actual RC respectively. \( (M+1), ..., N_{U} \) indicate the identification of virtual RC respectively. \( \gamma_{i(M+1)} = -k_{i} \), if \( i = 1, ..., M \), then \( \gamma_{ij} = (w_{ij} - d_{ij}) \), \( d_{ij} \) is the number of bytes dropped by the \( i \) th UE, when the \( i \) th UE is allocated to the \( j \) th RC. We use the same traffic matrix \( W \) in DHAM, \( W \) is made up of \( w_{i,j} \), \( w_{i,j} \) is the flow generated when the \( i \) th UE sends data through the \( j \) th RC. If the metric of the \( i \) th user is \( k_{i} \), then \( k_{i} = m_{i}^{vo} + m_{i}^{vi} + m_{i}^{d} \), where \( m_{i}^{vo} \) indicates the number of voice packets that will be dropped when the user is not scheduled in the current TTI, \( m_{i}^{vi} \) indicates the number of video packets that will be dropped when the user is not scheduled in the current TTI, \( m_{i}^{d} \) indicates the number of bytes in the
buffer that is above a pre-defined buffering threshold \( B_{th} \) in bytes), \( k_i \) indicates that emergency UE is always scheduled first.

### 3.2. Priority Adjustment Algorithm for UE

Usually priority of voice traffic is higher than priority of video traffic, priority of video traffic is higher than priority of data, so there will be constant arrival of traffic in the higher priority buffers when the higher priority traffic composition is sufficiently high. When all the higher priority traffic buffers are empty, the lower priority packets will be transmitted. Obviously, the lower priority packet transmission is delayed. So the lower priority packets may suffer from starvation. In order to improve the problem, we have provided a priority adjustment algorithm for UE. UE can increase the priority value of the lower priority packets, we associate rewards to packets and structure the objective function, the objective function is given by:

\[
\text{Maximize } \sum_u \sum_v \alpha_{uv} r_{uv}
\]  

(9)

We structure the constraint for the objective function (9), the constraint is given by:

\[
\sum_u \sum_v \alpha_{uv} w_{uv} \leq G
\]  

(10)

\[
\alpha_{uv} = 0 \text{ or } 1
\]  

(11)

Where \( v \) indicates voice, video and data traffic , \( \alpha_{uv} \) is a binary variable, \( \alpha_{uv} \) indicates the scheduling information of the \( u \) th packet of the \( v \) th class traffic, \( r_{uv} \) is the reward associated with the \( u \) th packet of the \( v \) th class traffic, \( w_{uv} \) is the size of the \( u \) th packet of the \( v \) th class traffic, \( G \) is the allocated bandwidth.

The reward associated with voice, video and data traffic packet is given by (12), (13) and (14):

\[
r_{uv} = \frac{D_{u,v}}{D_{th,v}}
\]  

(12)

Where \( D_{u,v} \) indicates the \( u \) th voice packet delay, \( D_{th,v} \) indicates the pre-defined voice delay threshold.

\[
r_{uv} = \frac{D_{u,v}}{D_{th,v}}
\]  

(13)

Where \( D_{u,v} \) indicates the \( u \) th video packet delay, \( D_{th,v} \) indicates the pre-defined video delay threshold.

When voice packets have high input, video is getting starved. As shown in (12) and (13), the reward \( r_{uv} \) associated with the \( u \) th packet of video traffic is higher than the reward \( r_{uv} \) associated with the \( u \) th packet of voice traffic, and the video packet will be transmitted first.
\[
    r_{av} = \begin{cases} 
    \frac{B_c - B_{th}}{(B - B_{th})} & \text{if } B_c > B_{th} \\ 
    0 & \text{otherwise} 
    \end{cases}
\]

(14)

Where \( B_c \) is the current buffer occupancy, \( B_{th} \) is the buffer threshold and \( B \) is the buffer capacity.

Data packets are not real time traffic, as shown in (14), when \( B_c < B_{th} \), data packets have no priority. While when \( B_c > B_{th} \), data packets are being starved, there are higher priority packets. As more and more data packets fill the buffer, the algorithm will increase the priority of the data packets, so that the data packets can be transmitted soon.

