ON THE PERFORMANCE OF OPPORTUNISTIC SCHEDULERS IN OFDMA TECHNOLOGIES

Roxana CÎRSTEA[1], Silviu CIOHINĂ[2], Horia ŞTEFĂNESCU[3]

Algoritmii de alocare a resurselor pentru sisteme fară fir, reprezintă una dintre temele de cercetare importante ale momentului. Acest articol evaluează câştigul unui planificator oportunist prin comparație cu un planificator care nu ține cont de starea canalului, în cazul nostru, o comparație între un planificator Proportional Fair şi un planificator Round Robin. Următorul pas este să se demonstreze că pentru o zonă dens populată în cadrul căreia utilizatorii sunt dstribuiți uniform, probabilitatea ca un utilizator să se găsească mai aprope de marginea celulei este mai mare decât probabilitatea ca acelaşi utilizator să fie în apropierea stației de bază.

The area of scheduling algorithms for wireless systems is one of the hottest research topics of the moment. This paper evaluates the gain of an opportunistic scheduler over a non-opportunistic one, in our case a comparison between a Proportional Fair scheduler and a Round Robin resource allocation algorithm. The next step is to show that in a dense populated area with uniform distribution of the population inside the considered area, the probability for a user to be closer to cell edge than to cell center is higher.

Keywords: resource allocation, scheduling, opportunistic schedulers, Proportional Fair, Round Robin

1. Introduction

During the last years, telecommunication industry has experienced a huge development and the speed of this continuous evolution is increasing every day. The traffic profile of the subscriber, the application types, the mobility and the traffic volume in a commercial network is changing very often and it is really difficult to have a correct forecast of this boost.

Although access technologies, features and algorithms evolve rapidly there are still a lot of things to improve to be able to accommodate future traffic and to satisfy the QoS needs of the end users. One delicate chapter is the radio resource

[1] Phd student., Faculty of Electronics, Telecommunications and Information Technology, University POLITEHNICA of Bucharest, Romania, e-mail: elena.cirstea@orange.com
[2] Prof., Faculty of Electronics, Telecommunications and Information Technology, University POLITEHNICA of Bucharest, Romania, e-mail: silviu@comm.pub.
[3] Phd student., Faculty of Electronics, Telecommunications and Information Technology, University POLITEHNICA of Bucharest, Romania, e-mail: horia.stefanescu@orange.com

allocation in OFDMA (Orthogonal Frequency Division Multiple Access) [1] technologies, like WIMAX or LTE, both of them being 4G access technologies. Long Term Evolution (LTE) is the new standard [2] of the 3GPP (3rd Generation Partnership Project) and it was designed to increase capacity and improve service performance. LTE represents the natural evolution of the 3G existing networks and the main goals of this technology are: to improve spectral efficiency, to increase uplink and downlink data rates, to support scalable bandwidth and all IP network and to reduce latency.

The challenge in allocating the radio resources in LTE comes from the fact that the wireless channel [3] is randomly changing in time on slow and fast scale. The radio capacity of a wireless system is limited and this way it needs a correct management and an efficient use. The final scope of resource allocation is to maximize system capacity while maintaining the fairness between users.

Scheduling mechanism in OFDMA technologies can be seen as a time-frequency resource allocation. Using the terminology specified in the 3GPP LTE standard, the unitary resources are: TTI – Transmission Time Interval, the minimum time resource of 1ms and PRB – Physical Resource Block, the minimum frequency resource of 180 kHz. Every TTI, the scheduler selects some of the users and assigns a number of PRBs to them by taking into account their QoS requirements like data rate or latency. The scheduler should be able to identify those users that can be excluded from resource allocation during current TTI and that can be postponed for a future TTI without degrading their QoS.

Considering the associated QoS requirements, there are two major different traffic types. The first one is elastic traffic or non-real time traffic and the second one is real time traffic. The elastic traffic or data transfer is characterized by a fixed size while the real time traffic is characterized by a fixed duration. The performance metric of elastic flows is the throughput and it is directly connected with the time spent in the network to download/upload a file. Real time traffic, like streaming uses delay as a performance metric. The duration of this service is fixed but it is strongly dependent on delay and error rate.

