A New Channel-Aware Downlink Scheduling Algorithm for LTE-A and 5G HetNets

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Abstract. Current and future cellular mobile networks, such as Long Term Evolution Advanced (LTE-A) and 5G, should provide wireless broadband access over radio channels for a growing number of users each day. However, in order to satisfy the service requirements of the User Equipments (UEs) applications, Radio Resource Management (RRM) mechanisms implemented in evolved NodeB (eNB) need to use efficient techniques to overcome limitations such as bandwidth scarcity, path loss, and channel fading. Therefore, this paper proposes a new channel-aware scheduling algorithm. Evaluation results show that the proposed algorithm is able to improve the cell edge throughput if compared to other algorithms. In addition, it offers better fairness performance.

Keywords: LTE-A and 5G networks · Channel-aware scheduling · Cell edge throughput

1 Introduction

The volume of data traffic generated on cellular mobile networks is continuously increasing [1]. The efficient radio resource management (RRM) schemes are necessary in order to meet this demand. The main RRM function is scheduling, which is responsible for periodically allocate the resources to User Equipments (UEs).

One of the main features of wireless mobile communications is the fast variation in channel conditions due to the phenomenon called channel fading, distance-dependent path loss and interference [2]. The Signal-to-Interference-plus-Noise Ratio (SINR) level is a parameter that enables to qualify the channel condition between the evolved NodeB (eNB) and the UE. The greater the distance between these devices, as well as the interference, the lower the SINR and, consequently, the lower UE throughput. Therefore, the UEs present at the cell edge are the most injured.

The Resource Allocation (RA) mechanisms that consider channel conditions, also known as channel-aware, have better throughput performance when compared to channel-unaware mechanisms. This is possible because channel-aware mechanisms exploit the so-called multi-user diversity gain, which means that among several UEs

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with different channel conditions, those one with more favorable conditions for transmission must use the resources. Thus, more bits can be transmitted through the allocated resources and consequently the channel is used more efficiently [3].

Therefore, this paper proposes a new scheduling algorithm that considers the channel conditions for the downlink LTE-A and 5G networks, with the objective of increasing the cell edge throughput, and at the same time to improve the fairness. The remainder of this paper is organized as follows. In Sect. 2, we present the fundamental concepts of channel-aware scheduling, after in Sect. 3 we specifies the problem and in Sect. 4 present the solution, then follows Sect. 5 with performance evaluation, and finally, in Sect. 6 the general conclusions are made.

2 Channel-Aware Scheduling

The scheduling mechanism or Packet Scheduling (PS) is responsible for defining which Resource Blocks (RBs) are allocated to the UEs. The RBs, which convey the data bits, are the elementary frequency subcarrier allocation units (12 subcarriers of 15 kHz, totaling 180 kHz per RB) used for communication between eNBs and UEs in Long-Term Evolution Advanced (LTE-A) networks, standardized by the Third-Generation Partnership Project (3GPP).

The amount of RBs and the order of served UEs over time are the result of the scheduling strategy or policy adopted. Therefore, the scheduling strategy is a decision-making process, carried out by the MAC layer in eNB, based on input parameters such as channel state, Quality of Service (QoS) requirements, among others [4], as shown in Fig. 1.

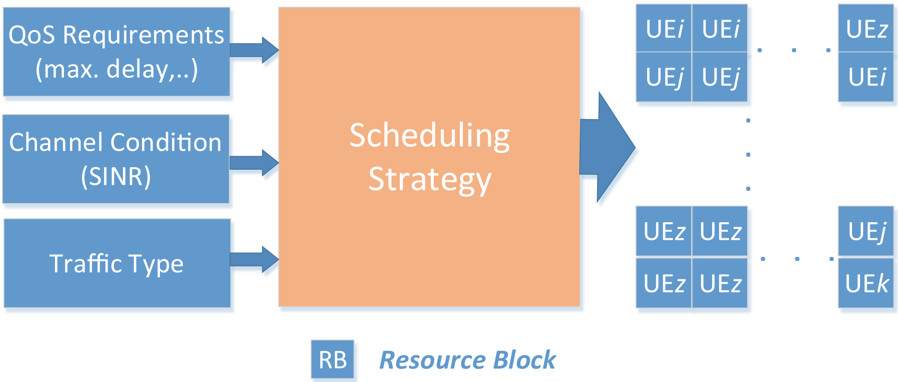

Fig. 1. Downlink scheduling: input parameters and UE-to-RB mapping.

