On the Analysis of Packet Scheduling in Downlink 3GPP LTE System

Oana Iosif, Ion Banica
Faculty of Electronics, Telecommunications and Information Engineering
"Politehnica" University of Bucharest
Bucharest, Romania
oana_iosif@yahoo.com, banica@comm.pub.ro

***Abstract*—This paper investigates the performance of packet scheduling in downlink LTE (Long Term Evolution) systems using Round Robin strategy in time domain and time and frequency domain. Two types of non-real time services are considered in the analysis performed, with and without priority set, as well as the limitation given by the physical downlink control channels (PDCCH) on the number of simultaneously scheduled users. Cell throughput, achievable user throughput and system capacity are evaluated in different scenarios with two mixed services, two packet scheduling approaches and priority impact on the generated traffic.**

Keywords-LTE; OFDMA; PDCCH; packet scheduling; Round Robin

I. INTRODUCTION

Long Term Evolution (LTE) is the name given to a 3GPP (3rd Generation Partnership Project) concerning UTRAN (Universal Terrestrial Radio Access Network) evolution to meet the needs of future broadband cellular communications. This project can also be considered as a milestone towards 4G (Fourth Generation) standardization. The requirements set for LTE specified in [1] envisage high peak data rates, low latency, increased spectral efficiency, scalable bandwidth, flat all-IP network architecture, optimized performance for mobile speed, etc. In order to fulfill this extensive range of requirements several key technologies have been considered for LTE radio interface of which the most important are: multiple-access through Orthogonal Frequency Division Multiple Access (OFDMA) in downlink and Single Carrier - Frequency Division Multiple Access (SC-FDMA) in uplink and multiple-antenna technology.

Packet Scheduling is one of LTE Radio Resource Management (RRM) functions, responsible for allocating resources to the users and, when making the scheduling decisions, it may take into account the channel quality information from the user terminals (UE), the QoS (Quality of service) requirements, the buffer status, the interference situation, etc. [2]. Like in HSPA or WiMAX, the scheduling algorithm used is not specified in the standard and it is eNodeB (Evolved NodeB) vendor specific.

In this paper, we evaluate the performance of packet scheduling in downlink LTE using the Round Robin strategy through the results obtained for the average cell throughput, the achieved user throughput and the system capacity. These results may be considered in the LTE network design, in order to approximate the number of users that can be served with a certain throughput in a commercial LTE network.

The remainder of this paper is organized as follows. Section II discusses several aspects on scheduling and assigned resources in downlink LTE system followed by the Round Robin model description for different resource assignment approaches in Section III. Section IV depicts the results of the simulated scenarios and the conclusions are driven in Section V.

II. SEVERAL ASPECTS ON RESOURCE ALLOCATION IN DOWNLINK LTE

The benefit of deploying OFDMA technology on downlink LTE is the ability of allocating capacity on both time and frequency, allowing multiple users to be scheduled at a time. The minimum resource that can be assigned to a user consists of two Physical Resource Blocks (PRBs) and it is known as chunk or simply Resource Block (RB) [2],[3]. In downlink LTE one PRB is mapped on 12 subcarriers (180 kHz) and 7 OFDM symbols (0.5 ms) and this is true for non-MBSFN (Multimedia Broadcast multicast service Single Frequency Network) LTE systems and for normal Cyclic Prefix (CP). Scheduling decisions can be made each TTI (Time Transmission Interval) that in LTE is equal to 1 ms.

For non-real time services dynamic scheduling is usually used as it provides flexible and even full utilization of the resource.This scheduler performs scheduling decisions every TTI by allocating RBs to the users, as well as transmission parameters including modulation and coding scheme. The latter is referred to as link adaptation. The allocated RBs and the selected modulation and coding scheme are signaled to the scheduled users on the PDCCH (Physical Downlink Control Channel). The dynamic packet scheduler also interacts closely with the HARQ (Hybrid Automatic Repeat Request) manager as it is responsible for scheduling retransmissions and it may also take into account the QoS attributes and buffer information [4].

The channel conditions may or may not play a role in scheduling decisions. An alternative to channel-dependent scheduling is Round Robin strategy that serves the users in cyclic order, regardless the channel information.

Although OFDMA technology allows the users to be multiplexed in time and frequency, the scheduler, according to the implemented algorithm, may choose to allocate the entire bandwidth to a single user, reducing the scheduling to be done only in time domain. The channel-sensitive

 ISBN: 978-1-61208-126-7

scheduling done in time domain only is called Non-Frequency Selective Scheduling (NFSS) and the scheduling exploiting the channel variations in both time and frequency is known as Frequency Selective Scheduling (FSS) as specified in [5]. Fig. 1 illustrates an example of FSS for two users [6].