Scheduling policies can be classified in two categories: opportunistic and non-opportunistic. Opportunistic schedulers allocate resources based on channel condition. This way a user that experiences good channel conditions will receive resources while a user with bad channel conditions will have to wait for a better channel. Although the meaning could be slightly different sometimes, opportunistic schedulers can be correlated with multiuser diversity.

This paper compares the performances of two schedulers. The first one is a non-opportunistic scheduler, RR (Round Robin) and the second one is an opportunistic-scheduler, PF (Proportional Fair). The scope of this comparison is to show the gain of an opportunistic scheduler over a non-opportunistic one. A PF scheduler is able to exploit good channel conditions and this way, system capacity is greatly improved.

The paper is structured in three parts. The first part is dedicated to a short introduction in the area of resource allocation algorithms. The second part is a comparison between the performances of a Proportional Fair and a Round Robin Scheduler. Then, several Matlab simulation results are presented in order to demonstrate the gain of the opportunistic scheduler over the non-opportunistic one. The last part of the paper is dedicated to some interesting conclusions related to SNR models for cellular systems, an important input that a scheduler should take into account. The results obtained here can be used for the future design of opportunistic scheduling policies.

2. Resource allocation algorithms

Before showing the simulation results, a short presentation of the scheduling policies is being done. The first one described is the non-opportunistic one, or the RR scheduler and the second one is the PF scheduler which takes advantage of the multi-user diversity. The RR scheduler is the reference when analyzing the performance of opportunistic scheduling policies.

2.1. Round Robin Scheduler

The RR scheduling policy allocates an equal part of the system resources to each user without taking into account user's channel conditions. This means that multi-user diversity is neglected.

Let N be the number of users in the cell, S_i is the average SINR of user i, w_i is bandwidth allocated to user i, φ is the function that maps channel condition into bit-rate and x is the channel fading state. L_φ is the Laplace transform of φ function. In applied probability, the Laplace transform can be defined using the expectation value. Let X be a random variable with probability density function φ, then the Laplace transform of φ is the expectation $L_\varphi=E[e^{-sX}]$. The ergodic data rate of one user that has been scheduled using a RR policy can be defined as in [4]:

$$\boldsymbol{r_{RR,i} = w_i \frac{1}{N} \int_0^\infty \frac{\varphi(x)}{S_i} e^{\frac{-x}{S_i}} dx = \frac{1}{NS_i} L_\varphi\left(\frac{1}{S_i}\right)} \qquad (1)$$

This is a simple scheduling policy that takes turns to serve the mobile stations in order. Although it is a fair scheduler that does not discriminate among concomitant users this resource allocation policy does not take advantage of the channel diversity.

2.2. Proportional Fair Scheduler

The Proportional Fair Scheduler is a particular case of the α-fair scheduler when α=1. As it was introduced in [5], the α-fair policy maximizes a concave utility function, like the one bellow:

$$\boldsymbol{u}_{\propto}(\boldsymbol{x}) = \begin{cases} \boldsymbol{logx}, & \propto = \mathbf{1} \\ (\mathbf{1}-\propto)^{-\mathbf{1}}\boldsymbol{x}^{\mathbf{1}-\propto}, & \propto \neq \mathbf{1} \end{cases} \tag{2}$$

The argument of the utility function is actually the average rate and the Proportional Fair algorithm is trying to maximize the following quantity $\sum_{i=1}^{N} \boldsymbol{u}_{\propto}(\boldsymbol{x})$.

Assuming that the eNodeB knows the channel state of each user in the cell and users also know their uplink channel states, the average rate being allocated by this Proportional Fair policy, as it was deduced in [6] is:

$$\boldsymbol{r}_{PF,i} = \boldsymbol{w}_i \frac{\mathbf{1}}{\boldsymbol{S}_i} \sum_{k=0}^{N-1} \binom{\boldsymbol{N}-\mathbf{1}}{\boldsymbol{K}} (-\mathbf{1})^{k} \boldsymbol{L}_{\varphi}\left(\frac{\boldsymbol{k}+\mathbf{1}}{\boldsymbol{S}_i}\right) \tag{3}$$