The PS strategy in LTE-A and 5G networks is not standardized by 3GPP, therefore performance depends on the implementation designed by each mobile cellular network operator or developer. In general, most of the scheduling schemes presented in the literature can be classified according to information used for decision-making process, such as QoS requirements, and channel conditions (Channel-Aware Scheduling).

The scheduling scheme operation that consider channel conditions can be summarized as follows. At each Transmission Time Interval (TTI), UEs estimate the channel condition and report the Channel Quality Indicator (CQI) to serving eNB. This is so-called CQI feedback [5]. In eNB there is a buffer for each UE, where incoming packets are queued and has to wait for scheduling opportunity. The scheduling strategy, whose decision-making process takes channel condition into account, can allocate one or more RBs to particular UEs, and a RRM module determines the Modulation and Coding Scheme (MCS) according to CQI feedback. For instance, RBs are allocated to high SINR UEs in each cell in order to maximize system throughput because the better the channel condition, the higher the MCS order and, hence, the higher the bit rate per RB. This is an opportunistic scheduling example that is efficient for exploiting variations in channel conditions to produce significant network throughput gains.

The effectiveness of these schemes depends on the channel condition information provided by the UEs. Outdated information may result in poor performance.

In general, the PS design should consider a mathematical model, so-called utility function, to quantify system performance. The utility function result may vary with each TTI according to the UE-to-RB mapping established by the scheduling strategy. The parameterization of this function depends on the project objective. Some examples of scheduling algorithms that consider channel conditions are Maximum Throughput (MT), whose purpose is to maximize system throughput; another example is the Proportional Fairness (PF), whose objective is the balance between spectral efficiency (SE) and fairness. In the Eqs. (1) and (2) are presented utility functions of MT and PF algorithms, respectively [3].

$$p_u^k = argmax_u\left(r_k^u(t)\right) \tag{1}$$

Where $r_k^u(t)$ represents the expected data rate at time t, u is the UE index, which ranges from 1 to N, and k is the RB index. In this case, the UEs with better channel conditions has resource allocation priority and it may result in traffic starvation of UEs with low SINR.

$$p_u^k = argmax_u\left(\frac{r_k^u(t)}{R_u(t-1)}\right) \tag{2}$$

Where $R_u(t-1)$ is the achieved throughput. In this case, the UEs with lower throughput achieved could have resource allocation priority. Therefore, PF algorithm also gives the scheduling opportunity to UEs with bad channel condition.

In the literature there are several proposals based on Channel-Aware Scheduling. For example, in [6] and [7] the resource allocation decision is based on comparing one metric, per UE, which is a function of CQI; the papers presented in [8–11] and [12] take into account channel conditions and QoS parameters for resource allocation. The balance between opportunistic scheduling and fairness scheduling types is the focus of the study presented in [13] and the proposed implementation in [14, 15] and [16].

3 Problem Description

The scheduling mechanisms performance depends on the techniques employed in their implementation. The scheduling disciplines adopted in wired networks, such as Round Robin (RR), are not efficient for the wireless network scenario, where channel conditions and traffic load vary dynamically. The RR scheduling discipline aims to allocate the same amount of RBs for each UE associated with an eNB, but the UE throughput may significantly vary as the amount of bits available in each RB varies with the established MCS. The MCS is set according to the channel condition because this condition defines the SINR level and, hence, CQI value reported by UE. The amount of bits per RB allocated to UEs with low SINR, which is typical of cell edge UEs, is smaller than for UEs with high SINR. Therefore, scheduling disciplines that do not consider channel conditions to allocate resources may not to be the most efficient for improving cell edge throughput in LTE-A and 5G networks.

