PFGBR Scheduling for Streaming Services over Wideband Cellular Network

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Abstract—This paper considers the multi-user scheduling for streaming services over wideband frequency-selective and time varying channel in cellular network such as E-UTRAN [1]. First, the frequency-selective proportional fair (PF) scheduling is proposed for multi-carrier system under user’s maximum transmission power capability and continuous resource constraints, which is used to reduce the peak to average power ratio (PAPR) for uplink. In addition, the proportional fair with guaranteed bit rate (PFGBR) is proposed to enhance the quality of service (QoS) of streaming service and improve the user experiences in terms of data rate and delay. The PFGBR is to optimize the concave utility function of $\sum \log R_i$ while provides guaranteed bit rate (GBR) specifically for streaming applications. The system simulation results for both frequency-selective PF and PFGBR are presented and it shows that the PFGBR can achieve better dynamics of rate and delay than PF algorithm.

Keywords- LTE uplink; Scheduling; QoS; Streaming

I. INTRODUCTION

The rapid growth in demand for multimedia services is creating the opportunities and challenges for the next-generation wireless networks. The LTE (long-term evolution) system is being specified in 3GPP to maintain UMTS long-term competitiveness with introduction of disruptive technologies such as OFDM (Orthogonal Frequency Division Multiplexing), link adaptation and distributed dynamic resource allocation (Node B scheduling) etc. It targets low latency, high user data rate, improved system capacity and coverage etc. One of the driven factors to develop the system with high spectrum efficiency is to meet the requirements of multimedia services. Mobile video streaming is a service that is becoming increasingly popular. With the deployment of wideband mobile systems, the operators have the possibility to provide multimedia services with satisfied QoS.

This paper considers scheduling algorithms for streaming applications over uplink in the FDD (frequency division duplex) based LTE system. The multi-user diversity is inherent in wireless networks, where channel conditions vary over time due to small-scale fading and large-scale fading such as pathloss and shadowing. Therefore the scheduling algorithm plays a key role in providing the satisfied performance for streaming users. The key issue of the scheduling algorithm is to allocate the resources to the UEs to make full use of the frequency selective gain and to meet the QoS requirement of streaming service simultaneously. Many scheduling algorithms are proposed and evaluated to provide QoS for streaming application in single carrier systems. Reference [2] proposes an algorithm which introduces the barrier function into the utility function to control the average throughput and proposes that the optimal solution can be obtained with a gradient ascent method. But in this paper, only the algorithms which combine the max C/I and barrier functions are evaluated and analyzed in detail. Reference [3] proposes an algorithm which is the optimal solution of a concave utility function of $\sum \log R_i$ subject to certain lower and upper throughput bounds. In [3], the performance comparison between PFMR (proportional fair with minimum/maximum rate) and the algorithm with modified utility function are made and it shows that the latter is less effective than PFMR at providing minimum rates and achieves significantly less system throughput. Reference [4] analyzes and simulates the performance of the M-LWDF and the fair version of the M-LWDF in HSDPA, it is concluded that the M-LWDF algorithm is an unfair scheduling principle and the fair version yields cell throughput reduction.

In this paper, an algorithm named PFGBR algorithm is proposed and analyzed, which introduces the factor of the difference between the average data rate and the guaranteed data rate into the priority calculation. The proposed algorithm aims to satisfy the guaranteed bit rate requirement while optimize the utility function of $\sum \log R_i$. In addition, the frequency-selective PF algorithm and PFGBR algorithm for LTE uplink system are proposed which are also suitable to other multi-carrier systems. At last, the performances of PFGBR algorithm and PF algorithm for streaming users are presented, and it shows that the PFGBR can achieve better dynamics of rate and delay than PF algorithm.