The Proportional Fair scheduler keeps track of the average throughput of each user i, $r_{PF,i}$ calculated over an exponential window of length l, as it was demonstrated in [7]:

$$\boldsymbol{r}_i(\boldsymbol{t}_m) = \boldsymbol{r}_i(\boldsymbol{t}_m - \mathbf{1})\left(\mathbf{1} - \frac{\mathbf{1}}{\boldsymbol{l}}\right) + \boldsymbol{\mu}_i(\boldsymbol{t}_m)\frac{\mathbf{1}}{\boldsymbol{l}}, \tag{4}$$

where t_m is the TTI number, $r_i(t_m)$ is the average rate of user i in TTI t_m and $\boldsymbol{\mu}_i(\boldsymbol{t}_m)$ is the instantaneous rate of user i in TTI t_m. Then, the recursive form in the relation above can be translated in:

$$\boldsymbol{r}_i(\boldsymbol{t}_m) = \sum_{j=1}^{m} \frac{\mathbf{1}}{\boldsymbol{l}}\left(\mathbf{1} - \frac{\mathbf{1}}{\boldsymbol{l}}\right)^{m-j} \boldsymbol{r}_i(\boldsymbol{t}_j) \tag{5}$$

2.3. Simulation results

To better illustrate the advantage of using an opportunistic scheduler over a non-opportunistic one like Round Robin, several Matlab simulations have been conducted in order to compare their performances.

The simulated network is a cellular one and the radio access is OFDMA based. Each base station has three sectors and the number of active mobiles is changing. The traffic generated is FTP and fixed size files are transmitted by the mobile subscribers. Because FTP is an elastic traffic it is important to analyze the time it spends in the network which is actually similar to look at the mean transfer time. The SNR range is from 20dB to -12dB, the last value meaning no radio coverage. The simulation period is 1000s.

Two main scenarios have been simulated. The first scenario is dedicated to the Round Robin scheduler and the second one is using Proportional Fair scheduling algorithm. Each of the two scenarios has been run for a system bandwidth of 1.6 MHz and 5 MHz and nine different arrival rates: 6, 7, 8, 10, 15, 20, 30, 40, and 100.

Analyzing the admission rate, the average data rate and the mean transfer time in figure 1, figure 2 and figure 4, it can be stated that the performances of the Proportional Fair scheduler are above the performances of the Round Robin algorithm.

Figure 1 shows the admission rate as a function of the arrival rate of the users. For a low bandwidth system the improvement is evident even for small values of the arrival rate. For higher bandwidth system and low arrival rates the performances of the two schedulers are comparable but as soon as the network becomes highly congested, the Proportional Fair is net superior to the Round Robin scheduling policy.

To illustrate the gain of the opportunistic scheduler over the non-opportunist one, a comparison between the associated average transmission rates has been done. The results are illustrated in figure 2. Using the Round Robin policy as a reference, the gain of the Proportional Fair algorithm is presented in figure 3. The higher the system bandwidth, the higher is the gain of the Proportional Fair resource allocation strategy and this happens because the frequency diversity is higher.

Another interesting metric to look at is the mean transfer time. As it was concluded in [8], the duration of the elastic traffic depends on its rate. It can be stated that the durations of elastic flows should be very short in order to have good performance. Looking at figure 4, the average transfer time is much shorter when Proportional Fair algorithm is configured. In the case of a low bandwidth system, the improvement is important even for a small arrival rate of the users.

For higher bandwidth system, the mean transfer time is consistently smaller for a Proportional Fair scheduler, even when network congestion is significant.

