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DOWNLINK PACKET SCHEDULING IN LTE-ADVANCED HETEROGENEOUS NETWORKS

Alexandru VULPE[1], Octavian FRATU[2], Simona HALUNGA[3]

In order to increase the system capacity in next generation wireless networks, optimizing packet scheduling and resource allocation can be an approach. In the context of the existence of multiple Component Carriers in LTE-Advanced, it becomes a complex optimization problem. This paper presents a scheduling algorithm, designed for use in an LTE-Advanced system. It is formulated as a convex optimization problem and is compared to traditional algorithms such as Round Robin and Proportional Fair. Results show that in some situations it provides better performances than the previous algorithms.

Keywords: LTE-Advanced, resource allocation, scheduling algorithm, convex optimization

1. Introduction

One of the problems that wireless cellular network face today is that many users share a limited amount of resources, these resources being the medium through which the users communicate (i.e. radio spectrum). Scheduling and resource allocation, thus, are essential components of wireless systems because different users experience different fading conditions at the same time [1].

Dynamic scheduling implies two aspects: how physical layer resources are allocated to each user, in each given time slot (Time Transmission Interval - TTI), and how this is optimized [2]. This is a very complex problem that has to take into account different variables like the user radio conditions, the user's traffic pattern or the user Quality of Service (QoS) and has to try to optimize the allocation of radio resources from the whole system point of view. In a nutshell, one has to decide when and how the available resources in the cell are assigned to each of the users. In the case of LTE or LTE-Advanced system, the resources are Physical Resource Blocks (PRBs). PRBs are defined as units consisting of 12 consecutive OFDM subcarriers in the frequency domain and two consecutive time slots or one

[1] PhD student., Telecommunications Dept., University POLITEHNICA of Bucharest, Romania, e-mail: alex.vulpe@radio.pub.ro
[2] Prof., Telecommunications Dept., University POLITEHNICA of Bucharest, Romania, e-mail: ofratu@elcom.pub.ro
[3] Prof., Telecommunications Dept., University POLITEHNICA of Bucharest, Romania, e-mail: shalunga@elcom.pub.ro

LTE subframe in the time domain, which constitutes the minimum scheduling unit for LTE and LTE-Advanced [3].

Some well-known scheduling algorithms include the max-C/I scheduling strategy, round-robin scheduling and the proportional-fair scheduling. While the max-C/I scheduling algorithm provides the highest cell throughput, it can lead to users that do not have favorable channel conditions never being served.

Proportional fair algorithm also proposes a good tradeoff between maximising throughput and providing data rate fairness. This type of scheduling has as objective the maximization of the long term received throughput.

Likewise, the Round Robin scheduling algorithm provides a “blind” allocation of users, without taking into account Channel State Information (CSI), meaning the cell resources are equally divided amongst users. It can be seen as fair in the sense that each communication link receives the same amount of radio resources (the same amount of time). Another advantage is that it does not involve too much computational effort for the scheduler and it seems the mobile operators prefer it, for its simplicity[3].

The emergence of LTE-Advanced with the Carrier Aggregation technique has opened new research possibilities for scheduling and resource allocation. Now, one has to take also into account the existence of multiple Component Carriers (CCs), which gives another degree of freedom in formulating scheduling and resource allocation problems.

Only recently, algorithms for joint scheduling have started to appear. One such example is given in [4], where the authors propose a modified Proportional Fair (PF) algorithm. Here, the authors compute the PF index for each user, by taking into account the past user throughput over all aggregated CCs. They find that their algorithm improves the fairness for Rel. 8 users and provides a gain in coverage for Rel. 10 users, with no degradation in the average cell throughput. Authors in [5] propose an improved PF scheduling algorithm, based on a PF algorithm that runs independently over each CC. Their algorithm is found to balance the throughput of LTE and LTE-A users and enhance the system fairness, while having a lower complexity than the algorithm in [4]. Their simulations, however, were conducted only with macro cells, without any pico cells. Finally, a joint component carrier assignment and packet scheduling approach is proposed in [6]. Authors formulate a combinatorial optimization problem with constraints. Their results show a lower average delay and a more flat distribution of the aggregated throughput. However, the simulations were conducted with only one eNodeB and 10 users, which, in the authors’ opinion, does not provide sound results.