When scheduling is done in time and frequency domain, independently if it is channel-aware or not, the number of multiplexed users at each TTI is limited by the number of PDCCHs that can be configured. This depends on the system bandwidth, the number of symbols signaled for PDCCH allocation, the PDCCH format number, etc. [3], [4], [7], [8]. The PDCCHs are intended to provide both uplink and downlink scheduling information and as a PDCCH is allocated to each user to be scheduled, the maximum number of scheduled users per TTI in downlink LTE is half of the number of PDCCHs available. The authors from [4] discussed this constraint and proposed a three-step packet scheduling algorithm as it is depicted in Fig. 2.

III. Round Robin Scheduling Model in Downlink LTE

As mentioned in Section II, Round Robin scheduling is a non-aware scheduling scheme that lets users take turns in using the shared resources (time and/or RBs), without taking the instantaneous channel conditions into account. Therefore, it offers great fairness among the users in radio resource assignment, but degrades the system throughput. Both Time Domain Round Robin (TD RR) and Time and Frequency Domain Round Robin (FD RR) scheduling models are described in this section.

A. Time Domain Round Robin scheduling

In TD RR the first reached user is served with the whole frequency spectrum for a specific time period (1 TTI), not making use of the information on his channel quality and then these resources are revoked back and assigned to the next user for another time period. The previously served user is placed at the end of the waiting queue so it can be served with radio resources in the next round. This algorithm continues in the same manner [9]. Fig. 3 illustrates the resource sharing between two users with TD RR algorithm. The colors make the difference between the users. In this

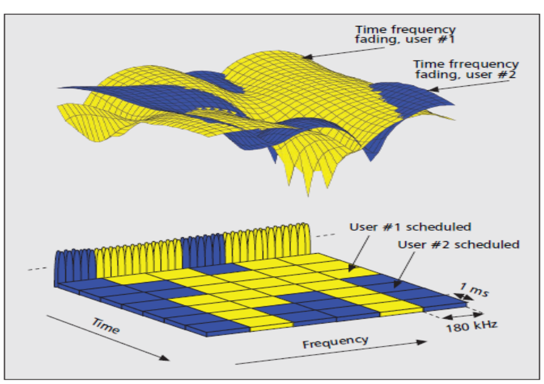

Figure 1. Frequency selective scheduling illustration for two users in downlink LTE

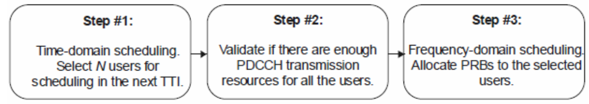

Figure 2. Illustration of a three step scheduling algorithm framework

example, every user is allocated 100% of the RBs and 50% of the time resource, so each gets 50% of the global resource.

Let us suppose a CBR (Constant Bit Rate) service of 250 kbps and a SNR (Signal to Noise Ratio) throughput per RB given by the radio conditions of 500 kbps. Assuming that there is one static user making the service and the same SNR is experienced in each RB and in all TTIs, the maximum amount of data that can be sent during one TTI per RB is 0.5 kb. Considering the system bandwidth of 20 MHz which consists of 100 RBs, the user needs to be allocated all resources for five TTIs to reach his service throughput. Therefore the user must be allocated 1/200 of the total resource in order to be served. This ratio is equal to service throughput / (SNR throughput*total number of RBs given by the system bandwidth). This represents the main idea in the TD RR model.

B. Time and Frequency Domain Round Robin scheduling

The FD RR allows multiple users to be scheduled within one TTI in cyclic order. Keeping in mind the PDCCH limitation discussed in Section II, the scheduling framework from Fig. 2 can be applied. The TDPS (Time Domain Packet Scheduling) may select N users in RR fashion to be scheduled in one TTI, but the PDCCH resources (M) must be checked in order to see if all users selected by the TDPS can be simultaneously scheduled. M users at most can be the input of FDPS (Frequency Domain Packet Scheduling), which schedules each user with RR strategy across different RBs. In the next TTI the users that were not selected in the previous one will be scheduled in the same manner and so on.

The FD RR is briefly presented in [10] where PDCCH constraint is not considered. The authors propose that all users be allocated one RB before reallocating to the same user. If the number of users waiting to be scheduled is less than the number of PDCCHs per TTI, this approach is correct. But if the users selected within one TTI are greater than the PDCCHs and if the idea of allocating one RB to each user is maintained, the result will be a waste of resources.