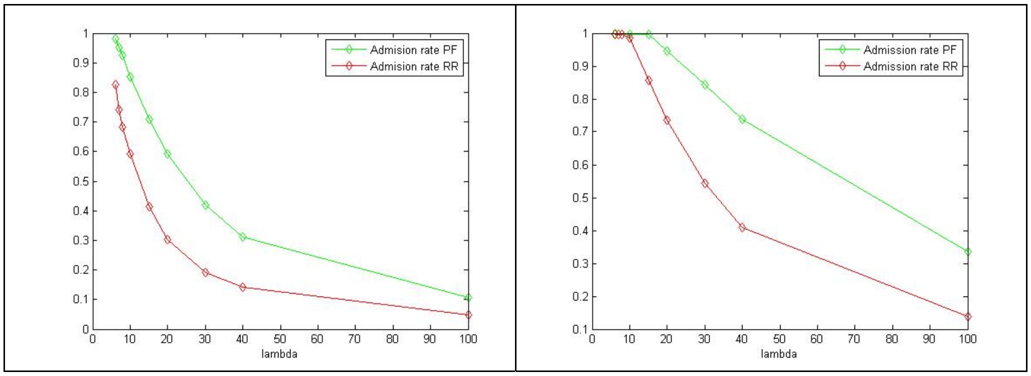

Fig.1. Admission rate for 1.6MHz and 5MHz

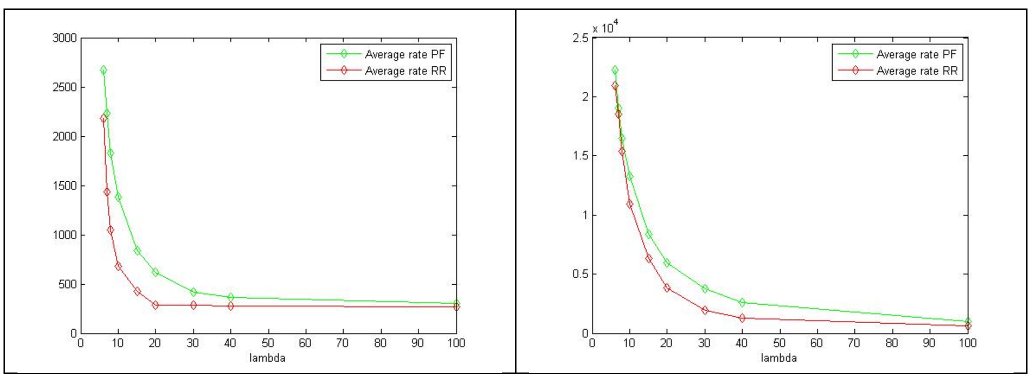

Fig.2. Average rate for 1.6MHz and 5MHz

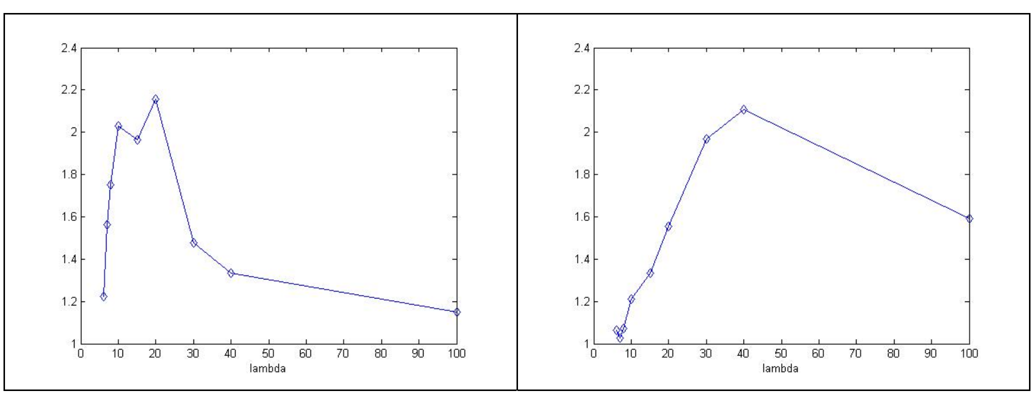

Fig.3 Scheduling gain for the Proportional Fair policy – system bandwidth 1.6MHz and 5 MHz