The paper is organized as follows. The mathematical expression of the proposed PFGBR algorithm is presented in section II. The main characteristics of LTE system are introduced in section III, together with the frequency-selective PF algorithm and PFGBR algorithm designed for FDD LTE uplink with constraints of maximum transmission power and continuous resource requirements. Traffic model and simulation model are described in section IV and followed by simulation results and analysis in section V. Finally, conclusions are drawn in section VI.
II. MATHEMATICAL EXPRESSION OF PFGBR ALGORITHM

The fundamental QoS requirement of streaming application is to satisfy guaranteed bit rate and delay jitter constraints. Here we discuss how to design a scheduling algorithm that can optimize certain utility function of the average rates \( R \) over rate region \( V \) and satisfy the guaranteed bit rate requirement simultaneously. The system rate region \( V \) is the set of all feasible long-term average service rate vectors \( R = (R_1, \ldots, R_I) \). This issue can be expressed by the following formulas:

\[
\max H(R)
\]

subject to

\[
R \in V
\]

\[
R = R_{gbr}, i \in I
\]

\( I \) is the set of the UEs which will be scheduled. \( R_i \) is the average rate of the \( i \)th user. The utility function is in the following form:

\[
H(R) = \sum_i H(R_i)
\]

The common PF algorithm is to optimize the utility function of \( \sum_i \log R_i \). This algorithm is widely employed recently because it not only makes use of instantaneous channel condition to improve the capacity but also considers the throughput fairness. Here we also choose \( \sum_i \log R_i \) as the utility function, i.e.

\[
H(R) = \sum_i \log R_i
\]

To solve the optimization problem of (1)-(5), an algorithm is proposed in this paper, it always selects the user to serve according to:

\[
i = \arg \max_{i \in I} \{\exp(\alpha T_i(n)) \cdot d_i(n) / R_i(n)\}
\]

Here, \( \alpha \) is a parameter that determines the timescale over which the rate constraint is controlled. \( d_i(n) \) is the estimated value of the supported bit rate in TTI (Transmission Time Interval) \( n \) for user \( i \). \( T_i(n) \) is a token bucket counter which is used to statistic the difference between the guaranteed bit rate and the actual data rate and can be defined as:

\[
T_i(n) = T_i(n-1) + R_{gbr} - R_i(n-1)
\]

\( r_i(n) \) is the amount of data which is correctly received from user \( i \) in TTI \( n \), it is set to 0 for users which packet is not being correctly received. \( R_{gbr} \) is the guaranteed data rate and it is measured in bits/slot. \( R_i(n) \) is the filtered user throughput for user \( i \) which is calculated as

\[
R_i(n+1) = (1 - 1/T_c) \cdot R_i(n) + r_i(n)/T_c
\]

Here \( T_c \) is the time constant of the low pass filter.

The proof of this algorithm is the solution of the optimization problem of (1)-(5) can refer to [3] where we can follow the similar procedures by setting \( R_{min} = R_{max} = R_{gbr} \). Here we ignore those detailed mathematical proof due to limited space.

Moreover, if we replace the actual data rate \( r_i(n) \) with the filter throughput \( R_i(n) \), \( T_i(n) \) can be replaced by \( R_{gbr} - R_i(n) \). The above algorithm can be further expressed in the following:

\[
i = \arg \max_{i \in I} \{\exp(\alpha (R_{gbr} - R_i(n))) \cdot d_i(n) / R_i(n)\}
\]

We call this algorithm as proportional fair with guaranteed bit rate (PFGBR) algorithm. The basic idea of this algorithm is that for the UE with the large difference between \( R_i(n) \) and the objective data rate, the flow is more likely to be served by introducing the weighting factor of \( \exp(\alpha (R_{gbr} - R_i(n))) \).

III. SCHEDULING ALGORITHMS FOR UPLINK LTE SYSTEM

A. Characteristics of LTE Uplink

The SC-FDMA is introduced as an orthogonal multiplex access scheme in LTE uplink [1]. The overall SC-FDMA time/frequency resource can be organized into a number of resource units (RU). Each RU consists of a number (M=12) of consecutive sub-carriers within one sub-frame and each sub-carrier occupies 15 kHz bandwidth. The RU is the basic resource unit for data transmission and resource allocation.

Both the synchronized N Stop-and-Wait non-adaptive HARQ and adaptive modulation and channel coding (AMC) are supported to increase the achievable data rate. The same coding and modulation is applied to all resource units assigned to a user within a TTI.