The main contribution of this paper is in formulating a joint two-dimensional (PRB-wise and CC-wise) optimization of the radio resource scheduling that can be applied in LTE-Advanced systems, that is loosely based on the idea of round robin scheduling. It does not take into account the channel state information and is a simple to deploy scheduling mechanism, and minimizes the overhead needed to transmit CSI.

2. System model

3GPP LTE-Advanced specifies the aggregation of up to 5 LTE Rel. 8/9 carriers, also known as component carriers (CCs), in order to achieve the overall bandwidth of 100 MHz. This work proposes a simple algorithm, which leverages the existence of multiple CCs and enables the user allocation over any number of CCs, with the objective of maximising the total network throughput. This is an extension of the Round Robin algorithm, in the sense that it does not take into account the user channel conditions and “blindly” allocates resources to users of the base station.

Although the algorithm proposed in this work enables the scheduling of users on up to 5 aggregated CCs, in this paper we chose to evaluate the algorithm on two CCs in the case of Contiguous Intraband Carrier Aggregation, i.e. the aggregated carriers are adjacent to each other. Depending on the capabilities of the User Equipment (UE), each user may be allocated to a single LTE carrier, or simultaneously to two carriers, meaning LTE and LTE-A users coexist. This does not restrict however the generality of the defined problem.

The LTE-Advanced network is deployed with hexagonal cells and with frequency reuse factor one, in order to evaluate the worst-case scenario in terms of interference, as mentioned in the 3GPP specifications. All the cells deploy two CCs, each CC being transmitted from different antenna connectors. In this case, for each cell, the adjacent cells become a source of interference (but only on each CC), which leads to a deterioration of the user received Signal-to-Interference-plus-Noise (SINR) ratio and, consequently, a drop in user throughput. The network topology is illustrated in Fig. 1.

The scheduler allocates packets to users at the beginning of each Time Transmission Interval (TTI). Each TTI is associated with the duration of one of the ten subframes that makes up an LTE frame (which is 10 ms long), which corresponds to a subframe duration of 1 ms.

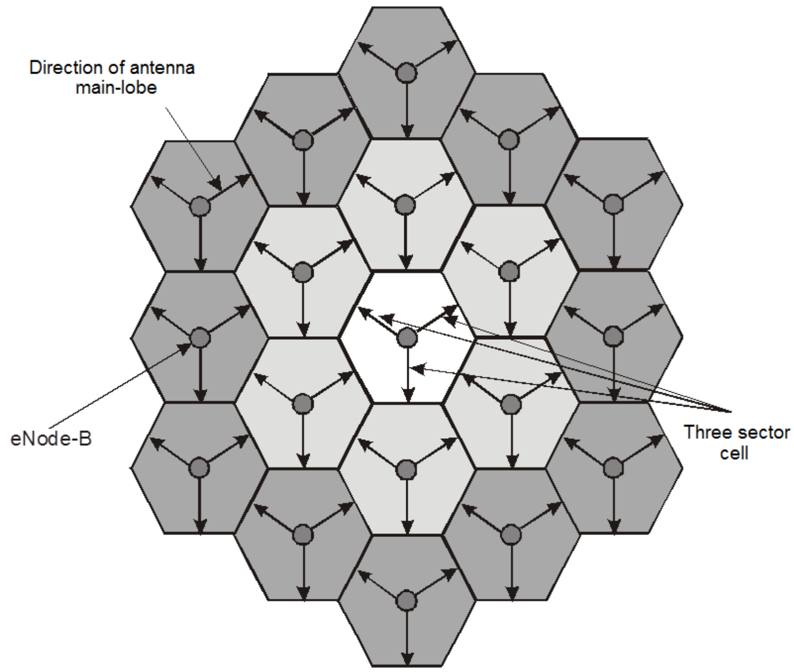

Fig. 1. Network Topology

The Radio Resource Management framework allocates the available radio resources (i.e. Physical Resource Blocks - PRBS) to the users according to the solution of the scheduling problem defined in the next section.