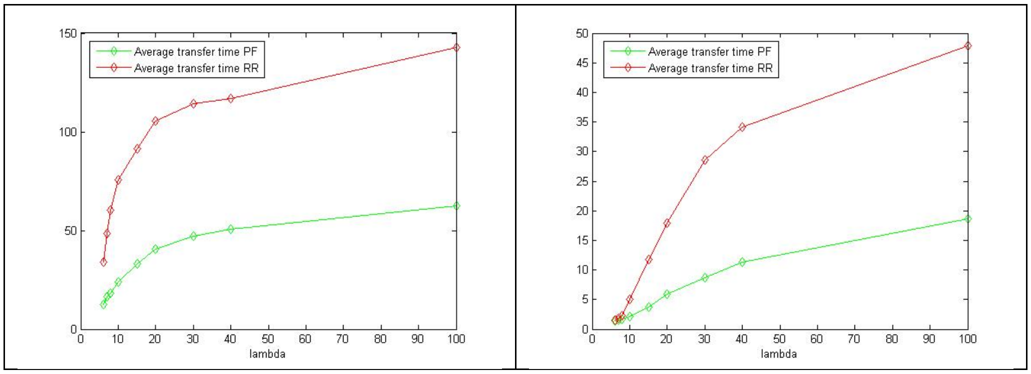

Fig.4. Average transfer time

3. Considerations related to cell modeling

When studying scheduling algorithms and in particular opportunistic schedulers, it is important to link the variable nature of the SNR with the performance of the scheduler. The approach will be similar to the one in [9] and assumes the cell decomposition into SNR rings as it is depicted in the figure bellow. The cell is divided into a number of concentric circles of radius R_i. Each region corresponds to an SNR value.

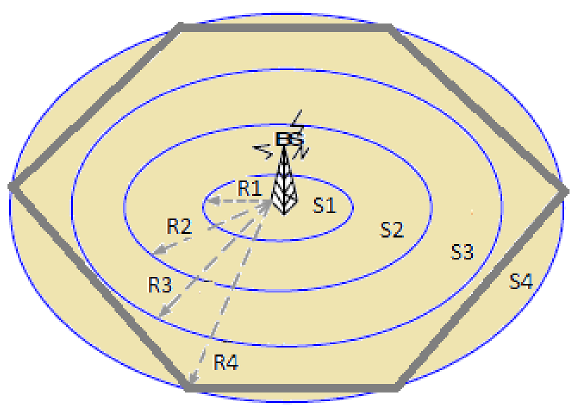

Fig.5. SNR rings

The radius of one region can be linked with the path loss calculated using the free space model. Let PL_i be the path loss corresponding to region i, G_E and G_R are the emitter and receiver antenna gains and λ is the wavelength corresponding to a 2.6GHz frequency, the LTE frequency. Also P_E is the emitted power of the eNodeB, SNR_i is the SNR value in region i and N is the thermal noise computed for a system bandwidth of 20MHz.

$$PL_i = -10logG_E - 10logG_R + 20log\left(\frac{4\pi R_i}{\lambda}\right) = P_E - SNR_i - N \qquad (6)$$

The relation between the radius R_i and SNR_i is the one bellow:

$$R_i = \frac{\lambda}{4\pi} 10^{(P_E + 10logG_E + 10logG_R - SNR_i - N)/20} \qquad (7)$$

Now let's calculate the surface of region i. $S_1 = \pi R_1^2$ is the surface of the first region, a circle of radius R_1.

$$S_i = \pi\left(R_i^2 - R_{i-1}^2\right) \qquad (8)$$

The next step is to calculate the probability of having a SNR_i value. This can be calculated by dividing the surface S_i by the cell area which is actually the sum of all defined SNR regions, S_i. Another way to calculate the cell surface is to use the cell radius which is the radius of the last defined SNR ring. Let's consider n be the number of SNR regions.

$$P_1 = \frac{S_1}{S_n} = \frac{R_1^2}{R_n^2} \qquad (9)$$

$$P_i = \frac{S_i}{S_n} = \frac{(R_i^2 - R_{i-1}^2)}{R_n^2} \qquad (10)$$

After finding the closed-form expression for the probability of having a SNR_i it is useful for future design of resource allocation policies to show its trend. The figure bellow illustrates the dependency of the R_i radius, S_i surface and P_i probability of the associated SNR value for different n values, the number of SNR regions (42, 16 and 10).