4. Simulation and Result

In order to verify the effectiveness of our algorithm, the simulation studies have been carried out on a system level simulator developed in the OMNET++ network simulator. Firstly, we compare the performance of uplink scheduling algorithm (USCH, introduced in Section 1) with DHAM in the fairness, the MAC throughput, the number of packets delivered by the user having worst channel conditions and the delay. The result of the fairness is shown in Fig. 1, USCH is better than DHAM, USCH can provide opportunity for user that has bad channel conditions to occupy the channel. While DHAM always provide opportunity for user that has better channel quality. As show in Fig. 2, USCH and DHAM are basically consistent in MAC throughput, because packets can be transmitted within the delay period, there are fewer dropped packets for USCH.

![Figure 1. Fairness comparison](image1.png)

![Figure 2. MAC throughput comparison](image2.png)
As shown in Fig. 3, USCH is better than DHAM in worst user packet count, USCH can consider the delay constraints of real-time traffic, so user that has the poor channel quality can get opportunity, packets can be transmitted within the delay period. Therefore the worst user packet count is larger. As shown in Fig. 4, the delay of USCH is slightly larger than that of DHAM, but the delay of USCH is allowed, it remains within a certain range.

Figure 3. Number of worst user voice packets delivered

![Graph showing worst user packet count vs network load](image)

Figure 4. Voice delay comparison

![Graph showing delay vs network load](image)

Secondly, we compare X1, X2 with DHAM[15] in the fairness, the MAC throughput, packets dropped, number of packets received and so on, where X1 indicates multi-class traffic scheduling algorithm for eNodeB(introduced in Section 3.1), X2 indicates priority adjustment algorithm for UE(introduced in Section 3.2), the results are shown in Fig. 5 to Fig. 9. each one includes three sub-plot, the voice load is varied in (a), the video load is altered in (b), data load is varied in (c).

As shown in Fig. 5, the MAC fairness provided by X1 and X2 is higher than that of DHAM. Because when users have poorer channel conditions, X1 and X2 can give more priority for the users.
As shown in Fig. 6, MAC throughput is higher for DHAM, because DHAM always seeks to maximize MAC throughput. While X1 and X2 need to meet delay constraints, as a result, the MAC throughput of X1 and X2 is slightly lower.

As shown in Fig. 7, when the percentage of voice traffic is high, X1 has higher video packets dropped, because X1 has lower MAC throughput. While X2 is better than X1 in video packets dropped. X2 can rectify this shortcoming of X1 by the application of priority adjustment. X2 also yields lower MAC throughput than DHAM, and hence drops higher number of video packets as compared to DHAM. When the percentage of voice is low in the traffic mix, performance of DHAM, X1 and X2 are basically the same.

The result of number of packets received is shown in Fig. 8, X2 performs the best, because X2 can increase the priority value of the lower priority packets, X1 performs better than DHAM, because X1 has a good scheduling way. As shown in Fig. 8, when load increases, the number of video packets delivered by the worst user decreases. lack of the transmission opportunities increases the number of packet dropped. all the UEs accumulate large number of packets in their queues when the load is high. The video performance of the X2 is improved by borrowing the bandwidth that was to be used for
transmitting voice packets in X1, the worst user voice performance is poorer for X2 than it is for X1, Nevertheless, both X1 and X2 perform better than DHAM for heavy load conditions.

![Number of packets received comparison](image)

**Figure 8.** Number of packets received comparison

5. Conclusion
We have provided an optimization algorithm for LTE uplink scheduling, eNodeB guarantees that packets can be transmitted within the delay period by considering the delay constraints of real-time traffic. We have also provided the other optimization algorithm for multi-class traffic to solve the problem of insufficient resources of low priority traffic when there are many high priority traffic. Finally, we have provided a priority adjustment algorithm to improve low priority traffic QoS and maintain minimum QoS requirements of high priority traffic. The experimental results show that the proposed algorithm can significantly improve LTE uplink performance.

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