Even channel-aware scheduling disciplines such as MT, which optimizes system throughput at the cost of starvation of traffic flows generated by UEs with low SINR that are mainly those located at the cell edge, is not ideal algorithm for optimizing the throughput of these UEs. It is noteworthy that resource allocations projects that cannot balance spectral efficiency and fairness are not practical for real cellular mobile network scenarios. Thus, we present in the next section a new solution to improve the cell edge throughput while achieving fairer resource allocation.

4 Channel-Aware Downlink Scheduling Algorithm for LTE-A and 5G Networks

To improve the cell edge UEs average throughput, we must implement a channel-aware scheduling algorithm. Therefore, based on channel condition, we developed a novel RRM mechanism called Resource Allocation Scheme to Optimize the Throughput (RASOT). We present the RASOT operation in Fig. 2 and in the following pseudo code.

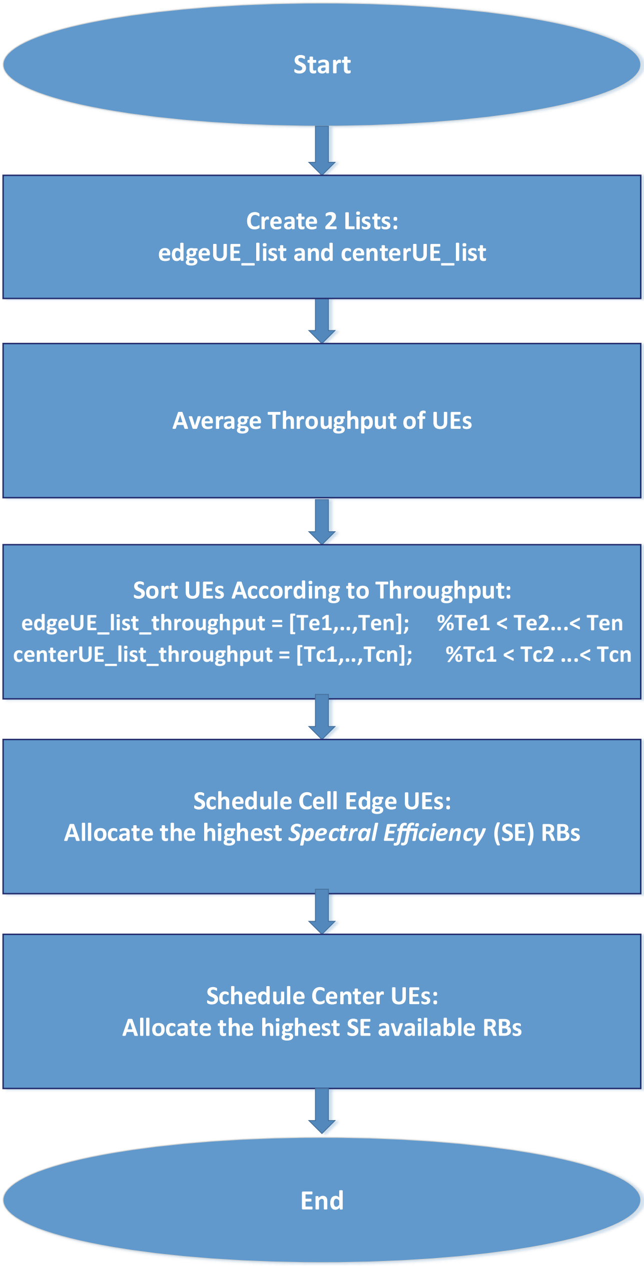

Fig. 2. RASOT basic steps.