The resource sharing between two users with FD RR, assuming a hypothetical system bandwidth of two RBs, is depicted in Fig. 4. As in Fig. 3, each user is allocated 50% of the global resource. Taking the example given in Section III.A, but considering the limitation of 20 PDCCHs per TTI

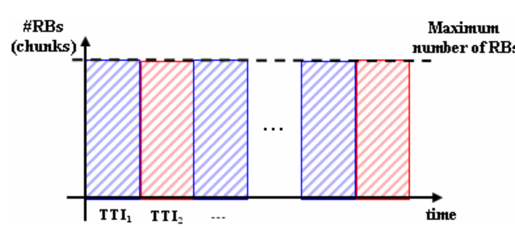

Figure 3. Resource sharing between two users with TD RR

 ISBN: 978-1-61208-126-7

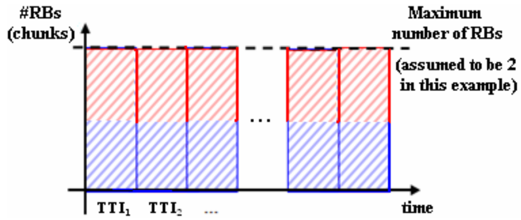

Figure 4. Resource sharing between two users with FD RR

for downlink LTE as it is concluded from [4], [7] and [8] and 40 users having the same radio conditions and making the same service, one user needs to be allocated 1 RB for 500 TTIs. The global resource in this case is reduced due to PDCCH constraint i.e. the maximum throughput given by the radio conditions * number of PDCCHs. The radio resource ratio assigned to each user is 1/40, higher than in TD RR example, so the capacity will be smaller. A solution to address this problem would be the allocation of more RBs at once to each user in order to exploit all transmission bandwidth. Knowing that for 20 MHz band in downlink LTE 20 users can be simultaneously scheduled at most, each user can be allocated 5 RBs before assigning resources to another one. In this case, the FD RR cell throughput will be the same as for TD RR, with the only advantage of being more suited to services with small packets and some delay requirements.

IV. Simulation Scenarios and Results

A computer simulation using C++ platform is conducted to evaluate the performance of RR scheduling in downlink LTE. For the simulations performed a single cell eNodeB is considered, with a carrier frequency of 2.6 GHz FDD (Frequency Division Duplex) and a system bandwidth of 20 MHz. The antenna configuration used in all scenarios is SISO (Single Input Single Output) which leads to category 1 terminal with ~10Mbps for all users. In order to reduce the complexity of the system simulations, we assume that equal downlink transmit power is allocated on each RB and all transmitted packets are received correctly. Moreover, the users are static and experience the same SNR values for all RBs allocated for all the simulation period (they are all located in the same bin).

The downlink SNR values used in this paper, resulting from the pathloss, shadow fading, multipath fading, eNodeB transmit power and thermal noise, are listed in Table I, along with the corresponding modulation and coding schemes and data rates.

The following sub-sections present the simulation results for cell throughput, average user throughput and system capacity in downlink LTE with RR scheduling. There are two categories of users considered: the first makes a CBR streaming service with 2 Mbps expected throughput (under this value the users cannot be served) and the second makes a VBR best effort service with 2 Mbps minimum accepted throughput, but it can reach more . The maximum best effort throughput reached is limited by the minimum between the data rate corresponding to the SNR experienced and the maximum throughput given by the user terminal category.

TABLE I. Downlink SNR to Data Rate Mapping

Minimum downlink SNR values (db)	Modulation and coding scheme	Data rate (kbps)
1.7	QPSK (1/2)	138
3.7	QPSK (2/3)	184
4.5	QPSK (3/4)	207
7.2	16 QAM (1/2)	276
9.5	16 QAM (2/3)	368
10.7	16 QAM (3/4)	414
14.8	64 QAM (2/3)	552
16.1	64 QAM (3/4)	621

A. *Cell throughput results*

Fig. 5 and Fig. 6 show the cell throughput with TD RR and FD RR for streaming users and best effort users.

The dependence of the cell throughput on the SNR values with 30 users in the cell is depicted in Fig. 5. An interesting evolution is shown by the cell throughput in FD RR for streaming service, where the cell saturation is reached. The explanation lies in both PDCCHs limitation of 20 per TTI and the CBR service of 2 Mbps. Despite the PDCCH limitation in FD RR for best effort users, cell saturation is not reached due to their capability of achieving a higher throughput compared to their service throughput. All 30 users are served only in TD RR for the last SNR throughput value.

When comparing TD RR with FD RR based on the results illustrated in Fig. 6 it can be concluded that for best effort users they show the same cell throughput evolution, This is not the case for streaming users because in TD RR the cell throughput is higher due to a higher number of users served. From the cell throughput saturation it can also be seen that in TD RR there are 31streaming users served, while in FD RR only 20 users reach their service requirements.

B. *Average user throughput results*

Fig. 7 shows the evolution of average user throughput with the number of users in the cell. For streaming service the user throughput is constant at 2 Mbps, while for best effort users it varies until the cell saturation is reached, the saturation point being the maximum number of users served. The maximum best effort user throughput is limited by the terminal category. The achievable best effort user throughput is higher in FD RR than in TD RR for more than 20 users in the cell because there are fewer users served and the cell resource is shared between a smaller number of users.