3. Cross-CC Round Robin Scheduling Algorithm

Carrier aggregation adds a new dimension for the scheduling of the users in an LTE-Advanced system and raises an optimisation problem for the best use of network resources. The following Profit Function is proposed in order to maximize the total throughput of the user.

$$(PF):\sum_{c=1}^{N_c}\sum_{u=1}^{N}x_{cu} \tag{1}$$

In the above equation, x_{cu} is the allocation variable. Also N_c is the numbered of configured component carriers (CCs) in the cell and N is the number of users attached to the cell. The allocation variable x_{cu} reflects the resource allocation (i.e. allocated PRBs) for a specific user u on a specific component carrier c. We can therefore define the allocation variable as

$$x_{cu} = \begin{cases} n, & \text{if } n \text{ PRBs are allocated to user } u \text{ on component carrier } c \\ 0, & \text{if no PRBs are allocated to user } u \text{ on component carrier } c \end{cases} \quad (2)$$

The above problem is a convex optimization problem because x_{cu} is a constant for each given TTI [7]. In order to solve it, the following constraints are defined:

1. **Allocation Constraint**: the sum of allocated PRBs for each user *u* has to be equal to the number of PRBs available for each CC. This can be written as:

$$\sum_{u=1}^{N} x_{cu} = N_{PRB_c}, \forall c \in \{1, 2, ..., N_c\} \quad (3)$$

where N_{PRB_c} represents the number of PRBs available for component carrier *c*.

2. **User constraint:** the allocated PRBs on each component carrier *c* for each user *u* are forcefully 0, if the user is not configured on the respective component carrier. This can be written as:

$$x_{cu} = 0, \text{if user } u \text{ is not attached to component carrier } c \quad (4)$$

The objective is, therefore, to maximize the Profit Function, so, for each component carrier *c* and user *u*, a number of PRBs x^*_{cu} is allocated, according to :

$$x^*_{cu} = \arg\max_{x_{cu}} PF \quad (5)$$

4. Simulator description, simulation scenario and assumptions

The network scenarios that have been analysed were chosen taking into account the carrier aggregation scenarios presented by 3GPP. We designed our own MATLAB LTE simulator, and enhanced it to support Carrier Aggregation.

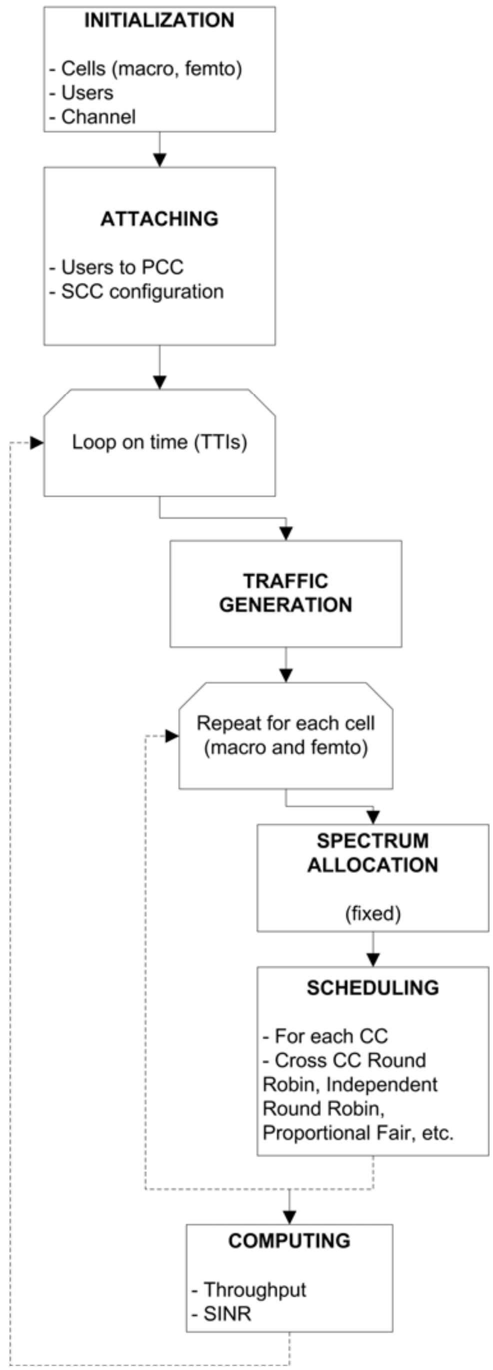

Fig. 2. Simulator flow

The flow of the simulator is depicted in Fig. 2. Following the recommendations of 3GPP [8] the worst interference-case scenarios were considered, where there is Frequency Reuse 1 between the femto-cells and Macro cells.