Algorithm – RASOT

```
Input(s): eNB_set, associated_ue.
Output(s): user_alloc.
edgeUE_list = [ ];
centerUE_list = [ ];
nRBs_allocated = 0;
for eNB_i = 1:length(eNB_set) do
    RB_allocated{eNB_i} = [ ];
    for num_ue = 1:length(associated_ue{eNB_i}) do
       if associated_ue(num_ue).sinr < SINR_threshold then
                   edgeUE_list  =  [edgeUE_list          associated_ue(num_ue)];
       else
                   centerUE_list = [centerUE_list        associated_ue(num_ue)];
       end if
    end for
end for
[edgeUE_list_throughput]  = average_throughput(edgeUE_list);
[centerUE_list_throughput]  = average_throughput(centerUE_list);
[throug_edgeUE, throug_edgeUE_id] = sort(edgeUE_list_throughput);
[throug_centerUE, throug_centerUE_id] = sort(centerUE_list_throughput);
for eUE = 1:length(throug_edgeUE_id) do
  enb =UE(throug_edgeUE_id(eUE)).associated_eNB.id;
  nRBs = eNB_set(enb).RB_grid.n_RBs;
  nRBs_allocated = floor(nRBs/length(associated_ue));
  [se,rb_index] = sort(spectral_efficiency{enb},'descend');
  for eRB = 1:nRBs do
     if (n_RBs_allocated > 0)&~isMember(rb_index(eRB),RB_allocated{enb})then
         RB_grid.user_alloc(rb_index(eRB)) = throug_edgeUE_id(eUE);
         RB_allocated{enb} = [RB_allocated{enb}        rb_index(eRB)];
         nRBs_allocated = n_RBs_allocated - 1;
     end if
  end for
end for
for cUE = 1:length(throug_centerUE_id) do
  enb=UE(throug_centerUE_id(cUE)).associated_eNB.id;
  nRBs = eNB_set(enb).RB_grid.n_RBs;
  nRBs_allocated = floor(nRBs/length(associated_ue));
  [se,rb_index] = sort(spectral_efficiency{enb},'descend');
  for cRB = 1:nRBs do
     if (n_RBs_allocated > 0)&~isMember(rb_index(cRB),RB_allocated{enb})then
         RB_grid.user_alloc(rb_index(cRB)) = throug_centerUE_id(cUE);
         RB_allocated{enb} = [RB_allocated{enb}        rb_index(cRB)];
         nRBs_allocated = n_RBs_allocated - 1;
     end if
  end for
end for
```

First, there is a comparison, if the SINR level is less than a default value called *SINR_threshold*, then the procedure insert UEs into the *edgeUE_list* array, that forms a cell edge UEs group. However, if the SINR level is greater than *SINR_threshold*, the procedure insert UEs into the *centerUE_list* array, that forms a center UEs group. This has implemented in pseudo code between lines 6–15. Next, another procedure, between lines 16–17, calculate UEs throughput, then sort the UEs in ascending throughput order, between the lines 18–19.

We implement the procedures for allocating the highest spectral efficiency (SE) RBs for cell edge UEs between lines 20 and 32. The variable *nRBs_allocated* (line 23) represents the amount of RBs allocated to each cell edge UE, which results from the ratio between the total of RBs that eNB can allocate (*nRBs*) and the number of UEs associated with eNB (*length*(*associated_ue*)).

The variable *rb_index* represents the RB index and the variable *se* represents the spectral efficiency value. Line 24 defines a sequence of RBs from the highest SE value to the lowest SE value. When *eRB* and *eUE* are equal to one, the higher SE RB (*RB_grid.user_alloc* (*rb_index* (1)) is allocated to the first UE (*throug_edgeUE_id* (1)), i.e. the lowest throughput UE is serviced first, and so on. After to schedule cell edge UEs, RASOT algorithm schedule center UEs similarly to the previous UEs, which means to schedule first the center UE with lowest throughput, and so on. We implement this operation between the lines 33–45.

5 Performance Evaluation

To evaluate the proposed algorithm presented in Sect. 4, we used the MATLAB software with LTE-A System Level Simulator module developed by TU Wien's Institute of Telecommunications [17].

We present the values of the main parameters set in this modeling and simulation in Table 1.

Table 1. Simulation parameters values.