By analyzing the results in the figure bellow there are several interesting conclusions that can be drawn. First of all, R_i, the distance between cell center and the boarder of the i region, has an exponential shape for higher n values. As n decreases, the shape of the R_i curve linearizes.

n=42	n=16	n=10

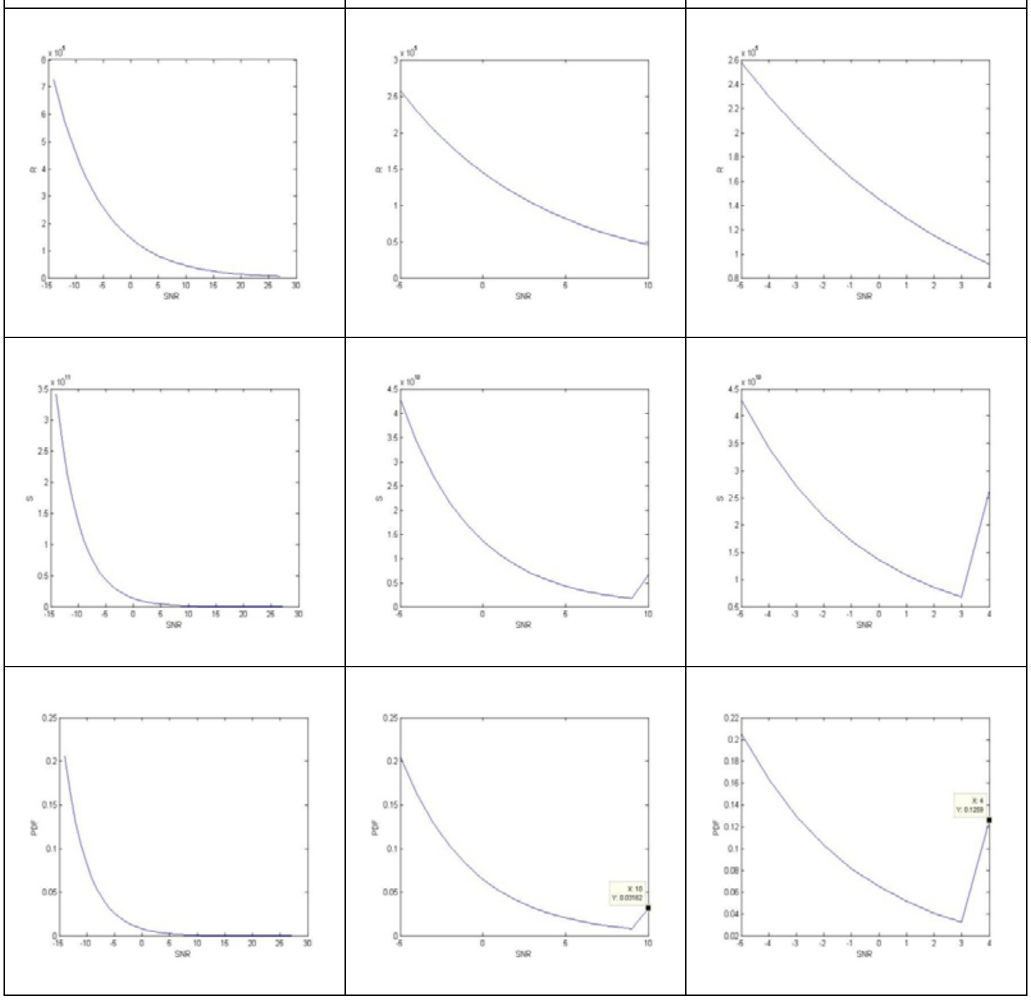

Fig.6 – R_i, S_i and P_i as a function of SNR

Looking at the representations of the S_i surface as a function of SNR and comparing it to the graphs of the P_i probability, the shapes are similar. As it can be depicted from the figure above, as n decreases, the surface of the first SNR region is higher and also the probability to be in that region is higher.