The scenario simulated here represents an urban environment with 19 sites with 3 Macro BS per site. The Macro BSs have a height of 30 meters and an electrical downtilt of 15° following 3GPP specifications.

The PathLoss Model is Model 2 proposed by 3GPP, which considers different PathLosses for Line of sight (LoS) and Non-LoS conditions, where the transmitter and the receiver do not have a direct channel between them [8].

To solve problem (5) we used CVX, a package for specifying and solving convex programs [9, 10].

Table 1 lists the main simulation parameters used for this work. All other parameters are also taken from the 3GPP specifications.

Table 1

Main simulation parameters

Parameter	Value
Topology	Hexagonal grid, 19 macro BSs, 3 sectors per BS, 19 femto BS
Carrier Frequency	2 GHz
Component Carrier Bandwidth	20 MHz
Number of Component Carriers	2
Duplexing	FDD
Antenna pattern for macro BS	As described in [8]
Antenna pattern for femto BS	Omnidirectional
Inter-site distance	500 m between macro
Distance between macro and femto	75 m
Distance between femto	40 m
Tx Power for Femtocell	30 dBm
Tx Power for Macrocell	49 dBm
Path loss	As described in [8]
Shadowing standard deviation	8 dB
Penetration loss	20 dB
Number of users per Femtocell	10
Number of users per Macrocell	20
User distribution in site area	Uniform
Traffic model	Full buffer

5. Results

Fig. 3 shows the average cell throughput obtained with the proposed scheduling algorithm and compared with the Round Robin and Proportionally Fair algorithms broken down into femto cells and macro cells. It can be seen that the proposed algorithm achieves slightly better results for Macro Cells than the other existing algorithms. For the Femto Cell case, compared to the Round Robin algorithm, it is superior, marking an increase in cell throughput of about 3.8%.

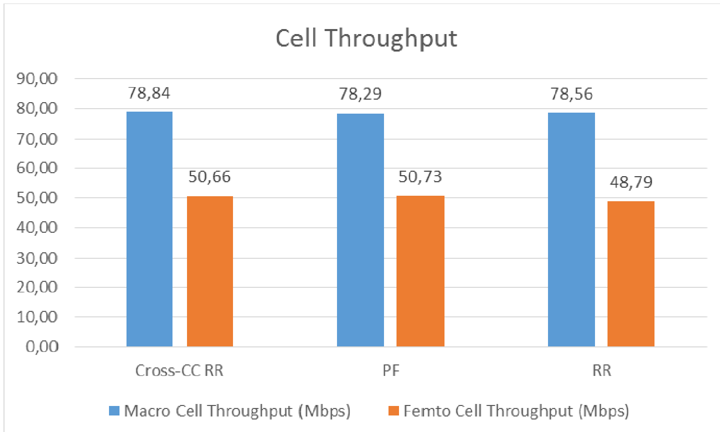

Fig. 3. Average cell throughput for different scheduling algorithms

Fig. 4 provides a breakdown of the user throughput results into Rel. 8 users, with no Carrier Aggregation, and Rel. 10 users, aggregating two CCs. It can be seen that, as expected, the proposed algorithm performs marginally poor in terms of user throughput for Rel. 10 users. As we may have intuited, the Proportional Fair algorithm, ran separately for each CC, gives users a better throughput, since it takes into account channel conditions.

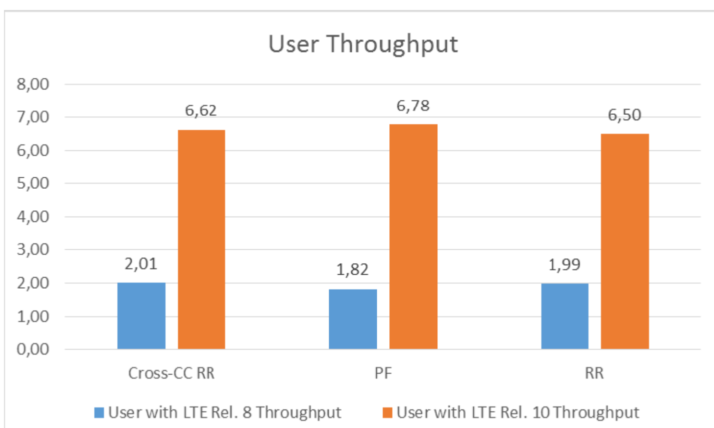

Fig. 4. Average user throughput for different scheduling algorithms

An interesting result is for macro cell users, where PF gives the worst throughput. This can be attributed to the fact that the existence of femto cells implies an increase in Inter-Cell Interference, which in turn means a lot of users