Parameter	Value
Simulation time	100 TTIs
Inter-site distance (MC)	500 m
Inter-site distance (SC)	250 m
Max. power transmission (MC)	46 dBm
Max. power transmission (SC)	30 dBm
Bandwidth	10 MHz
Channel model	PedA
CQI *feedback delay*	3 TTIs

The modeled scenario has 7 sites, each consisting of 3 sectors, totaling 21 Macro Cells eNBs (MCs) and 30 Small Cells eNBs (SCs), which characterize the system as a Heterogeneous Network (HetNet). This model was choose because the addition of small cells under the coverage area of traditional cells is one of the main strategies for increasing the capacity of 5G systems. In addition, the significant amount of eNBs, together with 825 UEs, that is the maximum number of UEs, as in [18], characterizes a denser network than most models presented in related works.

The average throughput and the fairness are the chosen parameters to evaluate algorithms performance. In the next figures, we present results with a 95% confidence interval.

Figure 3 shows the comparison of throughput performance for cell edge UEs among the proposed RASOT, RR, PF, and MT scheduling algorithms. RASOT outperforms the others algorithms because it gives priority to the service of cell edge UEs, as presented in Sect. 4. In addition, the proposed algorithm allocate more efficiently the RBs, which can carry more bits, since they have higher spectral efficiency. Therefore, the RASOT algorithm has better cell edge throughput for the simulated amount of UEs.

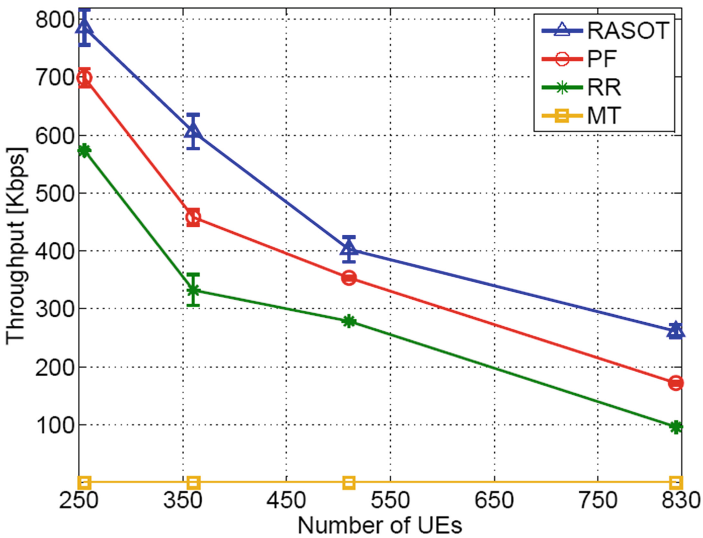

Fig. 3. Average throughput of cell edge UEs.

The results shown in Fig. 4 demonstrate that the proposed algorithm, RASOT, has a slightly lower performance than the other algorithms, except for the MT that maximizes the system throughput by sacrificing the cell edge UEs throughput. Thus, we can state about the RASOT algorithm that the improved throughput performance achieved with cell edge UEs does not occur at the expense of significant performance degradation of other UEs.

We quantify the fairness performance using the Jain's fairness index, represented in Eq. (3) by the variable J, which is a function of the throughput obtained by each of the

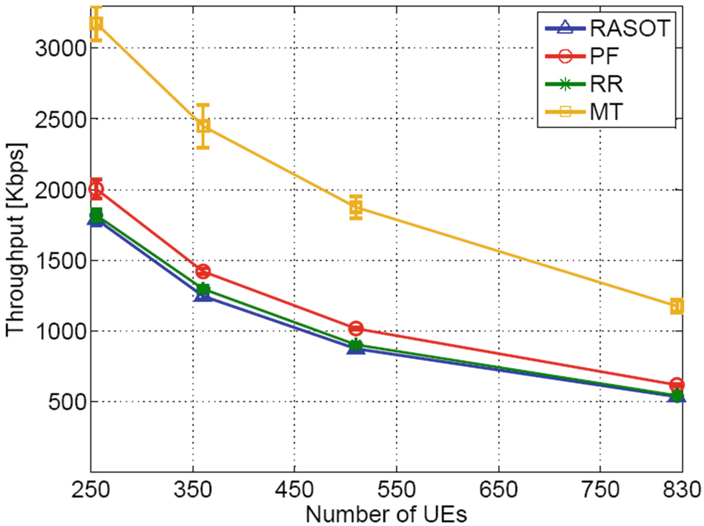

Fig. 4. Average throughput of system UEs.