The most important fact that must be highlighted here is that the probability to be at cell edge is higher than the probability of being close to the base station. The probability to be inside S_1 area is the first SNR region. As n decreases, the probability of being inside S1 becomes higher. The gap between the probability of being inside area S_i (i greater than 1) and the probability of being inside S_1 area is more important as n decreases. This can be written this way:

$$S_n > S_{n-1} \dots > S_2 \tag{11}$$

$$S_n = \max_i S_i \tag{12}$$

$$S_1 < S_n \tag{13}$$

In the same manner, the expressions above can be rewritten:

$$P_n > P_{n-1} \dots > P_2 \tag{14}$$

$$P_n = \max_i P_i \tag{15}$$

$$P_1 < P_n \tag{16}$$

Returning back to the scheduling policies, the results above can be very useful when designing resource allocation algorithms. For example, in a dense populated area, it can be considered that users are uniformly spread inside the area of one cell. Also, the dense populated area is the worst case scenario when doing scheduling and the performance of the scheduling policy is really critical. Having in mind the result above regarding the surface of the i^{th} SNR region and the probability of having that SNR value, it can be stated that the majority of the users in one cell will be concentrated closer to cell edge than to cell center.

6. Conclusions and future work

This paper evaluates the performance of a Proportional Fair, an opportunistic scheduling policy by comparing it to a Round Robin Scheduler. The first scheduling algorithm offers better performance compared to the non-opportunistic scheduler in terms of admission rate, average transfer rate and mean transfer time. The gain of the Proportional Fair algorithm is due to the fact that it takes advantage of the multi-user diversity.

OFDMA technologies can benefit from both time and frequency diversity at the same time. The Round Robin scheduler ignores this advantage and it does not take into account the state of the radio channel. On the contrary, the Proportional Fair policy uses the advantage of diversity to improve service performance.

An important aspect in developing opportunistic schedulers is the way to model SNR inside the cell because this parameter can trigger different behaviors of the resource allocation policy. The conducted simulations have shown that for a dense populated area, there are more users concentrated closer to the cell edge that to cell center. This is the case for a dense populated area where users' distribution inside one cell can be considered uniform. This is an important aspect that can be used when developing a scheduler.

Two of the most important factors that can influence the performance of a scheduler are traffic classes and SNR. The second one has been studied here. Although very simple to implement, the Round Robin scheduler ignores traffic type and its associated QoS requirements. This can be considered another big disadvantage because QoS requirements are completely ignored.

This paper has shown that opportunistic schedulers overcome the performance of non-opportunistic ones. Some aspects need to be further explored. For instance, it would be useful to study how a minimum rate guarantee can be achieved by a scheduling policy. Other interesting perspective is to analyze the impact of mobility and the integration of data services with streaming traffic.

Acknowledgment

Elena-Roxana C□rstea is the grant beneficiary offered through POSDRU/6/1.5/S19 contract.

Horia Ştefãnescu is the grant beneficiary offered through POSDRU/6/1.5/S/16 contract.

R E F E R E N C E S

[1] *N. Soltani*, Cmparison of Single-Carrier FDMA vs. OFDMA as 3GPP Long-Term Evolution Uplink, EE359 Project, 2009
[2] *GPP TS 36.213 v10.2.0, E-UTRA Physical layer procedures, pp. 87–114, June 2011*
[3] *D. Tse,P. Viswanath*, Fundamentals of Wireless Communication, Cambridge University Press, 2005, pp. 228-289,
[4] *R. Combes, Z. Altman, E. Altman,* On the use of packet scheduling in self-optimization process: application to coverage-capacity optimization, Orange Labs, WiOpt – Modeling and Optimization in Mobile Ad Hoc and Wireless Networks, 2010, pp. 11-20
[5] *J. Mo, J. Walrand,* Fair End-to-End Window-Based Congestion Control, Transactions on Networking, vol.8, no. 5, 2000, pp. 556-567
[6] *B. Blaszczyszyn, M. K. Karray,* Faiding Effect on the Dynamic Performance Evaluation of OFDMA Cellular Networks, Communications and Networking, 2009
[7] *H. J. Kushner, P. A. Whiting,* Convergence of Proportional-Fair Sharing Algorithms Under General Conditions, Transactions on Wireless Communications, vol. 3, no.4, 2004, pp. 1250-1259

[8] *T. Bonald, A. Proutiere,* On Performance Bounds for the Integration of Elastic and Adaptive Streaming Flows, SIGMETRICS, 2004, pp. 235-245
[9] *C. Tarhini, T. Chabed,* On capacity of OFDMA-based IEEE802.16 WIMAX including Adaptive Modulation and Coding (AMC) and inter-cell interference, LANMAN, 2007, pp. 139-144