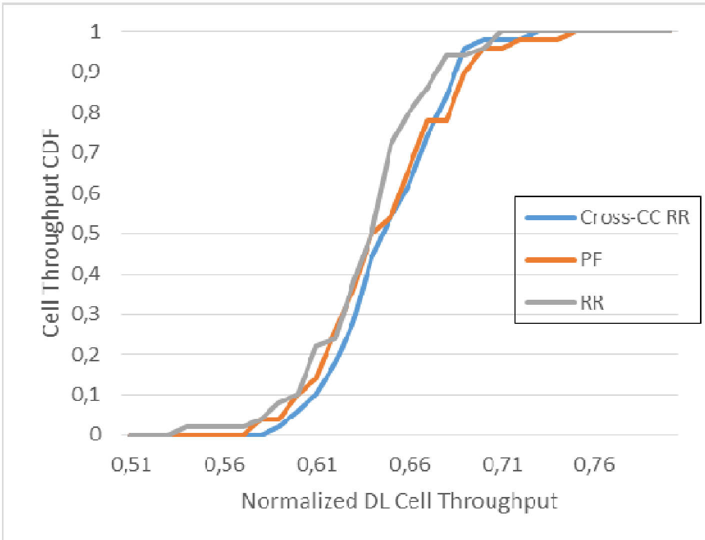

Fig. 5. Cell Throughput CDF

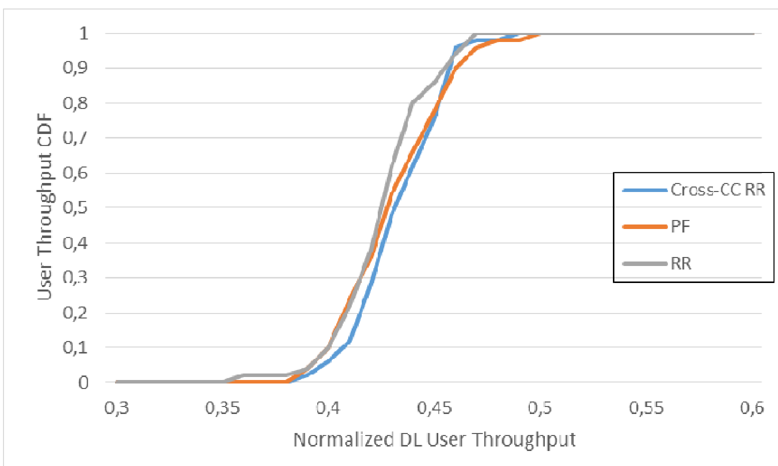

Fig. 6. User throughput CDF

that have a low PF index, leading to some users never being scheduled, or being scheduled very few times.

Fig. 5 and Fig. 6 show the Cumulative Distribution Function (CDF) of the average normalized cell and user throughput, respectively, for the three scheduling algorithms considered.

We can see that the proposed algorithm has slightly better results for the cell throughput case. This mean that, for a specified value of the normalized DL cell throughput, there is a higher probability of achieving that throughput when using the proposed algorithm, compared with the others. Similarly, in the case of user throughput, Cross-CC RR has better results for lower throughput values, being surpassed by PF for higher values.

6. Conclusions

This paper presented and evaluated a scheduling algorithm for LTE-Advanced that takes into account the existence of multiple aggregated LTE Rel. 8 Component Carriers and targets the maximization of allocated resources. Results showed that, by using this algorithm, the average user throughput is greater compared to the traditional Round Robin algorithm but lower than using Proportionally Fair. The algorithm can be used as an alternative to Round Robin, without having to use Channel State Information that can provide unnecessary overhead for network signaling.

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