In LTE uplink data transmission, the frequency resource that UE can use is determined by eNB (enhanced Node B) scheduling. The allocated frequency resource and corresponding MCS (Modulation and coding scheme) are informed to UE through eNB grant signaling. The eNB scheduling plays a critical role to improve the radio resource utilization while guarantee the QoS requirement as well. To achieve this, several important factors should be considered in designing the scheduling algorithm such as different QoS requests, UE buffer size, UE capability (power limitation, bandwidth limitation), HARQ retransmission and uplink channel condition in term of channel quality indicator (CQI) information.

B. PF algorithm for LTE uplink system

A great deal of work on PF algorithm has been done in single carrier system in recent years [5]. The algorithm selects user from the set of users with pending data according to

\[
i = \arg \max_{i \in I} \{d_i(n) / R_i(n)\}
\]
In the above formula, it is assumed all the resources are allocated to one UE in one TTI. But in wideband system like LTE, it is not only possible but also necessary to simultaneously allocate the resources to multiple users in one TTI to leverage the multi-user diversity and avoid the power shortage of user’s capability. Thus the frequency-selective PF algorithm should be considered. For LTE uplink system with both the HARQ retransmission, maximum user’s transmission power (e.g. 24dBm) and continuous RU constraint, the detailed algorithm can be as the following three steps:

Step1: Determine the maximum supported data rate for each UE considering the CQI on each RU, user’s transmission power and potential continuous RUs, i.e., determine the number of RUs $M_i$ which will be allocated to the UE:

$$M_i = \arg \max_{M_i, i} \left\{ M_i W \log_2 \left( 1 + \frac{P_i / M_i \cdot CQI_{iM}}{N + I_{Mi}} \right) \right\}$$  \hspace{1cm} (11)

and

$$\text{SINR}_{eq,M_i} \geq \text{SINR}_{th}$$  \hspace{1cm} (12)

where $W$ is the bandwidth of one RU, $P_i$ is the transmission power of user $i$, and $\text{CQI}_{iM}$ is the average channel quality of user $i$ on the continuous $M_i$ numbers of RUs, $N$ is the thermal noise, $I$ is the set of the available RUs, $\text{SINR}_{eq,M_i}$ is the equivalent-SINR for the continuous $M_i$ numbers of RUs and $\text{SINR}_{th}$ is the threshold [6]. Thus the supported data rate can be derived as follows:

$$d_i(n) = M_i W \log_2 \left( 1 + \frac{P_i / M_i \cdot CQI_{iM}}{N + I_{Mi}} \right)$$  \hspace{1cm} (13)

How to determine $d_i(n)$ for each user is a key issue and will be adaptive to different system constraints. For different practical system, the maximum supported data rate for each user in (11) to (13) should be defined correspondingly. However, this principle is also suitable to other multi-carrier wideband systems.

Step 2: Schedule the user according to the scheduling principle defined in (10).

Step 3: Iteratively re-execute the procedure of Step1 and Step2 for the unscheduled UE set on the remaining RU set until all UEs are scheduled or all RUs are allocated. If there are still RUs left when all users are scheduled, the left RUs are allocated to user randomly.

C. PFGBR algorithm for LTE uplink system

We can easily derive the PFGBR for LTE uplink from the PF for LTE uplink system by replacing (10) in step 2 with the priority function in (9).

We can see PFGBR algorithm is compatible with PF which is proved good for best effort service and thus is easily extended to mixed service scenario later. It is also one advantage of PFGBR algorithm.

IV. SIMULATION MODEL AND PARAMETERS

A. Traffic model and play out buffer

The video traffic model is the same as the model in reference [7]. For streaming application, there is a buffer in the receiver which makes a streaming application resistant against latency and jitter. A parameter $T_B$ is the length (in seconds) of the de-jitter buffer window. De-jitter buffering capabilities determine the maximum allowable delay jitter of the communication. In the receiver, the video frames are stored in the de-jitter buffer. Once the amount of buffered data reaches the initial buffer size ($T_B \cdot \text{source data rate}$), play-out is started. If the buffer runs empty, then a re-buffering occurs and $T_B$ seconds of the video is again buffered before play out re-starts.

There are several import performance criterion used to evaluate the performance of streaming application: the initial buffering time $T_1$, re-buffering time $T_2$, and initial buffering size $T_B \cdot T_1$, $T_2$ and $T_B$ is set to 8s, 10s and 5s respectively.