n UEs, represented by the variable x_i [19]. The higher the fairness, the greater the value of this index, where 1 is the maximum value [20].

$$J = \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{n. \sum_{i=1}^{n} x_i^2} \tag{3}$$

In Fig. 5 we present the fairness index obtained by the four techniques mentioned above. The performance of the RASOT algorithm was better than the RR algorithm, which allocates the same amount of RBs for each UE regardless of channel condition, and PF, which performs the distribution of RBs relatively fairly. The MT algorithm performance was much lower than the performance of the other algorithms because it serves only the UEs with high SINR and therefore causes traffic starvation in UEs with low SINRs.

Since the objective of the RASOT algorithm is to improve the cell edge UEs throughput by first scheduling one from the lowest throughput to the highest achieved throughput, the cell edge UEs average throughput increases. However, the center UEs average throughput decreases because it has lower scheduling priority than cell edge UEs. Thus, the difference between the throughput values of the cell edge UEs and the center UEs present a significantly reduction when compared to the other algorithms. This reduction has a positive impact on the value obtained through Eq. (3), which is a function of the throughput achieved by each UE. Therefore, the proposed algorithm is the most suitable algorithm for providing the minimum throughput required by certain applications, which can be performed on both center UEs and cell edge UEs.

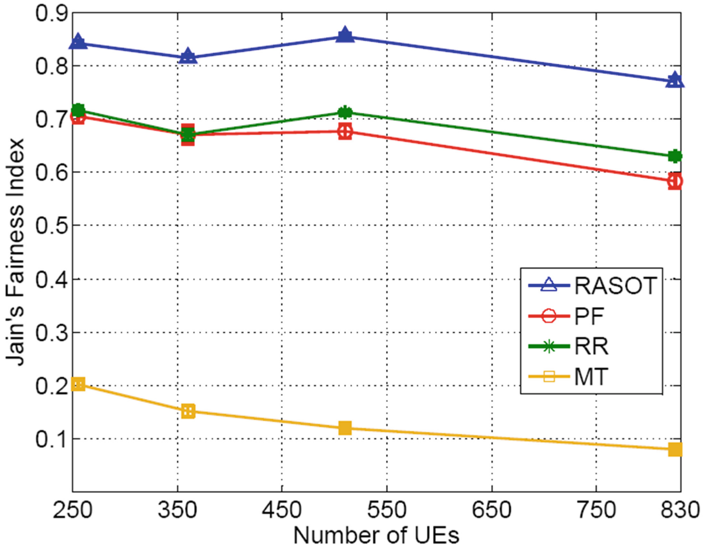

Fig. 5. Fairness.

6 Conclusion

In this paper, we present a new channel-aware scheduling algorithm, which gives priority to attend the traffic flows generated by UEs at the cell edge of LTE-A and 5G HetNets. The results obtained through modeling and simulation reveal that the proposed scheme improves the cell edge UEs throughput performance, if compared to well-known schemes such as RR, which does not consider channel conditions, and channel-aware schemes, such as MT and PF. In addition, the proposed scheme presented better fairness performance if compared to the reference schemes. Thus, we can say that it is best suited for applications with minimum throughput requirements, performed in both the center UEs and the cell edge UEs.

As future work, we aim to minimize Inter-Cell Interference (ICI), and consequently maximize the cell edge UEs throughput performance. We will design a power control module based on game theory that jointly with the proposed algorithm will meet this objective.

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