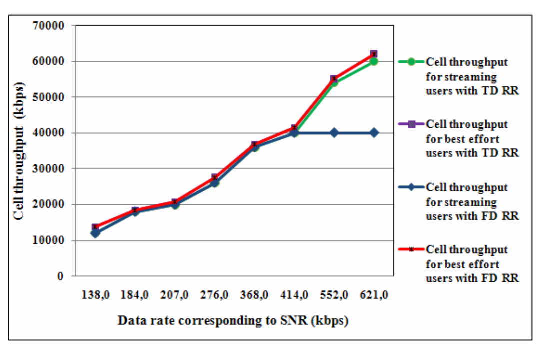

Figure 5. Cell throughput vs. SNR for TD RR and FD RR

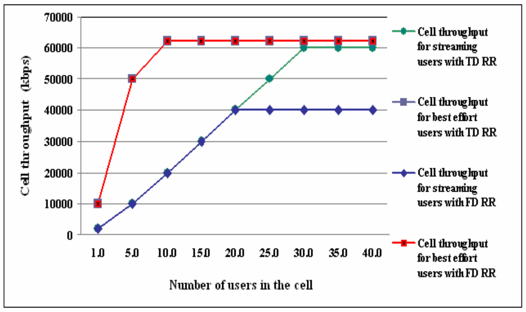

Figure 6. Cell throughput vs. the number of users in the cell for TD RR and FD RR

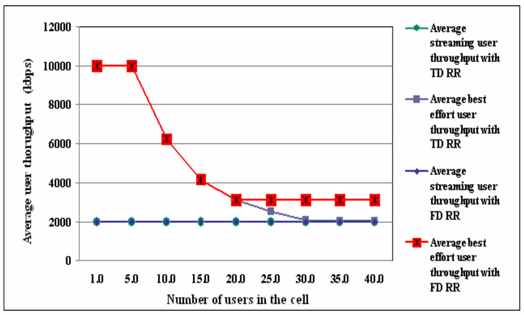

Figure 7. Average user throughput vs. the number of users in the cell for TD RR and FD RR

C. *System capacity results*

Fig. 8 and Fig. 9 show for both scheduling strategies how many users are served from the total number of users in the cell and the impact of the priority set for streaming service on the number and types of users scheduled. Half of the users in the cell are best effort users. The cell saturation is reached for 31 users served in TD RR and 20 in FD RR. When no priority is set, the number of served streaming users is equal to that of best effort users. For 50 users in the cell and priority set, in TD RR there are 6 best effort users and 25 streaming users served, while in FD RR there is no best effort user served and 20 streaming users served.

V. CONCLUSIONS AND FUTURE WORK

This paper illustrates the performance of Time Domain Round Robin and Time and Frequency Domain Round Robin scheduling in downlink LTE in what concerns the cell throughput, the average user throughput and the system capacity, in the assumption of two types of services with the possibility of applying a higher priority to one of them, having an impact on which number and type of users are served. The constraint of PDCCHs on the number of users scheduled each TTI has also been outlined and depicted in the simulation results, making FD RR less efficient when the number of users in the cell is higher than the PDCCHs. These results may be considered when designing a real LTE network. Future work will focus on the analysis of packet scheduling in uplink LTE system.

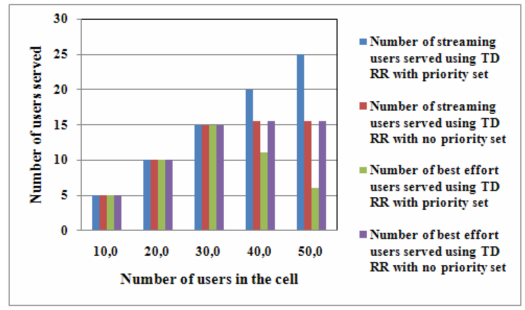

Figure 8. Number of users served vs. number of users in the cell w/o priority in TD RR

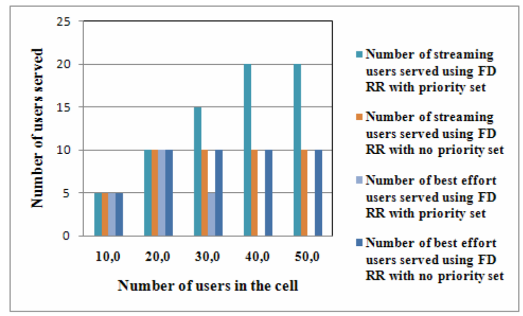

Figure 9. Number of users served vs. number of users in the cell w/o priority in FD RR

ACKNOWLEDGMENT

Oana Iosif is POSDRU grant beneficiary offered through POSDRU/6/1.5/S/16 contract.

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