B. Simulation parameters

A dynamic system simulator for LTE system is built in OPNET to simulate the system performance of the frequency-selective PF and PFGBR algorithms. The traffic model, mobility model, RLC layer, MAC layer and physical layer are modeled elaborately according to the requirement of 3GPP [1]. The pipeline of OPNET is used to calculate the received SINR. The corresponding BLER can be derived by the interface to link level simulation results which support HARQ with chase combining. Moreover, the measurement model provides the channel condition to scheduling.

The detailed simulation parameters are listed in Table I and Table A.2.1.1-3 in [1].

<table>
<thead>
<tr>
<th>Parameter</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>TTI duration</td>
<td>0.5ms</td>
</tr>
<tr>
<td>UE transmission power</td>
<td>24dBm</td>
</tr>
<tr>
<td>Site to site distance</td>
<td>500m</td>
</tr>
<tr>
<td>Path loss</td>
<td>L=128.1+37.6log(d), d in km</td>
</tr>
<tr>
<td>Std. of Shadow fading</td>
<td>8dB</td>
</tr>
<tr>
<td>Mobility</td>
<td>3km/h</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>10MHz</td>
</tr>
<tr>
<td>HARQ</td>
<td>HARQ process number = 6</td>
</tr>
<tr>
<td></td>
<td>Maximum transmission number = 4</td>
</tr>
<tr>
<td>AMC Set</td>
<td>(QPSK,1/3) (QPSK,1/2) (QPSK,3/4)</td>
</tr>
<tr>
<td></td>
<td>(16QAM,1/3) (16QAM,1/2) (16QAM,3/4)</td>
</tr>
<tr>
<td>Streaming source data rate</td>
<td>256kbps</td>
</tr>
<tr>
<td>Scheduling parameter</td>
<td>$T_c = 1.6s$, $R_{gbr} = 1.1 \times 256kbps$, $\alpha = 6.25 \times 10^{-5}$</td>
</tr>
<tr>
<td>$\text{SINR}_{th}$</td>
<td>The SINR for MCS (QPSK,1/3)</td>
</tr>
</tbody>
</table>

V. SIMULATION RESULTS

In this section, the performances of the proposed PFGBR algorithm are investigated and compared with PF algorithm in different load conditions.
We run the simulation for 50 seconds with four different seeds. At the end of each 10 second interval, we calculate the average data rate that the user received during this interval. We plot the cumulative distribution function of the average throughput for all users in Fig. 1. The detailed statistics of mean values and variances of user throughput are shown in Table II.

In Fig.1, the cumulative distribution functions of average throughput for the scenarios with different number of users are shown. The top plots show the cumulative distribution functions for PF algorithm and the bottom plots show the distribution for PFGBR algorithm. We can see that as the number of users increases, the minimum of the average rate for both algorithm decreases. The curves for PFGBR algorithm are steeper than the curves for PF algorithm and the average throughputs for PFGBR centralize around the objective data rate.

We note that in the case of 30 users, the curve for PFGBR is almost identical with the curve for PF algorithm. This is because for small number of users, PF algorithm can achieve the average data rate of 254.7kbps (from Table II). The difference between the average data rate and GBR is almost zero, so PFGBR is nearly identical with PF algorithm. However, in high load condition, PF algorithm can’t provide the average throughput of 256kbps for all users, the average value of the average user throughput is 229.4kbps and 206.0kbps respectively in the cases of 50 users and 60 users. But for PFGBR algorithm, we note that in the cases of 50 users, 40 users and 50 users, it can provide similar distribution and the average throughput about 256kbps. Even in the case of 60 users, PFGBR can achieve the average throughput of 237.6kbps because it can provide more chances to the user with larger difference between the average data rate and objective data rate.

As discussed in section II, the PF and PFGBR algorithm are both to maximize $\sum \log R_i$. In Table II, we show the values of the utility function in different load conditions. It can be noted that in the cases of 30 users and 40 users, the values of $\sum \log R_i$ for these two algorithms are almost the same. In the cases of 50 users and 60 users, we see that PFGBR has a little higher value of $\sum \log R_i$ than PF algorithm.

In Table II, we also observed PFGBR algorithm has higher mean value and lower variance of average user throughout than PF algorithm.

Moreover, we model the play out function in the receiver to observe the top level performance of streaming application. Take the scenario with 40 users as example, we run the simulation with four different seeds and get the results of 160 users totally, we can observed that re-buffer occurs for only 2 users for PFGBR algorithm, but re-buffer occurs for 14 users for PF algorithm.

VI. CONCLUSIONS

In this paper, the PFGBR algorithm is proposed to control the average throughput for streaming application, which introduces a weighting function based on the difference between the measured average throughput and the objective average data rate in the priority function. It not only makes use of the channel condition to get the multi-user diversity gain, but also puts the constraint on average throughput. The performance of this algorithm is evaluated in different load conditions. The simulation results show that the PFGBR can achieve better dynamics of rate and delay than PF algorithm. Moreover, PFGBR algorithm also provides better user experience.

The PFGBR algorithm not only provides good performance for streaming application, but also be compatible with the widely employed PF, which is good for best effort service. More investigation on the mixed traffic scenario should be done in the next step.

In addition, this paper also introduces how to apply the PF and PFGBR to the uplink of the frequency-selective wideband system with power and PAPR constraints. This method is also applicable for other multi-carrier wideband uplink systems.

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### TABLE II MEAN VALUE, VARIANCE OF AVERAGE USER THROUGHPUT AND UTILITY FUNCTION

<table>
<thead>
<tr>
<th></th>
<th>PF</th>
<th>PFGBR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean(kbps)</td>
<td>254.7</td>
<td>255.0</td>
</tr>
<tr>
<td>Var</td>
<td>266.8</td>
<td>149.0</td>
</tr>
<tr>
<td>$\sum \log R_i$</td>
<td>1154</td>
<td>1154</td>
</tr>
<tr>
<td>Mean(kbps)</td>
<td>251.8</td>
<td>255.9</td>
</tr>
<tr>
<td>Var</td>
<td>532.2</td>
<td>83.8</td>
</tr>
<tr>
<td>$\sum \log R_i$</td>
<td>1530</td>
<td>1540</td>
</tr>
<tr>
<td>Mean(kbps)</td>
<td>229.4</td>
<td>256.2</td>
</tr>
<tr>
<td>Var</td>
<td>2630</td>
<td>47.8</td>
</tr>
<tr>
<td>$\sum \log R_i$</td>
<td>1874</td>
<td>1920</td>
</tr>
<tr>
<td>Mean(kbps)</td>
<td>206.0</td>
<td>237.6</td>
</tr>
<tr>
<td>Var</td>
<td>4678</td>
<td>659.4</td>
</tr>
<tr>
<td>$\sum \log R_i$</td>
<td>2186</td>
<td>2277</td>
</tr>
</tbody>
</table>
Figure 1 User average throughput distribution

Figure 2 User RLC SDU delay distribution

Table III: Mean Value and Variance of RLC SDU Delay

<table>
<thead>
<tr>
<th></th>
<th>Mean (ms)</th>
<th>Var.</th>
</tr>
</thead>
<tbody>
<tr>
<td>30UE</td>
<td>PF</td>
<td>PFGBR</td>
</tr>
<tr>
<td></td>
<td>69.59</td>
<td>27.13</td>
</tr>
<tr>
<td></td>
<td>4.76*10^4</td>
<td>1.03*10^4</td>
</tr>
<tr>
<td>40UE</td>
<td>PF</td>
<td>PFGBR</td>
</tr>
<tr>
<td></td>
<td>140.89</td>
<td>34.49</td>
</tr>
<tr>
<td></td>
<td>1.08*10^5</td>
<td>8.12*10^3</td>
</tr>
<tr>
<td>50UE</td>
<td>PF</td>
<td>PFGBR</td>
</tr>
<tr>
<td></td>
<td>356.95</td>
<td>67.92</td>
</tr>
<tr>
<td></td>
<td>2.76*10^5</td>
<td>1.78*10^4</td>
</tr>
</tbody>
</table>

REFERENCES